# CAASTRO

ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS

FIVE

ANNUAL REPORT 2015

CAASTRO acknowledges the support of the Australian Research Council and of NSW Trade and Investment. We also acknowledge the financial and in-kind support provided by our participating organisations: The University of Sydney, The University of Western Australia, The University of Melbourne, Swinburne University of Technology, The Australian National University, Curtin University and The University of Queensland.



**www.caastro.org**

Design by Go Media Design

Australian Government
Australian Research Council

NSW GOVERNMENT Trade & Investment

# CONTENTS

# INTRODUCTION FROM THE CHAIR

**DR ALAN FINKEL AO FTSE**
**CHAIR, CAASTRO ADVISORY BOARD**

I have been privileged to be the Chair of the Advisory Board of CAASTRO since its inception but at the end of 2015 I formally retired in order to take up my new role as Chief Scientist for Australia. Although I am excited by the opportunities in this new role I am saddened to be leaving CAASTRO. To satisfy my ongoing wonder about our presence in the Universe I will have to make do with keeping an eye on CAASTRO's outputs in coming years.

As CAASTRO Chair I have been supported by a superb Board that has a skills mix covering research methodology, astronomy expertise, science communication, organisational management and commercial knowledge. Bronwyn Evans, Rachel Nowak and Hugh Durrant-Whyte this year completed their first full year as Board members. Peter Davies joined us later in the year. They and the more seasoned members contributed to the ongoing responsibilities of the Board across the full range of CAASTRO's activities.

But without doubt the credit for leading CAASTRO to success should go to the Director Elaine Sadler, the Chief Operating Officer Kate Gunn and the other members of the Executive. During the year Brian Schmidt accepted the Vice-Chancellorship of the Australian National University (ANU) and Steven Tingay was appointed the founding director of the new Italian Radio Astronomy Observatory. I wish them both much success, and take this opportunity to welcome Carole Jackson (Curtin University) and Christian Wolf (ANU) as new members of the 2016 CAASTRO Executive team.

CAASTRO itself has not submitted a bid for another round of Australian Research Council Centre of Excellence funding; instead, we have supported a new bid for a Centre called CAASTRO-3D. This has been shortlisted, and if funded will come into existence in 2017. Our near-term ambition within CAASTRO is to achieve as many of our goals as possible, irrespective of the outcome of the CAASTRO-3D bid. To this end we undertook a strategy-planning session in November to identify our highest-impact research opportunities and a transition plan that will ensure the best outcomes for ongoing careers and projects. We also identified enduring contributions beyond the science that might assist future Centres of Excellence, for example in their management methodology or gender-equity programs.

One of our key responsibilities beyond astronomy is outreach. As expected, CAASTRO scientists talk frequently to the public but we also run novel programs such as the *Astronomer in Residence* program at Uluru. Our *CAASTRO in the Classroom* initiative uses video conferencing to bring our young astrophysicists into the classroom to inspire students about science and technology.

Sometimes outreach opportunities emerge directly from the science. When Undergraduate Student Cleo Loi, supervised by Tara Murphy (University of Sydney), was using the Murchison Widefield Array for astronomy, she followed her curiosity to examine atmospheric distortions and discovered huge tubular congregations of electrons in the atmosphere. Cleo's work won the 2015 Canon Extreme Imaging prize and the video featuring her work has been viewed 1.1 million times.

Australian science, research and innovation received a big boost in early December with the announcement of the Federal Government's *National Innovation and Science Agenda*. The existing operators of national-scale research equipment were provided with funding for the next ten years, as was the Australian Synchrotron, and the Square Kilometre Array telescope project received substantial funding. Equally important is the newfound optimism among the research and innovation community reflecting the fact that we now have a government that understands and cares about science, is willing to take a risk and to invest in the future.

My final task is to thank my fellow Board members, the staff and the students of CAASTRO for providing me personally with an extraordinary opportunity to intersect with the brilliance and the imagination inherent in the world of astronomy.

# VISION & MISSION STATEMENT

Molongolo shows the Milky Way
*Credit: Fabian Jankowski*

## The CAASTRO Vision

CAASTRO aims to be an international leader in widefield astronomy, positioning Australia to address fundamental unsolved questions about the Universe with the dramatic capabilities of next-generation telescopes and advanced instrumentation.

## The CAASTRO Mission

CAASTRO is carrying out key science with 21st century telescopes. Our underlying goals are:

**DISCOVER** To make groundbreaking advances in our understanding of the Universe, thereby cementing Australia's reputation as a world leader in astrophysical research;

**INNOVATE** To develop innovative new ways of surveying the entire sky, of processing enormous volumes of astronomical measurements, and of visualising complex datasets, so as to build unique expertise in widefield radio and optical astronomy;

**PERFORM** To make high-impact discoveries using Square Kilometre Array pathfinder telescopes, thus positioning Australia to lead the science programs planned for the SKA;

**EDUCATE** To provide compelling new opportunities for students and early-career researchers and exciting stories to inform the public; and

**UNITE** To bring the top astronomers from Australia and around the world together into a focused collaborative environment.

## About CAASTRO

Astronomy has entered a golden age, in which we seek to understand the complete evolution of the Universe and its constituents. But the key unsolved questions in astronomy demand entirely new approaches, requiring enormous datasets covering the entire sky.

In recent years, Australia has invested more than $420 million both in innovative widefield telescopes and in the powerful computers needed to process the resulting torrents of data. Using these new tools, Australia now has established itself at the vanguard of the upcoming information revolution centred on all-sky astrophysics.

The ARC Centre of Excellence for All-sky Astrophysics (CAASTRO) has assembled the world-class team who now lead the flagship scientific experiments on these new widefield facilities. CAASTRO is delivering transformational new science by bringing together unique expertise in radio astronomy, optical astronomy, theoretical astrophysics and computation, and by coupling all these capabilities to the powerful technology in which Australia has recently invested.

CAASTRO is pursuing three interlinked scientific programs, each of which can be addressed only with the all-sky perspective provided by widefield telescopes:

- The Evolving Universe: When did the first galaxies form, and how have they evolved since?
- The Dynamic Universe: What is the high-energy physics that drives change in the Universe?
- The Dark Universe: What are the dark energy and dark matter that dominate the cosmos?

All CAASTRO activities are based on the principle that international leadership comes from commensurate investment in cutting-edge facilities and human capital. In particular, the CAASTRO research program is underpinned by a strong focus on training and enabling the next generation of scientists, thus providing a legacy extending well beyond the Centre's lifetime. The students we mentor and inspire will lead the scientific discoveries made on future widefield facilities, culminating in the ultimate all-sky telescope, the Square Kilometre Array. CAASTRO is further motivated by the belief that science is a passionate undertaking and this passion should be contagious. We aim to leverage the high impact of our discoveries and the strong public interest they generate to highlight Australian innovation to the general public, and to inspire students to consider careers in science and engineering.

CAASTRO is receiving more than $30 million in funding over the period 2011–2018. CAASTRO is led by The University of Sydney, in conjunction with The University of Western Australia, The University of Melbourne, Swinburne University of Technology, The Australian National University, Curtin University and The University of Queensland, complemented by a group of world-class Australian and international partners.

## A Universal Perspective

A universal perspective of the cosmos, exploring the sky in its entirety not just section by section.

A universal perspective of science, engaging teams, scientists and the public in an inclusive and egalitarian way.

A universal perspective of insight and discovery, understanding how knowledge can be used practically in the wider world.

# DIRECTOR'S REPORT

**PROFESSOR ELAINE SADLER FAA**
**CAASTRO DIRECTOR**

2015 has been another exciting and productive year for CAASTRO. Our activities and research projects across the Evolving, Dark and Dynamic themes are in full swing, and I hope you will enjoy reading about our progress in this year's Annual Report.

I'd like to highlight two research results published in 2015 that have had a worldwide impact, attracting attention both from experts in the field and the general public. CAASTRO student Cleo Loi used the Murchison Widefield Array (MWA) radio telescope to make the first detailed images of large tubular ducts of plasma in the ionosphere. These ducts are aligned with the Earth's magnetic field lines and link the upper ionosphere with the inner plasmasphere. From MWA observations, Cleo was able to deduce the heights and sizes of the ducts and image their motion in real time.

A short video explaining Cleo's discovery, made with assistance from CAASTRO's Education and Outreach Manager Wiebke Ebeling, has now scored over one million hits on YouTube, and Cleo has also published her findings in international academic journals.

A second eye-catching result this year came from CAASTRO PhD student Emily Petroff, who published a landmark paper identifying the source of *perytons*: transient radio signals, lasting for just milliseconds. Astronomers had suspected they were terrestrial in origin, yet they showed frequency-swept emission, like that of an astrophysical pulse propagating through tenuous cold plasma. Emily's work revealed that a peryton can be generated locally when a microwave oven door is opened prematurely and a nearby telescope is at an appropriate angle to receive it! But, significantly, her paper also demonstrated that the fast radio bursts (FRBs) detected by the Parkes telescope could not have been produced locally in this way, and remain excellent candidates for genuine extragalactic transients. These are just two examples of the amazing work done by our CAASTRO students, and I am delighted that CAASTRO has been able to attract such an outstanding cohort of young researchers.

Congratulations go to CAASTRO Advisory Board Chair, Dr Alan Finkel AO FTSE, whose appointment as Australia's next Chief Scientist was announced in October. Alan stepped down as Board Chair in January 2016 when he started his new role, and we are now in the process of appointing his replacement. Alan's involvement with CAASTRO dates back to early 2010, and he agreed to take on the role of Advisory Board Chair even before the Centre had been funded. As Board Chair, Alan helped to give CAASTRO the shape and structure it has today, and he has been an engaged, enthusiastic and inspiring figure throughout his involvement with the Centre. We will miss you, Alan, and wish you well in this important and exciting new role. Many thanks for all you have done for CAASTRO!

The past year has also seen some changes within the CAASTRO Executive Committee. Brian Schmidt (ANU Node Leader) took office as the new Vice-Chancellor of the Australian National University in January 2016, but will remain as a Chief Investigator in CAASTRO and co-Chair of our Gender Action Committee. Christian Wolf (ANU) will step into Brian's position as the new ANU Node Leader, and will join the CAASTRO Executive as well as overseeing the SkyMapper project. Steven Tingay (Curtin Node Leader) recently moved to Italy to take up a new position as Founding Director of the INAF Osservatorio di Radioastronomia. In his place, we welcome Carole Jackson as a new Executive member and Curtin Node Leader. Both Brian and Steven have made tremendous contributions to CAASTRO, and I wish them every success in their new roles. Our new Theme Scientists this year are Ixandra Achitouv (Dark), Christene Lynch (Dynamic) and Dan Taranu (Evolving), and I'd like to acknowledge the important work they do in supporting CAASTRO's research across the three themes.

Matthew Bailes (Swinburne Node Leader, and leader of CAASTRO's Dynamic Universe theme) received a 2015 Australian Research Council Laureate Fellowship award for research into fast radio bursts, pulsar physics and the search for gravitational waves, and Tara Murphy was awarded an 2015 ARC Future Fellowship.

CAASTRO hosted a reception at the August 2015 IAU General Assembly in Honolulu to allow our overseas Partner Investigators to meet and talk with Australian researchers. Those attending included CAASTRO PIs Michael Kramer (Germany), Mara Salvato (Germany) and Ravi Subrahmanyan (India), along with Advisory Board member Ron Ekers (CSIRO). In September, CAASTRO Executive members Brian Schmidt, Lister Staveley-Smith, Kate Gunn and I, together with Michael Burton from the University of New South Wales and Mita Brierley from Astronomy Australia Limited, travelled to Beijing for the launch and inaugural meeting of ACAMAR, the Australian-ChinA ConsortiuM for Astrophysical Research. ACAMAR is a 'virtual' centre,

serving as an umbrella and coordination point for bilateral astronomical collaborations between Australia and China. We had a very cordial and productive meeting with our Chinese colleagues in Beijing. CAASTRO will host the 'return' meeting, an ACAMAR workshop in Western Australia, in April 2016.

This year again saw a full program of CAASTRO scientific workshops and events, the largest of which was the *Astronomical Data Analysis Software and Systems* (ADASS) meeting, held in Sydney in October. This meeting of ADASS, the first in the southern hemisphere, attracted more than 300 local and overseas participants. ADASS provides an international forum for scientists and programmers to come together to discuss algorithms and software relevant to astronomical data and its analysis. CAASTRO's Kate Gunn and Kylie Williams were co-Chairs of the local organising committee, and once again ensured that everything ran smoothly.

It was great to see so many CAASTRO members at our recent Annual Retreat, held this year at Leura in the Blue Mountains where we enjoyed peaceful surroundings, fine weather and a wide range of activities. Because CAASTRO is a distributed Centre, comprising seven Australian universities and our national and international partner institutes, our Annual Retreat is an important opportunity for us to meet together in one place to build and strengthen our connections. Special thanks go to those who travelled long distances to attend, to our overseas guest speakers Vernesa Smolcic (University of Zagreb) and Alex Kim (Lawrence Berkeley National Laboratory), and to our inspiring breakfast speaker, Nalini Joshi (University of Sydney), who spoke eloquently on gender issues and the *Science in Australia Gender Equity* initiative.

Our education and outreach activities continue to expand, and a major activity this year was the planetarium show we are producing in partnership with Museum Victoria. This will be launched in Melbourne in March 2016.

CAASTRO is now more than a year past its halfway point, and the Executive and Advisory Board have been discussing strategies to maximize the long-term impact and legacy of our Centre. At the same time, we are keen to identify and support new initiatives wherever possible. At this year's Retreat we held the first CAASTRO Innovation Challenge, in which small groups were invited to brainstorm and pitch ideas that could potentially be developed into a marketable product. As we had hoped, there was an enthusiastic response and some excellent ideas. We will take this further in 2016 by providing resources and mentors to help some of these groups to develop their concepts in more detail.

The Federal Government's *National Innovation and Science Agenda*, released in December 2015, contained welcome news for astronomy, in particular the announcement of long-term funding for the National Collaborative Research Infrastructure Scheme (NCRIS) and indicative funding for the Square Kilometre Array (SKA) project. The agenda statement also included funding for programs to promote women in science, such as the pilot stage of the *Science in Australia Gender Equity* (SAGE) program, and for initiatives to promote research-industry collaboration and public awareness of science. Many of these initiatives are well aligned with current CAASTRO activities and should offer us new opportunities in 2016.

This year was my first full year as CAASTRO Director, and I would particularly like to thank Deputy Director Lister Staveley-Smith, COO Kate Gunn and the CAASTRO Executive team for their support. Lister played a key role in setting up ACAMAR and liaising with our Chinese colleagues this year, and has also streamlined many of CAASTRO's internal processes to make it easier to track our publications and the progress of our students. I am grateful for his wise advice on many CAASTRO-related issues. Kate's upbeat enthusiasm, management skills and tireless energy make her the ideal person to oversee CAASTRO's daily operations, and it is a real pleasure to work with her. We are lucky to have a first-rate team of administrative and professional staff working across our seven University nodes, and I thank them and all our CAASTRO members (175 at last count) for the enthusiasm, hard work and collegiality that combine to make our Centre so successful.


**Dr Ashley Ruiter and Professor Brian Schmidt discussing research at the ANU node.**
***Credit: Bill Roberts***

# RESEARCH PROGRAMS

# THE EVOLVING UNIVERSE

**Theme Leader: Professor Stuart Wyithe | The University of Melbourne**

**Theme Scientist: Dan Taranu | The University of Western Australia**

Researchers working under the Evolving Universe theme are the fossil hunters of space. Just as palaeontologists seek to understand how life formed and evolved on Earth, and how ancient life-forms relate to today's, researchers in the Evolving theme strive to trace the evolution of galaxies, from the earliest Universe to the present.

Last year we saw major new Australian instruments – the Murchison Widefield Array (MWA), the initial form of the Australian SKA Pathfinder, and the SAMI instrument on the Anglo-Australian Telescope – start to produce results. This year the publications have been flowing.

In studies of the Epoch of Reionisation (EoR), Sokolowski and colleagues demonstrated that the ionosphere is not a fundamental impediment to detecting an EoR signal (this page), while Trott and Tingay showed that the EoR power spectrum is detectable in the presence of interplanetary scintillation (page 11). Both are promising results for direct detection of the EoR signal. Meanwhile, the Murchison Widefield Array (MWA) EoR project also announced limits on the 21-cm (neutral hydrogen) power spectrum based on the project's first three hours of data (page 11). Encouragingly, the MWA project this year received funding from the Australian Research Council that will allow it to double the number of MWA tiles, from 128 to 256, increasing the telescope's sensitivity and resolution.

Radio observations of galaxies have been prominent this year: they include a survey paper for the MWA's GaLactic Extragalactic All-sky MWA (GLEAM) survey, and the detection and modelling of an extreme gigahertz-peaked radio source with the MWA and the Australia Telescope Compact Array (page 25). Researchers working on FLASH (First Large Absorption Survey in H I) have taken about 100 hours of data using the Boolardy Engineering Test Array, BETA (the initial form of the Australian SKA Pathfinder), and early science is on the way. While the WALLABY and DINGO surveys are awaiting data, software development is in full swing with the release of new methods for source detection, modelling warped H I (neutral hydrogen) discs, and measuring the Tully-Fisher relation from stacked spectra.

On the optical side, the SAMI Galaxy Survey is steaming along, with about 1400 galaxies observed to date. Science results from 2015 include papers on gas kinematics and outflows, stellar kinematics, star-formation aperture corrections (page 31), star-formation morphology and gradients, dynamical disturbances, and disk-rotation curves. Observations will continue through 2016 and beyond, and recent internal data releases on gas kinematics and stellar kinematics will be followed by a public data release in 2016.

These are just a few of the highlights of 2015, which was a very productive year for the Evolving Universe theme. Some of its diverse work is discussed in more detail below.

## Is the ionosphere a show-stopper for studying the first galaxies?

*CAASTRO researchers have investigated the effect of the ionosphere on signals from the Epoch of Reionisation.*

Immediately after the Big Bang, the hydrogen gas that filled the Universe was hot and ionised, having had its electrons stripped off by radiation. As the Universe expanded and cooled, the hydrogen assumed its neutral, un-ionised state. There were no stars: the Universe had entered the Dark Ages. Towards the end of this period, collapsing matter formed the first objects (stars or quasars) that later generated ionising radiation (ultraviolet or X-rays); this radiation created bubbles of ionised hydrogen gas in the neutral hydrogen, like the bubbles in Swiss cheese. Carried to completion, the process led to today's Universe, in which the gas between galaxies is fully ionised.

Researchers wish to understand the astrophysics (and cosmology) underlying this Epoch of Reionisation (EoR). When did the process take place, and how rapidly? How was matter distributed at this time? And what were the first 'ionisers': stars, or black holes born from the violent collapse of those stars?

The ionising radiation from the first entities not only created bubbles of ionised hydrogen (H II) but also triggered the emission of radio waves from the surrounding neutral hydrogen (H I). This emission has a rest-frame wavelength of 21 centimetres but is redshifted on its long journey to Earth, arriving with a much longer wavelength. The future Square Kilometre Array radio telescope will directly image its distribution. But meanwhile other attempts are being made to detect the EoR signal. The simplest detection

# PERFORM

would be of a 'global' signal, averaged over the whole sky: this would allow us to date the onset of the EoR and measure its duration.

The H I radiation is expected to be extremely weak (~100 millikelvin), and to identify the global EoR signal we will need to measure it with a precision of about one per cent (that is, a millikelvin). The challenges in doing this include man-made radio interference; instrumental uncertainties; and emission from our own Galaxy, which is 10,000 times stronger than the EoR signal. Finally, there is the ionosphere, a layer of the Earth's atmosphere significantly ionised by radiation from the Sun. This refracts and absorbs low-frequency radio signals, and adds some thermal emission of its own. The effects of the ionosphere vary with the incoming radio signal's frequency (as $\nu^{-2}$), so they change its frequency structure. Recently, Datta *et al.* (2015) have asserted that the nature of the ionospheric 'noise' is such that it cannot be adequately removed from ground-based measurements. So, is it even feasible to study the EoR signal from the ground?

A team led by CAASTRO's Marcin Sokolowski (Curtin University) has looked at this issue, using data from the BIGHORNS instrument installed at CSIRO's Murchison Radio-astronomy Observatory in Western Australia in October 2014. BIGHORNS (the Broadband Instrument for Global HydrOgen ReioNisation Signal) is designed to detect the global EoR signal, which is predicted to lie in the range 50–200 MHz. BIGHORNS captures data continuously, at a rate of about 30 GB a day, and is highly sensitive to weak signals.

Sokolowski's team first examined the magnitude of the ionosphere's effects on their data, looking separately at three individual months. They found that in spectra taken at night, the effect of refraction was negligible compared to that of absorption and emission. Overall, the nighttime data was superior; in fact the team concluded that only about two hours a day (centred on a local sidereal time of 2.9 hours) were optimal for collecting data.

Datta *et al.*'s key claim was that ionospheric noise is 'flicker noise', its power varying as $1/f^{\alpha}$ ($\alpha \leq 2$). The average value for such noise changes over time, and the noise cannot be 'averaged down' by integrating over long periods. Testing this claim, Sokolowski and his colleagues found that with a sufficiently large number of sample spectra, the standard deviation of the calibrated sky temperature converges and then remains constant as the number of integrations is increased. This means that the statistical noise can be suppressed by a factor of $1/\sqrt{N_s}$, where $N_s$ is the number of averaged spectra.

To probe this finding further, the team applied the same test to model data (without any extra variability due to ionosphere or instrumental effects). The standard deviation of the model data converged to a value slightly lower than that observed in the real data, the difference corresponding to the standard deviation of intra-day variability attributed to the ionospheric effects. So it appears that the spectra can be averaged down to the precision required by global EoR studies, even with ground-based instruments.

In trying to understand this result, Sokolowski's team examined the power spectrum of the fluctuations of its nighttime data. The power spectrum does indeed exhibit flicker noise, but appears to 'turn over' at a period of about a day, and become constant (white noise) at lower frequencies. (This behaviour is seen in other systems, such as audio amplifiers.) The power present in the lowest frequencies is finite, and long-timescale fluctuations should not prevent long integrations from achieving the required precision, which explains the observed convergence of the standard deviation. This encouraging finding brightens the prospects for ground-based global EoR experiments.

## Publication

Marcin Sokolowski and nine co-authors, "The impact of the ionosphere on ground-based detection of the global Epoch of Reionisation signal". The Astrophysical Journal, Volume 813, Issue 1, article id. 18, 21 pp. (2015)

**Marcin Sokolowski (left) and Randall Wayth at work on the BIGHORNS antenna at the Murchison Radio-astronomy Observatory.**
***Credit: The MWA Collaboration***

## Murchison Widefield Array (MWA) EoR project

This year saw progress in Epoch of Reionisation (EoR) science, particularly with regard to quantifying foreground contamination and techniques for removing it. Using the BIGHORNS instrument, Marcin Sokolowski and colleagues showed that the ionosphere is not a fundamental impediment to detecting an EoR signal (details, page 9). In another encouraging result, Cathryn Trott and Steven Tingay (both Curtin University) showed that a second possible source of signal contamination, *interplanetary scintillation* (the 'twinkling' of radio sources due to electrons from the solar wind) is in fact negligible for the parameter space that is being searched for the EoR signal.

But EoR experiments still have to contend with galactic and extragalactic foreground sources, some 10,000 times stronger than the EoR signal itself. The removal of foregrounds is not a new problem: studies of the cosmic microwave background have wrestled with it, as have surveys aimed at determining the clustering patterns of galaxies (galaxy power spectra). Jennifer Riding (PhD student, University of Melbourne) has been working on modeling and removing extended sources (details, page 28). In a more general approach, Joshua Dillon (MIT) and colleagues this year developed a different technique for removing foregrounds, one that builds on earlier work (Liu and Tegmark 2012).

Liu and Tegmark's method has a number of important advantages: for instance, by treating foregrounds as a form of correlated noise, both foregrounds and noise can be down-weighted in a way that is unbiased and loss-less in the sense that it maintains all the cosmological information in the data. But it involves multiplying and inverting very large matrices, which is a slow process. Dillon and his collaborators have speeded up this approach. The first explication of their new method was the basis for predicting (in 2013) that an MWA with 128 tiles would require only 1000 hours of observation to detect the EoR power-spectrum signal. This year they have used it to put limits on the 21-cm (neutral hydrogen) power spectrum, based on an initial three hours of data. Using the same three hours of data, Cathryn Trott and her collaborators this year published a 2σ upper limit on the EoR signal, using the *Cosmological H I Power Spectrum Estimator* (CHIPS), an algorithm they have developed to compute the two-dimensional and spherically-averaged power spectrum of brightness-temperature fluctuations. The next 30–50 hours of data from the MWA EoR experiment are now being processed through the two independent pipelines developed for the project.

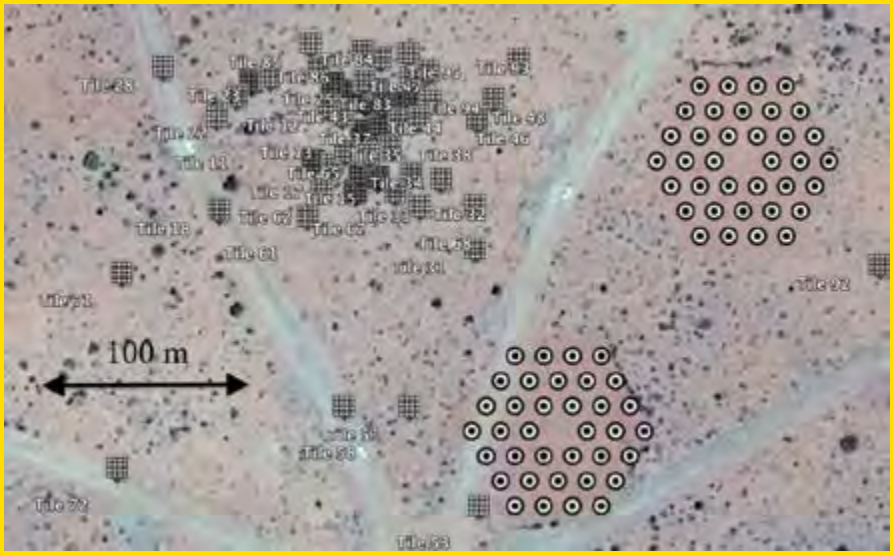
Progress is being further made in EoR science with the MWA's Phase II expansion. This project, due to yield science-quality data during 2016, adds an additional 128 tiles to the array, and allows the formation of an 'EoR Special' array using two hexagonally-shaped sub-arrays combined with existing tiles. Such an array provides a technical advantage over the current one by allowing more precise and straightforward calibration of the data, and forming a custom EoR instrument.

### Publications

Cathryn Trott and Steven Tingay, "The Effect of Interplanetary Scintillation on Epoch of Reionisation Power Spectra". Accepted for publication by The Astrophysical Journal. arXiv:1510.02283

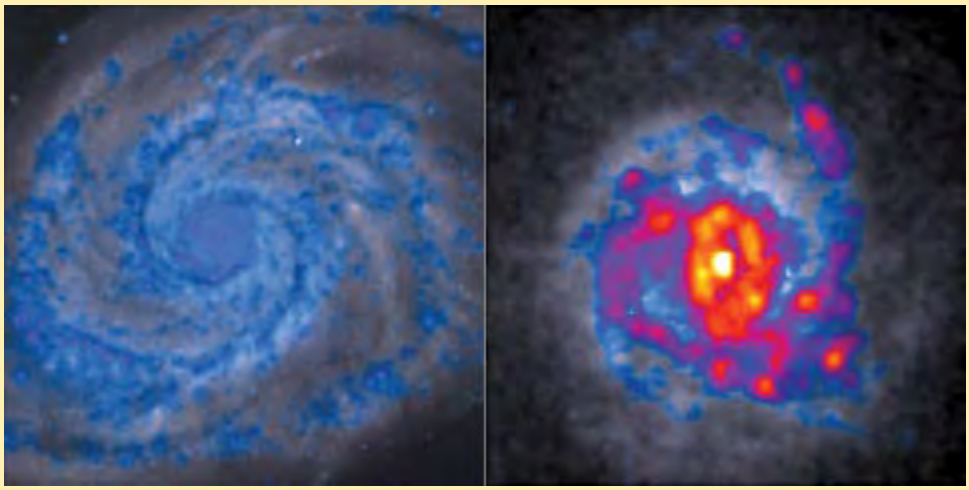
Joshua S. Dillon and 54 co-authors, "Empirical Covariance Modeling for 21 cm Power Spectrum Estimation: A Method Demonstration and New Limits from Early Murchison Widefield Array 128-Tile Data". Physical Review D, Volume 91, Issue 12, id.123011 (2015)

Cathryn Trott and 51 co-authors, "CHIPS: The Cosmological H I Power Spectrum Estimator". The Astrophysical Journal, 818 (2), article id. 139. (2016)




**The MWA expansion: the two hexagonal, regularly-spaced sub-arrays will combine with the irregularly-spaced MWA core tiles to provide a hybrid instrument capable of precisely calibrating data, and obtaining high-quality Epoch of Reionisation (EoR) science data. Combining the regularly and irregularly-spaced components yields a powerful EoR instrument.**
***Credit: The MWA Collaboration***

**The Whirlpool Galaxy (left) is forming stars far more slowly than the clumpy galaxy of the DYNAMO sample (right). The colours represent low (blue) to high (red-yellow) star-formation densities.**
***Credit: Danail Obreschkow (ICRAR). Images use HST data.***



## Early star formation: the key driver

*CAASTRO Associate Investigator Danail Obreschkow (ICRAR/UWA) and colleagues may have solved a major question of astrophysics: what allowed galaxies in the early Universe to form stars far faster than galaxies do today.*

Looking back in time, we can measure the rate at which stars have been formed at every epoch. And ever since the Universe was 3.5 billion years old (corresponding to $z \sim 2$), star formation has been dominated by galaxies in a specific mass range, around $10^{10.7}$–$10^{11}$ solar masses. But the galaxies of this mass at $z \sim 2$ are very different from their equally massive counterparts today. Today's dominant star-forming galaxies are spiral galaxies like the Milky Way. They have stable disks, forming stars at a rate of about one solar mass a year. The $\sim 10^{11}$ solar-mass galaxies at $z \sim 2$ are also disk-like, but composed of giant clumps of gas, forming stars 10–100 times faster. The $z \sim 2$ galaxies have a much higher fraction of molecular hydrogen gas, which is the 'fuel' for star formation. On theoretical grounds, the expansion of the Universe should also mean that these early galaxies have much lower angular momentum. This raises the fundamental question of whether the high gas fraction itself or the low angular momentum is the main reason that makes $z \sim 2$ galaxies form stars so efficiently.

It's difficult to measure the angular momentum of such distant galaxies. Obreschkow and his colleagues from the DYNAMO team, lead by CAASTRO Affiliate Karl Glazebrook, instead studied four highly unusual galaxies in the local Universe that seem to closely match the $z \sim 2$ galaxies of interest: the four are clumpy and turbulent, have a high fraction of molecular gas, and form stars rapidly. Obreschkow measured the stellar angular momentum of these galaxies using the Keck and Gemini telescopes, and found it to be only a third of that of local spiral galaxies of the same stellar mass.

Does the galaxies' low angular momentum cause their high clumpiness, or vice versa? Or are both the result of another factor?

Angular momentum is a conserved quantity. "Another factor" decreasing angular momentum while increasing clumpiness would have to be some kind of external torque, and the galaxies studied showed no sign of recent interactions. Could high clumpiness cause low angular momentum? For this to work, star-forming clumps would need to somehow transfer angular momentum from a galaxy's disk to its dark halo. But simulations show that star-forming regions preferentially remove low-angular-momentum gas via the winds of supernovae, increasing the angular momentum of the disk rather than reducing it. This leaves only the first proposal: that low angular momentum causes high clumpiness.

While the $z \sim 2$ galaxies enjoyed much larger inflows of fresh gas than today's galaxies, conditions had to be right to allow that gas to collapse and actually form stars. Low angular momentum appears to be the key condition. Both theoretical arguments and simulations suggest that stellar angular momentum falls off with increasing redshift: star-forming disks at $z \sim 2$ will have only half as much as their local counterparts. It thus seems that the cosmic growth of angular momentum is behind the change in the population of star-forming disks over time.

### Publication

D. Obreschkow and ten co-authors, "Low angular momentum in clumpy, turbulent disk galaxies". The Astrophysical Journal, Volume 815, Issue 2, article id. 97 (2015).

## SAMI tightens the Fundamental Plane

*Dr Nicholas Scott (University of Sydney) and colleagues have used the new SAMI instrument to investigate a fundamental relationship between the key features of elliptical galaxies.*

Early-type galaxies, ellipticals and lenticulars, are simpler than their spiral cousins. Basically just big balls of stars, they have little gas and dust, and no spiral arms or disc. Once past youth they should be 'dynamically relaxed': that is, their stars should have reached a stable distribution of speeds.

The simplicity of these systems means that, in theory, they should be describable by just three parameters: their total mass (of stars, gas and dark matter); the velocity dispersion of their stars; and their effective radius (the radius within which half their light is emitted). Stellar luminosity has often been used as a proxy for total mass, as it is easier to measure. The three parameters define a plane, a *Fundamental Plane* on which early-type galaxies should lie. This Fundamental Plane is used to predict the properties of galaxies. It is also used in cosmology: for instance, to separate a galaxy's motion due to the expansion of the Universe from the motion caused by the gravitational pull of nearby matter.

Numerous studies have measured galaxy properties to construct this Fundamental Plane. Some of them involved samples of tens of thousands of galaxies. But the Fundamental Plane they generate doesn't match the one predicted by theory: it is slightly tilted. This might be due to galaxies varying in shape as you move across the Plane, or to a systematic variation in the mass-to-light ratio. CAASTRO researcher Dr Nicholas Scott (University of Sydney) and colleagues set out to determine the cause, using data from the SAMI Pilot Survey.

For this investigation Scott's team studied 74 early-type galaxies located in three nearby ($z \sim 0.05$) clusters. Galaxy distances have been one of the most significant sources of uncertainty in Fundamental-Plane studies, but studying clusters, in which all galaxies are at essentially the same distance, eliminated that. The data were drawn from the SAMI Pilot Survey of galaxies, SAMI being a multi-fibre, multi-object integral field unit on the 4-m Anglo-Australian Telescope. SAMI has a field of view of 15 arcseconds and provides velocity information for up to 61 points across a galaxy. Using it allowed the researchers to measure the velocity dispersion of the stars across the effective radius of each galaxy, rather than in just a small central region. And from SAMI's velocity measurements they were able to calculate a mass for each galaxy that took into account stars, gas and dark matter, and to use this instead of its traditional proxy, luminosity.

The result was a Fundamental Plane with scatter so small (rms 0.072) as to be consistent with zero intrinsic scatter: a powerful demonstration of the value of integral field spectroscopy for these studies. However, the Plane's tilt still differed significantly from the predicted one. The data also suggest that there is a non-linear relationship between velocity dispersion and the dynamical mass-to-light ratio.

The full SAMI Galaxy Survey, already under way, will observe about 3,400 galaxies, with about 800 of these coming from a small number of clusters. With this sample of galaxies it will be possible to measure the Fundamental Plane with tiny uncertainties.

### Publication

Nicholas Scott and 18 co-authors. "The SAMI Pilot Survey: the fundamental and mass planes in three low-redshift clusters." MNRAS 451, 2723–2734 (2015)

**The SAMI instrument**
***Credit: AAO***

# THE DYNAMIC UNIVERSE

**Theme Leader: Professor Matthew Bailes | Swinburne University of Technology**

**Theme Scientist: Dr Christene Lynch | The University of Sydney**

Observers in ancient China recorded 'guest stars', stars that suddenly appeared where none had been before, and later vanished. We now know that many of these were supernovae. They are just some of the violent, short-lived phenomena that abound in the Universe. Indeed, we now also know that cosmic processes and violent change can take place on all timescales, down to fractions of a second. The Dynamic Universe theme is concerned with such phenomena.

Many of the theme's researchers are studying the enigmatic *fast radio bursts* (FRBs), trying to characterise them and, ultimately, determine their origin. This work is described on this page. We are also developing a coordinated program to search for counterparts to FRBs using simultaneous observations with the Parkes and Molonglo radio telescopes, the DECam optical imager on the CTIO Blanco telescope, and the Swift satellite.

Much work has been done this year to detect and characterise pulsars. The end of the year saw the re-launch of the University of Sydney's Molonglo Observatory Synthesis Telescope (page 80). The upgraded telescope has now timed more than 200 pulsars and recorded glitches from three. We have also looked at ways to detect pulsars with imaging: this work is described on page 16. And we have used the Murchison Widefield Array's new high-time-resolution voltage-capture system to study the low-frequency scintillation patterns of millisecond pulsars (page 26).

Using data from the MWA Transient Survey, the Slow Transient project has made great strides in understanding how the ionosphere will affect time-domain science at low frequencies. Blind searches for slow transients were carried out at 5.5 GHz in the extended Chandra Deep Field South (by Martin Bell), at 1.4 GHz in the Phoenix Deep Survey fields (by Paul Hancock), and at megahertz frequencies in one of the MWA Epoch of Reionisation fields (by Antonia Rowlinson). While none of these blind searches detected transient events, they were able to place stringent upper limits on the surface density of transients.

In the area of supernovae, we are developing models for Type Ia events from different progenitor systems (page 17). We are also searching for more actual Type Ia supernovae with SkyMapper (page 19): combined with observations from surveys such as OzDES, these will help us to improve constraints on the equation of state for dark energy.

Some of the work done in the theme this year is discussed in more detail on the following pages.

## Bringing fast radio bursts down to Earth

*CAASTRO researchers are vigorously pursuing 'fast radio bursts', one of the hottest topics in astronomy.*

Fast radio bursts (FRBs) are mysterious bursts of radio energy, lasting only a few milliseconds, that appear to have come from the distant Universe. They were discovered in 2007 in archival data from CSIRO's Parkes radio telescope. Around 20 FRBs have been reported to date: most have been found with Parkes, a few by other telescopes. Their origin is unknown. In 2014 CAASTRO student Emily Petroff made the first real-time detection of an FRB, and this year CAASTRO researchers continued to be at the forefront of FRB studies.

To date FRBs have been detected only at high frequencies (above 800 MHz), but a low-frequency detection would help to rule out some proposed models. This year CAASTRO's Steven Tingay (Curtin University) led a pilot search for FRBs with the low-frequency Murchsion Widefield Array (MWA): this used 10.5 hours' worth of data taken for the Epoch of Reionisation survey (page 11) in the form of two-second 'snapshot' images, made over 400 square degrees of sky. No FRBs were found, leading Tingay and his colleagues to conclude that FRBs of a specific energy (700 Jy.ms below 200 MHz) must occur less than 700 times per day over the whole sky. This limit allowed them to discount the possibility that FRBs could be supergiant pulses from young neutron stars in relatively nearby galaxies.

A much larger search for FRBs has begun with the upgraded Molonglo Observatory Synthesis Telescope, UTMOST (page 80), which operates at frequencies around 843 MHz. Modelling by CAASTRO student Manisha Caleb (Australian National University) and her colleagues has shown that at least 50 FRB detections will be required to distinguish between a population of FRBs that evolves with redshift like star formation and one that exists at a constant density through the Universe. UTMOST has a collecting area of 18,000 square metres and a field of view of almost eight square degrees. When fully operational in 2017, it should see an FRB every few days, a rate up to ten times faster than that of Parkes. The key to this rate, and the heart of the telescope's upgrade, is a new digital backend designed by Swinburne University of Technology. Being an interferometer, UTMOST will also be able to get precise east-west positions for the FRBs it detects. Caleb and her colleagues have now made preliminary surveys for pulsars and FRBs, using seven and 14 per cent respectively of UTMOST's final sensitivity. These surveys discovered several pulsars via the detection of single pulses, but no FRBs. The

non-detection puts a limit on FRBs at 843 MHz (for pulses of less than 11 Jy.ms) of 1000 events on the sky per day, which is consistent with the limits obtained at other observing frequencies.

While the UTMOST survey ramps up, investigations continue with Parkes. A team led by David Champion (Max Planck Institute for Radioastronomy) and including seven CAASTRO members this year reported the discovery of an FRB with two components separated by 2.4 milliseconds. Many proposed models for FRBs are based on single high-energy events and could not explain such a finding. Champion *et al*. suggest that some FRBs may have multiple components that can't be distinguished because they are broadened by scattering and other effects.

While this work revealed an event that appears to repeat, a study by CAASTRO student Emily Petroff (Swinburne University), also done with Parkes, points in another direction. Petroff and her colleagues observed eight fields in which FRBs had already been seen, to look for repetition. They detected none, and were able to put limits on repeatability for various time frames. On the basis of this they suggested that FRBs are unlikely to be caused by the interaction of, for instance, a planet with a pulsar wind.

Associate Investigator Jean-Pierre Macquart (Curtin University), together with Partner Investigator Simon Johnston (CSIRO), worked to explain the fact that FRBs are preferentially found at high Galactic latitudes (that is, away from the plane of the Galaxy). Macquart and Johnston suggest that the bias arises from rapid intensity fluctuations (scintillation) at low latitudes, which are caused by small-scale irregularities in the Galaxy's interstellar medium. At low Galactic latitudes, they say, FRB signals travel through a lot of turbulent interstellar material and their intensity averages out to near the true mean value, while at higher latitudes scintillation preferentially boosts signals above the threshold of detection, lifting the number of sources we see. Macquart and Johnston conclude that the enhancement at high latitudes is such that the all-sky rate of FRBs may have previously been over-estimated by a factor of three.

The most far-reaching result in FRB studies this year was the detection, by CAASTRO Affiliate Evan Keane (SKA Organisation) and his colleagues (many also from CAASTRO) of the first radio afterglow from an FRB and the identification of its host galaxy. This work, published in *Nature*, is the strongest evidence yet that FRBs lie at cosmological distances.

Keane leads a dedicated search for pulsars and FRBs running on the Parkes telescope, SUPERB (SUrvey for Pulsars and Extragalactic Radio Bursts). In April Parkes detected a burst (FRB 150418), triggering follow-up observations with a number of telescopes. One, CSIRO's Australia Telescope Compact Array, detected a radio source lasting for six days that was identified as the FRB's radio afterglow. The FRB field was also followed up at optical wavelengths with the 8.2-m Subaru Telescope. These observations identified a radio source that could be matched with the putative host: further work showed this to be an elliptical galaxy of about $10^{11}$ solar masses at a redshift of 0.492. Having localised the FRB, Keane and his colleagues were able to derive a number of important parameters for the object, including its distance and the energy it released. That this event occurred in an old, 'red' galaxy, well past its heyday for star formation, suggests that it may have arisen from two compact objects merging rather than from a phenomenon related to recent star formation: the afterglow also supports this. But there could be more than one class of FRB, the researchers say.

Using FRB 150418 as a tool, Keane *et al*. were also able to make the first direct measurement of the density of the ionised gas in the intergalactic medium, which is thought to house the 'missing baryons': normal (non-dark) matter the Universe was predicted to contain, but which had not yet been located. Their result for the fraction of the critical density (4.9 $\pm$ 1.3%) agrees with the prediction derived from observations of the cosmic microwave background and captures, for the first time, the 'missing baryons'.

These FRB studies were reported in the following papers:

Steven Tingay and 28 co-authors, "A search for Fast Radio Bursts at low frequencies with Murchison Widefield Array high time resolution imaging". The Astronomical Journal, 150 (6), article id. 199 (2015)

Manisha Caleb and seven co-authors, "Are the distributions of Fast Radio Burst properties consistent with a cosmological population?". Accepted for publication by Monthly Notices of the Royal Astronomical Society. arXiv:1512.02738

Manisha Caleb and 14 co-authors, "Fast Radio Transient searches with UTMOST at 843 MHz". Accepted for publication by Monthly Notices of the Royal Astronomical Society. arXiv:1601.02444

David Champion and 20 co-authors, "Five new Fast Radio Bursts from the HTRU high latitude survey: first evidence for two-component bursts". Submitted to Monthly Notices of the Royal Astronomical Society. arXiv:1511.07746

Emily Petroff and 15 co-authors, "A survey of FRB fields: limits on repeatability". Monthly Notices of the Royal Astronomical Society, 454 (1), pp. 457–462 (2015)

Jean-Pierre Macquart and Simon Johnston, "On the paucity of Fast Radio Bursts at low Galactic latitudes". Monthly Notices of the Royal Astronomical Society, 451 (3), pp. 3278–3286 (2015)

Evan Keane and 40 co-authors, "A Fast Radio Burst host galaxy". Nature, 530, 453–456 (25 February 2016) doi:10.1038/nature17140

## Finding pulsars through imaging

*CAASTRO researchers have explored new ways to find pulsars.*

First detected in 1967, pulsars continue to surprise. These small spinning neutron stars are defined by the regular trains of radio pulses they produce. But they can be remarkably wayward. Some suddenly switch off, or generate giant pulses. *Rapidly rotating radio transient sources* (RRATS) are now thought to be otherwise undetected neutron stars that occasionally belt out a few bright pulses. A pulsar's signal can be amplified or dampened by the thin charged gas of particles between the stars, the interstellar medium (page 26), or it can be eclipsed altogether by a companion star. It is useful, then, to have a way to find pulsars that does not rely on detecting a regular pulse train.

CAASTRO's Martin Bell (CSIRO) and colleagues have explored whether pulsars can be detected through the variability of their signal strength over time. This variability is scintillation, analogous to the twinkling of stars, and is caused by irregularities in the interstellar medium. Small irregularities create diffractive scintillation, which manifests as variability on timescales of tens of minutes, while larger irregularities cause refractive scintillation, which results in variability over weeks and months.

Bell and his team examined data taken for the Murchison Widefield Array Transient Survey, a survey carried out at 154 MHz over almost the whole southern sky with the Murchison Widefield Array (MWA) interferometer. A snapshot was taken of each of the MWA's fields (about 900 square degrees in size); these were mosaiced together and the resulting images searched for 2,297 known pulsars. Bell's team focused on bright pulsars with a high signal-to-noise ratio, of which there were 17. They fitted light curves for each of these pulsars and calculated their variability. Only four objects were deemed to be highly variable, two apparently as a result of diffractive scintillation and two from refractive scintillation.

These pulsars could be detected through their variability. But how many new ones could we find with this technique? To be discoverable, a pulsar must have a scintillation bandwidth of a least a few megahertz (at 154 MHz). It also has to have a signal strong enough to be detected by the Murchison Widefield Array Transient Survey (MWATS), about 100 millijansky. This strength need not be intrinsic: it could arise from scintillation boosting the signal of a weak pulsar. Working from an electron-density model, Bell's team calculated that their method could probe the Galaxy out to a distance of about 2,000 light-years. Simulating a pulsar population for the Galaxy that has ~130,000 pulsars beaming along our line of sight, they calculate that around 125 objects would be detectable. The current pulsar catalogue contains about 50 that meet the criteria.

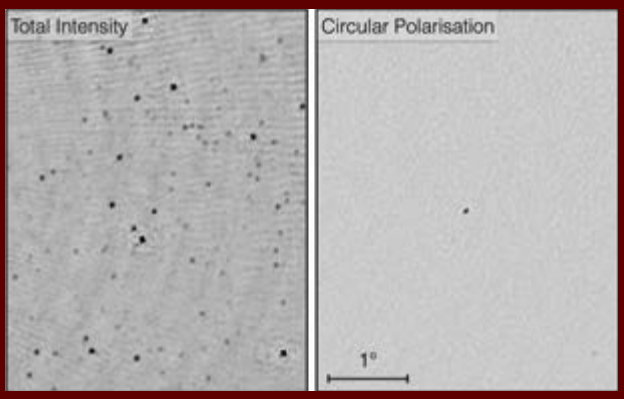
Two other methods for finding pulsars with the MWA have been proposed: these look promising but require further investigation. The first again uses pulsar scintillation, but it is based on how scintillation makes the pulsar's signal vary in frequency, rather than how the total signal intensity changes over time. Variations in the pulsar's signal strength with frequency can be represented in an image. For most radio sources other than pulsars, this image is effectively featureless. But a pulsar will stand out clearly, as CAASTRO's Emil Lenc (University of Sydney) has shown using MWA data.

Lenc has also proposed a second technique. This one relies on the fact that at long wavelengths, such as those the MWA receives, most extragalactic sources are depolarised by the interstellar medium (the thin, charged gas between the stars). Looking at linearly polarised sources in an MWA field, Lenc found only pulsars (which are in our Galaxy) and a small number of external galaxies with active black holes. There were twice as many of the former as of the latter! And looking at circularly rather than linearly polarised sources, the pulsars stood out even more clearly as there were no other competing objects. To reveal bright pulsars this way, just two minutes is needed to image each 900-square-degree MWA field. Longer observations may reveal weaker pulsars that have not yet been discovered.

These new techniques may well turn up exotic pulsars whose extreme properties will change our understanding of these objects. They may also be fruitful if applied to parts of the Galaxy that traditional pulsar surveys have only skimmed.

### Publication

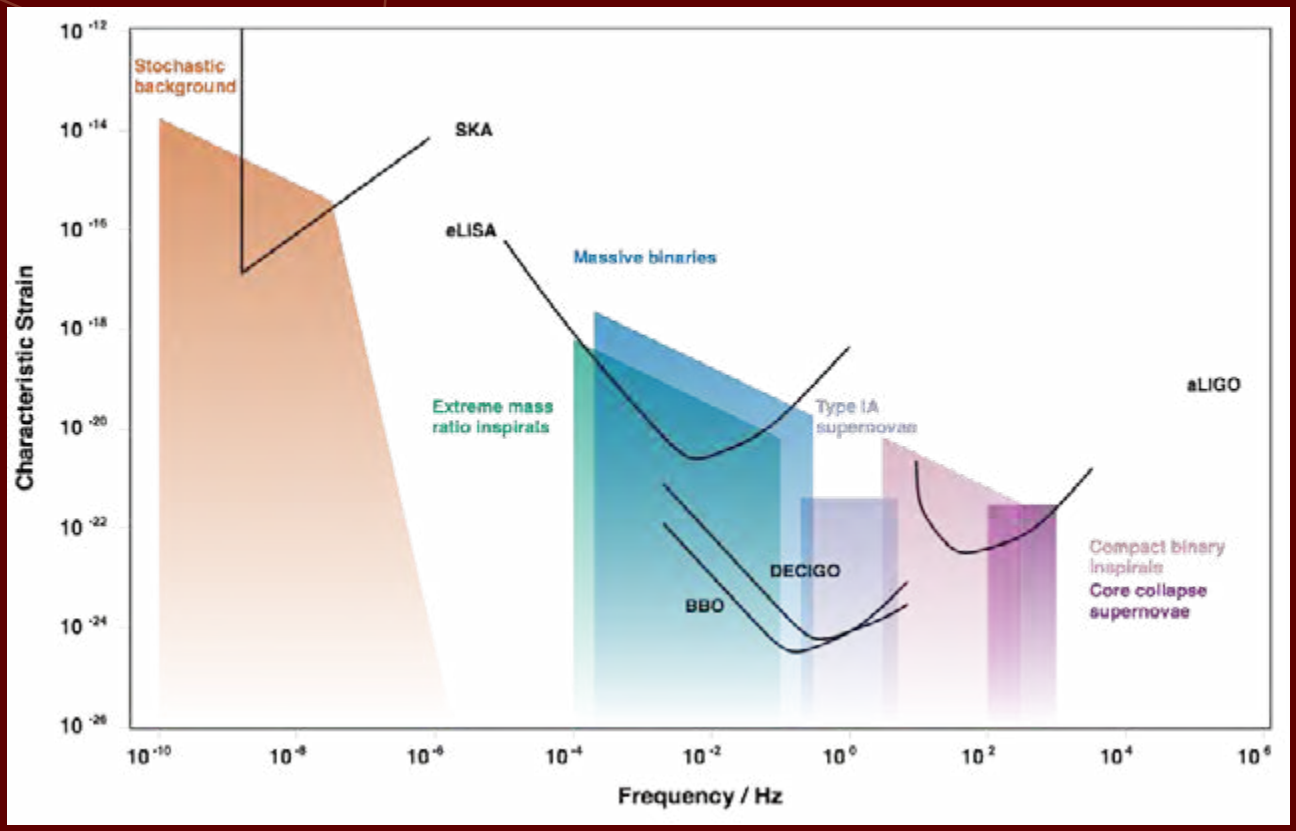
Martin Bell and 35 co-authors, "Time-domain and spectral properties of pulsars at 154 MHz". MNRAS (2016, submitted).




**Murchison Widefield Array radio observations at 215 MHz of the field surrounding the millisecond pulsar PSR J0437–4715. When observed in total intensity (at left), the pulsar is indistinguishable from the many other sources in the field, but when viewed in circular polarisation (right) it stands out clearly.**

***Image: Emil Lenc***

## Predicting observables from delayed-detonation supernovae




**Characteristic strain for several astrophysical gravitational wave sources as a function of frequency. The Type Ia supernova signal fills the gap in frequency between massive binaries and compact binary inspirals. For the assumed distance of 30 kpc in this figure, the SN Ia signal would be well within the detection limits of future gravitational wave observatories BBO and DECIGO. For more information see *http://rhcole.com/apps/GWplotter/*.**

*CAASTRO researchers have predicted the observable properties of different supernova models.*

Type Ia supernovae (SNe Ia) are defined by the lack of hydrogen absorption lines in their spectra. They were originally considered a fairly homogenous group but several spectral subtypes are now recognised. SNe Ia are a key tool in cosmology (for instance, they are the basis of the international Dark Energy Survey), and so it is crucial to understand how intrinsically variable they are. This variability was emphasised in 2014 when work by CAASTRO's Richard Scalzo and colleagues showed that the masses of SN Ia progenitors, long assumed to hover around 1.4 solar masses, were often quite different. In fact, Scalzo *et al*. found that 25–50 per cent of the progenitor masses of the systems they studied were not of the canonical mass. They concluded that there is more than one route to an SN Ia.

Other lines of research lead in the same direction. It appears that SN Ia progenitor systems must contain at least one white dwarf, but there are also models that invoke two (violently colliding). Even the models based on a single white dwarf, which involve matter transfer from a companion star, vary in how they see the detonation of the white dwarf being initiated and progressing. These models have been tested against reality in several ways. Researchers have looked for evidence of the nature of the white dwarf's companion, past and present. They have compared the observed rate of SN Ia with predictions obtained from populations of white-dwarf binaries, synthesised or observed. And they have made detailed simulations of SNe Ia to predict observables such as light curves and spectra. In 2015 CAASTRO's Ivo Seitenzahl (Australian National University) and colleagues followed this third approach, in a pair of papers.

In the first, the researchers looked at a specific spectral line, one at X-ray wavelengths that is generated by the decay of $^{55}$Fe. They computed the strength of this line for two explosion models: the violent merger of two white dwarfs (of 1.1 and 0.9 solar masses respectively) and a 'delayed detonation' of a single white dwarf near 1.4 solar masses. (In 'delayed detonation' an initial phase of slow (nuclear) burning – *deflagration* – initiates a rapid thermonuclear explosion – *detonation*). The delayed-detonation model posits higher densities in the progenitor white dwarf: as a consequence, it synthesizes significantly more radioactive $^{55}$Fe than the merger model, leading to the X-ray line being ~4.5 times stronger than in the merger model. In both models the X-ray signal peaks five to six years after the explosion. Existing X-ray instruments, such as Chandra and XMM–Newton, should be able to detect the line from events within the Local Group of galaxies with sufficiently high signal-to-noise to distinguish between the two models.

In the second paper, Seitenzahl and his colleagues ventured away from the electromagnetic spectrum to predict the neutrino flux and gravitational-wave signal generated by the delayed detonation of a single white dwarf of around 1.4 solar masses. For this work they used a revised version of Seitenzahl's three-dimensional N100 model, which generates light curves and spectra that well match those of typical SNe Ia.

In core-collapse (Type II) supernovae, neutrinos carry off about 99 per cent of the energy released by the explosion. The details of this process, and the prospects of detecting it, have been thoroughly explored, but the neutrino production of SNe Ia has been less well looked at. Seitenzahl's team showed that under the delayed-detonation model neutrinos carry away (in one second) $\sim 2 \times 10^{49}$ erg, energy comparable to that of the supernova's total photon output; however, they reduce the explosion's kinetic energy by only two per cent, and their total energy is 10,000 times less than that of the neutrinos from core-collapse supernovae. The two cases also differ in their neutrino energy spectrum: the typical energy of an individual SN Ia neutrino is around 3 MeV, while for core-collapse SNe it is around 10–20 MeV. If an SN Ia were indeed produced by the delayed-detonation process, its neutrino signal would be stamped with a feature marking the deflagration-to-detonation transition. Detecting SN Ia neutrinos would require a sizable neutrino detector (for instance, the mooted next-generation HyperKamiokande detector in Japan), a relatively nearby event (within about 3,000 light-years), and a certain amount of luck. In collaboration with researchers from North Carolina State University and Duke University, Seitenzahl and colleagues are now investigating, for the first time, the effects of neutrino-flavor oscillations on this model.

The gravitational-wave signature of SNe Ia has been a little more worked on, but this new study is the first to generate it from a 3D simulation of a 'typical' SN Ia. Seitenzahl and his colleagues found that their model system would generate $7 \times 10^{39}$ erg in gravitational waves, and the spectrum would peak around 0.4 Hz, with a secondary peak at 1.28 Hz (again, this pattern is a marker of the deflagration-to-detonation transition). The researchers concluded that, under favourable conditions, future space-based missions designed to detect gravitational waves from the very early Universe could also detect the team's model SN Ia out to a distance of about four million light-years.

## Publications

Ivo Seitenzahl and 14 co-authors, "5.9-keV Mn K-shell X-ray luminosity from the decay of $^{55}$Fe in Type Ia supernova models". Monthly Notices of the Royal Astronomical Society, 447 (2), 1484–1490 (2015)

Ivo Seitenzahl and six co-authors, "Neutrino and gravitational wave signal of a delayed-detonation model of type Ia supernovae". Physical Review D, 92 (12), id.124013 (2015)

## Searching for supernovae with SkyMapper

**The Milky Way above the SkyMapper telescope at Siding Spring Observatory.**
***Credit: O Chul Kwon***

*The SkyMapper supernova search has progressed this year – with a little help from the BBC and citizen scientists.*

SkyMapper is a 1.35-m robotic telescope of the Australian National University (ANU) located at Siding Spring Observatory in New South Wales, Australia's main site for optical astronomy. Equipped with a 269-megapixel camera, and capturing six square degrees of sky (an area 29 times larger than the full Moon) in each one-minute 'glance', the telescope is dedicated to making the first comprehensive digital survey of the southern sky. It can cover 1000 square degrees a night and will image each patch of sky repeatedly, every three or four days, over five years, creating a detailed record of more than a billion stars and galaxies, to a sensitivity one million times fainter than the human eye can see. The SkyMapper team made its first public data release, of test data, in July 2015. Early science from SkyMapper also appeared in *Nature* that month: the discovery of stars in the Milky Way's bulge that are 13.6 billion years old. These are the oldest stars ever found in our Galaxy, and finding them has changed ideas about our Galaxy's history.

The Southern Sky Survey uses 75 per cent of the telescope's time. Within that, the bottom quartile of seeing conditions is used specifically for a search for supernovae: observations are dynamically scheduled each night by software, and can adapt to changing seeing conditions over the course of a single night. The supernova search team, led by CAASTRO's Professor Brian Schmidt (ANU), expects to detect 50–100 'good' Type Ia supernovae a year. The survey itself gathers only photometric information: supernova candidates are identified by a 'Random Forest' classifier (a machine-learning algorithm) and their spectra are then obtained with other telescopes, such as the ANU 2.3-m telescope, the 2-m Faulkes Telescope South of the Las Cumbres Observatory Global Telescope Network, and the European Southern Observatory's 3.6-m New Technology Telescope. Combined with observations from surveys such as OzDES (page 20), the SkyMapper supernovae will enable us to improve constraints on the equation of state for dark energy (reducing the uncertainty on the parameter $w$ to 5 per cent), and allow us to test suggestions that the Universe is 'over dense' at large scales. The supernova search will also produce a large number of interesting transients that can be studied both individually and as a population.

During the initial Science Verification period (September 2013 to March 2014), SkyMapper produced ten spectroscopically-confirmed supernovae, including eight SNe Ia, one SN II, and SN 2013hx, one of the very rare superluminous ($M_g < -21$) supernovae. A paper on SN 2013hx is currently being prepared by our collaborators in the *Public ESO Spectroscopic Survey of Transient Objects* (PESSTO). A highly visible observing campaign in March 2015, carried out in partnership with the Zooniverse citizen-science community and the BBC, yielded an additional five supernovae (including two excellent nearby SNe Ia) from data taken over an 8-day period. In late June this year SkyMapper discovered SN 2015J, which has a peculiar triple-peaked light curve: we are observing this object further with the WiFeS imaging spectrograph on the ANU 2.3-m telescope and CSIRO's Australia Telescope Compact Array. In July and August SkyMapper observed the fields monitored by the Kepler's K2 mission and detected one SN Ia in a K2 galaxy. SkyMapper's observations will help to constrain the nature of the explosion while K2's superior time-sampling of the supernova light curve is expected to provide insights about the progenitor system.

# THE DARK UNIVERSE

**Theme Leader: Professor Tamara Davis | University of Queensland**

**Theme Scientist: Dr Ixandra Achitouv | Swinburne University of Technology**

If galaxies are the actors in the cosmic drama, then the Universe as a whole is the stage on which they play. This 'stage' is the subject of the Dark Universe theme. Its researchers tackle the big, overarching questions about the forces and entities that make our Universe what it is: gravity, dark energy, and dark matter. To do this, they use observables (such as the 'peculiar' velocities of galaxies, or the brightness of Type Ia supernovae), in combination with simulations and theory.

In the *Peculiar Velocity Surveys* projects this year, the Dark team derived the peculiar velocities for the 2MASS Tully-Fisher Survey and described the velocity field of the nearby Universe. Peculiar velocities from the 6dF Galaxy Survey velocities (6dFGSv) were used to measure the bulk flow of galaxies and to make novel tests of model-independent gravity.

*OzDES*, which began in 2013, is an Australian survey aimed at measuring the redshifts of about 3,000 Type Ia supernovae, as a contribution to the international Dark Energy Survey (DES). Its first publications appeared this year. Team members also collaborated on other papers using OzDES data that were led by members of DES.

The *Large Scale Structure* team this year finished a number of important projects including the measurement of the growth factor and the baryon acoustic oscillations (a measure of galaxy clustering) from the overlap of BOSS and WiggleZ surveys (page 21). Researchers in this area developed a new theoretical technique to improve the measurement of the *baryon acoustic oscillations*.

The *Theory and Simulations* team began modelling that assumes dark energy to be a quintessence field. This will be needed to constrain non-standard cosmology.

Finally, in a collaboration between two ARC Centres of Excellence, CAASTRO members from the Dark Universe theme are taking part in the project to build the first dark-matter detection experiment in the southern hemisphere (page 29).

Examples of work done this year under the Dark Universe theme appear below.

## Tensions in testing general relativity

*A test of general relativity has highlighted the differing implications of datasets related to different times in cosmic evolution.*

General relativity, now a century old, is one of the most successful physical theories ever developed. It has withstood tests of all kinds. Yet it cannot be the last word in understanding gravity: for one thing, it has not yet been reconciled with quantum mechanics, another supremely successful theory. Astronomers have an additional reason for scrutinising general relativity: the accelerating expansion of the Universe, discovered in the 1990s, is usually attributed to an unknown 'dark energy' component of the Universe, but it could also result from gravity differing from the predictions of general relativity.

The equations of general relativity can be modified by introducing two parameters, Q and R, which relate to the strength of the gravitational force as generated by matter and the difference between the gravitational force as experienced by massive particles and massless particles, such as light. These quantities are predicted to have different values in different modified gravity theories, but both equal one in Einstein's theory. CAASTRO's Jason Dossett (University of Queensland) and his colleagues this year examined such a form of modified gravity, testing it with large, rich datasets.

The researchers compared three cases in which Q and R (or quantities derived from them) evolved with time, or varied with scale, in different ways. The first parameterisation was *traditional binning*. This used two bins for scale ($k \leq 0.01$ and $k > 0.01$) and two for redshift ($0 < z \leq 1$ and $1 < z \leq 2$): four in all. The second parameterisation, *hybrid evolution*, used the same two bins for redshift, but allowed the parameters to vary monotonically as a function of scale. The third, *scale-independent evolution*, used parameters that were independent of scale and evolved only in time (that is, with redshift).

