CAASTRO

ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS

SIX

ANNUAL REPORT 2016

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.

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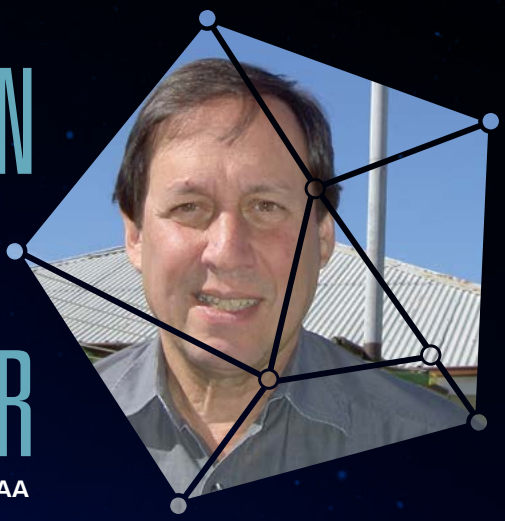
INTRODUCTION FROM THE CHAIR



PROFESSOR ROBERT WILLIAMSON AO FRS FAA
CHAIR, CAASTRO ADVISORY BOARD

First impressions count for a lot, and my first impression when I started as Chair of the CAASTRO Advisory Board – an impression that has been totally validated over the past six months – is that CAASTRO is a very well run and effective Centre of Excellence. All too often academics come up with great ideas but don't have the skills to follow through and implement them. When you are asked to Chair an Advisory Board, this is always a worry, but a worry that in this case was totally unfounded. Elaine Sadler, our Director, with Kate Gunn and her team, make sure that CAASTRO's objectives are always clearly in view, and effectively pursued.

The proof of this is that, in the current ARC grant round for new Centres of Excellence, CAASTRO has spawned not one child but two! Perhaps we might think of them as a son and a daughter, forming the sort of dynasty that we see in science as well as in industry, medicine, politics and law. Perhaps the most important legacy that any scientific enterprise can leave, with pride, is a legacy of great people trained in a solid tradition of adventurous scientific enquiry. We hope that the coming successes of CAASTRO-3D and OzGrav led by Professors Lisa Kewley (Australian National University) and Matthew Bailes (Swinburne University) will also be seen as a credit to Elaine, Kate, and everyone else who has contributed to CAASTRO over the past seven years.

CAASTRO members continue to do excellent work across a wide range of areas. This year saw the publication of a catalogue of 300,000 sources from the Murchison Widefield Array's GLEAM (GaLactic and Extragalactic All-sky MWA) survey. Many researchers are now excavating this mine of goodies and starting to produce papers from it (page 11). Results also continue to appear from the productive SAMI Galaxy Survey: on page 10 of this report we feature work by CAASTRO PhD student Adam Schaefer (University of Sydney). Many CAASTRO researchers have been working on the enigmatic *fast radio bursts* (FRBs).

Our PhD student Manisha Caleb (ANU) made her mark in the field this year by being the first to detect an FRB with an interferometer, thus establishing definitively that they originate at celestial distances (page 14). When CAASTRO was first mooted the Dynamic radio sky was a prime science target, and CAASTRO has played a pivotal role in the development of this nascent field. In 2016 CAASTRO published papers in both Science (Ravi *et al.*) and Nature (Keane *et al.*) on the topic. Both of these lead authors were former CAASTRO postdocs who still collaborate with CAASTRO. And an outstanding project by a CAASTRO Honours student, Daniel Muthukrishna (University of Queensland), showed the amazing impact that machine-learning techniques are starting to have in astronomy (page 28).

We scientists, particularly astronomers, will see CAASTRO's success in terms of solid advances reported in the literature and acknowledged by professional awards and advancement. The general community judges us more broadly: its view will be shaped not only by the latest discoveries about the mass of neutrinos or the shenanigans of black holes, but also by our other contributions. As a 'new chum', I've been impressed with CAASTRO's efforts to bring astrophysics to the community by taking the subject to schools, to planetaria, and even at Uluru at the heart of 'country'.

To the extent that we have an informed community that understands the connections between space, our planetary system, our Earth and our environment, we will also have succeeded in giving people the tools to understand satellites, global warming and the ways minerals are distributed around the globe.

Finally, I want to offer some 'thank you' bouquets to key people in CAASTRO. First to my predecessor, Alan Finkel, now occupying an extremely important role as Chief Scientist to the Australian Government. Alan was a far more appropriate Chair of the CAASTRO Advisory Board than me; I am constantly aware of what a polymath he is, and the extent to which this serves him well in his new role. Thanks go the Elaine Sadler and her colleagues in the senior scientific team, who charted the course of CAASTRO for the past seven years, leading to a clutch of scientific advances that have been part of the transformation of astrophysics over the past decade. It was their efforts that set the scene for the funding of CAASTRO-3D and OzGrav. Finally, in addition to vision, a Centre of Excellence also needs work! That work has been provided by Kate Gunn and her team, who have the rare distinction of being friendly and approachable while, at the same time, running an efficient and accountable 'tight ship'.

In 2017, CAASTRO's final full year, the Advisory Board, the scientific leadership and the administration will all devote attention to ensuring that we leave a clear and vibrant legacy, passing on many of our best ideas and programs to the two new astronomy Centres and to the astronomy and astrophysics communities more generally, and ensuring that the rest of the excellence we have fostered continues to flourish in future.

VISION & MISSION STATEMENT

Light at the end of the road
Credit: Josh Calçino

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 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, processing enormous volumes of astronomical measurements, and 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

2016 has been a particularly exciting and productive year for CAASTRO, and I hope you enjoy reading about our progress in this year's Annual Report.

Early in the year Professor Robert Williamson AO, FRS, FAA accepted our invitation to join the CAASTRO Advisory Board as the new Board Chair. He has taken over from our founding Chair Dr Alan Finkel AO, who is now Australia's Chief Scientist. Bob Williamson is an eminent medical researcher and geneticist, and a former Director of the Murdoch Children's Research Institute in Melbourne (an organisation with over 1500 researchers). He has a strong interest in national science policy and medical and scientific ethics, and has been an advisor to governments at both state and federal level. Bob recently served as Secretary for Science Policy at the Australian Academy of Science, and is a strong advocate for gender equity as well as an exceptional mentor of young scientists. I am delighted to have him working with us in CAASTRO.

March 2016 saw the launch of our planetarium show *Capturing the Cosmos* at Scienceworks in Melbourne, with a 'satellite' launch at Scitech in Perth. This was a collaborative project between CAASTRO and Museum Victoria, and staff from both organisations were present at the launch. It was an amazing experience to see the final production, and I'd like to record my thanks to Dr Wiebke Ebeling at CAASTRO and Dr Tanya Hill and her team at Scienceworks for bringing this project to such a successful conclusion. *Capturing the Cosmos* is now being shown in planetaria and museums across Australia and around the world.

On 8 September 2016, the Australian Research Council announced funding for nine new ARC Centres of Excellence for 2017–24. The successful Centres include two with strong links to CAASTRO: the Centre of Excellence for All-sky Astrophysics in Three Dimensions (CAASTRO-3D), led by Professor Lisa Kewley at the Australian National University, and the Centre of Excellence for Gravitational Wave Discovery (OzGrav), led by CAASTRO CI Professor Matthew Bailes at Swinburne University. This is wonderful news, and the funding of these two new Centres represents a strong vote of confidence in the achievements of CAASTRO and the wider Australian astronomy community.

Both new Centres will start operation in 2017. OzGrav will have a new science program distinct from that of CAASTRO. CAASTRO-3D will also begin a range of new science programs, but some current CAASTRO projects (including the MWA Epoch of Reionisation program and the SAMI Galaxy Survey) will also be included in CAASTRO-3D. These projects will transition from CAASTRO to CAASTRO-3D in late 2017 or early 2018 after all the activities funded by CAASTRO have been completed. Several of our CAASTRO Outreach programs (including *CAASTRO in the Classroom* and the Uluru Astronomer in Residence program) will also move across to CAASTRO-3D during the transition period when both Centres are operating, and we are pleased that these programs will continue in the new Centre.

The Australian Research Council (ARC) has agreed that CAASTRO will continue as an ARC Centre of Excellence until 31 March 2018 (seven years from our starting date of 1 April 2011), allowing us to complete all our planned and funded science programs. CAASTRO Deputy Director Lister Staveley-Smith (University of Western Australia), Chief Operating Officer (COO) Kate Gunn (University of Sydney) and I will also continue in our current roles until 31 March 2018. CAASTRO and CAASTRO-3D will hold a joint Annual Retreat and science meeting in South Australia in November 2017, and we hope to have some OzGrav members join us there as well.

CAASTRO's science program continued at full speed in 2016, and I'd like to highlight just two new research results out of the many published this year.

CAASTRO PhD student Manisha Caleb (Australian National University and Swinburne University) is studying a population of millisecond-duration transient bursts called fast radio bursts (FRBs). Just over a dozen of these bursts have been detected to date, and their origin remains uncertain. In 2016, Manisha and her colleagues discovered three new FRBs with the refurbished Molonglo radio telescope (UTMOST). These were the first FRBs detected with an interferometer, making it possible to measure their positions more accurately. Manisha published two other FRB papers this year, including a detailed analysis of nine FRBs from which she and her colleagues concluded that the properties of these objects are generally consistent with them arising in distant galaxies at cosmological distances, rather than within our own Galaxy.

CAASTRO researcher Emil Lenc (University of Sydney) has used polarisation observations with the Murchison Widefield Array (MWA) to image the large-scale magnetic field within our own Milky Way Galaxy. By scanning across a range in radio frequency, Emil and his colleagues were able to map out structures at different distances and build up a three-dimensional 'CT scan'

of magnetic structures out to a distance of about 160 light years in the direction of the South Galactic Pole. The same technique can be applied to MWA data to map out structures in the Earth's ionosphere – paving the way for novel future applications in Solar and atmospheric science.

Among individual honours and awards to CAASTRO members, former CAASTRO student Cleo Loi (now at Cambridge University) was a 2016 NSW State Finalist for Young Australian of the Year. CAASTRO affiliates Dr Danail Obreschkow and Dr Ivy Wong were Western Australian Tall Poppy Award winners, and CAASTRO Associate Investigator Professor Joss Bland-Hawthorn (University of Sydney) was the 2016 NSW Physical Scientist of the Year. Samuel Hinton (University of Queensland) won the ASA Bok Prize for his Honours thesis, and CAASTRO PhD student Joe Callingham was one of eight young Australian scientists selected to attend the 66th Lindau Nobel Laureates meeting in Germany. CAASTRO COO Kate Gunn won the University of Sydney's inaugural Vice-Chancellor's Award for Outstanding Contribution to Research Excellence.

This year saw the usual full program of CAASTRO scientific workshops and events, including two major international conferences. The first, *Diving into the Dark: Bridging Cosmological Theory and Observation*, was held in Cairns, Queensland, in July and brought together theorists and observers studying the dark sectors of the universe – dark energy and dark matter. The second conference, *The Changing Face of Galaxies*, took place in Hobart, Tasmania, in September and brought together researchers from around the world to discuss the key physical processes that transform galaxies across cosmic time. As usual, CAASTRO's Kate Gunn and Kylie Williams organized the venue and logistics of both meetings and ensured that everything ran smoothly.

There was also a strong CAASTRO presence at the meeting *Innovation and Discovery in Radio Astronomy*, held in honour of CAASTRO Advisory Board member Professor Ron Ekers in Queenstown, New Zealand, in September 2016. This was a wonderful opportunity to reflect on Ron's many contributions to Australian and international astronomy, and to discuss how best to create a research environment in which innovation can flourish.

This year's CAASTRO Annual Retreat was held at Abbey Beach in Western Australia. CAASTRO is a distributed Centre: we have seven Australian member universities spread across five cities, plus national and international partner institutes, so 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 this year's overseas guest speakers Dr Emma Chapman (Imperial College London) and Dr Claudio Linares (Durham University), as well as to our inspiring guest speaker on Diversity issues, Professor Robyn Owens from the University of Western Australia.

2016 was a busy year for ACAMAR, the Australian-China Consortium for Astrophysical Research, which CAASTRO helped to launch in September 2015. ACAMAR is a 'virtual' centre, serving as an umbrella and coordination point for bilateral astronomical collaborations between Australia and China. The inaugural ACAMAR Australia-China Workshop on Astrophysics was held in Perth in April this year, and was followed by a second workshop in Suzhou, China, in December. Both workshops were well-attended and stimulating events, with sessions on Antarctic astronomy, gravitational waves, radio astronomy, instrumentation and big-data challenges. They provided an excellent opportunity to meet with our Chinese colleagues to strengthen existing research collaborations and plan new ones.

Our education and outreach activities continue to progress well, with the *CAASTRO in the Classroom* program reaching more students than ever this year. New initiatives this year, in addition to the planetarium show, include a CAASTRO calendar for schools and a model solar system kit, with a children's book in the final stages of preparation for publication early next year.

The smooth running of CAASTRO is due in large part to the efforts of Deputy Director Lister Staveley-Smith, COO Kate Gunn and the CAASTRO Executive team. I thank them most warmly for their support throughout the year. I would also like to thank retiring Theme Leaders, Stuart Wyithe (who is moving to CAASTRO 3D) and Matthew Bailes (who is moving to OzGrav) for their hard work and commitment since the beginning of CAASTRO. Without them CAASTRO would not be as strong as it is today. I would also like to acknowledge the work of our administrative and professional staff, who collaborate seamlessly across our seven University nodes to keep the Centre running well. I thank them, our Advisory Board and all our CAASTRO members (184 at last count) for the enthusiasm, hard work and collegiality that allow us to achieve so much together.

RESEARCH PROGRAMS

Engineering development array of the Murchison Widefield Array
Credit: Emil Lenc

THE EVOLVING UNIVERSE

Theme Leader: Professor Stuart Wyithe | University of Melbourne

Theme Scientist: Dan Taranu | University of Western Australia

Paradoxically, we know more about the very earliest stages of the Universe than we do about the details of some of its later history. Partly this is because of the difficulties of observing those later stages: for instance, the Epoch of Reionisation that ended the cosmic Dark Ages is still our biggest observational challenge. It is also partly because the complexity of the later Universe makes it difficult to distinguish the relative contributions of 'nature' and 'nurture' – galaxies' intrinsic evolution and the effects of their environments. Researchers in the Evolving theme have this year worked on projects to further our knowledge in these difficult areas. Cathryn Trott (Curtin University) has proposed a way to better preserve the information coming to us about the Epoch of Reionisation, while Adam Schaefer (University of Sydney) has used data from the SAMI Galaxy Survey to investigate how a galaxy's environment can switch off star formation. These projects are described in more detail on the following pages.

To meet our great observational challenges, astronomers are developing new tools and techniques. Worldwide we are seeing a renaissance of low-frequency radio astronomy. In Australia, the instrument leading the charge in this area is the Murchison Widefield Array (MWA). This year we have seen the first results from the MWA's GaLactic and Extragalactic All-Sky Murchison Widefield Array (GLEAM) survey, and we can expect to see many more in 2017 and beyond. CAASTRO postdocs Jongwhan Rhee (University of Western Australia) and Laura Wolz (University of Melbourne) and colleagues have contributed to our understanding of a relatively new observing procedure, intensity mapping. In the process, they have shown that we may be able to learn about the neutral hydrogen content of distant galaxies, far beyond the reach of usual radio observations, by working with optically selected galaxies. These projects too are described below.

Probing the Epoch of Reionisation with wavelets

A new approach could preserve additional information from a distant era.

The grandly titled Epoch of Reionisation (EoR) is a major chapter in the Universe's history. It marks the end of the cosmic Dark Ages, when the Universe was filled with a fog of atomic hydrogen gas. During the EoR, the first stars and galaxies began to produce ionising radiation, clearing away the fog and leaving the transparent Universe we have today. The EoR falls between the time when we detect tiny temperature fluctuations in the otherwise uniform cosmic microwave background (300,000 years after the Big Bang), and the time of the most distant quasars (one billion years after the Big Bang). But we have not yet directly detected it, let alone explored it. Doing so is one of the primary scientific goals of low-frequency radio telescopes such as the Murchison Widefield Array (MWA) and the future Square Kilometre Array (SKA).

The tool of choice is the characteristic 21-cm emission line from neutral hydrogen gas. Coming from the distant EoR, it will be highly redshifted, moving into the low-frequency radio band. Observing it requires a careful unpicking of many hundreds of hours of data to extract the weak cosmological signal from all other radio sources in the sky and disentangle it from effects of the instrument. The usual procedure is to use statistical methods to detect the signal, adding together large amounts of information to make the signal more detectable. Such an approach has its limitations, however, because this process can destroy the very information we are seeking: how the hydrogen signal evolves over time.

To address this problem, Cathryn Trott (Curtin University) has proposed a way to extend the statistical analysis that would allow us to have the best of both worlds: adding the data to maximise the signal's detectability, plus spatially localising the signal to accurately measure the evolution. This approach uses wavelets, a way of representing information that balances sensitivity with localisation. Wavelets are routinely used in image processing but have not yet been applied to EoR data. Trott has been able to show that using wavelets makes measurements of the cosmological information more precise, and makes it easier to disentangle it from the contaminating

PERFORM

signal from all other radio galaxies in the sky and the effects of our own Galaxy's magnetic field. This contamination, and its treatment, is one of the largest challenges facing current experiments, and a wavelet approach could provide the additional information we need to overcome it.

In Trott's initial work she explored the improvement offered by wavelets using a mathematical model for the signal, foregrounds and instrument, and a single type of wavelet. However, wavelets represent a broad suite of representations of the data, and future work will try to identify the best wavelets for undertaking this science. After this exploration, Trott aims to apply the new approach to data from the MWA EoR experiment.

Publication

Cathryn Trott, "Exploring the evolution of reionization using a wavelet transform and the light cone effect". MNRAS, 461, 126 (2016)

Galactic dieback begins in the 'burbs

Researchers have used data obtained with the SAMI instrument to investigate how a galaxy's environment can suppress star formation.

Young stars are blue, old ones red: galaxies actively forming stars are blue but as star formation peters out, they become redder. Galaxies had their 'baby boom' of star formation ten billion years ago. The number of red galaxies has grown steadily since then. The evidence is that the more near neighbours a galaxy has – the denser its environment – the more likely it is to be red. How does the environment rob galaxies of the ability to make stars?

Star formation relies on long supply chains. First, neutral hydrogen gas (HI) from intergalactic space falls onto a galaxy, suffusing through it. Some regions become denser and cooler, and here the gas converts to molecular hydrogen, H_2. Swathes of H_2, mixed with dust and other molecules, can collapse to form stars. This chain of events can be disrupted at several points. The supply line of intergalactic gas can be cut off when a galaxy falls into a cluster (a large group of galaxies). The galaxy's own HI, and perhaps even the better-protected H_2, can be swept out when the galaxy moves at speed through the intracluster medium (the gas between cluster galaxies). The medium's turbulence can cause gas to billow out and leach away. Finally, neighbouring galaxies' gravitational pull can rip gas out. All these processes can *quench* (suppress) star formation, and they are probably all at work in an environment of any significant density.

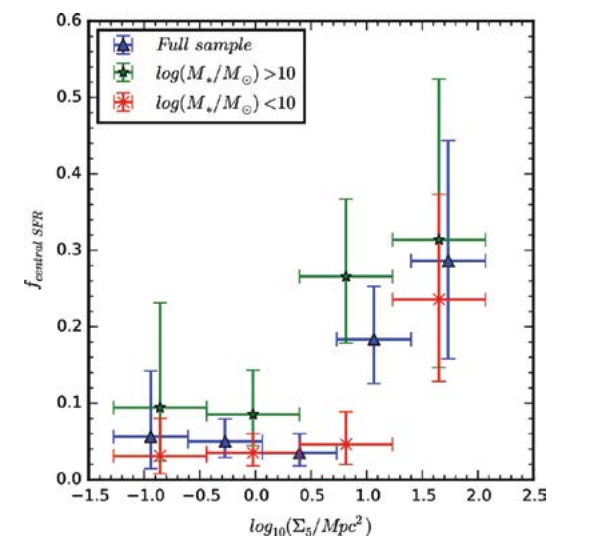
Adam Schaefer (University of Sydney) and colleagues set out to investigate these environmental effects, looking at the pattern of quenching in a sample of 201 galaxies from the SAMI Galaxy Survey. SAMI, the Sydney University–AAO Multi-object Integral-field spectrograph mounted on the Anglo-Australian telescope, samples the light from up to 61 points across the face of a galaxy, 12 galaxies at a time, obtaining a spectrum for each point. It can thus measure the gradients of certain properties across the face of a galaxy. To measure star formation, Schaefer's team recorded Hα, an optical emission line of hydrogen, both globally and across each galaxy's face. To measure each galaxy's redness (and hence the age of its stellar population) they used the Dn4000 index, a ratio between two regions of its optical spectrum.

Schaefer found that star-forming regions were very varied in extent and distribution, even among galaxies matched for mass and environmental density. This made the influence of the environment difficult to discern; nevertheless, some conclusions could be drawn. First, consistent with previous studies, the higher-mass galaxies have a higher rate of star formation than lower-mass ones, at all distances out from the galaxy's centre. Second, for galaxies of a given mass, the central star-formation density does not decline with increasing environmental density, but the global rate of star-formation does. There is a specific environmental density at which the fraction of red, non-star-forming galaxies begins to rise steadily. Below that density, just five per cent of galaxies show centrally concentrated star formation, while above it, 30 per cent do. The clear implication is that star-formation is reduced mainly in the outskirts of galaxies: quenching occurs outside-in.

Teasing out the relative importance of different environmental influences will require an even larger sample of galaxies. The full SAMI survey will include ~3400, and should provide ~900 objects suitable for this kind of analysis.

Publication

Adam Schaefer and 35 co-authors, "The SAMI Galaxy Survey: spatially resolving the environmental quenching of star formation in GAMA galaxies". MNRAS, 464, 121 (2017) (Online publication 12 September 2016)



Fraction of galaxies with centrally concentrated star formation as a function of local environment density. Blue triangles show the fractions for the full star-forming sample, red crosses are the fractions for star-forming galaxies with log10(*M/M⊙) < 10, while green star symbols are the fractions for galaxies with log10(*M**/M⊙) > 10. Fractions and vertical errors are calculated after Cameron (2011) while the horizontal error bars show the range in environment densities over which each fraction was computed. (From Schaefer *et al*. 2017)**

GLEAM survey bears first fruits

Early studies with GLEAM data have investigated both Galactic and extragalactic sources.

This year saw the first results published from the GaLactic and Extragalactic All-sky Murchison Widefield Array (GLEAM) survey, an observing program with the Murchison Widefield Array (MWA) that took data during 2013–2015. GLEAM's unique feature is its frequency coverage: it is the first survey to observe contemporaneously 5 contiguous bands between 72 and 231 MHz. This allows unprecedented measurements to be made of sources' spectral energy distribution (signal strength as a function of frequency) at 20 discrete frequencies, which is important information for identifying them and understanding their physics.

GLEAM was partly motivated by the need to measure Galactic foregrounds (i.e. radio sources), so that they could be characterised and removed from observations aimed at measuring the faint signal of the Epoch of Reionisation (EoR), the period when the first stars or galaxies burst into life. But GLEAM offers much more than that. Its observations promise to be valuable for studies of many kinds of object: radio galaxies and active galactic nuclei; galaxy clusters; Galactic magnetic fields and cosmic rays; and supernova remnants and pulsars.

The first year of GLEAM data has been processed and presented in a catalogue of 307,455 objects.

The catalogue covers 24,831 square degrees, over declinations south of +30°: it excludes the region within 10° of the Galactic plane and the Milky Way's companion galaxies, the Magellanic Clouds. A number of low-frequency surveys have been made around the world in the last decade: with its 20 measurement frequencies, GLEAM has the largest fractional bandwidth of any of them, and it also covers the largest sky area. Furthermore, it calibrates the flux-density scale of the southern sky at low frequencies to better than 10 per cent.

Like other low-frequency surveys, GLEAM faced several challenges. Distortion caused by the ionosphere is worse at low frequencies; so too is unwanted synchrotron emission from the Galaxy itself. Low-frequency observing entails larger fields of view, making imaging more difficult. And the MWA, a large array of dipoles, is more challenging to make images with than a traditional array of dishes. But meeting these challenges has given the GLEAM team much experience in low-frequency observing. This experience will be directly valuable for SKA1-Low, the low-frequency component of the Square Kilometre Array, which, like the MWA, will be built at the Murchison Radio-astronomy Observatory.

Peaked-spectrum sources

GLEAM's 20 measurement frequencies make it ideal for picking out peaked-spectrum sources, sources whose radio energy output peaks noticeably in a particular region of the spectrum. Astronomers assign such sources to different categories according to where their peak lies. The relationship between these categories is unclear: does one kind of source evolve into another? And are some or all of them giant radio galaxies in embryo, as has been proposed, or are they 'frustrated' radio sources, confined by a dense ambient medium? We can determine if a peaked-spectrum source is 'young' or 'frustrated' by identifying the mechanism responsible for the peak in the radio spectrum, synchrotron self-absorption or free-free absorption. And to discriminate between these two mechanisms we need to thoroughly sample the source's spectrum at frequencies below the peak – ideally, with simultaneous observations.

