This is the report of the CSIRO Australia Telescope National Facility for the calendar year 2015, approved by the Australia Telescope Steering Committee.

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Cover image: Work being done on an antenna of the Australian SKA Pathfinder. Credit: CSIRO

Inner cover image: An observer in the ATNF Science Operations Centre. Credit: Flornes Yuen
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This year saw great progress on the Australian SKA Pathfinder (ASKAP). The first ASKAP science papers appeared, demonstrating the potential of phased array feeds (PAFs) for radio astronomy and the uniqueness of the Murchison Radio-astronomy Observatory. While the Boolardy Engineering Test Array (ASKAP with six first-generation PAFs) was being used for commissioning, the second-generation phased array feeds began to roll off the production line. These feeds have improved performance and maintainability and reduced cost. In October the ASKAP PAF team received CSIRO’s highest award, the Chairman’s medal.

However, ASKAP will now remain a stand-alone instrument longer than envisaged. The Square Kilometre Array project was re-baselined early in 2015: SKA Survey, which was to have comprised ASKAP and 60 other antennas, was indefinitely deferred, and the low- and mid-frequency SKA telescopes were scaled down. Australia’s SKA component will now be SKA-Low, an array of around 130,000 dipoles. With the SKA re-baselining done, negotiations began for the Convention under which the SKA Observatory will be constituted. Towards the end of the year the Australian Government announced $294m of funding for hosting the SKA, as part of its National Innovation and Science Agenda.

At Parkes and Narrabri this year we consolidated the changes of recent years and continued to support world-class science. Instrumentation at the Parkes telescope had been reduced and all observing is now conducted remotely. However, as 2015’s publication statistics indicate, Parkes remains a world-class facility. As part of a program to renew the telescope’s instrumentation, we began this year to build an ultra-wideband low-frequency receiver and installed an ASKAP PAF at Parkes for commissioning tests. Proven Parkes technology was chosen for China’s Five-hundred-metre Aperture Spherical Telescope (FAST), with CSIRO to produce a 19-beam multibeam receiver for FAST. We also signed a contract to observe for Breakthrough Listen, the first major SETI program to run on Parkes since Project Phoenix in 1995.

At the Compact Array, 2015 was the first year in which remote observing became the default. We have kept the ‘user-operator’ model, but have also begun the first trials of unattended observing. As at Parkes, the telescope systems worked well and scientific productivity has not shown any immediate change. However, if our instrumentation program is to flourish we must keep the connection between engineers and scientists, local or visiting, alive. A synergy of large research infrastructure, technology development and scientific excellence remains what the ATNF aims to deliver.
The Steering Committee welcomed the operational and technological achievements of the Australia Telescope National Facility (ATNF) in 2015 and the high-quality science outcomes to which they contributed, and expressed appreciation for the leadership of the Director, Dr Lewis Ball, and his team in delivering them. The award of the CSIRO Chairman’s Medal to the ASKAP team for the implementation of the phased array feeds (PAFs) was a significant acknowledgement of the innovation and engineering excellence of the team.

The committee convened on two occasions and consulted throughout the year, with the aim of providing high-level advice to guide the strategic directions, performance and allocation of observing resources for the facility. Advice to the Director and the CSIRO Board was especially focussed around three key areas: the Square Kilometre Array (SKA) strategy; operations and funding of the ATNF; and astronomy governance.

In response to the re-baselining of the international SKA project, especially the decision to defer SKA Survey, the committee highlighted the significant investment that CSIRO, the Australian Government and the astronomy community have made in ASKAP and in the development of the innovative PAF technology that provides its unique field of view, and acknowledged the world-class science it will deliver for many years to come. The committee emphasised the value of ongoing Australian engagement in the SKA, especially in SKA-Low.

In relation to the future of ASKAP, it advised that the maximum benefit for Australia, in terms of scientific leadership and impact, technology development and intellectual property, would be derived through retaining Australian ownership and control of ASKAP and actively seeking to further develop the instrument, its technology and the survey science, including through international partnerships.

The Steering Committee recognised the need to sustain the current suite of radio astronomy facilities (Parkes, the Compact Array, ASKAP) for the next 5–10 years in order to deliver on the priorities of the 2016–25 Decadal Plan for Australian astronomy. The committee acknowledged the lean operations model implemented by CASS for Parkes, the remote operations of the Compact Array and the plan to cease funding Mopra operations from October 2015. It welcomed the arrangement reached with the Breakthrough Prize Foundation and encouraged investigation of further external funding opportunities, noting the need for careful consideration of the impact on other astronomy programs. The committee urged the ATNF to continue community consultation in the development of science priorities for the Compact Array and, with an eye to the foreseeable end of Compact Array science on the timescale of a decade, to additionally call for large-scale ‘Legacy’ science projects, which would feature an open-access data policy with no proprietary period.

The Steering Committee supports a consolidated astronomy governance model for the future of Australian astronomy as Australia engages in global-scale astronomy facilities, but recognises that close involvement with the entire community is critical to achieving a successful outcome. The committee expressed confidence that in the event such consolidation does occur, an appropriate governance and delivery structure could be implemented under CSIRO to deliver a broader range of astronomy infrastructure for the community. In order to maximise community alignment, the implementation of such a model should reflect the community’s priorities articulated in the 2016–25 Decadal Plan and should include a representative community-based steering committee or equivalent.

The Steering Committee looks forward with enthusiasm to a positive future for the ATNF and for Australian astronomy more generally.
After three successful years leading CSIRO Astronomy and Space Science, Dr Lewis Ball left CSIRO on 17 March 2016.

As CASS and ATNF Director Lewis secured the funding necessary to ensure that ASKAP will deliver on its primary science goals. He oversaw the successful demonstration of the wide field of view that can be delivered by an array of antennas equipped with phased array feeds, moving radio astronomy into a leading position in Big Data. Under Lewis’s leadership CASS ensured the future of the Parkes Telescope as a world-leading pulsar instrument and key element of the new Breakthrough Listen SETI project, and led a community-driven process to identify the key science priorities for the Australia Telescope Compact Array into the next decade.

Lewis enhanced the external linkages of CSIRO astronomy, establishing partnerships with overseas observatories and astrophysical engineering groups and securing contracts that will see CSIRO deliver instruments to observatories around the world. He also worked to consolidate CSIRO’s place in the global project to build and operate the Square Kilometre Array.

Following Lewis’s departure, Dr Douglas Bock (Assistant Director, Operations) has taken on the role of Acting Director of CASS and the ATNF.
The ATNF in brief

Members of the SKA Science and Engineering Advisory Committee visiting the Murchison Radio-astronomy Observatory Credit: CSIRO
The ATNF in brief

The Australia Telescope National Facility (ATNF) is a set of world-class radio-astronomy observatories operated by CSIRO (the Commonwealth Scientific and Industrial Research Organisation).

LOCATIONS
ATNF observatories are located near the towns of Parkes, Narrabri and Coonabarabran in eastern Australia, and in the Mid West region of Western Australia. The ATNF is headquartered in Sydney, New South Wales, and has offices in Perth and Geraldton in Western Australia.

The Murchison Radio-astronomy Observatory (MRO) in Western Australia sits on land traditionally owned by the local Wajarri Yamatji community. CSIRO manages the MRO under an Indigenous Land Use Agreement (ILUA) for the site.

CSIRO also manages Australian astronomers’ access to the antennas of NASA’s Canberra Deep Space Communication Complex, which is located at Tidbinbilla in the Australian Capital Territory. These antennas are often used in conjunction with ATNF telescopes.

OPERATIONS
ATNF telescopes support a broad range of studies in Galactic (interstellar medium, pulsar, X-ray binaries, star formation, stellar evolution, magnetic fields), extragalactic (galaxy formation, ISM, Magellanic Clouds, cosmic magnetism) and cosmological science.

The ATNF is a national facility, providing all astronomers at Australian and overseas institutions with the opportunity to use its telescopes. Access is given free of charge and is based on the scientific merit of the proposed observing project. This ‘open skies’ policy is the general practice of the international radio-astronomy community and Australian astronomers obtain access to overseas facilities on the same principle.

The proposals received each semester typically include about 600 authors: on average, about 50 are from CASS, 80 are from other Australian institutions and 470 are from 175 overseas institutions. The three overseas countries with the greatest numbers of proposers are the USA, UK and Germany.

About 60 per cent of the refereed publications derived from observations with ATNF telescopes result from collaborations between Australian and international researchers.

Right: The 64-m diameter Parkes telescope, near the town of Parkes, New South Wales. This telescope has been used for an extremely wide range of Galactic and extragalactic science. Its major area of work is now studies of pulsars and fast radio bursts. It is also frequently used for joint observations with other telescopes. Credit: Cormac Purcell

Observatories and support sites for CSIRO radio astronomy
GOVERNANCE

The ATNF comprises the major part of CSIRO Astronomy and Space Science (CASS), one of CSIRO’s business units. CASS also operates the Canberra Deep Space Communication Complex, a station of NASA’s Deep Space Network, on behalf of NASA. The Director of CASS is also the ATNF Director.

CASS is part of CSIRO’s Digital, National Facilities and Collections group, along with other national facilities that are owned and operated by CSIRO but used extensively by external researchers. The Executive Director, Digital National Facilities and Collections, reports to the Minister for Industry, Innovation and Science via the CSIRO Executive.

ATNF policy is shaped by the Australia Telescope Steering Committee (ATSC), an advisory body that usually meets twice a year. The ATSC advises the Director on long-term strategy. It also appoints the Australia Telescope Users Committee (ATUC), which represents the interests of astronomers who use ATNF telescopes, and the Time Assignment Committee (TAC), which reviews observing proposals. The members of these three committees are listed in Appendix A.

STAFF AND FUNDING

The ATNF receives CSIRO appropriation funding, supplemented by external (contract) funding. A financial summary appears in Appendix B.

In 2015 CSIRO employed about 190 staff on activities related to radio astronomy. Their names and locations are given in Appendix C.

Antennas of the Australian SKA Pathfinder, ASKAP, at the Murchison Radio-astronomy Observatory in Western Australia. ASKAP began operating in 2014 with the first six of its 12-m antennas to be outfitted with CSIRO-developed phased-array feeds. Its final form the telescope will comprise 36 antennas. (Details, pages 34–35.) Credit: Flornes Yuen

Antennas of the Australia Telescope Compact Array, six 22-m diameter dishes near the town of Narrabri in New South Wales. The Compact Array can operate at frequencies between 1.0 GHz and 105 GHz, and its antennas ride on a six-kilometre track that allows multiple configurations and observing baselines. Credit: Cormac Purcell
Performance indicators

Antennas of the Compact Array at dusk.

Photo: Karen Hodge Photography
TELESCOPE USAGE

Observing time on ATNF telescopes is awarded twice a year to astronomers on the basis of the merits of their proposed research programs, as judged by the Australia Telescope Time Assignment Committee (members listed in Appendix A).

Demand for telescope time is higher in winter because the weather is better for higher-frequency (millimetre-wavelength) observations with Mopra and the Compact Array.

The ‘oversubscription’ rate (the factor by which proposals exceed the telescope time available) was 1.9 for the Compact Array for the winter season and 1.6 for the summer season; for Parkes it was 1.4. The Long Baseline Array (Parkes, Mopra and the Compact Array used together) continued to be in demand, with proposals exceeding available time by more than a factor of two.

On both the Compact Array and Parkes, approximately ten per cent of time is made available as ‘Director’s time’. This is time that is initially not allocated in the published version of the schedule, but which can be made available later for approved observing projects. The key performance goals for the Compact Array and Parkes are:

- at least 70 per cent of telescope time should be successfully used for observing
- no more than five per cent of observing time should be lost through equipment failure.

This year:

- time allocated to observing was 79 per cent at Parkes, 76 per cent at the Compact Array, and 74 per cent at Mopra (this is for all Mopra time, not just National Facility time). These are world-class levels of performance: they exceed, for instance, the observing-time figure for the world’s largest radio telescope, the Karl G. Jansky Very Large Array in the USA
- time lost through equipment failure was four per cent at Parkes, three per cent at Mopra, and twoper cent at the Compact Array.

Observing proposals received

| Winter semester (April – September 2015) | 148 |
| Winter semester (October 2014 – March 2015) | 113 |

Figure 1: Telescope usage in 2015. Mopra statistics are for dates between 09 March and 31 October, which corresponded to the ‘millimetre season’ for 2015.

Performance indicators
TIME ALLOCATION

This year observing proposals were received from 846 individual researchers from 31 countries. Sixteen per cent were led by ATNF staff, 26 per cent by staff of other Australian institutions, and 57 per cent by overseas researchers (rounded figures).

For the period from 1 October 2014 to 30 September 2015, 156 proposals were allocated time on ATNF telescopes (counting each proposal only once each calendar year even though some are submitted twice). This was fewer than in 2014 (when the figure was 207), partly because fewer proposals were received but also because more time was given to large projects.