There is now a wealth of data against which to test such formulations. To probe the expansion history of the Universe, Dossett's team used three large-scale galaxy surveys (6dFGS, SDSS DR7 and BOSS DR9). To probe its large-scale structure, they used data from the WiggleZ Dark Energy Survey and other sources. Measurements of weak gravitational lensing (see page 27) gave information about the distribution of

matter in the nearby Universe: these data came from the Canada France Hawaii Telescope Lensing Survey (CFHTLenS). Observations of cosmic microwave background (CMB) made with the Planck satellite provided the yardstick against which the Universe's evolution could be measured.

Overall, general relativity was consistent with the data at the 95 per cent confidence level. But there were some differences between the parameterisations. In *traditional binning*, all the parameters for modified gravity were consistent with their value in general relativity (that is, one) at the 95 per cent confidence level. That was the case also for *hybrid evolution*, with a single exception: a parameter that was much larger than one. In the case of *scale-independent evolution* the parameters, as single numbers, seemed unexceptional, but when plotted against each other in two dimensions they told a different story. Probing further showed that the parameters in question had non-Gaussian distributions, one of them distinctly bimodal. This result, and the wayward parameter in the *hybrid evolution* case, could be sheeted home to a problem known from previous studies: a tension between the CMB data and the weak-lensing datasets. The two favour, for instance, different values of $\sigma_8$, a cosmic parameter describing the growth of fluctuations in the early Universe: the CMB data gives a high value and the weak-lensing data a lower one. Given that they probe very different eras of cosmic evolution, researchers have attempted to resolve the tension between them by suggesting that there is a neutrino species that suppresses the late time growth of structure in the Universe. Whether this is the case, or whether there are problems with the observations, is still an open question.

This study improved significantly on previous comparable work by two of the authors (Dossett and Ishak) as it was able to use better lensing data from CHTLenS and also include the galaxy power spectrum as measured by the WiggleZ Dark Energy Survey. It demonstrated the impressive utility of these datasets to constrain these parameters, and set the pattern for future studies of this type.

### Publication

Jason Dossett and three co-authors, "Constraints and tensions in testing general relativity from Planck and CFHTLenS data including intrinsic alignment systematics". Physical Review D 92, 023003 (2015)

## Better together: using the overlap of galaxy redshift surveys

*CAASTRO researchers have used the overlap between the two of the largest galaxy redshift surveys, WiggleZ and the Baryon Oscillation Spectroscopic Survey, to look for possible sources of systematic effects in the datasets.*

About 20 years ago advances in optical-fibre instruments made it possible to start surveying hundreds of thousands of galaxies and determine how they are distributed in space, creating maps of the large-scale structure of the Universe. The datasets that underlie these maps can tell us a great deal about the Universe's history: combined with information about the early Universe gleaned from the cosmic microwave background, they can indicate the rate at which the Universe has expanded and the rate at which structure (the web of galaxies) has grown.

The galaxy surveys used for these analyses differ in the types of galaxies they include. They were also made with different instruments and their data analysed in different ways. So, how comparable are their results? Do their data contain systematic errors as a result of the galaxy types they have used? And is it feasible to combine datasets from different surveys? CAASTRO researchers have tackled these questions by looking at the regions where the WiggleZ and BOSS surveys overlap.

WiggleZ, carried out with the 4-m Anglo-Australian Telescope, selected star-forming ('blue') galaxies, while BOSS (the Baryon Oscillation Spectroscopic Survey) used luminous, mostly 'red' galaxies (that is, ones not actively forming stars). The two galaxy types are highly complementary, in that the BOSS galaxies favour high-density environments while WiggleZ galaxies eschew them. The two surveys overlapped in five patches of sky, the overlap region containing a total of 69,180 galaxies from WiggleZ and 46,380 from BOSS.

Measurements of galaxy clustering show an effect called *redshift-space distortion*. Redshift, a measurable change to a galaxy's light, results primarily from the expansion of the Universe, and is therefore a key estimator of galaxy distance. But a component of a galaxy's redshift arises from motion caused by the gravitational field in which it finds itself: this component, therefore, is related to how structure grows in the Universe, that is, how galaxies aggregate

over time. By measuring galaxy clustering at different epochs of the Universe's history, we can in theory trace the growth of structure through time, and from this we can get constraints on cosmological models and the nature of dark energy. But to do this we need to be able to account for other effects that creep into the data: effects related to the limited size of any sample of galaxies, non-linear effects modifying the growth of structure, and *galaxy bias*, a difference in the clustering pattern of galaxies and dark-matter halos.

This year CAASTRO researcher Felipe Marín (Swinburne University) and his colleagues investigated redshift-space distortion in the WiggleZ and BOSS galaxies in the region of overlap. They constructed models for the growth of structure that included both linear and non-linear effects, and tested them using mock galaxy catalogues. They then applied these models to the WiggleZ and BOSS data, and found no sign of strong systematic errors related to galaxy type. Combining the data from both surveys gave a value for the growth-of-structure coefficient that agreed well with the figures from other surveys.

In a companion paper, Florian Beutler (Lawrence Berkeley National Laboratory), CAASTRO's Chris Blake (Swinburne University) and their colleagues also analysed the large-scale clustering of galaxies in the overlap region, but this time to determine the *baryon acoustic feature*, a preferred spacing between galaxies. This preferred spacing is the result of pressure waves 'frozen' into the structure of the young Universe when it cooled. Measuring it with sufficient precision allows us to determine the dark-energy parameter *w*, and so to rule out some possible dark-energy candidates. Beutler and his colleagues measured the baryon acoustic feature in the WiggleZ and BOSS data for the region of overlap, separately and with the data combined. This is the first time this has been done. All three measurements were consistent. The researchers also tested for a proposed source of systematic error (the *relative velocity effect*, arising from the different velocities of dark and non-dark matter in the early Universe), but found no evidence for it. And, importantly, they calculated a scaling relation (a covariance matrix) that will allow WiggleZ data to be combined with future data releases from BOSS.

### Publications

Florian Beutler and six co-authors, "The BOSS-WiggleZ overlap region I: Baryon Acoustic Oscillations". Monthly Notices of the Royal Astronomical Society, 455 (3), 3230 (2016)

Felipe A. Marín and five co-authors, "The BOSS–WiggleZ overlap region II: dependence of cosmic growth on galaxy type". Monthly Notices of the Royal Astronomical Society, 455 (4), 4046 (2016)

## A recently quenched galaxy?

*The OzDES survey has turned up a galaxy with a unique combination of features, ones suggesting a connection between the central black hole and the end of an active phase of star formation.*

At some point all galaxies run out of fresh cosmic gas and their star formation dwindles. That much is agreed on. But how this 'quenching' happens, and how fast it happens, is contested. The orthodox picture is that blue, star-forming galaxies merge, triggering the gas they contain to blossom into stars. At the same time, their central black hole (or holes) get an extra helping of 'food' and become increasingly active, pouring winds of particles into space. It is thought that these outflows eventually put a stop to the star party, pushing the gas fuelling it out of the galaxy, like giant hands.

This may not be the only way to quench a galaxy. Some galaxies show signs of having simply starved to death over billions of years after their gas supply was turned off. And some low-mass local galaxies still in their starburst phase show no sign that they ever had a lively central black hole. But winds from around black holes are thought to play a part in quenching at least some galaxies. And we now have some evidence for this process from a unique galaxy found by the OzDES project.

OzDES is an Australian galaxy survey being run on the 4-m Anglo-Australian Telescope (AAT). Its main purpose is to measure redshifts of supernova host galaxies for the international Dark Energy Survey (DES), but it is also monitoring galaxies to measure the masses of their central black holes.

In the course of this monitoring program, in 2015 the OzDES team found an unusual galaxy, provisionally dubbed DES QSO 0330−28. It lies about 3.9 gigaparsecs away. The galaxy's spectrum stood out because of a curious combination of features. It has broad absorption lines of iron and magnesium, which indicate a high-speed outflow from the central black hole; there are also hints of absorption in the Hß line. Broad absorption in iron is only seen in a small fraction of galaxies of this type (that is, quasars). The object also has a pattern of absorption typically associated with A stars, which indicates a recently-truncated period of star formation: light dominated by A stars means that the shorter lived O and B stars have already left the scene, and that no ongoing star formation has replaced them. Other post-starburst galaxies are known to have quasar activity but lack broad absorption line outflows: QSO 0330−28 may be the first post-starburst object known to have them.

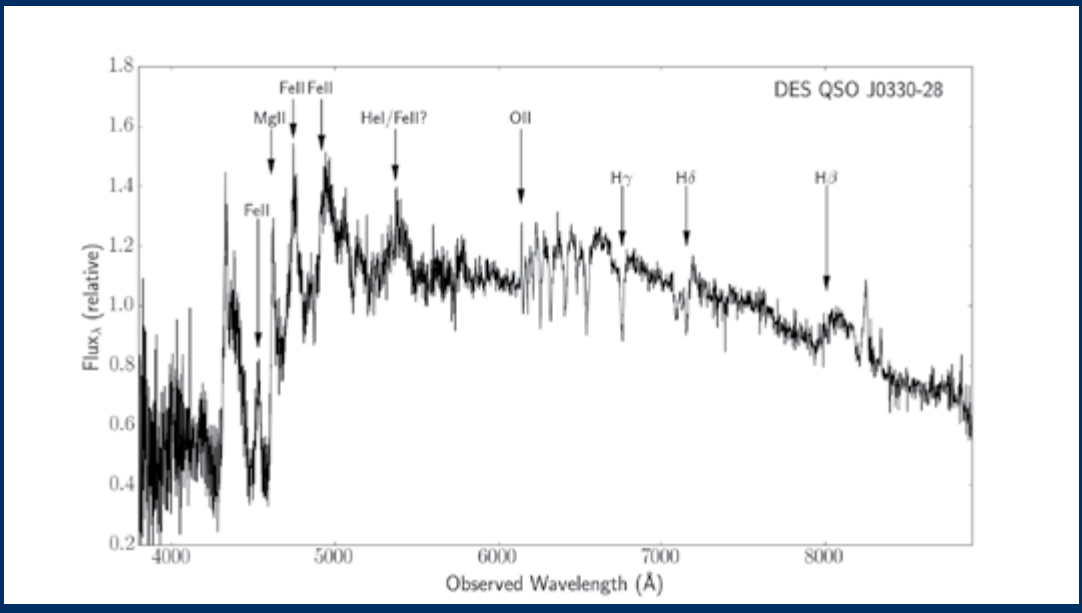
Fitting to model spectra suggests that star formation stopped about 50 million years ago. If we assume

that the black hole's quasar activity and star-formation quenching occurred simultaneously, that would imply that this is an older quasar rather than a young one, since 50 million years is comparable to current estimates for quasar lifetimes. However, it is not certain that the black hole's outflow caused the star formation to stop: for instance, a starburst and quasar activity might have been triggered by an inflow of gas, and feedback from supernovae could have killed the star formation. So QSO 0330−28 provides circumstantial evidence of a link between outflows and the shut-off of star formation, not absolute evidence of a causal relationship. But it is definitely an object worth further study.

The discovery of QSO 0330−28 is an example of how large surveys turn up rare objects. OzDES should uncover more such gems. The project has just completed its third observing season, and is now halfway through its allocation of 100 nights on the AAT. To date, OzDES has obtained the redshifts of about 20,000 sources, and has spectroscopically confirmed over 100 supernovae, including a couple of the rare superluminous supernovae.

## Publication

Dale Mudd and seven co-authors, "Discovery of a Post-Starburst BAL Quasar in the DES Supernova Fields" (in prep.)




**The stacked spectrum of DES QSO J0330-28 at z = 0.65. The low-ionisation broad absorption line features are prominent blueward of the MgII line at rest-frame 2798Å, whereas the absorption features around rest-frame 3900Å are from stellar atmospheres in the host galaxy.**

***Credit: OzDES Collaboration***

# CASE STUDIES

Ms Caitlin Adams and Professor Tamara Davis discuss challenges for females in science at the Women in Astronomy Workshop

*Credit: CAASTRO*

National Innovation Priority: Research

# THE HIGHS AND LOWS OF GPS SOURCES

Radio astronomy began as a low-frequency science, with instruments that worked at about 100 MHz. When higher-frequency radio telescopes such as CSIRO's Parkes telescope came on-stream in the late 1950s and early 1960s, astronomers began to see new radio sources. Some of these had a peak in their radio spectrum at a frequency around 1 GHz and so were christened *gigahertz peaked spectrum* (GPS) sources. Later work showed that GPS sources are compact, and remarkably constant in their power output on timescales from hours to decades.

From the beginning there was debate about how GPS sources related to other kinds of celestial objects. "The question of whether or not [they] represent the very early stages of quasi-stellar sources or radio galaxies is clearly an important one," wrote Ken Kellermann, an American postdoctoral fellow working in Australia, in 1966. Researchers later found that some GPS sources have a core-jet structure and appear to be related to quasars, while others, at low redshifts, have little radio lobes and look like miniature versions of 'regular' radio galaxies.

In his 1966 paper Kellermann also considered mechanisms that could produce the characteristic peaked spectra of GPS sources. The two contenders were *free-free absorption*, in which radiation from the source is absorbed by a 'screen' of ionised gas, and *synchrotron self-absorption*, absorption of the radiation by relativistic electrons within the emitting medium itself. Kellermann opted for the latter, mainly because it was hard to see how to maintain the large mass of ionised gas that the free-free model required.

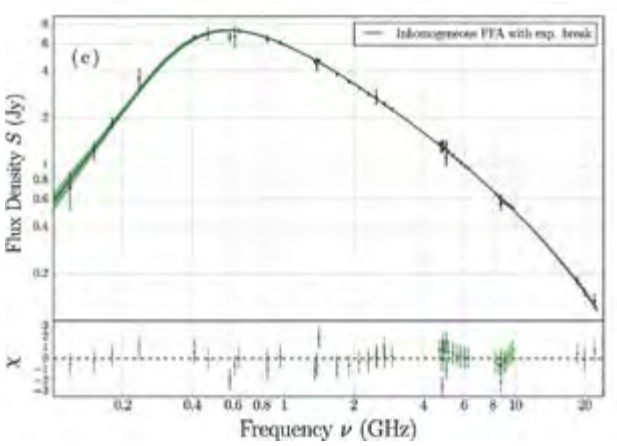
But fast-forward to 2013, and the question of the mechanism had still not been answered definitively (although synchrotron self-absorption was the more generally favoured model). CAASTRO student Joseph Callingham (University of Sydney) decided to tackle it for his PhD thesis, by examining a GPS source called PKS B0008–421.

An oddball in several ways, PKS B0008–421 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. Technically, PKS B0008–421 was just a candidate GPS source when Callingham began studying it, but he was able to demonstrate that it is, indeed, the real thing. As well as being extreme, the source has been observed many times, at many frequencies: its constancy means that it has been used as a calibrator (a source whose strength is known) by most of the radio telescopes in the southern hemisphere. To those many existing observations Callingham added new ones made with the Murchison Widefield Array (at low frequencies) and CSIRO's Australia Telescope Compact Array (at high frequencies). He thus had an extremely well-sampled spectrum, covering the range 0.118–22 GHz.

Callingham tried fitting nine models to his data, all variants of synchrotron self-absorption (SSA) and free-free absorption (FFA). Free-free absorption (with an inhomogenous absorbing screen) came out ahead, beating synchrotron self-absorption by a nose. 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, Callingham 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. Once no new electrons are being injected, high-energy electrons in the source are preferentially depleted as time goes on, and the radio spectrum changes shape. (The high-frequency observations are particularly important in showing this change.) That the source should turn off like this is not a complete surprise: some other GPS sources exhibit signs of intermittent activity.

Astronomers have long known that there are far more GPS sources (and similar, related objects) than there are giant radio galaxies, which the GPS sources and their relatives are thought to evolve into. Perhaps many of the GPS sources 'die young' and simply fade away rather than evolving into 'proper' radio galaxies. Once its central black hole had turned off, PKS B0008–421 could 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 new low-frequency radio telescopes such as the MWA. It may be possible to find a large number of GPS sources that have 'died young', and so reconcile the numbers of GPS sources and giant radio galaxies.




**The spectral energy distribution of PKS B0008–421 fitted with the inhomegenous free-free absorption model, the best-fitting of the models considered.**

***Credit: Callingham et al. (2015)***

National Innovation Priority: Research

# PROBING THE LOCAL INTERSTELLAR MEDIUM USING A PULSAR'S TWINKLING

Researchers have used the Murchison Widefield Array to study the properties of the local interstellar medium, through the phenomenon of pulsar scintillation – a radio analogue of stellar twinkling.

This year Advanced LIGO (the Laser Interferometer Gravitational-Wave Observatory) made the first, groundbreaking detection of a gravitational wave. Astronomers too are looking to detect these waves, particularly the 'stochastic background' of low-frequency ones from the early Universe. Rather than use a ground-based detector, they are monitoring sets of 'millisecond pulsars'. These small stars produce highly regular trains of radio pulses and act like clocks in space.

Researchers record the arrival times of the pulsar signals to an accuracy of ten billionths of a second. A gravitational wave passing between Earth and a millisecond pulsar squeezes and stretches space, changing the distance between them by about ten metres, a tiny fraction of the pulsar's distance from Earth. This changes, very slightly, the time that the pulsar's signals arrive on Earth.

This technique requires extreme precision. Every possible source of error must be hunted down and accounted for. One, which we don't know very much about as yet, is the effect of the pulsar's signal being scattered by the interstellar medium (ISM), a tenuous gas of charged particles that lies between the stars. Such scattering can delay the pulsar's signal.

The lower the frequency at which you are observing, the greater the effect of the ISM. As a result, timing arrays of pulsars are usually observed at high frequencies (>1 GHz). But it also means that the effects of the ISM are more easily studied at low frequencies. In addition, lower-frequency observations can sample a larger volume of the ISM.

Using the Murchison Widefield Array (MWA), a team led by CAASTRO Associate Investigator Ramesh Bhat (Curtin University) has investigated the ISM using a well-characterised pulsar called J0437–4715, a high-priority target for pulsar-timing observations. They observed at the MWA's frequency of 192 MHz, using the telescope's recently commissioned tied-array beam processing pipeline, which has increased tenfold its sensitivity for pulsar observations.

The researchers started by recording the 'dynamic spectrum' of the pulsar: a two-dimensional plot of the pulsar's pulse intensity as a function of time and frequency. By applying a 2D Fourier transform to this, they then created the pulsar's 'secondary spectrum', which presents information about the pulsar in a new way.

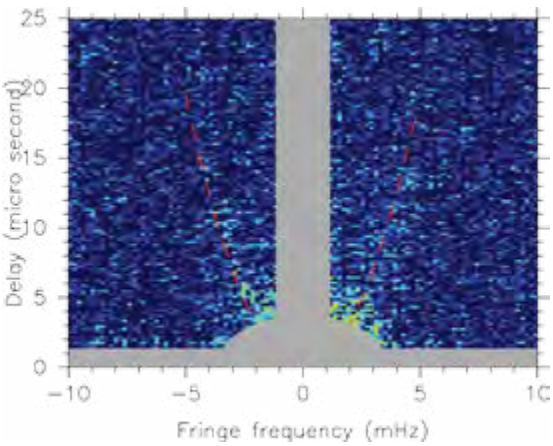
The interstellar medium is turbulent and irregular. Regions of enhanced density can have a marked effect on pulsar signals, acting as 'scattering screens'. Radiation scattered by the 'scattering screen' effectively produces many thousands of images of the same pulsar, all at once. The rays from each image interfere with those from every other image across the entire scattering region in a phenomenon known as *scintillation*, the radio analogue of the twinkling of stars.

The secondary spectrum captures the interference patterns produced by the interaction of those thousands of individual points. In particular, parabolic arcs in the secondary spectrum represent interference between the pulsar's bright central core and the 'halo' of points around it resulting from the scattering screen. The curvature of the arcs depends on the distance to the pulsar, on the motion of the pulsar relative to Earth, and on the location of the screen. Knowing the pulsar's distance and motion allows us to work out the distance to the screen.

First, however, the team had to measure the curvature of the arcs. For some pulsars, the arcs are very clear and can be picked out by eye. For J0437–4715, however, they are not so obvious. To measure the arcs' curvature the team used a technique based on the *Hough transform*, which involves repeatedly fitting for the curve while summing the power along the curve segments: the curve with maximum power is the fit. This is the first time this technique has been used to identify the arcs in a pulsar's secondary spectrum.

Combining the measurement of the arcs with the well-measured distance and velocity of J0437–4715 from the pulsar's timing observations, the researchers calculated that the scattering screen lies 115 ± 2 parsecs from Earth. As an important cross-check, they recalculated the figure using data taken with CSIRO's Parkes telescope at a higher frequency, 732 MHz: this gave 114 ± 2 parsecs. Significantly, this distance corresponds to near the edge of the *Local Bubble*, a large, elongated cavity in the local interstellar medium in which our Solar System lies.

This work demonstrates that the MWA will be able to play an important role in determining scattering delays in the signals of timing-array pulsars, and in elucidating the nature of the turbulent ISM.




**The secondary spectrum of PSR J0417–4715 from MWA data. The shaded region (in grey) was excluded from the analysis while estimating the curvature of the scintillation arc, which is shown as the dashed red curve.**

***From Bhat et al. (in press).***

National Innovation Priority: Research

# FIRST DIRECT MEASUREMENTS OF WEAK GRAVITATIONAL LENSING

To understand how galaxies form and evolve, we need to know how both baryonic ('normal') matter and dark matter are distributed throughout the Universe. The distribution of both kinds of matter can be mapped using weak gravitational lensing. But traditional techniques for doing this require many background galaxies, typically more than 100. Now a team led by CAASTRO PhD student Catherine de Burgh-Day (University of Melbourne) has developed a technique, *direct shear mapping*, that allows weak lensing to be mapped using just one background galaxy.

Any mass in space bends the path of light passing nearby. The effect is predicted by the general theory of relativity, and its detection in 1919 was one of the first confirmations of the theory. But only in the 1970s did astronomers notice galaxy clusters bending light this way, distorting images of background galaxies into giant luminous arcs.

Such arcs (and in extreme cases, rings) of light are a manifestation of 'strong' gravitational lensing. 'Weak' lensing, on the other hand, refers to deflections that are too small to be seen directly in individual sources. However, weak lensing can reveal an invisible foreground mass, by creating a systematic alignment of background sources.

While other techniques can measure the fraction of dark matter in the Universe, weak gravitational lensing is one of the few tools available for measuring the spatial distribution of both dark and non-dark (baryonic) matter. By comparing the dark-matter distribution mapped by lensing with the baryonic matter revealed by light, we can learn how dark matter interacts with the stars and gas in galaxies.

Weak gravitational lensing both magnifies the apparent size of the background objects and stretches their images around the foreground mass. This second effect is the *shear*: when measured, it can be used to calculate the density of the foreground mass that is doing the lensing.

Shear makes the images of the background galaxies more elliptical than they otherwise would be. Traditionally it has been calculated by measuring the galaxies' ellipticities and constructing a statistical estimate of their distortion. But galaxies are not intrinsically circular, and to derive a robust measurement for shear usually requires more than a hundred galaxies. This new technique developed by Catherine de Burgh-Day and her colleagues, *direct shear mapping*, allows shear to be calculated from just one background galaxy.

Rather than measuring the ellipticity of the galaxy, this method uses information about how it is rotating. If we can sample light from many points across a galaxy, we can construct a *velocity map*: an image of the galaxy that also indicates the velocity of the gas or stars at every point. SAMI (page 13) is an instrument that allows us to construct such a map; so too are radio telescopes. The position and velocity information so gained is usually presented in the form of a 3D data cube.

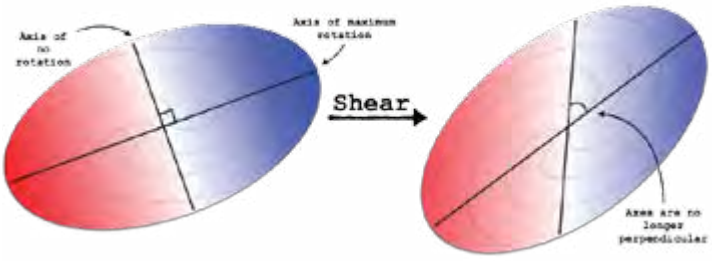
The *direct shear mapping* technique assumes that if an unlensed galaxy is rotating stably, its rotation map will be symmetric about two axes. Where the components of the galaxy follow circular orbits, as they do in spiral galaxies, the two axes are at an angle of 90°. Once a galaxy is lensed, however, its shape is distorted. The velocity axes no longer have an angle of 90° between them and symmetry has been destroyed. *Direct shear mapping* looks for the shear that best restores symmetry to the image, using a process of repeated trial fits (a Monte Carlo Markov Chain algorithm). Rather than just using the velocity axes, it works on the whole 3D data cube, which gives a better statistical fit. This method is unique among weak-lensing measurement methods in that it does not rely on fitting for the shape of the galaxy.

So, how well does it work? De Burgh-Day and her colleagues first tested their method on a model galaxy. It method stood up well, returning a null result when no lensing signal was present. The researchers found that in principle they could measure shear as small as 0.01.

Real galaxies, however, have characteristics that were not included in the models, such as central bars, warp instabilities and clumpiness in their discs, and turbulence in their outer regions. The researchers tested their method on two galaxies from THINGS (The H I Nearby Galaxy Survey), NGC 5236 (M83), a barred galaxy, and NGC 3621, which lacks a bar. Both of them are at low redshift and are unlensed. The warps and turbulence present in the outer discs of both galaxies biased the fits, but in each case masking to the optical radius rectified this. Applied to these two unlensed galaxies, *direct shear mapping* returned a null result with an error of $\pm 0.01$. This is a promising result, but the researchers will do further tests on the effect of kinematical features.

*Direct shear mapping* can be applied only at low redshifts, where a galaxy's rotation can be measured. It is most effective where the background source is an isolated, undisturbed, stably rotating disc. Happily, de Burgh-Day and her colleagues have found that such systems are reasonably easy to identify in large datasets such as the Galaxy and Mass Assembly (GAMA) Survey.

Spirals and rotating ellipticals are ideal targets. Suitable data will come from any large IFU or radio telescope, or indeed any instrument that does spatially resolved spectroscopy, such as SAMI, the Atacama Large Millimeter/submillimeter Array (ALMA), the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) and the Square Kilometer Array (SKA).




**Shear induced by gravitational lensing distorts a galaxy's image, causing it to lose symmetry. The *direct shear mapping* technique works by calculating the shear that best restores the image's symmetry.**

***Credit: Catherine de Burgh-Day***

National Innovation Priority: Frontier Technologies

# STUDENT SOFTWARE SPEEDS UP PROJECTS

Many CAASTRO members are involved in projects that are 'pushing the envelope' in terms of the volumes of data they deliver or the sensitivity they require. Such projects create new challenges in data analysis. Three students have been working on solutions to such challenges, solutions that will be applicable beyond the projects they were created for.

Jennifer Riding (University of Melbourne) is investigating ways to speed up data handling for the Murchison Widefield Array. This telescope is being used to hunt for the extremely faint radio signal from the cosmic Epoch of Reionisation (EoR, page 9). Foreground sources, both Galactic and extragalactic, are some 10,000 times stronger than the expected EoR signal and must be 'peeled' away for the faint EoR signal to be detectable. Extended sources, such as sizable galaxies, are a particular bugbear. How can they be excised from the data quickly and effectively?

Most approaches involve developing a model of the source. The venerable CLEAN algorithm, much used in radio astronomy, models an extended source as a series of points: a good CLEAN model of an extended source requires many points. Sources can also be modelled with multiple Gaussian functions but this tends to leave 'holes', and the more Gaussians you subtract, the more complicated the residual pattern becomes. (But Gaussians do work well for some sources, such as a simple double-lobed radio galaxy.)

As an alternative to these methods Riding is looking at *shapelets*. Two-dimensional shapelets are a set of patterns derived from orthonormal (that is, non-redundant) polynomials. By using enough shapelets in the set, you can model cosmic images. Shapelets require fewer data points than the benchmark CLEAN process, and also produce a smoother function. They also eliminate a computational step that is part of all other modelling methods, namely, transforming the model from the image domain into the Fourier domain, as there is a simple scaling relationship between the shapelet images and their representation in the Fourier space. Using shapelets promises to be a quick and effective way to remove extended foreground sources.

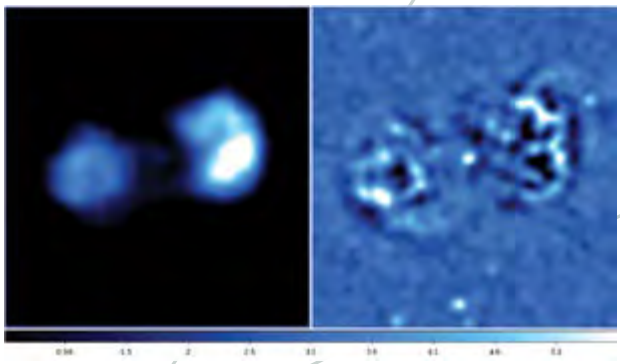
For another large survey project, OzDES (page 20), Samuel Hinton (University of Queensland) has developed the *Marz* software to automatically determine the redshifts of galaxies from their spectra. OzDES, running on the 4-m Anglo-Australian Telescope, is designed to measure the redshifts of many tens of thousands of galaxies. OzDES uses the 2dF fibre system and the AAOmega spectrograph, which together can capture and analyse almost 400 spectra at a time.

Once captured, these spectra then need to be identified: this is what *Marz* does, by comparing them to a library of 'template' spectra of stars and galaxies. The user simply drags and drops a file containing a galaxy spectrum into *Marz*, which then automatically processes the file and derives a redshift for the galaxy. Users can also verify automatic redshifts, perform manual redshifting and mark spectral lines. The software is written as a 'client-only' website, meaning that users don't have to install any software. And it is both faster and more effective than the previous fitting system, *runz*: it can automatically match 91 per cent of spectra, as against *runz's* 54 per cent. *Marz* is currently used for the OzDES and 2dFLenS projects, and will be used for the TAIPAN survey on the 1.2-m UK Schmidt telescope at Siding Spring Observatory. It could be further adapted for other instruments and projects.

PhD student Steven Murray (University of Western Australia) has created another useful web-based tool, one for calculating a function important in cosmology.

Our theories of how structure forms in the Universe predict that dark matter clusters into massive, gravitationally bound structures called halos; visible (non-dark) matter is merely the 'icing on the cake' of these halos. The dark-matter-halo mass function (HMF) quantifies the number of these halos per unit volume of the Universe as a function of their mass. The HMF is sensitive to cosmological parameters (mainly the density of dark matter and dark energy); it also depends on the nature of the dark matter. So the HMF is a potential probe of dark matter and dark energy, and determining it is a key science driver for a number of current and planned galaxy surveys.

Calculating the HMF for particular values of cosmological parameters is not completely straightforward. Until now, each researcher or research group has had to write their own code to do it; there has been no standard means of generating the HMF. But as part of his thesis work, Murray has created a web-based application, *HMFcalc*. This provides an intuitive graphical interface to calculate the HMF under a range of parameters and options, and is accessible from anywhere, anytime. The tool provides a 'one-stop-shop' for researchers requiring the HMF in their studies and has now been accessed by hundreds, from around the globe. The paper describing the tool has been cited more than 40 times. Usage of *HMFcalc* is ramping up as an increasing number of astronomers discover this reliable and useful resource.



**Source removal with shapelets: Fornax A (left); residuals after subtracting shapelet model (right), rescaled by a factor of 6.5.**
***Credit: Jennifer Riding***

National Innovation Priority: Interdisciplinary and International Collaboration

# A DEEP DIVE FOR DARK MATTER

*Australia is on track to host the first experiment in the southern hemisphere aimed at directly detecting dark matter.*

Eighty-five per cent of all matter in the Universe appears to be 'dark', that is, not emitting radiation by which we can detect it. First proposed in the 1930s, dark matter became a mainstream idea in the '70s. It is now backed by large body of evidence: the motions of stars in galaxies, the bending of light (gravitational lensing), and the distribution of mass in individual objects, notably the Bullet Cluster. But we still don't know what kind of entity it is.

Measurements of the cosmic microwave background and the cosmic abundances of light elements point to dark matter consisting mainly of a particle not found in the Standard Model of particle physics. The most favoured candidate is WIMPs, weakly interacting massive particles. WIMPs are predicted to be their own antiparticle, meaning that a pair could annihilate and produce radiation and/or high-energy particles, particularly electrons and their antiparticles, positrons.

Astronomers have looked for signs of WIMP annihilation, in the form of excesses of gamma-rays and positrons. Unfortunately, black holes, supernovae and even rapidly rotating (millisecond) pulsars also produce signals of this nature, signals that can be confused with those from WIMPs. The chance of observing WIMPs in the wild will be boosted by the coming Square Kilometre Array radio telescope, which will be able to observe large numbers of dwarf spheroidal galaxies, one of the prime hunting grounds for WIMPs.

Meanwhile, researchers are trying to detect WIMPs in the lab. Most of these direct-detection experiments are based on detecting the recoil of an atomic nucleus when it scores a direct hit from a WIMP, an extremely rare event. The strongest result to date comes from the DAMA/LIBRA experiment housed at LNGS (Laboratori Nazionali del Gran Sasso) in Italy. Seven years of observations from this experiment were published in 2013, apparently showing a strong ($9\sigma$) annual modulation in the WIMP signal. This modulation is attributed to a 'headwind' of WIMPs that we run into as the Sun moves through our Galaxy's WIMP halo. (That wind should appear to blow from the direction of the constellation Cygnus, but Cygnus is not thought to be the source of the WIMPs.) The DAMA/LIBRA result is contested: some researchers believe it could arise from background particles such as muons. To be accepted, the signal needs corroboration. A counterpart experiment in the southern hemisphere would be ideal, for modulations measured in the two hemispheres would be in phase if they are caused by a WIMP wind but in anti-phase if the effect is seasonal.

The idea of hosting such an experiment in Australia has been pursued by CoEPP, the ARC Centre of Excellence for Particle Physics, and was a major subject of discussion at the joint CAASTRO–CoEPP workshops held in 2013 and 2014. CoEPP, Northern Grampians Shire Council and Canadian company Newmarket Gold have now come together to make it possible to host this new experiment at Newmarket's underground gold mine at Stawell in central Victoria. The mine is still operating but work has ceased at the lowest levels, meaning that space is available 1000 m underground for a WIMP detector. Newmarket will provide services such as power, water and ventilation.

Called SABRE (Sodium iodide with Active Background Rejection), the detection experiment is being developed by a consortium of institutions from Australia, Italy and the USA. The detector, an improved version of the one currently used for DAMA/LIBRA, will be installed at both Stawell and Gran Sasso, so that results from the two sites are completely comparable. The heart of the detector is an ultra-pure sodium iodide crystal of low intrinsic radiation, doped with thallium. When struck by a WIMP the crystal will emit a gamma-ray. This will travel into a metres-thick jacket of liquid scintillating material around the crystal, triggering the release of a photon. Light detectors will be placed through and around the liquid layer to capture such an event. The detection system will sheathed in several metres of water, to further reduce any externally induced 'background events': SABRE will cut the number of such events to a fifth (or less) of those seen by DAMA/LIBRA. CAASTRO Chief Investigator Jeremy Mould and CAASTRO Affiliate Alan Duffy, both at Swinburne University, are among the lead researchers on the project to build the detector, while CAASTRO researcher Katherine Mack (Melbourne University) is helping to plan the experiment and do preliminary calculations of event rates: she was also involved in the liaison with the mine owners that led to the contract to build the detector in the mine.

Thanks to Commonwealth Government funding of $1.75 million, matching funding from the Victorian State Government, and further support from the Australian Research Council, the project now has $5.5 million committed to it, allowing detailed design of the underground laboratory to proceed. Construction will start in 2016 and should be finished in 2017, when the first experiment will go in.


**Katie Mack in the mine at Stawell**
*Credit: CoEPP*

National Innovation Priority Case Study: International Collaboration

# CAASTRO PART OF MAJOR SETI SEARCH IN AUSTRALIA

**(This picture)** ***Breakthrough Listen*** **team members at CSIRO's Parkes telescope**
***Credit: John M. Sarkissian***

**(Below) Left to right**
**Jamie Peter, Tor Drew – Breakthrough Prize Foundation**
**David MacMahon – University of California, Berkeley**
**Andrew Siemion – ASTRON/Radbaul-Nijmegen**
**Danny Price – Harvard Cfa/UC Berkeley**
**Dan Werthimer – University of California, Berkeley**
***Credit: John M. Sarkissian***

CAASTRO staff will play a role in an international search for extraterrestrial intelligence.

CAASTRO Chief Investigator Professor Matthew Bailes, ARC Laureate Fellow at the Centre for Astrophysics and Supercomputing at Swinburne University of Technology, is the nominated lead of the Australian component of a major international search for extraterrestrial intelligence, *Breakthrough Listen*.

Under an agreement signed in July this year, *Breakthrough Listen* will run on CSIRO's 64-m Parkes radio telescope in New South Wales. Swinburne is working closely with the University of California Berkeley and CSIRO to design and implement a massive signal-processing and data-storage system for the project that will maximise the sensitivity of the telescope. This system will simultaneously 'hunt for ET' and search for naturally occurring phenomena such as pulsars and fast radio bursts.

Citizen-science project *SETI@home* will aid in processing the data and a team from the University of California Berkeley will coordinate the alien search. The project is keen to ensure that as much data as possible is made public and *Breakthrough Listen* may well become the largest data-sharing science project in the world.

*Breakthrough Listen* is funded by the Milner Global Foundation, established by Internet investor Yuri Milner. It is administered by the Breakthrough Prize Foundation, which was set up by Milner and other entrepreneurs to give awards that celebrate scientists and their work.

The Parkes observations are part of a larger set of initiatives to search for life in the Universe to which the Milner Global Foundation is committing US$100 million over ten years. The ET hunters will also use time on the Green Bank telescope in West Virginia, operated by the US National Radio Astronomy Observatory, and on a telescope at the University of California's Lick Observatory. More telescopes may join the project in future.

*Breakthrough Listen* will use 25 per cent of the Parkes telescope's time for five years from July 2016 and will target the nearest million stars in our galaxy, the Galactic Plane, and another 100 galaxies. It will be 50 times more sensitive than previous searches for extraterrestrial intelligence (SETI), covering ten times more sky and scanning at least five times more of the radio spectrum – and doing so 100 times faster than previously possible.

Parkes has contributed to SETI searches before. The largest effort was in 1995, when the California-based SETI Institute used the telescope for six months for its *Project Phoenix* search. The technology available for SETI searches has developed considerably since then.

The Breakthrough Prize Foundation's connection with Australia began last year, when CAASTRO Chief Investigator Professor Brian Schmidt (Australian National University) and colleagues were awarded the US$3 million 2014 Breakthrough Prize for their discovery of the accelerating expansion of the universe, work that had also won them the 2011 Nobel Prize. Professor Schmidt has strongly supported the Milner Global Foundation's SETI search being carried out in Australia. He will serve on the *Breakthrough Listen* Advisory Board for the next three years, to advise on the optimum observing strategy.

Many of the same techniques that CAASTRO and its partners have developed to find fast radio bursts and time millisecond pulsars are very applicable to alien searches. The deployment of the new infrastructure at Parkes opens new scientific windows to the Universe, promising greater time and frequency resolution to better elucidate the nature of fast radio bursts and aid in the discovery of millisecond pulsars.

National Innovation Priority: Frontier Technologies

# SAMI PROBES BIAS IN LOCAL STAR-FORMATION RATES

*Observing a nearby galaxy with a single optical fibre captures only the light from its central region. This introduces a bias into the estimation of the galaxy's star-formation rate. CAASTRO researchers have used the new SAMI instrument to investigate the details of this bias.*

Estimating the rate at which galaxies form stars is central to understanding how they evolve. For low-redshift galaxies ($z < 0.3$), this has been done mainly through optical-fibre spectroscopy. But local galaxies loom (relatively) large on the sky, and a single fibre captures only their central light. This introduces a bias into the estimation of the galaxy's star-formation rate, a bias that becomes particularly important if the fibre captures less than 20 per cent of the galaxy's light (which it does at redshifts lower than $\sim 0.05$). Elaborate methods ('aperture corrections') have been used to compensate for this bias. But how good are these methods? Using the SAMI instrument (the Sydney–AAO multi-object integral field unit), a team led by CAASTRO PhD student Samuel Richards (University of Sydney) probed the assumptions behind them.

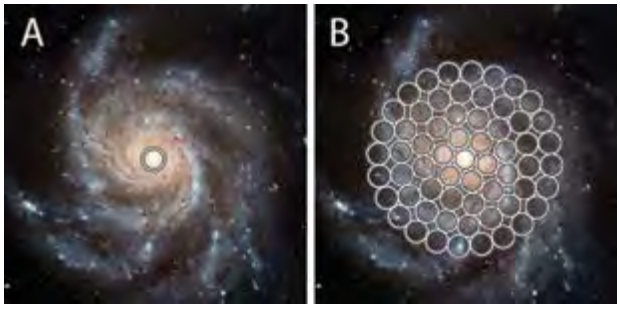
Integral field spectroscopy is the preferred method for testing aperture corrections because it provides spatially resolved data. Several previous studies have compared the star-formation rates predicted by aperture corrections with those obtained directly from H$\alpha$ emission. But all of them have been limited by errors, many arising from the small numbers of objects they could study. SAMI overcomes that problem: it covers 15 arcseconds on the sky and can sample the light from up to 61 points in a galaxy, for thirteen galaxies at a time, taking data an order of magnitude faster than traditional, monolithic, integral field units. The new study was based on 1212 galaxies from the SAMI Galaxy Survey.

To date, the largest single-fibre surveys of local galaxies have been the Sloan Digital Sky Survey (SDSS) and the Galaxy And Mass Assembly survey (GAMA): their fibres cover three and two arcseconds respectively. For galaxies with a redshift of less than 0.2, this means that only light from the innermost few kiloparsecs of each galaxy is selected. The two surveys use different methods to estimate the star-formation rate (SFR) from their incompletely sampled light. In GAMA, the SFR is calculated from the galaxy's H$\alpha$ emission as a fraction of its total light, and the galaxy's luminosity. In SDSS, the estimate is based on the colours of the sampled light (SDSS filters *g*, *r* and *i*). Important assumptions underlie the two methods. The GAMA method assumes that the strength of the H$\alpha$ emission is constant across the galaxy, and that so too is the level of cosmic dust, which attenuates the galaxy's light. The SDSS method, on the other hand, assumes that optical colours are a good indicator of the star-formation rate as measured by H$\alpha$, and that the light sampled from the galaxy's nucleus is also representative of the light emitted from its disc.

If the two assumptions of the GAMA method are true, then the star-formation rate this method estimates will be the same no matter how much light from the galaxy is captured. So the research team tested the assumptions by analysing the light captured by SAMI at ever increasing radius, from the innermost two arcseconds out to SAMI's full diameter of 15 arcseconds, in one-arcsecond steps. The result? The assumption about dust remaining constant across the galaxy generally held good, but in many galaxies the strength of the H$\alpha$ emission varied greatly across the face of the galaxy, sometimes by an order of magnitude between the smallest area sampled (the innermost two arcseconds) and the largest (the 15-arcsecond diameter). In fact, the trend in H$\alpha$ was flat only a third of the time: in the other cases, it increased or decreased.

The SDSS method assumes that a correction factor derived from the light from the central part of the galaxy applies to the galaxy as a whole. To test this, the research team used SAMI data to construct two 'correction cubes' for each galaxy, one for the galaxy's nucleus and one for its disc. They were found to differ significantly. The team also compared star formation rates derived from H$\alpha$ with those derived from the correction cubes. Again, in most cases they were found to differ significantly, with the measures matching closely in only a third.

These results suggest the limitations of the two methods. The GAMA technique over-predicts the star-formation rate in galaxies that are forming few stars. It also overestimates the star-formation rate in galaxies where star formation is centrally concentrated (merging galaxies, for example) and underestimates it where the star formation is extended. The SDSS technique, on the other hand, is insensitive to starbursts, because it relies on optical continuum emission, which alters on a much longer timescale than H$\alpha$. It underestimates the star-formation rate in galaxies where the rate is high, and overestimates it in galaxies where the rate is low. For any survey, the best aperture correction to apply will depend on the data sample in question, the SAMI team concludes.




**The coverage of (A) a single optical fibre, and (B) a SAMI hexabundle of fibres.**
***Credit: Joss Bland-Hawthorn***

National Innovation Priority: International Collaboration

# NEW AUSTRALIA—CHINA CENTRE TO FOSTER ASTRONOMY


**ACAMAR signing ceremony, Beijing, September 2015** ***Credit: Sean Stamer***

*Australia and China have established a new joint research centre in astronomy that will facilitate cooperation on future telescopes such as the Square Kilometre Array and boost Antarctic astronomy.*

On 12 September 2015 the ARC Centre of Excellence for All-sky Astrophysics (CAASTRO) and the National Astronomical Observatories of the Chinese Academy of Sciences (NAOC) signed into existence a new joint centre for coordinating astronomical projects between Australia and China. Called ACAMAR, the Australia-ChinA Consortium for Astrophysical Research, it will serve as an umbrella and coordination point for bilateral astronomical collaborations. The centre's stellar namesake, *Acamar* (θ Eridani), is a bright naked-eye star visible from both countries.

The new centre will be overseen by two Directors, one from Australia (Nobel Laureate Professor Brian Schmidt) and one from China (Professor Lifan Wang). Its Australian secretariat will be hosted by CAASTRO at The University of Sydney, and its Chinese secretariat by the Purple Mountain Observatory of the Chinese Academy of Sciences, in Nanjing. Professor Ji Yang, Director of Purple Mountain Observatory will be the Manager, China, for ACAMAR; his Australian counterparts will be CAASTRO's Deputy Director Professor Lister Staveley-Smith (ICRAR, University of Western Australia) and the CAASTRO Chief Operating Officer, Ms Kate Gunn (University of Sydney).

ACAMAR will maximise the scientific return on investments in astronomy infrastructure, particularly by helping the two countries to cooperate in running telescopes based in Australia and China, and to coordinate observations and share data. It will also help to develop skills and knowledge, by facilitating the exchange of students, researchers and technical staff between institutions.

Both Australia and China participate in the international project to build the Square Kilometre Array (SKA) radio telescope, which will be located in Australia and South Africa. ACAMAR will facilitate cooperation in science and development associated with the SKA. China has already provided state-of-the-art dishes for the Australian SKA Pathfinder (ASKAP) telescope, an SKA precursor.

The new centre will also build on existing astronomy collaborations between Australia and China in Antarctic astronomy. The cold, dry and stable air above the high Antarctic plateau provides the best atmospheric conditions of any terrestrial site for optical and infrared observations. Australian and Chinese astronomers are involved in a number of pioneering projects to exploit this unique environment, including a series of robotic observatories that have been deployed at several sites on the Antarctic plateau in collaboration with other partners.

Dome A, the highest point of the Antarctic plateau, is one of these sites. In 2008 China established a presence at Dome A and began building four small binocular telescopes for its Antarctic Survey Telescope project. In a significant collaboration with Australian astronomers, these telescopes are now being used for a large survey for extrasolar planets. Australia is building instruments for the telescopes.

NAOC employs about 750 staff, organised into more than 50 research groups. It has built and now operates a number of astronomical facilities, including an innovative large optical telescope in northern China, a low-frequency radio telescope for studying the early Universe, and another radio telescope for studying the Sun. It is now building the world's largest single-dish radio telescope, FAST (the Five-hundred-meter Aperture Spherical Telescope), in southwest China. Australia's CSIRO has designed a powerful 19-beam receiver system for FAST and is negotiating a contract for its construction. Both Australia and China are members of international collaborations to build radio and optical telescopes.

ACAMAR has grown out of a 2013 Memorandum of Understanding between the Chinese Academy of Sciences and the Australian Department of Industry, Innovation, and Science, which proposed collaboration on areas of common interest in astronomy.

CAASTRO will host the *Inaugural Australia–China Workshop on Astrophysics* in Perth, Western Australia, in April 2016.

## National Innovation Priority: Collaboration with Business

# CAPTURING THE COSMOS

The radio sky as 'seen' by the Murchison Widefield Array

*Credit: "Capturing the Cosmos"/Museum Victoria*

*CAASTRO has been working in partnership with Museum Victoria to create the new planetarium show "Capturing the Cosmos".*

A planetarium dome presents a simulated display of the night sky that allows people to enjoy the wonder of the stars in a comfortable environment regardless of the time of day – or the weather. But it is also perfect for the display of astronomical data, which otherwise has to be warped to fit a flat projection.

*Capturing the Cosmos*, a collaboration between CAASTRO and Museum Victoria, is a new planetarium show that highlights current astronomical research and state-of-the-art technologies in Australia. The partners first discussed the project in 2013. A legal agreement was signed later that year, and in 2014 the show concepts were jointly developed. The show was produced this year, and is scheduled to launch at Scienceworks in Melbourne on 21 March 2016, with simultaneous events happening across the country. It is narrated by award-winning Australian actor Geoffrey Rush, who previously worked with Museum Victoria on its show *Black Holes*. He is also an astronomy enthusiast!

Museum Victoria is Australia's largest public museum organisation. As the State museum for Victoria, it is responsible for looking after the State collection of nearly 17 million objects, documents, photographs and specimens. Museum Victoria's origins date back to 1854, and it houses long-term and temporary exhibitions at three venues: Melbourne Museum, the Immigration Museum and Scienceworks.

Melbourne Planetarium is housed within Scienceworks, in the Melbourne suburb of Spotswood. Its shows are informative and entertaining for a wide range of audiences. Dr Tanya Hill, Senior Curator (Astronomy) at Museum Victoria, develops new astronomy productions for Melbourne Planetarium and creates opportunities for the general public to find out about astronomical events and learn of discoveries about our Universe. Tanya and her team have worked closely with CAASTRO's Dr Wiebke Ebeling, Professor Steven Tingay, Ms Kate Gunn, Professor Elaine Sadler and Professor Bryan Gaensler to develop the new show.

Tanya joined Museum Victoria in 1999 and was part of the team that opened Melbourne Planetarium. She has drawn on her background in research astronomy to create more than a dozen planetarium productions. Tanya obtained her PhD from University of Sydney in 2002, where she studied active galaxies.

All-sky astronomy is a new way of looking at the sky to better understand our Universe, and *Capturing the Cosmos* highlights key research areas within CAASTRO. It focuses on the new and innovative telescopes our researchers work with: the optical SkyMapper telescope in New South Wales and the Murchison Widefield Array radio telescope in Western Australia. Both these telescopes have been designed to survey large sections of the sky and are finding things we've never seen before – things that will help us to unravel the mysteries of our Universe.

CAASTRO and Museum Victoria have also been developing resources for teachers and students to accompany the show. These will be available through the Museum Victoria and CAASTRO websites.

*Capturing the Cosmos* will be an exceptional legacy product of CAASTRO, and looks likely to screen in over fifty planetariums, in sixteen countries. It is our first major commercialisation project.

# ACTIVITY PLAN 2016

**CAASTRO expects to have another stimulating and rewarding 12 months with many interesting activities and research discoveries.**

## CAASTRO RESEARCH PROGRAM

### Evolving Universe Theme

Next year promises to be another very exciting year for science in the Evolving Theme, as we build on work done in 2015.

The SAMI Galaxy Survey has now observed more than 1,500 galaxies and is producing diverse science. Sixteen journal papers have been published from the survey so far. 2016 will see the second data release, and the use of that data for a variety of investigations: the discovery and characterisation of galaxy outflows; insights into the morphological transformation of galaxies; measuring the impact of non-regular rotation and dynamical disturbance; new views of galaxy scaling relations; studies of the spatial distribution of star formation; and much more. CAASTRO members will also conduct theoretical simulations to mimic aspects of the SAMI survey in support of these science goals.

During 2015 a further 350 hours of observing were completed for the Murchison Widefield Array (MWA) Epoch of Reionisation (EoR) survey, generating some 467 TB of data. The MWA EoR collaboration has developed three independent and parallel data-reduction pipelines, two for the targeted EoR fields and one for the driftscan observations. CAASTRO researchers lead the development of a pipeline for the MWA Realtime System. This pipeline, now operational, was applied to the MWA EoR survey data during 2015, resulting in the first publication of MWA power spectra generated through this pipeline. During 2016 and 2017 our goal is to process the first two years of MWA EOR data, some 700 hours, and to make a detection of the EoR power spectrum.

This year also saw the first results from CAASTRO's new intensity-mapping project, which is designed to study the H I content of the Universe at a wide range of cosmic times. Intensity mapping involves averaging together the neutral hydrogen (H I) emission from large numbers of galaxies observed in a wide-area survey. The radio-survey data are then combined with additional information from optical redshift surveys and galaxy simulations. The cross-correlation of redshifted 21-cm intensity with galaxies identified optically will allow us to measure H I at high redshift and study its distribution in galaxies. The first phase of the project includes observations and modelling of these datasets. We have completed a semi-analytic model of the intensity-mapping cross-correlation signal. In 2016, we will continue the CAASTRO intensity-mapping survey, and compare the predictions of this model with measurements of cross-correlation data taken with the Parkes radio telescope. The project will have implications for the science goals and design of the Square Kilometre Array radio telescope.

### Dynamic Universe Theme

The Murchison Widefield Array (MWA) is taking exquisite data of the radio sky at low frequencies. In 2016 the MWA team will publish its first catalogues of the low-frequency radio sky, part of its work conducted under the Dynamic theme. The team has also detected many known pulsars and used their variability to differentiate them from other variable sources. The effectiveness of the MWA for transient astronomy is currently limited by its spatial resolution. But the telescope's first upgrade, beginning in 2016, will improve that, enabling the MWA team to get maps of much higher resolution that will be even better for transient science. The MWA is also following up fast radio bursts detected with other telescopes and doing its own surveys for them. Finally, when the historic first detection of gravitational waves was made in 2015, the MWA took part in the international follow-up at low radio frequencies. Gravitational-wave detectors have large error boxes (that is, they cannot well determine the location of sources on the sky): when future detections are made, the MWA will again play an important role in the follow-up, because its wide field of view means it can rapidly survey a large area of sky.

The Parkes radio telescope has discovered over 90 per cent of all fast radio bursts (FRBs). The SUPERB survey running on Parkes detected a number of FRBs in late 2015 and searches for their afterglows will continue in 2016 with the Australia Telescope Compact Array and at other observatories. (FRB research is discussed further on page 14). Next year the *Breakthrough Listen* project (page 30) will deploy advanced new instrumentation at Parkes: this will be adapted to enable searches for FRBs and pulsars at higher time and spatial resolution. The CAASTRO Dynamic team has also used new spatial-filtering techniques to clean up


**CAASTRO node members have many research activities planned for 2016.**
***Credit: Bill Roberts***

badly contaminated data and will use them to mine the Parkes archive in 2016.

Over the last few years the University of Sydney's 50-year-old Molonglo telescope has been upgraded as part of CAASTRO's activities. It was formally re-launched in December 2015. Looking for pulsars and fast radio bursts, the upgraded telescope has already discovered three pulsar glitches. In 2016 it will monitor 250 pulsars and be upgraded to achieve higher temporal and frequency resolution.

Yet another Australian telescope that will look for counterparts of gravitational waves is SkyMapper, the 1.35-m optical robotic telescope of the Australian National University (ANU) at Siding Spring Observatory. SkyMapper has a field of view of six degrees. Under its rapid-response alert program, it will continue to follow up FRBs found with Parkes and Molonglo.

SkyMapper is also undertaking a supernova survey: for more on this, see page 19. But its main task is to make the first comprehensive digital survey of the southern sky, a detailed record of more than a billion stars and galaxies. This survey began in March 2014. Work progressed very well until September, when the telescope's cooling system reached the end of its life. Unfortunately, difficulties in obtaining a satisfactory replacement from the manufacturer meant a delay of several months before the survey could start again. Nevertheless, 2016 will see the first large-volume data release of SkyMapper's Short Survey and a release of the first data from the Main Survey. Plenty of spectroscopic follow-up is already planned, to verify candidates for the brightest quasars in the southern sky, the brightest metal-poor stars, and possibly a handful of ultra-cool white dwarfs.

## Dark Universe Theme

Dark theme activities in 2016 will span four areas: supernovae, peculiar velocities, large-scale structure and theory.

In the supernova-cosmology area we have two major projects running. The first is the Australian Dark Energy Survey, OzDES, which in 2016 will have completed three years of data collection, and used just over half of its allocated nights. Observing will continue for two more years, and we are currently working on our first cosmology analysis with the preliminary data.

In a second project, we are looking forward to many significant supernova discoveries from SkyMapper, which we hope will become the low-redshift sample to anchor the Hubble diagram for OzDES. We are working on cross-calibrating the two surveys. In related work on the Hubble diagram, we are investigating the scatter about it arising from lensing and peculiar velocities, with a view to using these as a signal to measure the strength of clustering.

Meanwhile we will be seeing the final results from our other peculiar-velocity surveys such as 6dFGSv and 2MTF. With the arrival of a new CAASTRO researcher (Cullan Howlett) at the University of Western Australia, we have new capacity to extend our peculiar-velocity studies, and during 2016 we plan to compile a master sample combining peculiar-velocity measurements from several different types of probes: Fundamental Plane from 6dFGSv, Tully-Fisher from 2MTF, and supernovae from SkyMapper and OzDES, plus other publicly available datasets. We will look at cross-calibrating these techniques and comparing zero-points. Alongside this we are also looking at different analyses we can do with peculiar velocities, such as pairwise measurements, non-Gaussianity, and joint fits with the density field. Perhaps the most exciting prospect is that the new TAIPAN survey will be starting in mid-2016. Using the new 'starbug' technology, it will be a fantastic peculiar-velocities survey, but our first goal with TAIPAN is to make a measurement of $H_0$ using baryon acoustic oscillations in the local Universe.

Which brings us to the area of large-scale structure. There is one last result we are expecting from the WiggleZ data, which is the baryon acoustic oscillation analysis separated by the direction with respect to the line of sight. Apart from that, most of our research in the area of large-scale structure has moved to the theoretical arena: we are looking, for instance, at clever new ways to analyse large-scale structure to mitigate the effects of non-linear structure formation and give more robust results, and at a method of using cosmic voids to measure the growth factor. Dark-theme researchers at Swinburne University are continuing to develop fast approximate simulations to accurately calculate covariance matrices. These advances will be important for the next generation of surveys.

Also in the area of theory and simulations, UQ-based researchers are carrying out simulations in non-standard gravity, taking into account relativistic effects in


**Tara Murphy presents at the University of Sydney as part of the "Enlighten" VIVID festival**
***Credit: Tara Murphy***

structure formation, while others at Swinburne and Melbourne are calculating the expected event rates for the new dark-matter detector in Stawell (page 29).

Encompassing all projects, we have recently ramped up discussions about how to ensure our data has the largest impact, and that includes making sure that our data and data products are widely available and easy to use once they are published.

## Education and Outreach

The beginning of the year will be dominated by the completion and launch of our planetarium show, *Capturing the Cosmos*, in collaboration with Museum Victoria. The main launch event will take place at Scienceworks in Melbourne on 21 March 2016, with simultaneous events across the country. This show will be an exceptional legacy product of CAASTRO Education and Outreach, going beyond our funding period.

We also aim to launch our new school-student mentoring program, *Bright Stars*, around this time, in conjunction with *CAASTRO in the Classroom* sessions and *Telescopes in Schools* observing nights and training workshops in school Term 1. Through *Bright Stars* high-school students get to know the personal story behind a career as a research scientist, what motivated our members to pursue a career in a STEM discipline, where it has led them and what advice they have for younger people.

The 2016 schedule for *CAASTRO in the Classroom* is already set, with 12 sessions laid out to match up with topics in the Australian curriculum. The first teachers' professional development workshop is planned for 19 February, with more to follow across Australia during 2016. Three casual science teachers will contribute to expanding the program nationally and create educational resources.

The inaugural *Sydney Astrofest*, organised by CAASTRO members, will take place at the University of Sydney in 2016: the program includes a number of keynote talks, family-friendly hands-on activities, information stands, planetarium shows and stargazing. A similar formula will be at the heart of the second astronomy festival to be held in Melbourne later in the year, again drawing on our fantastic partnerships with *Telescopes in Schools* and Mount Burnett Observatory.

In 2016 CAASTRO will again partner with Voyages Indigenous Tourism Australia to present outreach programs, the *Uluru Astronomer in Residence* (March to November) and the *Uluru Astronomy Weekend* (26–28 August).

We will continue to publish research stories and press releases to communicate our science to the public, and we will produce new animations to accompany these stories and to assist our researchers in their presentations. The first *CAASTRO Readers' Digest* booklet will be distributed in February, with another 2016 edition expected in the middle of the year.

In November we will run a professional training workshop in Perth, in association with the CAASTRO Annual Retreat in Western Australia.

A major new project in the Education and Outreach portfolio in 2016 is the production of an illustrated children's story book that will further broaden and complement the reach of our science communication (going to our youngest audience yet) and constitute another significant legacy product. We are aiming to launch the book in March 2017.

## Commercialisation and Knowledge Transfer

Given CAASTRO's primary focus on pure research, in 2016 we will approach commercialisation and knowledge transfer in innovative ways. There is a working group that will work on a business plan for a possible CAASTRO Innovations company, and we will progress the CAASTRO Innovation Challenge that began in November 2015.

CAASTRO continues to develop an e-book to educate and assist researchers in identifying and protecting intellectual property, industry engagement, and assisting with knowledge transfer. CAASTRO's key strength is in knowledge distribution through formal and informal networks, which is an essential part of Australia's economic performance. Innovation is driven by the interaction of producers and users in the exchange of both codified and tacit knowledge. The flow of information between industry, government and academia in the development of science and technology is an important economic determinant and in 2016 CAASTRO will continue to provide leadership in this area.

