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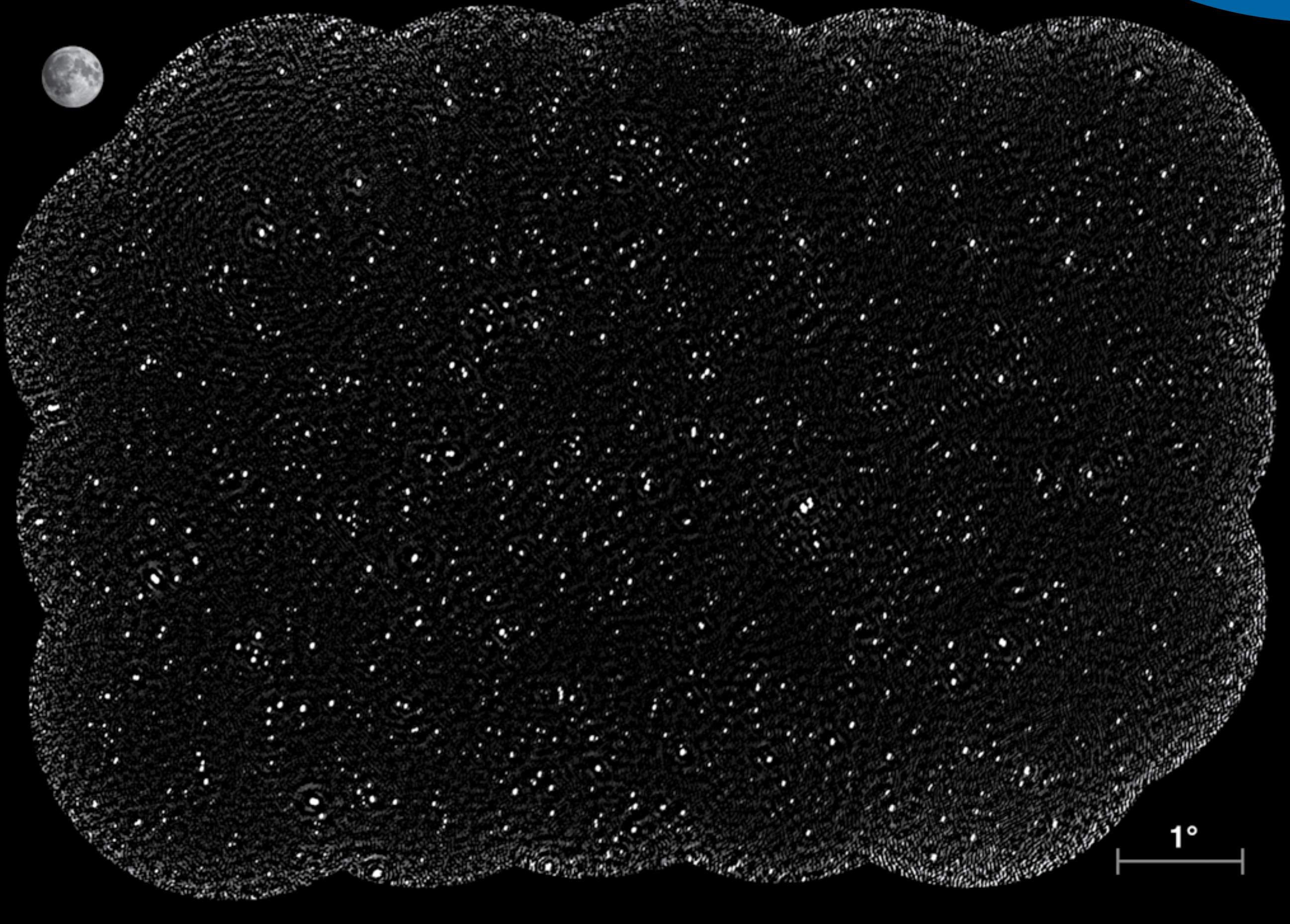
CSIRO — undertaking world-leading astronomical research and operating the Australia Telescope National Facility.



Front cover image

An image made with the Boolardy Engineering Test Array, BETA (six ASKAP antennas installed with first-generation phased-array feeds). Covering 50 square degrees of sky, it demonstrates ASKAP's rapid survey capability.

The image was made from five observations, of between seven and 12 hours each, of two areas in the constellation Tucana (the Toucan), with the nine BETA beams arranged to create a square 'footprint'. It reveals about 2,300 sources above a sensitivity of five sigma (sigma ~ 0.5 mJy). Gathering the data took about two days. Had BETA been fitted with single-pixel feeds instead of the phased-array feeds with their wide field of view, it would have taken nine times longer.

Credit: Ian Heywood and the ASKAP Commissioning and Early Science team

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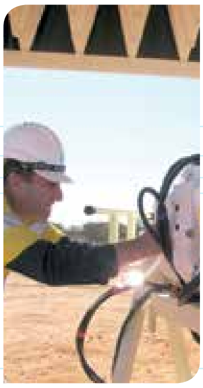
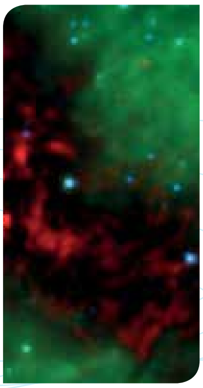
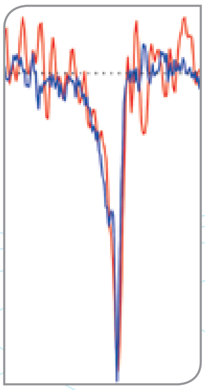






From the Director

This newsletter comes at a time that is both challenging and exciting, in similar measure. The challenging elements include the necessity to react rapidly to a significant reduction in CSIRO funding while trying to maintain the momentum of delivery of ASKAP and the SKA preconstruction activities so central to the future of radio astronomy in Australia and internationally. Of course, in parallel we are operating the current generation of observatories to ensure the continued flow of world-class science from the ATNF. The excitement stems largely from the excellent progress demonstrated by the commissioning of ASKAP using the Boolardy Engineering Test Array (BETA)—six antennas outfitted with the first-generation phased-array-feed receivers.

CSIRO has recently undergone a major restructure, collapsing its 'matrix' of divisions and flagships into three lines of business, Impact science (which consists of nine flagships),'National Facilities and Collections' (NFC) and CSIRO Services. CSIRO's Astronomy and Space Sciences (CASS) group moved into NFC and the effects of the restructure within CASS have been relatively minor, albeit with the positive effect that some eight staff previously in the Computational Informatics division who worked on CASS projects are now completely embedded in CASS—and it is great to have them. Most importantly, the creation of the National Facilities and Collections line indicates the commitment of CSIRO to the delivery of world-class national and global research infrastructure on behalf of the nation, which is precisely what CASS does through the ATNF, through CDSCC (the Canberra Deep Space Communication Complex), and what we stand ready to do in the SKA domain.

In May, the announcement of the Australian Government budget heralded a reduction of the baseline funding for CSIRO. That reduction is compounded by a reduction in funding from other government agencies as Australia pursues a "smaller and more rational government agenda". Despite the strategic importance CSIRO places on radio astronomy, CASS is not immune from the funding pressures and the result was a reduction in CSIRO funding for radio astronomy of 15%, effective from 1 July 2014. CASS's space tracking activities were not impacted since they are funded independently by NASA/JPL.

That reduction in CSIRO funding for radio astronomy occurs in the context of a significant increase of other revenue associated with the ramp up of ASKAP commissioning and early operation and our substantial SKA preconstruction work. Nevertheless, the situation is a painful one, and it required an immediate reduction of staff right across our radio-astronomy activities, and steps to reduce other ongoing costs. A total reduction of 25–30 staff relative to CASS's workforce plan has been implemented, around two-thirds of which has been effected by not filling planned positions or not replacing staff as positions become vacant. Recruitment of new Bolton Fellows has been put on hold, and a number of planned postdoctoral appointments will not be made. Approximately ten staff positions were declared redundant and as a result those members have sadly left or will soon leave the organisation. We wish them well and thank them all for their tremendous contributions to CASS and to CSIRO. Other measures implemented in order for CASS to live within its means include an acceleration of the reductions of capability at the Parkes telescope, cessation of on-site observing at the Compact Array, and the announcement that CSIRO will cease to contribute to the operation of Mopra as part of the National Facility in late 2015. Details of these changes have been discussed extensively with the astronomical community through a range of mechanisms, and we appreciate the guidance from the community in identifying the priorities.

Despite these challenges, we are a strong and resilient organisation and our staff continue to achieve wonderful things, as the content of this newsletter shows. The CASS Radio School is a tremendous event bringing together gurus and tyros for discussions of all things important and arcane in radio astronomy. Shari Breen pulled it all together against unusually stacked odds this year because of competing activities, and thanks to all the participants it was a great success. Ryan Shannon's award for Excellence in Young Scientists (see page 9) is tremendous recognition for his work on gravitational waves and is well deserved.

So to ASKAP and BETA and the future of radio astronomy. The ASKAP Commissioning and Early Science (ACES) team is making terrific progress and the flow of exciting commissioning results from the six-antenna BETA array has been remarkable over the past few months. Some of the results are featured in this newsletter: I hope they give an insight into the sense of excitement and potential that is so evident in the corridors of CASS right now. The team has been boosted by a number of postdocs seconded from participating universities, building on the engagement between CASS and the astronomy community that is driving ASKAP science. The construction team that has worked so hard for almost a decade has delivered systems that are just starting to show their capabilities, and the sense of anticipation is palpable. There is still a fair way to go, but the results described by James Allison identifying the first-ever 'blind' survey detection of a galaxy in redshifted HI demonstrates beautifully the capabilities of wide-bandwidth, wide field of view instruments in a truly radio-quiet location. Other early results from BETA are described at *http://www.atnf.csiro.au/projects/askap/BETA_results.html* and in the ASKAP commissioning updates linked to from the bottom of that page.

The other three science stories in this newsletter showcase results from the other ATNF facilities, Parkes and the Compact Array, and from ALMA. Collectively, these show the strength and breadth of the science being delivered by CASS astronomers, and by astronomers from other organisations who are using our facilities.

Finally I'd like to welcome our new postdoctoral fellows, Antonia, Josh, Jing, Martin and James, our new graduate program students, Kosuke, Marcin and Claire-Elise and a new staff member Mary D'Souza, based at our Geraldton site supporting ASKAP, who have all joined us at a very exciting time. We look forward to featuring their achievements, and those of some of the 35 students who attended this year's Radio School, and even of some of the PULSE@Parkes participants, in future newsletters.