CAASTRO PhD student Joseph Callingham (University of Sydney) has used the GLEAM catalogue, plus data from two previous surveys, to construct the largest sample to date of peaked-spectrum sources. Callingham found 1,410 new sources with a peak between 72 MHz and 1.4 GHz, more than six times as many peaked-spectrum sources as were known previously in this sky region. Callingham drew a number of conclusions from his data set. The source characteristics suggest that the position of the spectral peak is determined by an inhomogenous medium that varies from source to source. Some characteristics appeared to be associated with high redshift sources ($z > 2$) and could potentially be used to identify such sources. The peak frequency did not depend on

INNOVATE

redshift, suggesting that the sample was a mix of nearby and distant sources of different kinds. Finally, some sources had spectral indices near or above the limit consistent with synchrotron self-absorption. Further investigation is needed, but they may prove to be the first peaked-spectrum sources known to be inconsistent with this theory of emission.

NGC 253

Low-frequency observing is still in its infancy. To understand what it can reveal, it's often useful to study objects that have been well investigated at higher wavelengths. CAASTRO postdoc Anna Kapínska (University of Western Australia) used GLEAM to do just that, making the deepest measurements to date of the nearby starburst galaxy NGC 253. Observing at frequencies between 72 and 231 MHz, Kapínska detected a large-scale synchrotron radio halo, previously seen in other studies at higher radio frequencies. She was also able to measure the maximum vertical extent of the synchrotron emission (~8 kpc) at low frequencies. The radio spectrum of the galaxy's central starburst region is significantly curved, peaking at 230–240 MHz. Kapínska found that the radio emission they observed was best described as a sum of central starburst and extended emission: the central starburst component was best modelled as a synchrotron plasma undergoing internal free-free absorption, and the extended component as synchrotron emission that flattened at low frequencies.

Galactic HII regions

Other teams with CAASTRO members have drawn on the GLEAM observations this year. PhD student Luke Hindson (University of Victoria, Wellington) used GLEAM data to compile a catalogue of 306 regions of ionised hydrogen (HII regions), areas that show where massive stars have recently formed. This is the most extensive and uniform low-frequency survey of HII regions in the Galaxy to date. In a separate project, PhD student Hongquan Su (ICRAR – Curtin) used HII regions identified in GLEAM to begin to map where synchrotron radio emission is generated in the Galaxy. Synchrotron emission is generated by electrons moving in magnetic fields: most of these electrons are produced directly as cosmic rays or as one of their decay products, and so the synchrotron emission indicates the origins of cosmic rays. HII regions strongly absorb low-frequency synchrotron emission, and this opacity allows us to distinguish between radiation generated in front of the cloud and that behind it. Because the MWA can view both the inner and the outer Galaxy, it will be able to make the first overall map of Galactic cosmic rays and the magnetic fields that cause them to emit. This just one of the exciting areas of low-frequency science the GLEAM survey will facilitate.

Publications

Joseph Callingham and 23 co-authors, "Extragalactic peaked-spectrum radio sources at low frequencies". ApJ, 836, 174 (2017)

Luke Hindson and 42 co-authors (14 CAASTRO members), "A large-scale, low-frequency Murchison Widefield Array survey of Galactic H II regions between 260<*l*<340". PASA, 33, e020 (2016)

Natasha Hurley-Walker and 42 co-authors (17 CAASTRO members), "GaLactic and Extragalactic All-sky Murchison Widefield Array (GLEAM) survey – I. A low-frequency extragalactic catalogue". MNRAS 464, 1146 (2017) (Online publication 16 September 2016)

Anna Kapínska and 47 co-authors, "Spectral energy distribution and radio halo of NGC253 at low radio frequencies". ApJ (accepted). Arxiv e-print: arxiv.org/abs/1702.02434v1

Hongquan Su and 22 co-authors (six CAASTRO members), "Galactic synchrotron emissivity measurements between 250°<*l*<355° from the GLEAM survey with the MWA". MNRAS (accepted). Arxiv e-print: arxiv.org/abs/1611.05446

A new way to measure distant HI?

In the course of exploring a new technique, CAASTRO researchers may have found a novel way to determine the neutral hydrogen content of distant populations of galaxies.

Neutral hydrogen gas (HI) is an important component of galaxies; some of it is transformed into molecular hydrogen and then into stars. It emits a characteristic spectral line, the so-called 21-cm line, which radio telescopes can detect. The traditional way to find HI is to point a radio telescope at individual galaxies, one by one. But this is relatively slow; besides, the HI signal is weak and can be picked up only from relatively nearby galaxies.

HI intensity mapping is a way to overcome these problems. Rather than looking at individual galaxies, a radio telescope can capture the aggregate HI emission signal over relatively large patches of sky (tens of megaparsecs), in thin 'slices' of redshift (distance). This produces a map of HI with fairly large 3D pixels.

What use is intensity mapping? It can tell us more about how HI's abundance and distribution have changed over time. We can also use it to look for a preferred spacing between galaxies that was set when the Universe was very young. This preferred spacing, which persists to this day, gives cosmologists a 'standard ruler' they can use to measure the Universe's rate of expansion at different times in its history.

Intensity mapping has its difficulties. Telescope performance shifts slightly over time. Radio interference from human activities can mask or mimic cosmic signals. And, most significantly, many radio sources in our Galaxy are far stronger than the signal we're trying to detect from other galaxies. But we can magic these problems away, or at least greatly reduce them, by a special technique: cross-correlating the HI intensity map with an optical survey of galaxies (that is, a map of galaxies detected by their light rather than by radio waves).

Masui *et al*. published work of this kind in 2013, cross-correlating a 3D map of HI intensity made with the Green Bank Telescope in the USA with galaxies from the WiggleZ Dark Energy Survey carried out with the Anglo-Australian Telescope. They made the first detection of the cosmological HI signal and put a limit on the density of HI in the redshift range they studied. But a more refined analysis of the data, from this and future surveys, is possible. For cosmological analysis, we need accurate predictions of the shape of the cross-correlation power spectrum (that is, how it varies with scale), its amplitude, and how it differs for different types of galaxy.

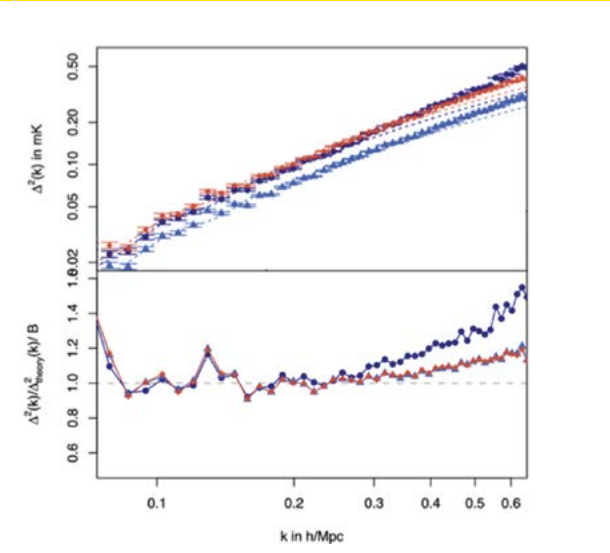
Laura Wolz (University of Melbourne) and colleagues have modelled the cross-correlation of HI intensity maps with optical surveys, using simulations. They generated sets of galaxies, using two different 'recipes' for star formation, and then made cross-correlations between these galaxies as they would appear in HI intensity maps and optical surveys. They looked separately at star-forming ('blue') galaxies, quiescent (non-star-forming, 'red') galaxies, and a set of galaxies that mimicked the ones from the WiggleZ survey, to examine the connections between star formation, HI abundance and galaxy colour.

The simulations showed that on large scales ($k < 0.2$ h Mpc^{-1}), the power of the cross-correlation varied little (< 10 per cent), no matter which star-formation recipe was used or which type of galaxy was being examined. But on small scales it was a different story. The correlation coefficient for the WiggleZ-like galaxies was consistently higher than that for the other kinds of galaxies: these galaxies tend have both very high star-forming activity and large amounts of HI. In addition, the shape of the correlation-coefficient power spectrum (how the coefficient varies with scale) was different for the quiescent and star-forming galaxies, with the latter producing a stronger correlation on small scales.

These differences in the cross-correlation power spectra are caused by the different types of galaxies having different amounts of HI. This suggests that we can measure the HI content of different *optically* selected populations of galaxies, using their intensity-mapping cross-correlation power spectra. The technique could be applied to galaxies at high redshifts, whose gas content is currently beyond the reach of our instruments to measure, and so reveal the relation between HI content and star-formation activity of different galaxy populations.

Publication

Laura Wolz and three co-authors, "Intensity mapping cross-correlations: connecting the largest scales to galaxy evolution". MNRAS 458, 3399 (2016)



The upper panel shows the cross-power spectrum of galaxies and intensity maps in units of milliKelvin as a function of wave number. Blue dots are WiggleZ-like galaxies, blue triangles are blue galaxies and red diamonds are red galaxies. The lower panel shows the dimensionless clustering behaviour of the cross-correlation, demonstrating the high clustering of WiggleZ galaxies with HI on scales smaller than $k \approx 0.3$. (From Wolz *et al*. 2016)

THE DYNAMIC UNIVERSE

Theme Leader: Professor Matthew Bailes | Swinburne University of Technology

Theme Scientist: Dr Christene Lynch | University of Sydney

Any cosmic source that flares, flickers, pulses or explodes is a *transient*. This category takes in a huge range of sources: flare stars, pulsars, fast radio bursts, supernovae, gamma-ray bursts, and more. The fast transients, those that occur on the scale of seconds or even milliseconds, are some of the most energetic events in the Universe.

Pulsars, discovered five decades ago, were some of the first transient phenomena found; they are also now among the best studied. But there is still more to learn about them. CAASTRO members continue to lead and be involved with pulsar searches such as SUPERB (Survey for Pulsars and Extragalactic Radio Bursts) and the High Time Resolution Universe survey (page 26), both of which are being carried out with CSIRO's Parkes telescope, and with UTMOST, the University of Sydney's refurbished Molonglo telescope.

The technology needed to find pulsars also detects the enigmatic *fast radio bursts* (FRBs). Both SUPERB and the UTMOST surveys are looking for FRBs, as are many other projects around the world, while many of the known FRBs were found in HTRU data. CAASTRO PhD student Manisha Caleb's (Australian National University and Swinburne University) work on FRBs with UTMOST this year is described below, as is work by Antonia Rowlinson (CSIRO; no University of Amsterdam/ASTRON) with the Murchison Widefield Array. Exciting developments in the area of FRBs include the *Deeper, Wider, Faster* program (page 25), an international collaboration led by CAASTRO members and involving 15 telescopes working at several wavelengths, and an upgrade to UTMOST (page 27) that will boost its ability to localise FRBs and so determine their environments and, possibly, their nature.

Even before we understand the nature of FRBs, we can use them as tools. This year Vikram Ravi and Ryan Shannon published a measurement of the 'cosmic web', the thin gas lying between galaxies, that they'd made using a brilliant fast radio burst. A second form of transient, Type Ia supernovae, is well established as a tool in cosmology, and the SkyMapper Transient Survey has now netted a number of them. And yet another form of transient, gamma-ray bursts, may hold the key to finding the Universe's first generation of stars. All three of these projects are described in the following pages (15–17).

The newest addition to the family of transients, one lying outside the electromagnetic spectrum, is gravitational-wave bursts. The groundbreaking detection of a gravitational-wave signal from the merger of two mid-sized black holes took place in September 2015 and was announced early in 2016. The multiwavelength follow-up (which returned a null result) was also described in a paper this year. Four Australian telescopes took part in this huge effort: in the optical, SkyMapper and the Zadko telescope in Western Australia; in the radio, the Murchison Widefield Array and the Australian SKA Pathfinder. All these facilities have a Memorandum of Understanding with the LIGO Scientific Collaboration to do follow-up, so this is undoubtedly only the first of many such efforts. We are now entering the era of 'multi-messenger astronomy', and Australia has a role to play.

UTMOST confirms fast radio bursts are cosmic

Short and bright, *fast radio bursts* (FRBs) are a relatively new class of transient. Their origins are unknown. The pulses typically last for a few milliseconds and are dispersed (broadened in frequency) as a result of encountering free electrons in space. The size of this dispersion suggests that FRBs have travelled for a considerable distance through the Universe rather than just through the Galaxy; however, other factors can contribute to a high dispersion measure.

A team led by CAASTRO PhD student Manisha Caleb (Australian National University and Swinburne University) surveyed the sky at 843 MHz for 180 days with the UTMOST array (page 14), and found three FRBs. Two were close to the Galactic plane; all three had dispersion measures far greater than the Galaxy alone would create. Using the dispersion measure as a guide to distance, Caleb's team gave these FRBs (160317, 160410 and 160608) upper limits on their redshifts of 0.7, 0.2 and 0.4 respectively (assuming no contribution from any host galaxy they might lie in).

This is the first time FRBs have been detected with an interferometer (an array of receiving elements) rather than with a single-dish telescope such as Parkes. As an interferometer, UTMOST has a number of beams on the sky; extensive pulsar observations with the telescope have shown that a pulsar from a far-field source is detected in no more than three adjacent beams at any given time. Radio-frequency interference, on the other hand, is usually local, and usually appears on more than three adjacent beams. Detecting FRBs in one or

two beams only, as Caleb's team did, means that they lie more than 10,000 km away, well away from the Earth. This is the first observation to definitively show a cosmic origin for FRBs.

Caleb and her team made extensive follow-up observations with UTMOST for each of the FRBs (more than 100 hours, in the case of FRB 160317). None of the bursts was found to repeat. This means that the sole confirmed repeating burst remains FRB 121102, found with the Arecibo telescope (Spitler *et al*. 2016).

Based on the three UTMOST detections, Caleb estimated an all-sky FRB rate, at 843 MHz and above a fluence of 34 Jy ms, of around 78 events per sky per day. This is twice the rate she had predicted in earlier work. Those earlier calculations, however, were based on particular assumptions about how the sources of FRBs are distributed in the Universe and how the bursts' strength varies with frequency. Slightly adjusting the assumption about distribution brings the rate into line with the rate calculated from Parkes' observations.

UTMOST has now reached 20 per cent of its full sensitivity for observing FRBs and is on track to achieve its target sensitivity within two years. We can expect it to find many more FRBs and, following the UTMOST-2D upgrade (page 27), to localise them.

Publications

Manisha Caleb and 14 co-authors, "Fast Radio Transient searches with UTMOST at 843 MHz". MNRAS, 458, 718–725 (2016)

Manisha Caleb and 17 co-authors, "The first interferometric detections of Fast Radio Bursts". MNRAS (accepted)

UTMOST
Credit: Fabian Jankowski

MWA tightens the screws on low-frequency transients

Conventional searches for *fast radio bursts* (FRB), such as the one being carried out with UTMOST (page 14), are made by searching through spectral channels. But it's also possible to search for FRBs, and other transients, by using images. Antonia Rowlinson (CSIRO; now University of Amsterdam/ASTRON) has led an international team of 35 researchers in a project to do just that, examining 10,000 images made with the Murchison Widefield Array (MWA).

Rowlinson and her colleagues drew on observations that had been made for the MWA's Epoch of Reionisation (EoR) project. The full EoR dataset comprises three fields, well away from the Galactic plane, that have been observed for 1000 hours at 156 and 182 MHz. To reduce the data processing involved to a tractable level, Rowlinson's team used 78 hours' worth of this data, from one field of approximately 900 square degrees and at one frequency, 182 MHz. They analysed the data for transient and variable sources on timescales from 28 seconds to about a year.

The spectral slope of FRBs – how their signal strength varies with frequency – isn't yet well understood; low-frequency observations will help to constrain it. They will also constrain the rates at which FRBs occur, which in turn will help rule out some of the many ideas about how the bursts might be generated. Rowlinson's project complements a previous study done with the MWA (Tingay *et al*. 2015) that used snapshot images with a much shorter integration time (two seconds rather than 28) and a different processing strategy.

Upon examination, the EoR field proved to be remarkably stable. Rowlinson and her colleagues detected no FRBs or transients, allowing them to put the tightest constraints to date – by orders of magnitude – on the rates of such sources at low frequencies. For FRBs they concluded that bursts brighter than 7980 Jy, and at a frequency of 182 MHz, are far from plentiful: there must be fewer than 82 over the whole sky each day. This (low) rate is consistent with other, recent estimates made for higher frequencies (e.g. Keane & Petroff 2015; Macquart & Johnston 2015). To capture FRBs and other transients at low frequencies we may need to increase both the size and sensitivity of our surveys tenfold or more.

Publication

Antonia Rowlinson and 35 co-authors, "Limits on Fast Radio Bursts and other transient sources at 182 MHz using the Murchison Widefield Array". MNRAS, 458, 3506–3522 (2016)

Fast radio burst used to measure the cosmic web

How *fast radio bursts* (FRBs) arise is still unclear, but their properties are not. These short, sharp flashes of radio waves appear to travel from considerable distances in space (redshifts up to ~ 2), well beyond our Galaxy, and hold promise as probes of otherwise hard-to-reach regions. We may be able to use FRBs to constrain the nature of dark energy or locate the Universe's 'missing baryons' (which are thought to lurk outside galaxies). Such projects might require dozens or hundreds of FRBs, a far cry from the two dozen observed to date. But even a single FRB can have its uses. An international team with many CAASTRO members, jointly led by former CAASTRO postdoc Vikram Ravi (Swinburne University; now Caltech) and Ryan Shannon (CSIRO/Curtin University), has used an extraordinarily bright FRB to measure the magnetic field and turbulence of the *cosmic web* – the gas lying between galaxies.

The burst, FRB 150807, came from a small patch of sky containing only distant galaxies, and seems to have originated more than a billion light-years away. It lasted for just a third of a millisecond, making it one of the shortest FRBs ever observed. But at the same time, it was astonishingly bright (the peak flux density was 120 ± 30 Jy); in fact it was the brightest FRB seen since the first one (the so-called Lorimer burst, published in 2007). The burst was also strongly linearly polarised. This combination of brightness, distance and polarisation meant that FRB 150807 was able to offer an unprecedented view of the thin gas in intergalactic space.

If a linearly polarised radio signal travels through a magnetic field, its plane of polarisation is 'twisted' (a phenomenon called *Faraday rotation*). Despite the distance FRB 150807 had travelled, it had undergone little Faraday rotation before reaching our Galaxy. From this the researchers inferred that the gas around the origin of the burst was not magnetised, or scarcely so; they also determined that the net magnetisation of the cosmic web (along this sightline, at least) must be less than 21 nano-Gauss. This weak magnetic field is consistent with predictions from many models for the cosmic web; interestingly, it is also *inconsistent* with the FRB coming from an object embedded in highly magnetised star-forming region or the centre of a galaxy. The scintillation (twinkling) of the burst suggests that intergalactic medium is slightly, rather than strongly, turbulent.

Publication

Vikram Ravi and Ryan Shannon, and 14 co-authors, "The magnetic field and turbulence of the cosmic web measured using a brilliant fast radio burst". Science, 354, 1249 (2016)

SkyMapper swoops on supernovae

The accelerating expansion of the Universe was discovered two decades ago, but we still don't know its cause. The problem is being attacked along many lines. One approach is to use the technique that revealed the acceleration in the first place, which is based on supernovae (exploding stars). Supernovae of a particular kind, Type Ia or SNe Ia, are of an essentially similar intrinsic brightness. Because more distant ones appear fainter, they can be used to map out distances in the Universe. The effects of dark energy are then determined by comparing these distances with distances measured in a different way.

This technique uses high redshift (very distant) supernovae. But low-redshift ($z < 0.1$) supernovae support the effort: we need many of these to determine the average brightness of SNe Ia with great exactness. Several surveys have been undertaken to gather a greater number of them, but the varied telescopes involved, and the non-uniform nature of the surveys, have exacerbated the systematic errors intrinsic to all surveys.

The need for a better sample of SNe Ia is being met by SkyMapper, a 1.35-m robotic telescope of the Australian National University (ANU) located at Siding Spring Observatory in New South Wales. SkyMapper is a dedicated survey telescope, equipped with a 269-megapixel camera and capturing six square degrees of sky (almost 30 times the area of the full Moon) in a single 'look'. Its Main Survey will be first comprehensive digital survey of the southern sky. But in addition, 25–30 per cent of the telescope's time is devoted to a survey for transient sources, the main aim of which is to net low-redshift SNe Ia. SkyMapper is addressing the problems encountered with other low-redshift searches for SNe Ia by searching a wide area in a uniform fashion, with a short cadence (≤ 5 days) and at multiple, well-determined wavelength ranges. This will produce a sample well matched to the high-redshift SNe Ia that have been picked for measuring the effects of dark energy. SkyMapper's survey gathers only photometric information (an object's brightness): supernova candidates are identified by a *random forest* classifier (a machine-learning algorithm) and then confirmed with spectra taken by other telescopes.

To date, the SkyMapper Transient Survey has covered an area of more than 2200 square degrees. Its ~400 fields have each been visited an average of more than 40 times. Most of the fields lie away from the Galactic plane, to reduce the dimming of light caused by dust there. Although impeded by bad weather in 2016, the survey has found about 30 SNe Ia candidates:

SkyMapper Telescope

Credit: Dilyar Barat

their details will be published in 2017. The survey has also turned up a number of other interesting objects: a rare superluminous supernova, SN 2013hx, the closest one discovered to date; SN 2015J, an object that may be a 'supernova impostor' or the first known supernova powered by a magnetar (a kind of neutron star); SN2016hhd, a SN Ia seen just a few days after its explosion (only ~10 others have been caught this early); and SN2016doj, a supernova in the so-called 'superluminous gap' – that is, intermediate between normal and superluminous objects.

Publication

Richard Scalzo and nine co-authors, "The SkyMapper Transient Survey". PASA (submitted). Arxiv e-print: arxiv.org/abs/1702.05585

Do some gamma-ray bursts signpost the first stars?

The very first stars in the Universe, formed from the pristine gas generated by the Big Bang, are no longer with us – or rather, none have yet been detected directly. Finding them is one of the major tasks for the future James Webb Space Telescope, Hubble's successor. It's an important task too, because the first generation of stars may have set off the start of the Epoch of Reionisation, the great 'de-fogging' that gave us the Universe we have today.

Exactly where we should look for these so-called Population-III or Pop-III stars is a matter of debate: theoretical arguments suggest that they might have formed at redshifts as low as $z \sim 5–7$, and be the dominant population up to $z \sim 20$. Their masses are uncertain also: over 100 solar masses, we used to think, but more recently it's been suggested that they might be just tens of solar masses.

What does seem clear is that Pop-III stars, at least the more massive of them, would have died by collapsing to form a black hole, a form of star-death that generates a long (> 2 s) gamma-ray burst (GRB). Such an event is characterised an immediate outburst of X-rays and gamma-rays (the prompt emission), followed by a lower-frequency afterglow that can last for months. GRBs from Pop-III stars would be distinguished by being extremely energetic and having a long-lasting gamma-ray outburst. But the characteristics of these outbursts mean that they will barely register with our current gamma-ray detectors.

Can we detect Pop-III stars from their afterglows? Models suggest that it's possible, even with present-day facilities. The radio afterglow of a Pop-III GRB would peak several weeks (at 'late times') after the initial outburst, at gigahertz frequencies, and be brighter than a standard GRB.

Davide Burlon (University of Sydney) and CAASTRO co-authors have explored the hypothesis that particularly long and dim GRBs detected by NASA's *Swift* satellite, and which have not been detected in the infrared, could originate from Pop-III progenitors: in other words, that we have already recorded the evidence for Pop-III stars, and it is lurking in *Swift* data. These GRBs would initially appear indistinguishable from standard GRBs, but at late times they could be identified by their radio brightness. A clear detection at gigahertz (GHz) frequencies, made more than 100 days after the initial outburst, would point to an extremely energetic GRB.

To test their hypothesis, Burlon and colleagues carried out a pilot experiment with CSIRO's Australia Telescope Compact Array (ATCA). They observed three target GRBs, already recorded by *Swift*, and one normal GRB as a control, at 17 GHz. The observations were made at times ranging from 650 to 1320 days after the GRBs were first detected.

None of the objects was detected by the ATCA, even at signal levels just a fraction of the predicted level. There could be a number of reasons for this: for instance, it may be that Pop-III stars do not have exceptionally large masses, but are similar to the progenitors of 'regular' GRBs, or that their redshift (distance) distribution is different from the one assumed. It could also be that the environments around the GRBs absorb most of their photons: in fact one of the sources in the sample, GRB 111215A, was later shown to be one of these 'dark GRBs'. Whatever the reason, this pilot work can be used to design further attempts to find the first Pop-III star, before these objects become directly observable.