# 2015 PUBLICATIONS

Achitouv, I., Blake, C., "Improving reconstruction of the baryon acoustic peak: The effect of local environment", Physical Review D, 92, 083523, 2015

Allen, J. T., Croom, S. M., Konstantopoulos, I. S., Bryant, J. J., Sharp, R., Cecil, G. N., Fogarty, L. M. R., Foster, C., Green, A. W., Ho, I.-T., Owers, M. S., Schaefer, A. L., Scott, N., Bauer, A. E., Baldry, I., Barnes, L. A., Bland-Hawthorn, J., Bloom, J. V., Brough, S., Colless, M., Cortese, L., Couch, W. J., Drinkwater, M. J., Driver, S. P., Goodwin, M., Gunawardhana, M. L. P., Hampton, E. J., Hopkins, A. M., Kewley, L. J., Lawrence, J. S., Leon-Saval, S. G., Liske, J., Lopez-Sanchez, R., Lorente, N. P. F., McElroy, R., Medling, A. M., Mould, J., Norberg, P., Parker, Q. A., Power, C., Pracy, M. B., Richards, S. N., Robotham, A. S. G., Sweet, S. M., Taylor, E. N., Thomas, A. D., Tonini, C., Walcher, C. J., "The SAMI Galaxy Survey: early data release", Monthly Notices of the Royal Astronomical Society, 446, 1567, 2015

Allen, J. T., Schaefer, A. L., Scott, N., Fogarty, L. M. R., Ho, I.-T., Medling, A. M., Leslie, S. K., Bland-Hawthorn, J., Bryant, J. J., Croom, S. M., Goodwin, M., Green, A. W., Konstantopoulos, I. S., Lawrence, J. S., Owers, M. S., Richards, S. N., Sharp, R., "The SAMI Galaxy Survey: unveiling the nature of kinematically offset active galactic nuclei", Monthly Notices of the Royal Astronomical Society, 451, 2780, 2015

Allison, J. R., Sadler, E. M., Moss, V. A., Whiting, M. T., Hunstead, R. W., Pracy, M. B., Curran, S. J., Croom, S. M., Glowacki, M., Morganti, R., Shabala, S. S., Zwaan, M. A., Allen, G., Amy, S. W., Axtens, P., Ball, L., Bannister, K. W., Barker, S., Bell, M. E., Bock, D. C.-J., Bolton, R., Bowen, M., Boyle, B., Braun, R., Broadhurst, S., Brodrick, D., Brothers, M., Brown, A., Bunton, J. D., Cantrall, C., Chapman, J., Cheng, W., Chippendale, A. P., Chung, Y., Cooray, F., Cornwell, T., DeBoer, D., Diamond, P., Edwards, P. G., Ekers, R., Feain, I., Ferris, R. H., Forsyth, R., Gough, R., Grancea, A., Gupta, N., Guzman, J. C., Hampson, G., Harvey-Smith, L., Haskins, C., Hay, S., Hayman, D. B., Heywood, I., Hotan, A. W., Hoyle, S., Humphreys, B., Indermuehle, B. T., Jacka, C., Jackson, C., Jackson, S., Jeganathan, K., Johnston, S., Joseph, J., Kendall, R., Kesteven, M., Kiraly, D., Koribalski, B. S., Leach, M., Lenc, E., Lensson, E., Mackay, S., Macleod, A., Marquarding, M., Marvil, J., McClure-Griffiths, N., McConnell, D., Mirtschin, P., Norris, R. P., Neuhold, S., Ng, A., O'Sullivan, J., Pathikulangara, J., Pearce, S., Phillips, C., Popping, A., Qiao, R. Y., Reynolds, J. E., Roberts, P., Sault, R. J., Schinckel, A., Serra, P., Shaw, R., Shields, M., Shimwell, T., Storey, M., Sweetnam, T., Troup, E., Turner, B., Tuthill, J., Tzioumis, A., Voronkov, M. A., Westmeier, T., Wilson, C. D., "Discovery of H I gas in a young radio galaxy at z = 0.44 using the Australian Square Kilometre Array Pathfinder", Monthly Notices of the Royal Astronomical Society, 453, 1249, 2015

Appleby, S., Shafieloo, A., Johnson, A., "Probing bulk flow with nearby SNe Ia data", The Astrophysical Journal, 801, 76, 2015

Arora, B. S., Morgan, J., Ord, S. M., Tingay, S. J., Hurley-Walker, N., Bell, M., Bernardi, G., Bhat, N. D. R., Briggs, F., Callingham, J. R., Deshpande, A. A., Dwarakanath, K. S., Ewall-Wice, A., Feng, L., For, B.-Q., Hancock, P., Hazelton, B. J., Hindson, L., Jacobs, D., Johnston-Hollitt, M., Kapinska, A. D., Kudryavtseva, N., Lenc, E., McKinley, B., Mitchell, D., Oberoi, D., Offringa, A. R., Pindor, B., Procopio, P., Riding, J., Staveley-Smith, L., Wayth, R. B., Wu, C., Zheng, Q., Bowman, J. D., Cappallo, R. J., Corey, B. E., Emrich, D., Goeke, R., Greenhill, L. J., Kaplan, D. L., Kasper, J. C., Kratzenberg, E., Lonsdale, C. J., Lynch, M. J., McWhirter, S. R., Morales, M. F., Morgan, E., Prabu, T., Rogers, A. E. E., Roshi, A., Shankar, N. U., Srivani, K. S., Subrahmanyan, R., Waterson, M., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., "Ionospheric modelling using GPS to calibrate the MWA. I: comparison of first order ionospheric effects between GPS models and MWA observations", Publications of the Astronomical Society of Australia, 32, e029, 2015

Avila, S., Murray, S. G., Knebe, A., Power, C., Robotham, A. S. G., Garcia-Bellido, J., "HALOGEN: a tool for fast generation of mock halo catalogues", Monthly Notices of the Royal Astronomical Society, 450, 1856, 2015

Banerji, M., Jouvel, S., Lin, H., McMahon, R. G., Lahav, O., Castander, F. J., Abdalla, F. B., Bertin, E., Bosman, S. E., Carnero, A., Kind, M. C., da Costa, L. N., Gerdes, D., Gschwend, J., Lima, M., Maia, M. A. G., Merson, A., Miller, C., Ogando, R., Pellegrini, P., Reed, S., Saglia, R., Sánchez, C., Allam, S., Annis, J., Bernstein, G., Bernstein, J., Bernstein, R., Capozzi, D., Childress, M., Cunha, C. E., Davis, T. M., DePoy, D. L., Desai, S., Diehl, H. T., Doel, P., Findlay, J., Finley, D. A., Flaugher, B., Frieman, J., Gaztanaga, E., Glazebrook, K., Gonzalez-Fernandez, C., Gonzalez-Solares, E., Honscheid, K., Irwin, M. J., Jarvis, M. J., Kim, A., Koposov, S., Kuehn, K., Kupcu-Yoldas, A., Lagattuta, D., Lewis, J. R., Lidman, C., Makler, M., Marriner, J., Marshall, J. L., Miquel, R., Mohr, J. J., Neilsen, E., Peoples, J., Sako, M., Sanchez, E., Scarpine, V., Schindler, R., Schubnell, M., Sevilla, I., Sharp, R., Soares-Santos, M., Swanson, M. E. C., Tarle, G., Thaler, J., Tucker, D., Uddin, S. A., Wechsler, R., Wester, W., Yuan, F., Zuntz, J.,"Combining dark energy survey science verification data with near-infrared data from the ESO VISTA Hemisphere Survey", Monthly Notices of the Royal Astronomical Society, 446, 2523, 2015

Banfield, J. K., Wong, O. I., Willett, K. W., Norris, R. P., Rudnick, L., Shabala, S. S., Simmons, B. D., Snyder, C., Garon, A., Seymour, N., Middelberg, E., Andernach, H., Lintott, C. J., Jacob, K., Kapinska,

A. D., Mao, M. Y., Masters, K. L., Jarvis, M. J., Schawinski, K., Paget, E., Simpson, R., Klockner, H.-R., Bamford, S., Burchell, T., Chow, K. E., Cotter, G., Fortson, L., Heywood, I., Jones, T. W., Kaviraj, S., Lopez-Sanchez,. R., Maksym, W. P., Polsterer, K., Borden, K., Hollow, R. P., Whyte, L., "Radio Galaxy Zoo: host galaxies and radio morphologies derived from visual inspection", Monthly Notices of the Royal Astronomical Society, 453, 2326, 2015

Bates, S. D., Thornton, D., Bailes, M., Barr, E., Bassa, C. G., Bhat, N. D. R., Burgay, M., Burke-Spolaor, S., Champion, D. J., Flynn, C. M. L., Jameson, A., Johnston, S., Keith, M. J., Kramer, M., Levin, L., Lyne, A., Milia, S., Ng, C., Petroff, E., Possenti, A., Stappers, B. W., van Straten, W., Tiburzi, C., "The high time resolution universe survey - XI. Discovery of five recycled pulsars and the optical detectability of survey white dwarf companions", Monthly Notices of the Royal Astronomical Society, 446, 4019, 2015

Bell, M. E., Huynh, M. T., Hancock, P., Murphy, T., Gaensler, B. M., Burlon, D., Trott, C., Bannister, K., "A search for variable and transient radio sources in the extended Chandra Deep Field South at 5.5 GHz", Monthly Notices of the Royal Astronomical Society, 450, 4221, 2015

Bryant, J. J., Owers, M. S., Robotham, A. S. G., Croom, S. M., Driver, S. P., Drinkwater, M. J., Lorente, N. P. F., Cortese, L., Scott, N., Colless, M., Schaefer, A., Taylor, E. N., Konstantopoulos, I. S., Allen, J. T., Baldry, I., Barnes, L., Bauer, A. E., Bland-Hawthorn, J., Bloom, J. V., Brooks, A. M., Brough, S., Cecil, G., Couch, W., Croton, D., Davies, R., Ellis, S., Fogarty, L. M. R., Foster, C., Glazebrook, K., Goodwin, M., Green, A., Gunawardhana, M. L., Hampton, E., Ho, I.-T., Hopkins, A. M., Kewley, L., Lawrence, J. S., Leon-Saval, S. G., Leslie, S., McElroy, R., Lewis, G., Liske, J., Lopez-Sanchez. R., Mahajan, S., Medling, A. M., Metcalfe, N., Meyer, M., Mould, J., Obreschkow, D., O'Toole, S., Pracy, M., Richards, S. N., Shanks, T., Sharp, R., Sweet, S. M., Thomas, A. D., Tonini, C., Walcher, C. J., "The SAMI Galaxy Survey: instrument specification and target selection", Monthly Notices of the Royal Astronomical Society, 447, 2857, 2015

Bulla, M., Sim, S. A., Kromer, M., "Polarization spectral synthesis for Type Ia supernova explosion models", Monthly Notices of the Royal Astronomical Society, 450, 967, 2015

Callingham, J. R., Gaensler, B. M., Ekers, R. D., Tingay, S. J., Wayth, R. B., Morgan, J., Bernardi, G., Bell, M. E., Bhat, R., Bowman, J. D., Briggs, F., Cappallo, R. J., Deshpande, A. A., Ewall-Wice, A., Feng, L., Greenhill, L. J., Hazelton, B. J., Hindson, L., Hurley-Walker, N., Jacobs, D. C., Johnston-Hollitt, M., Kaplan, D. L., Kudrayvtseva, N., Lenc, E., Lonsdale, C. J., McKinley, B., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Offringa, A. R., Ord, S. M., Pindor, B., Prabu, T., Procopio, P., Riding, J., Srivani, K. S., Subrahmanyan, R., Udaya Shankar, N., Webster, R. L., Williams, A., Williams, C. L., "Broadband spectral modeling of the extreme gigahertz-peaked spectrum radio source PKS B0008-421", The Astrophysical Journal, 809, 168, 2015

Childress, M. J., Hillier, D. J., Seitenzahl, I., Sullivan, M., Maguire, K., Taubenberger, S., Scalzo, R., Ruiter, A., Blagorodnova, N., Camacho, Y., Castillo, J., Elias-Rosa, N., Fraser, M., Gal-Yam, A., Graham, M., Howell, D. A., Inserra, C., Jha, S. W., Kumar, S., Mazzali, P. A., McCully, C., Morales-Garoffolo, A., Pandya, V., Polshaw, J., Schmidt, B., Smartt, S., Smith, K. W., Sollerman, J., Spyromilio, J., Tucker, B., Valenti, S., Walton, N., Wolf, C., Yaron, O., Young, D. R., Yuan, F., Zhang, B., "Measuring nickel masses in Type Ia supernovae using cobalt emission in nebular phase spectra", Monthly Notices of the Royal Astronomical Society, 454, 3816, 2015

Chuang, C.-H., Zhao, C., Prada, F., Munari, E., Avila, S., Izard, A., Kitaura, F.-S., Manera, M., Monaco, P., Murray, S., Knebe, A., Scoccola, C. G., Yepes, G., Garcia-Bellido, J., Marin, F. A., Muller, V., Skibba, R., Crocce, M., Fosalba, P., Gottlober, S., Klypin, A. A., Power, C., Tao, C., Turchaninov, V.,"nIFTy cosmology: Galaxy/halo mock catalogue comparison project on clustering statistics", Monthly Notices of the Royal Astronomical Society, 452, 686, 2015

Collet, C., Nesvadba, N. P. H., De Breuck, C., Lehnert, M. D., Best, P., Bryant, J. J., Dicken, D., Johnston, H., Hunstead, R., Wylezalek, D., "Defying jet-gas alignment in two radio galaxies at z ~ 2 with extended light profiles: Similarities to brightest cluster galaxies", Astronomy and Astrophysics, 579, A89, 2015

Corstanje, A., Schellart, P., Nelles, A., Buitink, S., Enriquez, J. E., Falcke, H., Frieswijk, W., Horandel, J. R., Krause, M., Rachen, J. P., Scholten, O., ter Veen, S., Thoudam, S., Trinh, T. N. G., van den Akker, M., Alexov, A., Anderson, J., Avruch, I. M., Bell, M. E., Bentum, M. J., Bernardi, G., Best, P., Bonafede, A., Breitling, F., Broderick, J., Bruggen, M., Butcher, H. R., Ciardi, B., de Gasperin, F., de Geus, E., de Vos, M., Duscha, S., Eisloffel, J., Engels, D., Fallows, R. A., Ferrari, C., Garrett, M. A., Griebmeier, J., Gunst, A. W., Hamaker, J. P., Hoeft, M., Horneffer, A., Iacobelli, M., Juette, E., Karastergiou, A., Kohler, J., Kondratiev, V. I., Kuniyoshi, M., Kuper, G., Maat, P., Mann, G., McFadden, R., McKay-Bukowski, D., Mevius, M., Munk, H., Norden, M. J., Orru, E., Paas, H., Pandey-Pommier, M., Pandey, V. N., Pizzo, R., Polatidis, A. G., Reich, W., Rottgering, H., Scaife, A. M. M., Schwarz, D., Smirnov, O., Stewart, A., Steinmetz, M., Swinbank, J., Tagger, M., Tang, Y., Tasse, C., Toribio, C., Vermeulen, R., Vocks, C., van Weeren, R. J., Wijnholds, S. J., Wucknitz, O., Yatawatta, S., Zarka, P., "The shape of the radio wavefront of extensive air showers as measured with LOFAR", Astroparticle Physics, 61, 22, 2015

Cseh, D., Webb, N. A., Godet, O., Barret, D., Corbel, S., Coriat, M., Falcke, H., Farrell, S. A., Kording, E., Lenc, E., Wrobel, J. M.,"On the radio properties of the intermediate-mass black hole candidate ESO 243–49 HLX-1", Monthly Notices of the Royal Astronomical Society, 446, 3268, 2015

de Bruyn, A. G., Macquart, J.-P., "The intra-hour variable quasar J1819+3845: 13-year evolution, jet polarization structure, and interstellar scattering screen properties", Astronomy and Astrophysics, 574, A125, 2015

de Burgh-Day, C. O., Taylor, E. N., Webster, R. L., Hopkins, A. M., "Direct shear mapping – a new weak lensing tool", Monthly Notices of the Royal Astronomical Society, 451, 2161, 2015

de Burgh-Day, C. O., Taylor, E. N., Webster, R. L., Hopkins, A. M., "Direct shear mapping: prospects for weak lensing studies of individual galaxy-galaxy lensing systems", Publications of the Astronomical Society of Australia, 32, e040, 2015

D'Eugenio, F., Houghton, R. C. W., Davies, R. L., Dalla Bonta, E., "On the distribution of galaxy ellipticity in clusters", Monthly Notices of the Royal Astronomical Society, 451, 827, 2015

Dillon, J. S., Neben, A. R., Hewitt, J. N., Tegmark, M., Barry, N., Beardsley, A. P., Bowman, J. D., Briggs, F., Carroll, P., de Oliveira-Costa, A., Ewall-Wice, A., Feng, L., Greenhill, L. J., Hazelton, B. J., Hernquist, L., Hurley-Walker, N., Jacobs, D. C., Kim, H. S., Kittiwisit, P., Lenc, E., Line, J., Loeb, A., McKinley, B., Mitchell, D. A., Morales, M. F., Offringa, A. R., Paul, S., Pindor, B., Pober, J. C., Procopio, P., Riding, J., Sethi, S., Shankar, N. U., Subrahmanyan, R., Sullivan, I., Thyagarajan, N., Tingay, S. J., Trott, C., Wayth, R. B., Webster, R. L., Wyithe, S., Bernardi, G., Cappallo, R. J., Deshpande, A. A., Johnston-Hollitt, M., Kaplan, D. L., Lonsdale, C. J., McWhirter, S. R., Morgan, E., Oberoi, D., Ord, S. M., Prabu, T., Srivani, K. S., Williams, A., Williams, C. L., "Empirical covariance modeling for 21 cm power spectrum estimation: a method demonstration and new limits from early Murchison Widefield Array 128-tile data", Physical Review D, 91, 123011, 2015

Dolag, K., Gaensler, B. M., Beck, A. M., Beck, M. C., "Constraints on the distribution and energetics of fast radio bursts using cosmological hydrodynamic simulations", Monthly Notices of the Royal Astronomical Society, 451, 4277, 2015

Dossett, J. N., Ishak, M., Parkinson, D., Davis, T. M., "Constraints and tensions in testing general relativity from Planck and CFHTLenS data including intrinsic alignment systematics", Physical Review D, 92, 023003, 2015

Farrell, S. A., Murphy, T., Lo, K. K., "Autoclassification of the variable 3XMM sources using the random forest machine learning algorithm", The Astrophysical Journal, 813, 28, 2015

Franzen, T. M. O., Banfield, J. K., Hales, C. A., Hopkins, A., Norris, R. P., Seymour, N., Chow, K. E., Herzog, A., Huynh, M. T., Lenc, E., Mao, M. Y., Middelberg, E., "ATLAS - I. Third release of 1.4 GHz mosaics and component catalogues", Monthly Notices of the Royal Astronomical Society, 453, 4020, 2015

Fraser, M., Kotak, R., Pastorello, A., Jerkstrand, A., Smartt, S. J., Chen, T.-W., Childress, M., Gilmore, G., Inserra, C., Kankare, E., Margheim, S., Mattila, S., Valenti, S., Ashall, C., Benetti, S., Botticella, M. T., Bauer, F. E., Campbell, H., Elias-Rosa, N., Fleury, M., Gal-Yam, A., Hachinger, S., Howell, D. A., Le Guillou, L., Leget, P.-F., Morales-Garoffolo, A., Polshaw, J., Spiro, S., Sullivan, M., Taubenberger, S., Turatto, M., Walker, E. S., Young, D. R., Zhang, B., "SN 2009ip at late times – an interacting transient at +2 years", Monthly Notices of the Royal Astronomical Society, 453, 3886, 2015

Gentry, E. S., Marshall, H. L., Hardcastle, M. J., Perlman, E. S., Birkinshaw, M., Worrall, D. M., Lenc, E., Siemiginowska, A., Urry, C. M., "optical detection of the pictor a jet and tidal tail: evidence against an IC/CMB jet", The Astrophysical Journal, 808, 92, 2015

George, L. T., Dwarakanath, K. S., Johnston-Hollitt, M., Hurley-Walker, N., Hindson, L., Kapinska, A. D., Tingay, S. J., Bell, M., Callingham, J. R., For, B.-Q., Hancock, P. J., Lenc, E., McKinley, B., Morgan, J., Offringa, A., Procopio, P., Staveley-Smith, L., Wayth, R. B., Wu, C., Zheng, Q., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Corey, B. E., Deshpande, A. A., Emrich, D., Goeke, R., Greenhill, L. J., Hazelton, B. J., Kaplan, D. L., Kasper, J. C., Kratzenberg, E., Lonsdale, C. J., Lynch, M. J., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Ord, S. M., Prabu, T., Rogers, A. E. E., Roshi, A., Shankar, N. U., Srivani, K. S., Subrahmanyan, R., Waterson, M., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., "An analysis of the halo and relic radio emission from Abell 3376 from Murchison Widefield Array observations", Monthly Notices of the Royal Astronomical Society, 451, 4207, 2015

Gereb, K., Morganti, R., Oosterloo, T. A., Hoppmann, L., Staveley-Smith, L., "From star-forming galaxies to AGN: the global HI content from a stacking experiment", Astronomy and Astrophysics, 580, A43, 2015

Ghirlanda, G., Salvaterra, R., Campana, S., Vergani, S. D., Japelj, J., Bernardini, M. G., Burlon, D., D'Avanzo, P., Melandri, A., Gomboc, A., Nappo, F., Paladini, R., Pescalli, A., Salafia, O. S., Tagliaferri, G., "Unveiling the population of orphan gamma-ray bursts", Astronomy and Astrophysics, 578, A71, 2015

Greig, B., Bolton, J. S., Wyithe, J. S. B., "The impact of temperature fluctuations on the large-scale clustering of the Ly$\alpha$ forest", Monthly Notices of the Royal Astronomical Society, 447, 2503, 2015

Gronke, M., Dijkstra, M., Trenti, M., Wyithe, S., "Connecting faint-end slopes of the Lyman-alpha emitter and Lyman-break galaxy luminosity functions", Monthly Notices of the Royal Astronomical Society, 449, 1284, 2015

Holwerda, B. W., Keel, W. C., Kenworthy, M. A., Mack, K. J., "The dependence of the $A_V$ prior for SN Ia on host mass and disc inclination", Monthly Notices of the Royal Astronomical Society, 451, 2390, 2015

Hopkins, A. M., Whiting, M. T., Seymour, N., Chow, K. E., Norris, R. P., Bonavera, L., Breton, R., Carbone, D., Ferrari, C., Franzen, T. M. O., Garsden, H., Gonzalez-Nuevo, J., Hales, C. A., Hancock, P. J., Heald, G.,

Herranz, D., Huynh, M., Jurek, R. J., Lopez-Caniego, M., Massardi, M., Mohan, N., Molinari, S., Orru;, E., Paladino, R., Pestalozzi, M., Pizzo, R., Rafferty, D., Rottgering, H. J. A., Rudnick, L., Schisano, E., Shulevski, A., Swinbank, J., Taylor, R., van der Horst, A. J., "The ASKAP/EMU source finding data challenge", Publications of the Astronomical Society of Australia, 32, e037, 2015

Hoppmann, L., Staveley-Smith, L., Freudling, W., Zwaan, M. A., Minchin, R. F., Calabretta, M. R., "A blind H I mass function from the Arecibo Ultra-Deep Survey (AUDS)", Monthly Notices of the Royal Astronomical Society, 452, 3726, 2015

Howell, E. J., Rowlinson, A., Coward, D. M., Lasky, P. D., Kaplan, D. L., Thrane, E., Rowell, G., Galloway, D. K., Yuan, F., Dodson, R., Murphy, T., Hill, G. C., Andreoni, I., Spitler, L., Horton, A., "Hunting gravitational waves with multi-messenger counterparts: Australia's role", Publications of the Astronomical Society of Australia, 32, e046, 2015

Hurley-Walker, N., Johnston-Hollitt, M., Ekers, R., Hunstead, R., Sadler, E. M., Hindson, L., Hancock, P., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R., Corey, B., Deshpande, A. A., Emrich, D., Gaensler, B. M., Goeke, R., Greenhill, L., Hazelton, B. J., Hewitt, J., Kaplan, D. L., Kasper, J., Kratzenberg, E., Lonsdale, C., Lynch, M., Mitchell, D., McWhirter, R., Morales, M., Morgan, E., Oberoi, D., Offringa, A., Ord, S., Prabu, T., Rogers, A., Roshi, A., Shankar, U., Srivani, K., Subrahmanyan, R., Tingay, S., Waterson, M., Wayth, R. B., Webster, R., Whitney, A., Williams, A., Williams, C., "Serendipitous discovery of a dying Giant Radio Galaxy associated with NGC 1534, using the Murchison Widefield Array", Monthly Notices of the Royal Astronomical Society, 447, 2468, 2015

Johnson, M. C., Kamphuis, P., Koribalski, B. S., Wang, J., Oh, S.-H., Hill, A. S., O'Sullivan, S., Haan, S., Serra, P., "Blasting away a dwarf galaxy: the `tail' of ESO 324-G024", Monthly Notices of the Royal Astronomical Society, 451, 3192, 2015

Kamphuis, P., Jozsa, G. I. G., Oh, S.-. H., Spekkens, K., Urbancic, N., Serra, P., Koribalski, B. S., Dettmar, R.-J., "Automated kinematic modelling of warped galaxy discs in large H I surveys: 3D tilted-ring fitting of H I emission cubes", Monthly Notices of the Royal Astronomical Society, 452, 3139, 2015

Kaplan, D. L., Rowlinson, A., Bannister, K. W., Bell, M. E., Croft, S. D., Murphy, T., Tingay, S. J., Wayth, R. B., Williams, A., "A deep search for prompt radio emission from the short GRB 150424A with the Murchison Widefield Array", The Astrophysical Journal, 814, L25, 2015

Kaplan, D. L., Tingay, S. J., Manoharan, P. K., Macquart, J. P., Hancock, P., Morgan, J., Mitchell, D. A., Ekers, R. D., Wayth, R. B., Trott, C., Murphy, T., Oberoi, D., Cairns, I. H., Feng, L., Kudryavtseva, N., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Deshpande, A. A., Gaensler, B. M., Greenhill, L. J., Hurley Walker, N., Hazelton, B. J., Johnston Hollitt, M., Lonsdale, C. J., McWhirter, S. R., Morales, M. F., Morgan, E., Ord, S. M., Prabu, T., Udaya Shankar, N., Srivani, K. S., Subrahmanyan, R., Webster, R. L., Williams, A., Williams, C. L., "Murchison Widefield Array observations of anomalous aariability: a serendipitous night-time detection of interplanetary scintillation", The Astrophysical Journal, 809, L12, 2015

Karakas, A. I., Ruiter, A. J., Hampel, M., "R coronae borealis stars are viable factories of pre-solar grains", The Astrophysical Journal, 809, 184, 2015

Katsianis, A., Tescari, E., Wyithe, J. S. B., "The stellar mass function and star formation rate-stellar mass relation of galaxies at z ~ 4–7", Monthly Notices of the Royal Astronomical Society, 448, 3001, 2015

Keane, E. F., Petroff, E., "Fast radio bursts: search sensitivities and completeness", Monthly Notices of the Royal Astronomical Society, 447, 2852, 2015

Kessler, R., Marriner, J., Childress, M., Covarrubias, R., D'Andrea, C. B., Finley, D. A., Fischer, J., Foley, R. J., Goldstein, D., Gupta, R. R., Kuehn, K., Marcha, M., Nichol, R. C., Papadopoulos, A., Sako, M., Scolnic, D., Smith, M., Sullivan, M., Wester, W., Yuan, F., Abbott, T., Abdalla, F. B., Allam, S., Benoit-Levy, A., Bernstein, G. M., Bertin, E., Brooks, D., Carnero Rosell, A., Carrasco Kind, M., Castander, F. J., Crocce, M., da Costa, L. N., Desai, S., Diehl, H. T., Eifler, T. F., Fausti Neto, A., Flaugher, B., Frieman, J., Gerdes, D. W., Gruen, D., Gruendl, R. A., Honscheid, K., James, D. J., Kuropatkin, N., Li, T. S., Maia, M. A. G., Marshall, J. L., Martini, P., Miller, C. J., Miquel, R., Nord, B., Ogando, R., Plazas, A. A., Reil, K., Romer, A. K., Roodman, A., Sanchez, E., Sevilla-Noarbe, I., Smith, R. C., Soares-Santos, M., Sobreira, F., Tarle, G., Thaler, J., Thomas, R. C., Tucker, D., Walker, A. R., The DES Collaboration, "The difference imaging pipeline for the transient search in the dark energy survey", The Astronomical Journal, 150, 172, 2015

Kim, H.-S., Wyithe, J. S. B., Power, C., Park, J., Lagos, C. d. P., Baugh, C. M., "The H I mass function as a probe of photoionization feedback on low-mass galaxy formation", Monthly Notices of the Royal Astronomical Society, 453, 2315, 2015

Konstantopoulos, I. S., "The starfish diagram: visualising data within the context of survey samples", Astronomy and Computing, 10, 116, 2015

Kromer, M., Ohlmann, S. T., Pakmor, R., Ruiter, A. J., Hillebrandt, W., Marquardt, K. S., Ropke, F. K., Seitenzahl, I. R., Sim, S. A., Taubenberger, S., "Deflagrations in hybrid CONe white dwarfs: a route to explain the faint Type Iax supernova 2008ha", Monthly Notices of the Royal Astronomical Society, 450, 3045, 2015

Loi, S. T., Murphy, T., Bell, M. E., Kaplan, D. L., Lenc, E., Offringa, A. R., Hurley-Walker, N., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Corey, B. E., Deshpande, A. A., Emrich, D., Gaensler, B. M., Goeke, R., Greenhill, L. J., Hazelton, B. J., Johnston-Hollitt, M., Kasper, J. C., Kratzenberg, E., Lonsdale, C. J., Lynch, M. J., McWhirter, S. R., Mitchell, D. A.,

Morales, M. F., Morgan, E., Oberoi, D., Ord, S. M., Prabu, T., Rogers, A. E. E., Roshi, A., Shankar, N. U., Srivani, K. S., Subrahmanyan, R., Tingay, S. J., Waterson, M., Wayth, R. B., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., "Quantifying ionospheric effects on time-domain astrophysics with the Murchison Widefield Array", Monthly Notices of the Royal Astronomical Society, 453, 2731, 2015

Loi, S. T., Murphy, T., Cairns, I. H., Menk, F. W., Waters, C. L., Erickson, P. J., Trott, C. M., Hurley-Walker, N., Morgan, J., Lenc, E., Offringa, A. R., Bell, M. E., Ekers, R. D., Gaensler, B. M., Lonsdale, C. J., Feng, L., Hancock, P. J., Kaplan, D. L., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Deshpande, A. A., Greenhill, L. J., Hazelton, B. J., Johnston-Hollitt, M., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Ord, S. M., Prabu, T., Shankar, N. U., Srivani, K. S., Subrahmanyan, R., Tingay, S. J., Wayth, R. B., Webster, R. L., Williams, A., Williams, C. L., "Real-time imaging of density ducts between the plasmasphere and ionosphere", Geophysical Research Letters, 42, 3707, 2015

Loi, S. T., Trott, C. M., Murphy, T., Cairns, I. H., Bell, M., Hurley-Walker, N., Morgan, J., Lenc, E., Offringa, A. R., Feng, L., Hancock, P. J., Kaplan, D. L., Kudryavtseva, N., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Corey, B. E., Deshpande, A. A., Emrich, D., Gaensler, B. M., Goeke, R., Greenhill, L. J., Hazelton, B. J., Johnston-Hollitt, M., Kasper, J. C., Kratzenberg, E., Lonsdale, C. J., Lynch, M. J., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Ord, S. M., Prabu, T., Rogers, A. E. E., Roshi, A., Shankar, N. U., Srivani, K. S., Subrahmanyan, R., Tingay, S. J., Waterson, M., Wayth, R. B., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., "Power spectrum analysis of ionospheric fluctuations with the Murchison Widefield Array", Radio Science, 50, 574, 2015

Macquart, J.-P., Johnston, S., "On the paucity of fast radio bursts at low Galactic latitudes", Monthly Notices of the Royal Astronomical Society, 451, 3278, 2015

Macquart, J.-P., Kanekar, N., "On detecting millisecond pulsars at the galactic center", The Astrophysical Journal, 805, 172, 2015

Maio, U., Tescari, E., "Origin of cosmic chemical abundances", Monthly Notices of the Royal Astronomical Society, 453, 3798, 2015

Malarecki, J. M., Jones, D. H., Saripalli, L., Staveley-Smith, L., Subrahmanyan, R., "Giant radio galaxies – II. Tracers of large-scale structure", Monthly Notices of the Royal Astronomical Society, 449, 955, 2015

Marquardt, K. S., Sim, S. A., Ruiter, A. J., Seitenzahl, I. R., Ohlmann, S. T., Kromer, M., Pakmor, R., Ropke, F. K., "Type Ia supernovae from exploding oxygen-neon white dwarfs", Astronomy and Astrophysics, 580, A118, 2015

Matsuura, M., Dwek, E., Barlow, M. J., Babler, B., Baes, M., Meixner, M., Cernicharo, J., Clayton, G. C., Dunne, L., Fransson, C., Fritz, J., Gear, W., Gomez, H. L., Groenewegen, M. A. T., Indebetouw, R., Ivison, R. J., Jerkstrand, A., Lebouteiller, V., Lim, T. L., Lundqvist, P., Pearson, C. P., Roman-Duval, J., Royer, P., Staveley-Smith, L., Swinyard, B. M., van Hoof, P. A. M., van Loon, J. T., Verstappen, J., Wesson, R., Zanardo, G., Blommaert, J. A. D. L., Decin, L., Reach, W. T., Sonneborn, G., Van de Steene, G. C., Yates, J. A., "A stubbornly large mass of cold dust in the ejecta of supernova 1987A", The Astrophysical Journal, 800, 50, 2015

McElroy, R., Croom, S. M., Pracy, M., Sharp, R., Ho, I.-T., Medling, A. M., "IFU observations of luminous type II AGN – I. Evidence for ubiquitous winds", Monthly Notices of the Royal Astronomical Society, 446, 2186, 2015

McKinley, B., Yang, R., Lopez-Caniego, M., Briggs, F., Hurley-Walker, N., Wayth, R. B., Offringa, A. R., Crocker, R., Bernardi, G., Procopio, P., Gaensler, B. M., Tingay, S. J., Johnston-Hollitt, M., McDonald, M., Bell, M., Bhat, N. D. R., Bowman, J. D., Cappallo, R. J., Corey, B. E., Deshpande, A. A., Emrich, D., Ewall-Wice, A., Feng, L., Goeke, R., Greenhill, L. J., Hazelton, B. J., Hewitt, J. N., Hindson, L., Jacobs, D., Kaplan, D. L., Kasper, J. C., Kratzenberg, E., Kudryavtseva, N., Lenc, E., Lonsdale, C. J., Lynch, M. J., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Ord, S. M., Pindor, B., Prabu, T., Riding, J., Rogers, A. E. E., Roshi, D. A., Udaya Shankar, N., Srivani, K. S., Subrahmanyan, R., Waterson, M., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., "Modelling of the spectral energy distribution of Fornax A: leptonic and hadronic production of high-energy emission from the radio lobes", Monthly Notices of the Royal Astronomical Society, 446, 3478, 2015

Moldon, J., Deller, A. T., Wucknitz, O., Jackson, N., Drabent, A., Carozzi, T., Conway, J., Kapinska, A. D., McKean, J. P., Morabito, L., Varenius, E., Zarka, P., Anderson, J., Asgekar, A., Avruch, I. M., Bell, M. E., Bentum, M. J., Bernardi, G., Best, P., Birzan, L., Bregman, J., Breitling, F., Broderick, J. W., Bruggen, M., Butcher, H. R., Carbone, D., Ciardi, B., de Gasperin, F., de Geus, E., Duscha, S., Eisloffel, J., Engels, D., Falcke, H., Fallows, R. A., Fender, R., Ferrari, C., Frieswijk, W., Garrett, M. A., Griebmeier, J., Gunst, A. W., Hamaker, J. P., Hassall, T. E., Heald, G., Hoeft, M., Juette, E., Karastergiou, A., Kondratiev, V. I., Kramer, M., Kuniyoshi, M., Kuper, G., Maat, P., Mann, G., Markoff, S., McFadden, R., McKay-Bukowski, D., Morganti, R., Munk, H., Norden, M. J., Offringa, A. R., Orru, E., Paas, H., Pandey-Pommier, M., Pizzo, R., Polatidis, A. G., Reich, W., Rottgering, H., Rowlinson, A., Scaife, A. M. M., Schwarz, D., Sluman, J., Smirnov, O., Stappers, B. W., Steinmetz, M., Tagger, M., Tang, Y., Tasse, C., Thoudam, S., Toribio, M. C., Vermeulen, R., Vocks, C., van Weeren, R. J., White, S., Wise, M. W., Yatawatta, S., Zensus, A., "The LOFAR long baseline snapshot calibrator survey", Astronomy and Astrophysics, 574, A73, 2015

Mould, J., Colless, M., Erdogdu, P., Jones, H., Lucey, J., Ma, Y.-Z., Magoulas, C., Springob, C. M., "Modified

gravity and large scale flows", Astrophysics and Space Science, 357, 162, 2015

Murphy, T., Bell, M. E., Kaplan, D. L., Gaensler, B. M., Offringa, A. R., Lenc, E., Hurley-Walker, N., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Corey, B. E., Deshpande, A. A., Emrich, D., Goeke, R., Greenhill, L. J., Hazelton, B. J., Hewitt, J. N., Johnston-Hollitt, M., Kasper, J. C., Kratzenberg, E., Lonsdale, C. J., Lynch, M. J., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Ord, S. M., Prabu, T., Rogers, A. E. E., Roshi, D. A., Shankar, N. U., Srivani, K. S., Subrahmanyan, R., Tingay, S. J., Waterson, M., Wayth, R. B., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., "Limits on low-frequency radio emission from southern exoplanets with the Murchison Widefield Array", Monthly Notices of the Royal Astronomical Society, 446, 2560, 2015

Musaeva, A., Koribalski, B. S., Farrell, S. A., Sadler, E. M., Servillat, M., Jurek, R., Lenc, E., Starling, R. L. C., Webb, N. A., Godet, O., Combes, F., Barret, D., "H I study of the environment around ESO 243–49, the host galaxy of an intermediate-mass black hole", Monthly Notices of the Royal Astronomical Society, 447, 1951, 2015

Nelles, A., Schellart, P., Buitink, S., Corstanje, A., de Vries, K. D., Enriquez, J. E., Falcke, H., Frieswijk, W., Horandel, J. R., Scholten, O., ter Veen, S., Thoudam, S., van den Akker, M., Anderson, J., Asgekar, A., Bell, M. E., Bentum, M. J., Bernardi, G., Best, P., Bregman, J., Breitling, F., Broderick, J., Brouw, W. N., Bruggen, M., Butcher, H. R., Ciardi, B., Deller, A., Duscha, S., Eisloffel, J., Fallows, R. A., Garrett, M. A., Gunst, A. W., Hassall, T. E., Heald, G., Horneffer, A., Iacobelli, M., Juette, E., Karastergiou, A., Kondratiev, V. I., Kramer, M., Kuniyoshi, M., Kuper, G., Maat, P., Mann, G., Mevius, M., Norden, M. J., Paas, H., Pandey-Pommier, M., Pietka, G., Pizzo, R., Polatidis, A. G., Reich, W., Rottgering, H., Scaife, A. M. M., Schwarz, D., Smirnov, O., Stappers, B. W., Steinmetz, M., Stewart, A.,Tagger, M., Tang, Y., Tasse, C., Vermeulen, R., Vocks, C., van Weeren, R. J., Wijnholds, S. J., Wucknitz, O., Yatawatta, S., Zarka, P., "Measuring a Cherenkov ring in the radio emission from air showers at 110–190 MHz with LOFAR", Astroparticle Physics, 65, 11, 2015

Ng, C., Champion, D. J., Bailes, M., Barr, E. D., Bates, S. D., Bhat, N. D. R., Burgay, M., Burke-Spolaor, S., Flynn, C. M. L., Jameson, A., Johnston, S., Keith, M. J., Kramer, M., Levin, L., Petroff, E., Possenti, A., Stappers, B. W., van Straten, W., Tiburzi, C., Eatough, R. P., Lyne, A. G., "The high time resolution universe pulsar survey - XII. Galactic plane acceleration search and the discovery of 60 pulsars", Monthly Notices of the Royal Astronomical Society, 450, 2922, 2015

Nicholl, M., Smartt, S. J., Jerkstrand, A., Inserra, C., Sim, S. A., Chen, T.-W., Benetti, S., Fraser, M., Gal-Yam, A., Kankare, E., Maguire, K., Smith, K., Sullivan, M., Valenti, S., Young, D. R., Baltay, C., Bauer, F. E., Baumont, S., Bersier, D., Botticella, M.-T., Childress, M., Dennefeld, M., Della Valle, M., Elias-Rosa, N., Feindt, U., Galbany, L., Hadjiyska, E., Le Guillou, L., Leloudas, G., Mazzali, P., McKinnon, R., Polshaw, J., Rabinowitz, D., Rostami, S., Scalzo, R., Schmidt, B. P., Schulze, S., Sollerman, J., Taddia, F., Yuan, F., "On the diversity of superluminous supernovae: ejected mass as the dominant factor", Monthly Notices of the Royal Astronomical Society, 452, 3869, 2015

Noutsos, A., Sobey, C., Kondratiev, V. I., Weltevrede, P., Verbiest, J. P. W., Karastergiou, A., Kramer, M., Kuniyoshi, M., Alexov, A., Breton, R. P., Bilous, A. V., Cooper, S., Falcke, H., Griebmeier, J.-M., Hassall, T. E., Hessels, J. W. T., Keane, E. F., Oslowski, S., Pilia, M., Serylak, M., Stappers, B. W., ter Veen, S., van Leeuwen, J., Zagkouris, K., Anderson, K., Bahren, L., Bell, M., Broderick, J., Carbone, D., Cendes, Y., Coenen, T., Corbel, S., Eisloffel, J., Fender, R., Garsden, H., Jonker, P., Law, C., Markoff, S., Masters, J., Miller-Jones, J., Molenaar, G., Osten, R., Pietka, M., Rol, E., Rowlinson, A., Scheers, B., Spreeuw, H., Staley, T., Stewart, A., Swinbank, J., Wijers, R., Wijnands, R., Wise, M., Zarka, P., van der Horst, A., "Pulsar polarisation below 200 MHz: Average profiles and propagation effects", Astronomy and Astrophysics, 576, A62, 2015

Obreschkow, D., Glazebrook, K., Bassett, R., Fisher, D. B., Abraham, R. G., Wisnioski, E., Green, A. W., McGregor, P. J., Damjanov, I., Popping, A., Jorgensen, I., "Low angular momentum in clumpy, turbulent disk galaxies", The Astrophysical Journal, 815, 97, 2015

Offringa, A. R., Wayth, R. B., Hurley-Walker, N., Kaplan, D. L., Barry, N., Beardsley, A. P., Bell, M. E., Bernardi, G., Bowman, J. D., Briggs, F., Callingham, J. R., Cappallo, R. J., Carroll, P., Deshpande, A. A., Dillon, J. S., Dwarakanath, K. S., Ewall-Wice, A., Feng, L., For, B.-Q., Gaensler, B. M., Greenhill, L. J., Hancock, P., Hazelton, B. J., Hewitt, J. N., Hindson, L., Jacobs, D. C., Johnston-Hollitt, M., Kapinska, A. D., Kim, H.-S., Kittiwisit, P., Lenc, E., Line, J., Loeb, A., Lonsdale, C. J., McKinley, B., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Morgan, J., Neben, A. R., Oberoi, D., Ord, S. M., Paul, S., Pindor, B., Pober, J. C., Prabu, T., Procopio, P., Riding, J., Udaya Shankar, N., Sethi, S., Srivani, K. S., Staveley-Smith, L., Subrahmanyan, R., Sullivan, I. S., Tegmark, M., Thyagarajan, N., Tingay, S. J., Trott, C. M., Webster, R. L., Williams, A., Williams, C. L., Wu, C., Wyithe, J. S., Zheng, Q., "The low-frequency environment of the Murchison Widefield Array: radio-frequency interference analysis and mitigation", Publications of the Astronomical Society of Australia, 32, e008, 2015

Oh, S.-H., Hunter, D. A., Brinks, E., Elmegreen, B. G., Schruba, A., Walter, F., Rupen, M. P., Young, L. M., Simpson, C. E., Johnson, M. C., Herrmann, K. A., Ficut-Vicas, D., Cigan, P., Heesen, V., Ashley, T., Zhang, H.-X.,"High-resolution mass models of dwarf galaxies from LITTLE THINGS", The Astronomical Journal, 149, 180, 2015

Ord, S. M., Crosse, B., Emrich, D., Pallot, D., Wayth, R. B., Clark, M. A., Tremblay, S. E., Arcus, W., Barnes, D., Bell, M., Bernardi, G., Bhat, N. D. R., Bowman, J. D., Briggs, F., Bunton, J. D., Cappallo, R. J., Corey, B. E., Deshpande, A. A., deSouza, L., Ewell-Wice, A., Feng, L., Goeke, R., Greenhill, L. J., Hazelton, B. J., Herne, D., Hewitt, J. N., Hindson, L., Hurley-Walker, N., Jacobs, D., Johnston-Hollitt, M., Kaplan, D. L., Kasper, J. C., Kincaid, B. B., Koenig, R., Kratzenberg, E., Kudryavtseva, N., Lenc, E., Lonsdale, C. J., Lynch, M. J., McKinley, B., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Offringa, A., Pathikulangara, J., Pindor, B., Prabu, T., Procopio, P., Remillard, R. A., Riding, J., Rogers, A. E. E., Roshi, A., Salah, J. E., Sault, R. J., Udaya Shankar, N., Srivani, K. S., Stevens, J., Subrahmanyan, R., Tingay, S. J., Waterson, M., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., Wyithe, J. S. B., "The Murchison Widefield Array correlator", Publications of the Astronomical Society of Australia, 32, e006, 2015

Oronsaye, S. I., Ord, S. M., Bhat, N. D. R., Tremblay, S. E., McSweeney, S. J., Tingay, S. J., van Straten, W., Jameson, A., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Deshpande, A. A., Greenhill, L. J., Hazelton, B. J., Johnston-Hollitt, M., Kaplan, D. L., Lonsdale, C. J., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Prabu, T., Udaya Shankar, N., Srivani, K. S., Subrahmanyan, R., Wayth, R. B., Webster, R. L., Williams, A., Williams, C. L., "Simultaneous observations of giant pulses from the crab pulsar, with the Murchison Widefield Array and Parkes Radio Telescope: implications for the giant pulse emission mechanism.", The Astrophysical Journal, 809, 51, 2015

O'Sullivan, S. P., Gaensler, B. M., Lara-Lopez, M. A., van Velzen, S., Banfield, J. K., Farnes, J. S., "The magnetic field and polarization properties of radio galaxies in different accretion states", The Astrophysical Journal, 806, 83, 2015

Petroff, E., Bailes, M., Barr, E. D., Barsdell, B. R., Bhat, N. D. R., Bian, F., Burke-Spolaor, S., Caleb, M., Champion, D., Chandra, P., Da Costa, G., Delvaux, C., Flynn, C., Gehrels, N., Greiner, J., Jameson, A., Johnston, S., Kasliwal, M. M., Keane, E. F., Keller, S., Kocz, J., Kramer, M., Leloudas, G., Malesani, D., Mulchaey, J. S., Ng, C., Ofek, E. O., Perley, D. A., Possenti, A., Schmidt, B. P., Shen, Y., Stappers, B., Tisserand, P., van Straten, W., Wolf, C., "A real-time fast radio burst: polarization detection and multiwavelength follow-up", Monthly Notices of the Royal Astronomical Society, 447, 246, 2015

Petroff, E., Johnston, S., Keane, E. F., van Straten, W., Bailes, M., Barr, E. D., Barsdell, B. R., Burke-Spolaor, S., Caleb, M., Champion, D. J., Flynn, C., Jameson, A., Kramer, M., Ng, C., Possenti, A., Stappers, B. W., "A survey of FRB fields: limits on repeatability", Monthly Notices of the Royal Astronomical Society, 454, 457, 2015

Petroff, E., Keane, E. F., Barr, E. D., Reynolds, J. E., Sarkissian, J., Edwards, P. G., Stevens, J., Brem, C., Jameson, A., Burke-Spolaor, S., Johnston, S., Bhat, N. D. R., Kudale, P. C. S., Bhandari, S., "Identifying the source of perytons at the Parkes radio telescope", Monthly Notices of the Royal Astronomical Society, 451, 3933, 2015

Pietka, M., Fender, R. P., Keane, E. F., "The variability time-scales and brightness temperatures of radio flares from stars to supermassive black holes", Monthly Notices of the Royal Astronomical Society, 446, 3687, 2015

Prabu, T., Srivani, K. S., Roshi, D. A., Kamini, P. A., Madhavi, S., Emrich, D., Crosse, B., Williams, A. J., Waterson, M., Deshpande, A. A., Shankar, N. U., Subrahmanyan, R., Briggs, F. H., Goeke, R. F., Tingay, S. J., Johnston-Hollitt, M., R, G. M., Morgan, E. H., Pathikulangara, J., Bunton, J. D., Hampson, G., Williams, C., Ord, S. M., Wayth, R. B., Kumar, D., Morales, M. F., deSouza, L., Kratzenberg, E., Pallot, D., McWhirter, R., Hazelton, B. J., Arcus, W., Barnes, D. G., Bernardi, G., Booler, T., Bowman, J. D., Cappallo, R. J., Corey, B. E., Greenhill, L. J., Herne, D., Hewitt, J. N., Kaplan, D. L., Kasper, J. C., Kincaid, B. B., Koenig, R., Lonsdale, C. J., Lynch, M. J., Mitchell, D. A., Oberoi, D., Remillard, R. A., Rogers, A. E., Salah, J. E., Sault, R. J., Stevens, J. B., Tremblay, S., Webster, R. L., Whitney, A. R., Wyithe, S. B., "A digital-receiver for the Murchison Widefield Array", Experimental Astronomy, 39, 73, 2015

Purcell, C. R., Gaensler, B. M., Sun, X. H., Carretti, E., Bernardi, G., Haverkorn, M., Kesteven, M. J., Poppi, S., Schnitzeler, D. H. F. M., Staveley-Smith, L., "A radio-polarisation and rotation measure study of the gum nebula and its environment", The Astrophysical Journal, 804, 22, 2015

Raccanelli, A., Dore, O., Bacon, D. J., Maartens, R., Santos, M. G., Camera, S., Davis, T. M., Drinkwater, M. J., Jarvis, M., Norris, R., Parkinson, D., "Probing primordial non-gaussianity via iSW measurements with SKA continuum surveys", Journal of Cosmology and Astro-Particle Physics, 1, 042, 2015

Reeves, S. N., Sadler, E. M., Allison, J. R., Koribalski, B. S., Curran, S. J., Pracy, M. B., "H I emission and absorption in nearby, gas-rich galaxies", Monthly Notices of the Royal Astronomical Society, 450, 926, 2015

Riemer-Sorensen, S., Webb, J. K., Crighton, N., Dumont, V., Ali, K., Kotus, S., Bainbridge, M., Murphy, M. T., Carswell, R., "A robust deuterium abundance; re-measurement of the z = 3.256 absorption system towards the quasar PKS 1937-101", Monthly Notices of the Royal Astronomical Society, 447, 2925, 2015

Ryon, J. E., Bastian, N., Adamo, A., Konstantopoulos, I. S., Gallagher, J. S., Larsen, S., Hollyhead, K., Silva-Villa, E., Smith, L. J., "Sizes and shapes of young star cluster light profiles in M83", Monthly Notices of the Royal Astronomical Society, 452, 525, 2015

Schon, S., Mack, K. J., Avram, C. A., Wyithe, J. S. B., Barberio, E., "Dark matter annihilation in the first galaxy haloes", Monthly Notices of the Royal Astronomical Society, 451, 2840, 2015

Scott, N., Fogarty, L. M. R., Owers, M. S., Croom, S. M., Colless, M., Davies, R. L., Brough, S., Pracy, M. B., Bland-Hawthorn, J., Jones, D. H., Allen, J. T., Bryant, J. J., Cortese, L., Goodwin, M., Green, A. W., Konstantopoulos, I. S., Lawrence, J. S., Richards, S., Sharp, R., "The SAMI pilot survey: the fundamental and mass planes in three low-redshift clusters", Monthly Notices of the Royal Astronomical Society, 451, 2723, 2015

Seitenzahl, I. R., Herzog, M., Ruiter, A. J., Marquardt, K., Ohlmann, S. T., Ropke, F. K., "Neutrino and gravitational wave signal of a delayed-detonation model of type Ia supernovae", Physical Review D, 92, 124013, 2015

Serra, P., Koribalski, B., Kilborn, V., Allison, J. R., Amy, S. W., Ball, L., Bannister, K., Bell, M. E., Bock, D. C.-J., Bolton, R., Bowen, M., Boyle, B., Broadhurst, S., Brodrick, D., Brothers, M., Bunton, J. D., Chapman, J., Cheng, W., Chippendale, A. P., Chung, Y., Cooray, F., Cornwell, T., DeBoer, D., Diamond, P., Forsyth, R., Gough, R., Gupta, N., Hampson, G. A., Harvey-Smith, L., Hay, S., Hayman, D. B., Heywood, I., Hotan, A. W., Hoyle, S., Humphreys, B., Indermuehle, B., Jacka, C., Jackson, C. A., Jackson, S., Jeganathan, K., Johnston, S., Joseph, J., Kamphuis, P., Leach, M., Lenc, E., Lensson, E., Mackay, S., Marquarding, M., Marvil, J., McClure-Griffiths, N., McConnell, D., Meyer, M., Mirtschin, P., Neuhold, S., Ng, A., Norris, R. P., O'Sullivan, J., Pathikulangara, J., Pearce, S., Phillips, C., Popping, A., Qiao, R. Y., Reynolds, J. E., Roberts, P., Sault, R. J., Schinckel, A. E. T., Shaw, R., Shimwell, T. W., Staveley-Smith, L., Storey, M., Sweetnam, A. W., Troup, E., Tzioumis, A., Voronkov, M. A., Westmeier, T., Whiting, M., Wilson, C., Wong, O. I., Wu, X., "ASKAP H I imaging of the galaxy group IC 1459", Monthly Notices of the Royal Astronomical Society, 452, 2680, 2015

Serra, P., Westmeier, T., Giese, N., Jurek, R., Floer, L., Popping, A., Winkel, B., van der Hulst, T., Meyer, M., Koribalski, B. S., Staveley-Smith, L., Courtois, H., "SOFIA: a flexible source finder for 3D spectral line data", Monthly Notices of the Royal Astronomical Society, 448, 1922, 2015

Sharp, R., Allen, J. T., Fogarty, L. M. R., Croom, S. M., Cortese, L., Green, A. W., Nielsen, J., Richards, S. N., Scott, N., Taylor, E. N., Barnes, L. A., Bauer, A. E., Birchall, M., Bland-Hawthorn, J., Bloom, J. V., Brough, S., Bryant, J. J., Cecil, G. N., Colless, M., Couch, W. J., Drinkwater, M. J., Driver, S., Foster, C., Goodwin, M., Gunawardhana, M. L. P., Ho, I.-T., Hampton, E. J., Hopkins, A. M., Jones, H., Konstantopoulos, I. S., Lawrence, J. S., Leslie, S. K., Lewis, G. F., Liske, J., Lopez-Sanche,. R., Lorente, N. P. F., McElroy, R., Medling, A. M., Mahajan, S., Mould, J., Parker, Q., Pracy, M. B., Obreschkow, D., Owers, M. S., Schaefer, A. L., Sweet, S. M., Thomas, A. D., Tonini, C., Walcher, C. J., "The SAMI Galaxy Survey: cubism and covariance, putting round pegs into square holes", Monthly Notices of the Royal Astronomical Society, 446, 1551, 2015

Smartt, S. J., Valenti, S., Fraser, M., Inserra, C., Young, D. R., Sullivan, M., Pastorello, A., Benetti, S., Gal-Yam, A., Knapic, C., Molinaro, M., Smareglia, R., Smith, K. W., Taubenberger, S., Yaron, O., Anderson, J. P., Ashall, C., Balland, C., Baltay, C., Barbarino, C., Bauer, F. E., Baumont, S., Bersier, D., Blagorodnova, N., Bongard, S., Botticella, M. T., Bufano, F., Bulla, M., Cappellaro, E., Campbell, H., Cellier-Holzem, F., Chen, T.-W., Childress, M. J., Clocchiatti, A., Contreras, C., Dall'Ora, M., Danziger, J., de Jaeger, T., De Cia, A., Della Valle, M., Dennefeld, M., Elias-Rosa, N., Elman, N., Feindt, U., Fleury, M., Gall, E., Gonzalez-Gaitan, S., Galbany, L., Morales Garoffolo, A., Greggio, L., Guillou, L. L., Hachinger, S., Hadjiyska, E., Hage, P. E., Hillebrandt, W., Hodgkin, S., Hsiao, E. Y., James, P. A., Jerkstrand, A., Kangas, T., Kankare, E., Kotak, R., Kromer, M., Kuncarayakti, H., Leloudas, G., Lundqvist, P., Lyman, J. D., Hook, I. M., Maguire, K., Manulis, I., Margheim, S. J., Mattila, S., Maund, J. R., Mazzali, P. A., McCrum, M., McKinnon, R., Moreno-Raya, M. E., Nicholl, M., Nugent, P., Pain, R., Pignata, G., Phillips, M. M., Polshaw, J., Pumo, M. L., Rabinowitz, D., Reilly, E., Romero-Canizales, C., Scalzo, R., Schmidt, B., Schulze, S., Sim, S., Sollerman, J., Taddia, F., Tartaglia, L., Terreran, G., Tomasella, L., Turatto, M., Walker, E., Walton, N. A., Wyrzykowski, L., Yuan, F., Zampieri, L., "PESSTO: survey description and products from the first data release by the Public ESO Spectroscopic Survey of Transient Objects", Astronomy and Astrophysics, 579, A40, 2015

Smith, R., Flynn, C., Candlish, G. N., Fellhauer, M., Gibson, B. K., "Simple and accurate modelling of the gravitational potential produced by thick and thin exponential discs", Monthly Notices of the Royal Astronomical Society, 448, 2934, 2015

Sobey, C., Young, N. J., Hessels, J. W. T., Weltevrede, P., Noutsos, A., Stappers, B. W., Kramer, M., Bassa, C., Lyne, A. G., Kondratiev, V. I., Hassall, T. E., Keane, E. F., Bilous, A. V., Breton, R. P., Griebmeier, J.-M., Karastergiou, A., Pilia, M., Serylak, M., Veen, S. t., van Leeuwen, J., Alexov, A., Anderson, J., Asgekar, A., Avruch, I. M., Bell, M. E., Bentum, M. J., Bernardi, G., Best, P., Birzan, L., Bonafede, A., Breitling, F., Broderick, J., Bruggen, M., Corstanje, A., Carbone, D., de Geus, E., de Vos, M., van Duin, A., Duscha, S., Eisloffel, J., Falcke, H., Fallows, R. A., Fender, R., Ferrari, C., Frieswijk, W., Garrett, M. A., Gunst, A. W., Hamaker, J. P., Heald, G., Hoeft, M., Horandel, J., Jutte, E., Kuper, G., Maat, P., Mann, G., Markoff, S., McFadden, R., McKay-Bukowski, D., McKean, J. P., Mulcahy, D. D., Munk, H., Nelles, A., Norden, M. J., Orru;, E., Paas, H., Pandey-Pommier, M., Pandey, V. N., Pietka, G., Pizzo, R., Polatidis, A. G., Rafferty, D., Renting, A., Rottgering, H., Rowlinson, A., Scaife, A. M. M., Schwarz, D., Sluman, J., Smirnov, O., Steinmetz, M., Stewart, A., Swinbank, J., Tagger, M., Tang, Y., Tasse, C., Thoudam, S., Toribio, C., Vermeulen, R., Vocks, C., van Weeren, R. J., Wijers, R. A. M. J., Wise, M. W., Wucknitz, O., Yatawatta, S., Zarka, P., "LOFAR discovery of a quiet emission mode in PSR B0823+26", Monthly Notices of the Royal Astronomical Society, 451, 2493, 2015

Sokolowski, M., Tremblay, S. E., Wayth, R. B., Tingay, S. J., Clarke, N., Roberts, P., Waterson, M., Ekers, R. D., Hall, P., Lewis, M., Mossammaparast, M., Padhi, S., Schlagenhaufer, F., Sutinjo, A., Tickner, J., "BIGHORNS – Broadband Instrument for Global HydrOgen ReioNisation Signal", Publications of the Astronomical Society of Australia, 32, e004, 2015

Sokolowski, M., Wayth, R. B., Tremblay, S. E., Tingay, S. J., Waterson, M., Tickner, J., Emrich, D., Schlagenhaufer, F., Kenney, D., Padhi, S., "The impact of the ionosphere on ground-based detection of the global epoch of reionization signal", The Astrophysical Journal, 813, 18, 2015

Taubenberger, S., Elias-Rosa, N., Kerzendorf, W. E., Hachinger, S., Spyromilio, J., Fransson, C., Kromer, M., Ruiter, A. J., Seitenzahl, I. R., Benetti, S., Cappellaro, E., Pastorello, A., Turatto, M., Marchetti, A., "Spectroscopy of the Type Ia supernova 2011fe past 1000 d", Monthly Notices of the Royal Astronomical Society, 448, L48, 2015

Tingay, S. J., Macquart, J.-P., Collier, J. D., Rees, G., Callingham, J. R., Stevens, J., Carretti, E., Wayth, R. B., Wong, G. F., Trott, C. M., McKinley, B., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Corey, B. E., Deshpande, A. A., Emrich, D., Gaensler, B. M., Goeke, R., Greenhill, L. J., Hazelton, B. J., Johnston-Hollitt, M., Kaplan, D. L., Kasper, J. C., Kratzenberg, E., Lonsdale, C. J., Lynch, M. J., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Ord, S. M., Prabu, T., Rogers, A. E. E., Roshi, A., Udaya Shankar, N., Srivani, K. S., Subrahmanyan, R., Waterson, M., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., "The spectral variability of the GHz-peaked spectrum radio source PKS 1718−649 and a comparison of absorption models", The Astronomical Journal, 149, 74, 2015

Tingay, S. J., Trott, C. M., Wayth, R. B., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Deshpande, A. A., Feng, L., Gaensler, B. M., Greenhill, L. J., Hancock, P. J., Hazelton, B. J., Johnston-Hollitt, M., Kaplan, D. L., Lonsdale, C. J., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Murphy, T., Oberoi, D., Prabu, T., Udaya Shankar, N., Srivani, K. S., Subrahmanyan, R., Webster, R. L., Williams, A., Williams, C. L., "A search for fast radio bursts at low frequencies with Murchison Widefield Array high time resolution imaging", The Astronomical Journal, 150, 199, 2015

Tremblay, S. E., Ord, S. M., Bhat, N. D. R., Tingay, S. J., Crosse, B., Pallot, D., Oronsaye, S. I., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Corey, B. E., Deshpande, A. A., Emrich, D., Goeke, R., Greenhill, L. J., Hazelton, B. J., Johnston-Hollitt, M., Kaplan, D. L., Kasper, J. C., Kratzenberg, E., Lonsdale, C. J., Lynch, M. J., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Prabu, T., Rogers, A. E. E., Roshi, A., Udaya Shankar, N., Srivani, K. S., Subrahmanyan, R., Waterson, M., Wayth, R. B., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., "The high time and frequency resolution capabilities of the Murchison Widefield Array", Publications of the Astronomical Society of Australia, 32, e005, 2015

Valenti, S., Sand, D., Stritzinger, M., Howell, D. A., Arcavi, I., McCully, C., Childress, M. J., Hsiao, E. Y., Contreras, C., Morrell, N., Phillips, M. M., Gromadzki, M., Kirshner, R. P., Marion, G. H., "Supernova 2013by: a Type IIL supernova with a IIP-like light-curve drop, Monthly Notices of the Royal Astronomical Society, 448, 2608, 2015

Wayth, R. B., Lenc, E., Bell, M. E., Callingham, J. R., Dwarakanath, K. S., Franzen, T. M. O., For, B.-Q., Gaensler, B., Hancock, P., Hindson, L., Hurley-Walker, N., Jackson, C. A., Johnston-Hollitt, M., Kapinska, A. D., McKinley, B., Morgan, J., Offringa, A. R., Procopio, P., Staveley-Smith, L., Wu, C., Zheng, Q., Trott, C. M., Bernardi, G., Bowman, J. D., Briggs, F., Cappallo, R. J., Corey, B. E., Deshpande, A. A., Emrich, D., Goeke, R., Greenhill, L. J., Hazelton, B. J., Kaplan, D. L., Kasper, J. C., Kratzenberg, E., Lonsdale, C. J., Lynch, M. J., McWhirter, S. R., Mitchell, D. A., Morales, M. F., Morgan, E., Oberoi, D., Ord, S. M., Prabu, T., Rogers, A. E. E., Roshi, A., Shankar, N. U., Srivani, K. S., Subrahmanyan, R., Tingay, S. J., Waterson, M., Webster, R. L., Whitney, A. R., Williams, A., Williams, C. L., "GLEAM: The GaLactic and Extragalactic All-Sky MWA Survey", Publications of the Astronomical Society of Australia, 32, e025, 2015

Westmeier, T., Staveley-Smith, L., Calabretta, M., Jurek, R., Koribalski, B. S., Meyer, M., Popping, A., Wong, O. I., "On the neutral gas content of nine new Milky Way satellite galaxy candidates", Monthly Notices of the Royal Astronomical Society, 453, 338, 2015

Yu, Y., Zhang, P., Lin, W., Cui, W., "The source-lens clustering effect in the context of lensing tomography and its self-calibration", The Astrophysical Journal, 803, 46, 2015

Yuan, F., Lidman, C., Davis, T. M., Childress, M., Abdalla, F. B., Banerji, M., Buckley-Geer, E., Carnero Rosell, A., Carollo, D., Castander, F. J., D'Andrea, C. B., Diehl, H. T., Cunha, C. E., Foley, R. J., Frieman, J., Glazebrook, K., Gschwend, J., Hinton, S., Jouvel, S., Kessler, R., Kim, A. G., King, A. L., Kuehn, K., Kuhlmann, S., Lewis, G. F., Lin, H., Martini, P., McMahon, R. G., Mould, J., Nichol, R. C., Norris, R. P., O'Neill, C. R., Ostrovski, F., Papadopoulos, A., Parkinson, D., Reed, S., Romer, A. K., Rooney, P. J., Rozo, E., Rykoff, E. S., Sako, M., Scalzo, R., Schmidt, B. P., Scolnic, D., Seymour, N., Sharp, R., Sobreira, F., Sullivan, M., Thomas, R. C., Tucker, D., Uddin, S. A., Wechsler, R. H., Wester, W., Wilcox, H., Zhang, B., Abbott, T., Allam, S., Bauer, A. H., Benoit-Levy, A., Bertin, E., Brooks, D., Burke, D. L., Carrasco Kind, M., Covarrubias, R., Crocce, M., da Costa, L. N., DePoy, D. L., Desai, S., Doel, P., Eifler, T. F., Evrard, A. E., Fausti Neto, A., Flaugher, B., Fosalba, P., Gaztanaga, E., Gerdes, D., Gruen, D., Gruendl, R. A., Honscheid, K., James, D., Kuropatkin, N., Lahav, O., Li, T. S., Maia, M. A. G., Makler, M., Marshall, J., Miller, C. J., Miquel, R., Ogando, R., Plazas, A. A., Roodman, A., Sanchez, E.,