LEWIS BALL (DIRECTOR OF CSIRO ASTRONOMY AND SPACE SCIENCE)

Observatory and Project Reports

Parkes

During a two-week shutdown in August we installed a new electrical switchboard at the Parkes observatory. The new unit is almost three metres high and 80 centimetres deep, and weighs 2,500 kg, so some dexterity and gnashing of teeth were needed to unload it and move it into the power house (the old generator hut) on site.

In July the rear roller door of the master-equatorial room failed, but prompt attention by the contractor (from Bathurst, in mid west NSW) meant that the telescope was offline for less than a week.

We have commissioned a new spectral-line mode for the HI Parkes Swinburne Recorder (HIPSR), a fairly new digital backend designed for surveys for neutral hydrogen and pulsars. The previous spectral-line mode provided 8,192 channels across a 400-MHz bandwidth; the new one has 16,384 channels across a 200-MHz bandwidth, giving a frequency resolution of about 12 GHz—four times better than the old mode. This is one more step towards replacing the Parkes multibeam correlator, which is becoming less reliable, with HIPSR.

Installing the new electrical switchboard at Parkes

Compact Array

The Compact Array masers, used to supply the reference frequency for the array, were refurbished in June by technicians from Vremya, the Russian company that built them. The upgraded masers now match the newer one installed at the Murchison Radio-astronomy Observatory a couple of years ago.

In April, we found a subtle bug that had led to spectral-line data sometimes being mislabeled in the first correlator cycle of some scans when the 1-MHz zoom mode of the Compact Array Broadband Backend was being used. We posted a full description of the problem, and a means of addressing it, on the Compact Array Forum webpages, and informed the principle investigators of projects that might have been affected.

On 1 October the Marsfield Science Operations Centre (SOC) became the default location for Compact Array observations. First-time observers, and observers seeking to re-qualify for remote observing, must observe from there. The Duty Astronomer is now based at the SOC too.

Mopra

The National Astronomical Observatory of Japan (NAOJ) and a consortium of UNSW and the University of Adelaide contribute to the funding of Mopra's operations, and in return are allocated blocks of observing time. Some observing time is reserved as 'National Facility time': in the 2014APR semester this was used for a number of single-dish programs and for Mopra's participation in Long Baseline Array projects.

In May, CSIRO announced it would cease funding Mopra. Discussions have begun with parties interested in taking over operation (or ownership) of the telescope after the agreements with NAOJ and UNSW/Adelaide end in 2015.

Long Baseline Array

This year Long Baseline Array (LBA) blocks have been positioned, as far as possible, to meet requests from the RadioAstron space-VLBI mission. RadioAstron observations involving ATNF telescopes take place several times a month: requests for support are received only a month or two before the observations are made, and support must be supplied on a 'best efforts' basis. The Compact Array and Mopra have 'answered the call' fairly frequently. Parkes has done so about six times a year, when its H-OH receiver is on the telescope. This receiver covers 1.6 GHz, the frequency of the spacecraft's L-band receiver (which was provided by the ATNF two decades ago, and is still going strong).

In recent years a single ASKAP dish, with a traditional single-pixel feed, has supported some LBA observations. In June we took this connection a step further by detecting fringes between Parkes and an ASKAP antenna equipped with a phased-array feed (PAF). The source observed was a standard VLBI calibrator, PKS 0537-441. The necessary resampling and reformatting of PAF data meant that only a small part of the ASKAP data stream was accessible, but as an initial 'proof of concept' the exercise was a great success.

ASKAP

ASKAP commissioning

ASKAP commissioning powers on. The ASKAP Commissioning and Early Science team, ACES, is generating excellent results with the Boolardy Engineering Test Array, BETA (the first six ASKAP antennas installed with Mk I phased-array feed receivers).

In the last six months the ACES team has welcomed several members of the wider ASKAP community, on secondment to CSIRO to contribute to the commissioning effort. Emil Lenc (University of Sydney) has special interests in radio polarimetry and has recent experience with commissioning the Murchison Widefield Array (MWA). Hayley Bignall (Curtin University) has investigated the vulnerability of BETA to radio interference from the Sun. Pietro Procopio (University of Melbourne) also has experience with the MWA, and has begun a campaign to compare images produced by MWA and BETA. Attila Popping (UWA) has started observations with BETA for early experiments with stacking HI spectra. ACES is also benefiting from the presence of Bob Sault (under contract rather than as a secondee), who is contributing his considerable talent to the understanding of BETA's polarimetric performance.

In the April 2014 issue of ATNF News we reported on the installation of ASKAP's hardware correlator, the first HI absorption-line measurement (towards PKS 1830-211) and the first six-antenna continuum image. Since then, the ACES team has produced:

- a continuum image of an ASKAP test field near the south celestial pole, made with nine overlapping beams and showing a number of distant galaxies. The image quality demonstrated that the Mk I phased-array feeds used on BETA remained stable over the 12 hours it took to make the image
- a 'snapshot' of HI (neutral hydrogen gas) in the galaxy NGC 253. Made over just 11 hours, this image captures both the intensity of the radio waves and the rotational velocity of the galaxy
- an image of HI in the galaxy group IC 1459. For this BETA's beams were configured into a diamond-shaped 'footprint', to maximise the number of HI detections
- a spectrum across the 300-MHz instantaneous bandwidth of ASKAP that reveals an HI absorption line in the direction of the radio source PKS 2252-089. (See page 19 for more details.)
- an image covering 50 square degrees—an area of the sky equivalent to 250 full moons—that captures about 2,300 radio sources. (This is the image on the newsletter cover.)

These results make plain the value of ASKAP's novel features: the wide field of view we get from its phased-array feeds, its configurable beam patterns, and its third 'roll' axis, which eliminates the problem of the primary beam rotating.

In June, we achieved another milestone: using one of the ASKAP antennas equipped with a Mk I phased-array feed in a VLBI (very long baseline interferometry) experiment. (See page X for details.) As well as being a first step towards future VLBI experiments with ASKAP, the test gave the ACES team useful information about BETA's digital systems hardware.

For more details of BETA commissioning results, see *www.atnf.csiro.au/projects/askap/BETA_results.html*.

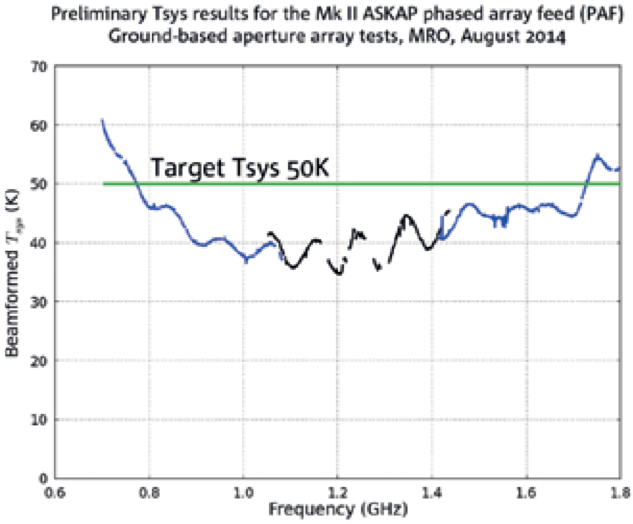
ASKAP Mk II phased-array feeds

The next phased-array feeds (PAFs) for ASKAP, referred to as 'Mk II', are designed to be lighter and easier to manufacture, and to perform even better, than the original design.

In our April issue of ATNF News we reported that the Mk II PAFs had given good results in tests at Parkes and Marsfield. In September, we delivered a prototype Mk II PAF to the Murchison Radio-astronomy Observatory (MRO) and tested it and its associated electronics on the ground. In 'hot' (absorber box) and 'cold' (sky) observations, the test system successfully captured 188 radio signals, each with 600 MHz of bandwidth, and transported them over 1.4 km of optical fibre to the digital backend in the MRO Control Building. As in the previous tests, the system-temperature results were good, and show that the Mk II PAFs will outperform their predecessors.

The set-up used for the 'hot' observation of an absorber box during 'on ground' tests of the prototype Mk II PAF at the MRO.

The Mk II prototype phased-array feed being installed onto ASKAP Antenna 29.



Early but encouraging results from the 'on ground' system-temperature tests of the prototype Mk II PAF at the MRO. The 'ripple' across the band is a common artefact of the measuring process; the gaps are due to the removal of unphysical data.

Antenna 29 with its new prototype Mk II PAF, and the happy installation team.

Following these tests, the PAF was installed on ASKAP Antenna 29 and readied for testing in situ. Eight more Mk II PAFs are now in the first stages of production at Marsfield.

Square Kilometre Array (SKA) activities

SKA pre-construction work

Construction of the SKA will begin in 2017–2018. Eleven consortia are carrying out pre-construction design work, from computing to infrastructure and antenna design. CSIRO leads two—the Dish Array and Infrastructure Australia consortia—and is a partner in another five. In 2013 and the first quarter of 2014 we concentrated on preparing concept designs relevant to these consortia, and on developing interface control documents that describe the demarcations between each consortia, to ensure that there are no overlaps or gaps. All SKA consortia submitted their initial costings to the international SKA Organisation in October, and are now preparing documents for the Preliminary Design Reviews, which will be held in early 2015. Following the Preliminary Design Reviews, the SKA Organisation will look at options to re-scope the project to fit within the €650m cost-cap for the first phase of the SKA (SKA1).

This year we have also given the Australian SKA Office technical advice on site issues, and provided technical input to the Hosting Agreement for the SKA and the Memoranda of Understanding and Consortium Agreements for SKA pre-construction work.

Site Establishment

CSIRO continues to work closely with the Department of Industry on SKA communications, stakeholder management, and establishing the Australian SKA site. This last area of work includes the environmental surveys required before SKA1 can be constructed at Boolardy Station, the property that houses the Australian SKA site. Environmental surveys for the current SKA1 configuration were completed in September 2014.

We have also been working with the Department of Industry and the international SKA Office on the best way to provide power for SKA1 in Australia. In August the Power Engineer from the international SKA Office, Adriaan Schutte, visited CASS for three days of intensive meetings. Further discussions took place at the SKA Engineering meeting in Fremantle in September. (See below for more about this meeting.)

Radio Quiet Zone policy and stakeholder relations

The CASS Radio Quiet Zone (RQZ) team has continued to provide technical advice to the Australian SKA Office, industry stakeholders and the Australian Communications and Media Authority (ACMA) on the impact on radio astronomy of activity within the Australian Radio Quiet Zone (WA). Highlights over the last year include briefing several visitors from the SKA Office on the RQZ policy and radio-frequency interference requirements; providing technical advice to governments on the Australian SKA Office RQZ work plan; and working with the ACMA and governments on the proposed revisions to the Radiocommunications Assignment and Licensing Instruction (RALI) MS32, which covers the Australian Radio Quiet Zone (WA).