Eighty-five proposals were given time on the Compact Array, 39 on Parkes, eight on Mopra (in National Facility time) and 19 on the Long Baseline Array: they are listed in Appendix D.

The ATNF also handles proposals requesting service observations with the 70-m and 34-m antennas of the Canberra Deep Space Communication Complex (CDSCC), part of NASA’s Deep Space Network. Five CDSCC projects were observed during the year.

Time allocated to observing teams on the Compact Array and Parkes, broken down in different ways, is shown in Figures 2–5. ATNF staff were allocated about 15 per cent of observing time on the Compact Array and 24 per cent on Parkes. Figures 4 and 5 show that the fraction of observing time allocated to ATNF staff has fallen over the last five years: this is both because the number of astronomers on staff has fallen, and because these staff have had (and continue to have) a strong focus on commissioning ASKAP.

Figure 2: Compact Array time allocation by primary investigator, October 2011–September 2015. For each year the time allocation is for 12 months from October to September.

Figure 3: Parkes time allocation by primary investigator, October 2011–September 2015. For each year the time allocation is for 12 months from October to September.
As of December 2015, 30 PhD students were being co-supervised by ATNF staff. Their affiliations and thesis titles are given in Appendix E. Eight students were awarded PhDs during the year; their theses are listed in Appendix F.

Figure 4: Compact Array time allocation by all investigators, October 2011–September 2015. Time allocated to each proposal has been divided evenly between all authors on the proposal. For each year the time allocation is for 12 months from October to September.

Figure 5: Parkes time allocation by all investigators October 2011–September 2015. Time allocated to each proposal has been divided evenly between all authors on the proposal. For each year the time allocation is for 12 months from October to September.

Figure 6: Numbers of postgraduate students affiliated with CASS.

Figure 7: Postgraduate student affiliations 2015.

TEACHING

As of December 2015, 30 PhD students were being co-supervised by ATNF staff. Their affiliations and thesis titles are given in Appendix E. Eight students were awarded PhDs during the year; their theses are listed in Appendix F.
This year 138 papers using data from the National Facility were published in refereed journals. Approximately 65 per cent included a CASS author or authors.

In 2015 there were 185 refereed publications by CASS staff, including scientific papers with data from other facilities. In total, 235 refereed papers – both those using National Facility data and other papers by CASS staff – were published during the year. They are listed in Appendix G, which also lists 47 conference papers that were either derived from ATNF facilities or include CASS authors.

The publication counts are very similar to those of the previous year.

Across CSIRO, citation performance is measured by the New Crown Index – the average number of citations per paper, body normalised to a baseline determined from the global average for all publications in a similar set of journals. (In astronomy the baseline is determined from papers published in refereed journals.) The index is calculated at least a year after the date of publication, to allow citations to accrue. For National Facility and other CASS staff papers published over the five-year period from 2010 to 2014, the new Crown Index (calculated over 906 refereed papers) is 1.8. This means that on average, papers published by CASS staff (including papers with National Facility data) receive around 80 per cent more citations per paper than the global average for refereed astronomy papers.

Figure 8: Publications that include data from, or are related to, ATNF facilities (Compact Array, Mopra, Parkes, VLBI, Tidbinbilla and ASKAP), published in refereed journals during 2011–2015. The count includes publications relating to the scientific goals or development of ASKAP but not IAU telegrams, abstracts, reports, historical papers or articles for popular magazines.

Figure 9: Publications that include data from, or are related to, the Compact Array, Mopra, Parkes, VLBI and ASKAP in 2011–2015. A small number of papers with data from more than one facility are counted more than once.

Figure 10: Publications that include data from, or are related to, the Compact Array, Mopra, Parkes, VLBI and ASKAP, grouped by year for 2011–2015. A small number of papers with data from more than one facility are counted more than once.
Science highlights

The Parkes telescope.

Photo: John Sarkissian
Stars form within ‘molecular clouds’, clouds of hydrogen gas liberally laced with other molecular species and made dark by copious dust. The ‘dark cloud’ SDC335.579–0.292 is such a site. Observations with ALMA (the Atacama Large Millimeter/submillimeter Array) have recently shown it to be home to one of the most massive star-forming cores yet observed in our Galaxy, SDC335–MM1, and a less massive companion, MM2. Both cores are infrared bright, and both are associated with 6.7-GHz class II methanol masers, MM1 with two masers and MM2 with one. Class II methanol masers trace massive star formation, meaning that SDC335 harbours young massive protostellar objects.

We set out to constrain the masses of the stars forming within these two cores, using Compact Array observations made at 6, 8, 23 and 25 GHz. These observations are of higher angular resolution than the ALMA data, revealed a surprise: the MM1 core is not one source but two, separated by about three arcseconds. We dubbed the two sources MM1a and MM1b. The directions of the outflows from MM1a suggest that they are independent objects. MM2, the less massive core, still appeared as a single source in our observations.

We had enough resolution to create partial spectral-energy distributions for each source at Compact Array frequencies, and we used these to classify the sources. MM1a is the simplest case: it appears to be a hyper-compact H II region. MM1b and MM2 are slightly less clear-cut, but on balance they are likely to be compact H II regions; their association with Class II methanol masers confirms that they are forming massive stars.

We fitted the free-free emission component of the spectral-energy distributions from each hyper-compact region, and used this to derive physical properties such as the sources’ emission measure, ionising photon flux, and electron density. From these we assigned a spectral type to each of the protostellar objects creating the hyper-compact regions. SDC335 appears to house two protostars with characteristics of spectral type B1.5 and one with a lower limit of B1–B1.5.

Having characterised the protostars, we were able to put limits on the eventual number of stars this cloud could create – a minimum, we calculate, of 60 stars of between one and 120 solar masses. SDC335 looks as though it will eventually become a cluster at least roughly similar to the well-known Trapezium cluster in the Orion nebula.

**PUBLICATION**

Large radio-continuum surveys help us understand how galaxies evolve over cosmic time. Most past surveys have been limited in sensitivity, and most radio sources they detected have been active galactic nuclei (AGN). More sensitive surveys pick up low-luminosity AGN and star-forming galaxies, but at present such surveys are time-consuming and can be carried out only over small patches of sky. In the coming decade, however, next-generation radio telescopes such as the Australian SKA Pathfinder (ASKAP) will perform sensitive surveys over huge swathes of the sky. These will find vastly more sources: for example, the EMU (Evolutionary Map of the Universe) survey to be done with ASKAP is expected to find 70 million, dwarfing the 2.5 million currently known.

To harvest new scientific knowledge from such surveys, we need to match the detected radio sources with galaxies observed at other wavelengths. This task is complicated by the large, complex structures often found in radio-loud AGN. (These complex sources are also likely to be the most scientifically interesting.) Cross-identifications have traditionally been made by eye. Automated radio classification algorithms are still in their infancy: 10 per cent of the radio sources expected from EMU are likely to be too complicated for current automated algorithms.

Would it work to bring more eyeballs to bear on the task? To test this idea we created Radio Galaxy Zoo, an online citizen-science project. In this, the public is asked to cross-match radio sources, often with complex structures, to galaxies observed in the infrared. We use data from two 1.4-GHz radio surveys (Faint Images of the Radio Sky at Twenty Centimeters, FIRST, and the Australia Telescope Large Area Survey, ATLAS) and mid-infrared images from the Wide-field Infrared Survey Explorer and the Spitzer Space Telescope. Radio Galaxy Zoo was launched in late 2013. When it is complete, participants will have inspected more than 170,000 radio sources.

In the project’s first year more than 4000 participants produced more than 30,000 host identifications. There was greater than 75 per cent consensus among participants and, importantly, the project participants are as effective as the science team at identifying host galaxies for sources that are too complex for simple position-matching algorithms. Most of the identified host galaxies reside in the mid-infrared colour space dominated by elliptical galaxies, quasars and luminous infrared radio galaxies.

When all Radio Galaxy Zoo galaxies are identified we will have a measure of the relative populations of these hosts as a function of radio morphology and power. Already we have many interesting candidates to follow up: giant radio galaxies, late-type host galaxies with extended radio emission, and hybrid-morphology radio sources.

**PUBLICATION**
Radio sources with spectra that peak around 1 GHz are called, rather predictably, **gigahertz peaked spectrum** (GPS) sources. GPS sources are compact, and remarkably constant in their power output on timescales from hours to decades.

What makes their characteristic peaked spectra? Since the 1960s the two contending mechanisms have been **free-free absorption**, in which radiation from the source is absorbed by a ‘screen’ of ionised gas, and **synchrotron self-absorption**, where the radiation is absorbed by relativistic electrons within the emitting medium itself. The latter has been more favoured but the question had not been definitively settled. This was something we decided to tackle by looking at a GPS source called PKS B0008–421.

This source has the steepest-known spectral slope on the low-frequency side of its peak, a slope that is close to the limit of what synchrotron self-absorption can explain. It also has the virtue of having been observed many times, at many frequencies: its constancy meant that it had been used as a calibrator by most of the radio telescopes in the southern hemisphere. To those many existing observations we have added new ones made with the Murchison Widefield Array (at low frequencies) and the Australia Telescope Compact Array (at high frequencies). This gave us an extremely well-sampled spectrum, covering the range 0.118–22 GHz.

We tried fitting the data with nine models, all variants of synchrotron self-absorption (SSA) and free-free absorption (FFA). Free-free absorption with an inhomogenous absorbing screen gave the best fit. FFA is also bolstered by other arguments: for one, the source’s calculated magnetic field is more in line with FFA than with SSA.

But to make either FFA or SSA fit well, we had to assume that the source’s central black hole had stopped injecting high-energy electrons into the body of PKS B0008–421 about 550 years ago. When injection of new electrons stops, with time the high-energy electrons already in the source are preferentially depleted, and the radio spectrum changes shape. (The high-frequency observations in particular show this change.) That the source should turn off like this is not a complete surprise: some GPS sources show signs of intermittent activity.

Astronomers have long known that GPS sources and similar, related objects far outnumber giant radio galaxies, which the GPS sources and their relatives are thought to evolve into. Perhaps many GPS sources fail early and vanish. Once its central black hole had turned off, PKS B0008–421 might have been expected to fade rapidly. That it has not done so suggests that its central source of radiation is swathed in relatively dense gas (another argument in favour of free-free absorption being at work). Dying GPS sources with similar gas cocoons will be easily found by the new low-frequency radio telescopes. If we can find many GPS sources that have failed early, we will know why so few seem to grow into giant radio galaxies.

**PUBLICATION**

Our Galaxy forms stars at a modest rate overall. But one star-forming region really stands out: Sagittarius B2 (Sgr B2), a massive complex of more than 50 clouds of H II (molecular hydrogen gas) in the Galactic Centre. Rich in X-rays and cosmic rays, and with a high magnetic field, in many ways it resembles the centre of a ‘starburst’ galaxy.

Most spectral-line surveys of Sgr B2 have been conducted with single-dish telescopes at frequencies above 80 GHz. At these frequencies it can be difficult to identify lines with specific physical features. The problem can be reduced both by going to longer (centimetre) wavelengths and by using an interferometer, which can pinpoint where lines from different molecules peak. The ideal situation is to observe the same portion of the spectrum with both a single dish (to capture weak lines in extended gas) and an interferometer (to distinguish between chemically distinct regions on small scales).

The advent of broadband radio interferometers such as the Australia Telescope Compact Array (ATCA) means that interferometric line surveys are now efficient, providing access to the spatial distributions of hundreds of molecular lines within a reasonable observing time. With the new wealth of information available, however, come new challenges in data analysis that require automated methods.

We have used the ATCA to carry out a 30–50-GHz spectral-line survey of the northern part of Sagittarius B2, Sgr B2(N). This is the first such (published) survey made with a new-generation broadband interferometer. The ATCA data, collected in just 24 hours of observing, complement existing single-dish data covering the same frequency range from the PRIMOS survey done with the Green Bank Telescope.

The ATCA data contain around a thousand spectral lines, with significant spatial and kinematic structure. To handle this profusion, we extracted mean spectra from physically distinct regions of Sgr B2(N), transforming a three-dimensional problem into a set of one-dimensional problems, then applied new automated line-fitting routines.

This has revealed the spatial distributions of more than 50 identified molecules and the locations where hydrogen and helium are recombining, giving us a comprehensive picture of the chemistry, excitation, and kinematic structure of clouds of molecular gas in Sgr B2. The survey has also served as a pathfinder for a planned science-verification project with ALMA Band 1 (35–50 GHz) and demonstrated methods that will be useful for this and other future projects.

**PUBLICATION**

Circinus X-1 is a highly variable X-ray binary. Both its age and distance have been uncertain. Recent work (Heinz et al. 2013), placed an upper limit of 4600 years x (D_{Cir}/8 kpc) on the age of the system, where D_{Cir} is the distance to the source. This upper limit makes Circinus X-1 the youngest-known X-ray binary and an important test case for the study of both neutron-star formation and orbital evolution in X-ray binaries.