Scarpine, V., Schubnell, M., Sevilla-Noarbe, I., Smith, R. C., Soares-Santos, M., Suchyta, E., Swanson, M. E. C., Tarle, G., Thaler, J., Walker, A. R., "OzDES multifibre spectroscopy for the Dark Energy Survey: first-year operation and results", Monthly Notices of the Royal Astronomical Society, 452, 3047, 2015

## Proceedings of Science

Antoniadis, J., Guillemot, L., Possenti, A., Bogdanov, S., Gelfand, J., Kramer, M., Mignani, R., Stappers, B., Torne, P., "Multi-wavelength, multi-messenger pulsar science in the SKA era", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 157, 2015

Bignall, H. E., Croft, S., Hovatta, T., Koay, J. Y., Lazio, J., Macquart, J. P., Reynolds, C., "Time domain studies of active aalactic nuclei with the Square Kilometre Array", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 58, 2015

Blyth, S., van der Hulst, T. M., Verheijen, M. A. W., Catinella, B., Fraternali, F., Haynes, M. P., Hess, K. M., Koribalski, B., Lagos, C., Meyer, M., Obreschkow, D., Popping, A., Power, C., Verdes-Montenegro, L. L., Zwaan, M., "Exploring neutral hydrogen and galaxy evolution with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 128, 2015

Braun, R., Bourke, T., Green, J. A., Keane, E., Wagg, J., "Advancing Astrophysics with the Square Kilometre Array", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 174, 2015

Bull, P., Camera, S., Raccanelli, A., Blake, C., Ferreira, P., Santos, M., Schwarz, D. J., 2015, "Measuring baryon acoustic oscillations with future SKA surveys", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 24, 2015

Burlon, D., Ghirlanda, G., van der Horst, A., Murphy, T., Wijers, R. A. M. J., Gaensler, B., Ghisellini, G., Prandoni, I., "The SKA view of gamma-ray bursts", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 52, 2015

Ciardi, B., Inoue, S., Mack, K., Xu, Y., Bernardi, G., 2015, "21-cm forest with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 6, 2015

Fender, R., Stewart, A., Macquart, J. P., Donnarumma, I., Murphy, T., Deller, A., Paragi, Z., Chatterjee, S., "The transient universe with the Square Kilometre Array", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 51, 2015

Gaensler, B., Agudo, I., Akahori, T., Banfield, J., Beck, R., Carretti, E., Farnes, J., Haverkorn, M., Heald, G., Jones, D., Landecker, T., Mao, S. A., Norris, R., O'Sullivan, S., Rudnick, L., Schnitzeler, D., Seymour, N., Sun, X., "Broadband polarimetry with the Square Kilometre Array: a unique astrophysical probe", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 103, 2015

Han, J., van Straten, W., Lazio, J., Deller, A., Sobey, C., Xu, J., Schnitzeler, D., Imai, H., Chatterjee, S., Macquart, J. P., Kramer, M., Cordes, J. M., "Three-dimensional tomography of the galactic and extragalactic magnetoionic medium with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 41, 2015

Haverkorn, M., Akahori, T., Carretti, E., Ferriere, K., Frick, P., Gaensler, B., Heald, G., Johnston-Hollitt, M., Jones, D., Landecker, T., Mao, S. A., Noutsos, A., Oppermann, N., Reich, W., Robishaw, T., Scaife, A., Schnitzeler, D., Stepanov, R., Sun, X., Taylor, R., "Measuring magnetism in the Milky Way with the Square Kilometre Array", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 96, 2015

Heald, G., Beck, R., de Blok, W. J. G., Dettmar, R. J., Fletcher, A., Gaensler, B., Haverkorn, M., Heesen, V., Horellou, C., Krause, M., Mao, S. A., Oppermann, N., Scaife, A., Sokoloff, D., Stil, J., Tabatabaei, F., Takahashi, K., Taylor, A. R., Williams, A., "Magnetic field tomography in nearby galaxies with the Square Kilometre Array", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 106, 2015

Hessels, J., Possenti, A., Bailes, M., Bassa, C., Freire, P. C. C., Lorimer, D. R., Lynch, R., Ransom, S. M., Stairs, I. H., "Pulsars in globular clusters with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 47, 2015

Jarvis, M., Bacon, D., Blake, C., Brown, M., Lindsay, S., Raccanelli, A., Santos, M., Schwarz, D. J., "Cosmology with SKA radio continuum surveys", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 18, 2015

Johnston-Hollitt, M., Govoni, F., Beck, R., Dehghan, S., Pratley, L., Akahori, T., Heald, G., Agudo, I., Bonafede, A., Carretti, E., Clarke, T., Colafrancesco, S., Ensslin, T. A., Feretti, L., Gaensler, B., Haverkorn, M., Mao, S. A., Oppermann, N., Rudnick, L., Scaife, A., Schnitzeler, D., Stil, J., Taylor, A. R., Vacca, V., "Using SKA rotation measures to reveal the mysteries of the magnetised universe", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 92, 2015

Kapinska, A. D., Hardcastle, M., Jackson, C., An, T., Baan, W., Jarvis, M., "Unravelling lifecycles and physics of radio-loud AGN in the SKA Era", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 173, 2015

Karastergiou, A., Johnston, S., Karastergiou, A., Johnston, S., Andersson, N., Breton, R., Brook, P., Gwinn, C., Lewandowska, N., Keane, E., Kramer, M., Macquart, J. P., Serylak, M., Shannon, R., Stappers, B., van Leeuwen, J., Verbiest, J., Weltevrede, P., Wright, G., 2015, "Understanding pulsar magnetospheres with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 38, 2015

Keane, E., Bhattacharyya, B., Kramer, M., Stappers, B., Keane, E. F., Bhattacharyya, B., Kramer, M., Stappers, B. W., Bates, S. D., Burgay, M., Chatterjee, S., Champion, D. J., Eatough, R. P., Hessels, J. W. T., Janssen, G., Lee, K. J., van Leeuwen, J., Margueron,

J., Oertel, M., Possenti, A., Ransom, S., Theureau, G., Torne, P., 2015, "A cosmic census of radio pulsars with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 40, 2015

Kloeckner, H. R., Obreschkow, D., Martins, C., Raccanelli, A., Champion, D., Roy, A. L., Lobanov, A., Wagner, J., Keller, R., "Real time cosmology - a direct measure of the expansion rate of the Universe with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 27, 2015

Koopmans, L., Pritchard, J., Mellema, G., Aguirre, J., Ahn, K., Barkana, R., van Bemmel, I., Bernardi, G., Bonaldi, A., Briggs, F., de Bruyn, A. G., Chang, T. C., Chapman, E., Chen, X., Ciardi, B., Dayal, P., Ferrara, A., Fialkov, A., Fiore, F., Ichiki, K., Illiev, I. T., Inoue, S., Jelic, V., Jones, M., Lazio, J., Maio, U., Majumdar, S., Mack, K. J., Mesinger, A., Morales, M. F., Parsons, A., Pen, U. L., Santos, M., Schneider, R., Semelin, B., de Souza, R. S., Subrahmanyan, R., Takeuchi, T., Vedantham, H., Wagg, J., Webster, R., Wyithe, S., Datta, K. K., Trott, C., "The cosmic dawn and Epoch of Reionisation with SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 1, 2015

Macquart, J. P., Keane, E., Grainge, K., McQuinn, M., Fender, R., Hessels, J., Deller, A., Bhat, R., Breton, R., Chatterjee, S., Law, C., Lorimer, D., Ofek, E. O., Pietka, M., Spitler, L., Stappers, B., Trott, C., "Fast transients at cosmological distances with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 55, 2015

Meyer, M., Robotham, A., Obreschkow, D., Driver, S., Staveley-Smith, L., Zwaan, M., "Connecting the baryons: multiwavelength data for SKA HI surveys", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 131, 2015

Morganti, R., Sadler, E. M., Curran, S., "Cool outflows and HI absorbers with SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 134, 2015

Norris, R., Basu, K., Brown, M., Carretti, E., Kapinska, A. D., Prandoni, I., Rudnick, L., Seymour, N., "The SKA mid-frequency all-sky continuum survey: discovering the unexpected and transforming radio-astronomy", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 86, 2015

Obreschkow, D., Meyer, M., Popping, A., Power, C., Quinn, P., Staveley-Smith, L., "The SKA as a doorway to angular momentum", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 138, 2015

Perez-Torres, M., Alberdi, A., Beswick, R. J., Lundqvist, P., Herrero-Illana, R., Romero-Canizales, C., Ryder, S., della Valle, M., Conway, J., Marcaide, J. M., Mattila, S., Murphy, T., Ros, E., "Core-collapse and Type Ia supernovae with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 60, 2015

Popping, A., Meyer, M., Staveley-Smith, L., Obreschkow, D., Jozsa, G., Pisano, D. J., "Observations of the intergalactic medium and the cosmic web in the SKA era", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 132, 2015

Power, C., Lagos, C., Qin, B., Baugh, C., Cunnama, D., Fu, J., Kim, H., Lacey, C., Li, L., Obreschkow, D., Wang, J., Wang, Y., Zhu, M., "Galaxy formation & aark matter modelling in the era of the Square Kilometre Array", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 133, 2015

Santos, M., Bull, P., Alonso, D., Camera, S., Ferreira, P., Bernardi, G., Maartens, R., Viel, M., Villaescusa-Navarro, F., Abdalla, F. B., Jarvis, M., Metcalf, R. B., Pourtsidou, A., Wolz, L., "Cosmology from a SKA HI intensity mapping survey", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 19, 2015

Shao, L., Stairs, I., Antoniadis, J., Deller, A., Freire, P., Hessels, J., Janssen, G., Kramer, M., Kunz, J., Laemmerzahl, C., Perlick, V., Possenti, A., Ransom, S., Stappers, B., van Straten, W., "Testing gravity with pulsars in the SKA era", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 42, 2015

Staveley-Smith, L., Oosterloo, T., "HI science with the Square Kilometre Array", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 167, 2015

Tauris, T. M., Kaspi, V. M., Breton, R. P., Deller, A. T., Keane, E. F.,Kramer, M., Lorimer, D. R., McLaughlin, M. A., Possenti, A., Ray, P. S., Stappers, B. W., Weltevrede, P., "Understanding the neutron star population with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 39, 2015

Taylor, R., Agudo, I., Akahori, T., Beck, R., Gaensler, B., Heald, G., Johnston-Hollitt, M., Langer, M., Rudnick, L., Scaife, A., Schleicher, D., Stil, J., Ryu, D., "SKA eeep polarization and cosmic magnetism", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 113, 2015

Wolz, L., Abdalla, F. B., Alonso, D., Blake, C., Bull, P., Chang, T. C., Ferreira, P., Kuo, C. Y., Santos, M., Shaw, J. R., "Foreground subtraction in intensity mapping with the SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 35, 2015

Wyithe, S., Geil, P., Kim, H., "Imaging HII regions from galaxies and quasars during reionisation with SKA", Advancing Astrophysics with the Square Kilometre Array (AASKA14), 15, 2015

# STUDENT LIFE

## Jack Line

### University of Melbourne

I'm a third year PhD student at the University of Melbourne, supervised by Rachel Webster and co-supervised by Bart Pindor and Daniel Mitchell (CSIRO). I've been a member of the Evolving Theme for the duration of my PhD.

I did my Masters at the University of Durham investigating fibre optics for use in astronomical instrumentation. After that I wanted a new challenge, so I decided to switch not only fields but also hemispheres, and somewhat serendipitously ended up joining both CAASTRO and the Murchison Widefield Array (MWA) collaboration.

I'm part of the Epoch of Reionisation (EoR) experiment, trying to observe the effects of the first luminous sources on the early Universe. My work focuses on how to best model the radio point-source foregrounds we must remove to get the signal we want. To this end, I've written radio source cross-matching software, and have begun to run simulations of MWA data to study the effects of inaccurate foreground models.

CAASTRO has not only aided me academically but has also helped develop other areas of my career. CAASTRO funding has allowed me to travel abroad to various collaboration meetings and conferences, and to go observing on the GMRT in India. In March 2015 I took advantage of the *Astronomer in Residence* program, which allowed me to spend two weeks at Uluru, meeting the awesome astronomers out there and interacting with the public. On top of this, various CAASTRO workshops and the mentoring scheme have provided me with excellent advice.

I've been a member of the CAASTRO Student Committee for about a year now, and at the last CAASTRO retreat became the Chair from 2016.

## Caitlin Adams

### Swinburne University

I am a first year PhD student at Swinburne University of Technology, supervised by Chris Blake (Swinburne), Ixandra Achitouv (Swinburne), and David Parkinson (University of Queensland). I'm interested in cosmology and uncovering the cause of the Universe's accelerated expansion.

I completed my undergraduate Honours degree at the University of Queensland: I thoroughly enjoyed the research projects I worked on during my degree, and so had no hesitation about going straight into a PhD. I have long been fascinated by the large-scale structure of the Universe, and my PhD work focuses on cosmological analysis using low-redshift surveys, including the Six-degree-Field Galaxy Survey (6dFGS) and upcoming surveys such as TAIPAN and WALLABY. With these surveys, I hope to use galaxy positions and velocities to measure the effect of gravity on large scales, allowing me to test promising theories of modified gravity and improve our understanding of what's driving the accelerating expansion of the Universe.

I have had the good fortune of being a CAASTRO student for both my Honours year and now as a PhD student. CAASTRO has helped me to travel, access powerful supercomputing facilities and meet incredible researchers. I'm currently the CAASTRO Student Representative for Swinburne, and hope that in 2016 I can take up other CAASTRO opportunities such as *CAASTRO in the Classroom* and the *Uluru Astronomer in Residence* program.

## Scott Meyer

### University of Western Australia

I am a PhD student at University of Western Australia (UWA), working at the International Centre for Radio Astronomy Research (ICRAR) with Martin Meyer, Danail Obreschkow and Lister Staveley-Smith.

I completed my undergraduate degree in Physics at the University of Wollongong (UoW) in New South Wales. This cultivated my interest in astronomy. After meeting ICRAR Director Professor Peter Quinn I was quickly convinced that ICRAR in Perth would be a great place for future studies.

At ICRAR I completed an Honours year and then continued with a similar project and the same supervisor for my PhD. That was the point at which I first heard about CAASTRO and decided to become a student member. CAASTRO has supported my PhD in many ways over the years, allowing me to travel around Australia to meet important people in my field, use some world-famous telescopes and present my work at conferences. Most importantly, CAASTRO paired me with my mentor, Chris Blake from Swinburne University, who has been immensely helpful.

My PhD work revolves around using H I stacking, which is a way of combining radio signals from the hydrogen gas in galaxies. I have used this technique to create a new, more sensitive, method of measuring the Tully-Fisher relation, a fundamental scaling relation of spiral galaxies. I am currently investigating whether this new method could be used to measure the evolution of the Tully-Fisher relation through cosmic time.

## Manisha Caleb

### Australian National University

I am a PhD candidate at the Australian National University (ANU) working on pulsars and fast radio transients. I'm jointly supervised by Frank Briggs at the ANU and Matthew Bailes and Chris Flynn at Swinburne University. I hold a Bachelor's degree in Physics from India and a Masters in Spacecraft Technology and Satellite Communications from University College London. My penchant for pulsars and radio astronomy began during my Masters degree, when I worked on a project based on a neutron star.

Shortly after completing my Masters I moved to Melbourne to start a PhD. This involved recommissioning the 50-year-old Molonglo Observatory Synthesis Telescope near Canberra to hunt for the elusive *fast radio bursts* (FRBs), a phenomenon discovered only within the last decade. I am part of the Molonglo team at Swinburne that is taking part in a worldwide race to discover more of these exciting sources. In 2007 the astronomy community went into a frenzy with the detection of the bright, coherent and millisecond-duration fast radio bursts. What are they? We still don't know, although we do know that they lie at cosmological distances. The way forward in the future is to pin down their locations with interferometry, and the Molonglo array has been transformed into an 'FRB detection machine' to do exactly this. My main goal is to search for FRBs in the ongoing survey designed to hunt for them. I analyse a terabyte of data from the survey every day.

I am very grateful to CAASTRO for facilitating my PhD by arranging the joint supervision by ANU and Swinburne.

# CAASTRO STUDENTS

## 2015 CAASTRO NEW STUDENTS

### University of Sydney

**Matthew Varidel,** *Evolving, Student (Pre-PhD)*
SUPERVISOR Scott Croom
THESIS TITLE Resolved gas kinematics in a sample of low-redshift high star-formation rate galaxies

### University of Melbourne

**Stephanie Bernard,** *Dynamic, Evolving, Student (PhD)*
SUPERVISORS Rachel Webster, Jeff Cooke
THESIS TITLE Galaxies and supernovae at cosmic dawn

**Mahsa Rahimi,** *Evolving, Student (PhD)*
SUPERVISORS Rachel Webster, Bart Pindor
THESIS TITLE Measuring EoR signal with MWA

**Jarryd Rasti,** *Evolving, Student (Honours)*
SUPERVISORS Rachel Webster, Ben McKinley
THESIS TITLE Measuring the beam pattern of the MWA tiles

### Australian National University

**Dilyar Barat,** *Evolving, Student (Honours)*
SUPERVISORS Matthew Colless
THESIS TITLE Optimisation of fundamental plane for early type galaxies

**Fiona Panther,** *Dynamic, Student (PhD)*
SUPERVISORS Roland Crocker, Brian Schmidt
THESIS TITLE Stellar origins of galactic bulge positrons

### ICRAR | Curtin

**Samuel McSweeney,** *Dynamic, Student (Honours)*
SUPERVISORS Stephen Ord
THESIS TITLE A study of 47 Tuc pulsars with the MWA

**Mia Walker,** *Outreach Student (Honours)*
SUPERVISOR Randall Wayth
THESIS TITLE A USB Dongle Interferometer

### ICRAR | UWA

**Kamran Ali,** *Dark, Student (PhD)*
SUPERVISORS Danail Obreschkow, Chris Powers
THESIS TITLE Information on the cosmic large scale structure

**Katharine Kelley,** *Dark, Student (PhD)*
SUPERVISORS Lister Staveley-Smith, Peter Quinn, Ian MacArthur
THESIS TITLE A radio astronomy search for axion dark matter

**Khaled Said,** *Dark, Student (PhD) University of Cape Town/ University of Western Australia*
SUPERVISORS Renee C Kraan-Korleweg (UCT), Thomas Jarrett (UCT) & Lister Staveley-Smith
THESIS TITLE Peculiar flow fields in the ZoA from the NIR Tully-Fisher relation

### Swinburne University of Technology

**Igor Andreoni,** *Dynamic, Student (PhD)*
SUPERVISORS Jeff Cooke, Matthew Bailes
THESIS TITLE Deep multi-wavelength exploration of the fast transient Universe

**Christopher Curtin,** *Dynamic/Evolving Student (PhD)*
SUPERVISORS Jeff Cooke, Jeremy Mould
THESIS TITLE High red-shift superluminous supernovae: Theory, observatories and implications

### University of Queensland

**Per Andersen,** *Dark, Student (PhD) University of Copenhagen/University of Queensland*
SUPERVISORS Jens Hjorth (University of Copenhagen), Tamara Davis
THESIS TITLE Peculiar Velocities

**Joshua Calcino,** *Dark, Student (Honours)*
SUPERVISORS Tamara Davis
THESIS TITLE Investigating the effects our local Universe has on observational cosmology

**Simon Deeley,** *Evolving, Student (Honours)*
SUPERVISORS Michael Drinkwater, Tamara Davis
THESIS TITLE Galaxy types and galaxy growth in the group environment

**Diane Salim,** *Evolving, Student (Pre-PhD) University of Queensland*
SUPERVISORS Matthew Colless (ANU), Lisa Kewley, Christoph Federrath
THESIS TITLE Predicting gas properties of SAMI galaxies/ Metallicity gradients and calibrations of SAMI galaxies

**Jacob Seiler,** *Dark, Student (Pre-PhD)*
SUPERVISOR Tamara Davis
THESIS TITLE Using Bulk Flow to Constrain f(R) Gravity

**Natalia Sommer,** *Dark, Student (Masters) University of Oslo/ University of Queensland*
SUPERVISORS Tamara Davis, Signe Riemer-Sorensen (U OSLO)
THESIS TITLE Stacking AGN timelags: Performing reverberation mapping in bulk

## CONTINUING CAASTRO STUDENTS

### University of Sydney

**Jessica Bloom,** *Evolving/Dark, PhD*
SUPERVISORS Joss Bland-Hawthorn, Scott Croom, Lisa Fogarty
THESIS TITLE Dynamical Interactions in Nearby Galaxies

2015 CAASTRO Students

**Joseph Callingham,** *Evolving, PhD*
SUPERVISORS Bryan Gaensler, Sean Farrell, Randall Wayth, Ron Ekers
THESIS TITLE An MWA Source Catalogue: Compact Steep Spectrum and Gigahertz Peaked Spectrum Sources at Low Radio Frequencies

**Marcin Glowacki,** *Evolving, PhD*
SUPERVISORS Elaine Sadler, James Allison (CSIRO)
THESIS TITLE Studies of H I Absorption Against Distant Radio Sources with ASKAP

**Cleo Loi,** *Dynamic, Student (Honours)*
SUPERVISORS Tara Murphy
THESIS TITLE Waves in the sky: Probing the ionosphere with the Murchison Widefield Array

**Rebecca McElroy,** *Evolving, Student (PhD)*
SUPERVISORS Scott Croom, Michael Pracy
THESIS TITLE The host galaxies of luminous type II AGN

**Aina Musaeva,** *Evolving, PhD*
SUPERVISORS Elaine Sadler, Sean Farrell, Bärbel Koribalski
THESIS TITLE Intermediate Mass Black Holes in Dwarf Galaxies

**Samuel Richards,** *Evolving, PhD*
SUPERVISORS Joss Bland-Hawthorn, Julia Bryant
THESIS TITLE Novel new astrophotonic technologies and telescope instruments to address the role of star formation as a function of galaxy environment.

**Adam Schaefer,** *Evolving, PhD*
SUPERVISORS Scott Croom, James Allen
THESIS TITLE The modulation of star formation by galaxy environment using the Sydney-AAO Multi-object Integral Field Spectrograph (SAMI)

**Sarah Reeves** *Evolving, PhD*
SUPERVISORS Elaine Sadler, Tara Murphy, Bärbel Koribalski
THESIS TITLE H I and OH absorption line studies of nearby galaxies

## University of Melbourne

**Loren Bruns Jr** *Evolving, PhD*
SUPERVISORS Stuart Wyithe, Rachel Webster
THESIS TITLE Lyman alpha emitters as a probe of galaxy formation and ionisation history

**Catherine De Burgh-Day** *Dark, PhD*
SUPERVISORS Rachel Webster, Ned Taylor, Andrew Hopkins, Andrew Hopkins (AAO)
THESIS TITLE Direct Shear Mapping

**Antonios Katsianis** *Evolving, PhD*
SUPERVISORS Stuart Wyithe, Edoardo Tescari
THESIS TITLE Feedback and Evolution of High Redshift Galaxies

**Jack Line,** *Evolving, PhD*
SUPERVISORS Rachel Webster, Daniel Mitchell, Daniel Mitchell (CSIRO)
THESIS TITLE Detecting the Power Spectrum of the 21-cm Emission of Hydrogen from the Epoch of Reionisation

**Sinem Ozbilgen** *Dark, MSc*
SUPERVISORS Rachel Webster, Jeremy Mould
THESIS TITLE Calibrating the Tully-Fisher Relationship

**Tristan Reynolds,** *Evolving, Honours*
SUPERVISORS Rachel Webster
THESIS TITLE Detection of EoR

**Nastaran Rezaee** *Evolving, MPhil*
SUPERVISORS Stuart Wyithe, Daniel Mitchell
THESIS TITLE Simulations of Foregrounds in MWA Epoch of Reionisation Observations

**Jennifer Riding** *Evolving, PhD*
SUPERVISORS Rachel Webster, Daniel Mitchell
THESIS TITLE Extremely Low Frequency Radio Astronomy Techniques to Confirm Epoch of Reionisation Theories

## Australian National University

**Manisha Caleb,** *Dynamic, PhD*
SUPERVISORS Frank Briggs, Matthew Bailes, Brian Schmidt
THESIS TITLE A Pursuit for Celestial Radio Sources

**Sarah Leslie,** *Evolving, Pre-PhD*
SUPERVISORS Elaine Sadler, Scott Croom, Julia Bryant, Lisa Kewley
PROJECT TITLE A radio continuum study of SAMI galaxies

2015 CAASTRO Postdoctoral Researchers

**Mayuri Sathyanarayana Rao,** *Evolving, Student (PhD)*
SUPERVISORS Frank Briggs, Ravi Subrahmanyan (RRI), Charley Lineweaver, Brian Schmidt
THESIS TITLE On the detection of spectral ripples from the epoch of recombination

**Bonnie Zhang,** *Dark, Dynamic, Student (PhD)*
SUPERVISORS Brian Schmidt, Chris Lidman, Tamara Davis, Richard Scalzo, Fang Yuan, Michael Childress
THESIS TITLE Joint photometric calibration and cosmology analysis of Type Ia supernovae in the SkyMapper and Dark Energy Survey samples

## ICRAR | Curtin

**Samuel Oronsaye** *Dynamic, PhD*
SUPERVISORS Steven Tingay, Steve Ord, Ramesh Bhat, Steven Tremblay
THESIS TITLE Survey for Pulsars with the MWA

**Seonaid Rogers,** *Outreach, Student (undergrad)*
SUPERVISORS Wiebke Ebeling, Steven Tingay
THESIS TITLE Visualisations of astronomical all-sky datasets for researchers and public audiences

## ICRAR | UWA

**Scott Meyer,** *Evolving/Dark, PhD*
SUPERVISORS Martin Meyer, Danail Obreschkow, Lister Staeley-Smith
THESIS TITLE Investigating the Tully-Fisher relation and galaxy kinematics through neutral Hydrogen spectral line stacking techniques

**Steven Murray** *Evolving/Dark, PhD*
SUPERVISORS Chris Power, Aaron Robotham, Simon Driver, Lister Staveley-Smith
THESIS TITLE Non-Parametric Descriptions of Dark Matter Halos

**Paul Scott-Taylor,** *Evolving/Dynamic, PhD*
SUPERVISORS Danail Obreschkow
THESIS TITLE Large-scale computer simulation of radio continuum emission

## Swinburne University of Technology

**Caitlin Adams,** *Student (PhD)*
SUPERVISORS Chris Blake, David Parkinson, Ixandra Achitouv
THESIS TITLE Testing the cosmological model in the low-redshift Universe

**Shivani Bhandari,** *Dynamic, Student (PhD)*
SUPERVISORS Matthew Bailes, Willem van Straten, Evan Keane
THESIS TITLE Searching and localisation of sources of dispersed radio emission

**Alexandru Codoreanu,** *Evolving, Student (PhD)*
SUPERVISORS Emma Ryan-Webber, Michael Murphy, Neil Chrighton
THESIS TITLE Chemical fingerprints in the highest-redshift quasar absorption systems: Probing the epoch of hydrogen reionisation

**Angela Garcia,** *Evolving, Student (PhD)*
SUPERVISORS Emma Ryan-Webber, Edoardo Tescari, Stuart Wyithe
THESIS TITLE Diagnosing Hydrogen Reionization with metal absorption line ratios.

**Fabian Jankowski,** *Dynamic, PhD*
SUPERVISORS Matthew Bailes, Willem van Straten
THESIS TITLE The Radio Universe at 1000 frames per second

**Andrew Johnson** *Dark, PhD*
SUPERVISORS Chris Blake, David Wiltshire, Tamara Davis (UQ)
THESIS TITLE Testing Non-Standard Cosmological Models with Galaxy Surveys

**Emily Petroff** *Dynamic, PhD*
SUPERVISORS Willem van Straten, Matthew Bailes, Simon Johnston (CSIRO)
THESIS TITLE Our Dynamic Galaxy

**Syed Uddin** *Dark, PhD*
SUPERVISORS Jeremy Mould, Chris Lidman, Karl Glazebrook
THESIS TITLE On the Influence of the Host Galaxy in Supernova Cosmology

**Vivek Venkatraman,** *Dynamic, pre-PhD Student,*
SUPERVISORS Matthew Bailes, Willem van Straten, Evan Keane
THESIS TITLE Next generation Instrumentation for studies of Pulsars and Fast Transients with the SKA

### University of Queensland

**Samuel Hinton,** *Dark, Pre-PhD Summer Student,*
SUPERVISORS Tamara Davis
THESIS TITLE Measuring 2D BAO with WiggleZ

**Anthea King,** *Dark, Student (PhD)*
SUPERVISORS Tamara Davis, Darach Watson (University of Copenhagen) Marianne Vestergaard (University of Copenhagen)
THESIS TITLE Active Galactic Nuclei as high-redshift standard candles

**Conor O'Neill,** *Dark, Student (Honours)*
SUPERVISORS Tamara Davis, Chris Lidman (AAO)
THESIS TITLE Cosmological Investigations: Optimising novel observation techniques in OzDES and examining the precision of cosmological probes

**Adam Thomas,** *Evolving, Student (Hons)*
SUPERVISORS Michael Drinkwater
THESIS TITLE Searching for ram-pressure stripping in galaxy clusters with the SAMI Galaxy Survey

**Sarah Thomson,** *Dark, Student (Honours)*
SUPERVISORS David Parkinson, Ray Norris (CSIRO)
THESIS TITLE Probing the Early Universe with Large Area Radio Surveys

## CAASTRO ANNUAL REPORT OF THE STUDENT COMMITTEE

CAASTRO's Student Committee was established in 2014 to increase students' awareness of CAASTRO, and boost their representation and involvement. In 2015 it made solid progress on these aims.

To raise awareness both of CAASTRO in general and the activities of students in particular, the Committee has developed a dedicated web-page for the CAASTRO website that outlines the role of the Student Committee, lists its members, and links to useful information for CAASTRO students. We've also produced a striking poster advertising study with CAASTRO and distributed it to each CAASTRO node. This poster spells out five benefits of studying with CAASTRO.

Several nodes have also held 'student days' aimed at bringing together potential CAASTRO students and informing them of CAASTRO's research and the benefits of being involved. Dozens of students – undergraduates, Honours, Masters and even some non-CAASTRO PhDs – have attended and expressed considerable interest.

The biggest hurdle to recruiting students is their lack of awareness of CAASTRO's activities and research programs. Those with projects that naturally place them inside an active collaboration tend to be more involved in broader CAASTRO activity, but those with less collaborative projects are less likely to get involved. We have addressed this in two ways:

- we have produced a fact sheet, or 'survival kit', which contains tips on general study and also answers CAASTRO-specific questions. This sheet is available online, and we think it will help current students understand how they can become more involved with CAASTRO
- every node has held at least one student meeting, which all students (and some more senior members!) have been encouraged to attend. These meetings relay current research, encouraging a broader interest in CAASTRO's goals. They are also a forum for student representation, a safe environment in which to raise issues and concerns. These meetings have been extremely successful.

The Student Committee would like to thank the CAASTRO Executive for their support throughout the year, and in particular Kate Gunn, who has been our driving force. We look forward to 2016 being even bigger and better!

**Steven Murray**
**Chair 2015**

# CAASTRO GOVERNANCE

CAASTRO is a collaboration between The University of Sydney, The Australian National University, The University of Melbourne, Swinburne University of Technology, The University of Queensland, The University of Western Australia and Curtin University, the latter two participating together as the International Centre for Radio Astronomy Research (ICRAR). CAASTRO is funded under the Australian Research Council (ARC) Centre of Excellence program, with additional funding from the seven participating universities and from the NSW State Government's Science Leveraging Fund.

As the Administering Organisation, The University of Sydney manages the ARC grant and distributes funds in accordance with the signed Collaboration Agreement. This agreement covers how the Centre is managed, and how collaboration and intellectual property agreements are managed.

The seven collaborating universities are represented on the CAASTRO Executive, which meets every six weeks via video-conference, and twice a year at face-to-face meetings. The Centre also has an Advisory Board that meets twice per year via teleconference and annually face-to-face.

## Centre Management

The CAASTRO Executive team is responsible for the administration of the Centre, including research output, research training, partnerships, national and international liaison, policies, performance, financial management, commercialisation and outreach. CAASTRO staff and activities at each Collaborating Organisation are supported by a dedicated administrative officer.

The Management Team is:

**Professor Elaine Sadler**
Centre Director

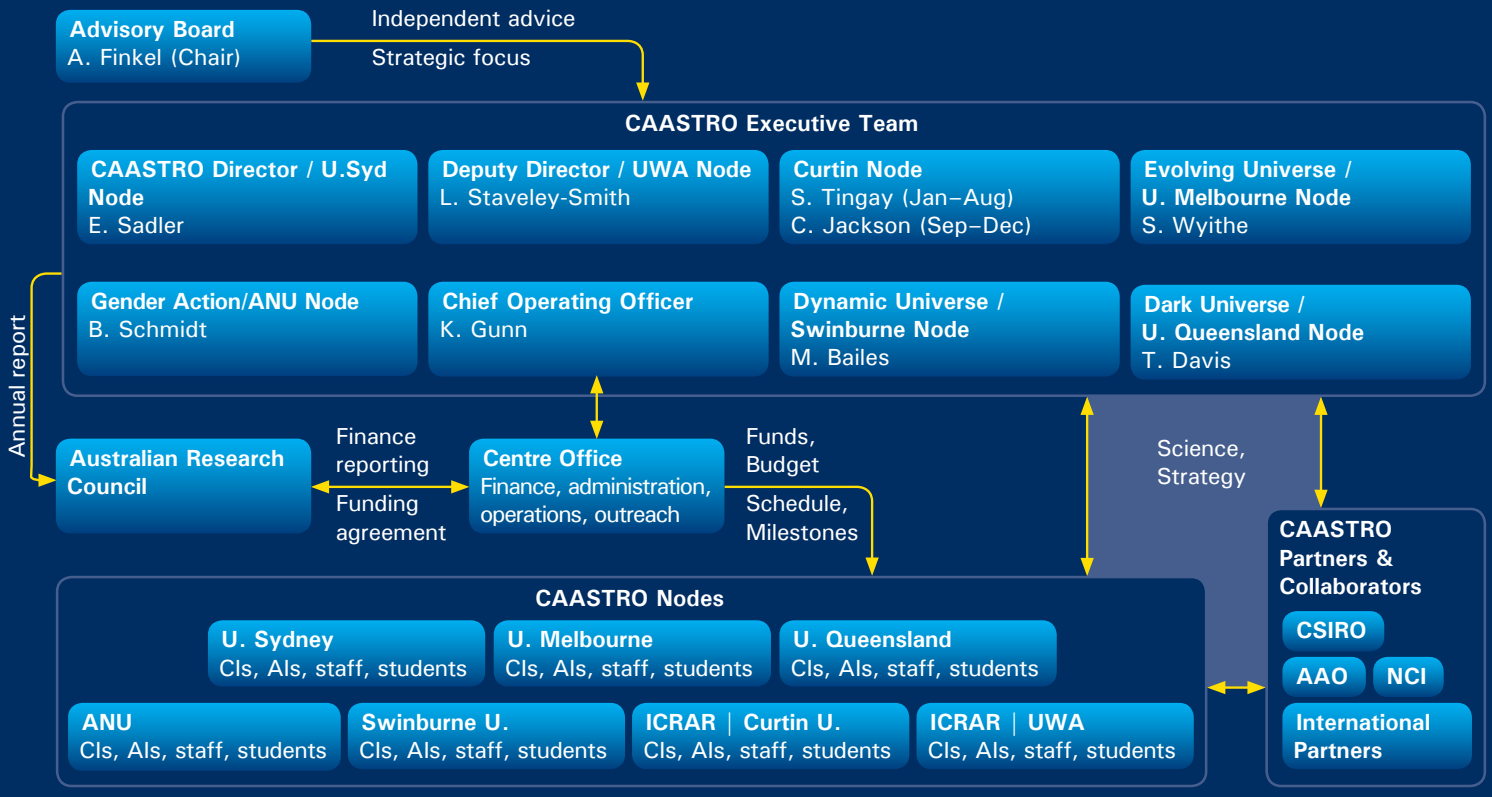
**Professor Lister Staveley-Smith**
Deputy Director

**Ms Kate Gunn**
Chief Operating Officer

In 2015, the CAASTRO Executive met 9 times, including face-to-face meetings at Swinburne, the University of Melbourne, ICRAR University of Western Australia and ICRAR Curtin University. During 2015 area meetings were held in Sydney, Canberra, Brisbane, Melbourne and Perth.

In 2015 CAASTRO's Theme Scientists continued to add value to the research program, and gain leadership experience and new skills during this time. Thanks must go to Dr Dan Taranu (Evolving), Dr Christene Lynch (Dynamic) and Dr Ixandra Achitouv (Dark) for their hard work as CAASTRO Theme Scientists in 2015. Their assistance in maintaining the Research Project Plans and organising the Theme Meetings has been invaluable.

**The following diagram shows the CAASTRO Governance structure:**



## CAASTRO Advisory Board

The CAASTRO Advisory Board met three times in 2015, including a two-day planning meeting held in Perth in November. At this meeting the Board assisted the CAASTRO Executive with its Strategic Plan for the remaining period of its funding. The Board has also considered matters of strategy, responding to the changing external environment, collaboration across distances, community outreach, intellectual property and industry engagement. They have also met with students, researchers and professional staff in order to understand CAASTRO activities.

**CHAIR**
**Dr Alan Finkel AO**
Chancellor
Monash University

**MEMBER**
**Ms Soula Bennett**
Director
Quantum Victoria

**MEMBER**
**Professor Elaine Sadler**
CAASTRO Director

**MEMBER**
**Professor Martha Haynes**
Goldwin Smith Professor of Astronomy
Cornell University

**MEMBER**
**Professor Garth Illingworth**
Professor of Astronomy & Astrophysics
University of California Santa Cruz

**MEMBER**
**Professor Hugh Durrant-Whyte**
The School of Information Technologies
University of Sydney

**MEMBER**
**Professor Peter Davies**
Pro Vice-Chancellor Research
University of Western Australia

**MEMBER**
**Dr Bronwyn Evans**
Chief Executive Officer
Standards Australia

**MEMBER**
**Professor Kenneth Freeman**
Duffield Professor of Astronomy, Australian National University

**MEMBER**
**Professor Ron Ekers**
CSIRO Fellow

**MEMBER**
**Dr Rachel Nowak**
Director The Brain Dialogue
Monash University

**CAASTRO Executive**
[L to R] Stuart Wyithe, Tamara Davis, Lister Staveley-Smith, Carole Jackson, Matthew Bailes, Brian Schmidt, Elaine Sadler and Kate Gunn.
Absent: Steven Tingay.
*Credit: Kirsten Gottschalk*

The CAASTRO Advisory Board in Perth, November 2015
*Credit Wiebke Ebeling*

# CAASTRO MEMBERSHIP

| | |
|---|---|
| The University of Sydney | Administering Organisation |
| ICRAR \| The University of Western Australia | Collaborating Organisation |
| The University of Melbourne | Collaborating Organisation |
| Swinburne University of Technology | Collaborating Organisation |
| The Australian National University | Collaborating Organisation |
| ICRAR \| Curtin University | Collaborating Organisation |
| The University of Queensland | Collaborating Organisation |
| CSIRO | Partner Organisation |
| Australian Astronomical Observatory | Partner Organisation |
| Max Planck Institute for Radio Astronomy | Partner Organisation |
| California Institute of Technology | Partner Organisation |
| The University of Oxford | Partner Organisation |
| Durham University | Partner Organisation |
| Max Planck Institute for Extraterrestrial Physics | Partner Organisation |
| The University of Arizona | Partner Organisation |
| The University of Toronto | Partner Organisation |
| Laboratoire de Physique Nucléaire et de Hautes Energies | Partner Organisation |
| Raman Research Institute | Partner Organisation |
| National Computational Infrastructure | Partner Organisation |

All members of CAASTRO agree to:

- Support the goals, objectives and research of CAASTRO.
- Accept the processes and procedures for joining, maintaining and leaving CAASTRO.
- Allow the CAASTRO Executive the right to refuse membership to any organisation or person at any time.
- Accept the legal obligations that the Administering Organisation has with the ARC.
- Accept the intellectual property policy of CAASTRO.
- Accept that all disputes regarding membership will be referred to the Director.
- Accept that membership is not transferable between individuals.

CAASTRO has defined categories of membership, and individuals and organisations must apply to the CAASTRO Executive addressing certain defined criteria to make their case for membership. The CAASTRO Membership categories are:

## Chief Investigators

Chief Investigators (CIs) are senior researchers employed by collaborating organisations named in the CAASTRO Collaborators' Agreement. CIs are responsible for making a substantial intellectual and strategic contribution to CAASTRO, and for supervising CAASTRO research staff, CAASTRO professional staff and CAASTRO students.

## Partner Investigators

Partner Investigators (PIs) are senior researchers employed by partner organisations named in the CAASTRO Multi-Institute Agreement. PIs are responsible for making a substantial intellectual and strategic contribution to CAASTRO. Where appropriate, they may also co-supervise CAASTRO students.

## Associate Investigators

Associate Investigators (AIs) are scientists who are funded from a Collaborating Organisation, Partner Organisation or other source, and who are participating in CAASTRO research projects with specific deliverables. Associate Investigators are responsible for making an intellectual and strategic contribution to CAASTRO in their specific area(s) of expertise. AIs are typically researchers for whom membership at the CI or PI level is not suitable for logistical or strategic reasons.

## Research Staff

CAASTRO Research Staff are employees of a CAASTRO collaborating organisation, who are classified on the academic pay scale, and are funded at FTE 0.2 or higher from the CAASTRO budget. Research staff are responsible for producing the research, technical and outreach results associated with the CAASTRO milestones and, where appropriate, may also co-supervise CAASTRO students. All CAASTRO Research Staff must have a CAASTRO CI as their line manager.

## Professional Staff

CAASTRO Professional Staff are employees of a CAASTRO collaborating organisation who are classified on the professional/general pay scale, or are working in a professional role, and are funded from the CAASTRO budget or as an in kind contribution to CAASTRO. Professional staff are responsible for coordinating the administrative, financial, educational and outreach activities within CAASTRO. All CAASTRO Professional Staff must have a CAASTRO CI or the CAASTRO Chief Operating Officer as their line manager.

## Affiliates

CAASTRO Affiliates are researchers who have a scientific association with CAASTRO, but who are not CIs, PIs, AIs or staff. CAASTRO Affiliates include independently funded researchers (e.g., Future Fellows, DECRAs working alongside CAASTRO researchers at CAASTRO nodes), or researchers who have an involvement in CAASTRO not warranting membership at the CI, PI or AI levels. Affiliates are not responsible for any CAASTRO research deliverables.

## Students

CAASTRO students are postgraduate, Honours, Masters or Pre-PhD students whose research projects make a substantial intellectual contribution to CAASTRO. A CAASTRO student can be enrolled at any higher degree granting institution, but must have a CAASTRO CI as an official supervisor or co-supervisor.

## Visitors

Visitors are academics from outside Australia who spend time working at one or more CAASTRO nodes on a research project with CIs and other research staff. A CAASTRO PI may also be a CAASTRO Visitor during time spent working at a CAASTRO node.

# AWARDS & HONOURS

External recognition for the CAASTRO team continued in 2015, with a number of team members receiving awards and honours for their achievements.

## Thomson Reuters ISI Citation Award

The Murchison Widefield Array (MWA) telescope in Western Australia is on track to contribute to our evolving picture of the Universe and our place in it. The MWA is a low-frequency radio telescope operating between 80 and 300 MHz. It is located at CSIRO's Murchison Radio-astronomy Observatory (MRO) in Western Australia, about 300 km inland from Geraldton in the State's Mid West. This is the planned site of the low-frequency component of the future Square Kilometre Array (SKA), a $2 billion international radio telescope. The MWA is one of three telescopes, designated as SKA 'precursors', that are intended to pioneer both science and technology for the later instrument. The MWA itself has been developed by an international consortium of institutions from Australia, India, New Zealand and the United States, led by Australia's Curtin University.

Researchers will use the MWA to help us understand how the first stars in the Universe formed. Or, to put it a bit more technically, the MWA will hunt for intergalactic hydrogen gas that surrounded early galaxies during the 'Epoch of Reionisation', the period in the Universe's early life when the first stars generated ultraviolet radiation that gradually cleared away the 'fog' of neutral hydrogen that filled the universe then. Members of CAASTRO are key members of this **Epoch of Reionisation project**. Their scientific productivity was formally recognised this year by an award from Thomson ISI, an organisation that tracks scientific citations, in the Space Science category.

Thomson Reuters ISI, the world's leading provider of intelligent information for businesses and professionals, honoured leading scientific research and innovation in Australia at the 2015 *Thomson Reuters Australian Citation and Innovation Awards* in June. The event took place at the University of Melbourne.

The scientific research awards, a subset of the *Thomson Reuters Citation Awards*, are determined by analysing the volume and impact of a researcher's contribution to his/her subject area. The recipients were selected by identifying the average number of citations their research generated over a period of time, as indexed in the Thomson Reuters *Web of Science*®. This covers all articles, reviews and proceedings papers with at least one Australia-based author. The average citation, in turn, reflects its impact and influence on the given subject and the importance attached to it by subsequent research. At the time of the award, the MWA Collaboration had resulted in 35 papers published in refereed journals, seven papers in refereed conference proceedings, five papers submitted to refereed journals, five papers under collaboration review and 19 live paper proposals posted for collaboration review.

**Caption: CAASTRO members receiving the Thomson ISI Citation Awards on behalf of the MWA awardees. L-R: Ms Kate Gunn (CAASTRO), Professor Steven Tingay (Curtin University), Professor Rachel Webster (University of Melbourne) Professor Frank Briggs (ANU) and Dr Randall Wayth (Curtin University). Awardees not pictured: Professor Bryan Gaensler (University of Toronto), Dr Daniel Mitchell (CSIRO), Mr Mark Waterson (Curtin University) and Professor Stuart Wyithe (University of Melbourne).**

***Credit: Thomas Reuters ISI***

We are also delighted to report individual award winners in 2015.

The Australian Optical Society awarded Professor **Joss Bland-Hawthorn** (University of Sydney) the 2015 *W.H. (Beattie) Steel Medal* in recognition of his leadership and significant contribution to the field of optics, particularly in the application of photonics to astronomical and space instrumentation. He is the first astronomer to receive this award.

Professor **Tamara Davis** (University of Queensland) was awarded the 2015 *Nancy Millis Medal* by the Academy of Science. This award recognises early- and mid-career women scientists who have demonstrated exceptional leadership and established an independent research program in any branch of the natural sciences. It honours the contributions made to science by the late Professor Nancy Millis AC MBE FAA FTSE and recognises her importance as a role model for aspiring female scientists in Australia. Tamara received the award at the Academy's annual *Science at the Shine Dome* event in Canberra in May.

The Astronomical Society of Australia (ASA) announced the recipients of the 2015 ASA Awards, and the prize-winners presented their research, at the ASA Annual Scientific Meeting, held during 5–10 July this year in Fremantle, Western Australia.

The *ASA Bok Prize* for outstanding research in astronomy by an Honours or eligible Masters student was awarded to CAASTRO student **Cleo Loi** for her thesis, "Waves in the Sky: Probing the Ionosphere with the Murchison

Widefield Array". Cleo completed her Honours research at the University of Sydney, supervised by Tara Murphy. For her work in imaging the ionosphere, Cleo also won the 2015 Canon *Extreme Imaging Competition* in the Open category. This annual competition, an initiative of Canon's local research and development arm, is open to all Australian university students who are producing images as part of their research, and is held to promote and celebrate innovations and advancement in imaging science. Cleo and the other winners received their awards on 24 November at an international conference, *Digital Image Computing: Techniques and Applications* (DICTA), in Adelaide, South Australia. Cleo also had the honour this year of being named one of the 'Top 25 under 25' by radio station TripleJ.

The *ASA Charlene Heisler Prize* for the most outstanding PhD thesis in astronomy was awarded to CAASTRO student **Morag Scrimgeour** for her thesis "Cosmology with Large-scale Structure and Galaxy Flows", which was completed at the University of Western Australia (UWA). Morag was supervised by Lister Staveley-Smith (UWA) and Tamara Davis (University of Queensland).

At the Fremantle meeting the ASA also formally presented **CAASTRO** with the *ASA Silver Pleiades Award*. The award, which recognises an institutional commitment to gender equity, had been announced in 2014; CAASTRO was one of only two organisations to win at the Silver level. Director Elaine Sadler and Founding Director Bryan Gaensler accepted the award on CAASTRO's behalf.

Professor **Stuart Wyithe** (University of Melbourne) was the winner of the Australian Institute of Physics' *Boas Medal*. The aim of this award is to promote excellence in research in Physics in Australia and to perpetuate the name of Walter Boas, a physicist and metallurgist. Stuart gave the prestigious Boas Medal Lecture on the topic of "Cosmic Hydrogen and the First Galaxies in the Universe" at the Australian Institute of Physics' Annual General Meeting in December.

Eight remarkable young women and men presented their work to a meeting of the Royal Society of Victoria on 24 September. Over two hours the audience was treated to the latest work of Victoria's emerging researchers, across four categories (and eight disciplines) of science. CAASTRO student **Catherine de Burgh-Day** (University of Melbourne) was a joint winner of the Royal Society of Victoria's *Young Scientist Research Prize for the Physical Sciences* for her new technique, *direct shear mapping* (page 27).

In June, **Kate Gunn**, the Chief Operating Officer of CAASTRO, was awarded a scholarship to attend the 2015 *Women's Leadership Program* at the Harvard Business School in Boston, USA.

CAASTRO is also delighted that its Advisory Board Chair, Professor **Alan Finkel,** was appointed as Australia's Chief Scientist, commencing 22 January 2016, and that Professor **Matthew Bailes** (Swinburne University) received an ARC Laureate Fellowship in 2015.

**Morag Scrimgeour (left) accepts the ASA Charlene Heisler Prize for the most outstanding PhD thesis in astronomy from ASA president Virginia Kilborn.**
***Credit: Andy Green***

**Elaine Sadler (Director) and Bryan Gaensler (Founding Director) accept the ASA Silver Pleiades Award for CAASTRO in July 2015 in Fremantle.**
***Credit: Andy Green***

**Cleo Loi (right) accepts the ASA Bok Prize for outstanding research in astronomy by an Honours or eligible Masters student from ASA president Virginia Kilborn.**
***Credit: Andy Green***

# GENDER ACTION COMMITTEE

By Professor Brian Schmidt, CAASTRO Gender Action Committee Chair

The CAASTRO Gender Action Committee had another productive year in 2015, its second year of operation. The committee is an initiative of the CAASTRO Executive, which has always considered itself a force for gender equality and has had strong oversight of gender initiatives and the monitoring of Key Performance Indicators (KPIs) and outcomes.

CAASTRO has taken many actions to support gender equity, such as offering all positions part-time since 2011. However, in 2013 the CAASTRO Executive considered its KPIs in relation to its gender program and decided that it was falling short in a number of desired outcomes. The CAASTRO Executive decided to form the CAASTRO Gender Action Committee to address these issues and Professor Brian Schmidt (Australian National University) agreed to lead it.

The Gender Action Committee's role is to contribute to the development of strategies to meet Gender Action challenges, to maximise the Centre's goals and objectives. The role includes making recommendations on ways in which CAASTRO can balance its gender representation, boost opportunities for our female staff and students, and monitor progress. The creation of the CAASTRO Gender Action Committee has fast-tracked many of our gender initiatives.

The members of the Gender Action Committee have a balance of gender and also represent a range of career levels, member institutions and nationalities. In 2015 they were Elaine Sadler (University of Sydney), Rachel Webster (University of Melbourne), Cathryn Trott (Curtin University), Fang Yuan (Australian National University), James Allison (CSIRO), David Parkinson (University of Queensland), Jessica Bloom (University of Sydney), Kate Gunn (University of Sydney) and Brian Schmidt (Australian National University, Chair). This year the Committee met three times via videoconference (two-hour sessions) and once face to face at the Australian National University (a half-day session).

In addition to continuing activities initiated in 2014, this year the Committee was busy drafting and finalising the CAASTRO Code of Conduct. This document provides guidance on personal and professional behaviour. Of course where there is conflict between CAASTRO policy and that of a CAASTRO member's University or Organisation, the latter overrides the CAASTRO policy and must be deferred to.

CAASTRO is committed to making all CAASTRO-sponsored and supported conferences and workshops productive and enjoyable for everyone, regardless of gender, sexual orientation, disability, physical appearance, race, nationality or religion. We will not tolerate discrimination or harassment of participants in any form, and the CAASTRO Code of Conduct documents our approach to this.

This year CAASTRO also initiated CAASTRO Exit Interviews for when members leave the team. This is an important step to ensure we are always improving the work we do. It provides us with anonymous feedback on whether the gender activities we have undertaken have been effective. To date the feedback on our achievements has been very positive, but the overriding concern from members has been "will my new organisation be so supportive?".

To assist other organisations to provide a gender-inclusive environment, the Gender Action Committee is now working on creating a 'tool kit' that they can use to implement initiatives. One of the major components is a case study on what CAASTRO has achieved thus far and how it has reached its goals.

CAASTRO measures a number of gender KPIs. They include the number of women at various levels within CAASTRO, the number of female-led CAASTRO-sponsored workshops, the number of female CAASTRO visitors, gender targets for speakers and Scientific Organising Committee roles in conferences and workshops, the number of females who apply for jobs, and the number who are shortlisted. In 2015 we continued to monitor these statistics, and the results continue to be of a positive nature.

The role of the Gender Action Committee is ongoing, and we are only in the first stage of our journey, but the work done in 2015 has provided a solid foundation on which CAASTRO can move forward.

Tamara Davis, *The Universe in a Nutshell*, Brisbane July 2015
*Credit: CAASTRO*

# PRESENTATIONS

# INVITED TALKS 2015

## Major Conferences

**this list does not include public talks or school talks*

**Science: humanity's universal bridge**
Brian Schmidt, 5th ASEAN event series "Bridges - Dialogues towards a Culture of Peace", Thailand, January 2015

**Fast radio bursts: the story so far**
Ramesh Bhat, The 33rd Meeting of the Astronomical Society of India, India, February 2015

**Large-scale structure and turbulence with widefield radio telescopes**
Bryan Gaensler, Canadian Institute for Advanced Research Cosmology and Gravity meeting, Canada, March 2015

**Cosmology: current surveys and instrumentation**
Matthew Colless, Multi-Object Spectroscopy in the next Decade, Spain, March 2015

**Humanity, despite being a tiny speck of existence in an unfathomably vast Universe, is piecing together the story of our Universe**
Brian Schmidt, Launch ceremony of the Millennium Institute of Astrophysics (MAS), Chile, March 2015

**Kunlun infrared sky survey**
Jeremy Mould, International Collaboration Meeting on Antarctic Survey Telescopes (AST3), Hong Kong, March 2015

**Sustaining humanity in the midst of climate change: a dialogue with Nobel Laureates**
Brian Schmidt, 4th Nobel Laureate Symposium on Global Sustainability, April 2015

**Impact of station size on calibration of SKA-Low**
Cathryn Trott, 40th International Conference on Acoustics, Speech and Signal Processing (ICASSP), Brisbane, April 2015

**Flares, pulses, burps and bursts: the dynamic radio sky**
Bryan Gaensler, Kavli Futures Symposium, Canada, April 2015

**EoR challenges for the SKA**
Bart Pindor, OzSKA: Radio Astronomy in the next Decade, Melbourne, April 2015

**The Epoch of Reionisation project**
Cathryn Trott, OzSKA: Radio Astronomy in the next Decade, Melbourne, April 2015

**Cyclic spectroscopy as a tool for pulsar scintellometry**
Jean-Pierre Macquart, Pulsar Scintellometry, Canada, April 2015

**Station calibration strategies**
Randall Wayth, SKA Low calibration consultation workshop, UK, April 2015

**arXiver: dealing with the big data of new scientific literature**
Vanessa Moss, Python in Astronomy, Lorentz Center, The Netherlands, April 2015

**The road to the MWA correlator**
Randall Wayth, AADCC AAVS1 design review, Italy, May 2015

**Radio astronomy in the widefield era**
Bryan Gaensler, Annual Scientific Meeting of the Canadian Astronomical Society Hamilton, Canada, May 2015

**Waves in the sky: probing the ionosphere with the Murchison Widefield Array**
Cleo Loi, International Union for Radio Science (URSI) Atlantic Radio Science, Spain, May 2015

**GPS/CSS radio sources and their relation to other AGN**
Elaine Sadler, 5th Workshop on Compact Steep Spectrum and GHz-Peaked Spectrum Radio Sources, Rimini, Italy, May 2015

**HECTOR: a new multi-object IFU instrument for the AAT**
Julia Bryant, Multiwavelength Dissection of Galaxies, Sydney, May 2015

**Kinematics of galaxies using the SAMI galaxy survey**
Lisa Fogarty, Multiwavelength Dissection of Galaxies, Sydney, May 2015

**The dark side of the Universe**
Tamara Davis, Science in the Shine Dome, Canberra, May 2015

**A 21st century career in research: a discussion about thriving in the face of career uncertainty.**
Brian Schmidt, 65th Lindau Nobel Laureate Meeting and 4th Interdisciplinary Meeting, Germany, June 2015

**On the detection of spectral ripples from the epoch of recombination**
Mayuri Sathyanarayana Rao, Cosmology with the H I 21 cm line, India, June 2015

**Modelling thermonuclear supernovae from different progenitor systems**
Ivo Seitenzahl, Fifty One Erg 2015, USA, June 2015

**The gas content of galaxies and fuelling of star formation over cosmic time**
Attila Popping, Many Pathways to Galaxy Growth Conference, Prato, Italy, June 2015

**What we think we know: the phenomenology of galaxy evolution from studies of galaxy demographics**
Edward Taylor, Many Pathways to Galaxy Growth Conference, Prato, Italy, June 2015

**The state of the Universe**
Brian Schmidt, 65th Lindau Nobel Laureate Meeting and 4th Interdisciplinary Meeting, Germany, July 2015

**Australia SKA science update**
Carole Jackson, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Perth, July 2015

**Dark matter**
Katherine Mack, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Perth, July 2015

**Supernovae in the synoptic survey era**
Fang Yuan, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Perth, July 2015

**Waves in the sky: probing the ionosphere with the MWA – Bok Prize talk**
Cleo Loi, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Perth, July 2015

**Dark energy down under: testing cosmological physics with redshifts and velocities**
Chris Blake, Theoretical and Observational Progress on Large-scale Structure, Munich, Germany, July 2015

**The Arecibo Ultra Deep Survey (AUDS)**
Lister Staveley-Smith, Frontiers in Radio Astronomy and FAST Early Sciences Symposium 2015, Guiyang, China, July 2015

**Exploring the Universe from Australia**
Brian Schmidt, The John Bolton Lecture, Parkes, July 2015

**Ellery Lecture: black holes, galaxies and the wider sky**
Elaine Sadler, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Radio Galaxy Zoo**
Julie Banfield, Australian Citizen Science Conference 2015: Maximising the Capacity of Citizen Science for Science and Society, July 2015

**Testing the laws of gravity with cosmological data**
Chris Blake, Theoretical and Observational Progress on Large-scale Structure, Germany, July 2015

**A Pu-pu platter of Swinburne Keck science**
Jeff Cooke, Astrofest 2015, USA, August 2015

**Deeper, wider, faster: detecting the fastest bursts in the sky**
Jeff Cooke, Boutiques and Experiment Surveys, USA, August 2015

**The Murchison Widefield Array: science, future plans and links to SKA developments**
Carole Jackson, International Astronomical Union (IAU), Honolulu, USA, August 2015

**The EoR/CD key science project**
Cathryn Trott, SKA Key Science Workshop, Sweden, August 2015

**A focus on the ingenuity of humankind to better understand our place in the Universe**
Brian Schmidt, Annual Meeting of New Champions World Economic Forum, China, September 2015

**The MWA Epoch of Reionisation experiment**
Rachel Webster, Astronomy Society of Japan Meeting, Japan, September 2015

**Australian astronomy and space science synergies: an opportunity for the future**
Brian Schmidt, Australian Space Research Conference Opening Address, September 2015

**Australian UV-sensitive synoptic imaging explore**
Jeff Cooke, Subaru-Keck Synergy Workshop, Japan, September 2015

**Probing the Epoch of Reionisation with supernovae**
Jeff Cooke, Subaru-Keck Synergy Workshop, Japan, September 2015

**Big Data and Big Astronomy**
Brian Schmidt, Astronomical Data Analysis Software and Systems (ADASS) 2015, Australia, October 2015

**Contributing to global issues**
Brian Schmidt, Australian Institute of International Affairs National Conference, Australia, October 2015

**Science is awesome**
Brian Schmidt, Skeptics Convention, Australia, October 2015

**Nurturing the next generation of Nobel Laureates**
Brian Schmidt, The World Academic Summit, Australia, October 2015

**Observational strategies for SKA-Low**
Cathryn Trott, EoR SWG Workshop, Groningen, The Netherlands, October 2015

**Observing the dark: cosmological constraints on gravity theory**
Tamara Davis, Information Universe, The Netherlands, October 2015

**Supernova cosmology: how to move forward**
Brad Tucker, BashFest 2015, Austin, Texas, USA, October 2015

**MWA surveys**
Carole Jackson, The many facets of Extragalactic Radio Surveys: Towards new scientific challenges, Bologna, Italy, October 2015

**Breaking the wall of the dark cosmos: how astronomy explores the past, present and future of the Universe**
Brian Schmidt, Falling Walls conference Berlin, Germany, November 2015

**KEGS: The Kepler extra-galactic survey**
Brad Tucker, K2SciCon, Santa Barbara, California, USA, November 2015

**Tully-Fisher Relations in the SKA era**
Martin Meyer, SKA in Seoul: Asia-Pacific Regional Workshop on H I Science, South Korea, November 2015

**Opening address**
Tamara Davis, Australasian Conference on GR and Gravitation, Australia, December 2015

**Gas in galaxies: the perspective of semi-analytic models and hydro simulations**
Claudia Lagos, ALPACA workshop, Tokyo, Japan, December 2015

**MWA update: status and plans**
Randall Wayth, Science at Low Frequencies II, Albuquerque, USA, December 2015

**BIGHORNS status and results**
Marcin Sokolowski, Science at Low Frequencies II, Albuquerque, USA, December 2015

**Future options for SKA-scale astronomical computing**
Attila Popping, Second ngVLA Technical Workshop, Socorro, USA, December 2015

## Other Presentations 2015

**(Conferences, workshops, colloquia, projects, collaborations)**

**Comparing the 2MTF and 6dFGS peculiar velocity surveys to models from redshift surveys**
Chris Springob, American Astronomical Society Meeting, USA, January 2015

**Origin of cosmic chemical abundances**
Edoardo Tescari, ANITA 2015 Astroinformatics School, Australia, February 2015

**Modelling thermonuclear SNe from different progenitor systems**
Ivo Seitenzahl, ANITA 2015 Astroinformatics School, Australia, February 2015

**Big problems in astrophysics**
Brian Schmidt, CoEPP Workshop keynote talk via Google Hangouts, Hobart, Australia, February 2015

**Kinematically offset AGN: binary supermassive black holes?**
James Allen, Massive Galaxies and their Precursors, Sydney, Australia, February 2015

**Massive galaxies and their precursors**
Lisa Fogarty, Massive Galaxies and their Precursors, Sydney, Australia, February 2015

**The link between structure and kinematics in massive early-type galaxies from 6dFGS and SAMI**
Matthew Colless, Massive Galaxies and their Precursors, Sydney, Australia, February 2015

**Nebular spectra of Type Ia supernovae**
Mike Childress, PESSTO Collaboration Meeting, Cambridge, UK, February 2015

**The COSMOS H I Large Extragalactic Survey (CHILES)**
Attila Popping, 2015 PHISCC Workshop: H I Surveys Get Real, New Jersey, USA, March 2015

**Strongly lensed H I: a game changer?**
Danail Obreschkow, 2015 PHISCC Workshop: H I Surveys Get Real, New Jersey, USA, March 2015

**GMRT observation of H I gas in the COSMOS field at z ~ 0.37**
Jonghwan Rhee, 2015 PHISCC Workshop: H I Surveys Get Real, New Jersey, USA, March 2015

**H I-multiwavelength synergies: connecting the baryons**
Martin Meyer, 2015 PHISCC Workshop: H I Surveys Get Real, New Jersey, USA, March 2015