WA welcomes 'largest ever' gathering of SKA engineers and scientists

In what has been called 'the largest ever gathering of people working on the international SKA project', some 300 engineers and scientists met in Fremantle, WA, in September. CSIRO was well represented: we lead two of the pre-construction consortia and are a member of another five. The aim of the meeting was "to refine the design of the SKA and make it a reality," as the SKA Organisation's Director General, Philip Diamond, put it in his opening remarks.

Following the meeting, we took a small number of the attendees to visit our Murchison Radio-astronomy Observatory (MRO), which is the intended site for SKA infrastructure in Australia and already home to two SKA precursors—our Australian SKA Pathfinder (ASKAP) and the Murchison Widefield Array (MWA). During the one-day visit the attendees toured the ASKAP antennas and the MRO Control Building, visited the core of the MWA, and inspected the small array, being developed by the SKA Low-Frequency Aperture Array Consortium, that is being tested as part of the MWA. They were impressed with the progress of the telescopes and the infrastructure already in place. And—thanks to the 350-km bus ride from Geraldton to the MRO—they also went home with the site's remoteness and radio quietness very much 'top of mind'.

Murchison Widefield Array (collaborator project)

The Murchison Widefield Array (MWA) at the Murchison Radio-astronomy Observatory has completed two semesters of observations and is now well into its third semester. The proposal deadline for the next semester, 2015-A (January–June 2015), has just closed and a record number of proposals (17) was received. 2015-A will be the first semester in which routine observations will be made with the MWA Voltage Capture System (VCS), for very-high-time-resolution science. This observing mode generates 28 TB of data an hour!

Planning is in train to extend and upgrade the MWA: we wish to double both the number of MWA antennas and the array's maximum baseline length, to enhance its Epoch-of-Reionisation and survey capabilities. An excellent two-day meeting to discuss this extension was held in October at the Sydney headquarters of the ARC Centre of Excellence for All-sky Astrophysics, CAASTRO; it was sponsored by CAASTRO and Astronomy Australia Ltd. MWA users presented a stunning range of MWA science results, with ideas for how an extended MWA could generate even better ones. Plans for the upgrade will be finalised over the next six months. We aim to start construction after the current phase of MWA operations ends in mid 2016.

Steven Tingay (Curtin University)

Participants of the SKA Engineering meeting in Fremantle during their visit to the Murchison Radio-astronomy Observatory.

Awards and Appointments

Ryan Shannon wins CSIRO 'young scientist' award

Demonstrating that pulsar observations can be used to detect gravitational waves has won CASS astronomer Dr Ryan Shannon CSIRO's *John Philip Award for the Promotion of Excellence in Young Scientists* for 2014. Ryan received the award at the annual CSIRO awards ceremony, held at the National Gallery in Canberra on 10 October.

Gravitational waves are predicted by Einstein's general theory of relativity, but are the only one of the theory's predictions not yet directly confirmed. Even so, it's possible to put observational limits on them, and to use those limits to discriminate between different cosmological theories. Ryan and his colleagues did just this in a paper published in Science last year, in the first instance of information about gravitational waves being used to test astrophysical ideas.

The work was part of a larger research program, on very precise timing of pulsars with the Parkes telescope, that is ultimately aimed at detecting gravitational waves. The Parkes data is combined with data from other major observatories in Europe and North America, in a project called the International Pulsar Timing Array (IPTA).

Ryan will use his award funding to travel to institutions collaborating in the IPTA, to extend the techniques applied to the Parkes datasets to other IPTA datasets. He will also travel to China to strengthen ties between CSIRO and major radio telescopes being constructed there, such as the Five Hundred Metre Aperture Spherical Telescope and the Qitai Radio Telescope.

"By combining observations from these facilities [around the world], we expect to use pulsars to detect gravitational waves and thereby open up a new window on the Universe," Ryan said. "The study that we published in *Science* showed that we are indeed quite close to opening up this window!"

The institutions Ryan will visit are also taking part in the Square Kilometre Array (SKA) project, the world's major next-generation radio-astronomy observatory located in both Western Australia and southern Africa. During his visits Ryan will help further plan pulsar-timing-array observations with the SKA.

In receiving the award, Ryan thanked the scientists, engineers and support staff of CASS, and "all those who have fostered my intellectual curiosity and creativity".

"The experience here [at CSIRO] is an important complement to the academic environment at the Universities that we all see during our postgraduate work," he said.

"CSIRO exposes young scientists to both the practicalities of operating and managing major facilities, access to these facilities, and the opportunity to participate in large projects. These experiences have greatly improved my skills as a scientist."

The John Philip award is given to scientists under the age of 35. John Philip was a precocious poetry-writing civil engineer who brought a physical-sciences approach to environmental problems, and who became the first director of CSIRO's (then) Institute of Physical Sciences: *http://www.csiropedia.csiro.au/display/CSIROpedia/Philip,+John+Robert*.

Reference

Shannon R.M. et al. "Gravitational-wave Limits from Pulsar Timing Constrain Supermassive Black Hole Evolution." Science, 342, 334–337 (2013). *www.sciencemag.org/content/342/6156/334.abstract*

New postdoctoral staff

In the last six months CSIRO has welcomed five new postdoctoral staff. They describe their backgrounds and current work below.

JOSH MARVIL

Office of the Chief Executive Postdoctoral Fellow

PhD: New Mexico Tech, USA, 2014

"During the commissioning of the Expanded Very Large Array I mapped several local star-forming galaxies and used these maps to investigate the origins of the galaxies' continuum emission. Within CASS, I'll be working with the ASKAP Commissioning and Early Science (ACES) group and with the Evolutionary Map of the Universe (EMU) survey team, using ASKAP to discover distant galaxies and to measure star formation over cosmic time".

ANTONIA ROWLINSON

Low-Frequency Postdoctoral Fellow

PhD: University of Leicester, UK, 2011

"For the past three years I've worked at the University of Amsterdam, using large imaging datasets from the Low Frequency Array (LOFAR) to test and train the LOFAR Transients Pipeline, an automated tool developed to probe the 'transient radio Universe'. At CASS I'll be extending this work to search for transient sources in datasets from the Murchison Widefield Array. Among other sources I'll be looking for the low-frequency counterparts to short gamma-ray bursts (GRBs), as part of my on-going research into the progenitors and central engines of GRBs".

JING WANG

Office of the Chief Executive
Postdoctoral Fellow

PhD: University of Science and Technology of China, 2012

"I study the evolution of galaxies in the local universe: the galaxies' stellar populations, structure formation, and relationship with their environments; and the role of HI in galactic processes. At CASS I'll be working on the LVHIS project done with Parkes and on ASKAP's future WALLABY survey, for which my skills in UV and optical imaging and SED analysis should be useful".

MARTIN BELL

Office of the Chief Executive
Postdoctoral Fellow

PhD: University of Southampton, 2011

"During my PhD I worked with LOFAR, helping to commission it and run a survey for transients. My first postdoc position was with CAASTRO, and there I began leading the MWA (Murchison Widefield Array) survey for transients and variables. At CASS, I'll continue to lead that survey as well as working as part of the ACES team to commission ASKAP. I'm also a member of the team for the VAST (Variables and Slow Transients) survey, part of ASKAP's Early Science program."

JAMES ALLISON

Bolton Fellow

PhD: University of Oxford, 2011

"Before joining CSIRO I was a Super Science Fellow at the University of Sydney, where I used the Compact Array Broadband Backend to directly measure the kinematics of HI around compact, young radio galaxies. In the course of this work I developed a Bayesian-based spectral-line detection and parameterisation technique for use in all-sky HI absorption surveys. At CASS I'll be working with the ASKAP Early Science and Commissioning Team, using BETA (the Boolardy Engineering Test Array) to look for the HI signal against distant radio galaxies".

Participants at *Powerful AGN Across Cosmic Time*

Meetings

Southern Cross Meeting VII: Powerful AGN Across Cosmic Time

16–20 JUNE 2014
PORT DOUGLAS, QLD

In June about 100 astronomers from around the world descended on tropical far-north Queensland to discuss powerful active galactic nuclei (AGN) and their effect on galaxy evolution. The meeting's topics ranged from AGN in the local Universe to the origin of the first black holes, the growth of black holes, the creation of AGN jets, and the influence of these jets on their environment. This was the seventh of the 'Southern Cross' meetings, which are organised alternately by the ATNF and the Australian Astronomical Observatory. Fittingly, it came 60 years after Baade and Minkowski's identification of Cygnus A as an extragalactic source and the first known AGN.

www.atnf.csiro.au/research/workshops/2014/SouthernCrossVII/index.html

The Periphery of Disks

3–6 NOVEMBER 2014
SYDNEY, NSW

Most galaxies have disks: these evolve in a number of ways, and drive the evolution of their parent galaxies. Some disks are rich in gas and grow by star formation. However, the details of how this star formation is fuelled are still a puzzle. Galaxy disks can also run out of gas and stop growing, change size due to low-mass mergers, or be destroyed and reformed altogether in major mergers.

This international conference brought together 68 astronomers who study these transition regions, and covered both the theoretical and observational sides of this field of research.

www.atnf.csiro.au/research/conferences/2014/ThePeripheryOfDisks

Participants at *The Periphery of Disks*

Outreach and Engagement

CASS Radio School

Thirty-five students. Five days. Eighteen presenters. Twenty-five presentations. Yes, as Spring rolled around once again so too did the CASS Radio School, held this year at Narrabri from 29 September to 3 October. Students went home from it having learned more about scheduling, observing and data reduction than they might have thought a human being could absorb. Truly, “There are more things in heaven and earth, Horatio/ Than are dreamt of in your philosophy”, as Hamlet said, even though he didn’t have the privilege of being a radio astronomer.

Rick Perley (US National Radio Astronomy Observatory) was our guest of honour, giving four lectures on various aspects of interferometry and imaging. The other presenters hailed from the Universities of Sydney and Tasmania, and of course CSIRO, while the students came from ten Australian universities and the Universities of Canterbury (New Zealand), Hong Kong, and Guangzhou (China).

The week’s sessions covered just about everything a radio astronomer would find useful to know, from observing strategies and polarisation to calibration and wideband imaging; from Fourier transforms and what correlators do with them, to how to ‘break free’ from connected-element interferometry with VLBI (very long baseline interferometry). And there was advice: on what to pack in your IT toolkit, how to avoid ‘eyeball carnage’ when dealing with large datasets, and the tactics to use to convince a TAC (Time Assignment Committee) of the worth of your observing proposal. The last lecture was given by CSIRO’s Aidan Hotan, who outlined the exciting recent results from the six-element BETA (Boolardy Engineering Test Array) and progress with outfitting the Australian SKA Pathfinder with second-generation phased-array feeds.