Publication

Davide Burlon and five co-authors, "Gamma-ray bursts from massive Population-III stars: clues from the radio band". MNRAS 459, 3356–3362 (2016)

THE DARK UNIVERSE

Theme Leader: Professor Tamara Davis | University of Queensland

Theme Scientist: Dr Ixandra Achitouv | Swinburne University of Technology

Observations of the Universe over the last eighty years have revealed features that we still can't account for. Twenty years ago we found that the expansion of the universe appears to be accelerating: the cause of this has been dubbed dark energy. And we've known since the 1930s that there appears to be a large proportion of matter out there that differs from the 'normal' matter: this is called dark matter. The Dark Universe theme is about understanding the Universe as a whole, particularly the nature of *dark matter* and *dark energy*, and the equations of gravity. We use many methods to measure the effects of dark energy and dark matter more precisely and to test whether new types of particles or new laws of gravity could explain them.

The first of these methods is to use *peculiar velocities*, the local motions of galaxies that are additional to the motions they have as a result of the expansion of the universe. This year we saw the completion of the 2MASS Tully-Fisher Survey, and published a paper mapping our local velocity field (Springob *et al*. 2016).

A second way to study the effects of dark energy is to use a special class of exploding star, Type Ia supernovae, to measure the acceleration of the expansion of the universe. We saw some significant milestones this area in 2016. The SkyMapper survey in now in full swing and has discovered about 30 low-redshift supernova candidates (page 17). The OzDES survey, being carried out with the Anglo-Australian Telescope, is in its fourth year of observing, and by the end of 2016 it had obtained more than 20,000 redshifts, spectroscopically confirmed more than 200 supernovae, and measured redshifts for over 2,500 galaxies that hosted supernovae. This is a groundbreaking amount of data: the Nobel-prize winning discovery of the acceleration used just 52 supernovae (between two teams) and the current state-of-the-art sample contains just 740.

In the course of these supernova searches we have found many objects that are interesting in their own right. SkyMapper has discovered at least three: a Type Ia supernova that shows interaction with a companion, providing the strongest evidence to date of a Type Ia being produced by a small main-sequence star; the strange SN 2015J, which has a strong case for being either a supernova imposter in a dense environment or a magnetar-powered supernova with a shock breakout; and a rapidly rising, superluminous supernova, an event in the gap between normal and superluminous supernovae. OzDES has discovered a broad absorption line quasar in a star-forming host, which is a previously unseen stage of quasar evolution.

In our 'large-scale structure' project we were excited to see the publication this year of the final WiggleZ Dark Energy Survey cosmology paper, led by Samuel Hinton (University of Queensland). This paper, described on page 20, showed the 2D baryon acoustic oscillation measurement, and won the Astronomical Society of Australia's Bok Prize for best Honours thesis of the year. Another paper in this area of work, led by Ixandra Achitouv (Swinburne University), showed that structure grows at the same rate around both the galaxies and voids found in data from the 6dFGS (six-degree-field galaxy survey). This finding contradicts some theories of modified gravity, which posit that the strength of gravity, and hence the rate of growth of structure, depends on the density of the environment. Andrew Johnson (Swinburne University) this year developed an approach to calibrating the source redshift distribution of the Kilo-Degree survey (KiDS), an imaging survey, through cross-correlation with the overlapping 2dFLenS (2-degree Field Lensing Survey) spectroscopic survey (page 21). In parallel, Shahab Joudaki (Swinburne University) performed a joint analysis of weak gravitational lensing and large-scale structure with the KiDS data.

Many of these advances rely on strong theoretical modelling, which is our third major area of research. Two of our researchers used machine learning to attack significant problems in supernova cosmology: photometric supernova classification (Anais Möller, Australian National University) and spectroscopic supernova classification (Daniel Muthukrishna, University of Queensland). Cullan Howlett (University of Western Australia) published a paper with forecasts for the growth-rate measurements from peculiar velocity surveys including the upcoming Australian surveys WALLABY and Taipan, while Jacob Seiler and David Parkinson (both University of Queensland) performed theoretical modelling to predict the magnitude of bulk flows in f(R) modified gravity, finding that most modifications predict higher bulk flows than are observed. Howlett's work is described in more detail on page 22 and Muthukrishna's on page 28.

Dark-theme researchers are also taking part in experiments to try to directly detect dark matter. One of these is SABRE (Sodium-iodide with Active Background REjection), which this year received funding that will allow it to be built in Stawell, Victoria.

SABRE will be the first direct-detection experiment in the southern hemisphere.

Finally, one of the Dark theme's significant highlights for the year was the *Diving into the Dark* conference in Cairns (page 78). This was hugely successful, with several of the participants reporting that it was the best conference they had ever attended. The time set aside for group discussions and interactions outside of the talk schedule was particularly popular and productive.

2D analysis wrings more value from WiggleZ

Almost 20 years ago two teams found that in relatively recent times the Universe's expansion has picked up speed. This acceleration is usually attributed to an unknown factor, *dark energy*, but it could also be that we're observing a universe governed by a modified version of general relativity. Cosmologists want to distinguish between these two possibilities.

To understand the acceleration better, it would be useful to have a 'ruler' that we could use to measure the Universe at different times in its history, to get its size and rate of expansion. Happily, Nature has provided such a ruler. Galaxies have a slight preference for existing at a particular spacing. This spacing, the result of sound waves travelling through the early universe (*baryon acoustic oscillations* or BAO) was 'frozen' into the distribution of galaxies when the young Universe had expanded and cooled sufficiently. It is detectable in the cosmic microwave background, which dates from when the Universe was just 380,000 years old; in today's Universe; and at every stage in between. The way galaxies are distributed can be described by a mathematical function. The position of the strongest peak in this function gives the preferred spacing of galaxies, the cosmic ruler.

Measuring the BAO pattern requires large datasets, lots of galaxies spread over a large volume of space. Eisenstein *et al*. (2005) were the first to detect the BAO at high significance and from it derive cosmological constraints. Some of the subsequent BAO measurements have used the WiggleZ dataset, a survey of mostly blue galaxies, carried out with the Anglo-Australian Telescope in NSW. Several analyses of this dataset were published during 2011–2014: they included measurements of the BAO peak at three different distances and a measurement of the rate at which structure in the Universe (defined by the arrangement of galaxies) has grown over time, and a non-BAO measurement of the Universe's expansion history.

CAASTRO's Samuel Hinton (University of Queensland) and colleagues have now analysed the WiggleZ data in one further way. The previous measurements of the BAO peak were 'one dimensional': that is, they were made without differentiating between spacings between the galaxies that were along the line of sight or transverse to it. A more subtle analysis can be made that uses the spacings separately. This '2D' analysis allows us to measure a greater number of cosmological parameters, and so differentiate between different cosmological models. It has now become possible now thanks to two recent pieces of work: one that removes the effects of the WiggleZ galaxies' individual motions from the analysis ('reconstruction'), which makes the BAO peak stand out more sharply; and a second, the creation of accurate mock catalogues of galaxies that can be used in the analysis. The analysis is also possible only because the WiggleZ galaxy numbers (225,415) and volume (1 Gpc^3) are big enough – just – to allow it.

Hinton and his team tackled the data in two ways. Their first approach used the full shape of the BAO distribution, not just the main peak. In this analysis, they modelled the BAO distribution as the sum of a small number of spherical harmonic functions ('multipoles') and fitted this model to the (unreconstructed) WiggleZ data. In the second approach, led by Eyal Kazin (Swinburne University), they separately analysed the distances between galaxies along the line of sight and transverse to the line of sight, this time fitting the models to reconstructed WiggleZ data (that is, the data with the effects of individual galaxy motions removed). Reconstruction washes out the full shape of the BAO distribution, and so this second approach gave them only information about the location of the main BAO peak.

Their results were reassuring: the parameters $\Omega c\, h^2$, $H(z)$, and $D_A(z)$ were measured for three redshift bins, with errors of between 5 and 22 per cent, and their values were consistent with a flat ΛCDM cosmology, the results of other BAO studies, and observations of the cosmic microwave background made with the Planck satellite.

This is likely to be the final BAO analysis of the WiggleZ dataset. Other surveys are now even larger than WiggleZ, and 2D BAO analysis is now setting the standard.

Publication

Samuel Hinton and 14 co-authors, "Measuring the 2D baryon acoustic oscillation signal of galaxies in WiggleZ: cosmological constraints". MNRAS 464, 4807–4822 (2017). Published online 23 October 2016.

Cross-correlation delivers redshifts for weak-lensing surveys

While light can be hidden, gravity can't be. And so, if we want to map the distribution of matter in the Universe, both dark and non-dark (baryonic), a method that detects its gravitational effects is ideal. *Weak gravitational lensing* is such a method. It is based on the fact that mass bends spacetime, and so bends the path of light and other radiation. Foreground masses (such as galaxies or clusters of galaxies) bend the path of light from background sources (galaxies or quasars). In the rare cases of *strong gravitational lensing* the light is bent into arcs or even rings. In the commoner case of *weak gravitational lensing* the bending is not noticeable for individual objects, but can be detected statistically.

Different cosmological models predict different patterns of the distribution of mass in the Universe: weak gravitational lensing can thus be used to distinguish between them. Deep imaging surveys have been undertaken with this goal in mind (the Kilo-Degree Survey, the Dark Energy Survey and the HyperSuprimeCam imaging survey) and similar surveys are planned with the Large Synoptic Sky Telescope and the European Space Agency's Euclid space mission. These surveys will obtain the positions on the sky of millions of galaxies.

But one more thing is needed. To calculate the weak lensing pattern that a particular cosmology (and hence mass distribution) will generate, we need to know the redshifts (effectively, distances) of the background sources. The weak-lensing surveys will image millions of objects: fortunately, we don't need the individual redshift of each source, just the distribution of the redshifts for the whole ensemble of galaxies. Even so, this is a challenging problem.

Attempts have already been made to solve it. Most of the techniques tried have required researchers to obtain spectroscopic redshifts for a subsample of the galaxies (that is, analyse the light of a number of individual galaxies). The catch is that this subsample must be highly representative of the whole survey population: this is hard to do, because it's difficult to obtain spectra of very faint galaxies, which are common in these surveys. The difficulty translates into needing impractically large amounts of observing time on even large (10-m class) optical telescopes. Approaches such as machine-learning algorithms and template fitting suffer from similar problems.

Andrew Johnson (Swinburne University) and colleagues have explored another path, one that skirts the problem of spectroscopic follow-up. This is a statistical technique, first developed by McQuinn & White (2013), which Johnson's team has now extended. It relies on having two galaxy datasets. One is the sample of galaxies from an imaging survey, for which we want to know the distribution of redshifts; the other is a sample of galaxies for which we have already measured the redshifts, using spectroscopy. The key is that the samples have to overlap on the sky and in redshift (distance). The two sets of galaxies are generated by the same underlying distribution of matter: they will therefore be positively cross-correlated (that is, there will be a degree of correspondence between them) regardless of how bright they are or which type of galaxy they are. The more the samples overlap, the more pronounced the cross-correlation will be. So we can divide the spectroscopic sample into a number of redshift bins (effectively, increments of distance) and for each bin measure the cross-correlation with the sample from the imaging survey.

The researchers applied their method to two sets of survey data, the first from the Kilo-Degree Survey (KiDS), an optical imaging survey for weak gravitational lensing that has been carried out with the 2.6-m VLT Survey Telescope in Chile, and the second from the 2-degree Field Lensing Survey (2dFLenS), a spectroscopic survey carried out with the 4-m Anglo-Australian Telescope in Australia. 2dFLenS was designed specifically to increase the area of overlap between spectroscopic galaxy surveys and gravitational-lensing imaging surveys, and so testing the cross-correlation technique is part of its *raison d'etre*. The 2dFLenS data was divided into 18 redshift bins in the range $0<z<0.9$. The amplitude of the cross-correlation signal increased with redshift but overall the results agreed qualitatively with those derived previously from KiDS.

The cross-correlation method shows promise, and is free of problems built into others methods for obtaining redshifts. It could be extended in a number of ways. The most important step to take would be to calibrate the bias of the photometric sample. Possible approaches to this problem include the use of redshift-space distortion, lensing magnification and galaxy-galaxy lensing.

Publication

Andrew Johnson and 18 co-authors, "2dFLenS and KiDS: determining source redshift distributions with cross-correlations". MNRAS 465, 4118–4132 (2017). Published online 23 November 2016.

Peculiar-velocity surveys: better together

The expansion of the Universe, and the rate at which this is accelerating, is increasingly well measured and seems indisputable. But the cause is a different matter. It could be that the accelerant, *dark energy*, is a so-called cosmological constant, a factor in the orthodox formulation of general relativity. Or it may be that our theory of gravity needs to be changed: for instance, to one in which the gravitational force varies with the density of the environment. We can distinguish between these two possibilities, dark energy and a modified theory of gravity, by measuring the rate at which the structure within the Universe grows; that is, the rate at which the large-scale distribution of galaxies takes shape.

This rate of growth of structure is most commonly measured through redshift-space distortion. Redshift is a measurable feature of a galaxy's spectrum: it is the shifting in frequency of emission (or absorption) from what would be recorded in the laboratory. Part of this shift is the result of *Hubble flow*, galaxies moving away from us as a result of the expansion of the Universe. But another part results from the *peculiar velocities* of galaxies, their individual motion as they fall towards concentrations of mass. Only infall along the line of sight will affect a galaxy's redshift; infall perpendicular to it will not. Infall affects how clustered galaxies seem. We can measure the clustering of galaxies along the line of sight and perpendicular to it, and the difference between the two measurements will give us a measure of the infall. The rate of infall is a consequence of the rate of growth of structure, and so measuring the former allows us to constrain the latter.

This technique is very precise. Unfortunately, it is also affected by a bias. Galaxies don't trace the underlying total mass field (which is dominated by dark matter) in a representative way; instead, galaxies tend to form first in the most over-dense regions. This *galaxy bias* varies with scale (it's worse on small scales) and over cosmic time (it's worse at earlier times). Galaxy bias affects the clustering of galaxies in almost the same way as redshift-space distortion, and so it limits the usefulness of the redshift-space distortion technique as a way to measure the rate of growth of structure.

We can skirt around this problem by instead measuring peculiar velocities. We do this by measuring the distance that the galaxy's redshift implies, and comparing it with a distance measurement made another way (e.g. using the Tully-Fisher relation, a Fundamental Plane relation, or supernovae as *standard candles*): the discrepancy indicates the peculiar velocity.

Peculiar velocities have, by themselves, already been used to constrain the rate of growth of structure, free of the galaxy bias. It's also been shown (for instance, by Burkey & Taylor (2004) and Koda *et al*. (2014)) that combining peculiar velocities and redshifts substantially improve the constraints on growth rate measured by redshift-space distortion alone. These authors also showed that such constraints will improve with the next generation of peculiar-velocity surveys, which will push to larger redshifts, cover greater volumes of space, and detect fainter galaxies.

Some peculiar-velocity surveys have been made in overlapping regions of the sky; future surveys will increase these areas of overlap. Therefore, as well as combining measurements within surveys, it is now worth looking at the value of combining data from different surveys. Cullan Howlett (University of Western Australia) and colleagues looked at such combinations this year, by extending a Fisher matrix method used by Burkey & Taylor (2004) and Koda *et al*. (2014). They studied the two-point correlations of the velocity and density fields that have been measured by existing surveys (2MTF, 6dFGSv) or which will be measured by future ones (Taipan, WALLABY and WNSHS).

Using peculiar velocities alone, combining data from various surveys improved the constraints on growth rate by 15–30 per cent compared to the results from the individual surveys. Using peculiar velocities plus redshifts gave an even better result, improving the constraints 30–50 per cent above those from individual surveys. Combining the optical Taipan survey with WALLABY and WNSHS (southern- and northern-sky radio surveys respectively) could potentially measure the rate of growth of structure to within three per cent, a level that would place tight limits on possible extensions to general relativity.

Publication

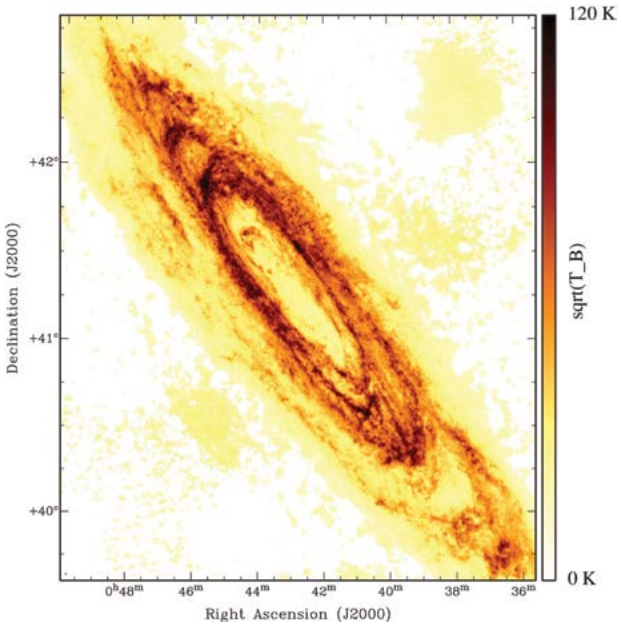
Cullan Howlett, Lister Staveley-Smith and Chris Blake, "Cosmological forecasts for combined and next-generation peculiar velocity surveys". MNRAS 464, 2517–2544 (2017). Published online 28 September 2016.

CASE STUDIES

Siding Springs Observatory
Credit: Dilyar Barat

National Innovation Priority: Research

STUDYING THE HISTORY OF H I WITH ASKAP



A map of the neutral HI (atomic hydrogen) gas in our nearest large neighbour M31 (the Andromeda Galaxy) imaged by the Westerbork Synthesis Radio Telescope (WSRT)

Credit: Braun R. et al., 2009, MNRAS, 695, 937-953

Astronomers aim to detect neutral hydrogen gas in the distant Universe through its 'shadow' – the radiation it absorbs.

Hydrogen gas is transformed at least twice on its way to becoming a star. Starting as hot, ionised gas in intergalactic space, after falling into a galaxy it becomes the *interstellar medium*: a sea of largely warm (1,000–10,000 K) neutral atomic hydrogen, HI, dotted with regions of colder (100 K) gas. The cold gas is further transformed into molecular hydrogen, H_2, the dominant component of the *molecular clouds* whose collapse creates stars.

Ten billion years ago stars were forming ten times faster than they are now. Why the decline? Evidence indicates that the molecular hydrogen has dwindled over that time: the history of HI, however, is not so clear. Recent studies with optical telescopes suggest that the total HI content of galaxies has changed little over the past ten billion years. But could the ratio of cold to warm HI have changed? And how is the gas distributed?

For answers, astronomers are turning to the next generation of radio interferometers, such as CSIRO's new Australian SKA Pathfinder (ASKAP) in Western Australia. ASKAP's thirty-six 12-m dishes are distinctive for being outfitted with 'phased-array feeds', which allow the telescope to capture a very large view of the sky (30 square degrees, equal to 150 full moons). The dishes are being brought online in stages: as of the end of 2016, ASKAP was operating as a 12-antenna array.

In October ASKAP began 'Early Science' observations, with CSIRO staff taking data on behalf of the international teams that will be using the telescope for large survey projects. The first observations were made for WALLABY, a project to search for the characteristic radio emission line of HI (the '21-cm' line) in galaxies as far away as three billion light years. The WALLABY team expects to detect 600,000 individual galaxies: it will measure the HI properties of each one and use those to derive the galaxy's distance, HI mass, total mass and dark-matter content. Most WALLABY galaxies will also be detected in continuum radio emission, allowing their star-formation rates to be determined. The preliminary WALLABY observations in 2016 involved mapping the NGC 7232 galaxy group in both HI emission and radio continuum emission, and making HI maps of IC 5201, a bright galaxy within the field. CAASTRO's Attila Popping (University of Western Australia) is an active member of the WALLABY team and contributed to this work.

Although neutral hydrogen is plentiful in the Universe, its 21-cm emission line is weak. To detect HI in distant galaxies, astronomers look for *absorption*, the imprint that HI leaves on the spectrum of radio emission from a strong background source such as a quasar. One of ASKAP's major survey projects will be FLASH (the First Large Absorption Survey in HI), which is aimed at detecting thousands of new HI absorbing-line systems. This project, led by CAASTRO Director Elaine Sadler (University of Sydney), will be the first major study of the relationship between HI and the rate of star formation in galaxies at redshifts between 0.5 and 1.0 – that is, galaxies four to eight billion years back in the history of the Universe. Thanks to the wide field of view of ASKAP, FLASH will cover a much larger volume of space than previous surveys. ASKAP's site, the Murchison Radio-astronomy Observatory, is also strikingly free of radio interference, meaning that faint signals that might be missed elsewhere will stand out clearly in the data.

How many galaxies FLASH will detect depends on several factors. One is the HI's *spin temperature*, a measure of how easily 'excited' the atoms are and, therefore, how readily they absorb radiation. A low physical temperature corresponds to a low spin temperature, and so cold HI absorbs radiation more strongly than warm HI. In a paper this year (Allison *et al*. 2016), CAASTRO's James Allison (CSIRO) estimated the number of HI absorbers an ASKAP survey could be expected to find, for different values of spin temperature. A yield of 1000 absorbers would imply a mean spin temperature of ~100 K in the HI gas, suggesting that more than 50 per cent of the gas is cold, while detecting only 100 absorbers would imply a mean spin temperature of ~1000 K and a cold gas fraction of less than 10 per cent. This method would allow the spin temperature of HI to be measured at intermediate redshifts (below $z \sim 1.7$) where it otherwise can't be determined, helping to trace how the temperature of HI changes through cosmic time.

National Innovation Priority: Research

DEEPER, WIDER, FASTER

Jeff Cooke and his team
Credit: Carl Knox

CAASTRO astronomers are pioneering a new approach to detecting transient phenomena.

Two of the hottest topics in astronomy right now are fast radio bursts or FRBs (page 14), which last just milliseconds, and events that create bursts of gravitational waves. The former were announced in 2007, the latter in 2016. Each has a range of possible causes. Narrowing down that range will require both spatial localisation and observations, preferably simultaneous, at several wavelengths. Other 'fast transient' phenomena – gamma-ray bursts, or supernovae in their early stages – would also benefit from such simultaneous or near-simultaneous multiwavelength observations.

Multiwavelength follow-up has traditionally relied on the telescope that makes the first detection triggering other telescopes into action. Sometimes, however, there are frustrating delays before follow-up takes place. To eliminate such delays, Jeff Cooke and Igor Andreoni (both of Swinburne University) have adopted a proactive approach: simultaneous observations at several wavelengths, plus follow up. This is the *Deeper, Wider, Faster* program.

Having decided on this approach, Cooke and Andreoni cast around for instruments that met their needs. CSIRO's Parkes radio telescope and the University of Sydney's Molonglo telescope (UTMOST) had large fields of view, and were well matched in the optical by the Dark Energy Camera (DECam), a wide-field imager (about three square degrees) which had been installed on the CTIO 4-m Blanco telescope in Chile in 2012. The first observing run for *Deeper, Wider, Faster* took place in January 2015 and involved DECam, Parkes, UTMOST and, on standby, the Very Large Array radio telescope in the USA. Since then the program has secured use of NASA's *Swift* satellite (observing in the gamma-ray, X-ray and UV/optical regions of the spectrum), the Australia Telescope Compact Array (radio), the Rapid Eye Mount Telescope in Chile (infrared) and the AST3–2 telescope in Antarctica (infrared); it also has a Memorandum of Understanding in place with the LIGO, Virgo and GEO gravitational-wave observatories.

Deeper, Wider, Faster now has connections with 15 facilities in Australia, North and South America, Europe, South Africa, Antarctica and space. A network of large and small optical telescopes, 1–10 m in size, stands ready to follow up its detections: to date, the program has triggered the AAT, ANU 2.3-m, Gemini, SALT, SkyMapper and Zadko telescopes into action. The project team takes quick spectra of the most interesting and rapidly evolving sources about 15 minutes after their initial detection, and it studies some candidates with further spectroscopy and photometry, hours or days after their discovery. DECam's field of view is well-matched not only to Parkes' but also to that of the 2dF system on the Anglo-Australian Telescope. This allows spectra to be taken of hundreds of transients during and after *Deeper, Wider, Faster* observing runs.

Detections are made in near-real time. DECam's deep optical imaging (mag_g ~23 with a 20 s exposure) allows tens of transients to be discovered in each target field: the project's custom pipeline, *Mary*, can process, calibrate and analyse a DECam image and generate a list of firm transient candidates in about a minute. The Parkes and Molonglo observatories can identify fast radio bursts in a few seconds, while *Swift* can detect high-energy sources, such as gamma-ray burst, in seconds.

Deeper, Wider, Faster's observing runs continued throughout 2016, and thousands of transients and variable sources were captured. Work is continuing on identifying the most rare and interesting among them.

National Innovation Priority: Research

CAASTRO COMPUTING POWERS HUNT FOR BLACK-HOLE BINARY

Supercomputing resources accessed through CAASTRO have been essential for the world's most ambitious pulsar survey.