But a firm distance to the system has remained elusive: because Circinus X-1 is deeply embedded in the Galactic disk, its distance can’t be determined by most standard methods. Estimates have ranged from 4 to 11 kpc.

Fortunately, the source has played into our hands. In late 2013 it generated a bright X-ray flare. X-rays from bright point sources can scatter off interstellar dust grains as they travel toward the observer, creating an arcminute-sized X-ray halo. Following the flare, observations with Chandra and XMM-Newton revealed a bright X-ray light echo: four well-defined rings that grew with time.

By deconvolving the radial intensity profile of the echo with the X-ray light curve of the flare, we were able to reconstruct the dust distribution toward Circinus X-1 into four distinct regions of concentration, which were most likely to be in molecular clouds. We then compared the peak in dust-scattering intensity with the peak intensity in CO maps of molecular clouds from the Mopra Southern Galactic Plane CO Survey. The Mopra data allowed us to identify the two innermost rings with clouds at the radial velocities of around -74 and -81 km s^{-1}.

For a number of putative distances to Circinus X-1 we calculated the expected radial velocities of the cloud components and compared them to the observed velocities, to find the distance that best matched the observed distribution of the clouds. We place Circinus X-1 at a distance of 9.4 kpc.

This result means that Circinus X-1 probably lies inside the far side of the Scutum-Centaurus arm of the Galaxy. Such a location, inside a star-forming spiral arm, accords with the young age of the binary.

**PUBLICATION**
Pulsars are usually discovered through the detection of their regular sequence of pulses. However, some skip pulses, suddenly switch off, or emit giant pulses. Pulsar flux densities can also vary significantly because of interstellar scintillation or because the pulsar signal is eclipsed by a companion object. The Compact Objects with ASKAP – Surveys and Timing (COAST) survey team will carry out traditional-style pulsar surveys with ASKAP, but the ASKAP transient surveys may also find pulsars through their bright individual pulses or by monitoring their variability in the image plane.

The intermittent pulsar PSR J1107–5907 is a perfect object with which to test the prospects of detecting pulsars this way. First found and studied with the Parkes telescope, it moves irregularly between three states (‘off’, ‘weak’ and ‘strong’), sometimes remaining ‘off’ for up to 40 minutes before emitting a giant pulse. Using the Boolardy Engineering Test Array, BETA (six ASKAP antennas equipped with first-generation phased array feeds), we tracked the pulsar over 13 hours, taking snapshots of the field around it every two minutes. We also observed it simultaneously with the Parkes telescope.

We analysed the snapshot images with three different transient-detection pipelines: one developed specifically for this study; the LOFAR transients pipeline (TRAP); and the VAST pipeline, developed to search for transients with the complete ASKAP telescope. All three easily detected the pulsar as a transient source.

Over the course of the observations, the pulsar switched into the strong emission state three times giving a typical timescale between the strong states of 3.7 hours. After the first switch it remained in the strong state for almost 40 minutes. The other strong states lasted less than four minutes. The second state change was confirmed with Parkes. The high-sensitivity Parkes observations enabled us to detect individual bright pulses during the weak state and to study the strong state over a wide observing band.

Traditional pulsar surveys are affected by radio-frequency interference and variations in telescope gain, and they are generally only sensitive to pulsars with periods of between a millisecond and ten seconds. We have simulated pulsars switching between ‘on’ and ‘off’ states on various timescales then determined whether different survey strategies – a traditional pulsar survey, and two types of transient survey – could detect them. The results are shown in the figure. Repeated, relatively short observations of the same region of sky appear to be the best survey strategy for discovering unknown intermittent pulsars. The advantages of using ASKAP for such a survey include its extremely radio-quiet environment and its sub-GHz frequency coverage, in which pulsars are likely to be brighter than at higher frequencies.

PUBLICATION
MEGAN JOHNSON  
(CASS)

It used to be thought that dwarf galaxies were “builders’ rubble” – leftovers from the assembly of massive galaxies. Recent studies suggest at least some formed later than that period of assembly. But regardless of when they formed, many are now being accreted by their weighty neighbours. We have studied one that may be on its way to that fate.

The giant elliptical galaxy NGC 5128, known to radio astronomers as Centaurus A (Cen A), has huge radio lobes that span 9°x4° on the sky. This behemoth is surrounded by a bevy of irregular dwarf (dIrr) galaxies. One, ESO 324–G024, was of particular interest to us. This dwarf has a peculiar H I morphology: a long, 3.5-kpc tail extending away from the core of NGC 5128. The distance to this dwarf is 3.37±0.43 Mpc, nearly the same as that to NGC 5128 (3.8±0.1 Mpc). And it lies a projected 104 kpc north of NGC 5128’s centre, meaning that it might be inside the giant’s northern radio lobe, which extends for ~300 kpc.

The orientation of Cen A’s radio lobes is not well known. By studying the characteristics of ESO 324–G024 we hoped to shed some light on this question, as well as on the dwarf’s unusual morphology. For this exploration we used H I spectral-line data from the Compact Array, data on the 1.4-GHz radio continuum and polarisation from the Compact Array and Parkes, and ancillary data from the SuperCOSMOS sky survey, GALEX and WISE (the Wide-field Infrared Survey Explorer).

To get a handle on whether ESO 324–G024 lies in front of, inside, or behind the northern radio lobe, we turned to the radio-continuum data of Cen A, in particular the Faraday rotation measure (RM), which is the angle through which linearly polarised radiation is turned as it passes through a magnetic field. If ESO 324–G024 were in front of the lobe, then we would expect the background emission from Cen A to be depolarised as it passes through the dwarf. But there is no sign of this in our data. Could the dwarf’s magnetic field be too weak to depolarise the Cen A signal? We considered this, but concluded that ESO 324–G024 probably lies behind the lobe.

If that’s the case, it puts some constraint on the orientation of the lobe and also on the distance to NGC 5128 and ESO 324–G024: the closer ESO 324–G024 is to the observer (relative to NGC 5128), the larger the required orientation angle. If we assume that ESO 324–G024 and NGC 5128 are at the same distance, and that the lobe is as deep as it is wide, then the lobe is inclined towards us by 60°.

Then there’s the question of how ESO 324–G024 got its tail. If it were formed from tidal interactions, then we would expect the gas kinematics in the tail to be distinct from the circular rotation in the dwarf’s central disc. But if it were formed from stripping via ram-pressure forces, then the kinematics of the gas would probably resemble the circular rotation of the disc. Fitting the data with tilted-ring models, we found that the kinematics of the tail closely resemble those expected from circular rotation in the disc. So ram-pressure stripping appears to be the culprit. ESO 324–G024 has a slightly positive peculiar velocity, which suggests that it is receding from our line of sight, and that it may have passed through the northern radio lobe of Cen A.

**PUBLICATION**

Long-duration gamma-ray bursts (GRBs) are generated by the collapse of massive stars. Such stars are short-lived, so these GRBs may trace star formation in the Universe. But are they an unbiased tracer? To determine this we have to measure the gas content of the GRB host galaxies, about which we have known relatively little.

Previous studies, mainly of gas in absorption, have suggested that GRB host galaxies have low levels of molecular hydrogen, $H_2$ (assumed to be the main fuel for star formation), but high levels of cool atomic hydrogen, $H_1$. However, to measure the total gas content of these galaxies (as opposed to column densities along a single line of sight), we need to detect gas in emission. We have carried out such a study, using the ATCA to make the first detection of $H_1$ in GRB host galaxies.

We targeted five nearby ($z<0.12$) GRB hosts in the southern hemisphere. Comparing their properties with those of galaxies from 22 previous studies, we found them to be normal star-forming galaxies.

However, while our galaxies have normal star-formation rates and $H_1$ masses, they have low stellar masses and $H_2$ masses. This suggests they have only recently started forming stars and have not yet had time to use up their $H_1$ and produce stars and dust (which catalyses the production of $H_2$). In this picture, star formation is directly fuelled by $H_1$ from the intergalactic medium. This has been shown to be theoretically possible, and must have been the case for the first stars in the Universe. It could also take place at any redshift, even in a galaxy not particularly metal-poor on average, as long as it happens at early stages of a star-formation episode, when the first stars are born in a collapsing cloud formed out of the newly accreted metal-poor gas.

We think it likely that GRB progenitors form in the first burst of star formation that takes place in low-metallicity gas freshly accreted from the intergalactic medium. (GRBs have been shown to explode in the most metal-poor regions of their hosts.) The progenitor would then end its life as a GRB before there is time for substantial $H_2$ to form. This would explain the paucity of $H_2$ absorption features seen in GRB afterglows and the low CO emission from host galaxies. The location of the $H_1$ emission in and around three of the host galaxies we studied also supports the ‘gas inflow’ scenario.

**PUBLICATION**

Fast radio bursts (FRBs) are short, bright pulses of radio waves with remarkably large dispersion measures (DMs), which show that they have passed through a considerable amount of ionised material (chiefly free electrons in space). The high DMs seem to point to an extragalactic origin, as the Galaxy lacks the necessary electron density to generate them. Since FRBs were discovered in 2007 many ideas have been put forward to explain them, perhaps almost as many as the number of published FRBs (currently ~20).

The first FRB found, discovered in the Parkes archives by Lorimer et al. (2007), lay towards the Small Magellanic Cloud. This motivated us to observe towards another of the Milky Way’s small companion galaxies, the Carina dwarf spheroidal (Car dSph), which lies 101±5 kpc away. Car dSph is unique among the Milky Way’s dwarf satellites in having undergone three widely spaced episodes of star formation, and the Galaxy’s contribution to the DM in its direction is expected to be low. We hoped to detect pulsars in Car dSph and use them to identify the Local Group’s contribution to the DM along this line of sight.

We observed the Car dSph field with the multibeam receiver on the Parkes telescope, making a series of one-hour observations. Just 20 minutes into the second hour, our real-time detection pipeline (HEIMDALL, developed by Swinburne University) registered a transient event at a DM of 779 cm⁻³ pc, with a signal-to-noise ratio of 30. We had found FRB 131104.

We re-observed the Car dSph field for the following three hours, then over the next three days, and yet again over the next year, for 78 hours in all. But the FRB did not repeat and we saw no other unusual events.

We detected FRB 131104 in only beam 5 of the 13-beam receiver. At the time, that beam was directed towards stellar debris associated with the Large Magellanic Cloud. But the beam was also close to Car dSph’s tidal ellipse, so the FRB may also have come from the direction of that galaxy.

Given the high DM, if the FRB came from Car dSph then its source must lie behind gas with an electron density ten times that of the Milky Way’s. This might be provided by the Magellanic Stream, part of which lies along the sightline to Car dSph.

If FRB 131104 did indeed originate so near the Milky Way, could it be a form of giant pulse emission? The brightest such event from the Crab pulsar was recorded with the Arecibo telescope: had it occurred at the distance of Car dSph, Parkes would have detected it with a signal-to-noise ratio of ~26. To investigate this possibility further, we need an independent estimate of the line-of-sight DM to Car dSph. For the moment, the origins of FRB 131104 remain open.

**PUBLICATION**

The 21-cm spectral line of neutral hydrogen (H I) can trace features showing interactions between galaxies and tell us about the size, mass and structure of galaxies at different epochs – clues as to how they have evolved over cosmic time. But H I in emission has been detected only out to z < 4 for individual galaxies. Stacking pushes detections to higher redshifts but gives the properties of ensembles, not individual galaxies. However, the H I absorption line can be detected at almost any redshift, provided there is a sufficiently bright background source against which to search.

Next-generation radio telescopes will conduct the first large-scale blind absorption-line surveys, such as FLASH (the ‘First Large Absorption Survey in H I’). FLASH will use the Australian Square Kilometre Array Pathfinder to search for H I absorption along 150,000 sightlines, studying the evolution of neutral hydrogen in the redshift range 0.5<z<1.0 (lookback times of ~4–8 Gyr). How many detections can we expect from FLASH? To get an indication, we have used the Compact Array to carry out a small-scale study in two stages, using a total of 16 nearby (z<0.04), gas-rich galaxies, viewed along 23 sightlines.

Our sample consisted of galaxies drawn from the HIPASS (HI Parkes All-Sky Survey) Bright Galaxy Catalogue, cross-matched with background sources from the SUMSS (Sydney University Molonglo Sky Survey) catalogue. By selecting low-redshift galaxies we were able to map the targets in H I emission, allowing us to directly relate the gas distribution to the absorption-line detection rate.

We detected absorption in just one target, NGC 5156 (a barred spiral galaxy at z= 0.01), 19 kpc away from the galaxy’s centre. Previous studies have estimated there is ~40–50 per cent chance of detecting an absorption line within 20 kpc of a galaxy’s centre so why did we not detect more? First, the background radio sources in our sample were generally much fainter than those in other surveys. Second, while previous studies used bright, compact quasars as their background sources, we used an unbiased sample of radio sources, selecting the sources only by radio flux and not source type (meaning that ~90 per cent were radio galaxies and only ~10 per cent were quasars). Both factors meant that our background sources were less likely to show absorption than those in previous studies.