**Extended Tully-Fisher relations using H I stacking**
Scott Meyer, 2015 PHISCC Workshop: H I Surveys Get Real, New Jersey, USA, March 2015

**2D tilted-ring fitting of disk galaxies in large H I galaxy surveys**
Se-Heon Oh, 2015 PHISCC Workshop: H I Surveys Get Real, New Jersey, USA, March 2015

**Can mergers drive galaxy morphology in low-mass clusters (groups)?**
Michael Drinkwater, Simulated Galaxy Clusters Workshop, Perth, Australia, March 2015

**Can mergers drive galaxy morphology in low-mass clusters (groups)?**
Simon Deeley, Simulated Galaxy Clusters Workshop, Perth, Australia, March 2015

***nIFTy* galaxy cluster simulations: the baryon effects**
Weiguang Cui, Simulated Galaxy Clusters Workshop, Perth, Australia, March 2015

**Peculiar velocities science case**
Chris Springob, TAIPAN Collaboration Meeting, Australia, March 2015

**Widefield radio astronomy and the dynamic Universe**
Bryan Gaensler, Tools for Astronomical Big Data, Tucson, USA, March 2015

**Cities, climate and civilisation**
Brian Schmidt, 4th Nobel Laureate Symposium on Global Sustainability, Hong Kong, April 2015

**HECTOR: overview**
Julia Bryant, HECTOR Science Workshop, North Ryde, Australia, April 2015

**OzDES reverberation mapping project: simulations and year 3 target selection**
Anthea King, OzDES/2dfLens group meeting at Swinburne University, Melbourne, Australia, April 2015

**SkyMapper: DES cross-calibration**
Bonnie Zhang, OzDES/2dfLens group meeting at Swinburne University, Melbourne, Australia, April 2015

**Photo-Zs from 2dFLenS for SkyMapper and ATLAS**
Christian Wolf, OzDES/2dfLens group meeting at Swinburne University, Melbourne, Australia, April 2015

**Testing modified gravity with cosmological data: existing results and future prospects**
David Parkinson, OzDES/2dfLens group meeting at Swinburne University, Melbourne, Australia, April 2015

**Gravitational signals from noise in the Hubble diagram**
Edward Macaulay, OzDES/2dfLens group meeting at Swinburne University, Melbourne, Australia, April 2015

**DES supernova survey**
Mike Childress, OzDES/2dfLens group meeting at Swinburne University, Melbourne, Australia, April 2015

**First Results of the COMOS H I Large Extragalactic Survey (CHILES)**
Attila Popping, OzSKA: radio astronomy in the next decade, Melbourne, Australia, April 2015

**Cosmology with the SKA**
Chris Blake, OzSKA: radio astronomy in the next decade, Melbourne, Australia, April 2015

**Probing photoionisation feedback**
Hansik Kim, OzSKA: radio astronomy in the next decade, Melbourne, Australia, April 2015

**What the SKA can tell us about dark matter**
Katie Mack, OzSKA: radio astronomy in the next decade, Melbourne, Australia, April 2015

**Intensity mapping with the SKA**
Laura Wolz, OzSKA: radio astronomy in the next decade, Melbourne, Australia, April 2015

**H I surveys in the era of SKA1**
Lister Staveley-Smith, OzSKA: radio astronomy in the next decade, Melbourne, Australia, April 2015

**Low frequency pulsar astronomy with the MWA and SKA-Low**
Ramesh Bhat, OzSKA: radio astronomy in the next decade, Melbourne, Australia, April 2015

**SKA-low and the aperture array verification system**
Randall Wayth, OzSKA: radio astronomy in the next decade, Melbourne, Australia, April 2015

**Ionospheric Calibration of SKA-Low**
Cathryn Trott, SKA-Low Calibration Consultation Workshop, Manchester, UK, April 2015

**Young and Frustrated: studying GPS/CSS sources with the MWA**
Joseph Callingham, 5th Workshop on Compact Steep Spectrum and GHz-Peaked Spectrum Radio Sources, Rimini, Italy, May 2015

**Gravitational signals from noise in the Hubble diagram**
Edward Macaulay, DES Collaboration meeting, Michigan, USA, May 2015

**KEGS: the Kepler Extra-Galactic Survey**
Brad Tucker, Hotwiring the Transient Universe IV, USA, May 2015

**Resolving the signatures of environmental quenching with SAMI**
Adam Schaefer, Multiwavelength Dissection of Galaxies, Sydney, Australia, May 2015

**The Cosmos H I Large Extragalactic Survey**
Attila Popping, Multiwavelength Dissection of Galaxies, Sydney, Australia, May 2015

**Dissecting Galaxies with ELTs**
Matthew Colless, Multiwavelength Dissection of Galaxies, Sydney, Australia, May 2015

**Stellar metallicity gradients with SAMI**
Nicholas Scott, Multiwavelength Dissection of Galaxies, Sydney, Australia, May 2015

**Star formation in nearby galaxies: combining IFS and radio data**
Sarah Leslie, Multiwavelength Dissection of Galaxies, Sydney, Australia, May 2015

**KEGS and MegaSH0ES: Gemini and Keck**
Brad Tucker, The 2015 Australian Gemini, Magellan and Keck Science Symposium, Australia, May 2015

**Observing the EoR with Low-frequency Aperture Arrays**
Cathryn Trott, The Olympian Symposium: Cosmology and the Epoch of Reionisation, Mt Olympus, Greece, May 2015

**The MWA EoR experiment: status and challenges**
Rachel Webster, The Olympian Symposium: Cosmology and the Epoch of Reionisation, Mt Olympus, Greece, May 2015

**FRD of starbugs and HECTOR update**
Julia Bryant, AAO Instrument Science Meeting, North Ryde, Australia, June 2015

**The true nature of kinematically offset AGN**
James Allen, Black Hole Accretion and AGN Feedback, Shanghai, China, June 2015

**How metallicity influences the evolution and rate of Type Ia supernovae**
Ashley Ruiter, European Week of Astronomy and Space-Science (EWASS), Spain, June 2015

**Nucleosynthesis constraints on the progenitors of Type Ia supernovae**
Ivo Seitenzahl, European Week of Astronomy and Space-Science (EWASS), Spain, June 2015

**KEGS: the Kepler Extra-Galactic Survey**
Brad Tucker, Fifty One Erg 2015, USA, June 2015

**Direct measurements of the spatial extent of high redshift DLAs using galaxy spectra**
Jeff Cooke, IGM@50: Is the Intergalatic Medium Driving Star Formation?, Italy, June 2015

**Dangerous liaisons: asymmetry in gas kinematics in the SAMI galaxy survey**
Jessica Bloom, Many Pathways to Galaxy Growth Conference, Prato, Italy, June 2015

**Stellar metallicity gradients with SAMI**
Nicholas Scott, Many Pathways to Galaxy Growth Conference, Prato, Italy, June 2015

**The many views of galaxy growth from SAMI**
Scott Croom, Many Pathways to Galaxy Growth Conference, Prato, Italy, June 2015

**Using the moon to detect the global EoR signal with the MWA**
Benjamin McKinley, MWA Technical Meeting, Melbourne, Australia, June 2015

**Searching for flaring brown dwarfs with The MWA**
Christene Lynch, MWA Technical Meeting, Melbourne, Australia, June 2015

**Polarisation and the MWA**
Emil Lenc, MWA Technical Meeting, Melbourne, Australia, June 2015

**Foreground models for the EoR1 field**
Pietro Procopio, MWA Technical Meeting, Melbourne, Australia, June 2015

**EoR: results from CHIPS/RTS**
Rachel Webster, MWA Technical Meeting, Melbourne, Australia, June 2015

**MWA GLEAM GEG-RG science update**
Carole Jackson, MWA Technical Meeting, Perth, Australia, June 2015

**Pulsar science with the MWA**
Ramesh Bhat, MWA Technical Meeting, Perth, Australia, June 2015

**GLEAM status**
Randall Wayth, MWA Technical Meeting, Perth, Australia, June 2015

**Probing diffuse linear polarisation with the MWA**
Emil Lenc, Origin, Evolution, and Signatures of Cosmological Magnetic Fields, Stockholm, Sweden, June 2015

**Metals in absorption at the conclusion of reionziation**
Emma Ryan-Weber, Reionzation: A multiwavlength Approach, South Africa, June 2015

**Lyman continuum galaxies**
Jeff Cooke, Reionzation: A Multiwavlength Approach, South Africa, June 2015

**Resolving the role of environment in quenching star formation with SAMI**
Adam Schaefer, A 3D view on Galaxy Evolution: from Statistics to Physics, Heidelberg, Germany, July 2015

**Stellar populations within galaxies: an IFU perspective**
Nic Scott, A 3D view on Galaxy Evolution: from Statistics to Physics, Heidelberg, Germany, July 2015

**Australian UV-sensitive synoptic imaging explorer**
Jeff Cooke, AAO - North Ryde, Australia, July 2015

**Gravitational signals from noise in the Hubble diagram**
Edward Macaulay, Accurate Astrophysics. Correct Cosmology, UK, July 2015

**Intensity mapping cross-correlations: connecting the largest scales to galaxy evolution**
Laura Wolz, Accurate Astrophysics. Correct Cosmology, UK, July 2015

**A personal view of my recent years in academia**
Ashley Ruiter, ASA Women In Astronomy Workshop, Australia, July 2015

**Tricky situations**
Brian Schmidt, ASA Women In Astronomy Workshop, Australia, July 2015

**The redshift evolution of the comoving mass density of MgII**
Alex Codoreanu, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Radio Galaxy Zoo: the hunt for hybrid morphology radio galaxies**
Anna Kapinska, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**The MWA EOR Experiment**
Bart Pindor, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**A window to the past: measuring the Universe's early evolution using lunar occultations**
Benjamin McKinley, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**The first data release of SkyMapper's southern sky survey**
Chris Onken, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Comparing the 2MTF and 6dFGS peculiar velocity surveys to models from redshift surveys**
Chris Springob, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Revealing ultracool dwarf magnetic activity through multifrequency radio observations**
Christene Lynch, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**The 2-degree Field Lensing Survey (2dFLenS)**
David Parkinson, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Chasing optical counterparts to the fastest bursts in the sky**
Igor Andreoni, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**PUMA: Smarter cross matching for calibration of radio data and source finding**
Jack Line, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**The galactic latitude dependence on FRB rates explained**
Jean-Pierre Macquart, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**ATESE: An ATCA survey for Extreme Scattering Events**
Keith Bannister, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Diagnosing hydrogen reionisation with metal absorption line ratios**
Luz Angela Garcia, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Impact of the ionosphere on ground-based detection of the global Epoch of Reionisation**
Marcin Sokolowski, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Deep H I surveys in the SKA era**
Martin Meyer, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Giant Magellan Telescope progress report**
Matthew Colless, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Source finding for the GLEAM catalogue**
Paul Hancock, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**MWA observations of timing-array millisecond pulsars**
Ramesh Bhat, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**GLEAM**
Randall Wayth, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**The SAMI galaxy survey: triggering and quenching of star formation**
Scott Croom, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Bright galaxies at z ~ 9–10 from Hubble Space Telescope observations**
Stephanie Bernard, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Observing millisecond pulsars with the MWA: applying coherent de-dispersion to polarimetric tied array beams**
Stephen Ord, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**The Murchison Widefield Array: project and science update after two years of operations**
Steven Tingay, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Low frequency single pulse astrophysics with the MWA**
Steven Tremblay, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**The accretion history of dark matter halos**
Stuart Wyithe, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**The impact of hosts on type Ia supernovae cosmology**
Syed Uddin, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Exploring neutral hydrogen in galaxies across 8 billion years using ASKAP-BETA**
Vanessa Moss, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**The evolving role of the AAO over the next decade**
Warrick Couch, Astronomical Society of Australia Annual Scientific Meeting (ASA 2015), Australia, July 2015

**Developing skills for astronomy and beyond**
Carole Jackson, Harley Wood School for Astronomy (HWSA), Australia, July 2015

**Statistics in astronomy**
David Parkinson, Harley Wood School for Astronomy (HWSA), Australia, July 2015

**Simulations: supernovae and polluting the ISM**
Edoardo Tescari, Harley Wood School for Astronomy (HWSA), Australia, July 2015

**FRBs and multiwavelength follow up**
Jeff Cooke, Harley Wood School for Astronomy (HWSA), Australia, July 2015

**High-resolution mass models of LITTLE THINGS**
Se-Heon Oh, H I in dwarf galaxies, Sydney, Australia, July 2015

**The MWA and pulsar timing arrays**
Ramesh Bhat, International Pulsar Timing Array 2015 Science Meeting, Leura, Australia, July 2015

**Gravitational signals from noise in the Hubble diagram**
Edward Macaulay, National Astronomy Meeting, UK, July 2015

**Searching for flaring ultracool dwarfs with the MWA**
Christene Lynch, Oxford Transient Workshop, Oxford, UK, July 2015

**Direct Shear Mapping: The first technique for measuring weak gravitational lensing directly**
Catherine de Burgh-Day, Royal Society of Victoria Young Scientist Research Prize Finals, Australia, July 2015

**Improving reconstruction of the baryon acoustic peak: the effect of local environment**
Ixandra Achitouv, Theoretical and Observational Progress on Large-scale Structure, Munich, Germany, July 2015

**Does metallicity influence the evolution and rate of Type Ia supernovae?**
Ashley Ruiter, Carnegie SN Ia Progenitor Workshop, USA, August 2015

**Nucleosynthesis constraints on the progenitors of SNe Ia**
Ivo Seitenzahl, Carnegie SN Ia Progenitor Workshop , USA, August 2015

**On the formation of elliptical galaxies via mergers in galaxy groups**
Dan Taranu, International Astronomical Union XXIX General Assembly, USA, August 2015

**H I galaxy science with the SKA**
Martin Meyer, International Astronomical Union XXIX General Assembly, USA, August 2015

**The SAMI survey: a baseline study for galaxy evolution**
Matthew Colless, International Astronomical Union XXIX General Assembly, USA, August 2015

**The Kunlun infrared sky survey**
Jeremy Mould, Scientific Committee on Arctic Research AAA, Hawaii, USA, August 2015

**Performance of SKA1**
Attila Popping, SKA Key Science Workshop, Stockholm, Sweden, August 2015

**SKA band definitions**
Lister Staveley-Smith, SKA Key Science Workshop, Stockholm, Sweden, August 2015

**H I galaxy science with the SKA**
Martin Meyer, SKA Key Science Workshop, Stockholm, Sweden, August 2015

**The origin of the fundamental plane**
Dan Taranu, ICRAR Con annual retreat, Australia, September 2015

**Parkes H I intensity mapping experiment at z ~ 0.9**
Jonghwan Rhee, ICRAR Con annual retreat, Australia, September 2015

**Robust statistical analysis of the clump structure of disk galaxies**
Kamran Ali, ICRAR Con annual retreat, Australia, September 2015

**The hidden Universe**
Lister Staveley-Smith, ICRAR Con annual retreat, Australia, September 2015

**MWA and Pulsara**
Ramesh Bhat, ICRAR Con annual retreat, Australia, September 2015

**Extended Tully-Fisher relations using H I stacking**
Scott Meyer, ICRAR Con annual retreat, Australia, September 2015

**Galaxy kinematics in the SKA era**
Se-Heon Oh, ICRAR Con annual retreat, Australia, September 2015

**A simple distribution for the halo mass function**
Steven Murray, ICRAR Con annual retreat, Australia, September 2015

**How gas feeds galaxies with a phased array feed**
Attila Popping, Life Cycle of Gas in Galaxies, Dwingeloo, The Netherlands, September 2015

**FRB searches with UTMOST**
Manisha Caleb, Caltech-Swinburne Transient workshop, Australia, October 2015

**Lensing effects on supernovae: noise, bias, and signal**
Tamara Davis, Dark Energy Survey Collaboration Meeting, Spain, October 2015

**OzDES Year 2 report**
Tamara Davis, Dark Energy Survey Collaboration Meeting, Spain, October 2015

**Reverberation Mapping Update and interesting QSO spectra**
Tamara Davis, Dark Energy Survey Collaboration Meeting, Spain, October 2015

**OzDES and clusters**
Tamara Davis, Dark Energy Survey Collaboration Meeting, Spain, October 2015

**Polarisation Studies with the MWA**
Emil Lenc, MWA SHI Busy Week, Curtin University, Perth, Australia, October 2015

**How to Use Twitter for Good (and science)**
Katie Mack, ICRAR Science Communication Workshop, Australia, October 2015

**Deeper, Wider, Faster: Detecting the fastest bursts in the sky**
Jeff Cooke, University of Illinois, USA, October 2015

**ICRAR/Curtin Science**
Cathryn Trott, Advancing towards SKA, Perth, Australia, October 2015

**Developing data processing pipelines for massive sky surveys: lessons learned from SkyMapper**
Chris Wolf, ADASS XXV, Australia, November 2015

**An infrared search for satellite orbital debris**
Greg Madsen, ADASS XXV, Australia, November 2015

**Real-time searching for fast radio bursts and other radio transients using the UTMOST telescope**
Matthew Bailes, ADASS XXV, Australia, November 2015

**SAMI galaxy survey: environmental quenching of star formation in galaxies**
Adam Schaefer, CAASTRO 5th Annual Retreat, Australia, November 2015

**The new complete sample of radio galaxies at 200 MHz from GLEAM MWA radio survey**
Anna Kapinska, CAASTRO 5th Annual Retreat, Australia, November 2015

**Binary star evolution and the birth of transient events.**
Ashley Ruiter, CAASTRO 5th Annual Retreat, Australia, November 2015

**MWA EoR experiment**
Bart Pindor, CAASTRO 5th Annual Retreat, Australia, November 2015

**The Kepler Extra-galactic Survey (KEGS)**
Brad Tucker, CAASTRO 5th Annual Retreat, Australia, November 2015

**The EoR power spectrum**
Cathryn Trott, CAASTRO 5th Annual Retreat, Australia, November 2015

**OzDes: Current progress and preliminary results**
Chris Lidman, CAASTRO 5th Annual Retreat, Australia, November 2015

**SkyMapper data release 1**
Christian Wolf, CAASTRO 5th Annual Retreat, Australia, November 2015

**Revealing magnetic activity in the coolest stellar objects using multi-frequency radio observations**
Christene Lynch, CAASTRO 5th Annual Retreat, Australia, November 2015

**New methods for estimating the statistical errors in large scale structure surveys**
Cullan Howlett, CAASTRO 5th Annual Retreat, Australia, November 2015

**Modelling and simulating SAMI galaxies**
Dan Taranu, CAASTRO 5th Annual Retreat, Australia, November 2015

**Low angular momentum in clumpy, turbulent disks**
Danail Obreschkow, CAASTRO 5th Annual Retreat, Australia, November 2015

**Measuring $\sigma_8$ with supernovae**
Edward Macaulay, CAASTRO 5th Annual Retreat, Australia, November 2015

**Deeper Wider Faster: optical counterparts to the fastest bursts in the sky**
Igor Andreoni, CAASTRO 5th Annual Retreat, Australia, November 2015

**Modelling thermonuclear supernovae from different progenitor systems: explosion simulations, nucleosynthesis, observables**
Ivo Seitenzahl, CAASTRO 5th Annual Retreat, Australia, November 2015

**Improving reconstruction of the baryon acoustic peak: the effect of local environment**
Ixandra Achitouv, CAASTRO 5th Annual Retreat, Australia, November 2015

**Direct spectroscopic detection of <912Å ionising photons from z~3 galaxies**
Jeff Cooke, CAASTRO 5th Annual Retreat, Australia, November 2015

**Using shapelets to subtract bright foregrounds for the MWA**
Jennifer Riding, CAASTRO 5th Annual Retreat, Australia, November 2015

**The low radio frequency view of gigahertz-peaked spectrum and compact steep spectrum sources**
Joe Callingham, CAASTRO 5th Annual Retreat, Australia, November 2015

**Radio Galaxy Zoo**
Julie Banfield, CAASTRO 5th Annual Retreat, Australia, November 2015

**Probing Information beyond matter power spectrum**
Kamran Ali, CAASTRO 5th Annual Retreat, Australia, November 2015

**Australia's first dark matter direct-detection experiment**
Katie Mack, CAASTRO 5th Annual Retreat, Australia, November 2015

**Intensity mapping cross correlations: connecting the largest scales to galaxy evolution**
Laura Wolz, CAASTRO 5th Annual Retreat, Australia, November 2015

**The variability properties of the Southern Hemisphere image plane pulsars at low frequencies**
Martin Bell, CAASTRO 5th Annual Retreat, Australia, November 2015

**Least squares fitting with correlated noise**
Paul Hancock, CAASTRO 5th Annual Retreat, Australia, November 2015

**Science highlights from high-sensitivity pulsar observations with the MWA**
Samuel McSweeney, CAASTRO 5th Annual Retreat, Australia, November 2015

**Star formation in the local Universe**
Sarah Leslie, CAASTRO 5th Annual Retreat, Australia, November 2015

**H I emission- and absorption-line studies of nearby galaxies**
Sarah Reeves, CAASTRO 5th Annual Retreat, Australia, November 2015

**Searching and localisation of the sources of dispensed radio emission**
Shivani Bhandari, CAASTRO 5th Annual Retreat, Australia, November 2015

**The evolution of deuterium**
Signe Riemer-Sorensen, CAASTRO 5th Annual Retreat, Australia, November 2015

**How elliptical galaxies grow in galaxy groups**
Simon Deeley, CAASTRO 5th Annual Retreat, Australia, November 2015

**Bright galaxies at z~9–10 with the brightest reionising galaxies survey**
Stephanie Bernard, CAASTRO 5th Annual Retreat, Australia, November 2015

**Influences of the host galaxies in supernova cosmology**
Syed Uddin, CAASTRO 5th Annual Retreat, Australia, November 2015

**FLASH with ASKAP-BETA: recent discoveries of neutral hydrogen absorption at high redshift**
Vanessa Moss, CAASTRO 5th Annual Retreat, Australia, November 2015

**The statistics of low frequency radio interference at the Murchison Radio-astronomy Observatory**
Marcin Sokolowski, GEMCCON 2015, IEEE Global Electromagnetic Compatibility Conference, Adelaide, Australia, November 2015

**Incidence of galactic outflows at low redshift: EAGLE simulations vs SAMI observations**
Edoardo Tescari, SAMI Simulations busy week, Sydney, Australia, November 2015

**Stacking galaxies with SKA pathfinders**
Attila Popping, SKA in Seoul, South Korea, November 2015

**The H I mass function as a probe of photoionisation feedback on low-mass galaxy formation**
Hansik Kim, SKA in Seoul, South Korea, November 2015

**Parkes H I intensity mapping experiment at z~0.9**
Jonghwan Rhee, SKA in Seoul, South Korea, November 2015

**The Arecibo ultra-deep survey**
Lister Staveley-Smith, SKA in Seoul, South Korea, November 2015

**Dark matter cores in dwarf galaxies**
Se-Heon Oh, SKA in Seoul, South Korea, November 2015

**Google Loon Ultra-Violet**
Brad Tucker, 5th Exoplanet Workshop, Sydney, Australia, December 2015

**Modelling galaxy formation and reionisation with DRAGONS**
Stuart Wyithe, Cosmology and First Light conference, Paris, France, December 2015

**Hunting for optical counterparts of FRBs**
Fang Yuan, Molonglo Reborn the dawn of a new era of discovery, Australia, December 2015

**FRB searches with UTMOST**
Manisha Caleb, Molonglo Reborn the dawn of a new era of discovery, Australia, December 2015

**OzPipe: the Australian MWA EOR pipeline**
Bart Pindor, MWA Project Meeting 2015, Toronto, Canada, December 2015

**MWA GLEAM Galactic and extragalactic science update**
Carole Jackson, MWA Project Meeting 2015, Toronto, Canada, December 2015

**Probing diffuse linear polarisation with the MWA**
Emil Lenc, MWA Project Meeting 2015, Toronto, Canada, December 2015

**The effects of positional precision in foreground removal**
Jack Line, MWA Project Meeting 2015, Toronto, Canada, December 2015

**The Murchison Widefield Array and pulsar timing arrays**
Ramesh Bhat, MWA Project Meeting 2015, Toronto, Canada, December 2015

**Single-pulse studies with the MWA**
Steven Tremblay, MWA Project Meeting 2015, Toronto, Canada, December 2015

**Chasing low frequency radio bursts from magnetically active stars**
Christene Lynch, Science at Low Frequencies II, Alburquerque, USA, December 2015

**The effects of positional precision in foreground removal**
Jack Line, Science at Low Frequencies II, Alburquerque, USA, December 2015

**Dying young and frustrated: studying GPS and CSS sources with the MWA**
Joe Callingham, Science at Low Frequencies II, Alburquerque, USA, December 2015

**Pulsars and fast transients with the MWA**
Steven Tremblay, Science at Low Frequencies II, Alburquerque, USA, December 2015

## Public Lectures 2015

**Science experience**
University of Queensland, Brisbane, Tamara Davis, January 2015

**Exploring the last frontier: Australia's capability in astronomy and astrophysics**
The Warren Centre, University of Sydney, Sydney, Brian Schmidt, February 2015

**The future of science**
Canberra Skeptics, Questacon, Canberra, Brian Schmidt, February 2015

**Spinning the cosmic web in a supercomputer**
Scitech, Perth, Emma Webber-Ryan, February 2015

**Engineering sensors for vision of the cosmos**
19th Sir C.V. Raman Memorial lecture, Bengaluru, India, Ravi Subrahmanyan, February 2015

**A tour of the Universe and selected cosmic mysteries**
Swinburne University, Melbourne, Katie Mack, March 2015

**Big is beautiful: why surveys are crucial for astronomy**
Macarthur Astronomical Society, Sydney, James Allen, March 2015

**How the Universe will get us in the end**
Dunlap Institute, Toronto, Canada, Bryan Gaensler, March 2015

**From the solar system to the edge of the Universe**
Uluru *Astronomer in Residence* seminar, Uluru, Jacinta den Besten, April 2015

**Keynote address**
Aspiring Women in Science, Brisbane, Tamara Davis, April 2015

**How the Universe grew up**
Swinburne University, Melbourne, Karl Glazebrook, April 2015

**Accelerating Universe**
Uluru *Astronomer in Residence* seminar, Uluru, Conor O'Neill, April 2015

**Public talk**
Mount Burnett Observatory, Melbourne, Vikram Ravi, April 2015

**Explosions and collisions in space**
Mount Stromlo Observatory, Canberra, Brad Tucker, April, May and June 2015

**Surveying the southern skies with the SkyMapper telescope**
Morris Loeb Lecture in Harvard, Boston, USA, Brian Schmidt, April 2015

**Type Ia supernovae, the accelerating cosmos, and dark energy**
Morris Loeb Lecture in Harvard, Boston, USA, Brian Schmidt, April 2015

**From the Big Bang to Uluru: the journey of a single atom**
Uluru *Astronomer in Residence* seminar, Uluru, Alex Codoreanu, April and May 2015

**After the dark ages: the first stars**
Morris Loeb Lecture in Harvard, Boston, USA, Brian Schmidt, April 2015

**Mapping the dark matter**
Gran Sasso Laboratory, Gran Sasso, Italy, Jeremy Mould, May 2015

**Observatories of Chile**
Swinburne University, Swinburne, Jeremy Mould, May 2015

**Warp drives and bending time**
Science fiction meets science fact, Academy of Science, Canberra, Tamara Davis, May 2015

**Things that go bump in the night - though radio eyes**
Uluru *Astronomer in Residence* seminar, Uluru, Manisha Caleb, May 2015

**The power of simple questions**
TEDxSydney, Sydney, Alan Duffy, May 2015

**How the cosmos will kill you**
Missassauga, Canada, Bryan Gaensler, May 2015

**The story of light: the astronomer's perspective**
ViVid Sydney, Sydney, Joss Bland-Hawthorn and Keith Bannister, May 2015

**Data for good**
ViVid Sydney, Sydney, Alan Duffy, May 2015

**Making the invisible visible: scintillation, turbulence, and radio astronomy**
Uluru *Astronomer in Residence* seminar, Uluru, Paul Hancock, May 2015

**What does an Innovation Policy Look Like**
ATSE Clunies Ross Award, Brisbane, Brian Schmidt, May 2015

**Australia's Place in the Future World of Science**
Australian Institute of International Affairs, Sydney, Brian Schmidt, June 2015

**Black holes and supercomputers**
Uluru *Astronomer in Residence* seminar, Uluru, Edoardo Tescari, June 2015

**Astronomy in the blink of an eye**
Swinburne University, Melbourne, Emily Petroff, June 2015

**What if we lived in a different solar system?**
Boroondara Libraries, Melbourne, Alex Codoreanu, June 2015

**The current status of the cosmological standard model**
Uluru *Astronomer in Residence* seminar, Uluru, Luz Angela Garcia, June 2015

**Origins of life**
Sydney Opera House, Sydney, Rachel Webster, June 2015

**Origins of life**
The Wheeler Centre, Melbourne, Rachel Webster, June 2015

**Mt Stromlo Observatory: past, present, and future**
Canberra Central Probus Club, Canberra, Brad Tucker, July 2015

**Exploding stars, dark energy, and the end of the Universe**
International Summer School, Australian National University, Canberra, Brad Tucker, July 2015

**The dark side of the Universe**
IEEE Women in Engineering talk, Brisbane, Tamara Davis, July 2015

**Accreting super-massive blackholes - the monsters at the centre of galaxies**
Uluru *Astronomer in Residence* seminar, Uluru, Rebecca McElroy, July 2015

**Supernova and cosmology**
RSAA Winter School Students, Canberra, Brad Tucker, July 2015

**Exploding stars, dark energy, and the end of the Universe**
Woden Sunrise Rotary Club Talk, Canberra, Brad Tucker, July 2015

**ConocoPhillips Science Experience lecture**
University of Queensland, Brisbane, Tamara Davis, July 2015

**The Universe in a nutshell: stars, galaxies, black holes and more**
Women in Astronomy, Brisbane, Tamara Davis, July 2015

**Astronomy for Fun: Introduction to Astronomy**
Mount Stromlo Observatory, Canberra, Brad Tucker, July 2015

**What can exploding stars tell us about the fate of the Universe?**
Uluru *Astronomer in Residence* seminar, Uluru, Bonnie Zhang, July 2015

**Distant light: reading the signals from the oldest light in the Universe**
Elisabeth Murdoch Theatre, University of Melbourne, Melbourne, Stuart Wyithe, July 2015

**Spiders in the outback and their view of plasma tubes in the sky**
SpaceNet, University of Sydney, Sydney, Cleo Loi, July 2015

**Three big questions for astronomy**
George Collins Oration, Swinburne, Melbourne, Brian Schmidt, July 2015

**Astronomy for Fun: Stars**
Mount Stromlo Observatory, Canberra, Brian Schmidt, July 2015

**Future of humanity, future of you**
Festival of Ambitious Ideas, Canberra, Brian Schmidt, July 2015

**SkyLab: lines of sight and forces of attraction**
Counihan Gallery, Brunswick, Melbourne, Alan Duffy, July 2015

**The dark side of the Universe**
Science Teachers Dinner, Brisbane, Tamara Davis, August 2015

**Revealing magnetic activity in the coolest stellar objects**
Sydney Observatory, Sydney, Christene Lynch, August 2015

**Stairways to Heaven: the coolest science happening right now**
Uluru *Astronomer in Residence* seminar, Uluru, Jessica Bloom, August 2015

**Birth of a spider army: The next generation of radio telescopes and their unique view of the sky**
Sutherland Astronomical Society, Sydney, Cleo Loi , August 2015

**Pulsars and gravitational waves**
Curtin University, Perth, Ramesh Bhat, August 2015

**Findings of the new horizons mission**
USA Embassy, Science in the Pub, Canberra, Brian Schmidt, Alan Duffy and Glen Nagle, August 2015

**Friends of science public forum: are we alone?**
National Library of Australia, Canberra, Brian Schmidt, August 2015

**Astronomy for Fun: Planets**
Mount Stromlo Observatory, Canberra, Brad Tucker, August 2015

**Scientists in schools**
Telopea Park, Canberra, Brad Tucker, August 2015

**Mt Stromlo Observatory: past, present, and future**
St Vincent de Paul Society, Canberra, Brad Tucker, August 2015

**Opening speech**
Neil de Grasse Tyson event, Brisbane, Tamara Davis, August 2015

**The revolution in radio astronomy**
NSW Chief Scientist Research Breakfast, Canberra, Elaine Sadler, August 2015

**Exploding stars, dark energy, and the end of the Universe**
Albury Science Festival, Albury, Brad Tucker, August 2015

**After-dinner speech**
Cromwell College Academic Dinner, Brisbane, Tamara Davis, August 2015

**Using light to discover the dark**
International Year of Light event, University of Southern Queensland, Brisbane, Tamara Davis, August 2015

**Astronomy for Fun: Galaxies**
Mount Stromlo Observatory, Canberra, Brad Tucker, August 2015

**Accelerating Universe**
World Record Stargazing Night, Australia National University, Canberra, Brian Schmidt, August 2015

**Space jam: stars, galaxies and more**
Museum of Applied Arts and Sciences, Sydney, Katie Mack, August 2015

**Galaxies and black holes**
Uluru *Astronomer in Residence* seminar, Uluru, Roger Davies, August 2015

**Astronomy for Fun: Cosmology**
Mount Stromlo Observatory, Canberra, Brad Tucker, August 2015

**Pluto flyby**
Swinburne University, Swinburne, Jeff Cooke, September 2015

**Intermediate-mass black holes in dwarf galaxies**
Sutherland Astronomical Society, Sydney, Aina Musaeva, September 2015

**Galaxies and black holes**
Swinburne University, Melbourne, Roger Davies, September 2015

**Space debris, space lasers at Mt Stromlo Observatory**
Australian Institute of Entertainment Lecture, Canberra, Brad Tucker, September 2015

**Exploring galaxy evolution: beyond the optical**
Uluru *Astronomer in Residence* seminar, Uluru, Marcin Glowacki, September 2015

**Space research capabilities of the next generation of radio telescopes**
Space Weather Services, Bureau of Meteorology, Sydney, Cleo Loi, September 2015

**Mt Stromlo Observatory: past, present, and future**
Ginninderra Rotary Club, Canberra, Brad Tucker, September 2015

**The Big Bang machine, the Universe and you**
Laby Theatre, University of Melbourne, Melbourne, Katie Mack and Suzie Sheeny, September 2015

**ConocoPhillips Science Experience lecture**
Australian National University, Canberra, Brad Tucker, September 2015

**Big Universe, big telescopes!**
Uluru *Astronomer in Residence* seminar, Uluru, Samuel Richards, September 2015

**The life and death of stars**
Mount Stromlo Observatory, Canberra, Ashley Ruiter, September 2015

**National mentoring for science and mathematics**
Mount Stromlo Observatory, Canberra, Brad Tucker, September 2015

**Taming the cosmic fireworks: how to (not) win a Nobel Prize**
Uluru *Astronomer in Residence* seminar, Uluru, Christian Wolf, October 2015

**Public talk**
Siding Spring Open Day, Coonabarabran, Matthew Colless, October 2015

**ANU Tomorrow**
Australian National University, Canberra, Brian Schmidt, October 2015

**Bush fires and bugs: why we map the Southern Sky and why it is still a challenge**
Uluru *Astronomer in Residence* seminar, Uluru, Christian Wolf, October 2015

**Everyone can change the world**
Wesley College, the University of Sydney Dinner, Canberra, Brian Schmidt, October 2015

**Exploding stars, rotating neutron stars and big telescopes**
Uluru *Astronomer in Residence* seminar, Uluru, Fabian Jankowski, October 2015

**Cosmology and Dark Energy**
Queensland Astronomical Association, Brisbane, Edward McCauley, October 2015

**Exploding stars**
Astronomy on Tap: Austin, Texas, USA, Brad Tucker, October 2015

**Tune into the skies: how to do cosmology in the radio**
Swinburne University, Melbourne, Laura Wolz, October 2015

**How to grow a galaxy**
Uluru *Astronomer in Residence* seminar, Uluru, Sarah Reeves, October and November 2015

**Does the Universe have a memory?**
Interrobang, The Wheeler Centre, Melbourne, Alan Duffy, November 2015

**The Accelerating Universe**
University of Southampton, Southampton, UK, Brian Schmidt, November 2015

**Science: why is it basically the coolest thing ever? Especially astrophysics**
University of Melbourne, Melbourne, Catherine deBurgh-Day, November 2015

**Public talk**
Mount Stromlo Christmas Seminars, Canberra, Vanessa Moss, December 2015

**Leadership and organisational culture**
IP Australia, Canberra, Brian Schmidt, December 2015

## International Visitors to CAASTRO in 2015

**Mohammad Akhlaghi**
Tohoku University, Japan

**Per Andersen**
University of Copenhagen, Denmark

**Jim Benford**
Microwave Sciences California, USA

**Richard Bower**
Durham University, UK

**Michele Cappelari**
University of Oxford, USA

**Claire Cashmore**
University of Leicester, UK

**Steve Croft**
University of California Berkeley, USA

**Daniel Cunnama**
University of Western Cape, South Africa

**Roger Davies**
University of Oxford, UK

**David Kaplan**
University of Wisconsin, USA

**Madhura Killedar**
Ludwig Maxmillians Universität, Germany

**Alex Kim**
Lawrence Berkeley National Laboratory, USA

**Alexander Knebe**
Universidad Autonoma de Madrid, Spain

**Rubina Kotak**
Queen's University Belfast, Northern Ireland

**Tom Kuiper**
Jet Propulsion Laboratory, NASA, USA

**Federico Lelli,**
Case Reserve Western University, USA

**Kai Marquardt**
University of Würzburg, Germany

**Stuart Muldrew**
University of Leicester, UK

**Sebastian Ohlmann,**
Heidelberg Institute for Theoretical Studies, Germany

**Lyndsay Old**
University of Nottingham, UK

**Santiago Avila Perez**
Unversidad Autonoma de Madrid, Spain

**Signe Riemer-Sørensen**
University of Oslo, Norway

**Friedrich Röpke**
Heidelberg Institute for Theoretical Studies, Germany

**Federico Sembolini**
Universidad Autonoma de Madrid, Spain

**Fergus Simpson**
University of Barcelona, Spain

**Paul Sutter**
Astronomical Observatory of Trieste (INAF), Italy

**Robert Thacker**
St Mary's University, Canada

**Patrick Tisserand**
Institut d'Astrophysique de Paris, France

**Meg Urry**
Yale University, USA

**Gustavo Yepes**
Universidad Autonoma de Madrid, Spain


**Mayuri Sathyanarayana Rao visited EPO in 2015**
***Credit: Mayuri Sathyanarayana Rao***

## Visits to overseas laboratories and facilities in 2015

**Vanessa Moss**
Adler Planetarium, USA

**Vanessa Moss**
ASTRON, The Netherlands

**Elaine Sadler**
ASTRON, The Netherlands

**Lister Staveley-Smith**
ASTRON, The Netherlands

**Ben McKinley**
ASTRON, The Netherlands

**Rachel Webster**
Astronomy Society of Japan, Konan University, Japan

**Brian Schmidt**
Beijing Planetarium, China

**Igor Andreoni**
Caltech, CA, USA

**Matthew Bailes**
Caltech, CA, USA

**Stephanie Bernard**
Caltech, CA, USA

**Shivani Bhandari**
Caltech, CA, USA

**Jeff Cooke**
Caltech, CA, USA

**Chris Curtin**
Caltech, CA, USA

**Jack Line**
Caltech, CA, USA

**Brad Tucker**
Caltech, CA, USA

**Vivek Venkatraman**
Caltech, CA, USA

**Bart Pindor**
Caltech, CA, USA

**Richard Scalzo**
Cambridge University, UK

**Edward Macaulay**
Case Western Reserve University, USA

**Rachel Webster**
City University of New York, USA

**Martin Meyer**
Columbia University, USA

**Attila Popping**
Columbia University, USA

**Chris Springob**
Cornell University, USA

**Bryan Gaensler**
Dominion Radio Astronomy Observatory, Penticton, Canada

**Joe Callingham**
Dunlap Institute, Toronto, Canada

**Jack Line**
Dunlap Institute, Toronto, Canada

**Mahsa Rahimi**
Dunlap Institute, Toronto, Canada

**Rachel Webster**
Dunlap Institute, Toronto, Canada

**Bart Pindor**
Dunlap Institute, Toronto, Canada

**James Allen**
Durham University, UK

**Mike Childress**
European Southern Observatory (ESO), Garching, Germany

**Vanessa Moss**
European Southern Observatory (ESO), Garching, Germany

**Richard Scalzo**
European Southern Observatory (ESO), Garching, Germany

**Ivo Seitenzahl**
European Southern Observatory (ESO), Garching, Germany

**Laura Wolz**
European Southern Observatory (ESO), Garching, Germany

**Ashley Ruiter**
European Southern Observatory (ESO), Garching, Germany

**Brian Schmidt**
Federico Santa María Technical University Valparaiso Chile, Chile

**Ramesh Bhat**
Giant Metrewave Radio Telescope, Khodad India, India

**Jack Line**
Giant Metrewavelength Radio Telescope, India

**Jennifer Riding**
Giant Metrewavelength Radio Telescope, India

**Brad Tucker**
Google, USA

**Jeremy Mould**
Gran Sasso Laboratory, Italy

**Brian Schmidt**
Harvard University, USA

**Jeremy Mould**
Hong Kong University, China

**Brian Schmidt**
Humboldt University of Berlin, Germany

**James Allen**
Imperial College London, UK

**Cathryn Trott**
Imperial College London, UK

**Andrew Johnson**
Imperial College London, UK

**Ixandra Achitouv**
Institut d'astrophysique de Paris (IAP), Paris, France

**Stuart Wyithe**
Institut d'astrophysique de Paris (IAP), Paris, France

**Ben McKinley**
Kapteyn Astronomical Institute, The Netherlands

**Lister Staveley-Smith**
Kavli Institute for Astronomy and Astrophysics at Peking University, China

**Emily Petroff**
La Serena, Chile

**Tamara Davis**
Lawrence Berkeley Laboratory, San Francisco, USA

**Vanessa Moss**
Leiden University, The Netherlands

**Brian Schmidt**
Liverpool John Moores University, UK

**Laura Wolz**
Ludwig-Maximilians-Universität, Germany

**Adam Schaefer**
Max Planck Institute for Extraterrestrial Physics, Garching, Germany

**Aina Musaeva**
Max Planck Institute for Extraterrestrial Physics, Garching, Germany

**Nic Scott**
Max Planck Institute of Astronomy, Germany

**Bryan Gaensler**
McGill University, Canada

**Brian Schmidt**
Millennium Institute of Astrophysics (MAS) Chile, Chile

**Jessica Bloom**
Monash University Prato Centre, Italy

**Scott Croom**
Monash University Prato Centre, Italy

**Michael Drinkwater**
Monash University Prato Centre, Italy

**Nic Scott**
Monash University Prato Centre, Italy

**Brad Tucker**
NASA Ames Research Center, CA, USA

**Cleo Loi**
NASA Goddard, Washington DC, USA

**Kate Gunn**
National Astronomical Observatories, Chinese Academy of Sciences, China

**Elaine Sadler**
National Astronomical Observatories, Chinese Academy of Sciences, China

**Brian Schmidt**
National Astronomical Observatories, Chinese Academy of Sciences, China

**Lister Staveley-Smith**
National Astronomical Observatories, Chinese Academy of Sciences, China

**Cleo Loi**
National Geospatial-intelligence Agency, Washington DC, USA

**Joe Callingham**
National Radio Astronomy Observatory, Sorroco, USA

**Mayuri Sathyanarayana Rao**
National Radio Astronomy Observatory, Sorroco, USA

**Mayuri Sathyanarayana Rao**
National Radio Astronomy Observatory, Sorroco, USA

**Attila Popping**
National Radio Astronomy Observatory, Sorroco, USA

**Bryan Gaensler**
National Research Council, Victoria, Canada

**Jamie Farnes**
Nordic Institute for Theoretical Physics, NORDITA, Stockholm, Sweden

**Bryan Gaensler**
Nordic Institute for Theoretical Physics, NORDITA, Stockholm, Sweden

**Emil Lenc**
Nordic Institute for Theoretical Physics, NORDITA, Stockholm, Sweden

**Ivo Seitenzahl**
North Carolina State University, NC, USA

**Brad Tucker**
North Carolina State University, NC, USA

**Ashley Ruiter**
North Carolina State University, NC, USA

**Edward Macaulay**
Ohio State University, OH, USA

**Christene Lynch**
Oxford University, UK

**Andrew Johnson**
Oxford University, UK

**Brian Schmidt**
Peking University, China

**Edward Macaulay**
Perimeter Institute for Theoretical Physics, USA

**Brian Schmidt**
Pontifical Catholic University of Valparaíso Chile, Chile

**Richard Scalzo**
Queen's University Belfast, UK

**Mayuri Sathyanarayana Rao**
Raman Research Insitute, Bangalore, India

**Martin Meyer**
Rutgers University, USA

**Se-Heon Oh**
Rutgers University, USA

**Lister Staveley-Smith**
Rutgers University, USA

**Attila Popping**
Rutgers University, USA

**Bryan Gaensler**
SKA Office, UK

**Ewan Barr**
SKA South Africa, South Africa

**Willem van Straten**
SKA South Africa, South Africa

**Emil Lenc**
SKA Telescope, Canada

**Brad Tucker**
Texas A&M University, USA

**Cathryn Trott**
The Olympian Symposium, Paralia, Greece

**Diane Salim**
Third La Serena School for Data Science, Chile

**Kate Gunn**
Tsunghua University, China

**Laura Wolz**
Universitäts-Sternwarte München, Germany

**James Allen**
University College London, UK

**Andrew Johnson**
University College London, UK

**Jeremy Mould**
University of Athens, Greece

**Bryan Gaensler**
University of British Columbia, Vancouver, Canada

**Rachel Webster**
University of California, Irvine, USA

**Brad Tucker**
University of California, Santa Barbara, USA

**James Allen**
University of Cambridge, UK

**Tamara Davis**
University of Copenhagen, Denmark

**James Allen**
University of Edinburgh, Scotland

**Andrew Johnson**
University of Edinburgh, UK

**Cathryn Trott**
University of Groningen, The Netherlands

**James Allen**
University of Hertferdshire, UK

**Jeff Cooke**
University of Illinois, Urbana-Champaign, USA

**Randall Wayth**
University of Malta, Malta

**Joe Callingham**
University of New Mexico, NM, USA

**Emil Lenc**
University of New Mexico, NM, USA

**Christene Lynch**
University of New Mexico, NM, USA

**James Allen**
University of Oxford, UK

**Richard Scalzo**
University of Oxford, UK

**James Allen**
University of Portsmouth, UK

**James Allen**
University of Southampton, UK

**Mike Childress**
University of Southampton, UK

**Richard Scalzo**
University of Southampton, UK

**Brian Schmidt**
University of Southampton, UK

**Ivo Seitenzahl**
University of Southampton, UK

**Bonnie Zhang**
University of Southampton, UK

**Ashley Ruiter**
University of Southampton, UK

**Brad Tucker**
University of Texas, Austin, USA

**Alex Codoreanu**
University of Texas, Austin, USA

**Angela Garcia**
University of Texas, Austin, USA

**Jean-Pierre Macquart**
University of Toronto, Canada

**Emil Lenc**
University of Toronto, Canada

**Vanessa Moss**
University of Victoria, Canada

**Brian Schmidt**
Universtiy of Concepción Chile, Chile

**Mayuri Sathyanarayana Rao**
Very Large Array, NM, USA

**Martin Meyer**
Yonsei University, KASI, South Korea

**Se-Heon Oh**
Yonsei University, KASI, South Korea

**Attila Popping**
Yonsei University, KASI, South Korea

**Elaine Sadler**
University of Vienna, Austria

# WORKSHOPS

**CAASTRO hosted a number of interesting, well-attended and stimulating workshops during 2015.**

## Simulated Galaxy Workshop

The first CAASTRO workshop for 2015, the *Simulated Galaxy Cluster Comparison Workshop*, was held in Perth at ICRAR/UWA during 23–27 March.

This workshop built on the foundation laid by the *nIFTy* cosmology workshop in 2014. It had two aims. The first was to continue working on the comparison of astrophysical codes, studying the properties of the same cosmologically simulated galaxy cluster with 12 state-of-the-art codes. By comparing results obtained with different codes, we can better understand how predictions vary depending on the code used and the assumed galaxy-formation model. This is important when comparing predictions against observations, and for understanding how two models can predict similar galaxy-cluster properties while invoking fundamentally different physical processes. The workshop's second aim was to compare the results of these state-of-the-art codes with observed galaxy clusters.

The workshop kicked off with an overview of the main results from the code comparison to date and of the kind of observational datasets that simulations should be compared with.

The early sessions were on simulations. The highlight was a talk showing that a previous discrepancy between mesh and particle (SPH-based) approaches had been resolved, with modern SPH codes now predicting entropy profiles in agreement with those of both mesh-based and moving mesh code. Other standout talks included a look at how simulated datasets can help us understand how the dynamical state of clusters influences estimates of cluster masses; work on strong lensing and how the simulated clusters can be used to investigate systematic biases in reconstruction of mass distributions; and a comparison of galaxy and subhalo properties in simulated datasets that model the physics of galaxy formation.

Following sessions focussed on observations. Speakers surveyed the properties of brightest cluster galaxies (BCGs) and showed how existing predictions from galaxy-formation models in the literature fared against observational data; looked at individual clusters and the signs of galaxy transformation; examined the red sequence in high-redshift galaxy clusters, and showed how the simulated data could be used to gain a deeper insight into the physics driving the evolution of this population; and explored how cosmological simulations using simple assumptions for assigning galaxy type can be used to understand the morphological distribution of galaxies in groups and clusters.

After the talks, it was down to work: groups formed to pursue new projects with the simulated data. Three broad projects were settled on: creating software to generate synthetic observations from the simulations in the form of optical images and X-ray, gravitational lensing and Sunyaev-Zel'dovich maps; an investigation of the properties of BCGs at $z = 0$ and their assembly since high redshift; and an examination of the different processes that drive galaxy transformation in cluster environments. The participants found a quiet spot, downloaded data, and started to analyse it, making interesting plots and writing useful code. We had updates on the following days and good progress was made in a number of areas.

The workshop fostered collaborations and initiated some new publications. At the end of the week we had three draft papers, plus plots that formed the basis for three or four more. The most pleasing aspect of the workshop was the coming together of simulators, modellers and observers to work on joint projects. The observers learned what can and can't be done with simulated datasets, and the simulators and modellers learned what can be recovered from observations. The workshop was a great success, and the collaborations it generated will continue into the future.

**Women in Astronomy Panel I - Jessica Bloom, Meg Urry, Brian Schmidt, Elaine Sadler, and Andrew Hopkins**
***Credit: CAASTRO***

## OzSKA: radio astronomy in the next decade

Over 8–10 April, the School of Physics at the University of Melbourne hosted the CAASTRO *OzSKA: radio astronomy in the next decade* workshop.

The Square Kilometer Array (SKA), the world's largest radio telescope, is to be built in Australia and South Africa. It heralds a new era in radio astronomy. This workshop provided an opportunity to explore the new science that will be possible with the increased sensitivity from this telescope, with a particular emphasis on exploring opportunities for young scientists to become engaged with new projects and ideas.

The science themes explored included the formation of the first stars and galaxies, galaxy evolution, cosmic magnetism, the nature of gravity and exploring life beyond Earth. Other topics included the impact of enabling technologies, including the processing and management of 'big data', new signal-processing and detector technologies and the role of 'blue sky' science in the education of our wider community. As the future custodians and users of this new infrastructure, young researchers were particularly encouraged to attend and contribute their ideas.

The three-day meeting included an excellent line-up of younger speakers and the attendance of key people from the SKA Office (Robert Braun), Department of Industry (David Luchetti), SKA key representative (Sarah Pearce), Chair of the ANZSCC Science Advisory Committee (Carole Jackson) and the outgoing SKA Director (Brian Boyle). Most key figures in Australian radio astronomy were able to attend for most of the workshop.

The topics covered included the basics of the Australian SKA site and organisation (such as how the MWA and ASKAP relate to the SKA) and core science interests, such as the Epoch of Reionisation/Cosmic Dawn, cosmology, magnetism and the Milky Way, transients and pulsars, the 'Cradle of Life', continuum surveys, and the detection of neutral hydrogen (H I).

The participants engaged in lively, early discussions on how the proposed scientific programs might be re-structured to take account of the re-baselining of the SKA. The involvement of our colleagues from the New Zealand astronomical community was appreciated and valuable. Excellent discussions were held on potential science engagement by the Australian Community in SKA1, the first phase of the SKA. Participants also discussed the role of the Australian SKA Pathfinder in the SKA1 era.

There was a pleasant workshop dinner on the Thursday night, and an opportunity to acknowledge Brian Boyle's outstanding contribution to the community in his years of service around the SKA. And, of course, the workshop's success was due to excellent organisation by the Melbourne and Sydney CAASTRO offices.


**Chris Blake, CAASTRO CI, speaking at the OzSKA Workshop**
***Credit: Emil Lenc***

**Participants of the pulsar scintillometry workshop in front of the 46-m antenna at Algonquin Radio Observatory in Canada**
***Credit: Franz Kirsten***

**Women in Astronomy Conference, University of Queensland**
***Credit: CAASTRO***

## Pulsar Scintillometry Workshop

Over 25–28 April 2015 a workshop on pulsar scintillometry was held at the Algonquin Radio Observatory (ARO) in the middle of the Algonquin Provincial Park, Canada. The event attracted not only members from the international scientific community but also representatives of industry. There was a mixture of theoreticians (Pen, Macquart, van Kerkwijk), observers (Antoniadis, Kirsten, Newburgh), engineers (Quine, Tsouvaltsidis, Roberts), and a number of students. This allowed for input from different perspectives in the lively discussions.

The contributed presentations and discussions at the workshops covered a focussed range of topics. The first was the observational characteristics and the physical explanations of pulsar scintillation. The scintillation is usually explained as diffraction caused by turbulent thin over-or-under-densities in the interstellar medium but, as was discussed, the data can be equally well explained by the refraction of light at current sheets.

Data-analysis methods were a second major topic. In addition to holographic techniques we discussed Schur's algorithm and Toeplitz matrix decomposition as a means for phase retrieval and image reconstruction in pulsar scintillometry. Also of major interest were the techniques and implementation of cyclic spectroscopy as a means to de-scatter and improve signal-to-noise ratio.

The development of appropriate software tools was another big issue. Astronomers are observing with many different telescopes that deliver data in different formats, and so we need to develop software that can handle all of them in a coherent fashion. Marten van Kerkwijk has already written a volume of suitable code, and our discussion focused mostly on how to improve that code and what other functionality will be required in the future.

Finally, we identified several other pulsars that we would like to observe with VLBI (very long baseline interferometry) for scintillometry studies: J1737+13, B1133+16 and Vela. Observations of these will aim at resolving the pulsars' emission regions.

A highlight of the workshop was the observations of the Crab nebula that ran in parallel on the Giant Metrewave Radio Telescope in India, the 13-m dish at Jodrell Bank in the UK, and the ARO dish. At ARO, two of our students (Ni and Liu) stayed up all night to run the observations. This workshop was fun, productive and effective.

## Women in Astronomy Workshop

The Annual *ASA Women in Astronomy Workshop* was held during 22–23 July 2015, at Women's College at the University of Queensland. This year it was organised by CAASTRO. For two days 90 members of the astronomical community met to discuss unconscious bias, dealing with conflict, voice projection, and the challenges faced by members affected by mental health issues, among other issues.

Inspiring presentations were given by Professor Meg Urry (Yale, President of the American Astronomical Society), Professor Judy Raper (Deputy Vice-Chancellor Research, University of Wollongong), Dr Sue Meek (CEO, Australian Academy of Science), Professor Polly Parker (Professor in Leadership, University of Queensland) and Louise McSorley (Acting Director of the Workplace Gender Equality Agency). A representative from *Beyond Blue* shared her very personal story of how anxiety and depression had shaped her life, and Professor Brian Schmidt (Australian National University) again created much discussion and debate with his challenging conversation session.

The workshop was followed by an amazing outreach event, *The Universe in a Nutshell*, showcasing the talents of four world-renowned female astronomers, Professor Meg Urry (Yale), Professor Tamara Davis (University of Queensland), Dr Lisa Harvey-Smith (CSIRO) and Dr Amanda Bauer (AAO). Dr Alan Duffy (Swinburne) chaired the event, which consisted of four short lectures followed by a 45-minute panel question-and-answer session. The event attracted over 200 people and the program was extended by an hour to accommodate all the audience questions.

**Cutting the ribbon to relaunch the Molonglo Observatory telescope. L-R: Professor Elaine Sadler, Director, ARC Centre of Excellence for All-sky Astrophysics; Mr Albert Wong, President, Physics Foundation, University of Sydney; Professor Anne Green, Professor of Astrophysics, University of Sydney; Professor Matthew Bailes, Australian Laureate Fellow, Swinburne University of Technology; The Hon. Dr Peter Hendy MP, Assistant Minister for Productivity and Member for Eden-Monaro (with scissors); Professor Aleksandar Subic, Deputy Vice Chancellor-Research and Development, Swinburne University; Professor Duncan Iverson, Deputy Vice Chancellor-Research, University of Sydney; Dr Lewis Ball, Director, CSIRO Astronomy and Space Science.**
***Credit: Nick Smith***

## Molonglo Reborn: Dawn of New Era of Discovery

On 3 December the University of Sydney's Molonglo Observatory hosted *Molonglo Reborn*, an event to celebrate both Molonglo's history and its future: the 50th anniversary of its opening in November 1965, and the upgrade that has put it on a new path for hunting transient sources, particularly pulsars and fast radio bursts. The 80-strong crowd included past and present students who have used the telescope; staff who have kept the place running over the years; members of the families of Bernard (Bernie) Mills and Michael Large (University of Sydney academics who were highly involved with the telescope); researchers from Swinburne University and the Australian National University who had worked on the upgrade; and other astronomers, academics and VIPs.

The Hon Dr Peter Hendy MP, the Federal MP for Eden-Monaro and Assistant Minister for Productivity, launched the telescope into its new role in both low-tech and high-tech ways, cutting a ribbon and tapping an iPad screen to start the telescope acquiring a pulsar signal. Professor Anne Green (University of Sydney) presided over the event as Master of Ceremonies, and the University of Sydney's Professor Duncan Ivison (Deputy Vice Chancellor, Research) and Swinburne University's Professor Aleksandar Subic (Deputy Vice Chancellor, Research and Development) spoke about the telescope from the point of view of their respective institutions. Albert Wong, President of the University of Sydney's Physics Foundation described the contribution of the late Professor Harry Messel, who was primarily responsible for the telescope's existence: he had recruited Professor Mills, the telescope's designer, to the University; negotiated the purchase of the land on which it stands; and facilitated a grant for the project from the US National Science Foundation.

The morning's formalities were followed by lunch and an afternoon of talks about science, past and future; those who wanted to had a look-see at the new technology in the control building. The telescope has kept its basic structure but acquired a new backend: a cluster of signal-processing computers that incorporate off-the-shelf graphics processing cards (GPUs). These can handle up to 22 gigabytes of data per second, and in the course of a year will process almost an exabyte ($10^{18}$ bytes). This backend is a landmark instrument; one of the first that can remove unwanted radio signals (from mobile phones, for instance) from the telescope's observations in real time. It can search simultaneously for pulsars and fast radio bursts. The revamped telescope has already discovered three pulsar glitches, massive discontinuities in the rotation of young neutron stars.

**Professor Anne Green, University of Sydney, being interviewed by the ABC**
***Credit: Nick Smith***

**Molonglo 50th anniversary event guests**
***Credit: Nick Smith***

**ADASS XXV Conference delegates in Sydney**
***Credit: Andy Green***


# CONFERENCES



**ADASS XXV optional activity, the Sydney Harbour Bridge Climb**
***Credit: Bridge Climb***

**Delegates at the ADASS XXV Conference in Sydney**
***Credit:***

## ADASS XXV 25-29 OCTOBER 2016

This year the annual *Astronomical Data Analysis Software and Systems (ADASS)* meeting was held in the southern hemisphere for the first time to celebrate its 25th anniversary. Three hundred scientists from 24 countries met in Sydney in the Rydges World Square for four and a half days of astronomy and software.

Key themes for this year's ADASS were: knowledge-discovery and data-management tools for astronomical Big Data; the Large Synoptic Survey Telescope, and lessons learned from current programs; algorithms for astronomical data reduction; real-time processing; visualisation and innovative user interfaces; and data pipelines. The conference kicked off with an inspiring keynote presentation by Professor Hugh Durrant-Whyte (University of Sydney) titled "Data, Knowledge and Discovery: Machine Learning Meets Natural Science". There were numerous presentations on interesting new programs, tools and facilities, including ESA's Astronomy Multi-Mission Interface and ESAsky, advanced metadata facilities in ADS, the Aladin HIPS tool for visualising large sky-area datasets using *healpix*, and the HST source catalogue.

Professor Brian Schmidt (Australian National University) addressed the international audience on the second day of the conference: his talk on the importance of unifying data standards in astronomy, and the pioneering efforts by ADASS participants in this area, was extremely well received. His attendance at the conference (and networking at the event) was much appreciated by delegates.

There were many presentations discussing details of current and upcoming observational programs that will generate massive volumes of data. Storing, accessing, processing and visualising big astronomical datasets was a common theme. Another was effective use of cloud-computing resources, and the emerging set of tools to deploy and manage astronomical data-processing systems in the cloud.

Delegates to ADASS were treated to fine Sydney weather and wonderful scenery. The conference 'welcome event' at historic Sydney Observatory, with a lovely backdrop of the harbour and Harbour Bridge, was equalled only by the amazing conference dinner at Luna Park, overlooking picturesque Milson's Point.

# ANNUAL RETREAT

**16–18 November 2015**

An early morning walk in the Blue Mountains
*Credit: Kate Gunn*

CAASTRO staff at the Annual Retreat
*Credit: Markus Jaaskelainen*

The 2015 CAASTRO Annual Retreat was held over three days at the Fairmont Resort in the Blue Mountains of New South Wales, on the edge of the beautiful Jamison Valley. As CAASTRO is a distributed Centre, spread across seven Australian universities and our national and international partner institutes, our Annual Retreat helps us to build and strengthen our connections by meeting together in one place.

Many CAASTRO members came, and we enjoyed peaceful surroundings, fine weather and a wide range of activities. Special thanks go to those who travelled long distances to attend, to our overseas guest speakers Vernesa Smolcic and Alex Kim, and to our inspiring breakfast speaker, Professor Nalini Joshi, who spoke eloquently on gender issues and the *Science in Australia Gender Equity* (SAGE) initiative.

The overall message was that CAASTRO is now mature both in research as well as processes. So too are most of its big survey projects, such as SAMI and GLEAM, and these are now beginning to bear fruit. The Epoch of Reionisation projects still have a way to go, but good progress was made this year in characterising and/or removing contaminating signals and setting up pipelines.

In cosmology, many people are working to get better value from their survey data, for instance by improving the BAO reconstruction (Ixandra Achitouv) and error estimates (Cullan Howlett). A number of new approaches are being tried: to the construction of a Hubble diagram (Chris Lidman), finding superluminous supernovae (Chris Curtin), modelling supernovae (Ivo Seitenzahl, Ashley Ruiter), following up fast radio bursts (Igor Andreoni), understanding the role of angular momentum in galaxy evolution (Danail Obreschkow) and explaining the absorption mechanism in gigahertz-peaked-spectrum sources (Joe Callingham).

And there was news: of the citizen-science project Radio Galaxy Zoo, of funding for the Dark Matter direct-detection experiment in the gold mine at Stawell (page 29), and of progress in understanding fast radio bursts (page 14).

CAASTRO is now more than a year past its halfway point, and the Executive and Advisory Board have been discussing strategies to maximise the long-term impact and legacy of our Centre. At the same time, we are keen to identify and support new initiatives wherever possible.

At this year's Retreat we held the first CAASTRO Innovation Challenge, in which small groups were invited to develop and pitch ideas that were innovative and could potentially be developed into a marketable product. As we had hoped, there was an enthusiastic response and some excellent ideas. In 2016 we will be providing resources and mentors to allow some of these groups to develop their concepts in more detail.

At every CAASTRO Annual Retreat, we schedule formal and informal time for our mentors and mentees to have face-to-face discussions. In 2015 we re-introduced 'speed mentoring' at the Annual Retreat to increase the mentoring opportunities for those who chose to participate.

Cullan Howlett was awarded the unofficial prize for Equation of the Week for his 10-line, page-filling expression for theoretical covariance. When her PowerPoint presentation failed, Cath Trott undauntedly explained the Epoch of Reionisation signal without a single picture. And combining the cerebral with the physical, the CAASTRO 'special activity' was an orienteering-meets-quiz event in the Great Outdoors.