Pulsars – extraordinarily dense, spinning *neutron stars*, left over from stellar explosions – were discovered 50 years ago. Since then astronomers have found around 2,500. The rate of discovery has picked up in recent years, and they've discovered some doozies: very fast (*millisecond*) pulsars, very slow ones, part-time (intermittent) pulsars, and even overweight pulsars (those of almost two solar masses). Some of these remain very challenging to explain. The jewel in the crown was the double pulsar, two pulsars orbiting each other, discovered with the Parkes telescope in 2003. The system allowed researchers to make five stringent, independent tests of predictions from Einstein's general theory of relativity – tests the theory passed with flying colours (a measurement uncertainty of only 0.05 per cent; Kramer, M. *et al.*, "Tests of general relativity from timing the double pulsar" (Science, 314, 97–102 (2006)).

But there is more to find. Astronomers lust after one kind of binary in particular: a pulsar orbiting a black hole. The pulsar, an excellent clock, will allow us to test the properties of the black hole: specifically, the *cosmic censorship conjecture*, which says that every black hole should have an event horizon, and the *no-hair theorem*, which says that a black hole can be completely described by only its mass, spin and charge. The future Square Kilometre Array radio telescope is expected to turbocharge the rate of pulsar discovery and hence pulsar science. It will surely find a black hole–pulsar binary. The only question is, will another telescope beat it to the punch?

Enter the High Time Resolution Universe (HTRU) survey, the most ambitious and comprehensive pulsar survey to date. HTRU has a number of scientific goals, but a key one is to search for ultra-compact binary systems such as the double pulsar or a black hole–pulsar binary. Run by an international team of more than 20 astronomers from four countries, HTRU uses the 64-m Parkes telescope in the southern hemisphere and the 100-m Effelsberg telescope, near Bonn, Germany, in the north. The multibeam receivers and backends used on these telescopes provide unprecedentedly high resolution in time and frequency, allowing the researchers to probe deeper into the Galaxy than in any previous such search.

HTRU is three surveys rolled into one: a search along the Galactic plane, where black hole-pulsar binaries are most likely to be found; a search at mid latitudes; and an all-sky survey that encompasses high latitudes. Observations for the surveys have generated over 1000 TB of data. Not only is there a lot of data to search through, but the process of searching for binary pulsars is also complex: the orbital parameters of the binary system must be taken into account, resulting in a large 7-dimensional parameter space to comb through. To probe the full parameter space for binary pulsars, at least 1.46 million Fourier transform operations are computed for each 'beam' (the region of sky a telescope receiver 'sees'). All this adds up to a huge computational task.

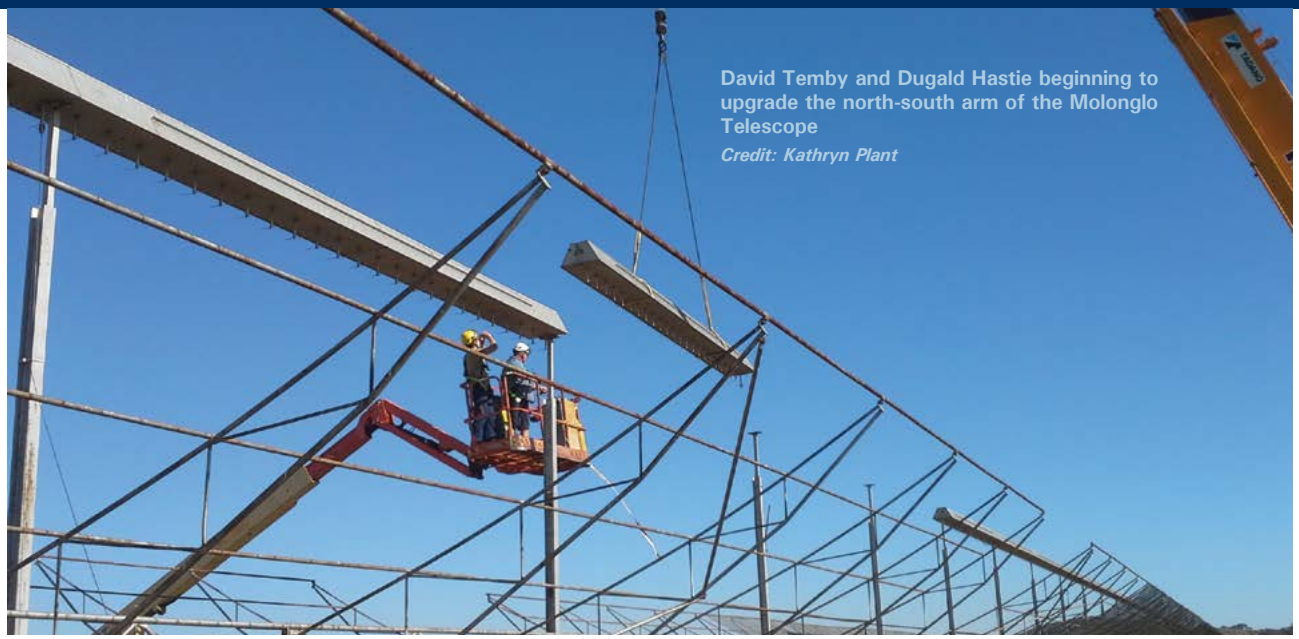
Fortunately, the project can make use of supercomputing time awarded to CAASTRO through the Flagship Allocation Scheme of the National Computational Infrastructure (NCI). CAASTRO receives a guaranteed allocation of 8 million CPU core-hours a year. Within CAASTRO, requests for this time are competitive. In 2016 many CAASTRO projects took advantage of this resource: they ranged from the modelling of feedback in galaxy evolution and simulations of core-collapse supernovae to searches for transient sources and tests of gravitational models.

The CAASTRO supercomputing time awarded to the HTRU survey has contributed directly to its progress: the depth of the parameter space to which the survey data can be explored is highly dependent on the available computing resources. In the first half of the year, processing of HTRU data on the NCI's facilities revealed a highly accelerated pulsar, which has since been confirmed as experiencing accelerations as high as 700 ms^{-2}. Although this object and its companion are still being investigated, their orbit is very tight and this appears to be the most relativistic pulsar system ever discovered – exactly the type of object that HTRU and its pipeline were designed to detect. To date, the HTRU Galactic plane survey has found about 100 pulsars. The first results from the survey were published in 2015, by Ng, C. *et al.*, "The High Time Resolution Universe Pulsar Survey – XII. Galactic plane acceleration search and the discovery of 60 pulsars" (MNRAS, 450, 2922–2947 (2015)). A second paper, detailing the next tranche of discoveries, is planned for mid-2017.

NCI Building
Credit: NCI

National Innovation Priority: Frontier Technologies

SHARPER EYES FOR FAST RADIO BURSTS



David Temby and Dugald Hastie beginning to upgrade the north-south arm of the Molonglo Telescope

Credit: Kathryn Plant

A CAASTRO-led team is using readily obtained hardware to upgrade the University of Sydney's Molonglo Telescope, making it able to localise the enigmatic fast radio bursts (FRBs).

Fast radio bursts, bursts of cosmic radio waves lasting just a few milliseconds, have intrigued astronomers since their discovery in 2007. The first few were found in archival data; the first real-time detection was published in 2014 by CAASTRO alumna Emily Petroff. January 2017 saw a burst associated with a steady radio source, confirming that FRBs originate in the distant Universe. This finding opens the way to using FRBs as tools: for instance, to study the thin gas lying between the galaxies, and to measure the parameters governing dark energy. But for such projects we might need to observe hundreds of FRBs, and so far we've found only two dozen. To understand FRBs themselves, we need to associate them with other phenomena. So we need to both find more and pinpoint their positions on the sky.

For the last few years a team led by CAASTRO's Dynamic Theme leader, Matthew Bailes (Swinburne University) has been converting the University of Sydney's Molonglo radio telescope near Canberra into a single-purpose machine for finding pulsars and fast radio bursts. The telescope is blessed with a large field of view (7.8 square degrees) and huge collecting area (18,000 square metres), and the search team has essentially total use of it. At full sensitivity the telescope, now dubbed UTMOST, may detect a fast radio burst every few days. (The exact rate will depend on the characteristics of the FRB population and the relative proportions of bright and faint bursts.)

The snag, though, is that until now UTMOST has been operated as an east-west array, able to localise FRBs in the north-south direction only poorly (to within two degrees). To overcome this, the Swinburne team is reviving a feature of the telescope unused for many years. The telescope was originally built as a cross, its east-west arm intersected by a similar north-south arm: the small patch of sky it observed was created by the intersection of 'fan beams' generated by the two arms. The north-south arm was decommissioned in 1978, but not removed. In a project called UTMOST-2D, the Swinburne team is bringing it back to life.

Two more changes will spruce up the telescope. One is the use of radio frequency over fibre on the north-south arm, bringing the analogue output of the telescope into the control building for digitisation rather than digitising it in the field and transporting the converted signal. This removes the need for distributing timing signals from the control room to the telescope and removes any self-created radio frequency interference from digitisers near the telescope. The second new feature is the use of SNAP (Smart Network ADC Processor) boards, which are now widely used on radio telescopes. A SNAP board for Molonglo contains the whole F-engine (digitisation and polyphase filterbank) on one board, and one board does three times the work of one of Molonglo's old, custom-built receiver boxes. (Again, the boards will be deployed only for the north-south arm.)

All these changes will improve the Molonglo telescope's resolving power in a north-south direction by a factor of up to 3600, from two degrees to two arcseconds for bright sources (around five arcseconds for fainter ones). This far outstrips the arcminute resolution of the single-dish radio telescopes that have found most FRBs to date. Equipment for the upgrade will be installed and commissioned in 2017. As UTMOST-2D, the telescope will be outstanding for detecting and localising FRBs, with an angular resolution far better than other high-yield facilities, and has a reasonable chance of making most of the next FRB localisations.

National Innovation Priority: Interdisciplinary and International Collaboration

DASH CUTS SUPERNOVA CLASSIFICATION TIMES

Daniel Muthukrishna receiving the GBST prize

Credit: University of Queensland School of Information Technology and Electrical Engineering

A new approach slashes the time it takes to classify spectra.

For his 2016 Honours thesis, CAASTRO student Daniel Muthukrishna (University of Queensland) has developed a way to classify supernovae over 100 times faster than at present, by building an award-winning machine-learning program that works in the same way as the human brain.

Daniel developed the software, DASH (Deep Automated Supernova and Host galaxy classification), for the CAASTRO-supported OzDES redshift survey (page 29). OzDES is obtaining the spectra of thousands of objects, panning for the 'gold' of Type Ia supernovae, a valuable tool for cosmologists. In searching for these useful spectra the OzDES team must sort through all the spectra it records, including those of many other types of supernovae. Classifying supernova spectra is time-consuming for astronomers, and prone to human bias and error. Daniel's goal was to automate the classification process, making it fast, accurate and nearly autonomous (requiring minimal input from people). It's a difficult problem because the light of the supernova is mixed with – that is, contaminated by – light from their host galaxies; the supernova's redshift and type, and the time since its maximum brightness, also affect its spectral features.

Daniel's original plan was to recreate in Python existing software tools such as *Superfit* (written in IDL) and *SNID* (written in Fortran), to make classification faster and more autonomous. However, these tools rely on repeatedly matching spectra against templates. This means that the time taken to classify a spectrum increases linearly with the number of templates. It also means that, instead of a classifying a program by using the intrinsic aggregate features of each supernova type, these tools compare a spectrum with only one template at a time. Daniel successfully recreated them in Python, but soon realised that this would not lead to significant improvements.

So he turned to *deep learning*, a machine-learning technique in which the program is trained to look for patterns in the supernova templates and use these to identify the new spectra, but without these patterns being specified beforehand. A deep-learning network, also known as a deep neural network, learns when it is iteratively presented with data, along with the correct answer to the pattern-recognition problem. If the training data are sufficiently varied, reflecting the real world, the network can then generalise well. At the time Daniel began this work, deep learning had not (as far as he knew) been applied to classifying supernovae spectra. He based his solution on methods for recognising faces and classifying images.

Using deep learning solved the problems encountered with template fitting. Daniel's algorithm, DASH, uses the entire set of all supernova spectra to make its classifications, rather than matching to one template at a time. Increasing the number of templates doesn't make classification slower; rather, it makes it better. Previous tools could take tens of minutes to classify a single spectrum: DASH can do hundreds within seconds.

DASH is currently being tested for OzDES, and has proven itself to be just as accurate as previous tools. Additional features, such as host-galaxy classification, will be added in the next few months. Although developed for OzDES, the code could be applied to spectra from any telescope (for example, follow-up spectra from LSST, which will soon record an unprecedented number of transients). DASH is available on both GitHub and PyPI.

For his work on DASH, Daniel received both the 2016 Student Thesis prize given by the Queensland chapter of the Institute of Electrical and Electronics Engineers (IEEE) and the GBST Prize for Best Software Project at the 2016 UQ Innovation Showcase.

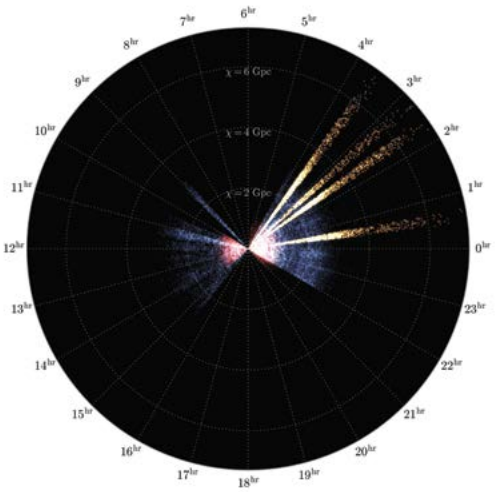
National Innovation Priority Case Study: International Collaboration

OZDES CRACKS 20,000 REDSHIFTS

OzDES, a major Australian survey for obtaining the redshifts of tens of thousands of objects, has now completed two-thirds of its observing.

OzDES's main target is the host galaxies of Type Ia supernovae (SNIa), the workhorse of cosmology. The program has an allocation of 100 nights, spread over six years, on the 4-m Anglo-Australian Telescope (AAT): by the end of 2016, the OzDES team had obtained more than 20,000 redshifts and spectroscopically confirmed more than 200 supernovae.

The supernova redshifts are Australia's contribution to a large international project, the Dark Energy Survey (DES), which aims to pin down what's driving the ever-faster expansion of the Universe. DES is tackling the problem through four kinds of observation: one is getting the redshifts of distant SN Ia, which are then compared with distances obtained from light curves (an object's changing brightness). The supernovae are first detected with the Dark Energy Camera, DECam, which is mounted on the 4-m Blanco telescope in Chile. The OzDES team – more than 20 people, from eight Australian institutions – then takes over, measuring redshifts with the 2dF fibre instrument and the AAOmega spectrograph, a combination that can obtain almost 400 spectra simultaneously. The 2dF system is ideal for this work because its field of view matches that of DECam. Given the number of supernovae, it's impossible to measure their spectra immediately, while they are still bright, so the redshifts of their host galaxies are measured instead.



A plot showing the much higher redshift reach of the OzDES survey (in gold) compared to 2dFLenS (in blue) and the 2dF Galaxy Redshift Survey (in red). Most of the OzDES sources below a distance of 3 Gpc are galaxies, whereas most of the sources above this distance are AGN.

Credit: Samuel Hinton

OzDES is also observing any transients that occur when it's taking data: the team has published 27 Astronomical Telegrams announcing the discovery of almost 200 supernovae. And the program is obtaining redshifts for thousands of objects other than supernovae, including radio galaxies from the ATLAS radio survey, galaxies in clusters and groups, luminous red galaxies and faint active galactic nuclei (AGN).

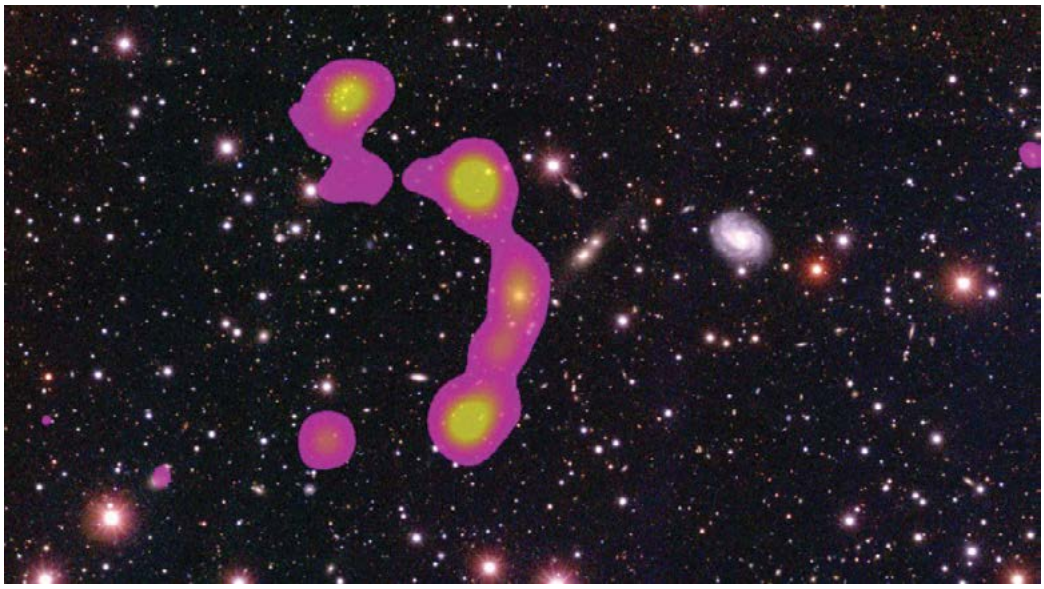
OzDES observes the ten DES SN fields at intervals of about a month (when they are visible from the AAT). This allows the team to make time series of spectra ('time-lapse spectra') of sources such as AGN and supernovae. It also means that OzDES can obtain redshifts for objects that are usually considered to be too faint for a 4-m class telescope such as the AAT (as faint as r-band magnitude of 24), by simply re-observing objects until the redshifts are obtained. OzDES reaches the same depth as the recently published VIPERS survey made with ESO's Very Large Telescope (VLT).

Obtaining SN1a spectra is OzDES's first major science goal: its second is to measure how supermassive black holes at the hearts of galaxies have grown over the past 12 billion years. The program team is monitoring Active Galactic Nuclei (AGN), galaxies that harbour active supermassive black holes, and will take 25 spectroscopic observations of each. These spectra will be combined with hundreds of photometric (brightness) measurements made by DES. In each AGN astronomers can observe light originating from both near the black hole and from a region further out (the broad-line region). If light from the central region changes in brightness, there will be a measurable delay (from days to a year or more) before the light from the *broad-line* region does too. The size of this time lag depends on the mass of the black hole. Before OzDES began, only about 50 AGN, mostly at low redshift, had had their black-hole masses measured this way; OzDES is targeting more than 700 AGN.

The OzDES team has spent four years observing, developing new algorithms, and writing and testing code. Within the next 12 months it will be ready to publish the survey's first major results, including constraints on the parameter *w* that governs the dark-energy equation of state, derived from a sample of 251 SNe Ia from the Dark Energy Survey (some with non-AAT spectra). This will be a foretaste of what's to come from the full DES sample, which will be ten times larger.

National Innovation Priority: Frontier Technologies

CITIZEN SCIENTISTS DELIVER FOR RADIO SURVEYS



A wide angle tail galaxy (in pink) found by Radio Galaxy Zoo participants.

Credit: Julie Banfield (ANU/CAASTRO)

Radio Galaxy Zoo is a citizen-science project in which ordinary people with minimal training match radio and optical images, to associate radio emission with its host galaxy. The project launched in 2013 and to date it has involved more than 10,000 participants: between them they have made more than 1.8 million visual identifications of over 110,000 sources. Radio Galaxy Zoo is led by two members of CAASTRO, Julie Banfield (Australian National University) and Ivy Wong (University of Western Australia).

The project was prompted by the impending flood of data from future radio surveys. The EMU (Evolutionary Map of the Universe) survey, which will run on CSIRO's ASKAP telescope in Western Australia, is expected to find 70 million extragalactic radio sources, dwarfing the 2.5 million known to date. To derive useful science from these sources – in particular, to obtain their redshifts – they need to be identified with optical sources (that is, host galaxies). Automated methods for doing this cross-matching already exist but they will probably not be able to deal with the complex radio sources that EMU will reveal. These could amount to ten per cent of the whole sample – that is, seven million objects. The only viable way to handle these sources is with *machine-learning* software. This needs to be trained on what to look for: it requires a training set of cross-matched galaxies. Radio Galaxy Zoo will provide that set. But the project is doing more than that, producing scientific results in its own right.

Radio Galaxy Zoo builds on the success of Galaxy Zoo, a project for classifying galaxies: both are housed on the Zooniverse website, a compendium of citizen-science projects. Users are presented with a screen showing radio data overlaid on an infrared background: they select all radio emission they consider to be originating from a single radio galaxy, then identify the probable host galaxy in the infrared image. The radio images are from NRAO's Very Large Array and CSIRO's Australia Telescope Compact Array, while the infrared images are from NASA's *Wide-field Infrared Space Explorer and Spitzer Space Telescope*.

Users can discuss the data online with other citizen scientists and with professional astronomers; some become super-users, and some join teams that focus on identifying particular kinds of objects. Significantly, for images in which the host galaxy is identified with more than 75 per cent consensus, the citizen scientists are as good as professional astronomers.

When Radio Galaxy Zoo is complete, participants will have eyeballed more than 170,000 radio sources. The main fruit of their labours will be a catalogue showing the relative frequency of radio source types by power and morphology. The project has also been extremely successful in finding rare objects: for example, it has revealed 201 new Giant Radio Galaxies (previously, only 231 were identified in the literature). It has also doubled the known number of HyMORS (hybrid-morphology radio sources), which are sources that show characteristics of both FRI and FRII radio galaxies: this work was led by CAASTRO postdoc Anna Kapínska (University of Western Australia), who is also the project manager for the ASKAP EMU survey.

Progress has also been made on using Radio Galaxy Zoo for machine learning. Radio Galaxy Zoo identifications for the EMU pilot field ATLAS-CDFS have been used to train a machine-learning algorithm, and the trained system tested on a second EMU pilot field, ATLAS-ELAIS S1. The system is already identifying sources as well as experts can, but its creator (Matthew Alger, Australian National University) aims to make it even better. This work will be published in 2017.

National Innovation Priority: International Collaboration

INTENSITY MAPPING

Installing one of CSIRO's second-generation phased array feeds on an antenna of the Australian SKA Pathfinder at the Murchison Radio-astronomy Observatory.

Credit: CSIRO

This year CAASTRO's Lister Staveley-Smith (University of Western Australia) led pilot observations that show how to speed up an already-rapid observing technique for cosmology, *HI intensity mapping*.

HI, hydrogen gas in the form of separate atoms, is ubiquitous in the Universe. It is a key component of galaxies, and one of the forms of the gas that hydrogen passes through on its way to forming stars. However, as discussed on page 24, its history in the Universe is somewhat sketchy, particularly for much of the past 10 billion years. This is because HI's characteristic emission line, which appears in radio spectrum at a rest frequency of 1.4 GHz, is weak. It can't be detected in individual galaxies out to any great distance.

Detecting and measuring the HI signal from individual galaxies is also a time-consuming business. But we can speed matters up by capturing the aggregate HI emission signal over relatively large patches of sky (tens of megaparsecs), in thin 'slices' of redshift (distance). To get this fine redshift resolution, the telescope must have excellent resolution in observing frequency: fortunately, modern telescope backends can now supply this. The technique, HI intensity mapping, is both faster than observing galaxy by galaxy and can 'see' to higher redshifts. CAASTRO's Jonghwan Rhee (University of Western Australia) is leading an ongoing survey of HI on CSIRO's Parkes radio telescope, with the aim of measuring the density of HI out to a redshift of 0.9.