Our results are therefore likely to be more representative of the expected detection rate for future blind surveys such as FLASH. We estimate that for an unbiased sample of radio sources brighter than 50 mJy the expected detection rate is probably around 5–10 per cent. This means that with FLASH we can expect to detect thousands of new H I absorption-line systems.

**PUBLICATIONS**


In 2015 the team operating LIGO (the Laser Interferometer Gravitational-Wave Observatory) made its first stunning discovery (announced in 2016) of gravitational waves from two merging black holes, each of about 30 solar masses. The confirmation of black holes in this mass range, and the rapidity with which LIGO detected the merger, sent scientists back to the drawing board. In 2015 we too published a study, based on observations from the Parkes telescope, which suggests that we need to revise ideas about a source of gravitational waves: in this case, supermassive black holes.

These black holes, of more than $10^6$ solar masses, seem to be ubiquitous in large galaxies in today’s Universe. The existence of quasars shows they also inhabited galaxies in the early Universe. Galaxy mergers, presumed to be common at that time, must create binary pairs of supermassive black holes that themselves eventually spiral together and coalesce. When the black holes get close enough together they become strong emitters of gravitational waves, sending space-time ripples on a billion-year trajectory toward Earth. The combined signal from all the binary supermassive black holes in the Universe creates a background rumble of gravitational waves.

We can search for this background by monitoring, over years to decades, a set of superfast ‘millisecond’ pulsars. When travelling across the line of sight between Earth and a pulsar, gravitational waves stretch and shrink the distance between the two by a tiny amount. This change should show up in the arrival times of the pulsar’s radio pulses, which can be measured with a precision of around 20 nanoseconds. The gravitational-wave background should become clearer as an observing campaign grows longer.

As part of the Parkes Pulsar Timing Array (PPTA) program, we have been monitoring 24 pulsars with the Parkes telescope to search for gravitational waves. We now have a dataset spanning 11 years, three years longer than any comparable one: its longer duration (plus better methods of analysis) means that it is more sensitive to gravitational waves. But when we analysed it in 2015 we found no sign of the gravitational-wave background! Consequently, we have been able to use this dataset to place a very strong limit on the background, six times more stringent than any before.

Our result suggests that at least one of the assumptions underlying the models of gravitational-wave backgrounds is incorrect. For instance, the black holes may lose energy through viscous drag from surrounding gas and so come together and coalesce more rapidly than expected; if that were so, the binaries would spend less time emitting gravitational waves, reducing the amplitude of the gravitational-wave background at low frequencies.

Our result implies that detecting gravitational waves will probably require observations over many more years. Higher-cadence and shorter-wavelength observations may also help. In addition, our observing sensitivity will be boosted by new technology, such as the ultra-wideband receiver planned for Parkes (page 36).
Since their discovery, dusty star-forming galaxies (DSFGs) at high redshifts have challenged models of galaxy evolution. Their infrared luminosities imply star-formation rates of 100–1000 solar masses per year, which would turn them into massive, quiescent galaxies in only a hundred million years. Dusty star-forming galaxies are faint, and only a handful of sources (mostly lensed) have been observed in detail. As a result, we have known little about the distribution and quantity of the star-forming gas within them.

A breakthrough occurred when the South Pole Telescope (SPT) discovered a population of rare but extremely bright millimetre-selected galaxies. Follow-up observations with several telescopes, including the Compact Array, showed that these objects are strongly gravitationally lensed. Using ALMA (the Atacama Large Millimeter/submillimeter Array) we obtained unambiguous CO-based redshifts for 19 SPT sources. This doubled the number of starbursts known at z>4; indeed, our sample has two of the highest-redshift DSFGs known. Both have lens models that allow us to derive the galaxies’ intrinsic gas and dust properties. SPT0538–50 appears to be a pair of merging galaxies (as Bothwell et al. 2013 posited), while SPT0346–52 looks more like a merger than like the massive rotating disks normally seen in star-forming galaxies at intermediate redshifts; however, deeper observations will be needed to confirm this.

With the wealth of high-resolution data provided by the Compact Array, we were also able to calculate the conversion factor between CO luminosity and molecular gas mass, $\alpha_{\text{CO}}$, in more than one way (we used gas-to-dust ratio, the dynamical gas of the galaxies, and the CO luminosity surface density) and compare the results of the different methods. There was reasonably good agreement, giving an average value for $\alpha_{\text{CO}}$ of 1.3 for SPT0346–52 and 1.5 for SPT0538–50. These conversion factors are similar to those determined for other rapidly star-forming systems.

**PUBLICATION**
Facility operations

CSIRO Chief Executive Larry Marshall admiring a feedhorn under construction at CASS
Input from the user community

The users of ATNF telescopes contribute to ATNF decision-making through an advisory group, the Australia Telescope User Committee (ATUC), the members of which are listed in Appendix A. ATUC considers current operations, priorities for future developments, and other matters raised by the user community, then makes recommendations to the ATNF Director: most recommendations are accepted and implemented. This year ATUC met in June and November. Its reports to the ATNF Director, and the Director’s replies, can be found at: http://www.atnf.csiro.au/management/atuc/index.html.

WORKSHOPS, MEETINGS AND COLLOQUIA

In 2015 the ATNF hosted a number of workshops and meetings for the benefit of the astronomical community:

- **ATNF data-reduction workshop** (2–5 June) – for all researchers needing to process data from ATNF telescopes
- **Australia Telescope Users Committee science discussion** (1 June) – an open discussion for all researchers on the use of ATNF facilities
- **H I in Dwarf Galaxies** (15–16 July) – for researchers studying dwarf galaxies
- **International Pulsar Timing Array student workshop** (19–24 July) – for students (primarily at PhD level) to hear from IPTA experts
- **International Pulsar Timing Array 2015 meeting** (20–31 July) – for international researchers using millisecond-pulsar timing to search for gravitational waves
- **Supermassive Black Hole Growth and Evolution workshop** (27 July) – for researchers working on the evolution of supermassive black holes
- **Radio Astronomy School** (28 September–2 October) – techniques of radio astronomy, mainly for postgraduate students
- **ASKAP Early Science community workshop** (8 October) – for all researchers involved in ASKAP’s Early Science program
- **Towards an SKA for WA seminar** (21 October) – the first major event held by CASS in Perth, this meeting was to update stakeholders and project partners about activities and planning for Square Kilometre Array project
- **Combined Bolton and student symposium** (2 December) – an event to showcase work carried out with Australian facilities.

In addition, at its Marsfield headquarters the ATNF runs a program of regular colloquia, usually given by researchers visiting from other countries or other parts of Australia. Thirty-three (33) talks were given this year.
Prototype feedhorns for the 4cm band were installed on the Compact Array in late 2012. These extended the top end of the receiver range from 10.8 GHz to 12 GHz. Following this successful upgrade, this year we added two further feeds to the array, leaving only antennas CA01 and CA06 with the old feeds.

An intermittent problem with occasional phase jumps, seen initially on antenna CA03, was finally traced to an on-board oscillator and we began a program of replacing this component.

During a two-week shutdown in May and June we replaced the control-building switchboard and installed a new generator.

The array’s cryogenic compressors are cooled by fans. In previous summers, hot westerly winds have sometimes overwhelmed these fans, leading the array to perform a ‘heat stow’. This December we solved the problem by installing new fan shrouds, which provide extra air movement. And, after many years of service, the last of the active hydrogen masers used at the Compact Array and Mopra were refurbished.

To supplement the existing documentation for the Compact Array, this year we made the first two of a series of planned observer-training videos. These have been well received by telescope users.

In November CASS informed the user community of its intention to implement a program of ATCA Legacy Projects from the 2016OCT semester. Legacy Projects will be large, coherent science investigations, not reproducible by any combination of smaller projects, that generate data of general and lasting importance to the broad astronomical community.

Legacy Projects will typically each require more than 2000 hours of observing time, with probably more than 300 hours being allocated each semester.

Legacy Projects recognise that the ATCA is a mature, highly versatile radio interferometer, and is set to remain a forefront instrument until at least the completion of SKA phase 1. Its broadband instrumentation provides high sensitivity for spectral-line, continuum and polarisation studies over an exceptionally wide frequency range (1–105 GHz), a range that complements those of ASKAP (0.7–1.8 GHz) and the Atacama Large Millimeter/submillimeter Array, ALMA (> 90 GHz). Up to 25 per cent of observing time may be allocated to Legacy Projects from 2016OCT onwards. A call for Expressions of Interest was issued in December to gauge the level of community interest and to help CASS put appropriate arrangements in place to conduct Legacy Projects.
FACILITY REPORT: PARKES

The Parkes telescope enjoyed another productive year of observations in 2015, with pulsar timing and searches for pulsars and fast radio bursts (FRBs) accounting for most of the observing time. Parkes remote observing has gone well, aided by the Telescope Protection System. Following feedback from telescope users, the remote-observing requirements were modified during the year. First-time observers still need to come to the Science Operations Centre (SOC) in Sydney for training ahead of their observations, but the many Parkes users who are frequent observers no longer have to visit the SOC annually to re-qualify.

A significant piece of sleuthing this year identified the source of perytons: transient radio signals, lasting for just milliseconds, which were first detected at Parkes in 2011. From the beginning, researchers had suspected that perytons were terrestrial in origin, yet they showed frequency-swept emission, mimicking (although imperfectly) fast radio bursts. They were detected only a handful of times every year, making them difficult to track down. But the installation of the new radio-frequency interference monitor at the observatory in December 2014 made it possible to clearly establish that they were terrestrial interference (from microwave ovens). The same work clearly distinguished them from the FRBs, which still appear to be genuine extragalactic transients.

Parkes will be used to commission a phased array feed (PAF) that CASS is building for the Max Planck Institute for RadioAstronomy (MPIfR) in Germany. The PAF is to be used on the Effelsberg 100-m telescope near Bonn. By testing the PAF on Parkes we will gain a more detailed understanding of PAF performance and ensure that the MPIfR will receive a fully characterised PAF. We prepared for the PAF’s installation during a two-week shutdown at Parkes in late November/early December, running optical fibre from the focus cabin to the telescope tower. The PAF will replace the 20-cm multibeam receiver for up to eight months from early 2016: users were advised of this in the proposal calls for the 2015APR and 2015OCT observing semesters. To allow pulsar timing to continue during this period there will be regular (monthly) changes of receiver, the 10-cm/50-cm and H-OH receivers being used alternately.

In November and December Parkes and the Compact Array were used together with the 70-m antenna of the Canberra Deep Space Communication Complex at Tidbinbilla to conduct bistatic radar observations of two near-Earth asteroids, the Tidbinbilla antenna transmitting while Parkes and the Compact Array received the reflected signals. During this experiment the data stream was recorded on both a NASA-format recorder and VLBI (very long baseline interferometry) data recorders, to test the feasibility of using the latter for future experiments.

In July it was announced that Parkes would be a key element of the Breakthrough Listen project, a search for extraterrestrial intelligence (SETI) program funded by the Breakthrough Prize Foundation. Breakthrough Listen will use 25 per cent of the available observing time from October 2016. Opportunities for commensal use of this time are being explored.
FACILITY REPORT: MOPRA
For the past three years, the National Astronomical Observatory of Japan (NAOJ) and a consortium of the University of New South Wales and the University of Adelaide have contributed to the funding of Mopra’s operations, and in return have been allocated blocks of observing time. Some observing time has been reserved as ‘National Facility time’: this has been used for a number of single-dish programs and for Mopra’s participation in Long Baseline Array projects (see below). The agreement that governed this operating arrangement came to an end in October this year.

In May 2014 CSIRO announced it would cease funding Mopra. We have since held discussions with parties interested in operating Mopra. We expect that routine maintenance of the facility will be contracted back to CASS on a full cost-recovery basis.

The bushfire of 2013 damaged Mopra’s site (although the telescope itself was little affected). This year we completed the final tidying-up, replacing the switchboard and putting a permanent roof over the remaining portion of the old control building.

FACILITY REPORT: LONG BASELINE ARRAY
The ATNF’s Long Baseline Array (LBA) is a set of telescopes used together for simultaneous observations, a technique called very long baseline interferometry (VLBI). The core elements of the LBA are the ATNF’s three telescopes in New South Wales (Parkes, Mopra and the Compact Array) and two telescopes of the University of Tasmania: the Hobart 26-m antenna (in Tasmania) and the Ceduna 30-m (in South Australia). Other telescopes that can be used in the VLBI network are: the 70-m and 34-m antennas at the Canberra Deep Space Communication Complex at Tidbinbilla; a single ASKAP antenna with a traditional ‘single-pixel’ feed; the Hartebeesthoek 26-m and 15-m antennas in South Africa; and the Warkworth 12-m and 30-m antennas in New Zealand. Since 2008, data from the Long Baseline Array has been correlated at Curtin University under a contract with ATNF. This arrangement came to an end in September 2015, and the task of correlating the data has returned in-house. Cormac Reynolds, previously at Curtin University, joined CASS in October and is putting his experience and expertise in operating the DiFX software correlator to good use in his new role.