But the week wasn’t all ‘chalk and talk’, with plenty of small-group tutorials and an antenna tour providing variety. And to offset their intense mental efforts during the day, the ‘Schoolies’ found time ‘after hours’ for barefoot bowls at the Narrabri bowling club, trivia quizzes, a pizza night, sky-viewing with a small telescope (optical, for a change of wavelength), and the traditional end-of-School barbecue.

Happily, the week passed without wildlife ‘incidents’: although the warm weather we had usually sees snakes emerging from hibernation, the repeated references to Python programming in the talks were the closest participants came to encountering a reptile. The School itself ran very smoothly: while all Narrabri staff contributed to its success, there were particularly noteworthy efforts from Meg Rees, Chris Wilson and Louise Prestage (in keeping the troops fed), Scott Munting (antenna tours), and Marg McFee, Liza-Jane McPherson, Robin Wark and Jamie Stevens (planning and preparation). Amanda Gray assisted with handling registrations, and the Scientific Organising Committee—Ian Heywood, Megan Johnson, Jamie Stevens and Shari Breen—assembled a well-balanced program with a good list of entertaining lecturers. Shari deserves special mention for deftly rearranging the program when a number of speakers unavoidably pulled out a few weeks before the School.

Graduate Student Program

The CASS Graduate Student program continues to attract high-quality students from around the world to study a huge array of different astrophysical problems. Current students are researching various astrophysical objects including masers, pulsars, black holes and galaxies and developing new techniques related to radio polarimetry, broadband observations and wide-field VLBI .

We have recently welcomed the following students into the program:

- ***Kosuke Fujii*** (The University of Tokyo), working on "The effects of large-scale stellar feedbacks on the molecular cloud formation in the Large Magellanic Cloud"
- ***Marcin Glowacki*** (The University of Sydney), working on a "Study of HI absorption against distant radio sources through ASKAP"
- ***Claire-Elise Green*** (University of New South Wales), working on "Milky Way dynamics and structure". (Note: Clair-Elise's project mentioned in the April 2014 issue of ATNF News, "The relationship between starbursts and black holes in galaxies", was for her Honours degree.)

If you are interested in joining the program, or wish to learn more about it, see *www.atnf.csiro.au/research/student* or contact George Hobbs (George.Hobbs@csiro.au).

Scientific Visitors Program

CASS welcomes applications to the CASS Scientific Visitors program for visits of between two weeks and one year. Financial support typically covers the cost of on-site accommodation at CASS headquarters in Marsfield, or its equivalent. Visitors are expected to deliver at least one colloquium or seminar during their stay.

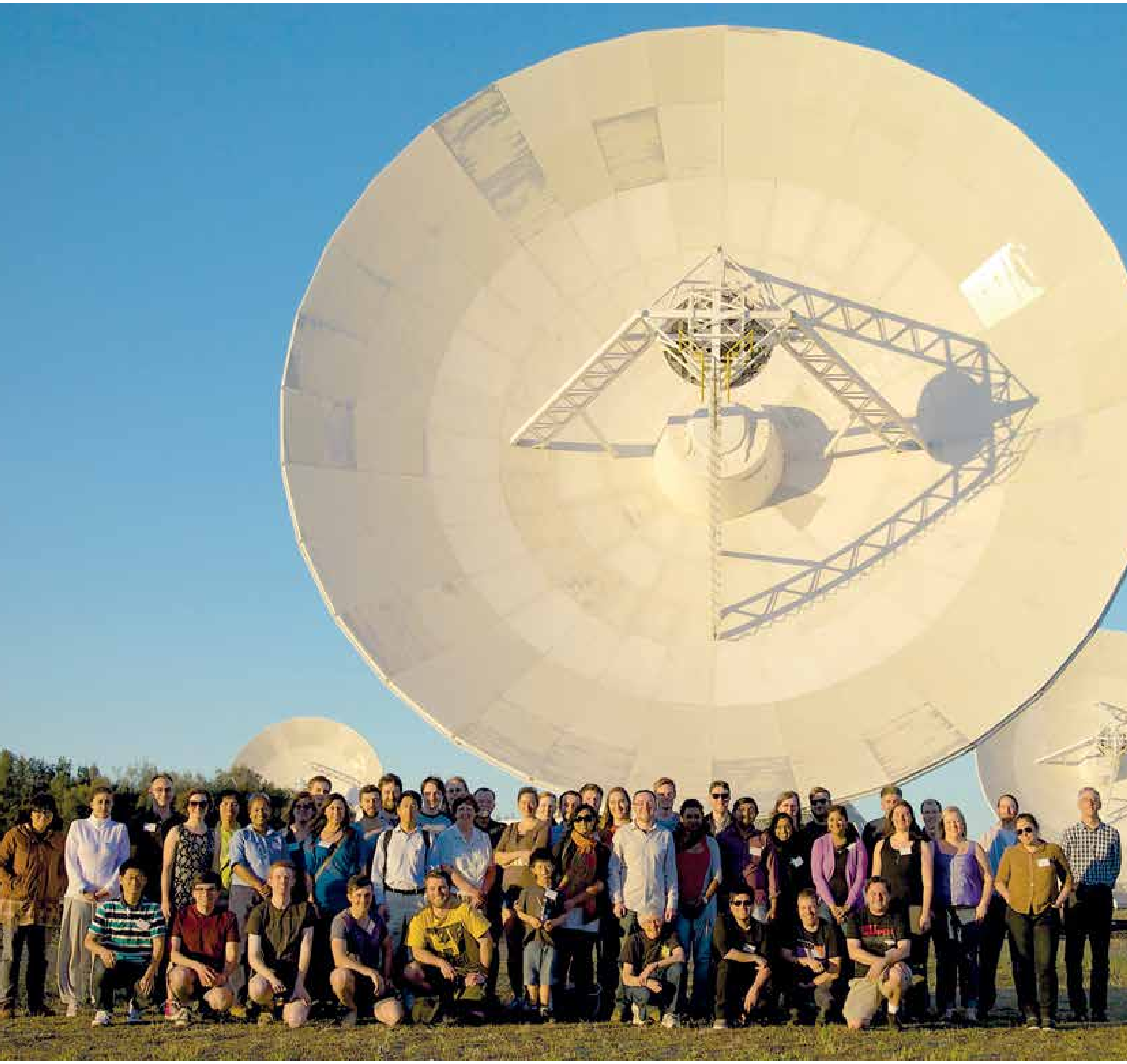
A written proposal for a visit must include a brief description of a collaborative project to be conducted during the visit, an estimate of the dates of the visit and any financial support required, a current CV, and a list of publications. Before you prepare a proposal, please contact a local member of staff or Simon Johnston (Head of Astrophysics) for information and advice.

Over the past six months we have hosted six visitors through the program:

- ***Kazufumi Torii*** (Nagoya University)
- ***Corrado Trigilio*** (National Institute of Astrophysics, Italy)
- ***Grazia Umana*** (National Institute of Astrophysics, Italy)
- ***Ian Stephens*** (Boston University)
- ***Yasuo Fukui*** (Nagoya University)
- ***Jim Jackson*** (Boston University).

We also encourage extended visits of six or twelve months. Significant funds from CSIRO can be obtained for these longer visits through a competitive process.

For more on the Scientific Visitors program see *www.atnf.csiro.au/people/scientific_visitors.html* or contact Simon Johnston (Simon.Johnston@csiro.au).



Students and presenters at the
2014 CASS Radio School

Education and Outreach

PULSE@ PARKES

PULSE@Parkes is an education program in which high-school students control the Parkes telescope and use it to observe pulsars. We now run the regular sessions of the program from the Science Operations Centre at Marsfield. We've been exploring new ways to use the technology here and in the nearby Interaction Space to give the students a more flexible and engaging experience.

In July, we ran our first session from the STARS Space Operations Centre next to DSN 46, the old Honeysuckle Creek antenna at the Canberra Deep Space Communication Complex at Tidbinbilla in the ACT. The event generated media interest with an ABC TV crew interviewing the students (who were from Mount Stromlo High School) and project scientist Ryan Shannon.

In September, we ran a special observing session for Canadian teachers in Toronto. This took place in the International Space Education Board (ISEB) forum at the International Astronautical Congress, being held in the city at that time: it was the keynote event of the forum and received a great response from participating teachers. Follow-up discussions with the astronomy education group at the University of Toronto have led to plans to hold a trial session, for local students with teachers from the ISEB forum, at the university in 2015.

In 2013 we took PULSE@Parkes to Japan. A grant from the Australia-Japan Foundation is funding a second tour to four locations in Japan in November this year.

Students from Mount Stromlo High School during the PULSE@Parkes session run at the Canberra Deep Space Communication Complex.

TEACHER WORKSHOPS

The annual *Astronomy from the Ground Up!* teacher workshop at Parkes Observatory in early May was a great success. Teachers from across Australia took part in the three-day event, which qualified as an international *Galileo Teacher Training Program* workshop. This was also the first workshop run under our new agreement with the Science Teachers' Association of NSW (STANSW), which gives attending NSW teachers full accreditation for professional learning hours with the Board of Studies, Teaching and Educational Standards.

As well as running the Parkes event, our Education Officer Rob Hollow presented workshop sessions at other professional-development events for teachers: CONASTA (the National Science Education Conference of the Australian Science Teachers Association) in July, and the STANSW (Science Teachers' Association of New South Wales) Physics Day and Annual Conference in September.

OUTREACH EVENTS

In June, CASS staff from Sydney and Geraldton discussed astronomy and career opportunities in science for Year 10 students from schools around Geraldton at the Mid West Youth Science Forum. Also in June, Rob Hollow gave a public talk on ASKAP (the Australian SKA Pathfinder) at the Scitech Planetarium in Perth, and ASKAP featured in a live cross from the Marsfield Science Operations Centre to the Cheltenham Science Festival in the UK.

In August, Rob Hollow, Lisa Harvey-Smith and Leonie Boddington made a 'mentoring visit' to Pia Wadjarri Remote Community School. Another visit is scheduled for November.

RADIO GALAXY ZOO

Radio Galaxy Zoo is a 'citizen science' project in the *Zooniverse*, led by Julie Banfield from CASS and former CASS staff member Ivy Wong. It was launched last December: since then more than 4,000 people have taken part in the project, helping to classify thousands of radio sources (including many obtained with the Australia Telescope Compact Array). *Radio Galaxy Zoo* lays the ground for developing similar projects for the massive datasets expected from the Australian SKA Pathfinder.

Lisa Harvey-Smith explaining black holes to students at the Pia Wadjarri Remote Community School.