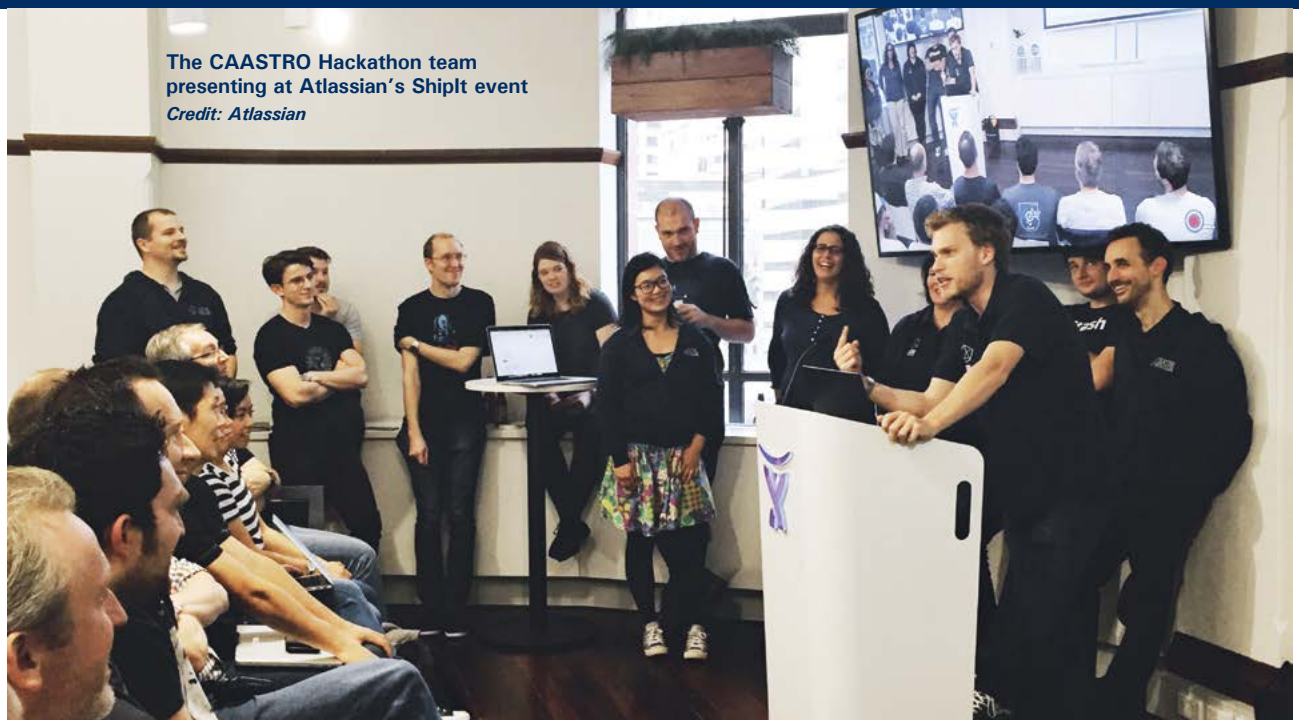
For his project Rhee has been using the telescope's regular 50-cm receiver. This year CAASTRO's Lister Staveley-Smith led pilot HI intensity-mapping observations using a different instrument on Parkes: a CSIRO built phased-array feed (PAF) receiver, which was on the telescope for testing before being shipped to Germany's Max Planck Institute for Radioastronomy. The PAF is at least four times faster than the 50-cm receiver. It also operates at lower frequencies than the other Parkes instrument that could be used, the multibeam receiver, meaning that it can see HI at higher redshifts.

The PAF was able to take useful data in both the 0.7–1.2 GHz and the 1.2–1.5 GHz bands. Applying a projection-based RFI mitigation technique, first developed for CSIRO's ASKAP telescope, the observers were able to significantly suppress strong broadband RFI in the lower band. The observations were designed to test the PAF's spectral-line observing mode: taking HI spectra of nearby galaxies previously observed for the earlier HIPASS survey showed that the PAF's spectrometer worked well, producing very flat HI spectra with significantly improved bandpass. The observers were also able to finish two of the target fields for the project being conducted with the 50-cm receiver, and obtain data for stacking or intensity mapping in regions covered by the GAMA survey. All in all, the PAF appears to be a very promising instrument for future HI intensity mapping.

If Parkes can successfully map the cosmic HI density to a redshift of ~ 1 then the researchers may tackle an even more demanding project: a *baryon acoustic oscillation* (BAO) survey. As explained on page 12, BAO surveys are carried out to measure the preferred spacing between galaxies, a spacing that was established in the very early Universe and which carries through to this day: it can be used as a standard ruler for measuring the size of the Universe at different epochs. HI intensity mapping combined with optical BAO surveys can strongly constrain the parameter w that governs dark energy; it can also measure the rate of growth of structure, which differentiates between different theories of gravity.

National Innovation Priority: Collaboration with Business

CAASTRO SHINES IN ATLASSIAN INDUSTRY SOFTWARE COMPETITION



The CAASTRO Hackathon team presenting at Atlassian's ShipIt event
Credit: Atlassian

A CAASTRO 'guest' team wowed professional software engineers in a 24-hour industry software marathon held in Sydney on 8–9 September, finishing fifth in a field of more than 200 teams.

The CAASTRO members were the first external group ever to make the finals of the Atlassian *ShipIt* Hackathon, a 24-hour development blitz the company runs four times a year. Atlassian, founded in Australia in 2002, develops enterprise software such as *Jira* and *Confluence*. The *ShipIt* events give its staff free rein to work on any projects they choose, usually but not exclusively software. The CAASTRO team was led by Samuel Hinton, a CAASTRO PhD student at the University of Queensland: his background in software engineering built a bridge between the team's astronomers – Anais Möller (Australia National University), Bonnie Zhang (Australia National University), Steven Murray (Curtin University) and Richard Scalzo (University of Sydney) – and the three Atlassian staff assigned to help them. CAASTRO Chief Operating Officer Kate Gunn also took part: she organised CAASTRO's participation in the event, after making initial contact with Atlassian.

The team decided to tackle a problem familiar to every astronomer: how to find the most relevant scientific papers on a given topic. Called *Get Lit* (Get Literature), its solution combined three approaches to identifying the most important and relevant papers for a specified astronomy subject in online repositories. The first was to use natural language processing to break down the title and abstract into base forms ('astronomy' and 'astronomical' are almost the same thing, for example), and to run basic comparison matches between the search query and title/abstract of all papers. The second was to take the base forms of the title/abstract and cluster those through unsupervised machine-learning algorithms, to show how similar papers are to each other. The final approach was a graphical network that worked similarly to the unsupervised machine learning, using citation trees to group papers in similar fields and those that are relevant to each other.

Get Lit used the three approaches together to determine how relevant a paper is to the search term and how important it is in the field, then combines these metrics, ranks them, and reports the top ten results. Work remains to get the backend operating perfectly but the basics were there within 24 hours and the CAASTRO team was able to demonstrate the system live.

To achieve so much was impressive enough, but the team also fought off the competition, coming first in its heat, third in what was probably the toughest of the five semi-finals, and then fifth of the 12 teams that made it through the finals. More than 800 people crowded the room, with more following the live-streamed event. Over 1,000 voted in the final round and the yelling and cheering rivalled that of a football grand final. The two teams who pipped CAASTRO in the semi-final were the main award winner and the team that won the non-technical product award: not bad company to be in!

CAASTRO's goal in taking part was to demonstrate, to both astronomers and potential employers, that astrophysicists' skills are transferrable to industry. That the team certainly did. As one participant said,

> *It was very intimidating to be competing against professional software developers at this level, but wonderful at the same time.*

CAASTRO thanks Atlassian for its excellent support for the team, and for the opportunity to take part in this exciting event.

National Innovation Priority: Nwational Collaboration

CAASTRO IN THE CLASSROOM

Jenny Lynch
Credit: CAASTRO

CAASTRO in the Classroom connects CAASTRO researchers with schools via free video conferencing sessions: it has been run from the University of Sydney since 2012. In 2016 the CAASTRO School Education Officer, Jenny Lynch (University of Sydney), expanded the program to reach a national audience of over 4,000 school students and teachers – an unprecedented number. Researchers this year delivered 11 curriculum-based presentations for students in Years 5 to 12. Recordings of the presentations were added to the CAASTRO YouTube channel, where they will be a flexible and continuing resource for schools.

Demand for the video conferencing program has been strong in New South Wales and is growing in Victoria – two States where access to school video conferencing systems is quite common. However, it is much less common in other States and territories, and so this year we trialled a new delivery format: live-streaming sessions, reaching schools via YouTube Live. To take part in these sessions, schools need only an Internet connection and access to a YouTube link. The sessions have proved to be extremely popular; they have reached schools all over Australia, including some in extremely remote locations. Presenters interact with the audience through Twitter, with schools tweeting questions throughout the session and the presenter answering at the end. Two live-streaming sessions were run in 2016: *Why Study Physics?* by Dr Vanessa Moss and *Awesome Astronomy* by Professor Scott Croom (both presenters from the University of Sydney). Recordings are available on the CAASTRO YouTube channel.

This year we also trialled question and answer sessions, delivered via Skype to one school at a time. Teachers, students and researchers all enjoyed them, and this format has been added to the *CAASTRO in the Classroom* offering for 2017.

A grant from the Australian Maths and Science Partnership Program allowed us to employ three experienced school teachers, Neill Dorrington, Silvia Choi and Sandra Woodward, to develop classroom resources to support the teaching of astronomy topics in Years 5, 7, 10, 11 and 12. The resources are linked to the Australian Curriculum and are freely available for download from the CAASTRO website. Each set of classroom resources includes a glossary of terms, curated online content (including YouTube videos and online simulations), and hands-on activities. Dr Fang Yuan (Australian National University) helped us to develop an investigation, using real data from the SkyMapper telescope, in which students use free online tools to manipulate images and search for supernovae.

We commissioned two new animations on curriculum-relevant topics for Year 11 and 12 Physics: *Redshift* and *Muon Decay*. These are available to schools via the CAASTRO YouTube channel, along with a list of existing CAASTRO animations linked to Australian Curriculum content.

To inform teachers about these new resources, and about CAASTRO in the Classroom in general, we ran workshops and presentations for teachers at science teachers' conferences, teacher networking events and online. Recordings of the webinars and a face-to-face workshop were made available online for those who could not attend the live events.

In December CAASTRO won a *Women in STEM and Entrepreneurship* grant from the Australian Government. This will fund sessions within *CAASTRO in the Classroom* that are aimed at encouraging girls and women to pursue careers in science, technology, engineering, mathematics and entrepreneurship, and also the *CAASTRO Galaxy Convention*, a multi-day workshop for female school students, teachers, university students, PhD candidates and university researchers.

Silvia Choi, Neill Dorrington and Jenny Lynch
Credit: Kate Gunn

ACTIVITY PLAN 2017

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

CAASTRO RESEARCH PROGRAM

Evolving Theme

Next year promises to be another very exciting year for science in the Evolving Theme as we build on work done in 2016. In fact we expect that, in this last full year of CAASTRO, some of our longer-term projects will be producing their best results! Our priorities for the year are as follows.

The MWA (Murchison Widefield Array) is one of the world's most sensitive instruments for detecting hydrogen gas's transition from a neutral to ionised state at the Epoch of Reionisation (EoR). As our understanding of the instrument has improved over the last few years, our measurements have become more sensitive, but key challenges remain. We processed 86 hours of EoR data during 2016 and we aim to increase this amount, using the new hexagonal configurations of MWA Phase II. Our goals for 2017 are to process the first two seasons of MWA EoR data to obtain the best possible sensitivity, and to incorporate the new hexagonal arrays into the calibration of EoR data. We will also study the impact of ionospheric activity on EoR observations, and improve our foreground models through direct observation and statistical clustering studies. The BIGHORNS instrument will continue to inform our understanding of the ionosphere and calibration techniques.

The SAMI Galaxy Survey will greatly improve our understanding of the links between galaxy mass, star formation, gas and stellar kinematics, and environment. SAMI has observed over 2,000 galaxies and is expected to reach 3,000 by mid-2018. The survey has already produced more than 20 refereed papers. Specific areas in which SAMI has already provided notable contributions include: the identification of ionised gas outflows in star-forming galaxies, the role of angular momentum in shaping the Hubble sequence and the effect of environment on the star formation activity of galaxies. The first SAMI public data release is scheduled within the next few months and it will include nearly 800 galaxies from the GAMA region. This will not only include raw data products but also value-added emission line data products – vital for star formation and AGN science and a first for integral field surveys.

The team running the CAASTRO HI absorption survey, FLASH, has been successful in taking data with the six-antenna BETA array in commissioning mode and progressing it to publication. The BETA array was a test bed for the full Australian SKA Pathfinder (ASKAP) telescope. Another HI project, the all-sky WALLABY survey, has also successfully published data from BETA. The WALLABY team has now embarked on observations with ASKAP-12, the 12-antenna Early Science array: it has been allocated 700 hours of observing time with this instrument. The third HI project on ASKAP, DINGO, will also take data during 2017. CAASTRO's three priorities for the HI projects are: to complete the analysis of HI absorbers detected with ASKAP BETA, including associated multiwavelength follow-up; to analyse data from the ASKAP-12 Early Science array and investigate the dependence of galaxy properties on environment; and to publish details of the final underlying component of the HI kinematic pipeline, namely an automated tilted-ring fitting algorithm, 2DBAT.

This year the Parkes radio telescope was used to gather data in several WiggleZ fields, as part of on ongoing project to more accurately measure the neutral hydrogen content of the Universe at a redshift of one (page 31). In 2017 we will cross-correlate the Parkes HI maps and the WiggleZ galaxies, as has already been done with data from the Green Bank Telescope.

Dynamic Theme

Next year should produce many new scientific results, as we build on the foundations developed in 2015 and 2016, in particular with several major surveys on radio telescopes and SkyMapper.

In 2017 the Dynamic theme scientists will continue to work with the newly upgraded Murchison Widefield Array (MWA) telescope to explore the low-frequency radio sky. This year they carried out studies to detect pulsars in the image plane, and searched for polarised radio emission from exoplanets and cool stars: with the upgraded telescope they will be able to image with even higher resolution and sensitivity. They will explore new algorithms for detecting variable sources through difference imaging and other rapid imaging techniques, and explore a new area of research, the use of interplanetary scintillation to detect extremely compact sources. Dynamic theme researchers will

CAASTRO's strong administration team will continue to support our Activity Plan in 2017. This photo of Kate Gunn, Kim Dorrell and Kylie Williams was taken at a conference we ran in Hobart in 2016.
Credit: Dilyar Barat

continue to use the MWA for studying pulsars, including the astrophysics of single objects and a census of low-frequency southern pulsars, which is currently underway.

In 2016 the team conducted the first follow-up observations for gravitational-wave events from Advanced LIGO (the Laser Interferometer Gravitational-Wave Observatory). In 2017 this work will continue with both the MWA and the Australian SKA Pathfinder (ASKAP) telescopes. Gravitational-wave detectors have large error boxes (that is, they cannot well determine the location of sources on the sky) and so radio telescopes can help because their wide fields of view means they can rapidly survey large areas of sky. The upgraded Molonglo telescope, UTMOST, and the 1.35-m optical robotic telescope, SkyMapper, will also participate in the LIGO follow-up program.

Detecting and localising fast radio bursts (FRBs) will remain a focus for the Dynamic theme. In 2016 the UTMOST project discovered three FRBs from the distant Universe – 75 per cent of all new FRBs discovered this year. The fourth object was discovered with Parkes: it had an extreme dispersion measure, 50 per cent higher than the greatest previously recorded. We will build on these discoveries in 2017. We have the prospect of detecting FRBs with ASKAP, which would let us investigate the baryonic content of the intergalactic medium, and the development of automatic classification pipelines will allow researchers to dig deep into telescope archives to find FRBs that have so far been overlooked.

This year saw the first large-volume data release from SkyMapper's Short Survey and a release of the first data from its Main Survey. Spectroscopic follow-up is underway to verify candidates for the brightest quasars in the southern sky and the brightest metal-poor stars. All discovered transients are being made public, and software is in place to trigger spectroscopic Target of Opportunity observations and reduce the associated data. In 2017 the SkyMapper team will use this software infrastructure to follow up supernovae and unusual transient sources. Several high impact results are currently in preparation. The SkyMapper team will also be leading a citizen-science search as part of BBC/ABC Stargazing Live, which will take place live from Siding Spring Observatory in the first half of the year.

Dark Theme

Dark theme activities in 2017 will span four areas: supernovae, peculiar velocities, large-scale structure and theory.

In early 2017 we will complete the first cosmology analysis of supernovae with the Dark Energy Survey, and its Australian arm, OzDES. We have spectra of over 250 Type Ia supernovae from just the first three years of data. We also have over 1,500 Type Ia supernovae with host-galaxy redshifts: these photometrically classified supernovae, for which we did not obtain a spectrum of the supernova itself but one of the host galaxy after the supernova has faded, are the really novel aspect of DES/OzDES. We expect to get the strongest supernova cosmology constraints yet, perhaps before the end of 2017. Meanwhile, SkyMapper will continue to discover supernovae apace. If the past year is any indication, we are also likely to observe several more exciting new or unusual types of transient events.

In peculiar-velocity studies, 2017 will see the final results of the 2MTF survey published: Cullan Howlett (University of Western Australia) has led the analysis. The team at University of Western Australia is looking at doing some major new cosmological simulations, in modified gravity models: these will be large enough to compare with our peculiar-velocity data, which would put new exciting constraints on these models. We are eagerly awaiting a whole new type and scale of data from the TAIPAN instrument, which will be commissioned during 2017. Some of the promising new science to come out of that will be a measurement of the Hubble parameter using low-redshift baryon acoustic oscillations.

The team at Swinburne University is leading the charge on measuring interesting aspects of large-scale structure. Caitlin Adams is performing a joint analysis of density and velocity fields, while Ixandra Achitouv is looking at cosmological analyses as a function of local environment.

We expect to see a lot of action on the theory side of the Dark theme during 2017. In addition to the modified-gravity simulations mentioned above, we are contributing in a variety of ways to theoretical developments that could have a wide impact in cosmology. For example, Samuel Hinton (University of Queensland) is developing Bayesian hierarchical models for supernova cosmology; we will be

implementing Daniel Muthukrishna's (University of Queensland) machine-learning algorithms for automatic supernova classification in OzDES (page 28); and we will be examining the effect of inhomogeneities in the Universe on our cosmological inferences.

Katherine Mack (University of Melbourne) will host a workshop, *Connecting Astrophysical Dark Matter with Direct Detection*, in Melbourne at the end of January, and we will host the *Dark Energy Survey Collaboration* meeting at the University of Queensland in November.

Education and Outreach

The first months in 2017, in particular, will be focused on distributing and publicising our two new major Education and Outreach legacy products, the *Bright Stars* wall calendar and a comic book, "The Cosmic Adventures of Alice and Bob". Every high school in Australia will receive a free copy of the calendar, and free copies will also be made available to participants in physics education programs such as teachers at the CAASTRO–ASELL workshop, our outreach partner 'Telescopes in Schools', science teachers' conferences, school groups visiting observatories, and planetaria.

The comic book will be launched at Perth Astrofest on 18 March 2017 in a keynote stage show, which will be followed by a chance to meet the creators. Primary and combined schools will receive a free copy of the book, and schools are also invited to order a free class set. The teaching notes associated with the story are freely available online. At CAASTRO public events and the open days of amateur astronomy societies, these resources will be given out for gold coin donations that will fund local outreach initiatives.

CAASTRO in the Classroom will be expanded in 2017 to include not only the traditional video-conferenced seminars but also YouTube live-streaming sessions and individual question-and-answer calls between individual schools and CAASTRO researchers. The schedule for Term 1 is set, with dates and topics later in the year still being finalised. This year the program will also incorporate sessions funded by CAASTRO's new WISE (Women in STEM and Entrepreneurship) grant.

CAASTRO will have a strong presence at Perth Astrofest in 2017 through the book launch and a screening of the planetarium show. We will also take part in the Sydney Astrofest and Melbourne's "Astronomy and Light Festival", with CAASTRO members presenting talks, staffing information tables, offering family-friendly hands-on activities and assisting with stargazing.

In 2017 CAASTRO will again partner with Voyages Indigenous Tourism Australia for two outreach programs, the Uluru Astronomer in Residence (from March 2017) and the Uluru Astronomy Weekend (20–22 October).

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 sixth edition of the CAASTRO Readers' Digest booklet was published in late 2016, with another edition expected in the middle of 2017.

CAASTRO Education and Outreach will wrap up at the final Annual Retreat in November, with a wealth of projects, resources and best practices available to schools, the public and the Australian and international astronomy and science-communication communities.

Commercialisation and Knowledge Transfer

CAASTRO's primary focus on pure research requires us to take an innovative approach to commercialisation and knowledge transfer, and we will continue to develop this in 2017. We expect to be involved in the NASA Space Apps Hackathon in April 2017, and participate in other interesting industry engagements later in the year.

CAASTRO has completed its e-book to educate and assist researchers to identify and protect intellectual property, engage with industry and understand knowledge transfer. A road show will be organised to support the book's messages. 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 2017 CAASTRO will continue to provide leadership in this area.

Last year we officially launched CAASTRO Connections, our alumni network. All CAASTRO alumni have been invited to join this new group and from 2017 we will have a variety of events each year for past and current CAASTRO members. We encourage alumni to participate actively in the CAASTRO community; to attend events, volunteer, create new ways for alumni to stay connected to CAASTRO, and to contribute to the centre. The purpose of CAASTRO Connections is to foster a spirit of loyalty, support CAASTRO's goals, and strengthen the ties between alumni, the community, and CAASTRO.

2016 PUBLICATIONS

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STUDENT LIFE

Jessica Bloom

University of Sydney

I am a PhD student at the University of Sydney, working with Scott Croom, Julia Bryant and Joss Bland-Hawthorn in the SAMI Galaxy Survey team.

I completed my undergraduate Honours degree at the University of Sydney in the quantum physics research group, studying quantum entanglement and developing a new mathematical proof of the Bell inequalities. I always had a passion for astronomy and wanted to pursue something more practical, so I joined the SAMI research team.

I study galaxy evolution, specifically kinematically disturbed galaxies (including those that are merging and turbulent), trying to understand how disturbance arises. I have worked extensively on kinematic modelling and have discovered that galaxy size is one of the most important factors in determining whether a galaxy is disturbed.

Working in CAASTRO has given me access to an Australia-wide network of scientists who are producing exciting work in a wide variety of areas. The organisation is full of examples of Australian innovation, such as the SAMI instrument itself. I have also benefitted from the travel resources available through CAASTRO, attending conferences and meetings that have helped enormously with my research.

As a member of the CAASTRO Gender Action Committee, I am also fortunate to witness the efforts being undergone to improve diversity within CAASTRO. There is much to be done, but the action and genuine commitment of CAASTRO members of all levels, from students to the most senior, has been inspiring and has already effected change that I hope will continue and spread outside our field.

Igor Andreoni

Swinburne University

I am a PhD candidate at Swinburne University supervised by Jeff Cooke and Matthew Bailes at Swinburne and by Stuart Ryder at the Australian Astronomical Observatory (AAO). I am affiliated with CAASTRO and the AAO as a PhD Scholarship Scheme awardee. I search for fast transient events across the whole electromagnetic spectrum, leading coordinated observations with radio, optical, and high-energy telescopes.

I completed my Bachelor and Masters degrees in Physics at the University of Milan. Fascinated by the transient sky and gravitational waves, I held my first research post in Washington DC, looking for nearby gamma-ray bursts. Back in Italy, I worked at the Astronomical Observatory of Brera to discover X-ray and UV transients in nearby galaxies using the *Swift* satellite.

I started my PhD at Swinburne in March 2015, choosing to work on a novel, multiwavelength program searching for fast transients, counterparts to fast radio bursts and gravitational waves. The *Deeper, Wider, Faster* program has grown exponentially in the last couple of years, supported by CAASTRO and the Australian astronomical community. Now we coordinate about 15 facilities, including world-class telescopes, and perform simultaneous, high-cadence observations in the radio, optical, UV, X-ray, gamma-ray regimes, with real-time analysis and rapid follow-up.

CAASTRO has contributed to my scientific growth in many ways, first by creating a positive and vibrant research context. It has supported my travels overseas, crucial for sealing collaborative deals and improving my knowledge and skills, especially during my three-month residency at Caltech. CAASTRO's Astronomer in Residence program at Uluru was another great opportunity to do public outreach and to look at the sky in a new way.

Dilyar Barat

Australian National University

I am a first year PhD student at the Australian National University, supervised by Matthew Colless, Francesco D'Eugenio, Elisabete da Cunha (all at the ANU) and Andrew Hopkins (Australian Astronomical Observatory). I study galaxy dynamical scaling relations with integral field spectroscopic surveys and investigate the distribution of matter in the local Universe.

My interest in astronomy research began during my undergraduate summer research projects at the University of Sydney. Upon completing my Bachelor degree in science with a physics major, I transferred to the Research School of Astronomy and Astrophysics (RSAA) at the ANU for my Honours year, to specialise in astronomy. During my Honours, I worked with Matthew Colless as part of the Sydney AAO Multi-object Integral field unit (SAMI) survey team. That is also when I became a student member of CAASTRO. After graduating, new surveys and opportunities opened at the RSAA, so I decided to remain at the ANU for my PhD studies.

For my PhD, I am studying the Tully-Fisher, Faber-Jackson and the Fundamental Plane kinematic scaling relations of nearby galaxies, using SAMI and other integral field unit surveys. With these scaling relations, I am hoping to construct a unified scaling relation that can include galaxies of all morphologies, and to optimise it to use as a distance estimator. I am also part of the Taipan survey team where my role is to use the peculiar velocities (the individual motions) of nearby galaxies to map the matter distribution in the local Universe.

CAASTRO has provided me with a platform to showcase my science to other researchers leading their fields. I have been able to communicate and exchange ideas with incredible people, both inside and outside CAASTRO. CAASTRO funding for travel and personal development has given me the chance to go to observing runs, outreach activities and workshops to further develop my academic career and receive professional training. With its cultural diversity and inclusiveness, CAASTRO has also been a source of personal enrichment, especially through the friends I have made and the places I have been.