The capabilities of the LBA have been enhanced by the AuScope antennas of the University of Tasmania, which join our telescopes for observations at 2.3 and 8.4 GHz when their other commitments allow. A new 15-m antenna at Hartebeesthoek (South Africa), operating at the same bands, has allowed that site to join observations too, even when the main 26-m antenna at the site has been unavailable. Auckland University of Technology has recently taken ownership of a 30-m antenna, previously used for telecommunications, at Warkworth in the South Island of New Zealand. The antenna’s 6.7-GHz receiver means it can join in observations of the 6.7-GHz spectral line from cosmic methanol masers, the subject of several ongoing LBA projects.

An out-of-session observation was made in September in support of Russia’s RadioAstron space VLBI mission, with a ground array that included the Australian LBA; the Green Bank Telescope, the Karl G. Jansky Very Large Array and the Very Long Baseline Array (all in the USA); the Korean VLBI Network; and the new 65m Tianma Shanghai telescope in China – possibly the largest network the LBA has ever observed with.
This year the ASKAP commissioning team collected about 192 TB of BETA data. Three terabytes (3 TB) have been publicly released as demonstration data and will be used by the team developing the CSIRO ASKAP Science Data Archive (CASDA), the first version of which was released in November. Another team is working closely with the commissioning team and the ASKAP Survey Science Teams to deliver the bespoke data-reduction software, ASKAPsoft (details, page 37).

At the year’s end there were around 20 more second-generation PAFs on the production line in the Sydney workshop, and a number of completed systems undergoing final tests or crated-up and ready for shipping to site.

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The 150-square-degree image of the Tucana field produced during commissioning observations with the Boolardy Engineering Test Array (BETA). This image contains around 2000 sources above five sigma. Credit: Keith Bannister (observations) and Ian Heywood
The ASKAP Early Science program will begin in 2016, using ASKAP antennas equipped with the second-generation PAFs. In December, a project team led by CASS’s Lisa Harvey-Smith secured 750,000 core hours of processing time for the Early Science data on the Magnus supercomputer at the Pawsey Supercomputing Centre in Perth, Western Australia. The time was awarded through the competitive National Computational Merit Allocation Scheme.

The first science papers based on BETA commissioning data were published this year:


Big strides were taken this year towards securing a permanent power supply for ASKAP’s site, the Murchison Radio-astronomy Observatory. CSIRO appointed Perth-based company EMC (Energy Made Clean) to supply around 6000 panels for a 1.6 solar array and a 2.5-MWh lithium storage battery (one of the largest in Australia), while the WA State Government approved a power supply agreement between Horizon Power and CSIRO for the supply of electricity to the MRO. Construction of a permanent hybrid (solar and diesel) power station will begin in 2016.
Technology and software development

AN ULTRA-WIDEBAND FEED FOR PARKES

About half the observing time on Parkes is used for pulsar studies that require a single beam, either the central beam of the multibeam receiver or the 10-cm/50-cm receiver. Making these observations more efficient would make the telescope significantly more efficient overall.

To do this, and to improve the sensitivity and precision of low-frequency observations, CASS is developing an ultra-wideband receiver that covers the band 0.7–4.0 GHz. CASS’s Alex Dunning has designed a new feed with exceptional polarisation properties and close to constant beamwidth (that is, dish illumination) and focal position over this nearly 6:1 frequency range. CSIRO has applied for a patent for this new design.

A new digital signal-processing system will complement the feed and receiver. This year CASS’s Paul Roberts developed both hardware and firmware for this, and assembled a prototype signal chain.

A PHASED ARRAY FEED FOR EFFELSBERG

Through an agreement with the Max Planck Institute for Radioastronomy in Germany (MPIfR), CSIRO has been building a phased array feed (PAF) receiver for the 100-m Effelsberg telescope in Germany. This PAF will operate in the 1150–1800 MHz band. It will be commissioned on the Parkes telescope from early 2016, remaining there for up to eight months. A specially designed GPU cluster and Ethernet switch will be installed as the system’s backend; MPIfR will coordinate the coding of the processing software. While on Parkes the PAF will be used to search for ‘fast radio bursts’—cosmic radio signals, lasting on the order of a millisecond, that have so far resisted explanation.
DATA REDUCTION FOR ASKAP

In its final form, ASKAP will produce an enormous data rate: 70 TB of correlated visibilities in an eight-hour observation. Handling this torrent will require high-performance calibration and imaging pipelines. The ASKAPsoft package has been developed to meet the challenge. The imaging algorithms and framework are designed to accord with the processing requirements on memory and run-time, and scientific requirements such as dynamic range.

ASKAPsoft will run in pipelines on the Galaxy supercomputer at the Pawsey Supercomputing Centre in Perth, Western Australia. Because ASKAP will be primarily a survey telescope, these pipelines will run in near real-time, starting when an observation is complete and finishing in time to process the next.

The Boolardy Engineering and Test Array (BETA) – six ASKAP dishes equipped with first-generation phased array feeds (PAFs) – was able to generate nine dual-polarisation beams. BETA datasets were small enough to not require real-time processing and could be processed by other, more established (if not high-performance) software packages. This has allowed us to validate the ASKAPsoft algorithms by comparing their performance with well-understood workflows.

We developed a pipeline that reflects the typical observing strategy used for BETA: dedicated calibrator observations, followed by a target or science field. Separate PAF beams were processed independently prior to mosaicing to form the final image.

The next-generation PAFs are now being deployed on ASKAP antennas, and will be used to conduct the ASKAP Early Science program. Early Science data will be processed by ASKAPsoft pipelines built on those used for BETA, and which incorporate improvements identified in commissioning.

As the ASKAP array grows, its increased sensitivity will mean a real-time calibration pipeline becomes more feasible, and the progressively larger data rates will eventually require a move to online (rather than offline, user-driven) processing.

NEW SOURCE-FINDING SOFTWARE

CASS’s Paolo Serra and colleagues have developed and made available for download new software, SOFIA, which is designed to detect and parameterise sources in 3D spectral-line datasets. SOFIA has been developed with future H I surveys in mind – surveys such as WALLABY and DINGO that will be done with the Australian SKA Pathfinder, and the APERTIF survey on the Westerbork telescope in the Netherlands. However, the software can be used on a wide range of datasets. It can search for line emission, on multiple scales, to detect 3D sources in a complete and reliable way; estimate the reliability of individual detections; look for signal in arbitrarily large data cubes; and provide output products that can be further analysed. SOFIA is modular, and can be expanded as new methods become available.
SPECTRUM MANAGEMENT

Both radio telescopes and the antennas of NASA’s Deep Space Network use extremely sensitive radio receivers, and both radio astronomy and spacecraft communications are impeded by man-made radio-frequency interference (RFI). For these activities to continue, the frequency bands allocated to them need to be protected. More general ‘spectrum management’ is also increasingly important because new telescopes such as the Square Kilometre Array will attempt to access most of the radio spectrum.

At the international level, the radio spectrum is regulated by the International Telecommunication Union (ITU); the international treaty called the ‘Radio Regulations’ is updated every four years via the World Radiocommunication Conference (WRC). In Australia, spectrum regulation is handled by the Australian Communications and Media Authority (ACMA).

CSIRO strives to protect spectrum for both radio astronomy and space research. This requires a good working relationship with ACMA, the ITU and other regional and international forums, and with the Department of Defence and other major users of the radio spectrum. CSIRO also works to gain more specific protection for radio observatories and deep-space facilities. These efforts have led to the establishment of a ‘Radio Quiet Zone’ around the Murchison Radio-astronomy Observatory in Western Australia and ‘Radio Notification Zones’ around other radio observatories.

Highlights of this work in 2015 were:

- active participation in the ITU-R World Radiocommunication Conference, which made substantial changes to international spectrum allocations. Prior to the WRC (held in November), CSIRO was involved in ACMA processes to develop Australia’s position for WRC agenda items, to ensure protection of radio astronomy and space research spectrum. CSIRO also participated in ITU meetings leading up to the WRC, developing studies relevant to the agenda items
- leading the ITU-R studies in Working Party 7D and Working Party 3M
- election of Carol Wilson from CSIRO as Chairman of ITU-R Study Group 3 (Radiowave Propagation)
- representing radio-astronomy and space research interests in the Department of Communications’ review of the spectrum-management framework.

The extreme radio quietness of the Murchison Radio-astronomy Observatory is protected by a Radio Quiet Zone. Photo: Pete Wheeler (ICRAR)
SQUARE KILOMETRE ARRAY PROJECT

The international Square Kilometre Array (SKA) project experienced a number of key events during the year that carried the telescope a step closer to the construction phase: these included the release of the SKA Science Book, the announcement of a permanent headquarters in the UK and annual meetings for the science and engineering communities.

In March, the SKA Board of Directors met to discuss Phase 1 design (SKA1) of the future mega-science project. A recommendation was made for a re-baselined SKA1, in which the design of the €650M first phase would consist of two complementary SKA instruments:

- SKA1-mid: 200 parabolic antennas in South Africa (including the 64 MeerKAT dishes)
- SKA1-low: 130,000 low-frequency aperture-array (dipole) antennas in Australia.

CSIRO continued its involvement in the SKA project through seven of the 11 SKA R&D consortia, as lead of the Dish and Infrastructure-Australia consortia, and as a key partner in Assembly, Integration and Verification (AIV).

Implications of the re-baselining process included a change to CSIRO’s involvement in the Central Signal Processing (CSP) Consortium. As of 2015, CSIRO now leads the CSP sub-element design team, Low.CBF, which is focused on the design of the correlator and beamformer for SKA1-Low. Collaborators from ASTRON (Netherlands) and the Auckland University of Technology (New Zealand) are also part of this team.

Negotiations also began with SKA member governments, including Australia, to establish the SKA Organisation as an Inter-Governmental Organisation (IGO) regulated by a convention. The IGO convention will ensure strong governance for the project and a structure for the 50-year lifetime of the observatory. Negotiations will continue in 2016.

Toward the end of the year, an announcement by Australian Prime Minister Malcolm Turnbull included a provisional funding allocation for the SKA as part of the National Innovation and Science Agenda.

As part of the announcement, $293.7 million over 10 years was set aside to meet Australia’s initial commitment to the SKA. The allocation means that, contingent on a successful conclusion to the Convention negotiations and the development of a satisfactory business case, funding is available to meet Australia’s obligations to the construction and initial operation of SKA1.
Outreach and education

VISITORS CENTRES
In 2015 the Visitors Centre at the Parkes observatory attracted 87,139 visitors, significantly more than in 2014 (68,427). The number of students and teachers rose to 1,396 (from 1,183 in 2014), while the number of tour-group visitors fell to 1,636 (from 1,893 in 2014). The revenue from the Visitors Centre shop (and the online shop) rose to $730,191, up significantly from the $602,640 received in 2014.

This year the Compact Array received 11,316 visitors, a number essentially unchanged from 2014 (11,600).

With fewer staff on site, not all groups can be given a structured talk by a staff member; however, coach operators still consider the site a good destination.

OUTREACH
In addition to outreach that took place at the observatory visitors centres, CASS staff contributed to the following key events:

Perth Astrofest
This annual event, held on 28 March, attracted 3,000 people for a half-day of astronomy talks, exhibitions and sky viewing. Several CASS staff ran a CASS/SKA booth at which visitors were able to build Lego ASKAP antennas and learn more about ASKAP, the MRO and the SKA.

Geraldton Science Festival
At this two-day event (30–31 March), CASS staffed a booth and ran a marathon ten-hour PULSE@Parkes observing run for students, teachers then the public. This festival drew 1,000 people from the local region.

Murchison Astrofest
CASS speakers were well represented at this biannual event, held on 5 September. Bärbel Koribalski and James Allison gave talks about their work while Rob Hollow gave a tour of the night sky and ran daytime activities for the children.
COMMUNICATIONS

The ATNF uses a variety of channels for external communications.

Media releases

This year CSIRO issued four media releases related to the ATNF:

• Cosmic radio burst caught red-handed (19 January)
• We’ve revealed a galaxy far, far away … (6 July)
• CSIRO and Internet investor Yuri Milner strike deal for ET research (21 July)
• Eleven year cosmic search leads to black hole rethink (25 September).

The release of 6 July, which concerned a detection by ASKAP of neutral hydrogen in absorption, resulted in more than 200 hits on traditional media (print, radio, TV) and an estimated reach of many millions across social-media platforms. A co-ordinated approach with partner organisations within the international SKA project contributed to the impact of this release.

Campaigns

In 2015 CSIRO Communications ran themed campaigns to highlight older stories and long-running projects. The #CSIROspace campaign, which ran from mid June to mid July, saw an average increase in views to the profiled web pages of 69 per cent. A link posted to the ATNF’s ASKAP page as the first instalment of the series on Facebook received over 400 likes, almost 60 shares, and reached an audience of 19,000 people; the ASKAP page itself saw a 286 per cent jump in traffic after the link was posted, and received more visits than the CSIRO home-page features did during that week.