Australia Telescope Compact Array
Credit: Jamie Stevens

Science Reports

Into the 'redshift desert' with BETA

JAMES ALLISON (CSIRO)

Cold atomic hydrogen (HI) fuels star-formation and feeds the radio-emitting jets of active galactic nuclei (AGN). For six decades astronomers have mapped the distribution and kinematics of HI in nearby galaxies using its 21-cm radio spectral line (e.g. Koribalski *et al.* 2004; Walter *et al.* 2008; Haynes *et al.* 2011). Optical surveys have explored HI in the distant, adolescent Universe through observations of the 1216 Å Lyman-alpha transition towards thousands of quasars (e.g. Noterdaeme *et al.* 2012). But until now it has been difficult to directly observe HI in individual galaxies in the intervening epoch—that is, at redshifts between 0.3 and 2. This redshift range spans seven billion years—half the Universe's history.

While diffuse 21-cm emission is too faint to detect at large distances, HI in absorption can be observed almost independently of redshift: detection depends only on the brightness of the background radio sources and the opacity of the foreground gas. So we can detect HI absorption in individual galaxies at much greater redshifts than we can the 21-cm emission line.

Searches for redshifted 21-cm absorption are not new (e.g. Carilli *et al.* 1998, Kanekar *et al.* 2009, Curran *et al.* 2013), but previous work has been limited by the available bandwidth, frequency range and sensitivity of the telescopes used, and, crucially, by radio-frequency interference at these telescopes. As a result, most absorption surveys have been able to target only the radio galaxies and quasars for which there is an optical (spectroscopic) redshift for the source or intervening galaxy, to which we may tune our radio telescopes. Square Kilometre Array (SKA) precursor telescopes, notably the Australian SKA Pathfinder (ASKAP; Schinckel *et al.* 2012) and MeerKAT (Booth *et al.* 2009), have both wide bandwidths and radio-quiet environments: with them, we'll be able to carry out the first 'blind' surveys for HI gas in the 'redshift desert'. Such searches look set to find ten times the number of galaxies now known from HI absorption.

We've begun the hunt by looking for HI absorption towards bright, compact radio sources in the southern sky with the six ASKAP antennas designated as the Boolardy Engineering Test Array (BETA; Hotan *et al.* 2014). BETA isn't sensitive enough to carry out a fully fledged all-sky survey, but selecting bright, compact sources gives us the best chance of discovering HI at largely unexplored redshifts. ASKAP has 304 MHz of instantaneous bandwidth: by observing at 712–1015 MHz we capture redshifts between 0.4 and 1.0, accessing more than four billion years' worth of galaxy evolution.

In an early demonstration of ASKAP's capability we re-detected the known absorption line from HI gas associated with the host galaxy of the radio source PKS 2252-089 (Figure 1), originally discovered by Curran *et al.* (2011) with the Green Bank Telescope. The BETA and Green Bank observations matched well in both flux density and the shape of the absorption line.

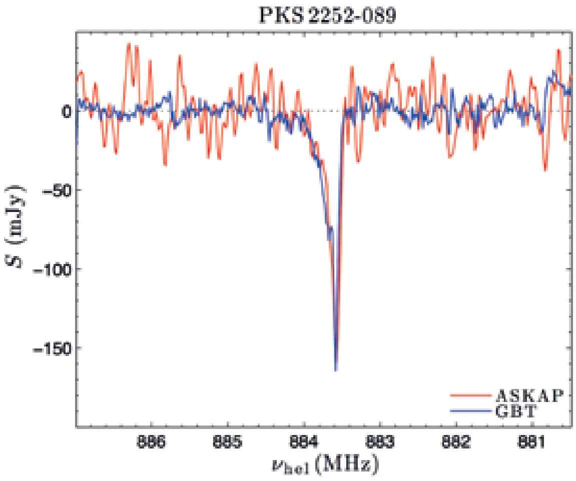


Figure 1. HI absorption detected with the ASKAP-BETA telescope (red line) arising from neutral gas in the host galaxy of the distant z = 0.6 radio source PKS 2252-089. The spectrum from the original discovery using the Green Bank Telescope is shown for comparison (blue line; Curran *et al.* 2011).

We have now also made our first 'blind' discovery of HI gas with BETA, by using all of BETA's instantaneous bandwidth towards a pilot sample of previously unexplored radio sources (Figure 2; Allison *et al.* in preparation). The background radio source, PKS B1740-517, did not have an existing optical spectrum from which to glean a redshift. Interestingly, this source has both a gigahertz-peaked radio spectrum and is resolved into two compact components separated by 50 milliarcseconds (King 1998), indicating that it's either particularly young or that its expansion is frustrated by a surrounding dense environment of gas. Following the BETA detection, we made optical observations towards the source with the Gemini South Telescope: these show that the absorption is intrinsic to the host galaxy, suggesting that we are seeing the radio source interacting with its environment. Our analysis continues!

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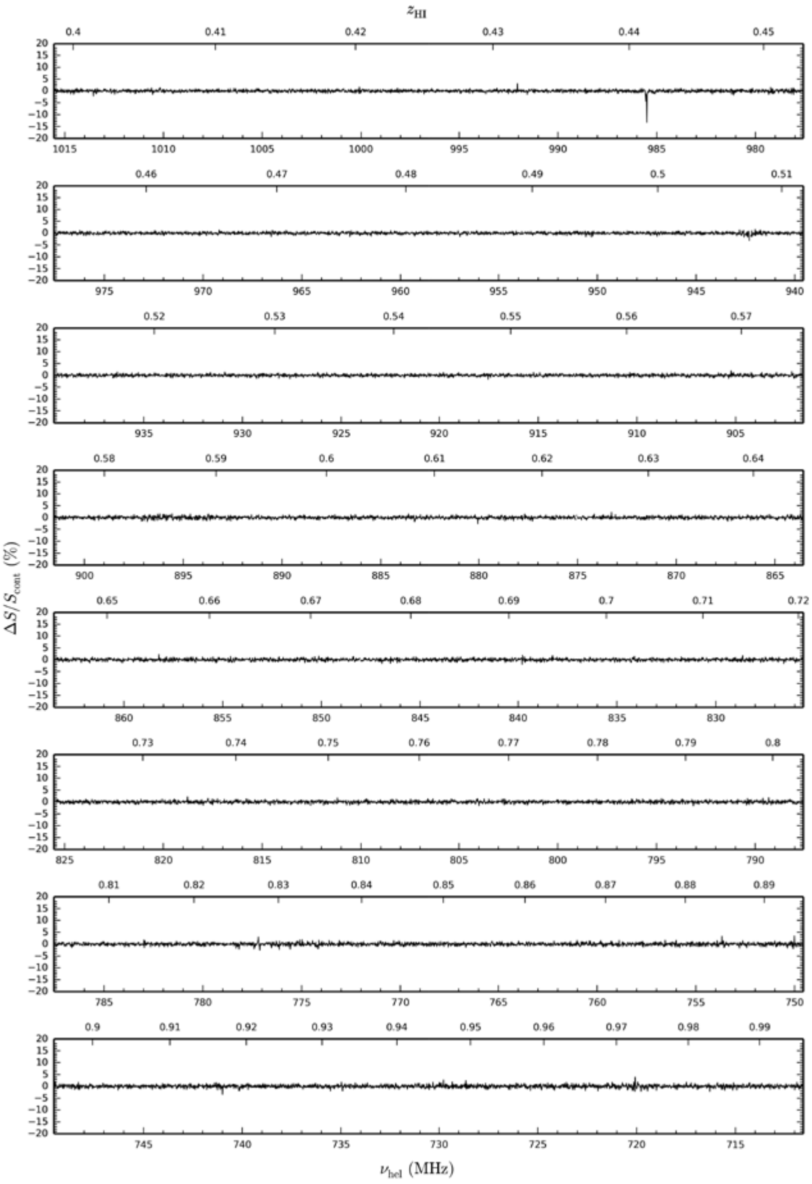

Figure 2. An ASKAP-BETA spectrum showing the available instantaneous bandwidth and redshift search space for HI absorption. Our new detection of 21-cm absorption can be seen at a frequency of 985.5 MHz (equal to a redshift of 0.44). The features seen in this line provide information about the kinematics of the absorbing neutral gas.

The Galactic Centre: a local analogue for the early Universe

JILL RATHBONE (CSIRO)

Most stars in the Universe formed under conditions very different from those in our solar neighbourhood today. So, does our current understanding of star formation, which is based on molecular clouds in our neighbourhood, hold for star formation in the early Universe? Recent observations of the Central Molecular Zone—the environment within the inner 200 pc of our Galaxy—suggest that it does.

The Central Molecular Zone (CMZ) differs greatly from the solar neighbourhood: its volume density, gas temperature, velocity dispersion, interstellar radiation field, pressure and cosmic-ray ionisation rate are all significantly higher (Walmsley *et al.* 1986; Morris & Serabyn 1996; Ao *et al.* 2013). But in these characteristics it resembles the environments in dense, star-forming galaxies at high redshift (Kruijssen & Longmore 2013). And it differs from those galaxies only modestly in metallicity (by less than a factor of 2–3: Erb *et al.* 2006; Longmore *et al.* 2013).

Thus, CMZ clouds can be used as local analogues of clouds in $z > 2$ galaxies (Kruijssen & Longmore 2013). Because they are thousands of times closer to us than the nearest starburst galaxy, they can be studied in detail unachievable for clouds at earlier epochs. In effect, we can use them to study the initial conditions of star formation in the early Universe.

Do the same 'rules' about star formation apply in the CMZ as in the solar neighbourhood? Theoretical models of supersonically turbulent, isothermal media successfully predict the observed gas structure and star-formation activity in low-pressure ($P/k < 10^5$ K cm^{-3}) molecular clouds in the solar neighbourhood. However, it hasn't been known if these models also apply to clouds in high-pressure ($P/k > 10^7$ K cm^{-3}) environments such as the CMZ and early Universe.

To determine the initial conditions for star formation we need to observe the gas and dust in a molecular cloud before star formation begins. Our target in this instance was G0.253+0.016, a cold (~20 K), dense (>10^4 cm^{-3}), massive (~10^5 Msun) molecular cloud in the CMZ that has the potential to form a stellar cluster (Lis & Carlstrom 1994; Lis & Menten 1998; Lis *et al.* 2001, Longmore *et al.* 2012, Rathborne *et al.* 2014b).

We observed this cloud with the Atacama Large Millimeter/sub-millimeter Array (ALMA). Despite still being in its 'early science' phase, ALMA already provides a deeper and sharper view of cold material in the universe than any other facility. Figure 1 combines infrared images of G0.253+0.016 from the *Spitzer Space Telescope* (blue and green) with a new millimetre-continuum image from ALMA that traces the cold dust emission (red; Rathborne 2014a).