In winding up the Retreat, CAASTRO Director Elaine Sadler urged everyone to "keep doing what you're doing" and also to think about the legacy CAASTRO should leave, and work towards that. "Finish up with no regrets," she said.

Once again, it was a very successful and enjoyable meeting, thanks to the efforts of the CAASTRO Executive, the A-team and, particularly, Kylie Williams.

# EDUCATION & OUTREACH

## Capturing the cosmos, and the audience

This year, we powered ahead with the production of our planetarium show, *Capturing the Cosmos*, in collaboration with Museum Victoria (MV). By the end of August, the CAASTRO and MV teams had worked through feedback from the public and agreed on a final script that was then presented to world-famous actor and 2012 Australian of the Year, Geoffrey Rush, for narration. His engaging voice now perfectly accompanies the stunning visuals created by the planetarium team, led by Dr Tanya Hill. Both the CAASTRO Executive and the Advisory Board were able to see a preview of the near-final show at Scitech during their respective visits to Perth in late 2015.

By the end of the year, our visualisation of astronomical data from SkyMapper and the Murchison Widefield Array had advanced so well that only finishing touches had to be made. While this was happening, the MV public relations team, together with CAASTRO Education and Outreach Manager Dr Wiebke Ebeling and outreach Affiliate Jacinta den Besten, started organising the national launch event for the show. This is now scheduled for 21 March 2016. CAASTRO member, Nobel Laureate and new Vice Chancellor of the Australian National University, Professor Brian Schmidt, will give a short keynote speech at the main Melbourne event. The show will be distributed free of charge to all members of the Australasian Planetarium Society ahead of the launch date, so that simultaneous screenings can be held across the country. Based on the annual attendance of affiliated planetaria, we expect to reach an audience of up to half a million people in Australia and New Zealand alone.

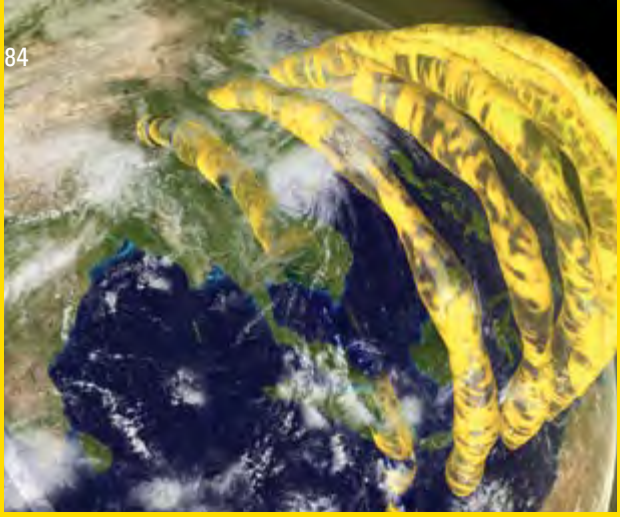
In a related project, a CAASTRO team composed of Wiebke Ebeling, Jacinta den Besten and Jennifer Lynch started working together with MV Program Coordinator of Astronomy and Space Sciences, Patricia Christies, to create educational resources. The aim is to provide a set of hands-on and digital resources that can be easily adopted by science teachers as a classroom activity and which are linked to the Australian curriculum.

CAASTRO is assisting by contributing images and videos, expert advice and our new collection of student profiles, *Bright Stars*. All resources will also be available to the *CAASTRO in the Classroom* and the University of Melbourne's *Telescopes in Schools* outreach programs, to increase uptake and re-use of the material.

## Our students' research in the spotlight

Two CAASTRO press releases dominated our media coverage in 2015, both portraying the fantastic work done by our student members. In January, Swinburne PhD student Emily Petroff's first-ever observation of a fast radio burst in real time landed her headline news, a number of interviews on major local, national and international media outlets – including live on ABC24 – and her own episode of SBS's *The Feed*. Emily's subsequent detective work, published in May, to identify the origin of 'perytons' at the CSIRO Parkes radio telescope immediately catapulted her name back into the public domain. In October, she won Swinburne's *3-Minute Thesis* (3MT) competition with her presentation 'Astronomy in the blink of an eye: The fastest events in the universe'. Emily submitted her PhD thesis in late 2015 with an impressive eight peer-reviewed publications under her belt. She will commence her post-doctoral work at ASTRON in the Netherlands in 2016.

In June we had another media star: our Honours student, Cleo Loi, who had been supervised by CAASTRO Chief Investigator Tara Murphy at the University of Sydney. We produced a press release for her paper on tubular plasma structures as imaged by the Murchison Widefield Array. Immediately it got fantastic traction. Within the first 48 hours, the story had become the eighth most read story in *The Sydney Morning Herald* online with 50,000 views, and had received 173,000 views on *news.com.au* and 400,000 views on Fairfax sites overall. Posts to the Facebook page 'I f***ing love science' generated over 130,000 'Likes'. An instrumental part of this huge success, and an excellent confirmation of our digital media strategy, was the use of video material. Our accompanying in-house production, led by Education and Outreach Manager Wiebke Ebeling, cracked the mark of one million views after six weeks, and numerous spin-off videos appeared on YouTube, some of which have also attracted tens of thousands of views. Tara Murphy's follow-up article in *The Conversation*, explaining the story behind the discovery, found 50,000 readers in the first two weeks alone, and even the three short technical videos that we published in support of her article attracted over 8,000 views. Cleo received many requests to speak to students and to other professional and general audiences and was even invited to visit the US National Geospatial Intelligence Agency and NASA



**Still frame from the exceptionally successful "Cosmic Cinema" Video Press Release for former CAASTRO Honours student Cleo Loi.**
***Credit: CAASTRO, Mats Björklund (Magipics)***

**CAASTRO's Jack Line and Dr Ben McKinley joined forces with Mount Burnett Observatory for the MWA tile display at the Melbourne *Astronomy and Light Festival***
***Credit: Roslyn Gupta***

in September. She was also awarded the *Bok Prize* of the Astronomical Society of Australia "for outstanding research in astronomy by an Honours student", won the 2015 Canon Extreme Imaging Competition in the open category, and was named one of the 'Top 25 under 25' by TripleJ. We trust that Cleo will continue to impress with her creative and analytical thinking at the University of Cambridge, where she started her PhD project in late 2015.

## Successful boost to "CAASTRO in the Classroom"


***CAASTRO in the Classroom* session about Special Relativity by CAASTRO PhD student Joe Callingham (University of Sydney).**
***Credit: Jennifer Lynch***

This year, we were successful in winning a grant from the Commonwealth Government Australian Maths and Science Partnership Program (AMSPP) to expand our *CAASTRO in the Classroom* video-conferenced seminar series. We are using the funding to make the series go national and map it to the Australian curriculum, offer teachers professional development, and create additional educational resources. In June 2015, we employed our new Schools Education Officer Jennifer Lynch (University of Sydney) to work towards these goals, and her expertise and drive had an immediate positive impact on the program. *CAASTRO in the Classroom* seminars have been coordinated with the help of our postdoc Dr Vanessa Moss (University of Sydney) and the New South Wales Department of Education (through its DART (Distance And Rural Technologies) Connections portal). Nine sessions were offered in 2015, to a total of 51 schools from across New South Wales, Victoria and the Australian Capital Territory: this means 685 students learned about electromagnetism, special relativity, the Big Bang and other astronomical subjects from our researchers. Many teachers told us that incompatible (or non-existent) technology or scheduling issues stood in the way of them dialing into our live sessions, so we started to make video recordings they could access via the CAASTRO YouTube channel and website. In August, students and teachers from Western and South-Western Sydney had the chance to meet our *CAASTRO in the Classroom* researchers in person, look through a solar telescope and learn about the program at the annual "Science and Maths EXPOsed" event at the University of Western Sydney's Parramatta campus. The event was attended by 1,000 students, most of them in Year 9, and their teachers. At least 200 of the students visited the CAASTRO stand and telescope (both run by Jennifer Lynch and Dr Christene Lynch) and sixteen teachers discussed *CAASTRO in the Classroom* with us.

The AMSPP grant is also funding the employment of science teachers, working on a casual basis at the University of Sydney, who are developing classroom resources to support the teaching of astronomy topics in schools. The first of three teachers to join the project, Neill Dorrington (science, maths and geology), started in November 2015 and will stay with us until March 2016. Two more will start early in 2016, Silvia Choi, science and maths, with an Honours degree in astrophysics from the University of Sydney and Sandra Woodward, science with experience in physics and a keen interest in astrophysics. This new interaction has already generated fantastic additions to the program such as scripts for new animations that will help teachers convey particularly complex topics, for instance muon decay and Doppler shift.

## CAASTRO stars under the outback skies

Our industry partnership with Voyages Indigenous Tourism Australia recorded another busy and successful year. The *Astronomer in Residence* program was in the capable hands of 17 CAASTRO members who worked with CAASTRO outreach Affiliate Mike Dalley and his Ayers Rock Resort Stars Department as part of their nightly star tours and at the information stall in the resort's town square.

Dr Karl's team took out the top prize at the lunchtime trivia quiz at the Uluru Astronomy Weekend.
*Credit: Dr Wiebke Ebeling*

Every participant also gave two seminars, one per week, to a small but enthusiastic audience in the resort's 'Astro Hub'. Many of our Astronomers in Residence have described their participation in the program as very enjoyable and have expressed interest in going back for another stint. The outlet for their short updates and photos, the dedicated Twitter account *@CAASTROatUluru*, now has 130 followers.

Building on the success of the inaugural 2014 event, we organised another Uluru Astronomy Weekend for National Science Week, 14–16 August 2015. Science communication celebrity and Master of Ceremonies Dr Karl Kruzselnicki (University of Sydney) joined our CAASTRO experts Associate Professor Emma Ryan-Weber (Swinburne University) and Professors Steven Tingay (Curtin University), Rachel Webster (University of Melbourne) and Roger Davies (Oxford University) and around 120 astronomy enthusiasts from Australia and overseas. New and popular additions to the weekend's program were the lunchtime trivia quiz (won by Dr Karl's team), the introduction to astrophotography (by Steven Tingay), and the entertaining 'Northern vs Southern hemisphere' debate between Roger Davies and Emma Ryan-Weber during the *Sounds of Silence* dinner experience.

## Astronomy engagement with a winning formula

CAASTRO has always embraced science awareness and public outreach with a healthy balance between face-to-face activities and digital media. Once again, 2015 saw many of our members taking opportunities to share their research with the public through lectures, for example at the *VIVID Light, Music and Ideas Festival* in Sydney in May (Dr Keith Bannister, Professor Joss Bland-Hawthorn, Dr Alan Duffy and Dr Tara Murphy); radio or TV interviews (Dr Duffy, in particular: he has become a fortnightly fixture on ABC News Breakfast); articles in popular science outlets such as *The Conversation* and *COSMOS Magazine;* and of course CAASTRO's very own website stories about current research papers, in which our researchers practise their science writing. In the past year, 40 stories were published on the CAASTRO website, which as a whole attracted just under 100,000 visitors. The stories are also a key contribution to the CAASTRO social media presence, which has reached a sizeable audience: we have more than 1,300 followers on Twitter and over 22,000 "Likes" on Facebook, where every post reaches between several hundred to several thousand users. As well as going online, the first 22 of these research stories (those written between March and July) were printed in the fourth edition of the *CAASTRO Reader's Digest* booklet and distributed to universities, science centres and outreach partners. The fifth edition, for August to December 2015, has been prepared and will be distributed in early 2016.

The Education and Outreach portfolio has always had a collaborative approach at its heart, allowing CAASTRO to allocate resources in a smart way and ensuring that activities are tailored for the needs of the audience. Two very successful partnerships for hands-on astronomy events that have been maintained for a number of years now are *Telescopes in Schools* (whose program coordinator Jacinta den Besten ia a CAASTRO Affiliate) and Mount Burnett Observatory. Together, the collaboration was successful in attracting a National Science Week grant from the federal Government to organise the *Astronomy and Light Festival* (2015 being the International Year of Light) at Melbourne's Scienceworks in August. CAASTRO was a co-sponsor. Several Melbourne-based CAASTRO members helped out on the night, staffing the information stall and the display tile of the Murchison Widefield Array, and Dr Katherine Mack (University of Melbourne) co-presented a talk. This inaugural event proved to be an excellent collaboration and a popular activity during National Science Week, so much so that CAASTRO now aims to run an annual *Melbourne Astrofest,* starting in 2016, and to adopt a similar format for a pilot *Sydney Astrofest*.

Also as part of National Science Week 2015, CAASTRO co-sponsored Mount Stromlo's attempt to break a dual Guinness World Record, which was led by CAASTRO postdoc Dr Brad Tucker. Using this and other sponsorships, the organisers bought small telescopes and distributed them to achieve the most people stargazing at the same location at the same time and the most people stargazing at multiple locations at the same time. CAASTRO's contribution went towards both attempts. Mount Stromlo received telescopes for their main event (which also included a keynote lecture by Professor Brian Schmidt), and *Telescopes in Schools* and Mount Burnett Observatory were supplied with telescopes for their satellite stargazing events. This ambitious endeavor had a very happy ending as Guinness officials confirmed that both attempts were

Dr Wiebke Ebeling demonstrates the MWA outreach tool to students
*Credit: James Campbell*

successful, with 1,869 stargazers at the ANU site and 7,960 people across 37 sites in Australia.

The MWA continued to feature strongly in CAASTRO Education and Outreach, both as a physical object and as the star in digital media. Four new MWA tile displays were deployed across Australia: at Mount Burnett Observatory in Melbourne's eastern fringes (for their Open Day on 23 January); at the Royal Institution of Australia in Adelaide (for an exhibition in April–June); at Perth Observatory (for its re-opening event on 26 September); at the Murchison Settlement in outback Western Australia (for the Murchison Astronomy Festival on 5 September, where CSIRO Affiliate Dr James Allison gave a keynote speech); and at the Penrith Observatory of the University of Western Sydney (October). New signage, showing real results from our postdocs, was produced and distributed to all current display venues. Thousands of visitors saw these displays during the year.

Courtesy of the MWA Collaboration, we were also able to make 20 videos (taken by an aerial drone at the Murchison Radio-astronomy Observatory) available through the CAASTRO YouTube channel: they have received over 800 views. These clips have proven useful for MWA scientists to embed in their presentations but also for CAASTRO's science communication purposes, such as the extraordinarily successful Vide Press Release "Cosmic cinema: astronomers make real-time, 3D movies of plasma tubes drifting overhead" (over 1 million views!) and a special video production for promotion at the 2015 Annual Scientific Meeting of the Astronomical Society of Australia in Fremantle in July (150 views) and the International Astronomical Union General Assembly in Hawai'i in August.

## Strategic thinking and career support

This year, CAASTRO Education and Outreach worked with the University of Sydney Research Development and Collaboration department to run "Looking after yourself and your career", a full-day training program to assist junior CAASTRO members. This workshop attracted about 30 participants – mostly CAASTRO members, plus a few students from the Sydney Institute for Astronomy.

The morning sessions were dedicated to getting participants to think about their career plan, strategic matters such as publications and funding opportunities, and available support resources. A presentation by Penny Oxford of the department was followed by a panel discussion with University of Sydney academics: Professor Thomas Hubble (geology), Dr Elizabeth New (chemistry), Professor Renae Ryan (pharmacology; also Chair of the Sydney Medical School Gender Equity Committee) and Professor Michael Thompson (biology). The panelists were very generous with their advice and their time, and their comments triggered lively discussion. The afternoon sessions were led by Philip Pryor from *Morphthink*, who provided tips on time and stress management, guided the group through exercises on how to increase efficiency, and introduced tools to handle difficult conversations and negotiations.

CAASTRO has continued its internal mentoring program, which matches up senior and junior members at different CAASTRO locations: it is designed to build and offer an initial professional network where questions around career progression can be discussed. The nature and frequency of our mentoring pairs' relationships is quite diverse: some catch up regularly via videoconference while others focus their interaction on the face-to-face meeting at CAASTRO's Annual Retreats. The overall feedback is positive, and we also receive enquiries from non-members who are interested in being mentored by a CAASTRO researcher.

EDUCATE


A/Professor Emma Ryan-Webber (Swinburne presenting at Curtin.
*Credit: James Campbell*

# CAASTRO LOCATIONS

International Centre for
Radio Astronomy Research

# CAASTRO AT THE INTERNATIONAL CENTRE FOR RADIO ASTRONOMY RESEARCH (ICRAR)

ICRAR hosts astronomy and astrophysics research in CAASTRO's two WA member Universities and is an equal joint venture between Curtin University and the University of Western Australia (UWA). ICRAR is a single organisation with two physical nodes, located near the main campus of each university. ICRAR has a unified business plan and conducts joint research programs, seminars and senior undergraduate astronomy programs. CAASTRO's engagement with ICRAR is through the CAASTRO Chief Investigators at the individual Universities, Steven Tingay and Carole Jackson the Node Leaders from Curtin, and Lister Staveley-Smith the Node Leader from UWA. They are also Directors at ICRAR. CAASTRO postdocs and students are mixed in with other ICRAR research groups, as encouraged by the ARC. Perth-area meetings are organised on a regular basis and alternate between Curtin and UWA. ICRAR's significant pre-existing involvement with radio astronomy projects has allowed CAASTRO to leverage greater science return from its investment and benefit from considerable in-kind support from ICRAR's engineering, ICT and science staff.

**2015 ICRAR members**
***Credit: ICRAR***

Curtin University

# CAASTRO AT CURTIN UNIVERSITY

Curtin University is a partner in the International Centre for Radio Astronomy Research (ICRAR), and is the managing organisation for the Murchison Widefield Array (MWA). Research at this node focuses on the Evolving and Dynamic themes.

During 2015 the Curtin node had 18 members. Node Leader Steven Tingay went on leave mid-year ahead of moving to a new position in Italy in January 2016, handing his role to Carole Jackson. Randall Wayth was nominated as the new MWA Director by the International Collaboration MWA Board members, and took up the role in December 2015.

In the Evolving theme, CAASTRO members at Curtin this year made advances in instrumentation, observations and theory. Using the BIGHORNS conical log-spiral antenna at the Murchison Radio-astronomy Observatory (MRO), a team led by Marcin Sokolowski studied whether the ionosphere would hinder the detection of the global Epoch of Reionisation (EoR) signal (page 9). Happily, the answer appears to be no. This is an important result and demonstrates the quality of the BIGHORNS antenna and systems design, as well as the extreme radio-quietness of the MRO.

This year also saw the completion of the GLEAM (GaLactic and Extragalactic All-sky MWA) survey's two-year observing run. Randall Wayth and Curtin co-authors Paul Hancock, Carole Jackson, Cathryn Trott, Stephen Ord and Steven Tingay, published a paper fully describing the survey. GLEAM covers a contiguous, broad frequency range (72–231 MHz) and is unique in being sensitive to radio emission from both compact and diffuse radio sources up to tens of degrees in angular size. GLEAM's raw data, and the source catalogues derived from them, will form a significant legacy dataset from the MWA, and will underpin the 'sky model' for the low-frequency component of the Square Kilometre Array, SKA-low.

Further demonstrating the versatility of the MWA, a group that included Steven Tingay, Jean-Pierre Macquart, Paul Hancock and other Curtin members serendipitously detected interplanetary scintillation (the scattering of radio signals by charged particles flowing off the Sun) in one of the fields observed for the MWA's Epoch of Reionisation (EoR) survey. Trott and Tingay analysed this scintillation to determine if it would contaminate the EoR signal. They found that interplanetary scintillation will stamp a unique but low-level signature onto the EoR observations, and that while this can be removed, it should be taken into account in detailed modelling of the EoR signal. Trott and colleagues also published a description of the Cosmological H I Power Spectrum Estimator (CHIPS), an algorithm developed and implemented with MWA data to compute the power spectrum of brightness-temperature fluctuations (that is, the signal coming from neutral hydrogen during the Epoch of Reionisation). Two postdoctoral staff, Steven Murray and Christopher Jordan, joined Trott's team in late 2015 to further develop the statistical analyses and modelling needed to detect the EoR signal.

In the Dynamic theme, work with the MWA continued to feature strongly. CAASTRO Associate Investigator Stephen Ord (now with CSIRO) published the system description of the MWA correlator, while Steven Tremblay and co-workers added high time and frequency resolution capabilities to the MWA, in the form of a new 'voltage capture system' that can record 10-kHz resolution voltage data at 100 microsecond periods. This new system enabled CAASTRO Associate Investigator Ramesh Bhat to analyse the dynamic spectrum of the well-known millisecond pulsar PSR J0437–4715 at a low frequency. Bhat detected scintillation arcs, which are consistent with the presence of a 'scattering screen' in the interstellar medium. The dynamic spectrum-analysis technique will be useful for determining scattering delays in the signals of timing-array pulsars. (See page 26 for details.)

Research into fast radio bursts (FRBs) continues across CAASTRO (page 14). Curtin Node Associate Investigator Jean-Pierre Macquart, together with CSIRO Partner Investigator Simon Johnston, worked to explain the fact that FRBs are preferentially found at high Galactic latitudes (that is, away from the plane of the Galaxy). Macquart and Johnston suggest that the bias is caused by rapid intensity fluctuations (scintillation) at low latitudes, resulting from small-scale irregularities in the Galaxy's interstellar medium. Their modelling is described further on page 15.

Three students at the Curtin node submitted theses this year. Samuel Oronsaye completed his Masters degree under the supervision of Tingay, Ord, Bhat and Tremblay. As part of this project, he published an analysis of giant pulses from the Crab pulsar that had been simultaneously observed with CSIRO's Parkes radio telescope and the MWA. Samuel McSweeney worked with the Curtin pulsar group for his Honours project, detecting pulsars in globular cluster 47 Tucanae with the MWA. Honours student Mia Walker further

CAASTRO Curtin University team members

built on an earlier CAASTRO Education and Outreach Honours project to use USB tuner dongles with MWA antennas to form a low-cost interferometer suitable for teaching and outreach purposes.

CAASTRO members, including Curtin node personnel, are key participants in the MWA collaboration. The collaboration has published far more papers than most projects do in their early years, and these papers have received a correspondingly high number of citations. This rapid scientific impact led Thomson ISI (the IP and Science business of the multinational information provider Thomson Reuters) to identify the MWA team as an outstanding research group. In June this year Thomson ISI presented Thomson Reuters Citation and Innovation Awards to eight individual Australian members of the MWA collaboration, seven of whom are CAASTRO members.

Steven Tingay, then MWA Director at Curtin, and Randall Wayth, then MWA Commissioning Engineer and now MWA Director, attended the award ceremony at the University of Melbourne together with CAASTRO members from other nodes.

CAASTRO members Cathryn Trott, Angela Dunleavy, Wiebke Ebeling and Paul Hancock served on the local organising committee of the successful and well-attended 2015 Annual Scientific Meeting of the Astronomical Society of Australia, which was held in Fremantle in July.

The Curtin node is the headquarters for CAASTRO Education and Outreach, and node members contributed significantly to this program in 2015. Their work has been the basis for twelve of the 40 research stories produced for recent publications. Three members (Oronsaye, Sokolowski and Tremblay) assisted CAASTRO Education and Outreach Manager Dr Wiebke Ebeling at the Perth *Astrofest* in March. Paul Hancock acted as Astronomer in Residence at Uluru (Ayers Rock Resort) in late May and early June 2015; Wiebke Ebeling and Steven Tingay attended the Uluru Astronomy Weekend in August and hosted a special session on using the MWA for outreach purposes. The Curtin node provided displays of MWA tiles that went on show at Mount Burnett Observatory (in January), the Royal Institution of Australia in Adelaide (April–June) and at the Murchison Settlement for the Murchison *Astrofest* (in September). Aerial drone footage taken at the Murchison Radio-astronomy Observatory for outreach purposes is now available on YouTube. The Curtin node hosted visits by the CAASTRO Executive (in September) and Advisory Board (November) and ran preview screenings of the planetarium show that CAASTRO has developed in collaboration with Museum Victoria (page 33). Two project interns joined CAASTRO Education and Outreach this year to expand school outreach and student mentoring and support CAASTRO media efforts.

The Curtin node's science goals for 2016 include:

- continuing to operate BIGHORNS at the MRO. Aspects of the backend processor for BIGHORNS will be incorporated into the MWA
- publishing the first GLEAM catalogue of 300,000 galaxies
- for the Epoch of Reionisation (EoR) project, modelling the ionosphere and diffuse emission foreground for MWA and processing MWA EoR data with the CHIPS power-spectrum estimator
- continuing to collect high time and frequency resolution data with the MWA for the study of pulsars
- using interplanetary scintillation (resulting from the solar wind) to trace extragalactic source structure.

The node will also host the MWA Project Meeting in June and the meeting of the Square Kilometre Array's *Cosmic Dawn–Epoch of Reionization Science Working Group* in late 2016.

## Professor Steven Tingay

**CAASTRO Node Leader until 1 August 2015**
**Chief Investigator, Leader: Outreach and Education**

**Theme: Evolving, Dynamic**

In 2015 Tingay continued to be involved in administration, as a member of the CAASTRO Executive and scientific activities. His interests in time-domain astronomy and instrumentation are reflected in his involvement with other CAASTRO staff in work to detect pulsars and fast radio bursts with the Murchison Widefield Array (MWA). Tingay's involvement in Epoch of Reionisation research, both via global signal and power spectrum techniques, continues strongly within CAASTRO. As Director of the MWA, Tingay played a high level role in delivering one of the key elements of Australia's next-generation astronomy infrastructure, an element that forms a significant pillar of CAASTRO's scientific success.

## Professor Carole Jackson

**CAASTRO Node Leader from 1 August 2015**

**Theme: Evolving**

Jackson, a WA Premier's Fellow, joined CAASTRO in the middle of 2015 after Steven Tingay went on long service leave. As Tingay was to take up a new role overseas in January 2016, Jackson also assumed the role of Node Leader from 1 August 2015. Her research interests lie in active galactic nuclei and the populations of powerful radio sources, particularly in mapping their distribution in the foreground of fields being observed in the Epoch of Reionisation project. Jackson is highly involved in technical and scientific developments for the Square Kilometre Array: she founded the Australian SKA Industry Consortium steering committee and has been a member of the international SKA Science Working Group since 2001.

## Dr Ramesh Bhat

**CAASTRO Associate Investigator**

**Theme: Dynamic**

Bhat's research continues to focus on observational pulsar astronomy and the transient radio Universe. Highlights from 2015 include the discovery of scintillation arcs in millisecond pulsar observations from the MWA and contributing to solve the mystery behind *perytons* – short-duration bursts that mimic certain astrophysical characteristics but have a local origin. In the year ahead, he plans to commence new science initiatives with the MWA, while actively pursuing research with multiple instruments including the MWA, GMRT and Parkes telescopes.

## Mrs Angela Dunleavy

**Administrative Coordinator**

Dunleavy is responsible for collating non-financial data for CAASTRO reports and provides administrative support to the CAASTRO team at Curtin, CAASTRO events held at Curtin and CAASTRO Annual Retreats.

## Dr Wiebke Ebeling

**CAASTRO Education and Outreach Manager**

**Theme: Education and Outreach**

Ebeling leads CAASTRO's science awareness programs through traditional and digital media, public astronomy events, school engagement and professional training activities. She produces media releases, videos, telescope displays, research stories (including the *CAASTRO Reader's Digest* booklets) and contents for CAASTRO's social media presence. She also maintains all outreach collaborations – for instance, those with Museum Victoria, Voyages Indigenous Tourism Australia, Telescopes in Schools and Mount Burnett Observatory – and supervises research students and project interns. This year she project-managed the CAASTRO planetarium show (page 33) and the production of a new children's book. Ebeling is a Steering Committee member of the Education and Public Outreach Chapter (EPOC) of the Astronomical Society of Australia.

## Dr Paul Hancock

**CAASTRO Affiliate**

**Theme: Dynamic**

Hancock has applied the 'stacking' technique to transient radio phenomena, to study Type Ia supernovae and long gamma-ray bursts. He is one of the main contributors to the VAST (Variables and Slow Transients) pipeline, an analysis and visualisation tool for detecting and classifying variable and transient radio sources. Hancock is processing MWA data with the VAST pipeline to detect various signatures of signal variability, such as scintillation caused by our Galaxy's interstellar medium.

## Dr Christopher Jordan

**CAASTRO Affiliate**

**Theme: Evolving**

In October 2015, Jordan began work with the Epoch of Reionisation (EoR) group at Curtin university. Using the MWA, he is investigating ionospheric effects on low-frequency observations, and how they can be characterised. Before this work, Jordan led a survey searching the plane of the Milky Way for tracers of High-Mass Star Formation (HMSF) in his PhD. He also contributes to an active group searching for regions of ionised hydrogen in the Milky Way, which allows us to identify the large structure of the Galaxy we live in.

## Mr Samuel McSweeney

**CAASTRO Honours student**

**Theme: Dynamic**

This year McSweeney worked with Bhat, Tremblay, and Ord on a project measuring scintillation arcs in MWA observations of the pulsar PSR J0437–4715 (page 26). In 2016 he has become a PhD candidate at Curtin, studying sub-pulse drifting behaviour to better understand how pulsars produce their emission.

## Dr Jean-Pierre Macquart

**CAASTRO Associate Investigator**

**Theme: Dynamic**

This year Macquart continued to work on how fast radio bursts (FRBs) can be used to measure the baryonic content of the intergalactic medium. Closer to home, he also worked on the interstellar medium in our Galaxy: in collaboration with Ger de Bruyn at ASTRON in the Netherlands, he discovered an exceptionally turbulent and dense patch of interstellar plasma just a few light-years from Earth. He also investigated optimal strategies for surveying the radio sky for transients whose bursts occur on relatively long (>10 seconds) timescales.

## Dr Stephen Ord

**CAASTRO Associate Investigator**

**Theme: Dynamic**

In 2015 Ord worked on the preliminary design of correlator for the Square Kilometre Array (SKA). The project involves industrial partnerships with NVIDIA, IBM and CISCO Systems, and these partnerships have generated considerable in-kind contributions to the SKA preconstruction effort and the expansion of the Murchison Widefield Array (page 11). This year Ord also developed prototype extensions to the MWA signal-processing system, and continued to work with Tremblay, Oronsaye, Bhat, and Tingay on the high-time-resolution pipeline for the MWA.

## Mr Samuel Oronsaye

**CAASTRO Masters student**

**Theme: Dynamic**

In 2015 Oronsaye performed a multi-frequency study of the giant pulses from the Crab pulsar. This formed part of his Masters thesis, which he submitted in October 2015.

## Dr Marcin Sokolowski

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

This year Sokolowski finalised the system description paper for BIGHORNS, an Epoch of Reionisation (EoR) project deployed at the Murchison Radio-astronomy Observatory (MRO). Data collected by BIGHORNS allowed him to study the impact of the ionosphere on the ground-based detection of the global EoR signal. The analysis, described on page 9, showed that the ionosphere is not a fundamental impediment to measuring the EoR signal. Using the same data Sokolowski also studied the statistics of radio-frequency interference at the (MRO).

## Ms Tina Sallis

**Finance Manager**

Sallis is responsible for financial support to the CAASTRO team members and Curtin and for reconciliation of financial data against the CAASTRO budget.

## Dr Steven Tremblay

**CAASTRO Postdoctoral Researcher**

**Theme: Dynamic**

This year Tremblay led the continued use of the Murchison Widefield Array's new system for recording signals with high time and frequency resolution, mainly to study pulsar signals (page 26) and search for fast radio bursts at low frequencies. He also worked on the BIGHORNS Epoch of Reionisation experiment (page 9).

## Dr Cathryn Trott

**CAASTRO Associate Investigator**

**Themes: Dynamic and Evolving**

Trott's work in the Evolving theme has focused on designing and implementing an Epoch of Reionisation (EoR) estimation algorithm, which is to be used with data from the MWA. She is also leading efforts to understand how contamination by foreground signals will affect estimation of the EoR signal. This year she played a large role in shaping the EoR experiment of the Square Kilometre Array (SKA), working as part of the Science Working Group Management Team and contributing to the telescope's design and specifications. Within the Dynamic theme, Trott contributes to a range of projects aimed at detecting fast radio bursts with the MWA and the low-frequency component of the SKA (SKA-low). She is also performing cross-theme work on how the detectability of the EoR signal may be affected by the ionosphere and the solar wind.

## Ms Mia Walker

**CAASTRO Honours student**

**Theme: Dynamic**

Throughout 2015 Walker designed and constructed an interferometer using USB TV tuner dongles and MWA antennas, to provide a cheap, portable and flexible method of observing at radio wavelengths. This work is likely to be continued by engineering students in the following years.

## Dr Randall Wayth

**CAASTRO Associate Investigator**

**Theme: Evolving**

Wayth is a Senior Research Fellow, MWA staff scientist, project manager for the CAASTRO-supported BIGHORNS EoR Global Signal project, and team leader for the GLEAM (GaLactic and Extragalactic All-sky MWA) survey. This year he also took up the role of Project Scientist in the SKA-low Aperture Array Design and Construction (AADC) consortium. Wayth also works on the MWA Epoch of Reionisation project.

# CAASTRO AT THE UNIVERSITY OF WESTERN AUSTRALIA (UWA)

The University of Western Australia (UWA) node of CAASTRO is located on the University's main campus in the Perth suburb of Crawley. Node researchers work alongside other colleagues at the International Centre for Radio Astronomy Research (ICRAR), which is an equal joint venture between UWA and Curtin University. The UWA node of CAASTRO has grown considerably in recent years and now comprises around 20 staff and students. Most research at the UWA node falls within the Dark and Evolving themes.

In the Dark theme this year there was considerable work on the peculiar velocities of galaxies. Cullan Howlett worked to combine the final peculiar-velocity measurements from the 2MASS Tully-Fisher survey (2MTF) and 6dF Galaxy Survey (6dFGS). The combined dataset will provide tighter cosmological constraints than the individual ones do. Howlett also assisted with the target selection, observing strategy and cosmological forecasts for the TAIPAN survey, which will begin on the UK Schmidt Telescope at Siding Spring Observatory in 2016. Christopher Springob completed analysis of the cosmography of the 2MTF peculiar velocity field, and published a paper reporting results. He also chaired the peculiar-velocity working group for the TAIPAN survey, and collaborated with other working groups on the planning of TAIPAN.

In other work under the Dark theme, Lister Staveley-Smith prepared a new H I catalogue of almost 1000 galaxies that lie behind the Galactic Plane, in a region that has a powerful gravitational influence on the motions of nearby galaxies. Only a few of the catalogued galaxies, found with the Parkes radio telescope, had previously known optical redshifts. This year PhD student Khaled Said, together with his supervisors, Springob and Staveley-Smith, calculated peculiar velocities for the new galaxies found behind the Galactic Plane. These will be used to extend the 2MTF survey.

In the Evolving theme, node personnel carried out a diverse range of activities, most connected with large surveys. Anna Kapinska and Lister Staveley-Smith worked towards the first public release of data from the Galactic and Extragalactic All-Sky MWA (GLEAM) survey, while Minh Huynh cross-matched sources from GLEAM with those from ATLAS (the Australia Telescope Large Area Survey) to obtain multi-wavelength counterparts. Dan Taranu developed a new method to build realistic three-dimensional models of galaxies with a bulge, disk and halo: this will be used to measure fundamental properties of galaxies from the SAMI Galaxy Survey. Taranu also ran hydrodynamical simulations (still being analysed) of mergers of groups of spiral galaxies. And together with 'citizen scientists', Kapinska searched the Radio Galaxy Zoo (RGZ) dataset for hybrid-morphology radio galaxies (HyMoRS). These objects challenge our understanding of how the relativistic jets of radio galaxies form and how different kinds of radio galaxies are related to each other.

Two projects addressed future surveys that will run on CSIRO's Australian SKA Pathfinder (ASKAP) telescope. Claudia Lagos worked to create mock catalogues for the FLASH and WALLABY surveys, and Se-Heon Oh developed a stand-alone software package to extract moment maps from ASKAP data cubes and perform tilted-ring analyses. In addition, Attila Popping became a member of the ASKAP Commissioning and Early Science team (ACES), helping with the reduction of the first data taken with ASKAP. Popping also wrote scripts to reduce and image large spectral-line datasets. These will be used in current and future large surveys.

As part of CAASTRO's contribution to the even larger international Square Kilometre Array (SKA) project, Oh co-chaired the organising committee for an international workshop on the Square Kilometre Array (SKA) telescope held in Seoul, Korea, during 2–4 November, and gave a contributed talk about dark-matter distribution in dwarf galaxies.

A number of the node's early-career researchers passed significant milestones or achieved notable success. PhD student Steven Murray completed his thesis, "Non-Parametric Descriptions of Dark Matter Halos", and has now started a postdoctoral position at Curtin University. Former CAASTRO PhD student Morag Scrimgeour was awarded the 2015 ASA Charlene Heisler Prize of the Astronomical Society of Australia for her 2014 thesis, "Cosmology with Large-scale Structure and Galaxy Flows". Following her earlier prize for the best PhD in Europe in the area of theoretical astrophysics, CAASTRO Associate Investigator Claudia Lagos was the recipient of a 2015 MERAC award from the European Astronomical Society to fund two new PhD studentships. She is also an ARC Distinguished Early Career Research Fellow at UWA: this takes effect in 2016.

As in previous years, UWA node members contributed to CAASTRO outreach activities, including a running a CAASTRO desk at Astronomy WA's *Astrofest* on March 28 and participating in the *Uluru Astronomer in Residence* program.

CAASTRO UWA team members

The goals for future work at the node are:

- distinguishing between dark-matter models by using statistical estimators such as the 'box-counting' method
- finalising the combination of the 2MTF and 6dFGS peculiar-velocity datasets and using the new sample to produce constraints on the rate of the growth of structure in the Universe
- starting to take data for the TAIPAN survey and preparing for the subsequent analysis; publishing a 'white paper' detailing the survey strategy and objectives
- releasing the first public data from the Galactic and Extragalactic All-Sky MWA (GLEAM) survey; working towards further data releases
- constructing a new sample of radio galaxies at 200 MHz from the GLEAM survey with which to study feedback from active galactic nuclei (galaxies with active black holes) over cosmic time
- completing the cross-matching of sources from the GLEAM sources with EMU ATLAS sources; studying the host galaxies of GLEAM sources and the GLEAM 200-MHz radio luminosity function
- beginning to acquire early-science data for the WALLABY and EMU surveys with ASKAP–12 (twelve antennas of the new Australian SKA Pathfinder telescope)
- completing mock catalogues for the FLASH and WALLABY surveys, and testing the pipeline for WALLABY
- modelling the broadband radio spectral energy distributions over the range 70 MHz–12GHz of galaxies observed with the Murchison Widefield Array and the Very Large Array in the USA
- establishing a new method of determining the Tully-Fisher relation using H I stacking
- holding a CAASTRO/SAMI workshop on the topic of kinematic scaling relations
- measuring fundamental properties of SAMI galaxies and comparing them to predictions from simulations
- creating a map of the large-scale structure of galaxies hidden in the Zone of Avoidance
- analysing intensity-mapping data obtained with CSIRO's Parkes telescope; investigating the suitability of phased-array feeds for this work.

## Professor Lister Staveley-Smith

**CAASTRO Deputy Director, Node Leader and Chief Investigator**

**Themes: Evolving and Dark**

Staveley-Smith has continued in his role as Node Leader and CAASTRO Executive member. He co-supervises three CAASTRO PhD students. This year he contributed to the running CAASTRO by improving the monitoring of its publications and driving the establishment of a new Australia-China collaboration, ACAMAR (page 32). His scientific work included a study of Zone of Avoidance galaxies; determining the parameters of Square Kilometre Array surveys aimed at understanding the evolution of galaxies; producing a science case for long baselines on the Murchison Widefield Array (MWA); and helping with the forthcoming MWA catalogue and image release.

## Mr Kamran Ali

**CAASTRO PhD student**

**Theme: Dark**

Under the supervision of Danail Obreschkow, Ali has focused on finding an efficient statistical estimator that can give us information from galaxy redshift surveys in addition to the matter power spectrum.

## Dr Weiguang Cui

**CAASTRO Affiliate**

**Themes: Evolving, Dark**

Cui uses numerical simulations to study the formation and evolution of the Universe on different scales, from the very large down to the scale of galaxy clusters. He also works on different cosmology models. For the Evolving theme, he is working on the cosmic web, using the cosmic web identification codes DISPERSE and Vweb, focusing on predictions of cosmic-web properties from simulations and comparisons with observations. For the Dark theme, he is mainly working on modified gravity/dark-energy simulations. He has a modified Gadget code to undertake cosmological simulations, and is applying a new Galileon modified gravity model to the new updated Gadget-3 code. In next step, he will runs cosmological simulations under standard cosmology model and alternative models, and distinguish them through different probes.

## Dr Cullan Howlett

**CAASTRO Postdoctoral Researcher**

**Theme: Dark**

After completing a PhD at the University of Portsmouth, Howlett joined CAASTRO in 2015. He works on the large-scale structure of the Universe, simulating its growth and comparing the results with the clustering of galaxies seen by large galaxy surveys. In 2016 he will continue this work using data from the 2MTF and 6dFGS peculiar velocity surveys and the upcoming TAIPAN survey.

## Dr Minh Huynh

**CAASTRO Associate Investigator**

**Theme: Evolving**

Huynh is a Senior Research Fellow at UWA. From 2010 to 2013 she was the Deputy International Project Scientist for the Square Kilometre Array. She studies galaxy formation and evolution, using sensitive multi-wavelength data from ground and space-based observatories.

## Dr Anna Kapinska

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Kapinska joined CAASTRO at UWA in August 2013, and has worked mainly on the Galactic and Extragalactic All-Sky MWA (GLEAM) survey, which will make its first public data release in 2016. Kapinska is also part of the Radio Galaxies, Clusters and Cosmic Web GEG Science Team, focusing predominantly on radio galaxies and large scale AGN feedback; she investigates these subjects with the use of radio data and semi-analytical models. In addition, she works on the LOFAR Deep Sky Surveys and is a science-team member of the citizen-science project Radio Galaxy Zoo. Kapinska has devised a pilot study for classifying complex radio sources from the upcoming EMU (Evolutionary Map of the Universe) survey, which is to be carried out with CSIRO's Australian SKA Pathfinder telescope. Since 2014 she has also been the Project Manager for EMU.

## Ms Katharine Kelley

**CAASTRO PhD student**

**Theme: Dark**

Kelley joined CAASTRO in 2015. Her doctoral research principally relates to understanding and modelling the interactions of particles called QCD axions, which have long been considered a strong candidate for cold dark matter, as they have mass, couplings and abundance that could account for a significant component of the dark matter density. Kelley's work will explore whether radio telescopes can be used to detect dark matter. Exploiting the experimental techniques first published by Sikivie in 1982, she is modelling the expected all-sky signal resulting from the conversion of QCD axions in the Galactic magnetic field and investigating potential axion signatures resulting from interactions in the early Universe.

## Dr Claudia Lagos

**CAASTRO Associate Investigator**

**Theme: Evolving**

Lagos has been a DECRA fellow at the UWA node of ICRAR since May 2015; prior to that, she was a Fellow at the European Southern Observatory in Germany. She works on galaxy formation simulations and semi-analytic models and has explored relevant physical processes such as black-hole accretion and galaxy co-evolution, and has modelled the interstellar medium modelling, star formation and supernovae dynamics and feedback. Lagos has been awarded several international prizes, including the Springer Theses 2014 (awarded to the best physics PhD theses worldwide every year) and the MERAC prize 2014 for the best PhD in Europe in the area of theoretical astrophysics (awarded by the European Astronomical Society).

## Dr Martin Meyer

**CAASTRO Associate Investigator**

**Theme: Evolving**

Meyer's research interests lie in studying the cosmic density of neutral hydrogen (H I), H I scaling relations and, most recently, the Tully-Fisher relation. He leads DINGO, a project that will make deep H I observations with the Australian SKA Pathfinder to understand how the H I content of the Universe has evolved. In the lead-up to this project he is contributing to H I stacking experiments to push the redshift limits achievable with current facilities. He also leads a widefield survey of the GAMA G09 region in the VLA field to that is studying the H I content of the Universe to $z \sim 0.4$.

## Mr Scott Meyer

**CAASTRO PhD student**

**Theme: Evolving and Dark**

Meyer is investigating the application of H I stacking to measuring Tully-Fisher parameters for galaxies that have no detectable H I emission. This technique is promising for studying low-mass or high redshift galaxies. This work is being undertaken with his supervisors (Martin) Meyer, Obreschkow, and Staveley-Smith. His research has used data from the S-cubed simulations, HIPASS, 6dFGS and he hopes to extend it to high-redshift datasets such as CHILES.

## Mr Steven Murray

**CAASTRO PhD student**

**Theme: Evolving and Dark**

In 2015 Murray completed his PhD thesis, and in it introduced three key new tools for interpreting the flood of data from huge new galaxy surveys. These

tools are designed to uncover the effect of the nature of dark matter on things we can observe: galaxies. Murray applied his methods to various statistical questions: how accurately do we know the halo mass function? How well do we need to know it in order to constrain the nature of dark matter? How much do the effects of dark matter and galaxy evolution scramble each other, and how can we disentangle them? What is the most efficient way to statistically characterise the mass distribution of objects in the Universe? And what biases will inevitably arise in doing so? One of Murray's tools has been implemented as a stand-alone web-application, and has been accessed by hundreds of researchers around the world.

## Dr Danail Obreschkow

**CAASTRO Associate Investigator**

**Theme: Evolving and Dark**

In 2015, Obreschkow was active in the Evolving and Dark science themes. Within Evolving, he focused on the measurement and modeling of angular momentum in galaxies, which is a topic of much current interest in the context of IFS surveys (such as those with SAMI) and modern hydro + gravity simulations. This work culminated in an ARC DP grant, shared with Glazebrook at Swinburne University of Technology. Obreschkow also works on applying H I stacking to the Tully-Fisher relation. Within the Dark theme, Obreschkow's main interest is the information on fundamental physical parameters contained in the large-scale structure of the Universe, in particular information not already apparent in the cosmic power spectrum. In this effort, he has recently been joined by CAASTRO PhD student Kamran Ali and CAASTRO postdoc Cullan Howlett.

## Dr Se-Heon Oh

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Oh has focussed on quantifying gas kinematics in disc galaxies, using state-of-the-art observational data and the results of high-resolution cosmological simulations. In preparation for upcoming galaxy surveys such as WALLABY and DINGO, which will run on the Australian SKA Pathfinder telescope (ASKAP), Oh has developed a software package for the kinematic analysis of resolved galaxies. The new software, based on Bayesian MCMC analysis, will be able to perform robust and systematic analysis of the dynamics of an unprecedented number of galaxies in a fully automated manner for the first time, removing the subjectiveness in the analysis usually caused by the manual derivation of galaxy kinematics using traditional methods.

## Ms Clare Peter

**CAASTRO Administrator**

Peter provides administrative support at the UWA node, looking after the UWA financials and reporting. She works alongside the ICRAR-UWA administration team.

## Dr Attila Popping

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Popping is an active contributor to the DINGO and WALLABY surveys that will run on the Australian SKA Pathfinder (ASKAP) telescope, and is a member of ACES, the ASKAP Commissioning and Early Science team. He is working on several experiments involving H I stacking and plans to use stacking techniques to do early science with ASKAP. Popping is also a core member of the CHILES survey (Cosmos H I Large Extragalactic Survey), a large project running on the Very Large Array in the USA.

## Dr Chris Power

**CAASTRO Associate Investigator**

**Theme: Evolving**

Power has contributed to a variety of CAASTRO projects throughout the last year, including modelling of feedback in galaxies for the SAMI survey in collaboration with Tescari at the University of Melbourne, analysing simulations of the Epoch of Reionisation with Wyithe and his team (also at the University of Melbourne), and doing non-standard cosmological simulations with Parkinson at the University of Queensland and semi-analytical modelling of the H I content of galaxies with Kim and Wyithe at Melbourne, Lagos at ICRAR/UWA, and collaborators at Durham University. He supervised CAASTRO PhD student Murray to completion on the topic of "Statistical Tools for Next Generation Galaxy Surveys"; he has also worked closely with CAASTRO affiliate Cui on simulations of galaxy clusters as part of the *nIFTy* cluster comparison, an international collaboration of simulators in which he plays a leading role.

## Dr Jonghwan Rhee

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Rhee's research interests lie in galaxy evolution and cosmology using H I observations. In particular, he is working on the evolution of H I gas out to a redshift of one using H I spectral stacking and an intensity-mapping technique. Currently, his main project is an H I intensity mapping experiment using the Parkes radio telescope, which is one of the CAASTRO Evolving projects. In 2015, he developed data reduction and analysis pipelines based on a large amount of data that had been already obtained, as well as collecting more data. More observations will be carried out in 2016 to complete surveying the target fields. Using existing and new data, he will work to improve the analysis pipelines including removal of radio-frequency interference and foreground contamination.

## Mr Khaled Said

**CAASTRO PhD student**

**Theme: Dark**

Said is a PhD student jointly supervised by Kraan-Korteweg and Jarrett at the University of Cape Town and Staveley-Smith and Springob at the University of Western Australia. The main goal of his thesis is to provide a map of the large-scale structure of galaxies hidden in behind the Milky Way in the 'Zone of Avoidance' and predict their flow fields using the Tully-Fisher relation. Two surveys have been launched that combine the H I 21-cm data, which is not affected by dust extinction, and near-infrared data, which suffers less from dust than optical to arrive at two distinct survey samples for ZOA galaxies. A merging of this survey with the 2MTF survey should give the first real whole-sky sample.

## Dr Paul Scott-Taylor

**CAASTRO PhD student**

**Theme: Evolving and Dark**

Scott-Taylor has been investigating the formation and evolution of galaxies through radio continuum emission from star-forming galaxies, using simulation models with supervisors Power and Obreschkow, and co-supervisors Staveley-Smith and Andrew Benson (Carnegie Observatories, Pasadena). His work is focused on the development of new semi-analytic models for the continuum emission. Scott-Taylor intends to use the simulation data produced by the software to create mock galaxy catalogues and simulated skies. These products will be delivered using the latest 3D visualisation techniques.

## Dr Christopher Springob

**CAASTRO Postdoctoral Researcher**

**Theme: Dark**

Springob has completed the final data reduction for the 2MTF survey and, together with Tao Hong of the National Astronomical Observatories, Chinese Academy of Sciences, has derived the final peculiar-velocity measurements for the survey samples. He also examined the cosmography of the 2MTF velocity field, comparing the observed velocity field with the predictions from models. He has chaired the galaxy peculiar-velocity working group for TAIPAN survey selection, and has been working with other working groups to plan the TAIPAN survey, which will start in 2016.

## Dr Dan Taranu

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Dan Taranu is a member of the SAMI Galaxy Survey team. He has been writing code to build realistic 3D models of spiral galaxies. These models include all three major components of a galaxy: a thin disk of rotating stars, a compact, spherical stellar bulge, and a halo of invisible dark matter. By adjusting the properties of each component, the models can be made to fully reproduce the motions of stars in galaxies as observed by the SAMI spectrograph, allowing for more precise measurements of the sizes and masses of each component (disk, bulge and halo) of the galaxy. Taranu has also run dozens of sophisticated supercomputer simulations of collisions of spiral galaxies in groups. Such galaxy mergers are thought to have created the most massive elliptical galaxies in the nearby universe, some of which have been observed by SAMI.

## Dr O. Ivy Wong

**CAASTRO Affiliate**

**Theme: Evolving**

Wong is currently working on multiwavelength observations of nearby galaxies. She aims to determine the physical processes that govern how galaxies start and stop forming stars, grow supermassive black holes and evolve. She plans to use the new radio telescopes located in Western Australia to help her figure out the answers to some of these questions. Wong co-leads Radio Galaxy Zoo (with Dr Julie Banfield, ANU), an online citizen-science project (*radio.galaxyzoo.org*) aimed at cross-matching radio jets to distant host galaxies from which the jets emanate.

THE UNIVERSITY OF SYDNEY

# CAASTRO AT THE UNIVERSITY OF SYDNEY

The CAASTRO Sydney node is located within the Sydney Institute for Astronomy (SIfA), which is part of the School of Physics within The University of Sydney. SIfA is one of Australia's largest research groups in astronomy and astrophysics, and carries out observational and theoretical research as well as developing novel astronomical techniques and instrumentation. SIfA's long-standing involvement in instrumentation and large-area astronomical surveys underpins many of the research activities at CAASTRO's Sydney node.

In 2015 there were 33 CAASTRO team members at the Sydney node, including nine students. The research activities at the Sydney node mainly fall within the Evolving and Dynamic themes.

In the Evolving Universe theme we pursued three major activities. The largest of these was the Sydney-AAO Multi-object Integral field spectrograph (SAMI) Galaxy Survey, an ambitious integral-field spectroscopic survey of 3,400 low-redshift ($z < 0.12$) galaxies including both isolated galaxies and those in groups and clusters. The SAMI instrument uses a novel 'hexabundle' technology jointly developed by Sydney and AAO, and the survey has now made its first public data release. This survey has involved CAASTRO members James Allen, Joss Bland-Hawthorn, Jessica Bloom, Julia Bryant, Scott Croom, Lisa Fogarty, Rebecca McElroy, Samuel Richards, Elaine Sadler, Adam Schaefer and Nicholas Scott.

Our second project within the Evolving theme was calibration and analysis of low-frequency radio data from the Murchison Widefield Array (MWA), with a particular focus on polarisation measurements, multi-frequency studies of the extragalactic radio sources, and characterisation of the foreground populations relevant to studies of the Epoch of Reionisation. This work was done by Joe Callingham, Emil Lenc, Tara Murphy and Elaine Sadler.

Third, we made studies of the redshifted 21-cm absorption line of neutral hydrogen, as a probe of the cold gas content of galaxies in the distant Universe. This work, carried out by Marcin Glowacki, Elizabeth Mahony, Vanessa Moss, Sarah Reeves and Elaine Sadler, is associated with the FLASH survey (the First Large Absorption Survey in H I), which is to run on CSIRO's Australian SKA Pathfinder telescope, ASKAP.

In the Dynamic Universe theme, we continued work on two ambitious new radio-transient surveys, analysing early data from the Murchison Widefield Array (MWA) transient survey and continuing development of the data pipeline for ASKAP's VAST (Variables and Slow Transients) survey. Areas of particular focus in 2015 were (i) understanding ionospheric effects in MWA data, (ii) searching for time-dependent radio emission from stars and planets, and (iii) analysing large archival radio, optical and X-ray datasets to identify new and rare classes of transient sources. This work was done by Martin Bell, Davide Burlon, Cleo Loi, Christene Lynch, Aina Musaeva, and Tara Murphy.

This year we also completed the upgrade to the Molonglo radio telescope, in collaboration with CAASTRO Chief Investigator Matthew Bailes and colleagues at Swinburne University, giving it a new digital correlator and much greater spectral bandwidth. The large collecting area and wide field of view of the upgraded Molonglo telescope (now called UTMOST) make it a powerful new facility for pulsar timing and identifying fast radio bursts. The Sydney node members involved in the upgrade were Duncan Campbell-Wilson and Anne Green.

Our 2015 science highlights from the Evolving Universe side include two newly published results from the SAMI team. CAASTRO student Rebecca McElroy has shown that outflows of ionised gas ('galactic winds') appear to be ubiquitous in galaxies with a luminous active galactic nucleus (AGN), providing direct evidence that an accreting black hole at the central of a galaxy can influence the physical state of the interstellar medium on galaxy-wide scales. CAASTRO Affiliate James Allen used SAMI data to identify galaxies whose central regions were offset in velocity from the rest of the galaxy. In the two cases he studied, he found that the offsets were the result of a recent galaxy merger rather than of the presence of a central binary black hole, as is often postulated.

CAASTRO PhD student Joe Callingham used the MWA and several other radio telescopes to carry out a detailed study of the radio galaxy PKS B0008–421, which has an unusually steep spectral peak at radio frequencies around 600 MHz. By testing a range of models, Joe was able to show that the unusual spectral features probably arise because the galaxy's central black hole recently 'switched off' as a radio source, even though the source itself still appears to be young (details, page 25).

In the Dynamic Universe theme, highlights included work by CAASTRO student Cleo Loi, who used the

CAASTRO University of Sydney team members

MWA to study the structure of ionospheric fluctuations and the impact of the changing ionosphere on time-domain astronomy. CAASTRO Chief Investigator Tara Murphy used the MWA to search for low-frequency radio emission from exoplanets, and CAASTRO PhD student Aina Musaeva studied the gaseous environment of a candidate intermediate-mass black hole, HLX–1, in the nearby galaxy ESO 243–49. Aina's goal was to test the idea that HLX–1 is the stripped remnant of a dwarf galaxy that has recently undergone an interaction with ESO 243–49. Since no neutral hydrogen was observed, a merger or recent interaction with a gas-rich dwarf can be ruled out.

This year our visitors included Roger Davies (Oxford) and Richard Bower (Durham), both of whom worked on aspects of galaxy evolution with the SAMI team. Roger also took part in the *Uluru Astronomy Weekend* in August. Sydney-based CAASTRO Chief Investigator Tara Murphy was on study leave in Oxford for the second half of 2015, working with members of the time-domain astronomy group there.

One of our main education and outreach activities continues to be the *CAASTRO in the Classroom* program, which uses our video-conferencing system to stream talks and discussion sessions with CAASTRO astronomers to high schools across Australia. We were fortunate to have Jenny Lynch join us this year to help us expand the program. Several Sydney node researchers and students again travelled to Uluru to take part in CAASTRO's new *Astronomer in Residence* program at the Voyages resort. (For more about these activities, see page 84).

The University of Sydney hosts CAASTRO's main administrative office, which in 2015 consisted of Kate Gunn (Chief Operating Officer), Debra Gooley (finance), Helen Keys (executive support), Jenny Lynch (school education officer), Kylie Williams (events and communications) and Helen Sim (media and Annual Report). This team oversees a transparent reporting system across the Centre, handles all our financial obligations and transactions, organises our scientific workshops, manages the CAASTRO Mentoring Program and prepares the regular CAASTRO newsletter. Planning is already under way for CAASTRO's two major international conferences in 2016, and for our next annual retreat, to be held in Western Australia in November 2016.

2016 promises to be another exciting year. The SAMI galaxy survey is continuing, next year will see the major MWA continuum and transient surveys move towards completion, and we will also start to see Early Science data flow from the next stage of ASKAP, so there is plenty to look forward to!

## Professor Elaine Sadler

**CAASTRO Director, Node Leader & Chief Investigator**

**Theme: Evolving**

Sadler is working with Allison (CSIRO), Mahony, Moss, Reeves, Glowacki and other members of the FLASH team to identify and study of redshifted 21-cm H I absorption in galaxies out to redshift $z = 1$, using new tools and techniques developed for the forthcoming ASKAP FLASH survey. This year the FLASH team used the six-element Boolardy Engineering Test Array (BETA) at the Murchison Radio Observatory to observe almost 100 bright southern radio sources. Although BETA was nominally an engineering test array for ASKAP, the FLASH team has been able to obtain some exciting science results from its observations, including the detection of at least five previously unknown H I-absorption systems. The team's first ASKAP science paper, describing the detection of neutral gas in the distant radio galaxy PKS 1740–517, was published in 2015 and several more papers are now in preparation; the team will start a new set of observations with a 12–antenna system as ASKAP moves into its Early Science phase. This year Sadler also co-authored (with Morganti and Curran) a chapter on extragalactic H I absorption as part of the updated science case for the international Square Kilometre Array.

## Professor Scott Croom

**CAASTRO Chief Investigator**

**Theme: Evolving**

Croom is leading the SAMI Galaxy Survey, a project to observe thousands of galaxies using spatially resolved spectroscopy with the Sydney-AAO Multi-object Integral Field Spectrograph (SAMI) on the Anglo-Australian Telescope. The survey continued apace this year and has now observed over 1,400 galaxies. Exciting new results published in 2015 include the analysis of possible merging supermassive black holes, the connection between stellar kinematics and galaxy morphology in clusters, and the most accurate estimate yet of the early-type galaxy

Fundamental Plane (details, page 13). There is a great deal of SAMI science to look forward to in 2016, including investigations into the role of environment in determining star formation and dynamics in galaxies, an examination of the distribution of young and old stars in galaxies, a study of the influence of outflows, and much more.

## Associate Professor Tara Murphy

**CAASTRO Chief Investigator**

**Theme: Dynamic**

Murphy's focus is on radio observations of transient and variable sources such as supernovae and gamma-ray bursts. She also works on developing intelligent algorithms for detecting transient events in the large volumes of data that will be produced by next-generation radio telescopes. In 2015 Murphy used new low-frequency data from the MWA to investigate ultra-cool dwarf stars and exoplanets, and conducted a blind survey for radio transients.

## Dr James Allen

**CAASTRO Affiliate**

**Theme: Evolving**

Allen led development of the data-reduction pipeline for the SAMI Galaxy Survey, which culminated in the Early Data Release of a subset of the survey galaxies. This data is now public, allowing researchers across the world to make use of the SAMI Galaxy Survey data. Allen has also been investigating the relationship between active galactic nuclei and their host galaxies, focussing on a small number of galaxies with unusual kinematic properties.

## Dr Martin Bell

**CAASTRO Affiliate**

**Theme: Dynamic**

Bell is Principal Investigator of the Murchison Widefield Array Transients Survey (MWATS), which aims to survey almost the entire southern hemisphere multiple times at low frequencies, on timescales of one month. The aim of the project is to search for dynamic and explosive objects in the Universe. Bell is also a member of the Australian Square Kilometre Array Pathfinder (ASKAP) commissioning team. In 2016 the team will prepare ASKAP for Early Science observations later in the year. Bell moved to a position at CSIRO in 2015.

## Professor Joss Bland-Hawthorn

**CAASTRO Associate Investigator**

**Theme: Evolving**

Bland-Hawthorn leads the development of new survey instruments for the Anglo-Australian Telescope. These include the SAMI 13-bundle spectrograph (in collaboration with Scott Croom), the Hector 100-bundle spectrograph (in collaboration with Julia Bryant), and the PRAXIS OH suppression spectrograph. His particular interest lies in understanding the evolution of galaxies in the context of their environment. As part of this effort he is a member of the SSimPL consortium, which is carrying out massive CDM + hydrodynamic simulations of how galaxies get their gas, over a cosmological volume. He is a member of the GASKAP survey team that targets gas on the Galactic halo, and a member of the GAMA and CALIFA galaxy survey teams. Bland-Hawthorn is an ARC Australian Laureate Fellow, and in 2015 was awarded the *W.H. (Beattie) Steel Medal* for optics by the Australian Optical Society.

## Ms Jessica Bloom

**CAASTRO PhD student**

**Themes: Evolving, Dark**

Bloom's focus is understanding the role of events such as mergers in galaxy evolution. In 2015 she used tools she had developed to identify perturbed galaxies and study the relationships between kinematic asymmetry, stellar mass and star formation. She demonstrated that kinematic asymmetry is inversely proportional to stellar mass and is linked to increased concentration of star formation. In future, she will further study the kinematics of low-mass galaxies, and the influence of environment on kinematic perturbation.

## Dr Julia Bryant

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Bryant works on both astronomy instrumentation and galaxy evolution. She is a member of the SAMI Galaxy Survey Executive team and chairs the Target Selection workgroup, selecting and creating tiles of the objects to be observed with SAMI. In 2015 she published the SAMI Target Selection paper. At the same time, she is the SAMI Instrument Scientist and supports other users of the SAMI instrument. Using the dynamics of gas and stars in galaxies from the SAMI Galaxy Survey, she continues to investigate how gas gets into galaxies and the influence of the galaxy environment on the morphology of galaxies. Hector is the next major instrument project for the Anglo-Australian Telescope, and Bryant is its Project Scientist: her role is to liaise between the astronomers and instrument teams to ensure that Hector will be built to deliver the best science to the astronomical community. The full science case requirements for Hector were developed this year and in 2016 the instrument will move forward to the design phase. Bryant supervises two PhD students, Sam Richards and Jess Bloom.

## Dr Davide Burlon

**CAASTRO Affiliate**

**Theme: Dynamic**

Burlon is an expert on high-energy emission from black holes. His main focus in the past year has been in paving the way to the Square Kilometre Array in the

area of stellar explosions known as gamma-ray bursts. He is advising the Transients working group of the Square Kilometre Array.

## Mr Joseph Callingham

**CAASTRO Postgraduate student**

**CAASTRO Theme: Evolving**

Callingham has been working on spectral modelling of young radio galaxies using data from the MWA and Australia Telescope Compact Array. He has helped produce the all-sky survey of the MWA, and a study into the accuracy of the low-radio-frequency flux scale for the southern hemisphere. Callingham has also produced a new catalogue of young radio galaxies from the MWA all-sky survey and investigated the circumstellar environment of supernova 1987A at low radio frequencies.