Websites

Visits to the central ATNF website reached 2.5 million this year, an increase of 22 per cent on 2014 numbers.

Blogs

The CSIROnews and CSIROuniverse blogs were merged in 2015 to become the CSIRO blog. During the year CASS contributed 28 posts, of which 19 were focused on the ATNF and nine on the CDSCC.

Internal CSIRO news

In 2015 we contributed 10 articles featuring ASKAP, ATNF people or sites/facilities to the CSIRO internal newsletter, Monday Mail.

ASKAP communications

CASS handles communication related to the Australian SKA Pathfinder project. In 2014 we generated 48 issues of the internal ASKAP weekly newsletter, two issues of the bulletin ASKAP Update and one ASKAP Commissioning Update, and provided support for public talks, visits to the Murchison Radio-astronomy Observatory, and other events.

ATNF Daily Astronomy Picture (ADAP)

The ATNF Daily Astronomy Picture (ADAP), which started in December 2014, has now launched more than 500 images to show ATNF science and engineering results, telescopes, colloquia and workshop announcements, and research highlights. Each day’s image can be accessed at www.atnf.csiro.au/ATNF-DailyImage, which has a link on the ATNF home page (www.atnf.csiro.au). The pictures also reach a broad audience through Twitter under the ‘handles’ of @CSIRO_ATNF and @HIgalaxies, and through Facebook and Feedly.
EDUCATION

The key education activities this year were:

Teacher workshops

Our Education and Outreach Specialist Rob Hollow ran a variety of workshop sessions at several science teacher events in Melbourne, Sydney and Geraldton.

School visit

In November students and staff from the Pia Wadjari Remote Community School visited the Murchison Radio-astronomy Observatory and toured ASKAP. This followed a day of hands-on astronomy activities at the school led by CASS staff.

PULSE@Parkes program

This program allows school students to observe with the Parkes telescope. A busy year of regular PULSE@Parkes sessions ended with a tour to Guangzhou, China, in December where team members Matthew Kerr, Shi Dai and Rob Hollow ran three sessions for students from a number of high schools in the Guangdong region. The sessions were webcast in China and attracted local media interest. The visitors also gave talks to students at Guangzhou University and public talks at the Guangdong Science Center. The tour was funded by Guangzhou University and organised by the University’s Professor Hongguang Wang.

Undergraduate Vacation Scholars

The 2015–2016 Undergraduate Vacation Scholarship Program saw 12 students from eight universities working on research projects with CASS staff over the summer. Their projects covered a diverse range of engineering and astrophysics topics, with several being related to PAFs and ASKAP. As well as working on their research projects the scholars visited the Australia Telescope Compact Array and in groups tackled an observing project of their choice, guided by Martin Bell and Robin Wark. The ten-week program concluded in mid-February with a student symposium.

The program continues to attract talented students eager to gain experience at CASS. Charlotte Ward, one of the 2015–2016 students, has now commenced an Honours project at the University of Sydney, co-supervised by CASS astronomer Matthew Kerr.
**STAFFING**

CASS's Perth office grew to eight staff by the year’s end. However, total ATNF staff levels rose only slightly, as recruitment was largely offset by cessations. Twenty-four staff ceased employment in 2015 as a result of resignation (8), retirement (3), term employment ending (11) and redundancy (2).

**DIVERSITY AND EQUITY**

In 2014 CASS formed a Diversity Committee to identify, implement, and monitor issues and initiatives related to diversity and equity, and to ensure that all staff are treated fairly and equitably. Chaired by Dr Jill Rathborne, the committee is itself diverse, with members from different sites, research programs and levels of the organisation.

Through its initial consultations the committee learned that staff were largely unaware of CSIRO’s policies and support related to diversity and equity, so as its first task this year the committee established a new CASS diversity website, [http://www.atnf.csiro.au/resources/diversity.html](http://www.atnf.csiro.au/resources/diversity.html). This is now the repository for information around diversity and inclusion, including CASS initiatives.

The topic of sexual harassment was vigorously discussed in the international astronomical community in 2015. This prompted the CASS Director, Lewis Ball, to clearly set out CASS policies and procedures in a notice to staff in October. The message sent a clear statement of support to anyone who had been the target of harassment or had reported inappropriate behaviour. It further reminded staff of our commitment to developing and maintaining a culture that respects, values and actively pursues the benefits of a diverse workforce, and in which discriminatory policies and practices are not tolerated.

The Diversity Committee has discussed developing and implementing a Code of Conduct that sets out appropriate behaviour for all the conferences we organise. At the committee’s recommendation, this was trialled at a CASS-organised event (the Supermassive Black Hole Workshop) in 2015. It was well received by the participants and provoked discussions about diversity issues throughout the week. The Astronomical Society of Australia (ASA) recently updated its own Code of Conduct for participants at ASA-endorsed meetings or activities. CASS will adopt this ‘community’ version of the Code of Conduct for all future meetings we host: we have already adopted it for the ASKAP conference planned for 2016.

The activities of the Diversity Committee are outlined in its annual report, [http://www.atnf.csiro.au/CASS_Diversity_Committee_AR15.pdf](http://www.atnf.csiro.au/CASS_Diversity_Committee_AR15.pdf). This also includes results of the annual demographic review and updates on other actions taken by the committee.
We carried out 19 reviews of HSE-related issues within CASS. This is similar to the number of reviews last year (23).

Reported lost-time injuries (LTI) in 2015 related to insect bites, verbal conflict and a fractured finger. The two medical-treatment injuries (MTI) related to manual handling.

Table 2. ATNF Health and Safety training sessions

<table>
<thead>
<tr>
<th>COURSE NAME</th>
<th>ATTENDEES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Resuscitation</td>
<td>5</td>
</tr>
<tr>
<td>Asbestos Awareness and Management</td>
<td>7</td>
</tr>
<tr>
<td>Emergency Management Overview</td>
<td>1</td>
</tr>
<tr>
<td>HSE Principles of Contractor Management</td>
<td>17</td>
</tr>
<tr>
<td>ICAM Lead Investigator Course</td>
<td>2</td>
</tr>
<tr>
<td>Introduction to Emergency Management</td>
<td>1</td>
</tr>
<tr>
<td>Managing Mental Health at Work – Leaders</td>
<td>11</td>
</tr>
<tr>
<td>Mental Health Awareness for Managers</td>
<td>1</td>
</tr>
<tr>
<td>Starting with Your Safety</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>53</strong></td>
</tr>
</tbody>
</table>

Table 3. CASS health and safety incidents, 2012–2015. (1) E incidents = environmental incidents (2) H&S = health and safety (3) LTI = lost-time injuries: injuries that resulted in the loss of one or more whole days after the date of the injury (4) MTI = medical-treatment injury: an injury requiring medical treatment other than first-aid.

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>E INCIDENTS</th>
<th>H&amp;S INCIDENTS *</th>
<th>LTI</th>
<th>MTI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 2012 to Dec 2012</td>
<td>0</td>
<td>16</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Jan 2013 to Dec 2013</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Jan 2014 to Dec 2014</td>
<td>1</td>
<td>14</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Jan 2015 to Dec 2015</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

* Injuries only (not inclusive of hazards and near miss incidents)
ASKAP TEAM WINS 2015 CHAIRMAN’S MEDAL

In October the team behind ASKAP received CSIRO’s highest honour, the Chairman’s Medal. This award recognises exceptional research teams that have made significant scientific or technological advances of national, international and/or commercial importance. The citation for the award reads,

“For revolutionising astronomy by developing a spectacular new capability for observing wide areas of the sky using the world’s first widefield imaging receivers for radio astronomy on the antennas of the ASKAP radio telescope.”

Eleven team members attended the awards ceremony in Canberra while the rest of the team, spread across six sites, celebrated simultaneously.

L’ORÉAL FELLOWSHIP

In September CASS’s Shari Breen was named as a L’Oréal – UNESCO For Women in Science Fellow, for her work on providing an evolutionary timeline for high-mass star formation. Along with three other outstanding female scientists, Shari was selected from a field of over 240 applicants from Australia and New Zealand. The Fellowship comes with a prize of $25,000 to help recipients further their research. L’Oréal and UNESCO founded the program in 1998 to promote greater participation of women in science.

EUREKA PRIZE FINALIST

In October CASS’s Lisa Harvey-Smith, the ASKAP Project Scientist, was named as one of three finalists in the Science Communication and Journalism section of the prestigious Australian Museum Eureka Prizes. The citation described her as “a dynamic communicator bringing to life astronomy and its real-world impacts, particularly for girls and Indigenous Australian students.”
ATNF management team

ATNF DIRECTOR AND DIRECTOR CSIRO ASTRONOMY AND SPACE SCIENCE
Lewis Ball

DEPUTY DIRECTOR
Sarah Pearce

ASSISTANT DIRECTOR, OPERATIONS
Douglas Bock

ASSISTANT DIRECTOR, ASKAP
Antony Schinckel

ASSISTANT DIRECTOR, ENGINEERING
Tasso Tzioumis

ASSISTANT DIRECTOR, ASTROPHYSICS
Simon Johnston

ASSISTANT DIRECTOR, WESTERN AUSTRALIA
Phil Crosby

OPERATIONS MANAGER
Warren Bax
Wildflowers at the MRO.

Photo: Mark Leach
A: Committee membership

ATNF Steering Committee in 2015

CHAIR
Dr Susan Barrell, Bureau of Meteorology

MEMBERS

Ex-officio
Professor Warrick Couch, Australian Astronomical Observatory
Mr Brendan Dalton, CSIRO Chief Information Officer
Dr David Williams, CSIRO National Facilities and Collections

Australian-based astronomers
Professor Elaine Sadler, University of Sydney
Professor Mark Wardle, Macquarie University
Professor Stuart Wyithe, University of Melbourne

International advisers
Professor Neal Evans, University of Texas at Austin, USA
Professor Raffaella Morganti, ASTRON, The Netherlands
Professor Na Wang, Xinjiang Astronomical Observatory, China

Broader community
Dr Susan Barrell, Bureau of Meteorology
Professor Robyn Owens, University of Western Australia

Australia Telescope User Committee in 2015

CHAIR
Associate Professor Virginia Kilborn, Swinburne University of Technology (2014–2017)

SECRETARY
Dr Joanne Dawson, (Oct 2014–May 2017) Macquarie University and CSIRO Astronomy and Space Science

MEMBERS
Dr Minh Huynh, University of Western Australia (Oct 2012–May 2015)
Dr Evan Keane, Swinburne University of Technology*(Oct 2014–May 2017)
Dr Vanessa Moss, University of Sydney (Oct 2015–May 2018)
Dr James Miller-Jones, Curtin University (Oct 2014–May 2017)
Dr Paolo Serra, CSIRO Astronomy and Space Science (Oct 2014–May 2017)
Dr Stuart Ryder, Australian Astronomical Observatory (Oct 2015–May 2018)
Dr Stas Shabala, University of Tasmania (Oct 2014–May 2017)
Dr Willem van Straten, Swinburne University (Oct 2015–May 2018)
Dr Tobias Westmeier, University of Western Australia (Oct 2012–May 2015)

STUDENT MEMBERS
Mr Andrew Butler, University of Western Australia (Oct 2015–May 2016)
Ms Claire-Elise Green, University of New South Wales (Oct 2014–Nov 2015)
Mr Vasaant Krishnan, University of Tasmania (Oct 2014–May 2015)

*Now at the Square Kilometre Array Organisation in Manchester, UK

The Australia Telescope Steering Committee appoints the members of the Australia Telescope User Committee (ATUC). New ATUC members usually start their three-year term with the October/November meeting in their first year and finish their term after the May/June meeting in their last year. Students are usually appointed for one year (two meetings). Dates of the first and last meetings are given.

Australia Telescope Time Assignment Committee (as of December 2015)

CHAIR
Professor Sarah Maddison, Swinburne University of Technology

MEMBERS

Ex-officio
Dr Douglas Bock, CSIRO Astronomy and Space Science (Assistant Director, Operations)
Dr Philip Edwards, CSIRO Astronomy and Space Science (Head of Science Operations)
Dr Jill Rathborne, CSIRO Astronomy and Space Science (TAC Executive Officer)

Voting members
Dr James Allison, CSIRO Astronomy and Space Science
Dr Hayley Bignall, Curtin University
Dr Julia Bryant, Australian Astronomical Observatory
Dr Joanne Dawson, Macquarie University and CSIRO Astronomy and Space Science
Dr Alan Duffy, Swinburne University of Technology
Dr Ryan Shannon, Curtin University and CSIRO Astronomy and Space Science
Dr Roberto Soria, Curtin University and CSIRO Astronomy and Space Science
Dr Ivy Wong, University of Western Australia

Professor Sarah Maddison, Swinburne University of Technology
Dr Ryan Shannon, Curtin University and CSIRO Astronomy and Space Science
Dr Roberto Soria, Curtin University
Dr Ivy Wong, University of Western Australia

Administrative support
Amanda Gray, CSIRO Astronomy and Space Science

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### B: Financial summary

The table below summarises the revenue and expenditure applied to CSIRO’s radio astronomy activities, also including related activities resourced from the CSIRO Digital Productivity Flagship.