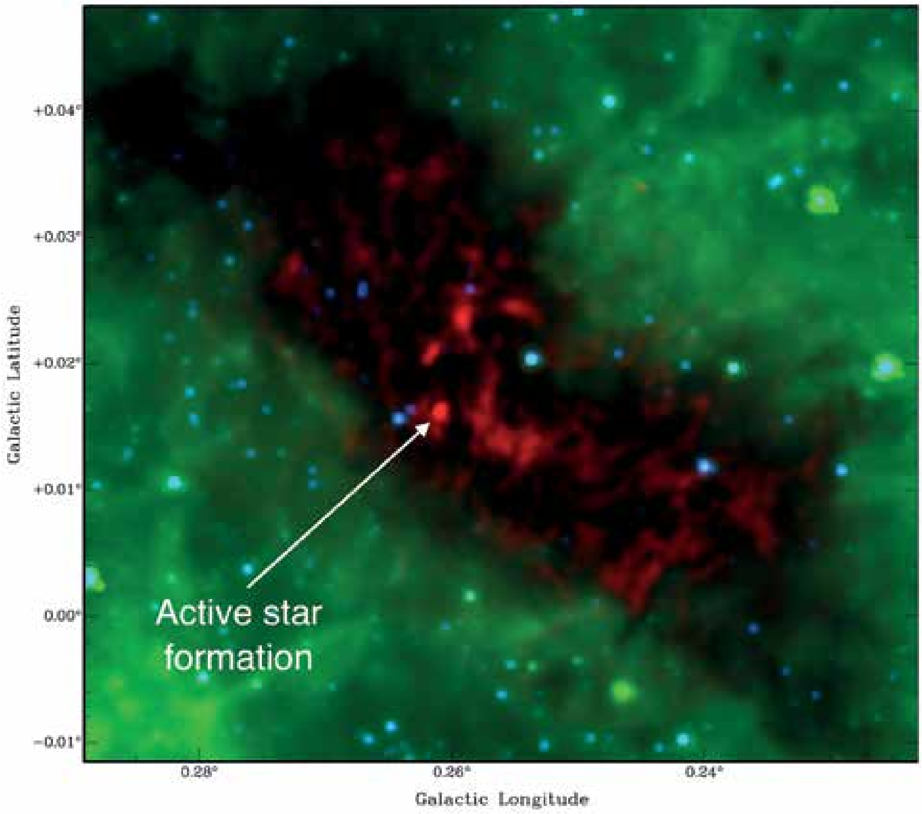

Figure 1. Three-colour image of G0.253+0.016 (blue is Spitzer 3.6-µm emission tracing stars, green is Spitzer 8.0-µm emission tracing the bright Galactic background, while red is ALMA 3-mm emission tracing dust from the cloud's interior; the cloud has an effective radius of 2.9 pc; from Rathborne et al. 2014c). The position of a water maser—evidence for active star formation—is marked. The cloud is so cold and dense that it is seen as an extinction feature against the bright IR emission from the Galaxy. Because ALMA sees through to the cloud's interior, we are now able to characterise its internal structure.

The sensitivity and angular resolution of the new ALMA data allowed us to derive the column-density Probability Density Function (N-PDF)—a statistical measure of the column-density distribution within a cloud—for G0.253+0.016, to high accuracy. The shape of the PDF is used to predict the level of star formation within a cloud; such predictions have been borne out by observation.

In theoretical models of supersonically turbulent, isothermal media, the volume-density PDF follows a log-normal function (Vázquez-Semadeni 1994). Clouds in the solar neighbourhood also have column-density PDFs that are well described by a log-normal distribution (Lombardi *et al*. 2008; Goodman *et al*. 2009; Kainulainen *et al*. 2009, 2013; Schneider *et al*. 2014). The column-density PDF for G0.253+0.016, derived from the new ALMA observations, has the same log-normal shape and dispersion as that for the solar-neighbourhood clouds. But there is an important difference: the mean column density of G0.253+0.016 is 10 to 100 times higher. Both this difference, and the similarities in the PDF's form, match the predictions made by models of turbulent clouds, when one takes into account the higher pressure within the CMZ.

At the highest column densities the PDF of G0.253+0.016 departs from a log-normal distribution. The dense material that causes this deviation coincides with a water maser—the only direct evidence for star formation in the cloud (Lis & Carlstrom 1994; Kauffmann *et al*. 2013). A forming star heats the gas immediately around it, and so the deviation in the PDF distribution may result from a higher temperature in this small region rather from than a higher column density. But in either case, it indicates the beginning of star formation: self-gravity.

Under what conditions does star-formation begin? Observations of solar neighbourhood clouds suggest that once a column density of ~1.4 × 10^{22} cm^{-2} is reached, star formation proceeds with very high efficiency on a 20-million-year time scale (Lada *et al*. 2010). In the CMZ, it's a different story: while most of the gas has N (H_2) far in excess of 1.4 × 10^{22} cm^{-2}, it is forming stars 10 to 100 times less efficiently than predicted by this threshold (Longmore *et al*. 2013). As noted above, only one region of the cloud, corresponding to 0.06% of its total mass, shows evidence for star formation (Figure 1). However, theoretical models of turbulent media predict a different, environmentally dependent threshold for star-formation—10^8 cm^{-3} in the case of the CMZ. The sole star-forming core in G0.253+0.016, with a derived volume density of more than 10^6 cm^{-3}, is consistent with this higher threshold—orders of magnitude higher than that derived for solar neighbourhood clouds (Kruijssen *et al*. 2014).

So our current theoretical understanding of the conditions leading to star formation seems to apply in high-pressure environments such as the CMZ. Given the CMZ's similarity to conditions in high-redredshift galaxies, it may also hold in the early Universe.

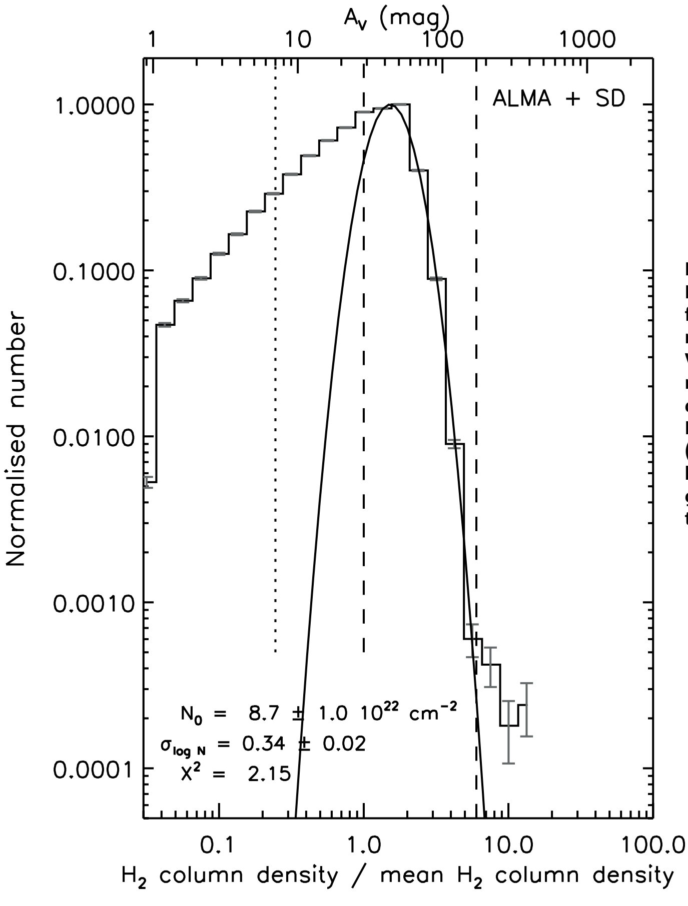

Figure 2. Normalised column-density Probability Density Function (PDF) for G0.253+0.016 (adapted from Rathborne et al. 2014c). The solid curve is a log-normal fit to the PDF: best-fit parameters are labelled. Vertical dashed lines show the fit range (the limits mark the approximate point at which the distribution deviates from log-normal). Vertical dotted lines mark N (H_2) = 1.4 × 1022 cm^{-2}. The error bars show the sort (number) uncertainties. The small deviation at the highest column densities traces material that is self-gravitating, and corresponds to the only location in the cloud where star formation is occurring.

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Students ‘suss out’ peculiar pulsar

MATTHEW KERR (CSIRO)

The hallmark of pulsars—by definition—is the steady stream of pulses they emit. The stability of this stream is the foundation of pulsar-timing experiments, including tests of the theory of general relativity with the double-pulsar system and searches for gravitational waves.

But some pulsars are wayward—intermittent. And these awkward customers might have something to teach us about how pulsars work.

Recent discoveries suggest that intermittency is related to changes in the pulsar’s magnetosphere, which is responsible for generating its pulses. In 2006 Kramer et al. discovered that the emission of PSR B1931+24 turns on and off on time scales of about a month, and that while off the pulsar spins down more slowly than while on. These different spin-down rates point to the pulsar’s magnetosphere reconfiguring itself: an altered radiation pattern is a natural consequence. Quasi-periodic magnetic reconfiguration can occur on a lesser scale too. In 2010 Lyne et al. identified correlations between the spin-down rate and pulse shape in a sample of pulsars timed over several decades. The changes in the spin-down rate were smaller than those observed in Kramer et al’s study, and the changes in the pulse profiles were small too.

In 2013, Hermsen et al. observed such state switching even more directly, finding that changes in the radio and X-ray emission from PSR B0943+10 were correlated. Here we could be seeing the magnetosphere plasma becoming more or less dense after a state switch, and so absorbing more or fewer X-rays.

Most pulsars that switch state do so over months or even decades, which makes it challenging to catch them in the act. To better understand how and why the magnetosphere changes, we’d like to study pulsars that change on time scales of hours or days.

Happily, we have found a new one. PSR J1717-4054 (or 1717 for short), a pulsar discovered with the Parkes telescope by Johnston et al. in 1992, switches on and off over a few hours. Even this modest intermittency makes observations a challenge, and 1717 was rarely observed until the PULSE@Parkes outreach program began in 2007. This program lets high school students operate the Parkes telescope and observe pulsars of their choice from a list of interesting candidates. Thanks to its intermittency, 1717 has been a popular target; students have made nearly 90 snapshot observations of it.

CSIRO summer vacation student Mitchell Kiczynski analysed these data in early 2014. He measured the switching timescale and found that, on average, the pulsar turns on after 72 minutes of ‘silence’, and turns off again after about 18 minutes.