Shivani Bhandari

Swinburne University

The Universe never fails to excite me, and after completing my Bachelors of Technology (BTech) in electronics and communication in India, I decided to make a U-turn from engineering to astronomy. I started my career in radio astronomy as a visiting student at Raman Research Institute (RRI) in Bangalore, India). I spent a year and a half learning concepts of radio synthesis imaging and working on data from the Giant Meterwave Radio Telescope and Murchison Widefield Array data at RRI and the International Centre for Radio Astronomy Research in Perth, Western Australia. I was then offered a PhD position at Swinburne University's Centre for Astrophysics and Supercomputing under the supervision of Professor Matthew Bailes, Dr Evan Keane, Dr Chris Flynn and Dr Willem van Straten.

My PhD revolves around exploring the transient/dynamic Universe, focusing particularly on one of the biggest discoveries of the decade in radio astronomy: fast radio bursts (FRBs). I am a student member of an ongoing survey called SUPERB (SUrvey for Pulsars and Extragalactic Radio Bursts) and a legacy survey called HTRU (HIgh Time Resolution Universe Survey). Both surveys use the big dish, CSIRO's 64-m Parkes radio telescope: SUPERB is more focused on finding FRBs in real time, allowing multiwavelength follow-ups aimed at localising them, which should help us understand their origins. I am leading those follow-up efforts, which involves working on data from three radio telescopes (ATCA, GMRT, VLA) and coordinating with collaborators around the planet who observe at other wavelengths. I am also part of the team commissioning the 'reborn' Molonglo Telescope, UTMOST (page 27), and leading synthesis-mapping efforts with that telescope.

It has been a great experience being a CAASTRO student and getting involved in public outreach activities, especially as an Astronomer in Residence at Uluru. CAASTRO has also provided travel support for conferences and workshops that have helped me to publicise my research and collaborate with other researchers around the world.

CAASTRO STUDENTS

2016 CAASTRO NEW STUDENTS

University of Sydney

Dougal Dobie, *Dynamic, Honours*
SUPERVISORS Tara Murphy (USYD), Keith Bannister (CSIRO)
THESIS TITLE Variability in the Australia Telescope Extreme Scattering Events Survey

Jing Li, *Evolving, Honours*
SUPERVISOR Julia Bryant (USYD)
THESIS TITLE Investigating SFRs and the impact of AGN on galaxies within clusters using SAMI

Charlotte Ward, *Dynamic, Honours*
SUPERVISORS Tara Murphy (USYD), Matthew Kerr (CSIRO)
THESIS TITLE Exploring machine learning techniques for classification of signals in pulsar search data

Andrew Zic, *Dynamic, Honours*
SUPERVISORS Tara Murphy (USYD), Emil Lenc (USYD)
THESIS TITLE Variance imaging of pulsars at low frequencies

Australian National University

Matthew Alger, *Evolving/Dark/Dynamic, Pre PhD*
SUPERVISORS Chris Wolf (ANU), Cheng-Soon Ong (ANU/NICTA)
THESIS TITLE A public Python module for active learning

Dilyar Barat, *Evolving, PhD*
SUPERVISORS Matthew Colless (ANU), Franscesco D'Eugenio (ANU), Elisabete da Cunha (ANU), Andrew Hopkins (AAO)
THESIS TITLE Measuring cosmological parameters in the local universe through galaxy scaling relations

Tania Barone, *Evolving, Honours*
SUPERVISOR Matthew Colless (ANU)
THESIS TITLE Determining the angular momentum profile of early type galaxies from the SAMI Galaxy survey

Jacob Golding, *Evolving, Pre PhD*
SUPERVISOR Christian Wolf (ANU)
THESIS TITLE What can SkyMapper do to map recent star formation changes in nearby galaxies?

Mason Ng, *Evolving/Dark/Dynamic, Pre PhD*
SUPERVISORS Chris Wolf (ANU), Chris Onken (ANU)
THESIS TITLE Improving SkyMapper imaging with machine language

Natalia Eiré Sommer, *Dark, PhD University of Oslo/ Australian National University*
SUPERVISORS Brad Tucker (ANU), Rob Sharp (ANU)
THESIS TITLE Probing the Transition From Cosmic Deceleration to Acceleration With Reverberation Mapping

Georgina Taylor, *Dark/Dynamic, Pre PhD*
SUPERVISORS Brad Tucker (ANU), Anais Möller (ANU)
THESIS TITLE Simulation of bypasses for transient search

ICRAR/Curtin

Ronniy Joseph, *Evolving, PhD*
SUPERVISORS Cath Trott (CUR), Randall Wayth (CUR), Carole Jackson (CUR)
THESIS TITLE Probing the Epoch of Reionisation with non-traditional hybrid radio interferometers

Samuel McSweeney, *Dynamic, PhD*
SUPERVISORS Ramesh Bhat (CUR), Steven Tremblay (CUR)
THESIS TITLE 3D tomography of pulsar magnetospheres

Bradley Meyers, *Dynamic, PhD*
SUPERVISORS Steven Tremblay (CUR), Ramesh Bhat (CUR)
THESIS TITLE A high time, low frequency study of intermittent emission phenomena in radio bursts

Mengyao Xue, *Dynamic, PhD*
SUPERVISORS Ramesh Bhat (CUR), Steven Tremblay (CUR), Stephen Ord (CSIRO)
THESIS TITLE New Polarimetric Pulsar Observations with the Murchison Widefield Array

Xiang Zhang, *Dynamic, PhD*
SUPERVISORS Randall Wayth (CUR), Paul Hancock (CUR), Steven Tingay (INAF), Carole Jackson (CUR)
THESIS TITLE Detection of radio emission from fireballs with the MWA

ICRAR/UWA

Rodrigo Canas Vazquez, *Evolving, PhD*
SUPERVISORS Claudia Lagos (UWA),Chris Power (UWA)
THESIS TITLE Active Galactic Nuclei throughout cosmic time

Garima Chauhan, *Evolving, Pre PhD*
SUPERVISORS Chris Power (UWA), Martin Meyer (UWA)
THESIS TITLE HI in galaxies

Guido Granda Munoz, *Evolving, PhD*
SUPERVISORS Claudia Lagos (UWA), Chris Power (UWA)
THESIS TITLE Simulated universes for the radio sky

Katherine Harborne, *Evolving, PhD*
SUPERVISORS Chris Power (UWA), Aaron Robotham (UWA)
THESIS TITLE Feedback processes in dwarf galaxies

Lincheng Li, *Evolving, PhD NAOC, China*
SUPERVISORS Lister Staveley-Smith (UWA), Jonghwan Rhee (UWA), Bo Qin (NAOC, China)
THESIS TITLE HI intensity mapping with the Parkes Telescope

Fei Qin, *Dark, PhD*
SUPERVISORS Lister Staveley-Smith (UWA), Cullan Howlett (UWA), Tao Hong (NAOC)
THESIS TITLE Bulk flow and the peculiar velocity field of galaxies

Tristan Reynolds, *Evolving, Pre PhD*
SUPERVISOR Lister Staveley-Smith (UWA)
THESIS TITLE Spectral line studies with the MPIPAF

Alexander Williamson, *Evolving, Pre PhD*
SUPERVISOR Ivy Wong (UWA)
THESIS TITLE HIPASS tidal streams

Swinburne University of Technology

Aditya Parthasarathy Madapusi, *Dynamic, PhD*
SUPERVISORS Matthew Bailes (SWIN), Willem van Straten (SWIN)
THESIS TITLE High precision pulsar timing in the SKA era

University of Queensland

Joshua Calcino, *Dark, PhD*
SUPERVISOR Tamara Davis
THESIS TITLE Supernova cosmology with the OzDES galaxy survey May15

Samuel Hinton, *Dark, PhD*
SUPERVISORS Tamara Davis, Alex Kim (LBNL)
THESIS TITLE Hierarchical Bayesian methods for supernova cosmology

Harry Hobson, *Dark, Honours*
SUPERVISOR Tamara Davis (UQ)
THESIS TITLE Preliminary reverberation mapping measurement of an AGN using DES/OzDES data

2016 CAASTRO Students

Daniel Mathukrishna, *Dark, Honours*
SUPERVISORS David Parkinson (UQ) and Tamara Davis (UQ)
THESIS TITLE Automated spectral: analysis of transient astronomical objects for OzDES

Henning Schmitz, *Dark, Masters*
SUPERVISOR Tamara Davis (UQ)
THESIS TITLE Gravitational lensing to search for MACHOS in the range of stellar black holes

Merryn Taylor, *Dark, Honours*
SUPERVISOR Tamara Davis (UQ)
THESIS TITLE Signal in the Noise – using scatter In Supernova magnitudes to test cosmology

2016 CAASTRO CONTINUING STUDENTS

University of Sydney

Jessica Bloom, *Evolving, PhD*
SUPERVISORS Joss Bland-Hawthorn, Scott Croom
THESIS TITLE Dynamical interactions in nearby galaxies

Joseph Callingham, *Evolving, PhD*
SUPERVISORS Bryan Gaensler, Sean Farrell, Randall Wayth, Ron Ekers (CSIRO)
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 HI absorption against distant radio sources with ASKAP

Rebecca McElroy, *Evolving, 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 (CSIRO)
THESIS TITLE Intermediate mass black holes in dwarf galaxies

Sarah Reeves, *Evolving, PhD*
SUPERVISORS Elaine Sadler, Tara Murphy, Bärbel Koribalski (CSIRO)
THESIS TITLE HI and OH absorption line studies of nearby galaxies

Samuel Richards, *Evolving, PhD*
SUPERVISORS Joss Bland-Hawthorn, Julia Bryant
THESIS TITLE Novel new astrophotonic technologies and telescope instruments to addres 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)

University of Melbourne

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

Jack Line, *Evolving, PhD*
SUPERVISORS Rachel Webster, Daniel Mitchell (CSIRO)
THESIS TITLE Detecting the power spectrum of the 21cm emission of hydrogen from the Epoch of Reionisation

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

Mahsa Rahimi, *Evolving, PhD*
SUPERVISORS Rachel Webster, Bart Pindor
THESIS TITLE Measuring EoR Signal with MWA

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

Jennifer Riding, *Evolving, PhD*
SUPERVISORS Rachel Webster, Daniel Mitchell (CSIRO)
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, Honours*
SUPERVISORS Elaine Sadler, Scott Croom, Julia Bryant, Lisa Kewley
THESIS TITLE A radio continuum study of SAMI galaxies

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

Mayuri Sathyanarayana Rao, *Evolving, PhD*
SUPERVISORS Frank Briggs, Ravi Subrahmayan, Charley Lineweaver, Brian Schmidt
THESIS TITLE On the detection of spectral ripples from the Epoch of Reionisation

Diane Salim, *Evolving, Pre PhD*
SUPERVISORS Matthew Colless, Lisa Kewley, Christoph Federrath
THESIS TITLE Predicting gas properties of SAMI galaxies/ Metallicity gradients and calibrations of SAMI galaxies

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

ICRAR/UWA

Kamran Ali, *Dark, PhD*
SUPERVISORS Danail Obreschkow, Chris Power
THESIS TITLE Information on the cosmic large scale structure

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

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

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

Paul Scott-Taylor, *Evolving, PhD*
SUPERVISOR Danail Obreschkow
THESIS TITLE Advanced computing of simulated galaxies in the SKA era

Swinburne University of Technology

Caitlin Adams, *Dark, PhD*
SUPERVISORS Chris Blake, David Parkinson, Ixandra Achitouv
THESIS TITLE Testing the cosmological model in the low-redshift universe

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

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

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

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

Angela Garcia, *Evolving, PhD*
SUPERVISORS Emma Ryan-Webber, Edoardo Tescari, Stuart Wyithe
THESIS TITLE Diagnosing hydrogen reionisation with metal absorption line ratios

Fabian Jankowski, *Dynamic, PhD*
SUPERVISORS Matthew Bailes, Willim van Straten (Auck Univ Technology, NZ), Evan Keane (SKA Organisation)
THESIS TITLE Spectral and rotational properties of radio pulsars

Andrew Johnson, *Dark, PhD*
SUPERVISORS Chris Blake, David Wiltshire (Canterbury Univ, NZ), Tamara Davis
THESIS TITLE Testing non-standard cosmological models with galaxy surveys

Vivek Venkatraman Krishnan, *Dynamic, PhD*
SUPERVISORS Matthew Bailes, Willem van Straten, Evan Keane
THESIS TITLE Next generation instrumentation for pulsar and fast transient studies with the SKA

University of Queensland

Per Andersen, *Dark, PhD University of Copenhagen*
SUPERVISORS Jens Hjorth (Univ. Copenhagen), Tamara Davis
THESIS TITLE Peculiar velocities

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

Jacob Seiler, *Dark, Pre PhD*
SUPERVISOR Tamara Davis
THESIS TITLE Using bulk flow to constrain f(R) gravity

SUPERVISORS **Sarah Thomson,** *Dark, Honours*
David Parkinson, Ray Norris (CSIRO)
THESIS TITLE Probing the early universe with large area radio surveys

2016 CAASTRO Postdoctoral Researchers

ANNUAL REPORT OF THE CAASTRO STUDENT COMMITTEE

Since its inception in 2014 the CAASTRO Student Committee has worked to support CAASTRO students and relay their thoughts to the Executive. While last year's goal was to increase students' awareness of CAASTRO activities and opportunities, this year we focused on how we could help CAASTRO students improve their skills.

The committee has helped design and implement workshops about two very important aspects of PhD life: writing publications and applying for jobs. These workshops are valuable for a number of reasons:

- communication is an essential skill for any researcher, and providing training and advice in writing and interviewing will help CAASTRO students as they prepare for work beyond their PhD, no matter where they choose to work
- the workshops will be run locally, fostering interaction between staff and post-doctoral researchers (who will present the materials) and students
- they will also serve as legacy items, CAASTRO materials that can be used by other research centres and institutions in future.

Throughout the year we have provided feedback to the organisers of these workshops, which has helped shape the focus and content of each workshop. The interview-training workshop is progressing well, and covers tips for interviews plus advice about what to do after receiving a job offer. The writing workshop covers aspects such as paper structure, writing style and responding to referee reports. We presented some preliminary materials from this workshop in an hour-long session at this year's CAASTRO retreat, and the feedback from students was overwhelmingly positive, with good suggestions for other topics that could be included. We expect to release these materials in early 2017. Committee members will work closely with their nodes to run the workshop.

It's been a great year for CAASTRO students, and the Student Committee would particularly like to thank Kate Gunn (Chief Operating Officer) for her incredible support in helping us to do the best we can for them.

Jack Line
Caitlin Adams
Chairs 2016

ANNUAL REPORT OF THE CAASTRO POST-DOCTORAL COMMITTEE

The inaugural CAASTRO Post-Doctoral Committee formed in early 2016. Most CAASTRO nodes were represented on this committee including: Chair Wiebke Ebeling (Curtin University), Cullan Howlett (University of Western Australia), Christene Lynch (University of Sydney), Steven Murray (Curtin University), David Parkinson (University of Queensland), Ashley Ruiter (Australian National University), Nicholas Scott (University of Sydney) and Laura Wolz (University of Melbourne). The committee's aim was to identify ways in which CAASTRO can support research staff and final-year PhD students in their training and career progression, beyond avenues that already exist within the Australian and international astronomy community.

One of the committee's first steps was to meet with members of the CAASTRO Executive, to capture discussions and strategic decisions about both existing CAASTRO structures and budding international collaborations (such as ACAMAR, eROSITA and LSST). Later in the year, following the ARC's funding announcement and successful bids of the new CAASTRO-3D and OzGrav Centres of Excellence, the committee met with the designated centre directors, Lisa Kewley and Matthew Bailes. Both directors detailed their plans for new postdoc jobs, fellowships, outreach projects, industry engagement, professional development, gender action and family-friendly workplaces.

Current job advertisements in astronomy research and related areas, such as data science, are usually distributed across many different channels, as is information about funding opportunities for travel or family support, training courses and relevant prizes. The committee has created a 'one-stop shop', a Google spreadsheet that brings together information from diverse sources.

In the second half of 2016, the committee produced two fact sheets about the application processes for ARC DECRA and Future Fellowship grants, containing links to essential online interfaces plus comprehensive 'insider' advice on how and when to prepare a successful application. Committee members also contacted previous successful grant applicants: many of these have now agreed to become mentors to more junior researchers.

Many early-career astronomers will move to another field: learning from those who have made the transition may smooth the path for others. Early in the year the committee heard from invited speaker Richard Scalzo, formerly an astronomer at CAASTRO's Australian National University node and now working in data science at the University of Sydney. In November, the CAASTRO Annual Retreat program included a session prepared and run by the committee, discussing careers both in and outside astronomy. Invited CAASTRO panellists Carole Jackson (Curtin University), Tara Murphy (University of Sydney) and Rachel Webster (University of Melbourne) were joined by Kate Brooks (Centre for University Teaching and Learning at Murdoch University, Perth; previously with CSIRO Astronomy and Space Science). The panellists gave insight into their personal experiences, provided valuable advice and engaged in lively conversation, prompted by questions from the committee and the session attendees.

Throughout the year the committee updated CAASTRO members about its activities through emails and the CAASTRO Newsletter, and invited them to browse the committee's online resources.

Dr Wiebke Ebeling
Chair 2016

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

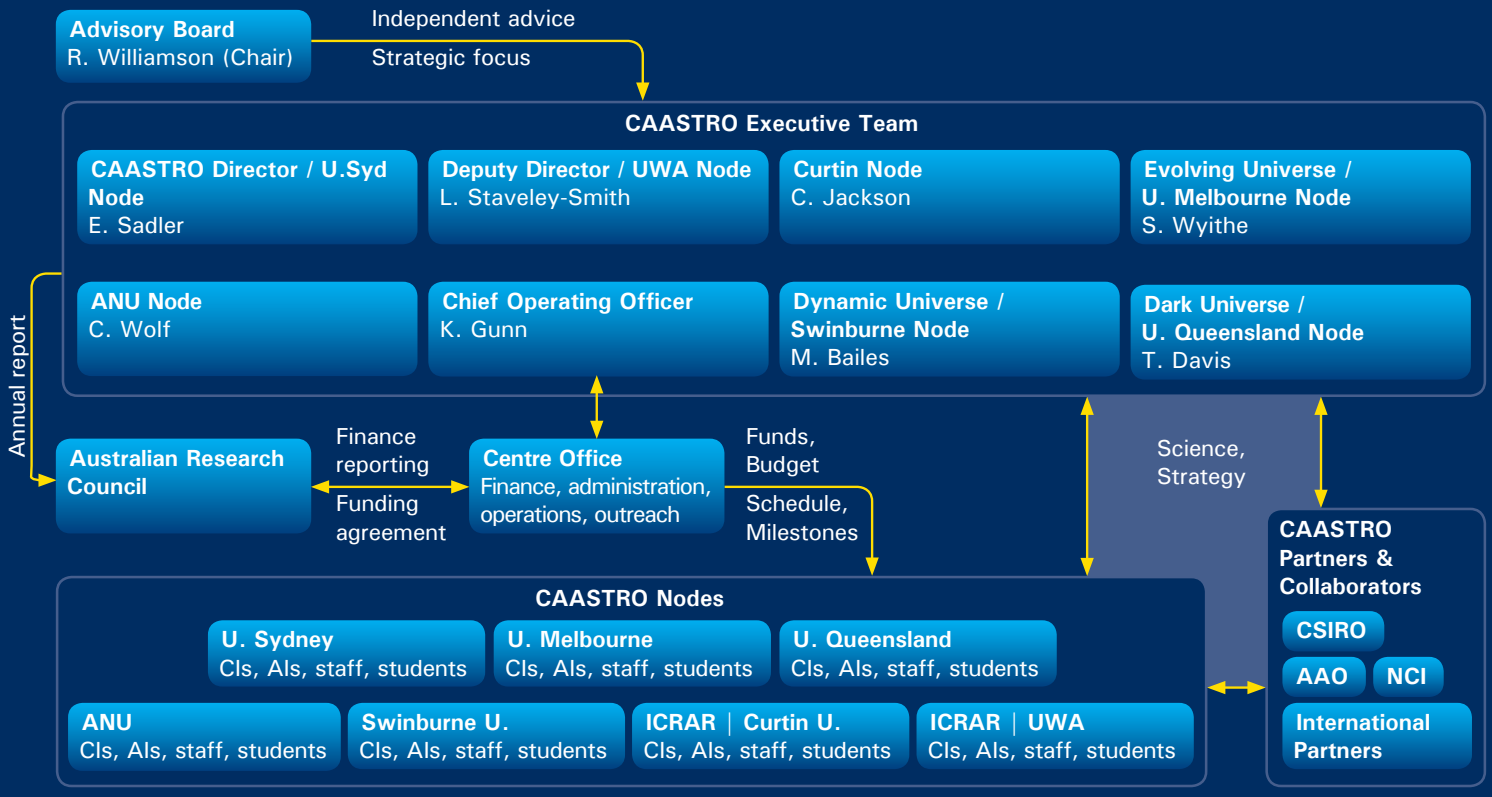
Professor Lister Staveley-Smith
Deputy Director

Ms Kate Gunn
Chief Operating Officer

In 2016, 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 2016 area meetings were held in Sydney, Canberra, Brisbane, Melbourne and Perth.

In 2016 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 2016. 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 2016, including a two-day planning meeting held in Sydney in November 2016. At this meeting the Board assisted the CAASTRO Executive with transition planning and legacy item discussions. The Board 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

Professor Robert Williamson AO FRS FAA

Medical researcher and geneticist

MEMBER

Ms Soula Bennett

Director
Quantum Victoria

MEMBER

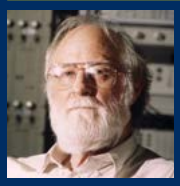
Professor Peter Davies

Pro Vice-Chancellor Research
University of Western Australia

MEMBER

Professor Hugh Durrant-Whyte

The School of Information Technologies
University of Sydney



MEMBER

Professor Ron Ekers

CSIRO Fellow

MEMBER

Dr Bronwyn Evans

Chief Executive Officer
Standards Australia

MEMBER

Professor Kenneth Freeman

Duffield Professor of Astronomy, Australian National University

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

Dr Rachel Nowak

Director The Brain Dialogue
Monash University

MEMBER

Professor Elaine Sadler

CAASTRO Director

CAASTRO Executive

(Left – right) Kate Gunn, Stuart Wyithe, Tamara Davis, Elaine Sadler Lister Staveley-Smith, Christian Wolf, Carole Jackson
Absent: Matthew Bailes
Credit: CAASTRO

The CAASTRO Advisory Board in Sydney, November 2016
Credit Kylie Williams

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 2016, with a number of team members receiving awards and honours for their achievements.

West Australian Tall Poppy Awards

The Young Tall Poppy awards recognise up-and-coming scientists who combine world-class research with a passionate commitment to communicating science. In October Dr Ivy Wong and Dr Danail Obreschkow, both from the University of Western Australia, were presented with Young Tall Poppy awards at a State ceremony. They were two of the seven WA recipients, who came from disciplines as diverse as genetics, plant biology and respiratory medicine. Dr Obreschkow was also named as Western Australia's overall Young Tall Poppy award winner.

Dr Ivy Wong

Dr Ivy Wong investigates how galaxies form stars and evolve. Recently she has been studying galaxies that live fast and die young; that is, galaxies that have had a very recent burst of star formation but then experience a shutdown of star production. By understanding these rare objects Ivy hopes to reveal the physical processes that are currently missing from our theoretical understanding of galaxy formation and evolution.

Dr Danail Obreschkow

Observations of the Milky Way have shown that stars are born at a rate of about one new star per year. Yet to account for all the stars in the Universe, galaxies in the past must have been forming stars at a rate 10 to 20 times this. Danail's research has uncovered the role that galactic rotation plays in star formation. His discovery has closed several big gaps in the theory of galaxy evolution.

NSW Premier's Prize for Science & Engineering and Australian Academy of Science Award

This year Professor Joss Bland-Hawthorn (University of Sydney) was awarded both a NSW Premier's Prize for Science & Engineering, in the category Excellence in Mathematics, Earth Sciences, Chemistry and Physics, and the prestigious Thomas Ranken Lyle Medal from the Australian Academy of Science.

Professor Bland-Hawthorn is an ARC Laureate Fellow Professor of Physics and Director of the Sydney Institute for Astronomy. His innovative astronomical research and instrumentation has helped keep Australia at the forefront of optical astronomy for the last two decades: unusually, he has made major contributions to both experimental physics and astrophysics. He pioneered the field of astrophotonics, developing key devices such as the photonic lantern, OH-suppression fibres, hexabundles, and the photonic integrated multimode microspectrograph.

ASTRONOMICAL SOCIETY OF AUSTRALIA (ASA) AWARDS

Peter McGregor Prize

Professors Joss Bland-Hawthorn and Scott Croom (both University of Sydney), together with the team that created the Sydney-AAO Multi-object Integral field instrument (SAMI), were this year awarded the inaugural Peter McGregor Prize for innovations in astronomical instrumentation. The prize was given in recognition of the international impact of hexabundle technology, the key innovation in the SAMI instrument.

Bok Prize for outstanding research in astronomy by an Honours or eligible Masters Student

This year's Bok prize was awarded to CAASTRO Honours student Samuel Hinton for his thesis, Extraction of Cosmological Information from WiggleZ. Samuel carried out his research at the University of Queensland, supervised by Tamara Davis (University of Queensland) and Chris Lidman (Australian Astronomical Observatory).