<table>
<thead>
<tr>
<th></th>
<th>YEAR TO 30 JUNE 2011 (A$’000)</th>
<th>YEAR TO 30 JUNE 2012 (A$’000)</th>
<th>YEAR TO 30 JUNE 2013 (A$’000)</th>
<th>YEAR TO 30 JUNE 2014 (A$’000)</th>
<th>YEAR TO 30 JUNE 2015 (A$’000)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Revenue</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External</td>
<td>7,181</td>
<td>13,726</td>
<td>4,213</td>
<td>10,179</td>
<td>13,209</td>
</tr>
<tr>
<td>Appropriation</td>
<td>36,419</td>
<td>35,623</td>
<td>35,668</td>
<td>41,803</td>
<td>40,473</td>
</tr>
<tr>
<td><strong>Total revenue</strong></td>
<td>43,600</td>
<td>49,349</td>
<td>39,881</td>
<td>51,982</td>
<td>53,682</td>
</tr>
<tr>
<td><strong>Expenses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salaries</td>
<td>14,046</td>
<td>14,884</td>
<td>16,688</td>
<td>17,723</td>
<td>19,545</td>
</tr>
<tr>
<td>Travel</td>
<td>1,080</td>
<td>1,093</td>
<td>1,432</td>
<td>1,325</td>
<td>1,429</td>
</tr>
<tr>
<td>Other operating</td>
<td>5,028</td>
<td>5,081</td>
<td>5,143</td>
<td>7,157</td>
<td>9,334</td>
</tr>
<tr>
<td>Overheads*</td>
<td>12,914</td>
<td>13,055</td>
<td>12,725</td>
<td>14,709</td>
<td>14,506</td>
</tr>
<tr>
<td>Corporate support services</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Depreciation and amortisation</td>
<td>3,953</td>
<td>4,081</td>
<td>4,628</td>
<td>7,095</td>
<td>7,513</td>
</tr>
<tr>
<td>Doubtful debt expense</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total expenses</strong></td>
<td>37,021</td>
<td>38,194</td>
<td>40,616</td>
<td>48,009</td>
<td>52,327</td>
</tr>
<tr>
<td>Profit/(Loss) on sale of assets</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Operating result</strong></td>
<td>6,579</td>
<td>11,155</td>
<td>– 735</td>
<td>3,973</td>
<td>** 1,355</td>
</tr>
</tbody>
</table>

**Notes**

*Overheads include corporate support services and business-unit support services. Appropriation includes the amount of approved loss to CSIRO representing the amount of unfunded depreciation on assets (for 2014–2015 the figure was $7,480k).

**Operating surplus in 2014 and 2015 is predominately a result of actual depreciation being lower than forecast.
## Staff list

**ALL STAFF WHO WORKED FOR CASS ON RADIO-ASTRONOMY RELATED ACTIVITIES, AS OF DECEMBER 2015**

This list includes casual staff and honorary fellows, but not students or contractors.

<table>
<thead>
<tr>
<th>MARSFIELD</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen Graham</td>
<td>Engineering</td>
<td></td>
</tr>
<tr>
<td>Allison James</td>
<td>Astrophysics</td>
<td></td>
</tr>
<tr>
<td>Amy Shaun</td>
<td>Operations</td>
<td></td>
</tr>
<tr>
<td>Ball Lewis CASS</td>
<td>Engineering</td>
<td>CASS Director and ATNF Director</td>
</tr>
<tr>
<td>Bannister Keith</td>
<td>Astrophysics</td>
<td></td>
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<tr>
<td>Barker Stephen</td>
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<td></td>
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<td>Bateman Tim</td>
<td>Engineering</td>
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<td>Bax Warren Finance</td>
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<tr>
<td>Beresford Ron</td>
<td>Engineering</td>
<td></td>
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<tr>
<td>Bock Douglas</td>
<td>Operations</td>
<td></td>
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<td>Bourne Michael</td>
<td>Engineering</td>
<td></td>
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<td>Breen Shari</td>
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<td>Broadhurst Steven</td>
<td>Operations</td>
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<td>Broadhurst Sue</td>
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<td>Brothers Michael</td>
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<td>Engineering</td>
<td></td>
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<td>Bunton John</td>
<td>Engineering</td>
<td></td>
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<td>Castillo Santiago</td>
<td>Engineering</td>
<td></td>
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<td>Chapman Jessica</td>
<td>Operations</td>
<td></td>
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<td>Chekkala Raji</td>
<td>Engineering</td>
<td></td>
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<td>Cheng Wanxiang</td>
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<td></td>
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<tr>
<td>Chippendale Aaron</td>
<td>Engineering</td>
<td></td>
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<tr>
<td>Chow Kate</td>
<td>Project Specialist</td>
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<td>Chung Yoon</td>
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<tr>
<td>Clampett Keith</td>
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<td>Craig Daniel</td>
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<td>D’Amico Andy</td>
<td>Stores</td>
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<td>Death Michael</td>
<td>Engineering</td>
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<td>Doherty Paul</td>
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<td>Drazenovic Vicki</td>
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<td>Fellow</td>
<td></td>
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<tr>
<td>Forsyth Ross</td>
<td>Engineering</td>
<td></td>
</tr>
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## Observations Allocated Time by the Time Assignment Committee

A small number of ‘Target of Opportunity’ observations are not listed. Proposal cover sheets are available through the ATNF proposal application system, OPAL (http://opal.atnf.csiro.au).

### Observations Made with the Compact Array, October 2014 to September 2015

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<td>Corbel, Tzioumis, Kaaret, Tomick, Orosz, Loh, Fender</td>
<td>Large scale radio/X-ray jets in microquasars</td>
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<td>Ryder, Kool, Stockdale, Kotak, Polshaw, Romero-Canizales, Amy, Burlon, Van Dyk, Immler</td>
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<td>Understanding periodic flares of the methanol masers</td>
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<td>Agliozzo, Buemi, Leto, Umana, Trigilio, Ingallinera, Pignata</td>
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<td>Corbel, Edwards, Wieringa, Tingay, Sadler, Thompson, Grenier, Cheung, Cameron, Ojha, Schinzel, Gehrels, Chaty, Dubus, Abraham</td>
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<td>Carina Parkes–ATCA Radio Centimetre-wavelength Survey (CARPARCS)</td>
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<td>Soria, Blair, Long, Godfrey, Miller-Jones, Kuntz, Winkler, Plucinsky, Stockdale, Dopita</td>
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<td>Keane, Bailes, Barr, Bates, Bhandari, Bhat, Burgay, Burke-Spolaor, Caleb, Eatough, Flynn, Jameson, Jankowski, Johnston, Keith, Kramer, Levin, Lyon, Morello, Ng, Petroff, Possenti, Stappers, van Stratten, Tiburzi</td>
<td>SUPERBx – The SUrvey for Pulsars and Extragalactic Radio Bursts Extension</td>
<td>P892</td>
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**OBSERVATIONS MADE WITH THE MOPRA RADIO TELESCOPE, OCTOBER 2014 TO SEPTEMBER 2015**

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<th>OBSERVERS</th>
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<tr>
<td>Indermuehle, Edwards</td>
<td>Maser and flux monitoring at 3 mm, 7 mm and 12 mm</td>
<td>M426</td>
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<tr>
<td>Barnes, Muller, Lowe, Cunningham, Indermuehle, Hernandez, Fuller, O’Dougherty, Nguyen Luong, Sharpe, Mizuno, Jones, Schuller, Nakanishi, Umemoto, Chibueze, Wakker, Crutcher, Whitney, Brogan, Molinari, Benjamin, Goodman, Bosi, Lo, Longmore</td>
<td>The Three-mm Ultimate Mopra Milky Way Survey (MALT110): Completion of phase II</td>
<td>M566</td>
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<tr>
<td>Indermuehle, Mcintosh</td>
<td>Monitoring SiO maser emissions in high time resolution</td>
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<td>Maxted, Renaud, Rowell, Puehlhofer, Chaves, Collaboration</td>
<td>A CO survey of the newly-discovered supernova remnant G323.7–1.0</td>
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<td>Fuller, Traficante, Lackington, Peretto</td>
<td>The structure and kinematics of a 90-pc-long massive filament</td>
<td>M679</td>
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<td>Contreras, Rebolledo, Breen, Green, Burton, Rathborne, Purcell</td>
<td>Physical and chemical evolution of high-mass star-forming clumps in the Carina Nebula</td>
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<td>Itam-Pasquet, Maxted, Lowe, Jasniwicz, Puy</td>
<td>A 3-mm survey of the region in front of the globular cluster NGC 4833</td>
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<tr>
<td>Andre, Shimajiri, Konyves, Schneider, Bontemps, Braine, Peretto, Roy, Arzoumanian, Ladjelate</td>
<td>Probing the detailed connection between dense gas and star formation in the Ophiuchus main cloud</td>
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**VLBI OBSERVATIONS, OCTOBER 2014 TO SEPTEMBER 2015**

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<th>OBSERVERS</th>
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<tbody>
<tr>
<td>Ryder, Tingay, Smith, Lenc, Kotak, Polshaw, Boettcher</td>
<td>LBA imaging of Supernova 1978K in NGC 1313</td>
<td>V157</td>
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<tr>
<td>Ojha, Kadler, Edwards, Carpenter, Team</td>
<td>Physics of gamma-ray-emitting AGN</td>
<td>V252</td>
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<td>Ellingsen, Reid, Krishnan, Zhang, Green, Honma, Dawson, Zheng, Menten, Fujisawa, Phillips, Goedhart, Xu, Breen, Voronkov, Dodson, Shen, Walsh, Brunthaler, Chen, Rioja, Sakai, Sanna</td>
<td>Astrometric observation of methanol masers: Determining Galactic structure and investigating high-mass star formation</td>
<td>V255</td>
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<tr>
<td>Bhat, Bailes, Deller, Tingay, Verbiest</td>
<td>Measuring the proper motion of the relativistic binary PSR J1141–6545</td>
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<td>Petrov, Phillips, Bertarini, Fomalont, Tzioumis, Murphy, Sadler, Burke-Spolaor, Booth, Pogrebenko, De Witt, Bietenholz</td>
<td>LBA Calibrator Survey – 8</td>
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<tr>
<td>Miller-Jones, Jonker, Maccarone, Nelemans, Sivakoff, Tzioumis</td>
<td>Constraining black-hole formation with LBA astrometry</td>
<td>V447</td>
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<td>Horiuchi, Phillips, Stevens, Jacobs, Sotuela, Garcia Miro</td>
<td>32-GHz Celestial Reference Frame Survey for declinations below −45 degrees</td>
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<td>Dodson, Rioja, Hobbs, Tzioumis, Reynolds, Godfrey</td>
<td>Multiview Pathfinder: The LBA demonstration</td>
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<td>Miller-Jones, Moldon, Deller, Shannon, Dubus, Johnston, Paredes, Ribo,</td>
<td>Mapping the orbit of PSR B1259–63 with LBA astrometry</td>
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<td>Tzioumis, Dodson</td>
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<td>Ellingsen, Macquart, Bignall, Dawson, Breen, Reynolds, Imai, Keller,</td>
<td>Measuring the proper motions of the Large and Small Magellanic Clouds</td>
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<td>Bekki, Krishnan, Cioni</td>
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<td>Sugiyama, Inayoshi, Tanaka, Hosokawa, Motogi, Fujisawa, Yonekura, Momose,</td>
<td>Astrometry of the 6.7-GHz methanol masers showing periodic flux variation</td>
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<tr>
<td>Ellingsen, Green</td>
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<td>Deller, Johnston, Burke-Spolaor, Romani, Kerr</td>
<td>LBA parallaxes to probe gamma-ray pulsar physic</td>
<td>V507</td>
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<tr>
<td>Reynolds, Kovalev, Kardashev, Bignall, Sokolovsky, Bietenholz, Gurvits,</td>
<td>RadioAstron–LBA Space VLBI survey of AGN at the highest angular resolution</td>
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<td>Garrett, Deller, Cimo, Macquart, Jauncey, Edwards, Tingay, Horiuchi,</td>
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<td>Tzioumis, Shabala, Lovell, McCallum, Koay</td>
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<td>Bannister, Walker, Johnston, Stevens, Bignall, Reynolds, Tuntsov</td>
<td>VLBI follow-up of ATCA Extreme Scattering Events</td>
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<td>de Witt, Bertarini, Charlot, Bourda, Quick</td>
<td>Southern-hemisphere observations towards the accurate alignment of the</td>
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<td>VLBI frame and the future Gaia frame</td>
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<td>Maini, Norris, Parker, Prandoni, Giovannini</td>
<td>Assessing the origin of the radio emission in radio-quiet AGN</td>
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<td>de Witt, Bertarini, Jacobs, Quick, Horiuchi, McCallum, Jung, Phillips</td>
<td>Completing the K-band CRF in the southern hemisphere − 2</td>
<td>V521</td>
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<td>Burns, Imai, Dodson, Ellingsen, Honma, Orosz, Handa, Omodaka, Sugiyama,</td>
<td>6.7-GHz maser parallax of a particularly interesting high-mass star-</td>
<td>V527</td>
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<tr>
<td>Sakai</td>
<td>forming region</td>
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<tr>
<td>Zaw, Greenhill, Dopita, Burtscher, Lopez-Gonzaga</td>
<td>Geometry of an AGN on parsec scales: NGC 5506</td>
<td>V533</td>
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<tr>
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<tr>
<td>Heise, Green, Horiuchi, Engels</td>
<td>A search for water masers in silicate-carbon star candidates</td>
<td>T208</td>
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<tr>
<td>Castangia, Tarchi, Caccianiga, Severgnini, Della Ceca, Horiuchi</td>
<td>Water maser in Compton-thick AGN</td>
<td>T212</td>
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<tr>
<td>Orosz, Gomez, Imai, Horiuchi</td>
<td>Monitoring of H₂O masers in all known water fountains</td>
<td>T215</td>
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<tr>
<td>Camarata, Miller-Jones, Jackson</td>
<td>The connection between anomalous NH₃ spectra and high-mass star formation</td>
<td>P870</td>
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<tr>
<td>Cordiner, Smith, Charnley, Milam, Gilles, Wirstrom</td>
<td>Quantifying nitrogen isotope enrichment around the young protostar</td>
<td>P881</td>
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<td></td>
<td>Chamaeleon MMS1</td>
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</table>