This prompted us to probe 1717 more carefully. Confident that we would detect multiple switches during a long observation, we made two rise-to-set tracks of high-time-resolution ‘single pulse’ data with Parkes.

On the first day of observations the pulsar switched largely as the snapshot observations had suggested it would (Figure 1). On the second day, however, the pulsar remained off for much of the observation, at one point falling silent for more than four hours. Such a long ‘off’ interval is only marginally consistent with an exponential distribution, which is what we’d expect if the switching were stochastic. Analysing single pulses also brought some surprises.

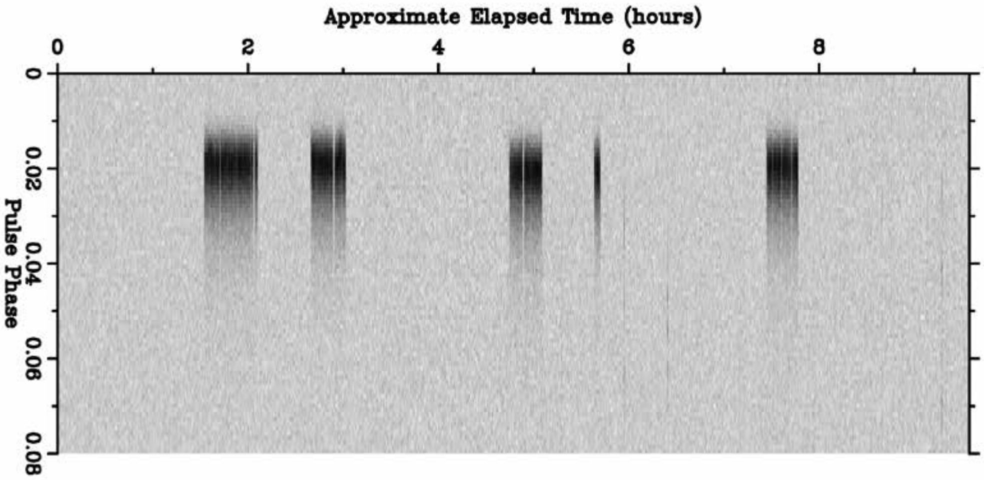

Figure 1. The phase-resolved intensity (in arbitrary units) obtained during the first day of the long-track observations, demonstrating the stochastic nature of the intermittency. (λ = 20 cm) (From Kerr *et al*. 2014)

When the pulsar is 'on', it also nulls; that is, it produces no detectable emission during one or more rotations. We observed about 100 such nulls during the first day; most lasted only one rotation. (See Figure 2.) Such nulling is relatively common among older pulsars (1717 is a venerable four million years old), and is tied to plasma fluctuations that temporarily destroy the coherence needed to produce radio emission.

However, we also observed 14 nulls lasting from 10 to 60 rotations: some are visible in Figure 1. This group of nulls is cleanly separated from the commoner short nulls, indicating that a different process is at work.

So we are left with something of a puzzle. The intermittency alone is challenging to explain. Time scales naturally associated with the pulsar range from nanoseconds (for processes related to small structures in the magnetosphere) to about one second (the pulsar's rotational period): all are far shorter than the hours for which 1717 remains off. Could the intermittency have an external cause? Cordes and Shannon have proposed that a pulsar may be surrounded by a debris disk, and that asteroids plunging from the disk into the magnetosphere might provide enough ionised material to alter the currents of the magnetosphere, re-igniting (or quenching) pulsed emission. This emission would persist until magnetospheric fluctuations return the system to quiescence.

In such a picture, the inner radius and density of the debris disk set the time scale of the intermittency. The short nulls are simply a feature of the plasma in the 'on' state. But the long nulls don't fit neatly into this picture. One the one hand, they last for tens of rotations—much longer than the time the magnetosphere needs to reconfigure itself. On the other hand, they are too short for the magnetosphere to have relaxed back to the 'off' state, as they are much shorter than the 'asteroid' time scale. Thus they seem to represent a third magnetospheric configuration.

Understanding the behaviour of the magnetosphere, and hence what drives state switches, could be important for pulsar timing. Is the magnetosphere 'dead' during long nulls? Or is it still 'alive' but producing only faint emission? Are there transient phenomena associated with the onset of intermittency and long nulls? At present we can't tell; we don't have the observational sensitivity. The answers must await the beautiful future of the Square Kilometre Array.

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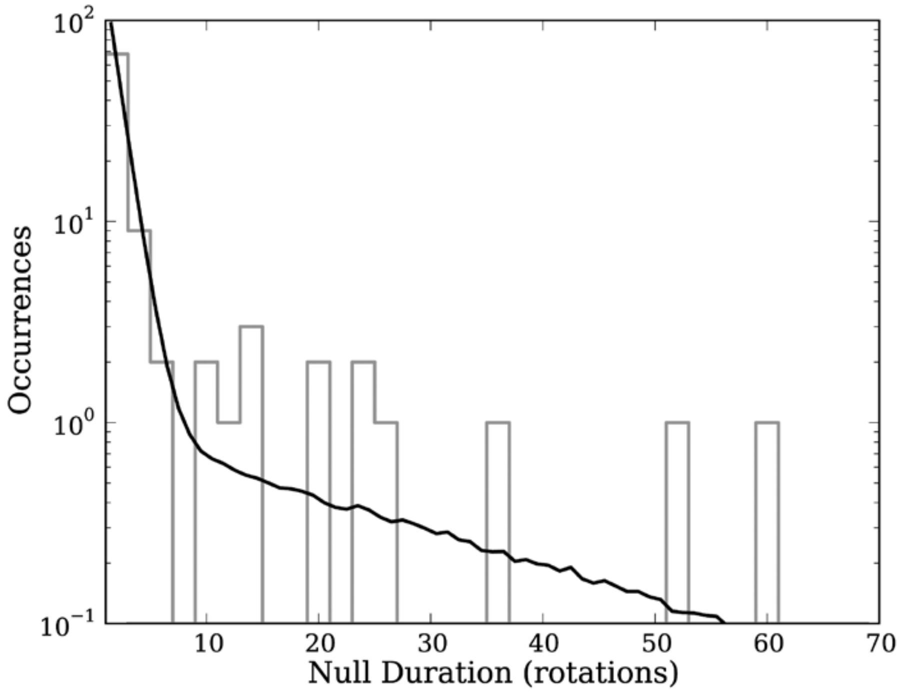

Figure 2. Duration of nulling intervals during active periods (in grey). The model shown in black is the mean value from simulations from a two-state Markov model. (From Kerr *et al.* 2014)

Discovery of the first extragalactic class 1 methanol maser

SIMON ELLINGSEN (UNIVERSITY OF TASMANIA)

The first strong and common methanol-maser transitions towards Galactic star-formation regions were found in the late 1980s and early 1990s. These discoveries were soon followed by searches for extragalactic examples, both in nearby galaxies and in more distant systems where luminous OH or H_2O maser emission had been observed. The Parkes telescope, the Compact Array and Arecibo targeted more than 100 extragalactic sources, looking for the 6.7-GHz methanol transition (the most common Galactic methanol maser), but made only three detections, all towards star-formation regions in the Large Magellanic Cloud (LMC)—and none of them megamasers. There is a close relationship between main-line OH and 6.7-GHz methanol masers in Galactic star-formation regions, but no-one has yet detected a 6.7-GHz counterpart to an OH megamaser in another galaxy.

Following these first, unsuccessful, searches for 6.7-GHz megamasers, Andrej Sobolev suggested (on the basis of maser pumping models) that the 36.2-GHz class I methanol masers were the ones most likely to show megamaser emission (Sobolev 1993). But in the early '90s very few telescopes had receivers that covered that transition, and Sobolev's conjecture remained untested for more than 20 years. During the Neapolitan of Masers meeting held at CASS in May 2013, we (the authors of Ellingsen et al. 2014) discussed class I methanol megamasers and realised that the Compact Array, with its 7-mm receiver system and broadband backend, could now be used to test Sobolev's 1993 prediction. Soon after the meeting, Yusef-Zadeh et al. published observations of the central region of the Milky Way that they'd made with the Jansky Very Large Array at 7 mm: these revealed widespread 36.2-GHz methanol maser emission, mostly *not* associated with high-mass star-formation regions. This encouraged us to search for counterparts further afield.

In April this year we used the Compact Array to observe the nearest starburst galaxy, NGC 253 (the Sculptor galaxy), at 36.2 GHz. The array was in the H168 configuration, giving an angular resolution of approximately 7”. Continuum emission from the nucleus of NGC 253 was used to self-calibrate the data. We detected 36.2-GHz methanol emission from two locations, both 10-20” away from the nucleus (Figure 1; Ellingsen *et al.*, 2014): as NGC 253 is at a distance of 3.4 Mpc, this represents a spatial offset of ~200–300 pc. The methanol emission is located towards the edge of the Central Molecular Zone in NGC 253, along the same position angle as the inner spiral arms (Figure 2).

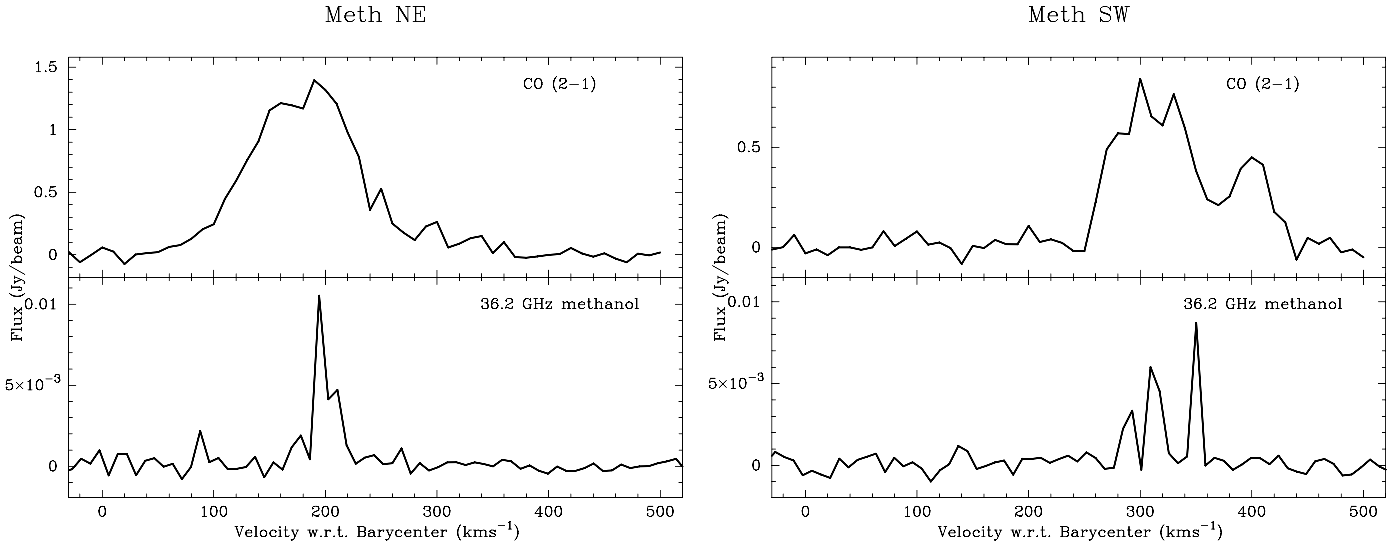

Figure 1. The 36.2-GHz methanol emission from the Compact Array observations of NGC 253 and the CO(2–1) emission from the same region. (From Ellingsen *et al.* 2014)