Charlene Heisler Prize for the most outstanding PhD thesis in astronomy

This prize was awarded to Dr Vikram Ravi for his thesis, *Evincing the histories of the cosmic massive black hole and galaxy populations with gravitational waves*. Vikram wrote his thesis at the University of Melbourne, supervised by Stuart Wyithe (University of Melbourne) and George Hobbs (CSIRO).

Redmond Barry Distinguished Professorship

In September Professor Rachel Webster, a CAASTRO Chief Investigator, was awarded the title of Redmond Barry Distinguished Professor at the University of Melbourne. This significant achievement recognises professors who demonstrate outstanding leadership in the University and wider community, coupled with pre-eminence in their research, teaching and creative activity.

Sydney Research Accelerator (SOAR) fellow

The first cohort of fellows of the University of Sydney's new Sydney Research Accelerator (SOAR) program has been announced, and this year included CAASTRO Chief Investigator, Associate Professor Tara Murphy. As part of the two-year program, Tara has been awarded $50,000 per year to support her research, innovation and development plans. She will also benefit from a personalised program of research development support and structured mentoring.

Eureka Awards

The Murchison Widefield Array (MWA) project was a finalist in the 2016 Eureka prize in the International Collaborations category. Randall Wayth was the lead for this award. The Murchison Widefield Array (MWA) is a radio telescope built and operated by an international consortium of universities and research institutions from five countries. Designed to pursue the highest priority goals in cosmology, the MWA is a versatile instrument that has produced diverse science results since commencing operations three years ago.

Vice-Chancellor's Awards for Excellence

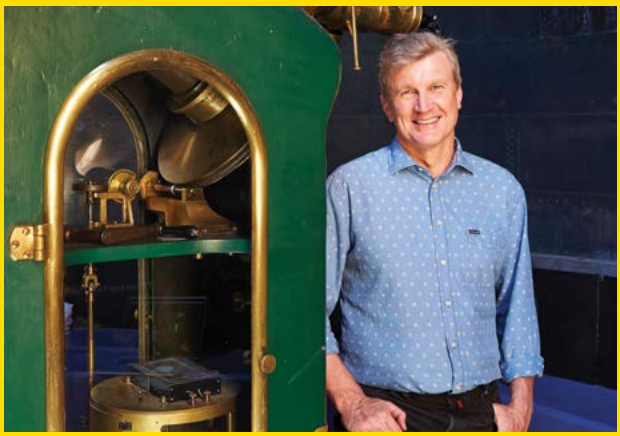
This year congratulations went to Kate Gunn, Chief Operating Officer of CAASTRO, on being recognised in the inaugural Vice-Chancellor's Awards for Excellence. Kate received one of four University awards for Outstanding Contribution to Research Excellence.

Young Australian of the Year Finalist

Cleo Loi, a former CAASTRO Honours student, was the State finalist for the 2017 Young Australian of the Year awards. Cleo authored five scientific papers as an undergraduate student and is now undertaking her PhD at Cambridge.

Dr Danail Obreschkow, WA Young Tall Poppy 2016
Credit: Australian Institute of Policy and Science

Dr Ivy Wong, WA Young Tall Poppy 2016
Credit: Australian Institute of Policy and Science



Professor Joss Bland-Hawthorn

Kate Gunn is presented her award by the University of Sydney Vice-Chancellor, Dr Michael Spence.
Credit: University of Sydney

GENDER ACTION COMMITTEE

Professor Brian Schmidt AC, FRS, FAA, CAASTRO Gender Action Committee Chair

The CAASTRO Gender Action Committee has had another productive year in 2016, its third year of operation. The CAASTRO Executive has always considered itself a force for gender equality and has had strong oversight of gender initiatives (such as allowing all positions in CAASTRO to be taken part time). In 2013 the CAASTRO Executive considered its Key Performance Indicators (KPIs) in relation to its gender program and decided that it was falling short in a number of desired outcomes, and so decided to form the CAASTRO Gender Action Committee to address these issues. Professor Brian Schmidt (Australian National University) became the first Chair.

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

The Gender Action Committee provides broad representation from its membership and different levels within the centre, and includes members from different institutions, genders and nationalities. In 2016 the committee comprised Elaine Sadler (University of Sydney), Rachel Webster (University of Melbourne), Cathryn Trott (ICRAR/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). At the last meeting of the year, following the retirements of Fang Yuan and Cathryn Trott, the Committee welcomed four new members: Anais Möller (Australian National University), Bonnie Zhang (Australian National University), Steven Tremblay (Curtin University) and Danail Obreschkow (University of Western Australia). The Committee met three times during the year via two-hour videoconferences and once face-to-face at the Australian National University for half a day.

In addition to continuing activities already initiated, in 2016 the Committee focused on creating the legacy it will leave for the new astronomy Centres of Excellence, CAASTRO-3D and OzGrav, and Australian science more broadly, when CAASTRO reaches the end of its funding period in 2018.

Work is nearly complete on a case study, "CAASTRO's path to Gender Equality", and on a *Gender Toolkit*, a set of tools other organisations can use to help them build more gender-inclusive workplaces. During 2016 we also progressed our new program, "Professors for Change". Based on "Male Champions of Change", this program is intended to encourage science-based research organisations to promote gender balance.

This year the Committee also worked on a sexual harassment survey for members, and had long discussions regarding the need for transparency in the reporting of incidents and events, to avoid situations where repeat offenders can thrive. While we have an incident database, it was agreed that we need to communicate clearly to all CAASTRO members that we do not tolerate an intimate or sexual relationship between a supervisor (any type) and a subordinate, and of sexual harassment generally. This is to avoid any perceptions of favouritism, conflict of interest, and power imbalance. We are continuing to work on this topic, and in 2017 we will add additional communication channels and tools to assist members.

CAASTRO is committed to making all the conferences and workshops it supports or sponsors 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. Overseas participants at our conferences have made note of our Code of Conduct and mentioned it favorably.

We have continued to undertake exit interviews when members leave CAASTRO. This is an important step to ensuring we are always improving the work we do. It provides the committee with anonymous feedback on whether the gender activities we have undertaken have been effective. For instance, these interviews have made us aware that we have not sufficiently communicated the work we are doing to counter sexual harassment.

CAASTRO sets and measures 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 at conferences and workshops, and roles on the scientific organising committees; and the number of women who apply for jobs and the number shortlisted. In 2016 we continued to monitor these statistics, and the results continue to be positive, with a 40–50 per cent gender balance being achieved a number of times during the year.

The work of the Gender Action Committee is ongoing, and we are only in the first stage of our journey, but the work done in 2016 has provided a solid foundation for CAASTRO moving forward and is building a legacy for other institutions.

PRESENTATIONS

CAASTRO members and the general audience listening to an Astronomical Society of Australia presentation

Credit: Astronomical Society of Australia

INVITED TALKS 2016

Major Conferences

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

Finding fast radio bursts
Matthew Bailes, Magnetar Thinkshop, Bormio, Italy, January 2016

Designing instruments for EoR and Cosmic Dawn: from MWA to SKA
Cathryn Trott, Physics of Cosmic Dawn and Reionization in the SKA era, San Candido, Italy, January 2016

Searching for HI absorption in the brightest southern radio galaxies
Elizabeth Mahony, PHISCC 2016: Upgrading our HI toolkit, Cape Town, South Africa, February 2016

HI SWG Update
Martin Meyer, PHISCC 2016: Upgrading our HI toolkit, Cape Town, South Africa, February 2016

DINGO update
Attila Popping, PHISCC 2016: Upgrading our HI toolkit, Cape Town, South Africa, February 2016

WALLABY
Lister Staveley-Smith, PHISCC 2016: Upgrading our HI toolkit, Cape Town, South Africa, February 2016

To infinity and beyond: the accelerating universe
Brian Schmidt, World Science Festival BNE, March 2016

A discussion on semi-analytic models and hydro-simulations: which one, when and why
Claudia Lagos, Mock Universes 2016: Preparing for the Next Generation surveys, Santiago, Chile, April 2016

Modelling molecular gas in hydro simulations
Claudia Lagos, The Cold Universe, Santa Barbara, USA, April 2016

Self-regulation of star formation
Claudia Lagos, The Cold Universe, Santa Barbara, USA, April 2016

What can the data tell us?
Cathryn Trott, MIAPP Cosmic Reionization Workshop, Munich, Germany, April 2016

Murchison Widefield Array: towards SKA-Low
Randall Wayth, OzSKA/ACAMAR, Perth, April 2016

CAASTRO, eROSITA and the southern radio sky
Elaine Sadler, Follow-up of wide-area X-ray surveys, Germany, April 2016

The Revolution in Radio Astronomy
Elaine Sadler, SERC Research Colloquium, Canberra, May 2016

First supernova cosmology paper with the Dark Energy Survey
Tamara Davis, Dark Energy Survey collaboration meeting, Stanford University, USA, May 2016

How to communicate science to the public
Tamara Davis, Dark Energy Survey collaboration meeting, Stanford University, USA, May 2016

Gender equality
Kate Gunn, CUDOS/Finisar inaugural women's workshop, Sydney, May 2016

Measuring sigma 8 with supernovae
Edward Macaulay, Dark Energy Survey collaboration meeting, Stanford University, USA, May 2016

Are we prepared to educate for the future?
Brian Schmidt, ADC Forum: Australian Leadership retreat, Hayman Island, May 2016

Succeeding as an innovative country
Brian Schmidt, ADC Forum: Australian Leadership retreat, Hayman Island, May 2016

Murchison Widefield Array
Randall Wayth, Low Frequency Aperture Array All-hands meeting, Bologna, Italy, May 2016

Preparing for an ARC Mid-Term Review
Elaine Sadler, ARC Centre Directors' Forum, Sydney, June 2016

Radio-source populations and AGN feedback in the nearby Universe
Elaine Sadler, MWA Project Meeting, Perth, June 2016

OzDES: the Australian Dark Energy Survey - synergies with ASKAP surveys
Tamara Davis, ASKAP 2016 - The future of radio astronomy surveys, Sydney, June 2016

Simulations in the radio waves regime
Claudia Lagos, ASKAP 2016 - The future of radio astronomy surveys, Sydney, June 2016

ASKAP FLASH – The First Large Absorption Survey in HI
Elaine Sadler, ASKAP 2016 - The future of radio astronomy surveys, Sydney, June 2016

WALLABY: the ASKAP HI all-sky survey
Lister Staveley-Smith, ASKAP 2016 - The future of radio astronomy surveys, Sydney, June 2016

State of the Universe
Brian Schmidt, 66th Nobel Laureate meeting dedicated to Physics, Lindau, Germany, June 2016

Dark dark universe
Brian Schmidt, STARMUS Festival: Beyond the horizon - A tribute to Stephen Hawking, Tenerife, Spain, June 2016

The Future of Education in Sciences
Brian Schmidt, 66th Nobel Laureate meeting dedicated to physics, Lindau, Germany, June 2016

High redshift IGM metal, Emma Ryan-Weber, Illuminating the Dark Ages: Quasars and galaxies in the reionization epoch, Heidelberg, Germany, June 2016

SkyMapper and ASKAP — synergies from two large Australian surveys
Christian Wolf, ASKAP 2016 - The future of radio astronomy surveys, Sydney, June 2016

Masterclass - Big questions, big instruments, big ideas
Brian Schmidt, 66th Nobel Laureate meeting dedicated to Physics, Lindau, Germany, June 2016

A review of fast radio bursts and the UTMOST project
Matthew Bailes, Boutiques and Experiments: 2016 Radio, Pasadena, USA, July 2016

Testing the laws of gravity with redshift-space distortions
Chris Blake, Diving into the Dark: Bridging cosmological theory & observation, Cairns, July 2016

Cosmological constraints from combined peculiar velocity surveys
Cullan Howlett, Large scale structure and galaxy flows, Quy Nhon, Vietnam, July 2016

The fundamental plane of star formation as revealed by EAGLE
Claudia Lagos, European Week of Astronomy and Space Science (EWASS2016), Athens, Greece, July 2016

Socio-economic disadvantages of students from developing countries
Claudia Lagos, European Week of Astronomy and Space Science (EWASS2016), Athens, Greece, July 2016

APSERa
Mayuri Sathyanarayana Rao, CMB spectral distortions from cosmic baryon evolution, Bangalore, India, July 2016

BIGHORNS status and results
Marcin Sokolowski, CMB spectral distortions from cosmic baryon evolution, Bangalore, India, July 2016

MWA telescope update and status
Randall Wayth, Astronomical Society of Australia Annual Science Meeting 2016, Sydney, July 2016

High redshift IGM metal
Emma Ryan-Weber, From Wall to Web, Berlin, Germany, July 2016

Invited reviewer and conference summary
Rachel Webster, GravLens2016, Leiden, The Netherlands, July 2016

Constraining the cosmic distance scale with type Ia supernovae: the Hubble constant H0
Bonnie Zhang, Diving into the Dark: Bridging cosmological theory & observation, Cairns, July 2016

The 2MASS Tully-Fisher survey and future TF surveys
Lister Staveley-Smith, Large scale structure and galaxy flows, Quy Nhon, Vietnam, July 2016

GPS and CSS sources at low radio frequency
Joe Callingham, Bruce Slee and 70 years of radio astronomy, Sydney, August 2016

Deep low-frequency surveys with LOFAR: 150 MHz observations of the Lockman Hole field
Elizabeth Mahony, Bruce Slee and 70 years of radio astronomy, Sydney, August 2016

AGN with the Parkes-Tidbinbilla Interferometer
Elaine Sadler, Bruce Slee and 70 years of radio astronomy, Sydney, August 2016

Supernova cosmology: prospects and pitfalls
Tamara Davis, Supernova through the ages, Easter Island, Chile, August 2016

Data use and publication policies
Christopher Onken, SkyMapper early data release: Maximising your science, Canberra, August 2016

Beyond DR1: outlook for main survey processing
Christopher Onken and Chris Wolf, SkyMapper early data release: Maximising your science, Canberra, August 2016

Rates and delay times of type Ia supernovae
Ashley Ruiter, MIAPP - Physics of supernovae, Garching, Germany, August 2016

Nucleosynthesis in type Ia supernovae
Ivo Seitenzahl, MIAPP - Physics of supernovae, Garching, Germany, August 2016

Astrobiology and SETI with MWA and the SKA
Randall Wayth, Astrobiology 2016, Perth, August 2016

Fast radio bursts discoveries with the UTMOST and SUPERB surveys
Matthew Bailes, Innovation & discovery in radio astronomy - a celebration of the career of Ron Ekers, Queenstown, New Zealand, September 2016

The defatigable power-law of radio sources? Ron Ekers curving the trend
Joe Callingham, Innovation and discovery in radio astronomy: A celebration for Ron Ekers, New Zealand, September 2016

Scintillating ideas in the frequency and time domain
Emil Lenc, Innovation & discovery in radio astronomy - a celebration of the career of Ron Ekers, Queenstown, New Zealand, September 2016

AT20G and the high-frequency radio sky
Elaine Sadler, Innovation and discovery in radio astronomy: A celebration for Ron Ekers, New Zealand, September 2016

Survey science
Lister Staveley-Smith, Innovation & discovery in radio astronomy - a celebration of the career of Ron Ekers, Queenstown, New Zealand, September 2016

Lessons learned from the AT20G
Paul Hancock, Innovation and discovery in radio astronomy: A celebration for Ron Ekers, New Zealand, September 2016

Fast radio bursts at UTMOST
Chris Flynn, Cherenkov Telescope Array Australia: Multiwavelength linkages, Adelaide, September 2016

Gas in galaxies: the view from the EAGLE cosmological hydrodynamic simulations
Claudia Lagos, The changing face of galaxies, Hobart, September 2016

The universe from beginning to end
Brian Schmidt, Supernova through the ages, Easter Island, Chile, September 2016

Dissecting disk galaxies with SAMI
Dan Taranu, Galaxy morphometrics, Leiden, The Netherlands, September 2016

Advanced efficient beam modelling for the MWA
Randall Wayth, International conference on electromagnetics in advanced applications 2016, Cairns, September 2016

The role of Science and Technology in Peace and National Development
Brian Schmidt, 20th Anniversary of the attribution of the Peace Nobel Prize 1996, Dili, Timor-Leste, October 2016

The first interferometric detections of fast radio bursts
Manisha Caleb, ASIONS conference, Goa, India, November 2016

Dark energy with the dark energy survey
Tamara Davis, Cosmology and Particle Astrophysics (CosPA), Australia, November 2016

Tests of modified gravity
David Parkinson, Cosmology and Particle Astrophysics (CosPA), Australia, November 2016

Variability and Slow transients with SKA-Low
Paul Hancock, The First Pietro Baracchi Conference: Italo-Australian Radio Astronomy in the Era of the SKA, Perth, November 2016

The Colour of Reionization
Cathryn Trott, The First Pietro Baracchi Conference: Italo-Australian Radio Astronomy in the Era of the SKA, Perth, November 2016

The future of astronomy in Australia
Elaine Sadler, The First Pietro Baracchi Conference: Italo-Australian Radio Astronomy in the Era of the SKA, Perth, November 2016

Murchison Widefield Array
Randall Wayth, The First Pietro Baracchi Conference: Italo-Australian Radio Astronomy in the Era of the SKA, Perth, November 2016

Galaxy formation and the ionisation structure of the intergalactic medium during reionisation
Stuart Wyithe, The First Pietro Baracchi Conference: Italo-Australian Radio Astronomy in the Era of the SKA, Perth, November 2016

Murchison Widefield Array
Randall Wayth, SKA Engineering Meeting, Stellenbosh, South Africa, October 2016

Neutral Hydrogen in the Distant Universe
Elaine Sadler, Colloquium, University of Manchester, UK, December 2016

Low frequency pulsar astronomy in the SKA era
Ramesh Bhat, 2nd ACAMAR Conference, Suzhou, China, December 2016

VLBI and FLASH
Elaine Sadler, 2nd ACAMAR Conference, Suzhou, China, December 2016

The SkyMapper Southern Survey
Christian Wolf, 2nd ACAMAR Conference, Suzhou, China, December 2016

Intensity Mapping
Laura Wolz, 2nd ACAMAR Conference, Suzhou, China, December 2016

A blinded determination of H_0 from low-redshift Type Ia Supernovae calibrated by Cepheid variables
Bonnie Zhang, Dark Energy Survey collaboration meeting, IoA Cambridge, UK, December 2016

Murchison Widefield Array
Randall Wayth, Science at Low frequencies III, Pasadena, USA, December 2016

The colour of reionization
Cathryn Trott, Science at Low frequencies III, Pasadena, USA, December 2016

Radio galaxies in the local Universe – the view from the South
Elaine Sadler, RAS Specialist Discussion 'Radio Galaxies in the Local Universe', London, December 2016

Other Presentations 2016

(Conferences. Workshops, colloquia, projects, collaborations)

Finding fast radio bursts
Matthew Bailes, CASPER workshop, Cape Town, South Africa, January 2016

DLAs in galaxy spectra: a new era in DLA studies and the HI distribution of the Universe
Jeff Cooke, 227th Meeting of the American Astronomical Society, Florida, USA, January 2016

Pulsars by accident with the Murchison Widefield Array
Emil Lenc, Searching for pulsars in radio continuums surveys, Sydney, January 2016

Host galaxies of luminous type II AGN: winds, shocks, and comparisons to The SAMI Galaxy Survey
Rebecca McElroy, 227th Meeting of the American Astronomical Society, Florida, USA, January 2016

SAMI & Hector: IFU studies of gas/stellar misalignments
Julia Bryant, RSAA ANU colloquium, Canberra, February 2016

SAMI science
Julia Bryant, Australian Astronomical Observatory Science Talk, February 2016

Chasing the fastest transients in the Universe: a new approach to time domain astronomy
Jeff Cooke, University of Melbourne, February 2016

The SAMI fundamental plane
Francesco D'Eugenio, SAMI kinematic scaling relations, Perth, February 2016

A hybrid multi resolution scheme to efficiently model the structure of reionization on the largest scales
Hansik Kim, Workshop on large scale structure: from galaxies to the cosmic web, Pune, India, February 2016

Cosmology with peculiar velocities, without peculiar velocities
Edward Macaulay, Taipan workshop, February 2016

SABRE/SUPL
Jeremy Mould, Colloquium, Monash University, Melbourne, February 2016

Superluminous supernovae
Jeremy Mould, SuperAGB/ECSN workshop, February 2016

Taipan
Jeremy Mould, ARC Centre of Excellence for Particle Physics at the Terascale (CoEPP), Melbourne, February 2016

SUPL
Jeremy Mould, DST group, Adelaide, February 2016

Remarks on angular momentum
Danail Obreschkow, SAMI kinematic scaling relations, Perth, February 2016

2D bayesian automated tilted-ring fitter (2DBAT)
Se-Heon Oh, WALLABY early science workshop, Perth, February 2016

2D bayesian automated tilted-ring fitter (2DBAT)
Se-Heon Oh, PHISCC 2016: Upgrading our HI toolkit, Cape Town, South Africa, February 2016

Birthrates of accretion-induced collapse neutron stars from binary evolution models
Ashley Ruiter, Electron capture supernovae and super-AGB star workshop, February 2016

Introduction and motivation
Lister Staveley-Smith, WALLABY early science workshop, Perth, February 2016

The fundamental plane of elliptical galaxies: motivation, theory and simulations
Dan Taranu, SAMI kinematic scaling relations, Perth, February 2016

Intensity mapping cross-correlations: connecting the largest scales to galaxy evolution
Laura Wolz, ANITA, Monash University, Melbourne, February 2016

Pre-processing of galaxies during cluster formation
Ivy Wong, WALLABY early science workshop, Perth, February 2016

Bright galaxies at z ~ 9–10 with the BoRG survey
Stephanie Bernard, The Reionization Epoch: new insights and future prospects, Aspen, USA, March 2016

A hybrid multi resolution scheme to efficiently model the structure of reionization on the largest scales
Hansik Kim, The Reionization Epoch: new insights and future prospects, Aspen, USA, March 2016

What reionization and the SKA can tell us about dark matter
Katie Mack, The Reionization Epoch: new insights and future prospects, Aspen, USA, March 2016

What can galaxy outskirts tell us about the nature of dark matter?
Chris Power, Formation and Evolution of galaxy outskirts, Spain, March 2016

Multibeam survey strategies
Lister Staveley-Smith, Breakthrough Listen workshop, Sydney, March 2016

Murchison Widefield Array perspectives on breakthrough listen
Randall Wayth, Breakthrough Listen workshop, Sydney, March 2016

MWA EoR experiment: latest results
Rachel Webster, The Reionization Epoch: new insights and future prospects, Aspen, USA, March 2016

Modelling galaxy formation and reionization with DRAGONS
Stuart Wyithe, The Reionization Epoch: new insights and future prospects, Aspen, USA, March 2016

EoR/CD science for SKA-LOW
Bart Pindor, 2nd OzSKA workshop, Perth, April 2016

Intensity mapping cosmology and synergies with the EoR
Laura Wolz, 2nd OzSKA workshop, Perth, April 2016

HI galaxy science with the SKA
Martin Meyer, 2nd OzSKA workshop, Perth, April 2016

Extragalactic continuum science with the Square Kilometre Array
Minh Huynh, 2nd OzSKA workshop, Perth, April 2016

Low-frequency pulsar astronomy in the SKA era: from the MWA to SKA-LOW
Ramesh Bhat, 2nd OzSKA workshop, Perth, April 2016

FAST detections of neutral hydrogen in the intergalactic medium
Attila Popping, ACAMAR Inaugural Australia-China workshop on astrophysics, April 2016

Low-frequency pulsar astronomy in the SKA era: from the MWA to SKA-LOW
Ramesh Bhat, ACAMAR Inaugural Australia-China workshop on astrophysics, April 2016

Green DRAGNs
Julie Banfield, AGN workshop, Hobart, April 2016

DINGO: how the HI content of galaxies has changed over cosmic time
Attila Popping, ASKAP 2016: The future of radio astronomy surveys, Sydney, June 2016

Searching for HI absorption in the brightest southern radio galaxies
Elizabeth Mahony, ASKAP 2016: The future of radio astronomy surveys, Sydney, June 2016

Synergies in joint MWA-ASKAP polarimetry
Emil Lenc, ASKAP 2016: The future of radio astronomy surveys, Sydney, June 2016

Prospects of intensity mapping with the SKA and its pathfinders
Laura Wolz, ASKAP 2016: The future of radio astronomy surveys, Sydney, June 2016

DINGO: how the HI content of galaxies has changed over cosmic time
Martin Meyer, ASKAP 2016: The future of radio astronomy surveys, Sydney, June 2016

Prospects of FRBs with ASKAP
Shivani Bhandari, ASKAP 2016: The future of radio astronomy surveys, Sydney, June 2016

EMU cosmology
David Parkinson, EMU international meeting, June 2016

Polarimetric postcards from the South Galactic Pole
Emil Lenc, MWA project meeting, Perth, June 2016

Impact of the ionosphere on EoR power spectra
Cathryn Trott, MWA project meeting, Perth, June 2016