## Mr Duncan Campbell-Wilson

**CAASTRO Affiliate**

**Theme: Dynamic**

Campbell-Wilson manages the University of Sydney's Molonglo telescope near Canberra. Over the past year he successfully refined the design of a new radio receiver using field-programmable gate arrays and fibre optics; worked to identify and successfully address a number of subtle difficulties that occur in operating digital technologies adjacent to very sensitive astronomical receiving equipment; and re-developed a number of critical systems within the telescope infrastructure.

## Dr Ilana Feain

**CAASTRO Affiliate**

Feain leads the development of a novel and cost-effective radiotherapy machines designed to level the playing field in global accessibility to equitable cancer treatment. Feain obtained her PhD in Astrophysics from the University of Sydney in 2006, and became a research astronomer and project scientist for the Australian Square Kilometre Array Pathfinder (ASKAP) telescope at CSIRO Astronomy and Space Science. This led her to develop a cross-disciplinary research program to enable ASKAP's novel receiver technology to be used beyond astronomy, including in health and defence. Feain then made a major career change in 2014, when she moved into medical physics, working in the Radiation Physics Laboratory at the School of Medicine of the University of Sydney. In 2015 Feain founded, and is CEO of, Nano-X Pty Limited, a company that provides global access to radiotherapy.

## Dr Lisa Fogarty

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Fogarty works on the SAMI Galaxy Survey, a project to observe 3,000 galaxies with integral field spectroscopy (IFS). She published the first paper on the SAMI Pilot Survey, an investigation of the angular momentum of early-type galaxies in clusters. In 2015 Fogarty extended this work, using the main SAMI Galaxy Survey observations to investigate the properties of galaxies in groups to infer their evolutionary history.

## Mr Marcin Glowacki

**CAASTRO PhD student**

**Theme: Evolving**

Glowacki is part of the FLASH (First Large Absorption Survey in H I) team working with ASKAP (the Australian SKA Pathfinder). The aim of FLASH is to search for cool, star-forming material in the early Universe through H I 21-cm absorption within the redshift range of $0.4 < z < 1.0$, and through this learn more about galaxy evolution across epochs. Glowacki has been working with a commissioning sample of radio-bright reddened quasars. He has also worked on H I 21-cm absorption with the Australian Telescope Compact Array (ATCA) on compact radio galaxies selected from drawn from the Australia Telescope 20-GHz survey (AT20G): a paper on this work will soon be submitted.

## Ms Debra Gooley

**CAASTRO Finance Officer**

Gooley is responsible for the co-ordination and management of ARC Centre of Excellence KPI and financial reporting and other associated reports for CAASTRO to support the achievement of the Centre's goals and objectives.

## Professor Anne Green

**CAASTRO Affiliate**

**Themes: Dynamic, Evolving**

Green is a collaborator on a project with CAASTRO's Swinburne Node to upgrade to capabilities of the Molonglo Telescope as a multi-tasking detector of transient sources. The UTMOST project was launched in December 2015 to coincide with the 50th Anniversary of the opening of the telescope. In 2016 Green will continue focus on searches for transient sources at cosmological distances and deep imaging of radio relics and halos around massive galaxies.

## Ms Kate Gunn

**Chief Operating Officer**

A start-up specialist with a wealth of business and University experience, Gunn has been well placed to establish the necessary foundations for CAASTRO to grow and achieve its goals. She has 25 years of management experience, and has a background in the commercialisation of University intellectual property. In 2015, Gunn won a scholarship to attend the Harvard Business School's Women's Leadership program.

## Ms Helen Keys

**CAASTRO Executive Assistant**

Keys joined CAASTRO to provide executive assistance to the Director and COO. She has had extensive experience working at The University of Sydney in various roles associated with the Senior Executive Group. In 2014–15 she was seconded to Macquarie University to assist the Director of the Centre of Excellence for Core to Crust Fluid Systems (CCFS) with the Centre's ARC mid-term review.

## Dr Emil Lenc

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

In 2015 Lenc primarily continued work to survey polarised point sources and diffuse polarisation as part of the GLEAM and Epoch of Reionisation projects within the MWA collaboration, and to investigate the effect of the ionosphere on polarisation at MWA wavelengths. He was also seconded to CSIRO half-time as a commissioning scientist for the Boolardy Engineering Test Array (BETA). In 2016 he will continue work on polarisation within the GLEAM and EoR projects and search for evidence of the synchrotron cosmic web in diffuse emission mapped with the MWA.

## Ms Cleo Loi

**CAASTRO Honours student**

**Theme: Dynamic**

Loi has been working with MWA data, looking for radio emission from low-mass stars and also characterising the ionosphere over the MWA. In 2015, she began a PhD project at Cambridge University with the aim of performing a climatological study of the ionosphere using existing data from MWA transient surveys. Loi is working to establish the MWA as a quantitative tool for geospace physics, its high sensitivity and widefield nature allowing it to image the ionosphere in a novel and detailed way.

## Dr Christene Lynch

**CAASTRO Postdoctoral Researcher**

**Theme: Dynamic**

In 2015 Lynch joined the Slow Transients group at the University of Sydney. Her research focuses on the detection and modelling of circularly polarised radio flares from low-mass stars and exoplanets. She recently completed a survey of 15 M and L dwarfs using the Australia Telescope Compact Array (ATCA), with the goal of better constraining the fraction of low-mass stars observed to be radio-bright. Lynch also worked with the Murchison Widefield Array (MWA) Transient group to develop and organise an observing program to test the capabilities of the MWA to detect 100 MHz emission from flare stars. In 2016 Lynch will continue her work with the MWA flare-star program, including updating the MWA triggering program to incorporate follow-up to X-ray superflares from stars. She also plans to develop analysis techniques that take advantage of the circularly polarised images coming from the MWA.

## Ms Jenny Lynch

**CAASTRO School Education Officer**

With a background in physics, medical science and science communication, Lynch is responsible for running the outreach program, *CAASTRO in the Classroom*. She has extensive experience in running national outreach programs and communicating science to children of all ages. With support from the Commonwealth Government through the Australian Maths and Science Partnerships Program (AMSPP), *CAASTRO in the Classroom* is being expanded to reach a national audience with video conferencing sessions for schools and Lynch is working with experienced classroom science teachers to develop classroom resources and delivery professional development workshops for teachers.

## Ms Rebecca McElroy

**CAASTRO PhD student**

**Theme: Evolving**

McElroy works on integral field spectroscopy of active galaxies and is also a member of the SAMI galaxy survey. In 2015 she helped with SAMI observations, and worked to combine her data set of active galactic nuclei (AGN) with the SAMI sample in a new comparison paper.

## Dr Elizabeth Mahony

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Mahony joined CAASTRO in October 2015 to work on the upcoming ASKAP First Large Absorption Survey in H I (FLASH), along with fellow CAASTRO members Sadler, Allison, Moss, Reeves, Glowacki and Curran. In particular, she has used the Boolardy Engineering Test Array (BETA, the precursor to ASKAP) to search for H I absorption in bright radio sources, with one confirmed detection seen in PKS0409–75. In 2016 the FLASH team will begin to carry out a large, blind survey for H I absorption, as part of ASKAP Early Science.

## Dr Vanessa Moss

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Moss joined the First Large Absorption Survey in H I (FLASH) team in mid-2014 and is working on science preparations for the upcoming survey to be made with the Australian SKA Pathfinder, as well as studies carried out with its precursor, the Boolardy Engineering Test Array. Her focus is on the galactic ecosystems of both intervening and associated absorbing systems, with an emphasis on their multiwavelength footprints as gleaned from large-scale datasets.

## Ms Aina Musaeva

**CAASTRO PhD student**

**Theme: Evolving**

In 2015 Musaeva was granted observing time with the XMM–Newton X-ray space telescope, Australia Telescope Compact Array and European VLBI Network to search for candidate intermediate-mass black holes (IMBHs) in nearby dwarf galaxies. She has presented her work at the Max Planck Institute for Extraterrestrial Physics, where a new X-ray telescope, eROSITA, once launched, is going to revolutionise our view of the X-ray sky and help find these elusive IMBHs. She is currently analysing her data and writing up her PhD thesis.

## Ms Sarah Reeves

**CAASTRO PhD student**

**Theme: Evolving**

Reeves is working on H I emission- and absorption-line studies of nearby galaxies using the Australia Telescope Compact Array (ATCA), as part of preparation for the ASKAP-FLASH survey. In mid-2015 she published her first paper on this work, detailing the results from the pilot sample of galaxies. A second paper, presenting an exciting new detection of intervening H I absorption in the outskirts of a nearby spiral galaxy, was also accepted for publication in late 2015. Reeves' focus now is on completing her PhD thesis, which she will submit in early 2016.

## Mr Samuel Richards

**CAASTRO PhD student**

**Theme: Evolving**

In 2014 Richards identified from the data of the SAMI Galaxy Survey an isolated dwarf galaxy with an intense H II region on its outskirts (a 'lonely twin' of the Large Magellanic Cloud). This dwarf galaxy, and others like it, help in the evolutionary understanding of 'clump-cluster' systems at higher redshift ($z \sim 1$). In 2015 Richards used SAMI data to test single-fibre aperture corrections that are used routinely in large surveys such as GAMA and SDSS. Identifying any systematic errors in these corrections is of great importance to studies of galaxy evolution in the local Universe.

## Mr Adam Schaefer

**CAASTRO Postgraduate student**

**Theme: Evolving**

Schaefer is a postgraduate student working in the Evolving Universe theme. He has been a member of CAASTRO since 2013 and since then he has been using spatially resolved spectroscopy from the SAMI Galaxy Survey to investigate the influence of galaxies' environments on their star formation.

## Dr Nicholas Scott

**CAASTRO Affiliate**

**Theme: Evolving**

In 2015 Scott worked on the SAMI Galaxy Survey, a groundbreaking new project to obtain spatially resolved spectroscopy of more than 3,000 galaxies. Scott is currently leading the work on stellar populations and galactic dynamics within the survey, and has published first results on the Fundamental Plane of SAMI galaxies from a pilot sample. In June 2015 Scott took up a University of Sydney Postdoctoral Research Fellowship to study and understand dwarf elliptical galaxies through spatially resolved spectroscopy, while continuing to work on the SAMI Galaxy Survey. Scott became a CAASTRO affiliate, and also handed over responsibility for coordinating the *CAASTRO in the Classroom* program at that time.

## Ms Helen Sim

**CAASTRO Public Relations Officer**

Sim has extensive experience in writing and performing public relations for scientists, and is skilled in translating complex information into language for non-technical audiences. She writes for CAASTRO's annual report, newsletters and the web. In 2015 she also publicised events that CAASTRO organised or contributed to, such as the ADASS XXV Conference (page 81) and a gathering to mark the upgrade and relaunch of the University of Sydney's Molonglo Observatory Synthesis Telescope.

## Ms Michelle Sullivan

**CAASTRO Executive Assistant**

Sullivan provides executive assistance to the CAASTRO Director and other CAASTRO staff, including assisting the COO and Events and Communications Officer with their duties.

## Ms Kylie Williams

**CAASTRO Events and Communications Officer**

Williams coordinates the regular CAASTRO newsletter and organises various events hosted by CAASTRO around Australia, which in 2015 included the ADASS XXV Conference (page 81). She also organised the ASA Women in Astronomy Conference 2015 at the University of Queensland, the Annual Retreat in the Blue Mountains and a number of other successful events.

THE UNIVERSITY OF MELBOURNE

# CAASTRO AT THE UNIVERSITY OF MELBOURNE

The University of Melbourne node of CAASTRO is housed within the School of Physics. The Astrophysics group at Melbourne was founded less than 20 years ago, but has an excellent record in observational and theoretical cosmology, areas that provide the basis for its contributions to CAASTRO. University of Melbourne researchers work mainly within the Evolving Universe theme, which is led by Professor Stuart Wyithe.

The Epoch of Reionisation (EoR) is the node's major area of research. One of the challenges of modelling reionisation is to account both for the sub-halo-scale physics of galaxy formation and the regions of ionisation on scales that are many orders of magnitude larger. To bridge this gap Han-Seek Kim, in collaboration with Stuart Wyithe, has calculated the statistical relationship between ionising luminosity and megaparsec-scale overdensity, using detailed models of galaxy formation. Kim then applied this relationship to the reionisation of the intergalactic medium over large volumes. The resulting simulations can be used to predict the contribution of very-large-scale clustering of galaxies to the structure of reionisation. Imaging this ionisation structure is a key goal for the Square Kilometre Array.

By the end of 2015 the EoR team within the Murchison Widefield Array (MWA) collaboration had observed for about 1,500 hours in two designated EoR fields, generating around two petabytes of data. The team has developed two software calibration and analysis pipelines, one based in the USA and the other a collaboration between the University of Melbourne and Curtin University. During the year, CAASTRO Principal Investigators Bart Pindor and Pietro Procopio contributed significantly to the preparation of a major paper (Jacobs *et al*. 2016) that compares the outputs of the two pipelines and establishes protocols for verifying them. Another major output this year was a deep catalogue for the EoR0 field, with sophisticated matching software developed by PhD student Jack Line.

The galaxies responsible for reionisation were also investigated theoretically. In collaboration with Edoardo Tescari and Stuart Wyithe, PhD student Antonios Katsianis examined how the relation between star-formation and stellar mass evolved in galaxies at redshifts in the range 1–4. Tescari also ran cosmological computations that followed atomic and molecular chemistry, gas cooling, star formation and production of heavy elements from stars. He used these to explore the origin of chemical abundance patterns and to study the metal and molecular content during simulated galaxy assembly. The synthetic spectra support the existence of metal-poor cold clumps at $z \sim 6$ that could be Population III sites at low or intermediate redshift.

At lower redshifts, Kim explored the low-mass end of the neutral hydrogen (H I) mass function in the local Universe, finding its shape to be most affected by the critical halo mass below which galaxy formation is suppressed by photoionisation heating. He found that an evolving critical halo mass is required to explain both the shape and abundance of the smallest H I masses. The model makes specific predictions for the relation between the H I and stellar-mass contents of galaxies: these can be tested by surveys that will be done with the Square Kilometre Array and its pathfinders.

Intensity mapping of H I is a new observational tool that can be used to efficiently map the large-scale structure of the Universe over wide redshift ranges. During 2015 Laura Wolz examined the cross-correlation between H I and galaxies at redshift $z \sim 0.9$ found in optical surveys, determining the scale-dependent cross-correlation power for different types of galaxies. Her work shows that the cross-correlation coefficient is not negligible when interpreting the cosmological cross-power spectrum, and that it contains information about the H I content of the optically selected galaxies.

Researchers at the University of Melbourne node have also contributed to the Dark Theme. During 2015 PhD student Catherine de Burgh-Day developed a new technique called *direct shear mapping* (DSM) to measure gravitational lensing shear directly from observations of a single background source (details, page 27). Katherine Mack investigated how energy released from self-annihilating dark matter (DM) could heat gas in the small, high-redshift dark-matter halos thought to host the first stars. She found that at redshifts above 20, the injected energy from dark matter exceeds the binding energy of the gas in a $10^5$–$10^6$ solar-mass halo. This would prevent star formation in early halos in which the primordial gas would otherwise cool: it thus suggests that dark-matter annihilation could delay the formation of the first galaxies.

This year the Melbourne node continued to make strong contributions in public outreach and education. Key events included public lectures. CAASTRO arranged a talk in Melbourne by the visiting President of the American Astronomical Society, Professor Meg Urry of

CAASTRO University of Melbourne team members

Yale University, who also spoke at the ASA Women in Astronomy workshop (page 79). In June Rachel Webster featured in a high-profile public panel discussion titled *For Thought: Origins of Life and the Universe,* which ran at both the Melbourne City Conference Centre and the Sydney Opera House. In December Stuart Wyithe, winner of the Australian Institute of Physics' 2015 *Boas Medal*, gave the Medal award public lecture, *Cosmic Hydrogen and the First Galaxies in the Universe*.

In March, April and June respectively, Jack Line, Jacinta den Besten and Edoardo Tescari represented Melbourne as the *Astronomer in Residence* at the Ayers Rock Resort (Uluru) in the Northern Territory (NT). In August Rachel Webster returned to the Northern Territory as one of four guest astronomers at the annual *CAASTRO Uluru Astronomy Weekend*.

Throughout the year many secondary school students engaged with CAASTRO as part of the *Telescopes in Schools* initiative and via Melbourne's Year Ten work-experience program, which now includes an observing night to which parents are invited.

Melbourne's research achievements were celebrated in September when PhD candidate de Burgh-Day was announced as the joint winner of the Royal Society of Victoria's *Young Scientist Research Prize* in the Physical Sciences category. They were recognised again at the end of the year, when postdoctoral researcher Ben McKinley, in his first year out of his PhD, was awarded an ARC Discovery Early Career Researcher Award, and Associate Investigator Ned Taylor won an ARC Future Fellowship through Swinburne University.

In 2016 the University of Melbourne node plans to:

- publish the first deep limits from the MWA experiment to detect the Epoch of Reionisation, together with a theoretical analysis based on the simulations developed during the first five years of CAASTRO
- apply simulated intensity maps to data taken as part of CAASTRO's Parkes H I intensity-mapping program. This will provide a new and novel probe of the relationship between gas and stars near the peak of the Universe's star-formation history
- publish the first results from a program to simulate the material ejected by winds from SAMI galaxies
- continue to investigate how decaying dark matter has modified gas and galaxy formation around the earliest galaxies.

## Professor Stuart Wyithe

**CAASTRO Node Leader, Chief Investigator**

**Themes: Evolving, Dark**

This year Wyithe worked on simulations of the star-formation rate functions and stellar-mass functions of high-redshift galaxies. He also developed new programs to model the cross-correlation between H I and optically selected galaxies and to perform hydrodynamic simulations of galaxies observed with the SAMI instrument.

## Professor Rachel Webster

**CAASTRO Chief Investigator**

**Theme: Evolving**

In 2015 Webster was the spokesperson for the Epoch of Reionisation (EoR) team in the Murchison Widefield Array collaboration. She managed the team across three continents, ensuring that the observing allocations were obtained and that the development of the software pipelines was coordinated. The next phase of the project will see the reduction and publication of very large datasets, resulting in new limits on the detection of the EoR.

## Ms Stephanie Bernard

**CAASTRO PhD student**

**Themes: Dynamic, Evolving**

Bernard's PhD work is focussed on galaxies during the Epoch of Reionisation, 500 million years after the Big Bang ($z \sim 10$). Bernard is part of the Brightest of Reionizing Galaxies (BoRG) survey, which uses the Wide Field Camera 3 on the Hubble Space Telescope to find the very brightest galaxies at this early time. She also works on supernovae at high redshift that are generated by extremely massive stars and those that occur far from their host galaxies.

## Ms Catherine de Burgh-Day

**CAASTRO PhD student**

**Theme: Dark**

De Burgh-Day has developed the *direct shear mapping* (DSM) technique for mapping weak gravitational lensing (details, page 27). This year she also took the first steps to extend the DSM algorithm to include *flexion* (an effect that arcs the images of large background sources). DSM can now recover the shear and flexion field variables around any projected lens-mass distribution, including non-analytic ones.

## Ms Jacinta den Besten

**CAASTRO Affiliate**

**Theme: Education and Outreach**

Den Besten's activities this year included a stint as the second *Uluru Astronomer in Residence* for the year and organising the inaugural *Astronomy and Light Festival* at Scienceworks in Melbourne during National Science Week. She continued to manage the Year-10 work-experience program and the high-school astronomy outreach program, *Telescopes in Schools:* under the umbrella of the latter, seven schools this year took part in the successful *World Record Star Gazing* attempt. Den Besten has also continued to collaborate with Ebeling and Lynch on educational astronomy resources for schools.

## Ms Kim Dorrell

**CAASTRO Executive Officer**

In 2015 Dorrell continued her role as node administrator, ensuring the appropriate integration of Centre activities into the University's overarching administrative structures, and organised and assisted at numerous CAASTRO events. Dorrell also supports the relationship between CAASTRO and the ARC Centre of Excellence for Particle Physics at the Terascale (CoEPP) by providing high-level administrative services to the project to build the Stawell Underground Physics Laboratory in regional Victoria (page 29).

## Mr Antonios Katsianis

**CAASTRO PhD student**

**Theme: Evolving**

Katsianis submitted his PhD thesis this year. Its topic was the properties of high-redshift galaxies, which he studied via numerical simulations of the stellar mass function and star formation rate function. Katsianis looked at what these simulations implied about the feedback mechanisms in high-redshift galaxies; he also extended this work to lower redshifts.

## Dr Hansik Kim

**CAASTRO Affiliate**

**Theme: Evolving**

In 2015 Kim worked to predict the power spectrum of the 21-cm radio emission from neutral hydrogen (H I) during the Epoch of Reionisation. He also studied the importance of reionisation for the H I mass function in the local Universe, and how galaxies with low H I mass affect the spatial distribution of neutral hydrogen in the Universe.

## Mr Jack Line

**CAASTRO PhD student**

**Theme: Evolving**

During 2015 Line finished developing his cross-matching software, PUMA. This was applied to many projects, including a new catalogue in development (KATALOGSS) and the Australian EoR pipeline. In the latter part of the year Line finished implementing a pipeline using new software (OSKAR) to accurately simulate Murchison Widefield Array data, opening the way to testing current algorithms.

## Dr Katherine Mack

**CAASTRO Affiliate**

**Theme: Evolving, Dark**

In 2015 Mack joined two Working Groups for the Square Kilometre Array (*Cosmology* and *Cosmic Dawn–Epoch of Reionization*) and joined the collaboration for a new dark-matter detector to be built in Victoria (page 29). She continued to develop her model of the evolution of the first structures in the Universe under the influence of dark-matter particles. She has also been co-supervising a Masters and PhD student with collaborators in CAASTRO and CoEPP (the ARC Centre of Excellence for Particle Physics at the Terascale).

## Dr Ben McKinley

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

This year McKinley continued to work as part of the team studying the Epoch of Reionisation (EoR) with the Murchison Widefield Array (MWA), developing and testing quality-assurance and calibration procedures for the Australian EoR pipeline. He also led an effort to measure the beam shapes of MWA tiles, a project which he is carrying out with new CAASTRO student Jarryd Rasti. In addition, McKinley is leading a new project to study the all-sky (global) EoR signal using the MWA and the Moon, and this year was awarded an ARC *Discovery Early Career Researcher Award* to pursue it full-time.

## Ms Sinem Ozbilgen

**CAASTRO PhD student**

**Theme: Dark**

Ozbilgen is studying the Tully-Fisher Relation (TFR) with a spiral galaxy sample from the HIPASS (H I Parkes All-Sky Survey) Catalogue. She is investigating whether the ratio of velocity dispersion to circular velocity is a good indicator of galaxy type and whether it could reduce the scatter in the TFR if included as a third parameter; if so, the TFR could be used for galaxies at higher redshifts. Ozbilgen will apply her results to SAMI data.

## Dr Bart Pindor

**CAASTRO Affiliate/CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Pindor was formally hired as a CAASTRO researcher in the first half of 2015. He works on the MWA's Epoch of Reionisation (EoR) experiment, the first limits of which were published this year. In 2016 Pindor will continue to lead the processing of the EOR observations and will apply lessons learned from the MWA to the design of the Square Kilometre Array's EoR experiment.

## Dr Pietro Procopio

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

Procopio this year continued his work on reducing data for the MWA's Epoch of Reionisation (EoR) experiment. In particular, he started developing tools for modelling extended sources in one of the EoR fields: precise models are important, because subtracting poor ones would leave residuals far stronger than the EoR signal researchers are seeking. Procopio is also modelling extended sources found by GLEAM (the GaLactic and Extragalactic All-sky MWA survey).

## Ms Mahsa Rahimi

**CAASTRO PhD student**

**Theme: Evolving**

Rahimi joined CAASTRO as a PhD candidate in July this year. Her thesis will use about 800 hours' worth of data from the MWA Epoch of Reionisation (EoR) experiment to measure or set limits on the statistical signal from the EoR. Her work will contribute to the processing pipeline, initially the quality-assurance algorithms.

## Mr Jarryd Rasti

**CAASTRO Masters student**

**Theme: Evolving**

Rasti joined CAASTRO this July. Working with McKinley, he is measuring the beam patterns of MWA tiles, using downlink transmissions from low-Earth-orbit satellites (the Orbcomm constellation in particular).

## Mr Tristan Reynolds

**CAASTRO Masters student**

**Theme: Evolving**

For his thesis Reynold is investigating how FAST, the Five-hundred-metre Aperture Spherical Telescope under construction in China, could be used to detect quasar-generated H II regions during the Epoch of Reionisation. He has modified code for simulating the 21-cm signal from the EoR to include quasar H II regions and added telescope and foreground noise. He will next determine what properties of H II regions FAST could recover from these spectra.

## Mrs Jennifer Riding

**CAASTRO PhD student**

**Theme: Evolving**

Riding has been working to model bright resolved sources for use in the RTS, a real-time imaging system for the Murchison Widefield Array. *Shapelets* have proven to be efficient and effective, and early testing within the RTS indicates good foreground removal of modelled sources (details, page 28). In 2015 Riding was awarded telescope time on the GMRT (Giant Meterwave Radio Telescope) in India to obtain low-frequency data that will help to refine her models.

## Dr Edward (Ned) Taylor

**CAASTRO Affiliate**

**Theme: Dark**

Taylor has explored a new approach to measuring the dark matter surrounding galaxies through weak gravitational lensing (page 27). He has also been an active member of the SAMI Galaxy Survey team. The SAMI survey, already the largest in its class, will map the distribution and dynamics of stars and star formation within thousands of galaxies, and shed new light on the processes that drive and regulate star- and galaxy-formation.

## Dr Edoardo Tescari

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

In 2015 Tescari worked on a SAMI project to study galactic outflows at low redshift using hydrodynamical simulations. He has developed and tested a pipeline to analyse EAGLE (Evolution and Assembly of GaLaxies and their Environments) simulations, which are aimed at understanding how galaxies form and evolve. Tescari also co-supervises CAASTRO PhD student Angela Garcia (Swinburne University) on a project to study the Epoch of Reionisation.

## Dr Laura Wolz

**CAASTRO Postdoctoral Researcher**

**Theme: Evolving**

This year Wolz finalised a project on H I (neutral hydrogen) intensity mapping, in which she looked at how the cross-correlation of H I intensity maps with optical galaxy surveys can trace star-formation activity and the H I content of optically selected galaxies. Wolz also led work on removing foregrounds in intensity mapping, and continued her involvement in the intensity-mapping project that will be carried out with the Parkes telescope.

# CAASTRO AT SWINBURNE UNIVERSITY OF TECHNOLOGY

The Swinburne node is mainly concerned with the Dynamic and Dark Universe themes and has three Chief Investigators, Professors Matthew Bailes, Chris Blake and Jeremy Mould. 2015 was a remarkable year for this node, seeing it complete the digital upgrade of the Molonglo Observatory Synthesis Telescope and win (in collaboration with other CAASTRO partners) significant resources for the search for dark matter (page 29). The node is housed in the Centre for Astrophysics and Supercomputing at Swinburne University in Melbourne; most of its science involves supercomputing.

CAASTRO has been spearheading a now worldwide effort to study the radio sky at millisecond timescales with the High Time Resolution Universe and SUPERB (SUrvey for Pulsars and Extra-galactic Radio Bursts) surveys on CSIRO's Parkes 64-m radio telescope. 2015 was an extremely exciting year in this field: CAASTRO students and postdocs helped make many breakthroughs, culminating in a paper, accepted by *Nature*, on the origin of the fast radio bursts (FRBs). FRB research across CAASTRO is summarised on pages 14–15.

Fast radio bursts are millisecond-duration flashes of radio emission that are notoriously difficult to detect, requiring large radio telescopes and advanced signal processing to yield results. This year CAASTRO scientists continued to find fast radio bursts at the Parkes radio telescope, including the first one discovered in real time: catching the burst as it happened enabled a massive worldwide follow-up campaign to be carried out at a variety of wavelengths. This work was published by CAASTRO student Emily Petroff. In a stellar year, Petroff also published an important paper that identified microwave ovens as a significant source of radio interference, won the Swinburne University of Technology prize for its *Three-Minute Thesis* competition, appeared in a national documentary on her discoveries, and completed her PhD (taking only three years).

The Molonglo telescope near Canberra this year clocked up 50 years of operation. It has now begun its third incarnation as UTMOST (a name bestowed by the late Professor George Collins of Swinburne), and was formally re-launched on 3 December by the Hon Dr Peter Hendy, Federal Member for Eden-Monaro. As part of the telescope revamp, Chris Flynn and Andrew Jameson this year completed the Molonglo digital correlator, a landmark instrument that is one of the first to use real-time spectral kurtosis to 'cleanse' an otherwise polluted radio band. The correlator simultaneously times radio pulsars and searches for fast radio bursts. As UTMOST the Molonglo telescope has already discovered three pulsar 'glitches', massive discontinuities in the rotation of neutron stars.

Since they were discovered in 2007, fewer than 20 fast radio bursts have been reported in the literature. In late 2015 the extended SUPERB survey on Parkes survey found three in less than a month, and twice broke the record for the most distant FRB. Next year will see these results published and the Molonglo telescope optimised. In other FRB news, Manisha Caleb, a student of the Australian National University who spent 2015 at the Swinburne node, published a paper on the consistency of the known FRBs with a cosmological population, and in October a large contingent of Swinburne staff visited Caltech (California Institute of Technology) to discuss fast radio bursts at a joint meeting organised by Jeff Cooke (Swinburne) and CAASTRO overseas Partner Investigator Shri Kulkarni (Caltech).

Staff movements at the Swinburne node this year included CAASTRO postdoc Vikram Ravi winning a prestigious postdoctoral position at Caltech, Evan Keane securing a permanent position at the Square Kilometre Array project office, and Chris Fluke moving into a Laureate Fellowship-funded position. Keane remains a CAASTRO Affiliate and continues to supervise CAASTRO students. Emily Petroff passed her viva and was awarded a postdoctoral position at ASTRON in the Netherlands. Chris Blake was promoted to the rank of full Professor and Jeff Cooke was promoted to Associate Professor. Matthew Bailes was named as the lead Australian Principal Investigator on the US$100m *Breakthrough Listen* project aimed at detecting extraterrestrial intelligent life (details, page 30).

CAASTRO Affiliate Alan Duffy continued his meteoric rise in the media, and was a regular presence on the ABC Breakfast show and Channel Ten's news program, 'The Project'.

In 2016 the Swinburne node plans to:

- continue the SUPERB program on the Parkes telescope, with shadowing by other telescopes
- continue to work with the Molonglo telescope in its new mode as UTMOST

CAASTRO Swinburne University of Technology team members

- continue to use Molonglo to monitor glitches from young pulsars and to search for fast radio bursts
- begin continuum observations and imaging searches for slow transients with Molonglo
- lead the *Breakthrough Listen* project (designed to hunt for extraterrestrial civilisations) on Parkes.

## Professor Matthew Bailes

**CAASTRO Node Leader, Chief Investigator**

**Theme: Dynamic**

Bailes is the Swinburne node leader. His research focuses on the changes in the radio sky at sub-millisecond timescales and he is an expert on radio-telescope instrumentation. Bailes won an Australian Research Council Laureate Fellowship in 2015 to extend the work he pioneered in CAASTRO on the new phenomenon of fast radio bursts (FRBs). Bailes's latest project involves re-engineering the giant Molonglo radio telescope so that it can operate on the radio sky with extremely high time resolution: this upgrade is being carried out in collaboration with the Australian National University and the host of the Molonglo radio telescope, the University of Sydney. In 2015 Bailes was the Acting Deputy Vice Chancellor for Research and Development. He returned to full-time research in November 2015. He is the lead Australian investigator on the *Breakthrough Listen* project, a search for extraterrestrial intelligence using CSIRO's Parkes radio telescope.

## Professor Chris Blake

**CAASTRO Chief Investigator**

**Theme: Dark**

Blake's research tests aspects of our orthodox cosmological model, such as how gravity operates on cosmic scales, using cosmological probes such as the large-scale structure of the Universe (that is, the distribution of galaxies), galaxy velocities, and weak gravitational lensing. He is currently the Principal Investigator of the 2-degree Field Lensing Survey, a new galaxy-redshift survey that overlaps with the best existing data for weak gravitational lensing. The combination of lensing data and galaxy redshifts will allow new tests of gravitational physics.

## Professor Jeremy Mould

**CAASTRO Chief Investigator**

**Theme: Dark**

During 2015 Mould and two CAASTRO students worked on improvements to two extragalactic distance indicators. The celebrated discovery of the accelerating expansion of the Universe (2011 Nobel Prize for Physic) was made using Type Ia supernovae as *standard candles*. Measurements of the distances to these supernovae can be made more precise by measuring the brightnesses of their host galaxies. A second distance indicator, the Tully-Fisher relation, can be improved by measuring the velocity dispersion of a galaxy's bulge as well as its rotation velocity. Mould is also the Chair of the Project Steering Committee for the Stawell Underground Physics Lab, which will house the first southern-hemisphere experiment aimed at directly detecting dark matter (page 29).

## Dr Ixandra Achitouv

**CAASTRO Postdoctoral Researcher**

**Theme: Dark**

Achitouv joined CAASTRO in 2014 as a postdoctoral fellow. Her research focuses on developing analytical models to describe the large scale structure of the Universe (that is, the distribution of galaxies). In particular, she has worked on predicting the abundances of galaxy clusters and of voids (regions with no galaxies) in non-standard cosmologies. Achitouv also studies non-linear gravitational processes leading to cosmological observables, and has developed processes to improve the measurement of the baryon acoustic oscillation. Achitouv became Theme Scientist for the Dark theme in 2015.

## Ms Caitlin Adams

**CAASTRO PhD student**

**Theme: Dark**

Adams is a first year PhD student working with Blake, Achitouv and Parkinson. Her research has focused on the use of galaxy positions and velocities to understand the accelerating expansion of the Universe. Both observables probe the underlying dark matter, and together they provide a strong testing ground for alternative gravitational models that could explain the expansion without requiring dark energy.

## Mr Igor Andreoni

**CAASTRO PhD student**

**Theme: Dynamic**

Andreoni is a PhD candidate at Swinburne supervised by Cooke and Bailes. His interests include transient phenomena and searching for electromagnetic counterparts to gravitational-wave signals. The research project in which he is most involved, *Deeper Wider Faster*, will explore fast transients (seconds to hours timescale) through simultaneous observations with radio, optical, UV, X-ray and gamma-ray telescopes.

## Dr Ewan Barr

**CAASTRO Affiliate**

**Theme: Dynamic**

Barr's research expertise lies in the fields of digital signal processing, data-mining and high-performance computing, particularly in pulsar astronomy. He has developed high-performance software for real-time searches for pulsars and fast radio bursts, and is now working on the design for the the pulsar processor for the Square Kilometre Array (SKA).

## Ms Shivani Bhandari

**CAASTRO PhD student**

**Theme: Dynamic**

Bhandari works on fast radio bursts. She is involved in two large projects, both being carried out with CSIRO's Parkes telescope: the High Time Resolution Universe Survey (HTRU) and the Search for PUlsars and Extragalactic Bursts (SUPERB). Bhandari looks for bright single pulses in the HTRU data and leads the multiwavelength follow-up for bursts discovered by SUPERB. She is also part of the team commissioning UTMOST (page 14).

## Mr Alex Codoreanu

**CAASTRO PhD student**

**Theme: Evolving**

Codoreanu began his PhD at Swinburne in May 2014 under the supervision of Associate Professor Emma Ryan-Weber, Professor Michael Murphy and Dr Neil Crighton. He is studying absorption systems in high-redshift quasar spectra as a way to understand the end of the Epoch of Reionisation and the stellar populations responsible for it.

## Associate Professor Jeff Cooke

**CAASTRO Associate Investigator**

**Theme: Evolving, Dynamic**

Cooke contributes to both the Dynamic and Evolving themes. In Dynamic he has focused on high redshift ($z > 2$) supernovae, finding events that occurred when the Universe was just 10–20 per cent of its current age. Such observations might reveal the first generation of stars that formed after the Big Bang and a long-theorised type of supernova, the *pair-instability* supernova. Cooke also leads the *Deeper, Wider, Faster* program of simultaneous multi-wavelength observations of transient phenomena. In Evolving, Cooke leads work on the detection and characterisation of galaxies in the early Universe and their contribution to the Epoch of Reionisation.

## Mr Chris Curtin

**CAASTRO PhD student**

**Theme: Evolving, Dynamic**

Curtin's research speciality is the rare superluminous supernovae. He is a member of the Survey Using DECam for Superluminous Supernovae (SUDSS) project, which is hunting for transient objects at redshifts 2–6. He also works on follow-up campaigns and new survey designs.

## Dr Alan Duffy

**CAASTRO Affiliate**

**Theme: Evolving, Dark**

Duffy has created a new simulation series tracking the formation of the first galaxies, the properties of which will be crucial for determining the visibility of the Epoch of Reionisation. He has also created an online pipeline to image the local Universe and probe the nature of the intergalactic medium. Duffy is Chief Investigator for the dark-matter detection experiment to be built at Stawell in central Victoria (page 29).

## Dr Chris Flynn

**CAASTRO Postdoctoral Researcher**

**Theme: Dynamic**

Flynn has been heavily involved with the refit of the Molonglo radio telescope: he and Jameson this year completed the telescope's digital correlator. Flynn is also a member of the teams using Molonglo to time

hundreds of pulsars a week and search around the clock for fast radio bursts.

## Ms Luz Angela Garcia

**CAASTRO PhD student**

**Theme: Evolving**

Garcia started her PhD in February 2014 at Swinburne under the supervision of Emma Ryan-Weber, Edoardo Tescari and Stuart Wyithe. She is studying the Epoch of Reionisation, looking for correlations among metal absorption-line ratios that may allow us to measure the ratio of neutral hydrogen to ionised hydrogen at high redshift.

## Professor Karl Glazebrook

**CAASTRO Affiliate**

**Theme: Dark**

In 2015 Glazebrook published 14 refereed papers, of which two were particularly important. One, discussed on page 12, concerns the low angular momentum of clumpy disk galaxies, which has significant implications for models of galaxy morphology. The second paper describes the extreme compactness of a newly discovered population of $z \sim 4$ massive galaxies, a finding which may challenge current models of early galaxy star formation. In October Glazebrook, together with CAASTRO colleagues Brian Schmidt and Tamara Davis, became a full member of the Dark Energy Survey collaboration: this honour recognised their efforts with the OzDES survey (page 20). This year also saw Glazebook complete his role on leading discussions of international infrastructure for the 2016–2025 Australian Astronomy Decadal Plan.

## Mr Andrew Jameson

**CAASTRO Affiliate**

**Theme: Dynamic**

Jameson is experienced in software development, systems administration, high-performance computing and scientific visualisation. He has substantial expertise in the design and implementation of radio-astronomy instrumentation in use at, or designed for, the Parkes and Molonglo telescopes, South Africa's MeerKAT, and the Square Kilometre Array. His work continues in the areas of data acquisition, high-speed networking, real-time systems, interference excision, GPU software development and the management of 'big data'. This year he worked with Flynn to complete the Molonglo telescope's new digital correlator.

## Mr Fabian Jankowski

**CAASTRO PhD student**

**Theme: Dynamic**

Jankowski is part of the UTMOST team using the Molonglo telescope and is responsible for the pulsar-timing programme. Using the telescope he has found three pulsar glitches and made a study of the southern pulsar population that he is preparing for publication. His work is proving useful for the Murchison Widefield Array telescope, and he has been collaborating with CAASTRO's Tara Murphy (University of Sydney) to study pulsar scintillation.

## Mr Andrew Johnson

**CAASTRO PhD student**

**Theme: Dark**

Johnson's research has focused on weak gravitational lensing (described on page 27). To understand the weak lensing signal one must understand how the imaged galaxies are distributed in their distance from us. Johnson has developed a new statistical estimator to calculate the distance distribution of galaxies, using angular cross-correlations between overlapping spectroscopic surveys.

## Ms Susan Lester

**Node Administrator**

Lester oversees all of the administrative and financial functions for Swinburne's CAASTRO members.

## Dr Felipe Marin

**CAASTRO Postdoctoral Researcher**

**Theme: Dark**

Marin is a member of the Swinburne cosmology group. This year he analysed the region of overlap between two major galaxy redshift surveys, the WiggleZ Dark Energy Survey and the Baryon Oscillation Spectroscopic Survey: this work is described on page 22. Marin also used supercomputing time available through the National Computing Infrastructure scheme to create new mock catalogues of galaxies that will be used to analyse current and future surveys.

## Mr Vincent Morello

**CAASTRO PhD student**

**Theme: Dynamic**

Morello's work stands at the boundary between statistics and astronomy. He uses neural networks to sift through vast quantities of data and statistics to remove contamination, and recently developed a new method to purify data polluted by radio interference. Morello is also active in pulsar searches.

## Ms Emily Petroff

**CAASTRO PhD student**

**Theme: Dynamic**

Petroff completed her PhD this year. Her supervisors were Willem van Straten and Matthew Bailes at Swinburne and Simon Johnston at CSIRO, and her thesis dealt with searches for radio transients with the Parkes radio telescope. Petroff's main area of interest is fast radio bursts (discussed on page 14). She made the first discovery of a radio burst in real time (that is, as it happened) and coordinated follow-up observations by telescopes around the world; she also put limits on the repeatability of bursts (page 14). In addition, she identified another mysterious local source of burst-like interference as coming from microwave ovens at the Parkes site.

## Dr Vikram Ravi

**CAASTRO Postdoctoral Researcher**

**Theme: Dynamic**

Ravi worked at Swinburne between completing his PhD and starting a postdoctoral position at Caltech with CAASTRO overseas Pricipal Investigator Shri Kulkarni. During his brief stay at the node he helped commission the Molonglo radio telescope and found a bright fast radio burst with the Parkes telescope.

## Associate Professor Emma Ryan-Weber

**CAASTRO Associate Investigator**

**Theme: Evolving**

Ryan-Weber's research in 2015 focussed on metal absorption-line systems in the high redshift Universe. She supervised two CAASTRO PhD students who are working in this area: Luz Angela Garcia, who is simulating metal absorption-line systems, and Alex Codoreanu, who is using high signal-to-noise spectra of redshift 6 quasars to search for metal lines in the intergalactic medium at the end of the Epoch of Reionisation.

## Mr Syed A Uddin

**CAASTRO PhD student**

**Theme: Dark**

Uddin has recently completed his PhD. For his thesis he compiled a dataset of 1,350 Type Ia Supernovae and studied the properties of their host galaxies, finding that although SNe Ia are significantly more luminous in massive galaxies, this does not affect their usefulness for determining cosmological parameters. Uddin has been selected as a President's International Postdoctoral Fellow of the Chinese Academy of Science. He will also be involved in establishing an astronomy centre in Bangladesh.

## Dr Willem van Straten

**CAASTRO Affiliate**

**Theme: Dynamic**

Van Straten is developing the pulsar processor for the Square Kilometre Array. He also supervises CAASTRO students on fast radio burst work, and was the principal coordinating supervisor for Petroff.

## Mr Vivek Venkatraman Krishnan

**CAASTRO PhD student**

**Theme: Dynamic**

Venkatraman is a PhD student working with Matthew Bailes, Willem van Straten and Evan Keane. He spent most of 2015 analysing timing data from a pulsar-white dwarf binary system to test the different theories of gravity. He also refurbished the telescope control system for the Molonglo telescope, as part of its overall upgrade, and worked on ways to cut radio-frequency interference from mobile phones out of telescope data.

Australian National University

# CAASTRO AT THE AUSTRALIAN NATIONAL UNIVERSITY (ANU)

The Australian National University's Mount Stromlo node of CAASTRO does research across the Centre's three themes, and includes 20 researchers ranging from the undergraduate to Professorial level. Our efforts include observations and theoretical modelling of optical and radio transients, characterisation of dark energy and dark matter through cosmological surveys, and work on understanding the evolving Universe through optical and radio observations.

Within the Dark Universe theme, Michael Childress, Richard Scalzo, Anais Möller, Brad Tucker, Christian Wolf, Fang Yuan, Bonnie Zhang and Brian Schmidt all actively participate in the OzDES survey. This international collaboration has now discovered and characterised nearly a thousand supernovae. The ANU team has helped to make the observations, and this year Yuan led a consortium paper describing the survey and its first results. The SkyMapper telescope's survey time was limited this year by hardware problems, but under the leadership of Möller a supernova survey has been designed that will obtain a significant sample of objects in the next three years.

A variety of work has been done in the Dynamic Universe theme. Manisha Caleb has been working on the upgrade Molonglo telescope, UTMOST, to detect fast radio bursts (FRBs). Her modelling has shown that, when fully developed, the UTMOST instrument will have world-leading sensitivity for detecting FRBs. Fang Yuan led SkyMapper's follow-up to LIGO's historic discovery of the first source of gravitational waves. While no source was detected, Yuan has positioned the SkyMapper telescope to be a major resource in the follow-up of gravitational-wave sources in the future. Ashley Ruiter and colleagues have modelled the rate at which white dwarfs merge and do not produce a Type Ia Supernovae. These mergers instead form R Coronae Borealis stars and lots of dust – in fact so much that these stars cannot be ignored as a source of dust, which they have been until now. Ivo Seitenzahl was part of a team that observed a Type Ia supernova, SN 2012fr: this event confirmed his 2009 prediction that radioactive decay of Cobalt-57 should dominate these objects' energy approximately 1,000 days after the explosion. This confirmation helps us understand the details of these explosions, which have generated much of the Universe's iron.

In the Evolving Universe theme, Matthew Colless has been working with node members Francesco D'Eugenio and Dilyar Barat, and other colleagues, on galaxy data from the SAMI survey. The aim is to better understand how galaxies evolve over time. The work will also allow us to improve distance estimates to these galaxies, which in turn will let us use the galaxies to more accurately map dark matter in the nearby Universe. Julie Banfield engaged the public with the citizen-science project, Radio Galaxy Zoo, to help understand how radio galaxies evolve over cosmic time. She also was part of the team that released the third Australia Telescope Large Area Survey (ATLAS) field, which is serving as the pilot field for the upcoming Evolutionary Map of the Universe (EMU) survey on the Australian SKA Pathfinder (ASKAP) telescope.

A number of new members joined the ANU node this year, including postgraduate researchers Dr Julie Banfield (from CSIRO), Dr Anais Moeller (from CEA France), Dr Brad Tucker (from Berkeley/ANU), PhD student Fiona Panther, and undergraduate students Dilyar Barat and Diane Salim. We had to say goodbye to Dr Michael Childress (to the University of Southampton), Dr Richard Scalzo (University of Sydney), and Sarah Leslie (MPIA Heidelberg), but were very proud that all of them were able to take up interesting positions.

In outreach, postdoc Brad Tucker led a world-record star party that had the most observers in a single site (Canberra) and at multiple sites (across Australia). He gave an interview about this to Leigh Sales for ABC Televison's *7.30 Report* – one that Ms Sales rated as one of her ten best in 2015.

In 2016 we can expect new breakthroughs in learning about the sources of gravitational waves and fast radio bursts, and progress on the supernova surveys from SkyMapper and OzDES. Work will also continue on the analysis of SAMI data, and the first data from ASKAP will define the EMU survey.

## Professor Brian Schmidt

**CAASTRO Gender and Diversity Committee Chair, Node Leader and Chief Investigator,**

**Themes: Evolving, Dynamic, Dark**

Schmidt continued to lead work on SkyMapper, which spent 2015 continuing its imaging of the southern sky. A substantial amount of work was done to improve operations of the telescope, and to undertake the data reduction and analysis of the 100 Terabytes of data

CAASTRO ANU team members

already collected. The telescope has surveyed a high percentage of the entire southern sky three times in all six colours. In the coming years it will fill in the last few remaining holes in the sky and survey the entire sky to fainter levels.

Schmidt continues to make many public appearances both in Australia and internationally, including being a keynote speaker at the World Economic Forum in Davos, the World Economic Forum *New Champions* event in Dalian, the World Academic Summit in Melbourne, and the *Falling Walls* event in Berlin. He was also this year's Loeb Lecturer at Harvard University.

This year Schmidt was named the 12th Vice-Chancellor of the Australian National University: he will take up the position on 1 January 2016. He continues to be involved in CAASTRO, remaining a Chief Investigator and chairing the Gender Action Committee.

## Professor Frank Briggs

**CAASTRO Chief Investigator**

**Themes: Evolving, Dynamic**

Briggs' research interests have focused on the use of the 21-cm radio spectral line of neutral hydrogen to follow the history of galaxy formation and evolution. Briggs has been a member since its inception of the MWA Collaboration that has designed, built and operated the Murchison Widefield Array in Western Australia. He has also been engaged in a long-term collaboration with astronomers in India and Australia to use India's Giant Metrewave Radio Telescope (GMRT) to measure the evolution of the gas content of galaxies over the last seven billion years, with the aim of learning how the gas is related to galaxies' star-forming properties.

## Professor Matthew Colless

**CAASTRO Chief Investigator**

**Themes: Evolving, Dark**

Colless led the 6dF Galaxy Survey that mapped the density and velocity fields in the local Universe. Within CAASTRO he will test whether the distributions of dark and luminous matter are the same on the largest scales by combining the WALLABY all-sky neutral hydrogen survey with the SkyMapper all-sky optical survey. Colless will compare the radio and optical surveys in the analysis of the velocity field and explore implications for cosmological models. He is also using the SAMI survey to investigate dynamical scaling relations in galaxies, both to understand galaxy evolution and to obtain more general and precise distance estimates. Colless will combine data from the SAMI, WALLABY and FLASH surveys carried out under CAASTRO to study the co-evolution of gas and stars at low redshifts, using the ASKAP radio surveys to measure the neutral hydrogen gas and the SkyMapper and SAMI optical spectroscopy to measure the stellar component.

## Dr Christian Wolf

**CAASTRO Associate Investigator**

**Theme: Evolving, Dark**

Wolf started work as SkyMapper Survey Scientist in April 2013 and previously led the COMBO-17 optical multiband survey, which explored the evolution of galaxies and quasars over most of cosmic time. He has worked for 20 years on photometric redshift and statistical classification techniques and pioneered high-precision photometric redshifts and their application to quasars. He led the measurement of 30,000 galaxy redshifts and identification of many thousand stars and quasars within the spectroscopic 2dFLenS Survey to underpin the photometric classification of the SkyMapper survey. He is now exploring Active Learning algorithms to design training sets of maximal value for minimal cost. His research interests include galaxy evolution and the decline of star formation in spiral galaxies, as well as dust extinction, supernovae, gamma-ray bursts and their host galaxies.

## Dr Julie Banfield

**CASTRO Research Staff**

**Theme: Evolving**

Banfield's research is centred around radio-galaxy environments. She is a co-principal investigator of the citizen-science program Radio Galaxy Zoo, a project to cross-match radio sources with their host galaxies in preparation for the radio-continuum surveys that will be carried out with the Australian Square Kilometre Array Pathfinder (ASKAP) and South African MeerKAT telescopes. Banfield's most recent work has been to map the host galaxies of radio-loud active galactic nuclei with the Australian National University's 2.3-m telescope, to examine the interaction between the radio source and the host galaxy.

## Mr Dilyar Barat

**CAASTRO Pre-PhD student:**

**Theme: Dark**

In 2015 Barat completed his Honours degree in Astronomy and Astrophysics at the Australian National University under the supervision of Professor Matthew Colless. Barat works with the SAMI Galaxy Survey (page 13), and his thesis involved constructing and optimising galaxy-scaling relations. By combining results from the SAMI and ATLAS3D surveys, Barat showed how such relations could be better constructed. Barat will continue to work with Colless on both the SAMI survey and the new TAIPAN galaxy survey, which starts in 2016.

## Ms Manisha Caleb

**CAASTRO PhD student**

**Theme: Dynamic**

Caleb began her PhD in July 2013 under the supervision of Frank Briggs at ANU and Matthew Bailes and Chris Flynn at Swinburne University. She studies fast radio bursts (FRBs): bright, coherent, millisecond-duration radio emission of unknown origin, thought to occur at cosmological distances. Only a handful of these sources have been discovered to date. Caleb is part of the team at Swinburne that is taking part in the worldwide race to discover more of these exciting sources. She is also performing Monte Carlo simulations to determine the discovery rates of these FRBs at the Parkes and Molonglo radio telescopes (details, page 14).

## Dr Michael Childress

**CAASTRO Postdoctoral Fellow**

**Theme: Dark**

Childress works primarily on the SkyMapper transient survey and the OzDES survey (page 20), and has conducted extensive observations of supernovae using the WiFeS spectrograph on the Australian National University's 2.3-m telescope. In 2015 Childress published a paper on late-phase Type Ia supernova spectra, and how they can be used to learn about the original supernova explosion. He is currently working on a major three-year data release for WiFeS spectroscopy observations and writing the OzDES second-year survey paper.

## Dr Francesco D'Eugenio

**CAASTRO Postdoctoral Fellow**

**Theme: Dark**

D'Eugenio is working on the SAMI Fundamental Plane, and on dynamical modelling of the early-type galaxies in the SAMI sample. His other research projects include galaxy evolution at intermediate redshift and the slow/fast rotator kinematic classification paradigm. His previous work focused on the kinematic morphologies of galaxies in the densest environments, and on the shape of early-type galaxies in relation to their dynamical properties.

## Ms Sarah Leslie

**CAASTRO Pre-PhD student:**

**Theme: Evolving**

In 2015 Leslie was the first student to graduate from ANU's new Masters in Astronomy and Astrophysics program. She works with the SAMI galaxy survey, and her thesis involved combining the optical data from SAMI with radio-continuum data from the VLA FIRST survey. Leslie is interested in measuring star-formation rates in galaxies to understand how galaxies evolve from star-forming discs into massive quiescent galaxies. In 2016 Leslie will start her PhD at the Max Planck Institute for Astronomy in Heidelberg, Germany.

## Dr Anais Möller

**CAASTRO Postdoctoral Fellow**

**Theme: Dark**

Möller is a postdoctoral fellow at the Australian National University and studies supernovae and Type Ia supernova cosmology. She has worked for the Supernova Legacy Survey (SNLS), improving the detection of supernovae (SNe) and developing a novel photometric classification of Type Ia SNe. From this work, a detection paper using morphological component analysis was published in 2015. Möller has now joined the SkyMapper and OzDES surveys.

## Dr Christopher Onken

**CAASTRO Associate Investigator**

**Themes: Dark, Dynamic, Evolving**

Onken is the Operations Manager for the SkyMapper Telescope, a facility contributing to all three CAASTRO themes. He joined CAASTRO in April 2015 as an Associate Investigator. His research interests are primarily related to active galactic nuclei and the measurement of black-hole masses.

## Ms Fiona Panther

**CAASTRO PhD student**

**Theme: Dynamic**

Panther began her PhD in July 2015. She is investigating sources of the mysterious positron annihilation signal in the Milky Way's bulge, with a particular focus on the role of sub-luminous Type Ia supernovae (SNe Ia) as positron production sites. Fiona is interested in rates at which sub-luminous SNe Ia occur across cosmic time and galaxy type, and aims to investigate this with data obtained by the Dark Energy Survey (DES) and

the spectroscopic follow-up survey OzDES. She is also interested in constraining the production of nuclei that decay to produce positrons in these objects, using explosion and nucleosynthesis models.

## Dr Ashley Ruiter

**CAASTRO Associate Investigator**

**Theme: Dynamic**

Ruiter works in binary star evolution modelling to understand the formation of interacting stars that give rise to explosive phenomena. She is interested in transient sources involving white dwarfs (for instance novae, Type Ia supernovae, RCrB stars, accretion-induced collapse events), and uses theoretical methods to uncover the evolutionary channels that lead to their formation, predict their birth rates, and constrain their birth sites and ages.

## Diane Salim

**CAASTRO undergraduate student**

**Theme: Evolving**

Salim is an undergraduate student supervised by Lisa Kewley and Christoph Federrath. Historically, the rate at which stars form in a molecular cloud has been predicted from factors such as the mean column density of available gas and the time it would take the molecular cloud to collapse under its own gravitational attraction. However, turbulence has also been found to be an important factor. In 2015 Salim led work to produce more global description of the behaviour of the molecules in a gas cloud, one that depends on the statistical definition of turbulence. As a follow-up study she inverted this relation and used data from galaxies in the SAMI survey to predict distributions for gas column densities in these galaxies. In 2016 Salim will continue to study star formation, molecular gas and turbulence in galaxies.

## Mayuri Sathyanarayana Rao

**CAASTRO PhD student**

**Theme: Dynamic**

Rao is in the second year of her PhD under the guidance of Frank Briggs at the Australian National University and Ravi Subrahmanyan at the Raman Research Institute in India. Theory predicts that photons emitted during the epochs of hydrogen and helium recombination will introduce distortions into the spectrum from the cosmic microwave background (CMB). These distortions are expected to be eight orders of magnitude weaker than the sky spectrum. Detecting them is extremely challenging, but doing so would provide a wealth of information about the early history of the Universe, such as the pre-stellar helium abundance. For her PhD Rao is developing a prototype element of an array to detect these and other cosmological distortions of the CMB. She is also working on modelling the radio foreground and algorithms to distinguish the foreground from cosmological signals, including those arising from the epoch of reionisation.

## Dr Richard Scalzo

**CAASTRO Associate Investigator**

**Themes: Dark, Dynamic**

Scalzo joined CAASTRO at its inception in 2011, focusing on optical-wavelength time-domain astronomy and on Type Ia supernova progenitors and explosion physics. The SkyMapper supernova search began operating at scale in 2015; Scalzo coordinated the first crowd-sourced search for supernovae in SkyMapper data in collaboration with the Zooniverse citizen-science community, which was featured on BBC Two's *Stargazing Live*. He has opened collaborations with other groups interested in using the SkyMapper supernova discovery pipeline as a software framework for their own optical transient searches (for example, BlackGEM and GOTO). Scalzo is also leading a new analysis, to be submitted in early 2016, that will triple the number of high-quality Type Ia supernova bolometric light curves in the literature and will present a detailed look at the connection between explosion physics and distance measurement in cosmology.

## Dr Ivo Seitenzahl

**CAASTRO Associate Investigator**

**Theme: Dynamic**

Seitenzahl is a theoretical nuclear astrophysicist and his research focuses on explosive nucleosynthesis and three-dimensional simulations of Type Ia supernova explosions. His current research also includes work on the neutrino and gravitational-wave signals of thermonuclear supernovae, the Galactic chemical evolution of Fe-peak elements, the atomic and nuclear physics of late-time supernova light curves, and optical observations (made with integral field units) of supernova remnants in the Large Magellanic Cloud.

## Dr Robert Sharp

**CAASTRO Associate Investigator**

**Theme: Evolving, Dark**

Sharp is instrument scientist for the Giant Magellan Telescope Integral Field Spectrograph, a new instrument being designed at the Australian National University and destined for the Giant Magellan Telescope in Chile in 2021. Within CAASTRO Sharp is a leader of the SAMI Galaxy Survey data-analysis group, for which the SAMI survey team delivered the first public data release in July 2014. For the OzDES supernova survey project (which completed the second full year of its five-year campaign in early 2015), Sharp is the local coordinator for the 'reverberation mapping' component that will measure the masses of giant black holes in distant quasars. In addition, Sharp has teamed up with radio astronomers interested in faint radio galaxies and is using the repeated visits to the OzDES supernova survey fields to record sensitive observations of these enigmatic galaxies, to identify the underlying source types and their distances from Earth.

## Ms Denise Sturgess

**CAASTRO Administrator**

Sturgess has worked as CAASTRO Node Administrator at the Australian National University's Mount Stromlo Observatory since CAASTRO's inception. She provides ongoing, broad administrative support to the team and works alongside Chief Investigator Professor Brian Schmidt as his assistant.

## Dr Brad Tucker

**CAASTRO Postdoctoral Researcher**

**Theme: Dark, Dynamic**

Tucker is currently working on projects aimed at understanding dark energy through a better use and understanding of supernovae. He studies early and multiwavelength observations of supernovae to learn about their physics and progenitors. Tucker is working on a variety of supernova surveys incl. the SkyMapper Supernova Survey, OzDES, ESSENCE (Equation of State: SupErNovae trace Cosmic Expansion) and the Carnegie Supernova Project. He is also the lead of the Kepler Extra-Galactic Survey, a NASA Kepler K2 key project to search for supernovae, black holes and other extragalactic transient objects.

As well as working on these projects, Tucker frequently speaks to school groups and the general public about astronomy, and has regular segments on various radio stations and the *Morning Show* on Channel 7, talking about astronomy news and events. He has also developed a series of astronomy coins in conjunction with the Royal Australian Mint, re-developed the Mt Stromlo and Siding Spring Observatories' Visitor Centres, and in 2015 led Australia's World Record Stargazing event.

## Dr Fang Yuan

**CAASTRO Postdoctoral Researcher**

**Theme: Dynamic**

Yuan is a member of the SkyMapper transient team. The SkyMapper transient search found its first supernova in late 2013; its discovery rate is expected to increase steadily as the survey area expands and the pipeline continues to be improved. Yuan's main science interest lies in understanding a diverse range of stellar explosions. She studies core-collapse supernovae and is responsible for coordinating SkyMapper and the Australian National University's 2.3-m telescope to follow up gamma-ray bursts, fast radio bursts and gravitational-wave candidate events. Yuan is also a member of the OzDES team.

## Ms Bonnie Zhang

**CAASTRO PhD student**

**Themes: Dark, Dynamic**

Zhang began her PhD in February 2014 under the supervision of Brian Schmidt. She studies observational cosmology with Type Ia supernovae, with the goal of constraining dark energy. As part of both the SkyMapper team and the OzDES collaboration, she will analyse light curves of supernovae discovered at low redshift in the SkyMapper Supernova Survey and at high redshift in the Dark Energy Survey. She will also compare the photometric calibrations of the two surveys to quantify and minimise the systematic uncertainty associated with the calibration.

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

# CAASTRO AT THE UNIVERSITY OF QUEENSLAND

The University of Queensland is the newest node of CAASTRO, having joined in 2014. Most of the node's research falls within the Dark and Evolving themes: its ten research personnel, staff and students, work on projects such as OzDES (page 20), EMU (the Evolutionary Map of the Universe survey) and the SAMI Galaxy Survey (page 13), as well as contributing to simulations and theory. Node Leader Tamara Davis is also leader of the Dark theme, and Associate Investigator David Parkinson leads the theory project within the Dark theme.

One of the major projects in the Dark theme, OzDES (page 20), saw several papers published this year. While most were led by our collaborators in the international Dark Energy Survey, two were led by Australians: one of these was a survey simulation paper by UQ's Anthea King. In an important development, some OzDES participants were recognised as full members of the international Dark Energy Survey (DES) and Davis was appointed to the DES Management Committee.

Observing for OzDES has progressed well: we are now halfway through, and have already spectroscopically confirmed more than 100 Type Ia supernovae and determined the redshifts of more than 1,000 host galaxies. That means we are well on our way to adding ~2500 supernovae to the Hubble diagram (showing magnitude vs redshift), improving our ability to test models of dark energy. The initial discovery of dark energy, which netted two teams the Nobel Prize, was based on only 52 supernovae. Now with thousands of supernovae we are able to do new *types* of tests. For example, we can use the dispersion about the Hubble diagram to identify both the signal of magnification (and de-magnification) due to gravitational lensing and the signal of *peculiar velocities* due to bulk flows and growth of structure. UQ CAASTRO postdoc Edward Macaulay is leading the OzDES efforts to convert measurements of the dispersion about the Hubble diagram into constraints on cosmology.

Planning has begun for cosmology with the EMU (Evolutionary Map of the Universe) survey, a deep, radio-continuum survey over three-quarters of the sky that will be done with CSIRO's Australian SKA Pathfinder telescope. UQ CAASTRO Associate Investigator David Parkinson is leading the project's Cosmology Working Group. EMU is expected to find 70 million radio sources: this year saw preliminary development of its analysis pipeline. In another cosmology project, former UQ CAASTRO member Jason Dossett led a paper on testing general relativity by combining cosmic microwave background data from the Planck satellite with weak-lensing shear measurements from the CHFTLens survey (details, page 20). David Parkinson started collaborating with Chris Power (UWA) and Pascal Elahi (University of Sydney) on making new cosmological simulations that include relativistic effects. With his student, Jacob Seiler, David has also been making predictions for peculiar velocities in f(R) gravity, and testing these against measurements of the bulk flows from the 2MTF and 6dFGS galaxy surveys.