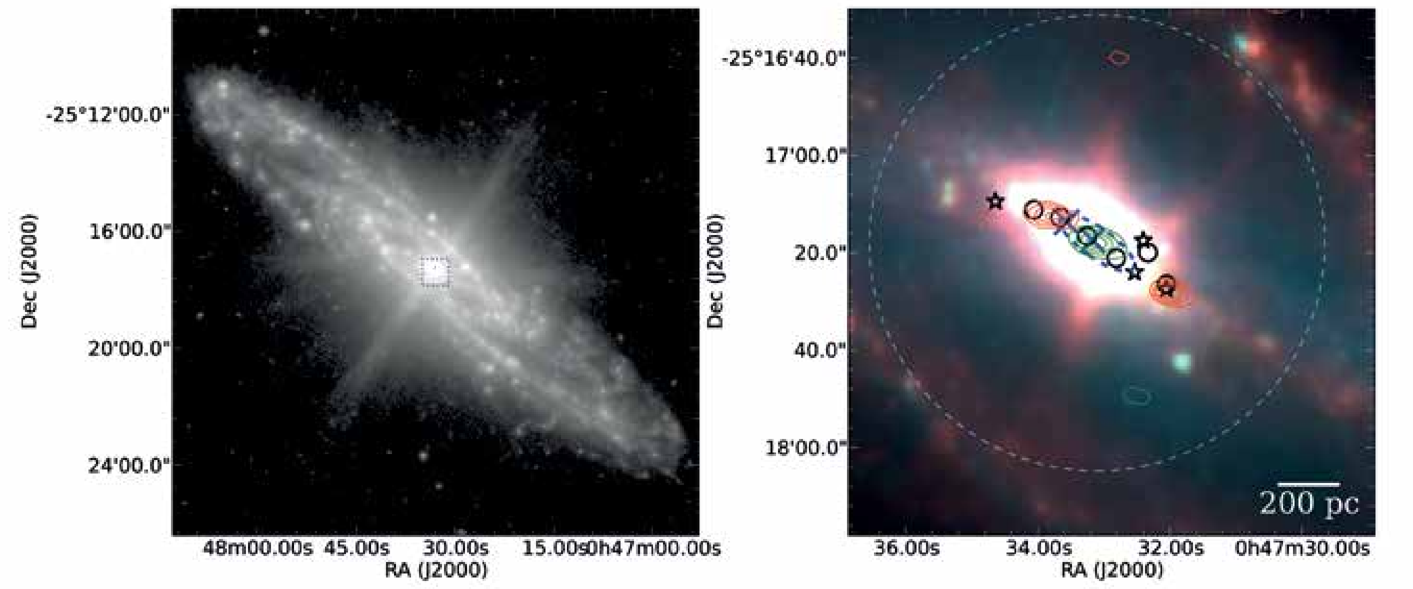

Figure 2. (Left) A *Spitzer* 24-µm image of NGC 253. The blue box marks the region shown in the right-hand panel. (Right) 36-GHz continuum (green contours) and 36.2-GHz (red contours) with a *Spitzer* three-colour image (8.0, 4.5, 3.6 µm for red, green, blue) as the background. The blue dashed ellipse shows the half-maximum intensity point of the Central Molecular Zone. The blue crosses mark the location of water masers, the black stars the location of supershells and the black circles the location of NH3 cores. The cyan dashed line shows the size of the Compact Array's primary beam. (From Ellingsen *et al.* 2014)

The 36.2-GHz methanol emission lines are narrower than those of thermal molecular lines at the same location (e.g. CO 2-1; Figure 1) and have an integrated luminosity more than ten times greater than that of the integrated 36.2-GHz methanol emission observed towards the centre of the Milky Way. This suggests that the emission in NGC 253 is almost certainly a maser, but to confirm that we need observations at higher angular and spectral resolutions.

This is the first detection of an extragalactic class I methanol maser and bears out Sobolev's prediction that the 36.2-GHz transition is the one most likely to manifest as a megamaser. The masers we've observed in NGC 253 are about five orders of magnitude more luminous than typical class I methanol masers in Galactic star-formation regions. (Gas-phase methanol is depleted relatively rapidly through chemical reactions and/or dissociation, and it's not obvious what's creating the elevated levels of methanol required for the NGC 253 masers. Cosmic rays may be desorbing methanol from cold dust grains, or the methanol abundance may be raised by shocks where an outflow from the galaxy's nucleus is interacting with the inner molecular disk.)

The emission we've detected is not quite luminous enough to be classified as the first methanol megamaser. But we could reasonably expect that the conditions that produce it will occur in the central regions of other starburst galaxies and of galaxies experiencing major mergers. If the maser luminosity scales with the star-formation rate, then there are good prospects for detecting class I methanol megamasers in such systems. That could give us a new and uniquely sensitive way to test for variations in one of the fundamental constants, µ (the proton-to-electron mass ratio). Of the molecules commonly detected in interstellar space, methanol is the only one with rotational transitions that are very sensitive to µ. The sensitivity varies between transitions. To date, the only detection of methanol at cosmological distances is the absorption observed towards the lensing galaxy in the PKSB1830-211 gravitational lens system (see ATNF News, April 2012; Ellingsen *et al.* 2012). Finding two or more methanol megamasers would give us a powerful way to test the constancy of µ (Ellingsen *et al.* 2011).

The Compact Array can observe all the known class I methanol transitions with rest frequencies of less than 100 GHz. With the spectral capabilities and bandwidths of the Compact Array Broadband Backend, it is the ideal instrument with which to undertake such investigations.

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Publications

The list below is of published refereed papers that use ATNF data or are by CASS authors, and has been compiled since the publication of the April 2014 issue of *ATNF News*. Papers that include CASS authors are indicated by an asterisk. Please email any updates or corrections to this list to *Julie.Tesoriero@csiro.au*.

Publication lists of papers that include ATNF data or CASS authors are also available on the ATNF website *www.atnf.csiro.au/research/publications*.

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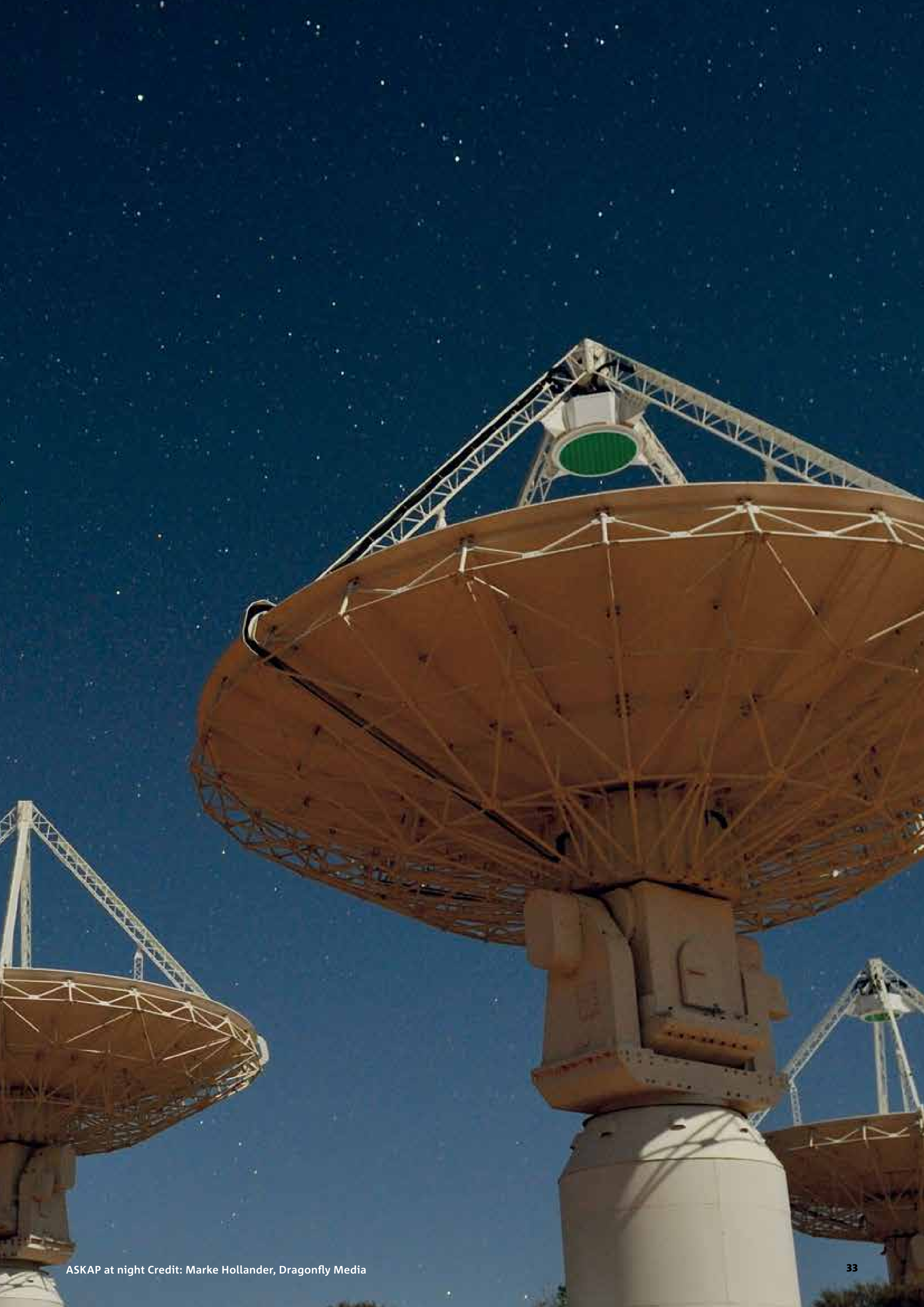

ASKAP at night Credit: Marke Hollander, Dragonfly Media

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