*Note: Two proposals were originally submitted for 22 GHz observations with Parkes but transferred to Tidbinbilla.*
### PHD STUDENTS CO-SUPERVISED BY CASS STAFF (AS OF DECEMBER 2015)

<table>
<thead>
<tr>
<th>NAME</th>
<th>UNIVERSITY</th>
<th>PROJECT TITLE</th>
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<tbody>
<tr>
<td>Shaila Akhter</td>
<td>University of New South Wales</td>
<td>Turbulence in the interstellar medium and its relationship to massive star formation</td>
</tr>
<tr>
<td>Tui Britton</td>
<td>Macquarie University</td>
<td>Methanol masers in star-forming regions</td>
</tr>
<tr>
<td>Joseph Callingham</td>
<td>University of Sydney</td>
<td>An MWA source catalogue: CSS and GPS sources at low radio frequencies</td>
</tr>
<tr>
<td>Francesco Cavallaro</td>
<td>University of Catania</td>
<td>Stellar radio emission in the SKA era: surveys of the Galactic plane</td>
</tr>
<tr>
<td>Jordan Collier</td>
<td>Western Sydney University</td>
<td>The history of supermassive black holes in the Universe</td>
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<tr>
<td>Phoebe de Wilt</td>
<td>Adelaide University</td>
<td>Investigating the connection between star forming regions and unidentified TeV gamma-ray sources</td>
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<tr>
<td>Timothy Galvin</td>
<td>Western Sydney University</td>
<td>Radio emission from star-forming galaxies at high and low redshift</td>
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<tr>
<td>Marcin Glowacki</td>
<td>University of Sydney</td>
<td>Study of H I absorption against distant radio sources through ASKAP</td>
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<tr>
<td>Claire-Elise Green</td>
<td>University of New South Wales</td>
<td>Milky Way dynamics and structure</td>
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<tr>
<td>Sarah Hegarty</td>
<td>Swinburne University of Technology</td>
<td>Accelerating and enhancing knowledge discovery for the ‘petascale astronomy’ era</td>
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<tr>
<td>Andreas Herzog</td>
<td>Ruhr University Bochum/</td>
<td>The broadband spectra of infrared-faint radio sources</td>
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<tr>
<td>Dane Kleiner</td>
<td>Monash University</td>
<td>The large-scale structure’s effect on the H I content of galaxies</td>
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<tr>
<td>Vasaant Krishnan</td>
<td>University of Tasmania</td>
<td>Astrometric observation of methanol masers</td>
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<tr>
<td>Katharina Lutz</td>
<td>Swinburne University of Technology</td>
<td>How do galaxies accrete gas and form stars?</td>
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<tr>
<td>Alessandro Maini</td>
<td>University of Bologna/</td>
<td>Modelling the faint radio sky: the pathway to SKA</td>
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<td>Aina Musaeva</td>
<td>University of Sydney</td>
<td>Intermediate-mass black holes in dwarf galaxies</td>
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<tr>
<td>Andrew O’Brien</td>
<td>Western Sydney University</td>
<td>ATCA–SPT: A survey of 100 square degrees of the southern sky</td>
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<tr>
<td>Daniel Reardon</td>
<td>Monash University</td>
<td>Bayesian analysis of pulsar timing array data to study noise properties of pulsars</td>
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<tr>
<td>Glen Rees</td>
<td>Macquarie University</td>
<td>Cosmology using next-generation radio telescopes</td>
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<tr>
<td>Sarah Reeves</td>
<td>University of Sydney</td>
<td>H I and OH absorption line studies of nearby galaxies</td>
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<tr>
<td>Elise Servajean</td>
<td>Universidad de Chile</td>
<td>The physical and kinematical structure of massive and dense cold cores</td>
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<tr>
<td>Jesse Swan</td>
<td>University of Tasmania</td>
<td>The evolution of star formation and black-hole activity across cosmic time</td>
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<tr>
<td>Anita Titmarsh</td>
<td>University of Tasmania</td>
<td>Investigating the earliest stages of massive star formation</td>
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<tr>
<td>Ross Turner</td>
<td>University of Tasmania</td>
<td>Dynamical and cosmological evolution of radio AGN and AGN feedback</td>
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<td>Stuart Weston</td>
<td>Auckland University of Technology</td>
<td>Data mining for statistical analysis of the faint radio sky: the pathway to EMU</td>
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<tr>
<td>Marion Wienen</td>
<td>University of Bonn</td>
<td>Galactic high-mass star formation at submillimetre wavelengths</td>
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<tr>
<td>Graeme Wong</td>
<td>Western Sydney University</td>
<td>Physics and chemistry of molecular gas in the Milky Way galaxy</td>
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<tr>
<td>Mustafa Yildiz</td>
<td>University of Groningen</td>
<td>Star formation in the outer regions of early-type galaxies</td>
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<tr>
<td>Tye Young</td>
<td>Australian National University</td>
<td>Multi-wavelength properties of dwarf galaxies in the Local Volume</td>
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</table>
THESES AWARDED IN 2015 TO STUDENTS CO-SUPERVISED BY CASS STAFF

Brook, Paul (University of Oxford, September 2015). “Variability in pulsars”.

Brown, Courtney (née Jones) (University of Tasmania, July 2015). “H I absorption in the fourth Galactic quadrant”.

Dai, Shi (Peking University, January 2015). “High precision pulsar timing”.

Fujii, Kosuke (The University of Tokyo, December 2015). “Giant molecular cloud formation at the interface of colliding supershells in the Large Magellanic Cloud”.

Jordan, Christopher (University of Tasmania, September 2015). “CS(1−0) observations with MALT-45: a 7-mm survey of the southern galaxy”.

Petroff, Emily (Swinburne University of Technology, September 2015). “Study of the interstellar medium through radio phenomena of short duration”.

Ravi, Vikram (University of Melbourne, February 2015). “Evincing the histories of the cosmic supermassive black hole and galaxy populations with gravitational waves”.

Zhu, Xingjiang (The University of Western Australia, July 2015). “Searching for continuous gravitational waves in the Parkes pulsar timing array data sets”.

G: Publications

*Indicates publications with CASS staff (not including CASS staff based at CDSCC).

C – Compact Array, M = Mopra, P = Parkes, V = VLBI, A = ASKAP, S = SKA, T = Tidbinbilla, O = other staff paper

REFEREED PAPERS WITH DATA FROM, OR RELATED TO, ATNF FACILITIES AND OTHER STAFF PAPERS


*Green, J.A.; Caswell, J.L.; McClure-Griffiths, N.M. "Excited-state hydroxyl maser polarimetry: who ate all the ns?" MNRAS, 451, 74–92 (2015). (C)


**PAPERS PUBLISHED IN CONFERENCE PROCEEDINGS**

*Indicates publications with CASS staff (not including CASS staff based at CDSCC).

C = Compact Array, M = Mopra, P = Parkes, V = VLBI, A = ASKAP, S = SKA, T = Tidbinbilla, O = other staff paper


**Dopita, M.A.; Shastri, P.; Scharwachter, J.; Kloeckner, H.R.** “Multiple supermassive black hole systems: SKA’s future leading role”. In: *Proceedings of Advancing Astrophysics with the Square Kilometre Array (AASKA14)*, Giardini Naxos, Italy, 9–13 June 2014, A151 (2015). (S)


Jarvis, M.; Seymour, N.; Afonso, J.; Best, P.; Beswick, R.; Heywood, I.; Huynh, M.; Murphy, E.; Prandoni, I.; Schinnerer, E.; and three coauthors. “The star-formation history of the Universe with the SKA”. In: Proceedings of Advancing Astrophysics with the Square Kilometre Array (AASKA14), Giardini Naxos, Italy, 9–13 June 2014, A68 (2015). (S)


Kimball, A.; Lacy, M.; Condon, J.; Lonsdale, C.; Macquart, J.P.; Seymour, N. “Sub-millimeter/far-infrared properties of the most optically luminous QSOs”. In: Demographics and environment of AGN from multi-wavelength surveys, Crete, Greece, 21–24 September, 2015, A53 (2015). (O)


McClure-Griffiths, N.M.; Stanimirovic, S.; Murray, C.; Li, D.; Dickey, J.M.; Burton, M.; Clark, S.E.; Miville-Deschenes, M.A.; and two coauthors. “Galactic and magellanic evolution with the SKA”. In: Proceedings of Advancing Astrophysics with the Square Kilometre Array (AASKA14), Giardini Naxos, Italy, 9–13 June 2014, A130 (2015). (S)
## H: Abbreviations

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<tr>
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<tr>
<td>AGN</td>
<td>Active Galactic Nuclei</td>
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<tr>
<td>ALMA</td>
<td>Atacama Large Millimeter/submillimeter Array</td>
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<tr>
<td>ASKAP</td>
<td>Australian Square Kilometre Array Pathfinder</td>
</tr>
<tr>
<td>ATCA</td>
<td>Australia Telescope Compact Array</td>
</tr>
<tr>
<td>ATLAS</td>
<td>Australia Telescope Large Area Survey</td>
</tr>
<tr>
<td>ATNF</td>
<td>Australia Telescope National Facility</td>
</tr>
<tr>
<td>BETA</td>
<td>Boolardy Engineering Test Array</td>
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<tr>
<td>CASS</td>
<td>CSIRO Astronomy and Space Science</td>
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<tr>
<td>CDSCC</td>
<td>Canberra Deep Space Communication Complex</td>
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<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
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<tr>
<td>EMU</td>
<td>Evolutionary Map of the Universe</td>
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<tr>
<td>GRB</td>
<td>Gamma-Ray Burst</td>
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<tr>
<td>H I</td>
<td>Neutral Hydrogen</td>
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<tr>
<td>HIPASS</td>
<td>H I Parkes All Sky Survey</td>
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<tr>
<td>IAU</td>
<td>International Astronomical Union</td>
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<tr>
<td>ICRAR</td>
<td>International Centre for Radio Astronomy Research</td>
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<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
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<tr>
<td>ISM</td>
<td>Interstellar Medium</td>
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<tr>
<td>LBA</td>
<td>Long Baseline Array, used for Australian VLBI observations</td>
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<tr>
<td>LMC</td>
<td>Large Magellanic Cloud</td>
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<td>LOFAR</td>
<td>Low Frequency Array</td>
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<td>MALT</td>
<td>Millimetre Astronomers Large-area multi-Transition</td>
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<td>MNRAS</td>
<td>Monthly Notices of the Royal Astronomical Society</td>
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<tr>
<td>MRO</td>
<td>Murchison Radio-astronomy Observatory</td>
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<tr>
<td>MWA</td>
<td>Murchison Widefield Array</td>
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<td>MYSO</td>
<td>Massive Young Stellar Object</td>
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<td>NAPA</td>
<td>Non A-Priori Assignable</td>
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<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>PTF</td>
<td>Parkes Testbed Facility</td>
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<tr>
<td>RFI</td>
<td>Radio Frequency Interference</td>
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<tr>
<td>SCORPIO</td>
<td>Spectral Camera with Optical Reducer for Photometrical and Interferometrical Observations</td>
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<tr>
<td>SKA</td>
<td>Square Kilometre Array</td>
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<td>SNe</td>
<td>Supernovae</td>
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<td>SNR</td>
<td>Supernova Remnant</td>
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<td>SPT</td>
<td>South Pole Telescope</td>
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<td>VLBI</td>
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