In the Evolving theme, Holger Baumgardt, Joel Pfeffer, and collaborators investigated how much the tidal stripping of dwarf galaxies has contributed to the population of ultra-compact dwarf (UCD) galaxies in the two closest large galaxy clusters, Virgo and Fornax. They found that the observed UCD population in both clusters is probably a combination of genuine globular clusters and stripped nuclei, with the contribution of stripped nuclei increasing towards the high end of the mass range. From this result they conclude that a large population of so-far-undiscovered supermassive black holes is present in these galaxy clusters. In related work, published in *Nature*, Holger was a member of the team that discovered the smallest galaxy known to harbour a supermassive black hole. His simulation of how that galaxy might have evolved can be seen on *https://vimeo.com/105370891*.

Michael Drinkwater and CAASTRO student Simon Deeley used data from the GAMA (Galaxy And Mass Assembly) survey to show that the fraction of elliptical galaxies in galaxy groups declines continually as group mass decreases, over a range of four orders of magnitude in group mass. Using cosmological dark-matter simulations, they showed that galaxy mergers can account for much of this effect. This year Drinkwater also became Chair of the Quality Control Working Group for the SAMI Galaxy Survey, which is preparing SAMI data for public release.

This year the UQ node hosted several events, most notably the *Women in Astronomy* conference for the Astronomical Society of Australia, co-sponsored by CAASTRO. This was a really exciting event, with many interesting speakers on topics as diverse as mental health and how to deal with challenging conversations. The discussion of the issues went

CAASTRO University of Queensland team members

beyond the conference room, reaching the public through radio interviews and articles. Our public talk featuring four female astrophysicists drew more than 300 people, and resulted in an hour-long radio interview on ABC (listenership approximately 200,000 people), *http:///blogs.abc.net.au/queensland/2015/07/women-out-of-this-world-.html*. The twitter hashtag for the meeting trended so well it was ranked seventh in Australia (pipping Katy Perry by one place!). The keynote speaker, Meg Urry, President of the American Astronomical Society, praised Australia's advances in gender equality. Her comments can be heard here: *http://www.biosciencetechnology.com/articles/2015/08/unusual-suite-women-science-initiatives-hailed-special-report.*

The UQ group took many opportunities to do outreach this year, from Davis's opening speech for visiting celebrity astronomer Neil deGrasse Tyson and her *Science Fiction meets Science Fact* talk on warp drives, to Parkinson's appearance in several forms of media (including live television) at the time of the 2015 leap second (1 July).

Several UQ CAASTRO members received accolades. Node leader Tamara Davis was recognised by the Australian Academy of Science through its Nancy Millis Medal, given to one woman in Australia each year for outstanding research leadership, and judged across all areas of science. CAASTRO Honours student Samuel Hinton received several prizes for his Honours thesis, including the Institute of Electrical and Electronics Engineers *Student Thesis Prize* for the best final-year thesis in all fields of electric engineering and information technology, and the *GroundProbe Prize* for the best project in microwave, photonics and communications. Hinton's *Marz* software, which he developed for viewing and redshifting spectra from the 2-degree Field (2dF) instrument on the Anglo-Australian Telescope, is now used for OzDES as its main redshifting tool (details, page 28). Finally, during the summers bracketing 2015, UQ students Conor O'Neill and Samuel Hinton received the Gemini Observatory studentships, and went to Chile for 10 weeks to work on astrophysics projects with researchers at Gemini.

In 2016 the UQ node plans to:

- continue work on the OzDES, SAMI, GAMA and EMU surveys
- work on TAIPAN, a large-scale galaxy survey that will begin in 2016 on the 1.2-m UK Schmidt Telescope at Siding Spring Observatory.

## Professor Tamara Davis

**CAASTRO Node Leader, Chief Investigator**

**Theme: Dark**

Davis studies dark energy and black holes, the large-scale structure of the Universe, and active galactic nuclei. 2015 was an exciting year for Davis: it saw her recognised as one of Australia's top female science leaders with the award of the Australian Academy of Science's *Nancy Millis Medal*. She was also promoted to Professor at the University of Queensland (making her only the second female physics Professor in the 100+ years of UQ's history) and joined the management committee of the Dark Energy Survey, an international project with more than 450 members.

## Mr Per Andersen

**CAASTRO PhD student**

**Theme: Dark**

Andersen is using observations of type Ia supernovae to study the bulk cosmological flow of our local group; and the bulk combined velocity of our own and nearby galaxies. The bulk cosmological flow is sensitive to large scale structures, and our cosmological models put a constraint on the size of large scale structure formation. By measuring the bulk flow of our local group we can test the current cosmological models and learn more about Dark Energy and Dark Matter.

## Dr Holger Baumgardt

**CAASTRO Affiliate**

**Theme: Dynamic**

Baumgardt's focus is direct collisions between white dwarfs and how much they contribute to the overall rate of Type Ia supernovae. In 2015 he and a student worked on calculating collision rates between single white dwarfs in various globular clusters. He also did simulations to investigate the role of stellar binaries in these collisions.

## Mr Joshua Calcino

**CAASTRO Honours student**

**Theme: Dark**

Calcino is doing his Honours degree under the supervision of Tamara Davis. In his thesis he has investigated the effects that gravitational redshifts

would have on baryon acoustic oscillations, and whether Type Ia supernovae show redshift bias.

## Mr Simon Deeley

**CAASTRO Honours student**

**Theme: Evolving**

Deeley is an Honours student at the University of Queensland (UQ) working under the supervision of Michael Drinkwater. For his thesis he has looked at how the fraction of elliptical galaxies varies across groups of different masses and compared the results with merger simulations, finding that mergers appear to be the most important factor driving the evolution of these galaxies.

## Professor Michael Drinkwater

**CAASTRO Associate Investigator**

**Theme: Evolving**

Drinkwater's research focus is on the origin and evolution of dwarf galaxies. He is using high-resolution observations and simulations to test models of the formation of the smallest galaxies, ultra-compact dwarf galaxies, which he discovered. With his student Simon Deeley he is also examining the importance of mergers on the formation of elliptical galaxies in galaxy groups.

## Mr Samuel Hinton

**CAASTRO Honours student**

**Theme: Dark**

Samuel Hinton is an Honours student at the University of Queensland. In his undergraduate software and physics theses respectively, he developed the redshifting code *Marz* (page 20) and performed an analysis of the two-dimensional baryon acoustic oscillation signal to constrain cosmology. Hinton is now looking into a fully Bayesian approach to supernova cosmology. In 2016 he will begin a PhD at the UQ node and take on a technical role in the development of the TAIPAN survey as well as of OzDES.

## Ms Anthea King

**CAASTRO PhD student**

**Theme: Dark**

Using a technique called *reverberation mapping* (RM), King is investigating whether active galactic nuclei (AGN) are useful and viable standard-candle candidates: if they are, we may be able to use them to constrain the properties of dark energy, and to learn how galaxies and their black holes evolve together. King is taking part in the OzDES project (page 20), which will regularly monitor 500 AGN over its five-year duration, allowing an RM investigation. Her current work concentrates on predicting the expected performance and scientific output of the OzDES RM project, and testing the most efficient survey extensions and optimal target selection.

## Mr Conor O'Neill

**CAASTRO Honours student**

**Theme: Dark**

O'Neill is a member of OzDES and has been working to optimise the observation strategy of the survey in order to maximise the number of redshift measurements, and therefore science results, that OzDES obtains. As part of his thesis he also investigated the effectiveness of supernovae and the baryon acoustic oscillation as measurement probes in the constraints they place on cosmological parameters.

## Dr Edward Macaulay

**CAASTRO Postdoctoral Researcher**

**Theme: Dark**

Macaulay's main research interest is testing fundamental physics with cosmological surveys. He is currently working on modelling the effects of peculiar velocities and gravitational lensing on supernova magnitudes. By modelling these effects we can use the dispersion of the magnitudes to provide novel constraints on the amplitude of density fluctuations in the Universe, and test a key feature of dark energy in many theories of modified gravity.

## Dr David Parkinson

**CAASTRO Associate Investigator**

**Theme: Dark**

Parkinson is leader of the Theory and Simulations project within CAASTRO and has been leading research into testing theories of modified gravity, which provide an alternative explanation for the accelerated expansion of the Universe. His work has focussed on using measurements of the large-scale structure of the universe to test these models. He is leading the cosmology analysis of the EMU (Evolutionary Map of the Universe) wide-area radio survey, and is an executive team member and observer for the 2dFLens survey, which will directly test our theory of gravity.

## Ms Natalia Sommer

**CAASTRO Masters student**

**Theme: Dark**

Sommer is using data from the DES and OzDES surveys (page 28) to study active galactic nuclei (galaxies with central supermassive black holes) through *reverberation mapping*. The DES/OzDES data allows her to estimate the time lags – or equivalently, distances – between different areas around the black holes. Such work may make it possible to use active galactic nuclei as 'standard candles' that we can use to determine distances to high redshifts, which in turn could teach us more about how dark energy has changed during the Universe's history.

## Ms Sarah Thomson

**CAASTRO Honours student**

**Theme: Dark**

Thomson has completed an honours project to determine whether a large-scale suppression in the primordial power spectrum could be detected by the EMU (Evolutionary Map of the Universe) radio galaxy survey. She found that a model with such a feature could not be distinguished from the standard power law model. Her project supervisor was Dr David Parkinson.

## Ms Candy Wu

**CAASTRO Administrator**

Wu joined the CAASTRO UQ node in March 2014, having worked for the School of Mathematics and Physics and the School of Business at UQ in finance and human resources for six years. She provides financial and administrative support to the UQ node members.

# CAASTRO LINKAGES

CAASTRO has very strong national and international linkages through an extensive network of high-performing Australian and overseas researchers who participate in one or more of CAASTRO's three research themes. These carefully selected Partner Investigators have some of the strongest scientific records in international astronomy: they have proven success in executing large survey projects and are from world-class institutions, including the Australian Astronomical Observatory, CSIRO, Oxford University, Caltech (California Institute of Technology) and the Max Planck Institutes. Our international Partner Investigators are not only active participants in research studies with Australian telescopes but also enhance these efforts by contributing results and techniques from other major international projects. We also have Associate Investigators and Affiliates within our Partner Organisations.

Australia has made large investments in widefield technologies and high-performance computing, in the form of the Australian Square Kilometre Array Pathfinder telescope, the Murchison Widefield Array, SkyMapper, the Square Kilometre Array Molonglo Prototype, and the Pawsey High Performance Computing Centre for SKA Science. CAASTRO has outstanding researchers at Australia's highest-ranked universities and fastest-growing astronomy centres, with expertise in radio astronomy, optical astronomy, theoretical astrophysics and computation. Combined, these facilities and researchers enable CAASTRO to do world-leading science in widefield astronomy.

This year the General Assembly of the International Astronomical Union (the global body for professional astronomers) was held in Honolulu, USA. This was a great opportunity to both connect with colleagues and see a wide range of presentations. At this meeting CAASTRO hosted a reception to allow our overseas Partner Investigators to meet and talk with Australian researchers. Those attending included CAASTRO Partner Investigators Professor Michael Kramer (MPIfR, Germany), Dr Mara Salvato (MPE, Germany), Professor Ravi Subrahmanyan (Raman Research Institute, India) and CAASTRO Advisory Board member Professor Ron Ekers (CSIRO, Australia).

# PARTNER ORGANISATIONS

## Australian Astronomical Observatory

**Professor Warrick Couch**
**CAASTRO Partner Investigator**

Professor Couch, Director of the Australian Astronomical Observatory (AAO) has a significant role in supporting the operations and management of CAASTRO because the AAO provides some of the key facilities CAASTRO uses. The AAO operates the Anglo-Australian Telescope (AAT) and the UK Schmidt Telescope (UKST), which both offer widefield optical spectroscopy. The AAT is equipped with the SAMI multi-object integral field unit and AAOmega multi-fibre spectrograph, and the UKST has recently been outfitted with its new TAIPAN positioner and spectrograph. All of these instruments play, or will play in the near future, a key role in research for CAASTRO's three theme areas. Furthermore, Couch has a major leadership role in the SAMI Galaxy Survey, being a member of its Executive, and directs and resources research on galaxy morphological transformation. In his position as AAO Director, he is also able to facilitate new scientific opportunities for CAASTRO through the AAO's involvement in projects such as the Dark Energy Spectroscopic Instrument (DESI) and the 4MOST instrument on the European Southern Observatory's 4-m VISTA telescope.

**Professor Andrew Hopkins**
**CAASTRO Partner Investigator**

Together with AAO Director Professor Warrick Couch, Professor Hopkins coordinates the AAO's contributions to CAASTRO. Hopkins manages CAASTRO-supported student and postdoctoral researchers who observe with, and use data from, the Anglo-Australian Telescope and the UK Schmidt Telescope. He facilitates AAO interactions with CAASTRO personnel, coordinating pipeline data processing for observations made with AAO telescopes and managing access to computing resources. Hopkins is responsible for identifying programs using AAO facilities that complement and add value to CAASTRO projects. Leveraging the existing effort on such projects allows more scientific goals to be achieved, increasing the return from existing investment. Hopkins' primary research activities within CAASTRO fall under the Evolving Universe theme, although some aspects of his work overlap with activities that CAASTRO will pursue under the Dark Universe theme. Within CAASTRO, Hopkins is mainly pursuing research on EMU (the Evolutionary Map of the Universe, a survey of 70 million galaxies), and projects proposed for TAIPAN.

**Dr Chris Lidman (AAO)**
**CAASTRO Associate Investigator**

Dr Lidman is an Associate Investigator in CAASTRO. His role is in the Dark Universe theme, where he is contributing to the follow-up of Type Ia supernovae discovered by SkyMapper and the Dark Energy Survey. His expertise is in observational cosmology, Type Ia supernovae, galaxy clusters, primordial galaxies, and exotic transient phenomena. Lidman is an expert in adaptive optics, near-IR imaging and optical spectroscopy.

**Dr Sarah Brough**
**CAASTRO Affiliate**

Dr Brough is a CAASTRO Affiliate. Her role is in the Evolving Universe theme, where she is working with CAASTRO to bring the Large Survey Synoptic Telescope (LSST) project to astronomers in Australia. Brough is also a member of the SAMI survey team and contributes environmental measurements and angular-momentum expertise to that survey. Her primary research interest is galaxy evolution, and the dependence of that evolution on environment, particularly for Brightest Cluster Galaxies.

**Dr Iraklis Konstantopoulos**
**CAASTRO Affiliate**

Dr Konstantopoulos was a CAASTRO Affiliate working in the Evolving Universe theme in 2015. Through his involvement in the SAMI Galaxy Survey he was revising the technological methodology of astronomical data archiving. Dr Konstantopoulos is now working in industry.

## Commonwealth Scientific and Industrial Research Organisation

**Dr Simon Johnston**
**CAASTRO Partner Investigator**

Dr Johnston is Head of Astrophysics for CSIRO Astronomy and Space Science. His research interests are pulsars, radio transients and Extreme Scattering Events (of signals by the interstellar medium): they are thus closely aligned with the Dynamic Universe theme. He is a key member of the VAST (Variables and Slow Transients) survey project proposed for the Australian SKA Pathfinder telescope, and is a member of the Pulsar Science Working Group for the Square Kilometre Array.

**Professor Ray Norris**
**CAASTRO Partner Investigator**

Professor Norris has been the Chief Research Scientist within CSIRO Astronomy and Space Science and the Project Leader for EMU (Evolutionary Map of the Universe), one of the two key projects (the other being WALLABY) that were selected to drive the design and construction of the Australian SKA Pathfinder telescope. EMU is an all-sky continuum survey that lies within CAASTRO's Evolving Universe theme. Its primary goal is to trace the origin and evolution of galaxies over cosmic time. EMU will also have a major impact on characterising dark energy and constraining modified gravity, which aligns it with the Dark Universe theme.

**Dr James Allison**
**CAASTRO Affiliate**

Dr Allison is an expert in using radio telescopes to detect in distant galaxies both reservoirs of neutral hydrogen gas (for star formation) and signs of actively accreting black holes. During 2015 he published the discovery of cold, dense clouds of neutral hydrogen circling the nucleus of a powerful, newly triggered radio galaxy. This demonstrated that the Australian Square Kilometre Array Pathfinder (ASKAP) can detect the absorption of radio waves by hydrogen gas more than five billion light-years away, marking the start of a new era in the use of this novel technique. In 2016 Allison will work with the FLASH team to analyse and interpret data collected during ASKAP commissioning.

**Dr Keith Bannister**
**CAASTRO Affiliate**

Dr Bannister is an Affiliate in CAASTRO, with expertise in radio data processing, radio transients and archival searches. His role in the Dynamic Universe theme is in modelling fast radio bursts, following-up astronomical transients at radio wavelengths and radio transients surveys; he has also developed a new technique for searching for Extreme Scattering Events. Bannister is currently helping to commission the Australian SKA Pathfinder, which he hopes to use to search for afterglows of gravitational-wave bursts.

**Dr Martin Bell**
**CAASTRO Affiliate**

Dr Bell is an Affiliate in CAASTRO. He is a principal investigator of the Murchison Widefield Array Transients Survey (MWATS), which aims to survey almost the entire southern sky multiple times at low frequencies, on timescales of one month. The aim of the project is to search for dynamic and explosive objects in the Universe. Bell is also a member of the Australian Square Kilometre Array Pathfinder (ASKAP) commissioning team.

**Dr Daniel Mitchell**
**CAASTRO Affiliate**

Dr Mitchell is a research scientist with the Software and Computing Group in CSIRO Astronomy and Space Science. He specialises in widefield interferometric imaging and calibration, and is a senior member of the Australian Square Kilometre Array Pathfinder calibration and imaging team; he is also a member of the Square Kilometre Array (SKA) Science Data Processor consortium and of the SKA's *Cosmic Dawn–Epoch of Reionisation* Working Group. Mitchell is a lead developer and maintainer of the Real-Time System, a GPU-accelerated calibration and imaging pipeline used to process Murchison Widefield Array data.

**Dr Antonia Rowlinson**
**CAASTRO Affiliate**

Dr Antonia Rowlinson was a CAASTRO Affiliate in 2015. Her role was in the Dynamic Universe theme, where she contributed to searches for slow transients and fast radio bursts, typically using low-frequency radio images from the Murchison Widefield Array. Her expertise is in the analysis of radio-transient and variability surveys using automated imaging and analysis pipelines, and in using multiwavelength data to constrain the progenitors of short gamma-ray bursts and the magnetar central-engine model for short gamma-ray bursts.

**CAASTRO's Dr James Allison (left) and Dr Martin Bell, CSIRO Affiliate Members at the CAASTRO Annual Retreat**
***Credit: CAASTRO***

**Signe Riemer-Sørensen, Alex Kim, Mike Dalley and Chris Lidman at the CAASTRO Annual Retreat**
***Credit: CAASTRO***

## California Institute of Technology, USA

**Professor Shri Kulkarni**
**CAASTRO Partner Investigator**

Professor Kulkarni's focus within CAASTRO is in the Dynamic Universe theme. He has long-standing collaborative links with Professors Matthew Bailes and Brian Schmidt, as exemplified by a history of ARC *Discovery* (and formerly *Large*) grants in the areas of software correlation and instrumentation development applicable to the Square Kilometre Array, and gamma-ray bursts. Kulkarni is one of the originators of the Palomar Transient Factory (PTF), a northern-hemisphere complement to the Skymapper project. Using these facilities in concert, the CAASTRO team can monitor the entire sky for optical transients, and can share algorithmic and software development between the two facilities. Swinburne and Caltech have already signed a Memorandum of Understanding of scientific collaboration that spans the early years of CAASTRO and provides access to the Keck telescopes for Swinburne astronomers. This MoU has triggered a number of new collaborative projects involving scientists from these two institutions. Professor Kulkarni has taken an interest in the origin of fast radio bursts, ruling out some scenarios and trying to ascertain whether they can come from cosmological distances.

## University of Arizona, USA

**Professor Xiaohui Fan**
**CAASTRO Partner Investigator**

Professor Fan's primary involvement in CAASTRO science is within the Evolving Universe theme. He is renowned for his expertise in the discovery of high-redshift quasars, and more generally for his use of all-sky surveys to discover rare objects, strengths that are especially valuable for the Skymapper survey's search for high-redshift quasars.

## University of Durham, USA

**Professor Carlos Frenk**
**CAASTRO Partner Investigator**

Professor Frenk contributes to CAASTRO in the Evolving and Dark Universe themes. Theoretical galaxy-formation models predict the abundance and distribution of neutral hydrogen gas in the Universe. Frenk, as the head of the Institute for Computational Cosmology and joint lead investigator on the *Millennium* simulation (the largest simulation of the Universe ever undertaken), is in a unique position to contribute the theoretical galaxy-formation models that will be needed to exploit CAASTRO's scientific observations.

## Max Planck Institute for Radio Astronomy, Germany

**Professor Michael Kramer**
**CAASTRO Partner Investigator**

Professor Kramer's research falls under CAASTRO's Dynamic Universe theme. His focus is on the exploration and exploitation of the dynamic radio sky, in the study of both pulsars and new types of transients, phenomena that allow us to address astrophysical questions ranging from the state of matter at extreme densities to cosmology and tests of theories of gravity. Kramer is contributing his expertise to the search for fast transients by developing hardware and software solutions in collaboration with CAASTRO partners.

## Max-Planck-Institut für Extraterrestrische Physik, Germany

**Dr Mara Salvato**
**CAASTRO Partner Investigator**

Dr Salvato works in the High Energy Group and is a member of the eROSITA team. eROSITA is an X-ray

satellite: soon to be launched, it will map the entire sky. As a Partner Investigator Salvato promotes collaboration between CAASTRO and eROSITA and leads project groups enhancing the synergy between X-ray, radio and optical surveys of active galactic nuclei.

## Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE), France

**Dr Reynald Pain**
**CAASTRO Partner Investigator**

Dr Pain is contributing to CAASTRO's Dark Universe theme within CAASTRO. Pain is the Director of LPNHE, a large physics research grouping that works in a broad range of high-energy and particle-physics experiments. As French lead investigator of the Supernova Legacy Survey (SNLS) project, Pain is a doyen of those using type Ia supernovae to measure the acceleration of the universe. Pain and his team at LPNHE actively participate in the SkyMapper supernova survey, taking leading roles in the calibration and precision photometric analysis of the supernova data.

## University of Toronto, Canada

**Professor Bryan Gaensler**
**CAASTRO Partner Investigator**

Gaensler is the former Director of CAASTRO, and is now the Director of the Dunlap Institute at the University of Toronto. In 2015 he worked on simulations of the cosmological distribution of fast radio bursts, low-frequency observations of young radio galaxies, and polarisation as a tracer of accretion states in active galaxies. In 2016 he will focus on a search for the cosmic web with the Murchison Widefield Array, and on early-science observations with the Australian SKA Pathfinder.

**Professor Ue-Li Pen**
**CAASTRO Partner Investigator**

Professor Pen brings to CAASTRO a wealth of experience in tackling the fundamental problems in cosmology that are associated with many of the Centre's science themes. He has considerable experience in studies of the Epoch of Reionisation and of extragalactic hydrogen, and has worked in these areas with fellow CAASTRO investigators. Within CAASTRO, Pen's research activities are primarily under the theme of the Evolving Universe. His specific focus is to quantify the errors in the power spectra of neutral hydrogen in galaxies, as measured by surveys on the Australian SKA Pathfinder, such as WALLABY and DINGO.

## Raman Research Institute, India

**Professor Ravi Subrahmanyan**
**CAASTRO Partner Investigator**

Professor Subrahmanyan's focus within CAASTRO is the Evolving Universe theme. His background is in developing methods and instrumentation for all-sky measurements of the radio background, in particular for detecting reionisation signatures in the cosmic radio background. Subrahmanyan and his colleagues at the Raman Research Institute are contributing primarily to the Murchison Widefield Array's efforts to detect the Epoch of Reionisation.

## University of Oxford

**Professor Roger Davies**
**CAASTRO Partner Investigator**

Professor Roger Davies is Head of Astrophysics at Oxford University. Within CAASTRO, Davies' contribution will be primarily in the Evolving Universe theme and the SAMI project. His research interests include cosmology (the distance scale, large-scale motions of galaxies and galaxies at high redshift); galaxy evolution (dynamics, stellar populations and galaxy clusters); and telescopes, instruments and techniques.

## National Computational Infrastructure

**Professor Lindsay Botten**
**CAASTRO Partner Investigator**

As Director of National Computational Infrastructure (NCI), Professor Lindsay Botten is supporting CAASTRO's access to, and usage of, NCI's high-end computing services, for all of its themes and from all CAASTRO nodes. In 2015 some eight million CPU hours were utilised.

# ASSOCIATED ORGANISATIONS

## University of Belfast

**Dr Stuart Sim**
**CAASTRO Associate Investigator**

Dr Sim's research focuses on the theory of supernova explosions. In particular, he works on developing models for Type Ia supernovae, the events that are used as 'standard candles' to map out the expansion history of the Universe.

## University of NSW

**Professor Brian Boyle**
**CAASTRO Affiliate**

Professor Boyle is the Pro Vice-Chancellor (Research) at the University of New South Wales. He is responsible for UNSW's international research strategy, research partnerships including affiliated research institutes, eResearch strategy, research ethics and safety, and effective promotion of the University's research capability and research profile. Professor Boyle was previously the Acting SKA (Square Kilometre Array) Director for the Australian Department of Industry, following his role as CSIRO SKA Director. Prior to that, he was the Director of the CSIRO Australia Telescope National Facility (2003–2009), where he initiated the construction of ASKAP, and Director of the Anglo-Australian Observatory (1996–2003).

## University of Nottingham

**Dr Jamie Bolton**
**CAASTRO Associate Investigator**

Dr Bolton is a Royal Society University Research Fellow and lecturer at the University of Nottingham, and is an Associate Investigator in CAASTRO. His research interests fall under the Evolving Universe theme. In 2015 he published work with former CAASTRO PhD student Brad Greig on developing simulations to calculate the effect of temperature fluctuations on Lyman-alpha absorption towards quasars. He also examined the impact of high-mass X-ray binaries on the ionisation state of the intergalactic medium, in collaboration with CAASTRO Associate Investigator Professor Chris Power and researchers at the University of Leicester, UK.

## National Astronomical Observatories, Chinese Academy of Sciences

**Dr Tao Hong**
**CAASTRO Affiliate**

Dr Hong is an Assistant Investigator in the National Astronomical Observatories, Chinese Academy of Sciences (NAOC), and is a CAASTRO Affiliate. He works in the Dark Universe Theme, mainly focusing on studying the peculiar-velocity field of the local Universe with the data from the 2MASS Tully-Fisher Survey. His research interests are H I in galaxies, observational cosmology, large-scale structures and galaxy clusters.

## University of Oslo

**Dr Signe Riemer-Sørensen**
**CAASTRO Affiliate**

Dr Riemer-Sørensen is a CAASTRO Affiliate working under the Dark Universe Theme. She investigates how non-standard particles such as dark matter and neutrinos affect the Universe, and how their properties can be derived from cosmological observations. These observations cover all scales and range from chemical abundances in quasar absorption systems to galaxy surveys (for example, WiggleZ) and X-ray emission from galaxy clusters. Riemer-Sørensen's work involves using advanced statistical methods for model selection and parameter determination, and comparing observations with simulations.

## SKA Organisation

**Dr Ewan Barr**
**CAASTRO Affiliate**

Dr Barr is a CAASTRO Affiliate. His role is in the Dynamic Universe Theme, where he is contributing to the ongoing efforts to discover fast radio bursts (FRBs) and identify their progenitors. At the core of this effort is the highly successful SUrvey for Pulsars and Extragalactic Radio Bursts (SUPERB), for which he manages the data analysis on Swinburne's gSTAR supercomputer. Dr Barr is also contributing to the ongoing development and commissioning of the UTMOST radio telescope. Barr is part of the Swinburne team responsible for the design and development of the pulsar-timing hardware that will be used on the Square Kilometre Array.

## Victoria University of Technology

**Dr Stephen Curran**
**CAASTRO Affiliate**

Dr Curran is a CAASTRO affiliate member based at the Victoria University of Wellington in New Zealand. His work is in the Evolving Universe theme. He maintains close collaborations with other CAASTRO members of the theme, particularly those involved with the survey team for FLASH (the First Large Absorption Survey in H I): this survey, to run on the Australian SKA Pathfinder, will research the reservoir of star-forming gas in the distant Universe.

# CAASTRO COLLABORATIONS

**CAASTRO team members have been involved in a number of collaborations with institutions both in Australia and overseas during the course of 2015. The most significant are listed below.**

## eROSITA

**Institutions: Max-Planck-Institut für Extraterrestrische Physik, CAASTRO**

The *extended ROentgen Survey with an Imaging Telescope Array* (eROSITA) is an instrument on the Russian Spektrum-Röntgen-Gamma (SRG) satellite, which will be launched in 2017. eROSITA will perform an X-ray survey of the entire sky with unprecedented angular resolution and sensitivity. The German eROSITA consortium (eROSITA_DE) and CAASTRO have signed a memorandum of understanding that enables collaboration on projects requiring combined data from eROSITA and from Australian widefield facilities such as ASKAP, MWA, Molonglo, Parkes, ATCA, SkyMapper, AAT and TAIPAN. The agreement is overseeing science projects that require the use of both eROSITA_DE and CAASTRO data, involve at least one member from each of eROSITA_DE and CAASTRO, do not conflict with existing eROSITA_DE or CAASTRO projects, allow participation by undergraduate and postgraduate students, and adhere to the existing policies for the individual facilities involved (regarding, for example, proprietary periods, data access, survey teams, observing time and publications). This arrangement will provide exciting new opportunities for multiwavelength astronomy projects across the southern sky.

## SkyMapper

**Institutions: Australian National University, CAASTRO, Monash University, AAO**

SkyMapper is a 1.35-metre telescope with a 5.7 deg$^2$ imager, located near Coonabarabran, New South Wales, which is owned and operated by the Research School of Astronomy and Astrophysics at the Australian National University. CAASTRO secured $1.16m in ARC Linkage Infrastructure Equipment and Facilities (LIEF) grant funding to secure membership of the SkyMapper consortium for all Australian astronomers during 2014–2019. This contributes to the operating costs needed for SkyMapper to undertake a 5-year survey of the entire southern sky, provides Australian astronomers with 20 per cent of non-survey observing time on SkyMapper, and allows the development of robust and efficient software pipelines, analysis tools and data-access facilities.

## TAIPAN

**Institutions: Australian Astronomical Observatory, Australian National University, CSIRO Astronomy and Space Science, Macquarie University, Monash University, Swinburne University of Technology, University of Melbourne, University of New South Wales, University of Queensland, The University of Sydney, University of Western Australia, University of Western Sydney**

TAIPAN is a new facility for the UK Schmidt Telescope (UKST) at Siding Spring Observatory. It encompasses a novel optical-fibre positioner using the new 'starbugs' technology and a purpose-built spectrograph; the project also involves refurbishment of the UKST itself. The TAIPAN facility will support two major new surveys:

The TAIPAN survey of half a million galaxies is aimed at making a 1%-precision measurement of the Hubble constant, $H_0$; measure the bulk motion of galaxies to better understand Dark Energy; and together with the WALLABY survey made with the Australian SKA Pathfinder, link the star-formation and gas-fuelling properties of galaxies to understand galaxy evolution.

The Funnelweb survey is designed to measure two million stars within our Milky Way Galaxy, uniquely characterising them and complementing the fainter GALAH Galactic Archaeology survey, as well as providing a robust input sample for the next-generation planet-finding satellite observatory, TESS. The TAIPAN observations will begin in late-2016, with preliminary observations during commissioning activities in mid-2016. While the scientific plans for the TAIPAN facility and surveys are closely aligned with CAASTRO goals, they are not presently receiving any funding from CAASTRO.

## OzDES

**Institutions: AAO, Australian National University, University of Queensland, The University of Sydney, University of Melbourne, Swinburne University of Technology, Monash University, Macquarie University, CSIRO, The Dark Energy Survey (~480 members from over 30 institutions worldwide)**

OzDES is a collaboration of over 20 Australian scientists, the vast majority of whom are CAASTRO members, using the Anglo-Australian Telescope to gather thousands of spectroscopic redshifts to complement the photometric Dark Energy Survey. Host-galaxy redshifts for Type Ia supernovae will facilitate

construction of the largest SN Ia Hubble diagram to date, while repeat spectroscopy of high-redshift active galactic nuclei (AGN) may make it possible to use AGN reverberation mapping for standard-candle cosmology beyond a redshift of two.

### Large Synoptic Survey Telescope

**Institutions: the Large Synoptic Survey Telescope (comprising more than 30 member organisations), Australian Astronomical Observatory and CAASTRO**

CAASTRO and the Large Synoptic Survey Telescope (LSST) have entered into a Memorandum of Agreement on how CAASTRO can contribute to the operational support of LSST, which is planned to begin full scientific operations around 2020. In 2015 the AAO and CAASTRO worked together to engage the whole Australian astronomy community in this project.

### Murchison Widefield Array EOR experiment

**Institutions: University of Melbourne, Australian National University, University of Sydney, Curtin University, Massachusetts Institute of Technology, Harvard-Smithsonian Center for Astrophysics, University of Washington, Arizona State University, Raman Research Institute**

CAASTRO staff are key members of the Epoch of Reionisation (EoR) project within the Murchison Widefield Array (MWA) collaboration. The EoR team will obtain a significant dataset with the MWA 128-tile array with the aim of either detecting or setting limits on the detection of the H I signals from the Epoch of Reionisation. In 2015 the MWA collaboration, led by Curtin University Chief Investigators, won a major ARC LIEF grant to expand the MWA array and to provide specific new configurations to improve its EoR observation capabilities.

### Stawell Underground Physics Lab

**Institutions: Swinburne University of Technology, University of Melbourne, University of Adelaide, Australian National University**

The design for the Stawell Underground Physics Lab (SUPL) began in 2015 and construction is expected to start in July 2016. The Australian SABRE (Sodium iodide with Active Background Rejection) collaboration has been formed to build the first direct-detection experiment for dark matter in the southern hemisphere. While this is primarily a physics experiment, CAASTRO astrophysicists are joining the collaboration to model the expected kinetic-energy distribution of dark-matter particles and do related work.

## Collaborations – Outreach

### Astronomy Weekend and *Astronomer in Residence* at Uluru

In collaboration with Voyages Indigenous Tourism Australia, CAASTRO again had *Astronomers in Residence* at Uluru for most of the year, and we held our second *Uluru Astronomy Weekend* as part of National Science week. CAASTRO team members gave presentations about the Universe and offered insights into current avenues of astrophysical research.

### Planetarium show and educational resources

With the view that CAASTRO all-sky data is most naturally presented on a domed screen, CAASTRO entered into a longer-term collaboration with Museum Victoria for the production of a planetarium show. With the premiere in early 2016, CAASTRO and the team at Melbourne Planetarium were working towards showcasing CAASTRO research results and real datasets for shows in several Australian and also overseas locations.

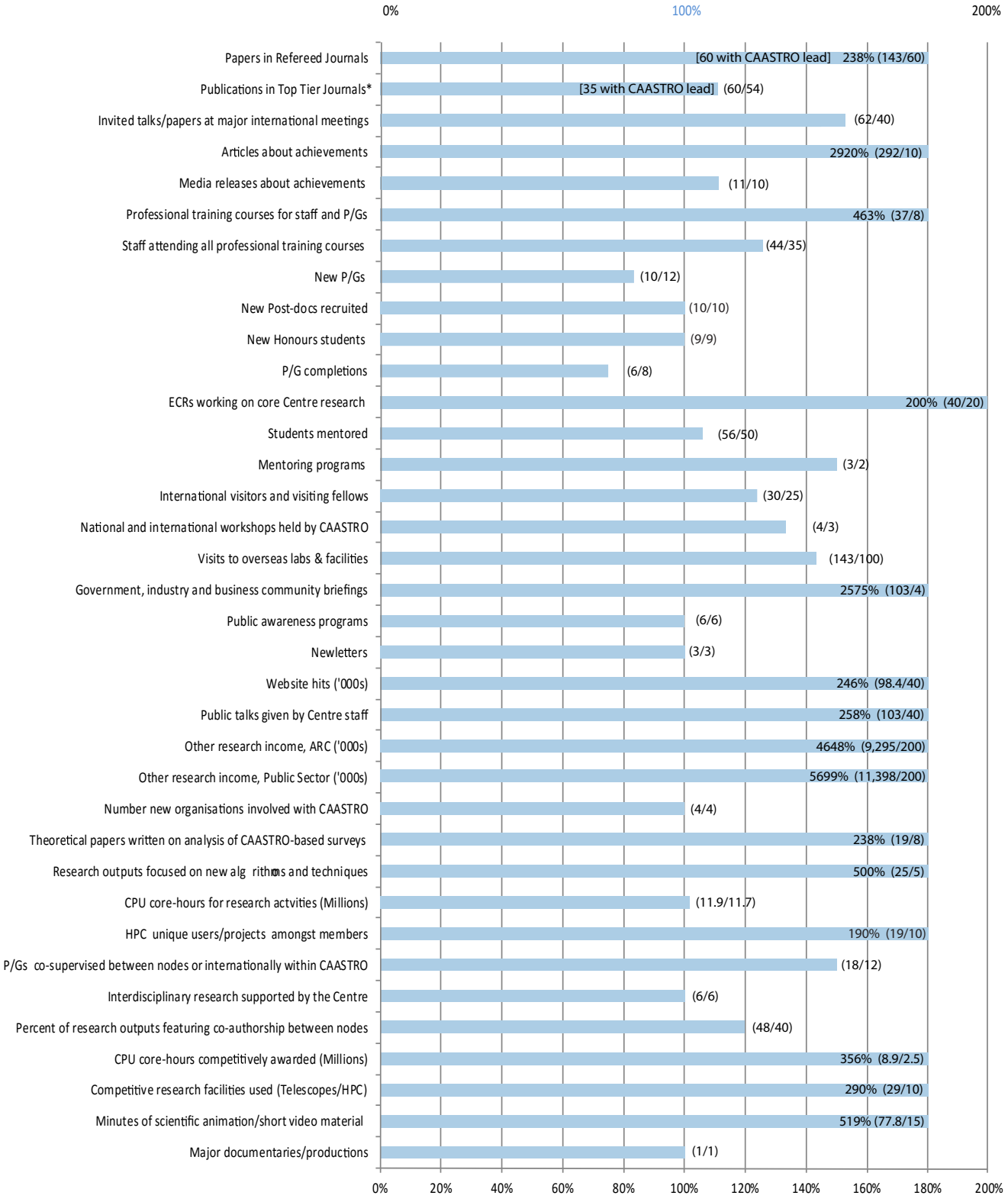
CAASTRO Education and Outreach was also working closely with the MV Astronomy and Space Sciences team to create educational resources – both hands-on and digital – that tie in with the show and with the Australian curriculum.

### Science writing for younger audiences

For the production of the mentoring program *Bright Stars* and an illustrated children's book, CAASTRO started working with freelance science communication professionals in Perth. *Bright Stars* features the personal profiles of our researchers and their advice to high-school students who are interested in astronomy. The program will officially launch in April 2016, in collaboration with CAASTRO's outreach partner *Telescopes in Schools*. The children's book will be a major legacy product of the CAASTRO Education and Outreach portfolio. We plan to launch it in March 2017.

# KPI DASHBOARD

## January – December 2015




* Nature; Science; Annual Review of Astronomy & Astrophysics; The Astronomy & Astrophysics Review; Physical Review (including Letters) The Astrophysical Journal (including Supplemental Series and Letters); The Astronomical Journal; Monthly Notices of the Royal Astronomical Society (including Letters); Astronomy & Astrophysics (including Letters and Short Communications etc.); Journal of Cosmology and Astroparticle Physics

# FINANCIAL STATEMENTS

## CAASTRO FINANCIAL REPORT 2015

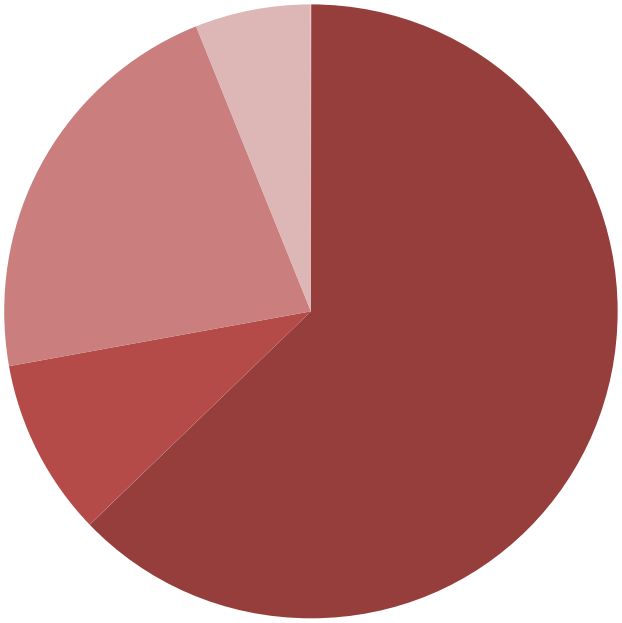
| | 2011 INCOME | 2012 INCOME | 2013 INCOME | 2014 INCOME | 2015 INCOME | ACTUAL | 2016 INCOME | ESTIMATED |
|---|---|---|---|---|---|---|---|---|
| ARC Income | $3,000,000 | $2,800,000 | $3,100,000 | $3,100,000 | ARC Income | $3,100,000 | ARC Income | $2,800,000 |
| ARC Indexation | $47,431 | $153,527 | $295,786 | $398,406 | ARC Indexation | $461,065 | ARC Indexation | $500,607 |
| Node Contributions | $912,272 | $1,039,569 | $842,002 | $1,206,663 | Node Contributions*** | $997,980 | Node Contributions | $1,012,017 |
| Other Grants | | | $750,000 | $1,264,437 | | | | |
| | | | | | | | | |
| | | | | | | | | |
| Other | $747,294 | $13,685 | $28,206 | $296,930 | Other * | $301,210 | Other | $112,982 |
| Grants won[¥] (and correction to 2011) | $400,000 | | -$400,000 | | | | | |
| **Total Income** | **$5,106,997** | **$4,006,781** | **$4,615,994** | **$6,266,436** | | **$4,860,255** | **Total Estimated Income** | **$4,425,607** |
| | | | | | | | | |
| Carry Forward | $- | $2,930,552 | $2,967,985 | $3,037,571 | Carry Forward | $3,456,823 | Carry Forward | $3,184,858 |
| **Total Funds Available** | **$5,106,997** | **$6,937,333** | **$7,583,979** | **$9,304,007** | **Total Funds Available** | **$8,317,078** | **Total Estimated Funds Available** | **$7,610,465** |

*Other income includes CAASTRO workshop income/sponsorship, Secondments (CSIRO, AAO), reimbursement from TAIPAIN project
[¥] Includes NSW SLF Grant Part II, DIISR Travel Grants and LIEF Grant won by UWA
*** ANU to contribute remaining 2015 funds of $84,215 in January 2016

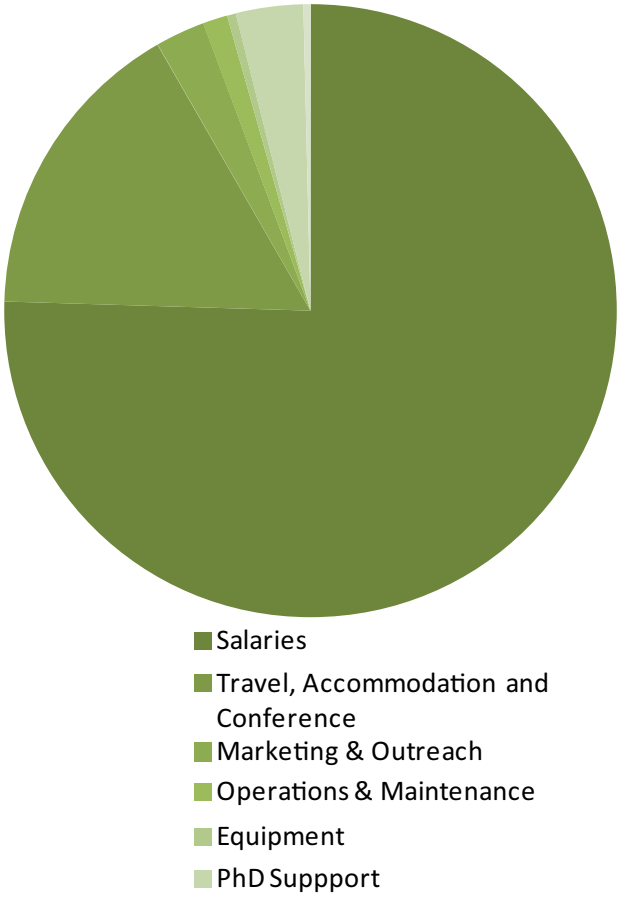
| | 2011 EXPENDITURE | 2012 EXPENDITURE | 2013 EXPENDITURE | 2014 EXPENDITURE | 2015 EXPENDITURE | ACTUAL | 2016 EXPENDITURE | ESTIMATED |
|---|---|---|---|---|---|---|---|---|
| Salaries | $1,467,096 | $2,807,859 | $2,875,061 | $3,320,256 | Salaries | $3,874,054 | Salaries | $4,054,925 |
| Travel, Accommodation and Conference | $363,516 | $503,587 | $778,788 | $810,779 | Travel, Accommodation and Conference | $831,743 | Travel, Accommodation and Conference | $644,000 |
| Marketing & Outreach | $124,914 | $139,732 | $20,336 | $92,675 | Marketing & Outreach | $133,937 | Marketing & Outreach | $175,000 |
| Operations & Maintenance | $103,342 | $81,706 | $56,535 | $124,237 | Operations & Maintenance | $66,916 | Operations & Maintenance | $44,900 |
| Equipment | $102,993 | $145,790 | -$59,721 | $29,891 | Equipment | $24,157 | Equipment | $35,000 |
| PhD Support | $5,709 | $101,763 | $126,522 | $201,402 | PhD Suppport | $182,211 | PhD Suppport | $126,000 |
| Research materials/ Experiments | $8,874 | $188,911 | $5,766 | $3,507 | Research materials/ Experiments | $19,202 | Research materials/ Experiments | $- |
| Corrections | | | -$6,879 | | | | | |
| 2013 Grants | | | $750,000 | $1,264,437 | | | | |
| | | | | | | | | |
| **Total Expenditure** | **$2,176,445** | **$3,969,348** | **$4,546,408** | **$5,847,184** | **Total Expenditure** | **$5,132,220** | **Total Estimated Expenditure** | **$5,079,825** |
| | | | | | | | | |
| **Balance** | **$2,930,552** | **$2,967,985** | **$3,037,571** | **$3,456,823** | **Balance** | **$3,184,858** | **Estimated balance** | **$2,530,640** |

** LIEF, SIEF & AMSPP Grants have been reported as fully expensed in 2014, although LIEF Grant to be spent over five years, SIEF Grant to be spent over 36 months and AMSPP Grant to be spent over two years.

## 2015 INCOME




## 2015 EXPENDITURE




| CAASTRO IN-KIND REPORT JANUARY - DECEMBER 2015 | |
|---|---|
| **In-Kind** | |
| University of Sydney | $503,014 |
| University of Western Australia | $230,855 |
| University of Melbourne | $253,573 |
| Swinburne University of Technology | $619,294 |
| Australian National University | $1,255,474 |
| Curtin University of Technology | $329,100 |
| CSIRO | $3,786,300 |
| Australian Astronomical Observatory | $1,267,253 |
| Max Planck Institute for Radio Astronomy | $146,696 |
| California Institute of Technology | $134,673 |
| The University of Oxford | $51,170 |
| Durham University | $202,108 |
| Max Planck Institute for Extra Terrestrial Physics (MPIEP) | $8,500 |
| The University of Arizona | $160,000 |
| The University of Toronto | $86,300 |
| Laboratoire de Physique Nucléaire et de Hautes Energies | $160,088 |
| National Computational Infrastructure | $1,000,000 |
| Raman Research Institute | $200,000 |
| University of Queensland | $136,211 |
| Voyages Indigenous Tourism | $50,000 |
| **Total In-Kind Contributions** | **$10,580,608** |

# GRANTS WON BY CAASTRO MEMBERS IN 2015

**ARC Discovery Early Career Researcher Award**
Project: This project seeks to measure a radio signal for the first time, using the Murchison Widefield Array telescope and a novel technique involving the Moon, to learn what luminous objects dominated the early Universe.
DE160100849
$326,637
Chief Investigator: Ben McKinley

**ARC Discovery Project**
Project: This project aims to support the TAIPAN (Transforming Astronomical Imaging-surveys through Polychromatic Analysis of Nebulae) survey, which is designed to measure redshifts for 500 000 galaxies and peculiar velocities for 50 000 galaxies in the nearby universe.
DP160102075
$710,800
Chief Investigator: Matthew Colless
Other CAASTRO Investigators: Chris Blake and Andrew Hopkins

**ARC Discovery Project**
Project: This project plans to measure how supermassive black holes have evolved over the last 12 billion years.
DP160100930
$360,900
Chief Investigator: Tamara Davis
Other CAASTRO Investigators: Robert Sharp and Christopher Lidman

**ARC Discovery Project**
Project: The project plans to develop new insights into how galaxies form.
DP160102235
$560,800
Chief Investigator: Karl Glazebrook
Other CAASTRO Investigators: Danail Obreschkow and Claudia Lagos

**ARC Laureate Fellowship**
Project: Exascale astronomy: real-time analysis of the transient radio universe.
FL150100148
$2,840,752
Chief Investigator: Matthew Bailes

**ARC Future Fellowship**

Project: This project plans to use three new Australian telescopes to conduct the most comprehensive search ever made for transient sources.
FT150100099
$824,960
Chief Investigator: Tara Murphy

**ARC Future Fellowship**
Project: This project aims to use a new approach to measuring dark matter, based on the way that it curves spacetime around it.
FT150100269
$682,352
Chief Investigator: Edward Taylor

**ARC LIEF**
Project: PRAXIS: Beating the infrared night sky with multicore fibre Bragg gratings.
LE160100191
$175,000
Chief Investigator: Jonathan Bland-Hawthorn
Other CAASTRO Investigators: Warrick Couch and Robert Sharp

**ARC LIEF**
Project: This project aims to build a Phase 2 Murchison Widefield Array (MWA) to boost the capabilities of the Phase 1 MWA by an order of magnitude.
LE160100031
$1,000,000
Chief Investigator: Steven Tingay
Other CAASTRO Investigators: Carole Jackson, Lister Staveley-Smith, Bryan Gaensler, Ue-Li Pen, Stuart Wyithe, Rachel Webster, Tara Murphy, Matthew Bailes and Simon Johnston

**ARC LIEF**
Project: Detector system for the first Australian experiment on dark matter.
LE160100080
$195,000
Chief Investigator: Elisabetta Barberio
CAASTRO Investigator: Jeremy Mould

**ARC LIEF**
Project: The objective of this project is to build the positioner at the Australian Astronomical Observatory to enable participation in the upcoming programs of the European Southern Observatory (ESO).
LE160100145
$430,000
Chief Investigator: Simon Driver
CAASTRO Investigators: Warrick Couch, Andrew Hopkins, Matthew Colless, Scott Croom, Christopher Blake, Karl Glazebrook and David Parkinson

**ARC Linkage Project**
Project: This project aims to develop an underground integrated laboratory at Stawell Gold Mine in Victoria to host the Southern Hemisphere's first-ever direct-detection dark matter experiment.
LP150100705
$1,188,085
Chief Investigator: Elisabetta Barberio
CAASTRO Investigator: Jeremy Mould

**Other Public Sector**
Project: Support the operations of the Murchison Widefield Array National Collaborative Research Infrastructure Strategy (NCRIS) Program
$1,257,000
Chief Investigator: Steven Tingay

**Other Public Sector**
Breakthrough Listen Project – Yuri Milner
$100m USD*
*total project funding (Only ~<10% to be spent in Australia)
Chief Investigator: Matthew Bailes

**Other Public Sector**
University of Queensland Fellowship
$91,000
Chief Investigator: Tamara Davis

**Other Public Sector**
University of Queensland Teaching Fellowship
$50,000
Chief Investigator: Michael Drinkwater

# CAASTRO PEOPLE


1


2


3


4


5


6


7


8


9


10


11


12


13


14


15

## CAASTRO Executive

1. Elaine Sadler (Director)
2. Lister Staveley-Smith (Deputy Director)
3. Kate Gunn (Chief Operating Officer)
4. Matthew Bailes (Dynamic theme leader)
5. Stuart Wyithe (Evolving theme leader)
6. Tamara Davis (Dark theme leader)
7. Brian Schmidt
8. Steven Tingay (Education and Outreach leader)
9. Carole Jackson

## Chief Investigators

10. Chris Blake
11. Frank Briggs
12. Matthew Colless
13. Scott Croom
14. Jeremy Mould
15. Tara Murphy


16


17


18


19


20


21


22


23


24


25


26


27


28


29


30


31


32


33

16. Rachel Webster

## Partner Investigators

17. Lindsay Botten
18. Warrick Couch
19. Roger Davies
20. Xiaohui Fan
21. Carlos Frenk
22. Bryan Gaensler
23. Andrew Hopkins
24. Simon Johnston
25. Michael Kramer
26. Shri Kulkarni
27. Ray Norris
28. Reynald Pain
29. Ue-Li Pen
30. Mara Salvato
31. Ravi Subrahmanyan

## Associate Investigators

32. Ramesh Bhat
33. Joss Bland-Hawthorn


34


35


36


37


38


39


40


41


42


43


44


45


46


47


48


49


50


51

34. Jamie Bolton
35. Jeff Cooke
36. Minh Huynh
37. Claudia Lagos
38. Chris Lidman
39. Jean-Pierre Macquart
40. Martin Meyer
41. Danail Obreschkow
42. Christopher Onken
43. Stephen Ord
44. David Parkinson
45. Chris Power
46. Ashley Ruiter
47. Emma Ryan-Weber
48. Ivo Seitenzahl
49. Robert Sharp
50. Stuart Sim
51. Cathryn Trott


52


53


54


55


56


57


58


59


60


61


62


63

52. Randall Wayth
53. Christian Wolf

## CAASTRO
## Research Staff

54. Ixandra Achitouv
55. Julie Banfield
56. Julia Bryant
57. Michael Childress
58. Francesco D'Eugenio
59. Chris Flynn
60. Lisa Fogarty
61. Cullan Howlett
62. Anna Kapinska
63. Anthea King
64. Emil Lenc
65. Christene Lynch
66. Felipe Marin
67. Anais Möller
68. Edward Macauley
69. Katherine Mack


64


65


66


67


68


69


70


71


72


73


74


75


76


77


78


79


80


81


82


83


84


85


86


87

70. Elizabeth Mahony
71. Ben McKinley
72. Vanessa Moss
73. Se-Heon Oh
74. Bart Pindor
75. Attila Popping
76. Pietro Procopio
77. Vikram Ravi
78. Jonghwan Rhee
79. Richard Scalzo
80. Nicholas Scott
81. Marcin Sokolowski
82. Christopher Springob
83. Dan Taranu
84. Edoardo Tescari
85. Steven Tremblay
86. Laura Wolz
87. Fang Yuan

## CAASTRO Professional Staff

88. Kim Dorrell (Executive Officer, U. Melbourne)
89. Angela Dunleavy (Administrative Coordinator, Curtin U)
90. Wiebke Ebeling (Education & Outreach Manager, Curtin U)
91. Debra Gooley (Finance Officer, U. Sydney)
92. Helen Keys (Executive Assistant to Director U. Sydney from Nov 2015)
93. Sue Lester (Administrator, Swinburne)
94. Jenny Lynch (School Education Officer, University of Sydney)
95. Clare Peter (Administrative Officer, UWA)
96. Helen Sim (Public Relations Officer, U. Sydney)
97. Denise Sturgess (Administration Officer, ANU)
98. Michelle Sullivan (Executive Assistant to Director, U. Sydney until Oct 2015)
99. Kylie Williams (Events & Communications, U. Sydney)
100. Candy Wu (Administration Officer, U. QLD)

## CAASTRO Affiliates

101. James Allen
102. James Allison
103. Keith Bannister
104. Ewan Barr
105. Holger Baumgardt


88


89


90


91


92


93


94


95


96


97


98


99


100


101


102


103


104


105


106


107


108


109


110


111


112


113


114


115


116


117


118


119


120


121


122


123

106. Martin Bell
107. Brian Boyle
108. Sarah Brough
109. Davide Burlon
110. Duncan Campbell-Wilson
111. Weiguang Cui
112. Stephen Curran
113. Mike Dalley
114. Jacinta den Besten
115. Jason Dossett
116. Michael Drinkwater
117. Alan Duffy
118. Jamie Farnes
119. Ilana Feain
120. Karl Glazebrook
121. Anne Green
122. Paul Hancock
123. Tao Hong



















124. Andrew Jameson
125. Christopher Jordan
126. Evan Keane
127. Hansik Kim
128. Iraklis Konstantopoulos
129. Greg Madsen
130. Daniel Mitchell
131. Richard Newton
132. Signe Riemer-Sørensen
133. Antonia Rowlinson
134. Edward Taylor
135. Brad Tucker
136. Willem van Straten
137. Oiwei Ivy Wong

## CAASTRO Students

138. Caitlin Adams
139. Kamran Ali
140. Per Andersen
141. Igor Andreoni


142


143


144


145


146


147


148


149


150


151


152


153


154


155


156


157


158


159

142. Dilyar Barat
143. Stephanie Bernard
144. Shivani Bhandari
145. Jessica Bloom
146. Joshua Calcino
147. Manisha Caleb
148. Joe Callingham
149. Alexandru Codoreanu
150. Christopher Curtin
151. Simon Deeley
152. Angela Garcia
153. Marcin Glowacki
154. Samuel Hinton
155. Fabian Jankowski
156. Andrew Johnson
157. Antonios Katsianis
158. Katharine Kelly
159. Sarah Leslie


160


161


162


163


164


166


167


168


169


170


171


172


173


174


175


176


177

160. Jack Line
161. Cleo Loi
162. Rebecca McElroy
163. Samuel McSweeney
164. Scott Meyer
165. Vincent Morello
166. Steven Murray
167. Aina Musaeva
168. Samuel Oronsaye
169. Sinem Ozbilgen
170. Conor O'Neill
171. Fiona Parker
172. Emily Petroff
173. Mahsa Rahimi
174. Jarryd Rasti
175. Sarah Reeves
176. Tristan Reynolds
177. Samuel Richards


178


179


180


181


182


183


184


185


186


187


188


189


190


191


192

193

178. Jennifer Riding
179. Khaled Said
180. Diane Salim
181. Mayuri Sathyanarayana Rao
182. Adam Schaefer
183. Paul Scott-Taylor
184. Natalie Eiré Sommer
185. Dana Tabbara
186. Adam Thomas
187. Sarah Thomson
188. Syed Ashraf Uddin
189. Matthew Varidel
190. Vivek Venkatraman
191. Mia Walker
192. Bonnie Zhang

## Not pictured

193. Tina Sallis (Operations Coordinator, Curtin U)

# GLOSSARY

| ACRONYM | DESCRIPTION | DEFINITION |
|---|---|---|
| 2MTF | Project | 2MASS Tully-Fisher |
| 6dFGS | Project | 6-degree Field Galaxy Survey |
| AAL | Organisation | Astronomy Australia Ltd |
| AAT | Facility | Australian Astronomical Telescope |
| ATCA | Facility | Australia Telescope Compact Array |
| ADASS | Conference | Astronomical Data Analysis Software and Systems |
| AGN | Object | Active Galactic Nuclei |
| ALMA | Facility | Atacama Large Millimeter Array |
| ANGUS | Project | AustraliaN GADGET-3 early Universe Simulations |
| ASKAP | Facility | Australian Square Kilometre Array Pathfinder |
| ASVO | Facility | All Sky Virtual Observatory |
| ASTRON | Organisation | Netherlands Institute for Radio Astronomy |
| ATLAS | Project | Australia Telescope Large Area Survey |
| ATNF | Facility | Australia Telescope National Facility |
| BAO | Term | Baryonic Acoustic Oscillation |
| BIGHORNS | Project | Broadband Instrument for the Global HydrOgen Reionisation Signal |
| CAASTRO | Research Centre | ARC Centre of Excellence for All-sky Astrophysics |
| CANDELS | Project | Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey |
| CASS | Research Centre | CSIRO Astronomy and Space Science |
| CitC | Outreach | CAASTRO in the Classroom |
| CTIO | Facility | Cerro Tololo Inter-American Observatory, Chile |
| DINGO | Project | Deep Investigation of Neural Gas Origins |
| DRAGONS | Project | Distant Radio Galaxies Optically Non-detected in the SDSS |
| EMU | Project | Evolutionary Map of the Universe |
| EoR | Object | Epoch of Reionisation |
| eROSITA | Project | extended ROentgen Survey with an Imaging Telescope Array |
| ESO | Facility | European Southern Observatory |
| FLASH | Project | First Large Absorption Survey in H I |
| FRB | Object | Fast Radio Bursts |
| GAMA | Project | Galaxy and Mass Assembly survey |
| GEG | Project | GaLactic and ExtraGalactic MWA group |
| GLEAM | Project | Galactic and Extragalactic MWA survey |
| GMRT | Facility | Giant Metrewave Radio Telescope, India |
| GMT | Facility | Giant Magellan Telescope |
| GRB | Object | Gamma-Ray Burst |
| HECTOR | Project | Follow-on IFU after SAMI |
| HETDEX | Project | Hobby-Eberly Telescope Dark Energy Experiment |
| HIPASS | Project | H I Parkes All-Sky Survey |
| HTRU | Project | High Time Resolution Universe |
| ICRAR | Research Centre | International Centre for Radio Astronomy Research |
| IFU | Instrument | Integral Field Unit (spectrograph) |
| LOFAR | Facility | Low Frequency Array telescope |
| LSST | Facility | Large Synoptic Survey Telescope |
| LWA | Facility | Long Wavelength Array, USA |

| ACRONYM | DESCRIPTION | DEFINITION |
|---|---|---|
| MOSFIRE | Project | Multi-Object Spectrometer for Infra-Red Exploration |
| MOST | Facility | Molonglo Observatory Synthesis Telescope |
| MWA | Facility | Murchison Widefield Array |
| NCI | Facility | National Computational Infrastructure |
| NRAO | Facility | National Radio Astronomy Observatory, USA |
| OzDES | Project | Australian Dark Energy Survey |
| PESSTO | Project | Public ESO Spectroscopic Survey of Transient Objects |
| PHISCC | Conference Committee | SKA Pathfinders H I Survey Coordination Committee |
| RFI | Term | Radio Frequency Interference |
| SAMI | Project | Sydney–AAO Multi-object Integral-field spectrograph |
| SKA | Facility | Square Kilometre Array |
| SKAMP | Facility | Square Kilometre Array Molonglo Prototype |
| SNe Ia | Object | Supernovae Ia |
| S-PASS | Project | S-band Polarisation All Sky Survey |
| SRG | Facility | Spektrum-Rötgen-Gamma, Russian satellite |
| SSA | Term | Space Situational Awareness |
| SSimPL | Project | Survey Simulations PipeLine |
| TAIPAN | Project | Transforming Astronomical Imaging surveys through Polychromatic Analysis of Nebulae |
| TESS | Facility | Transiting Exoplanet Survey Satellite |
| UKST | Facility | UK Schmidt Telescope |
| ULX | Object | Ultra Luminous X-ray sources |
| VAST | Project | Variable and Slow Transients |
| VLA | Facility | Very Large Array |
| VLA LITTLE THINGS | Project | Local Irregulars That Trace Luminosity Extremes; The H I Nearby Galaxy Survey |
| VLA THINGS | Project | The H I Nearby Galaxy Survey |
| WALLABY | Project | Widefield ASKAP L-Band Legacy All-sky Blind SurveY |
| WiFeS | Facility | Wide-Field Spectrograph, ANU |
| WiggleZ | Project | A large-scale galaxy redshift survey |
| WISE | Facility | Widefield Infrared Survey Explorer |
| WNSHS | Project | Westerbork Northern Sky H I Survey |
| WSRT | Facility | Westerbork Synthesis Radio Telescope |
| XMM-Newton | Facility | X-ray Multi Mirror Mission – Newton |

**CAASTRO Affiliate Mike Dalley is pictured with some of the CAASTRO members who were Astronomers in Residence at Uluru in 2015**

***Credit: CAASTRO***

CAASTRO
ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS

School of Physics
The University of Sydney
44-70 Rosehill Street
Redfern NSW 2016 Australia
Phone +61 2 9351 2893
Email info@caastro.org
www.caastro.org

THE UNIVERSITY OF SYDNEY

THE UNIVERSITY OF MELBOURNE


THE UNIVERSITY OF WESTERN AUSTRALIA

Australian National University


THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

International Centre for Radio Astronomy Research

Australian Government
Australian Research Council