A low frequency census of southern pulsars with the MWA
Mengyao Xue, MWA project meeting, Perth, June 2016

Millisecond pulsars with the MWA
Ramesh Bhat, MWA project meeting, Perth, June 2016

Director's report
Randall Wayth, MWA project meeting, Perth, June 2016

On using GPS to generate ionospheric corrections towards calibration of low frequency radio-astronomy
Balwinder Arora, SKA astronomy, Tasmania, June 2016

Modelling and simulating galaxies with SAMI
Dan Taranu, Great Lakes cosmology 2016, Canada, June 2016

Some big questions of the universe
Brian Schmidt, Tsinghua University, Beijing, China, April 2016

The distribution of old stars in the Galactic centre: A challenge for theory?
Holger Baumgardt, SFB workshop, Germany, June 2016

Resolving environmental quenching with the SAMI galaxy survey: where don't the stars form?
Adam Schaefer, Unravelling galaxies: where do the stars form?, Frauenchiemsee, Germany, June 2016

Lyman continuum galaxies: direct Lyman continuum flux measurements and mechanisms behind the escape
Jeff Cooke, Escape of lyman radiation from galactic labyrinths, Crete, Greece, April 2016

Accounting for eddington bias with hierarchical bayes
Steven Murray, Statistical challenges in 21st century cosmology, Chania, Greece, May 2016

The low frequency radio sky
Mayuri S.Rao, Raman Research Institute conference, India, May 2016

Detailed modelling of individual globular clusters using a large grid of N-body simulations
Holger Baumgardt, Cosmic lab conference, Italy, April 2016

Incidence of galactic outflows: EAGLE simulations vs SAMI observations
Edoardo Tescari, The interplay between local and global processes in galaxies, Cozumel, Mexico, April 2016

Discovering galaxy individuality with SAMI
Scott Croom, The interplay between local and global processes in galaxies, Cozumel, Mexico, April 2016

Pulsar science highlights from the Murchison Widefield Array
Ramesh Bhat, The IPTA 2016 science meeting, Stellenboch, South Africa, June 2016

Statistical challenges in modern astronomy: SNLS supernovae photometric classification with machine learning
Anais Möller, Carnegie Mellon University, Pittsburgh, USA, June 2016

Supernovae photometric classification of SNLS data with supervised learning
Anais Möller, Photo class workshop, Chicago, USA, April 2016

What shapes galaxies? Kinematics and structure of galaxies from IFU spectroscopy
Matthew Colless, STScI spring symposium, Baltimore, USA, April 2016

Are high redshift mergers factories for very massive stars
Jeff Cooke (and Tyler Pritchard), STScI spring symposium, Baltimore, USA, May 2016

Kinematics and structure of galaxies from SAMI
Matthew Colless, Texas A&M seminar, Texas, USA, April 2016

3 seasons of high-z SLSNe from SUDSS and DES: distribution and analysis
Chris Curtin, The ninth Harvard-Smithsonian conference on theoretical astrophysics: the transient sky, Boston, USA, May 2016

Testing modified gravity beyond cosmic variance
Caitlin Adams, Diving into the Dark: Bridging Cosmological Theory & Observation, Cairns, July 2016

Testing modified gravity beyond cosmic variance
Caitlin Adams, Cosmic flows, Quy Nhon, Vietnam, July 2016

Illuminating neutral gas in the $z = 0-1$ Universe: a case study towards two lensed quasars
James Allison, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Deeper, wider, faster: chasing the fastest bursts in the Universe
Igor Andreoni, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

New insights on the mysterious nature of extreme scattering events
Keith Bannister, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Transient pulsars in the Southern sky
Martin Bell, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Bright galaxies during the epoch of reionisation from the $z \sim 9$-10 brightest of reionising galaxies survey
Stephanie Bernard, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Prospects of FRBs with ASKAP
Shivani Bhandari, ASKAP 2016 conference, July 2016

Galaxies during the Epoch of Reionisation from the $z \sim 9$-10 brightest of reionising galaxies survey
Stephanie Bernard, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

SAMI galaxy survey: disturbed things come in small packages – asymmetric kinematics in low mass galaxies
Jessica Bloom, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Hector - a massive new instrument for the Anglo-Australian Telescope
Julia Bryant, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

SAMI Galaxy Survey: impact of environment on the origin of gas in galaxies
Julia Bryant, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

The first interferometric detections of fast radio bursts
Manisha Caleb, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Studying compact radio populations with the MWA using interplanetary scintillation
Rajan Chhetri, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Resolving a 40 year-old mystery on the nature of gas clouds in the early universe
Jeff Cooke, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Future strategic directions of the AAO
Warrick Couch, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Diagnosing the epoch of reionisation with metal absorption Line
Luz Angela Garcia, High redshift conference 2016: Signals from the deep past, Malta, July 2016

Tracing HI gas within dust-reddened quasars with ASKAP
Marcin Glowacki, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

The Molonglo Observatory – 50 years of world-class research
Anne Green, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Gas and magnetic fields on a wide range of scales in star-forming galaxies
George Heald, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

The UTMOST project: transients, maps and a lot of pulsars
Fabian Jankowski, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Photoionization modelling of the broad line region
Anthea King, AGN: what's in a name?, Germany, July 2016

The MWA EoR experiment: an update
Jack Line, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Searching for radio emission from young exoplanets
Christene Lynch, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Close AGN reference survey: QSO returns to the shadows after 30 years as a Seyfert 1
Rebecca McElroy, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Probing pulsar emission mechanisms with the MWA
Sammy McSweeney, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Connecting neutral hydrogen and x-ray absorption in radio galaxies with ASKAP
Vanessa Moss, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

The search for radio emission from gravitational wave events
Tara Murphy, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

What can the outskirts of galaxies tell us about dark matter?
Chris Power, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Spatially resolved measurements of star formation quenching with the SAMI galaxy survey
Adam Schaefer, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Unlocking galaxy formation histories with SAMI
Nicholas Scott, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Exploring the Epoch of Reionisation with wavelets
Cath Trott, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

The SkyMapper early data release
Christian Wolf, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

Supernovae photometric classification of SNLS data with supervised learning
Anais Möller, Diving into the Dark: Bridging Cosmological Theory & Observation, Cairns, July 2016

An empirical mass function distribution
Steven Murray, Diving into the Dark: Bridging Cosmological Theory & Observation, Cairns, July 2016

Subluminous SN1991bg like supernovae as a compelling source of galactic antimatter
Fiona Panther, IAU Symposium 322: Multimessenger astrophysics of the galactic center, Palm Cove, July 2016

Cosmology from the EMU survey
David Parkinson, Diving into the Dark: Bridging Cosmological Theory & Observation, Cairns, July 2016

Science as revolution
Brian Schmidt, European Science Open Forum (ESOF2016), Manchester, UK, July 2016

Cosmic flows: 2MTF and future surveys
Lister Staveley-Smith, Diving into the Dark: Bridging Cosmological Theory & Observation, Cairns, July 2016

Impact of the ionosphere on EoR power spectrum
Cathryn Trott, Astronomical Society of Australia Annual Science meeting, Sydney, July 2016

6–year results from ESSENCE
Brad Tucker, Diving into the dark: bridging cosmological theory and observation, Cairns, July 2016

Going beyond cosmology: hydrogen measurements using intensity mapping cross- correlations
Laura Wolz, Diving into the Dark: Bridging Cosmological Theory and Observation, Cairns, July 2016

Ionospheric conditions above the MRO using EoR datasets, and an update on MALT-45
Christopher Jordan, Colloquium at University of Tasmania, August 2016

Revealing ultracool dwarf magnetic activity through multi-frequency radio observations
Christene Lynch, National Centre for Radio Astrophysics, Pune University, India, August 2016

Supernova photometric classification in SNLS with machine learning
Anais Möller, Supernova through the ages, Easter Island, Chile, August 2016

Synaesthesia—a window into perception, thought and language
Mayuri Sathyanarayana Rao, Raman Research Institute science forum, Bangalore, India, August 2016

Keynote address
Randall Wayth, NI Week, Texas, USA, August 2016

SkyMapper progress update
Christian Wolf, SkyMapper workshop, August 2016

Future ASVO functionality
Christian Wolf (and Marc White), SkyMapper workshop, August 2016

On FRB hunt at intermediate frequencies
Ramesh Bhat, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

SAMI Galaxy Survey: gas/stellar misalignments in galaxies and the impact of morphology and environment
Julia Bryant, The changing face of galaxies, Hobart, September 2016

Hector - a new massively multiplexed IFS instrument for the Anglo-Australian Telescope
Julia Bryant, SPIE, Edinburgh, Scotland, September 2016

Galaxy-AGN co-evolution through cosmic time
Rodrigo Canas, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

Studying compact radio populations with the MWA using interplanetary scintillation
Rajan Chhetri, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

No stone unturned - A story of resolution
Rajan Chhetri, Innovation & discovery in radio astronomy - a celebration of the career of Ron Ekers, Queenstown, New Zealand, September 2016

Galaxy scaling relations with the SAMI survey… and beyond
Francesco D'Eugenio, The changing face of galaxies, Hobart, September 2016

Probing the hidden universe
Pascal Elahi, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

Testing gravity with peculiar velocity surveys
Cullan Howlett, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

SC3: epoch of reionisation 2016 update
Christopher Jordan, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

Large scale environment of a largest known giant tailed radio galaxy
Anna Kapinska, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

About CHILE and galaxy formation
Claudia Lagos, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

Fast radio bursts
Katie Mack, SkyHopper collaboration meeting, September 2016

Unveiling the high-frequency radio source population with AT20G
Elizabeth Mahony, Innovation & discovery in radio astronomy - a celebration of the career of Ron Ekers, Queenstown, New Zealand, September 2016

Sporadic pulsar emission (and me)
Bradley Meyers, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

Simulated universes for the radio sky
Guido Granda Munoz, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

Extra-Galactic Archaeology with SAMI
Nic Scott, The changing face of galaxies, Hobart, September 2016

Dissecting disk galaxies
Dan Taranu, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

Model of radio continuum emission by star-forming galaxies
Paul Scott-Taylor, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

Exploring indigenous astronomical knowledge in Australia and Central America: A cross-cultural collaboration
Edoardo Tescari, 16th Australian space research conference, Melbourne, September 2016

Galactic winds in EAGLE simulations and SAMI observations: the second part of the story
Edoardo Tescari, The changing face of galaxies, Hobart, September 2016

KEGS - The Kepler extra-galactic search
Brad Tucker, Supernova through the ages, Easter Island, Chile, September 2016

Constant-Q disk stabilities result in uniform star formation efficiencies
Ivy Wong, The changing face of galaxies, Hobart, September 2016

A low frequency census of southern pulsars
Mengyao Xue, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

Radio emission from fireballs
Xiang Zhang, ICRARCon - ICRAR annual retreat, Mandurah, September 2016

A search programme for glitches in radio pulsars at the UTMOST telescope
Fabian Jankowski, 626. Heraeus Seminar - Neutron Stars: A Cosmic Laboratory for Matter under Extreme Conditions, Bad Honnef, Germany, October 2016

The spatial distribution of neutral hydrogen as traced by low HI mass galaxies in hierarchical galaxy formation models
Hansik Kim, 7th KIAS workshop on Cosmology and Structure Formation, Seoul, Korea, October 2016

The dynamic radio sky: transient pipelines for ASKAP and the MWA
Tara Murphy, Hot-wiring the transient universe, PA, USA, October 2016

Origins and fate of the highest known redshift galaxy: Implications for JWST
Stuart Wyithe, Exploring the Universe with JWST-II, Montreal, Canada, October 2016

The statistics of radio frequency interference propagating from long distances to the Murchison Radio-Astronomy Observatory
Marcin Sokolowski, Socorro, USA, October 2016

Millisecond pulsars at low frequencies
Ramesh Bhat, 2016 Bolton and Student Symposium, Perth, November 2016

Being a bat in space: measuring distances inside active galactic nuclei using reverberation mapping
Natalia Eiré Sommer, 2016 Bolton and Student Symposium, Perth, November 2016

Understanding the pulsar emission mechanism by studying subpulse drifting
Samuel McSweeney, 2016 Bolton and Student Symposium, Perth, November 2016

The origin of galactic positrons
Fiona Panther, 2016 Bolton and Student Symposium, Perth, November 2016

A low frequency census of southern pulsars
Mengyao Xue, CAASTRO 6th Annual Retreat, Abbey Beach, Perth, November 2016

Radio emission from meteors
Xiang Zhang, 2016 Bolton and Student Symposium, Perth, November 2016

Illuminating the past 8 billion years of interstellar medium with ASKAP
James Allison, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Diagnosing the EoR with metal absorption lines
Luz Angela Garcia, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Measuring large-scale structure using angular cross-correlations
Jacobo Asorey, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

On the existence of massive black holes in globular clusters and ultra-compact dwarf galaxies
Holger Baumgardt, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Christmas FRBs and their multi-wavelength follow-ups
Shivani Bhandari, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Robust identification of stellar structures in simulation: the effect on scaling relations
Rodrigo Canas, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Compact populations in the low radio frequency sky
Rajan Chhetri, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Searching for supermassive black hole binaries and extreme scattering events with the ATESE survey
Dougal Dobie, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Reverberation mapping with OzDES
Natalia Eiré Sommer, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

nIFTy SURFS or building synthetic galaxies for the real Universe
Pascal Elahi, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Bubbles at dawn
Paul Geil, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

HI absorption in nearby compact radio galaxies
Marcin Glowacki, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Variability vs galactic latitude with MWA
Paul Hancock, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Hierarchical Bayesian methods for supernova cosmology
Samuel Hinton, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Testing gravity with peculiar velocity surveys
Cullan Howlett, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

The largest survey of pulsar spectral properties to date
Fabian Jankowski, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

First steps to characterising the ionosphere with EoR datasets from the MWA
Christopher Jordan, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

The brilliance of GLEAM NGC253 starburst galaxy at low radio frequencies
Anna Kapinska, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

MAJICK – developing interferometric imaging techniques for EoR experiments
Jack Line, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Searching for HI absorption in the brightest southern radio galaxies
Elizabeth Mahony, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Update on the SkyMapper transient survey
Anais Möller, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Connecting radio and x-ray absorption in galaxies with ASKAP
Vanessa Moss, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

An improved point-source foreground model for the EoR
Steven Murray, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

First results of LEnsS: Local environments of sub-luminous supernovae
Fiona Panther, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Pulsar variability imaging
Jean-Pierre Macquart, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Trialling new digital receivers at UTMOST in the search for FRBs
Kathryn Plant, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

The first direct halo mass measurements from targeted galaxy-galaxy weak lensing
Edward Taylor, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Studying pulsars using the higher order moments of electromagnetic radiation
Willem van Straten, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Going beyond cosmology: hydrogen measurements using intensity mapping cross-correlations
Laura Wolz, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Radio emission from meteors
Xiang Zhang, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

A blinded determination of H_0 from low-redshift type Ia supernovae, calibrated by Cepheid variables
Bonnie Zhang, CAASTRO 6th Annual Retreat, Abbey Beach, November 2016

Glitches in radio pulsars and spectral properties
Fabian Jankowski, Colloquium, Jodrell Bank Centre for Astrophysics, Manchester, UK, November 2016

Glitches in radio pulsars and spectral properties
Fabian Jankowski, Colloquium, Max-Planck-Institute for Radio Astronomy, Bonn, Germany, November 2016

Low frequency pulsar astronomy in the SKA era
Ramesh Bhat, First Pietro-Baracchi Conference, Perth, November 2016

Radio emission from meteors
Xiang Zhang, First Pietro-Baracchi Conference, Perth, November 2016

The Taipan survey
Jeremy Mould, Munich, Germany, and Shanghai, China, November 2016

Low frequency pulsar astronomy in the SKA era: MWA to SKA-LOW
Ramesh Bhat, Science for the SKA Generation, Goa, India, November 2016

The first interferometric detections of fast radio bursts
Manisha Caleb, SKA early career workshop, Goa, India, November 2016

HI absorption in nearby compact radio galaxies
Marcin Glowacki, University of Sydney CAASTRO Area Meeting, Sydney, November 2016

A low frequency census of southern pulsars
Mengyao Xue, 2nd ACAMAR Workshop on Astrophysics, Suzhou, China, December 2016

Reionization and galaxy formation
Stuart Wyithe, 2nd ACAMAR Workshop on Astrophysics, Suzhou, China, December 2016

The EMU Survey: a deep all-sky astronomical survey with ASKAP
David Parkinson, AIP-APPC conference (22nd Australian Institute of Physics Congress), Brisbane, December 2016

Search and localisation of Fast Radio Bursts.
Shivani Bhandari, ASIONS, Goa, India, December 2016

Current and future instruments on the AAT
Julia Bryant, Australia-Japan Workshop on Collaborative Science, Sydney, December 2016

Millisecond pulsars across the MWA band
Steven Tremblay, Low Frequency Science III, Pasadena CA, USA, December 2016

MWA phase IIa hex array imaging using LST-matched observations
Emil Lenc, MWA Project Meeting, Pasadena, CA, USA, December 2016

Attacking the pulsar emission mechanism problem with the MWA
Samuel McSweeney, MWA Project Meeting, Pasadena, CA, USA, December 2016

VCS system and high time resolution science update
Steven Tremblay, MWA Project Meeting, Pasadena, CA, USA, December 2016

Redundant calibration with phase II
Cathryn Trott, MWA Project Meeting, Pasadena, CA, USA, December 2016

Understanding compact sources at low frequencies using interplanetary scintillation with the Murchison widefield array
Rajan Chhetri, Science at low frequencies III, Pasadena, CA, USA, December 2016

Making a difference in transient science
Emil Lenc, Science at low frequencies III, Pasadena, CA, USA, December 2016

154 MHz detection of faint, polarized flares from UV Ceti
Christene Lynch, Science at low frequencies III, Pasadena, CA, USA, December 2016

Public Lectures 2016

3 big questions for astronomy
Brian Schmidt, Copenhagen, Denmark, January 2016

Exploding stars, dark energy, and the end of the universe
Brad Tucker, Kioloa, Australia, January 2016

Exploding stars, dark energy, and the end of the universe
Brad Tucker, Tour to Science Olympiad Students, Mount Stromlo Observatory, Australia, January 2016

Exploding stars, dark energy, and the end of the universe
Brad Tucker, Tour and stargazing for National Science Teachers Summer School, Mount Stromlo Observatory, Australia, January 2016

Exploding stars, dark energy, and the end of the universe
Brad Tucker, Tour and stargazing for STEM X Academy, Mount Stromlo Observatory, Australia, January 2016

Exploding stars, dark energy, and the end of the universe - 4 talks
Brad Tucker, Tour to NYSF Students, Mount Stromlo Observatory, Australia, January 2016

Exploding stars, dark energy, and the end of the universe
Brad Tucker, Canberra Sceptics, Canberra, Australia, February 2016

Intermediate-mass black holes in dwarf galaxies
Aina Musaeva, Science Teachers Association, UNSW, Sydney, Australia, February 2016

Most of our universe is missing (and how Australia will find it)
Tamara Davis, New Scientist event, Sydney, Australia, February 2016

The Future of Space: From Lasers to Asteroid Mining
Brad Tucker, Australian Institute for Interactive Entertainment, Canberra, Australia, February 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Natalia Eiré Sommer, Astronomer in Residence, Yulara, Australia, March 2016

Everything you wanted to know about dark matter but were afraid to ask
Katie Mack, Juilliard School, New York, USA, March 2016

Exploding stars, dark energy, and the end of the universe
Brad Tucker, Canberra Astronomical Society, Canberra, Australia, March 2016

Gravitational waves
Tamara Davis with Warwick Bowen, University of Queensland, Brisbane, Australia, March 2016

Mt Stromlo Observatory - past, present, and future
Brad Tucker, IES Sydney, Sydney, Australia, March 2016

Philosophy of cosmology
Brad Tucker, Mount Stromlo Observatory, Australia, March 2016

Let There be Light: The First Stars
Rachel Webster, Wheeler Opera House, Aspen, Colorado, USA, March 2016

Quantum science
Tamara Davis, University of Queensland, Brisbane, Australia, March 2016

Supermassive black holes. Big, violent … and useful for distance measurements
Natalia Eire Sommer, Astronomer in Residence, Yulara, Australia, March 2016

The future of physical science
Brad Tucker, Australian National University, Canberra, Australia, March 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Fiona Panther, Astronomer in Residence, Yulara, Australia, April 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Pietro Procopio, Astronomer in Residence, Yulara, Australia, April 2016

Do not go gently into that good night: the explosive lives and deaths of the stars - 2 talks
Fiona Panther, Astronomer in Residence, Yulara, Australia, April 2016

Fear of the dark in the Universe's childhood
Pietro Procopio, Astronomer in Residence, Yulara, Australia, April 2016

Mt Stromlo Observatory - past, present, and future
Brad Tucker, Springbank Circle, Canberra, Australia, April 2016

Mysteries in the Universe
Brad Tucker, Mount Stromlo Observatory, Australia, April 2016

Supermassive black holes. Big, violent … and useful for distance measurements
Natalia Eire Sommer, Astronomer in Residence, Yulara, Australia, April 2016

The storytelling of science
Tamara Davis, Brisbane, Australia, April 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Elizabeth Mahony, Astronomer in Residence, Yulara, Australia, May 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Shivani Bhandari, Astronomer in Residence, Yulara, Australia, May 2016

Exploding stars, dark energy, and the end of the Universe
Brad Tucker, San Mateo, California, USA, May 2016

Fear of the dark in the Universe's childhood
Pietro Procopio, Astronomer in Residence, Yulara, Australia, May 2016

Flashes in the radio Universe - 2 talks
Shivani Bhandari, Astronomer in Residence, Yulara, Australia, May 2016

Growing a galaxy: the role of gas, stars and supermassive black holes
Elizabeth Mahony, Astronomer in Residence, Yulara, Australia, May 2016

Mt Stromlo Observatory - past, present, and future
Brad Tucker, Mount Stromlo Observatory, Australia, May 2016

Dispatches from a dark universe
Katie Mack, Final Frontier Festival, Melbourne, Australia, June 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Igor Andreoni, Astronomer in Residence, Yulara, Australia, June 2016

Exploding stars, dark energy, and the end of the universe
Brad Tucker, Stockton, California, USA, June 2016

Explosions and Collisions in the Universe
Brad Tucker, Mount Stromlo Observatory, Australia, June 2016

Fishing in the sky: discover the most dramatic explosions in the Universe - 2 talks
Igor Andreoni, Astronomer in Residence, Yulara, Australia, June 2016

Growing a galaxy: the role of gas, stars and supermassive black holes
Elizabeth Mahony, Astronomer in Residence, Yulara, Australia, June 2016

Mt Stromlo Observatory - past, present, and future
Brad Tucker, Mount Stromlo Observatory, Australia, June 2016

Looking for the first galaxies in the Universe
Stephanie Bernard, Final Frontier Festival, Melbourne, Australia, June 2016

Astronomy and the media
Brad Tucker, Australian National Centre for the Public Awareness of Science, Canberra, Australia, July 2016

Astronomy in the era of big data
Tara Murphy, Sydney Astrofest 2016, Sydney, Australia, July 2016

Back to the future: the sky at low radio frequencies
Joe Callingham, Sydney Astrofest 2016, Sydney, Australia, July 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Julie Banfield, Astronomer in Residence, Yulara, Australia, July 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Sam McSweeney, Astronomer in Residence, Yulara, Australia, July 2016

Cosmology seminar
Katie Mack, Holy Trinity Lutheran Church, Thousand Oaks, California, USA, July 2016

Einstein's gravity: black holes, dark matter and gravitational lensing
Stuart Wyithe, University of Melbourne, Australia, July 2016

Exploding stars, dark energy, and the end of the universe
Brad Tucker, Brisbane, Australia, July 2016

Explosions and collisions in space
Brad Tucker, Mount Stromlo Observatory, Australia, July 2016

Journey through the Universe
Vanessa Moss, Sydney Astrofest 2016, Sydney, Australia, July 2016

Mt Stromlo Observatory - past, present, and future
Brad Tucker, Canberra, Australia, July 2016

Neutron Stars, the Beating Heart of the Phoenix - 2 talks
Sam McSweeney, Astronomer in Residence, Yulara, Australia, July 2016

Space science in the movies
Alan Duffy, Sydney Astrofest 2016, Sydney, Australia, July 2016

Supermassive black holes: friend or foe? - 2 talks
Julie Banfield, Astronomer in Residence, Yulara, Australia, July 2016

Supernova cosmology
Brad Tucker, RSAA Winter School, Mount Stromlo Observatory, Australia, July 2016

The Dark Universe – Outreach at midnight
Rachel Webster, Uluru Astronomy Weekend, National Science Week, Yulara, Australia, August 2016

ANU science - making science fiction a reality
Brad Tucker, Canberra, Australia, August 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy
Edoardo Tescari, Astronomer in Residence, Yulara, Australia, August 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Christene Lynch, Astronomer in Residence, Yulara, Australia, August 2016

CAASTRO – aiming to establish Australia as the world leader of wide-field astronomy - 2 talks
Vanessa Moss, Astronomer in Residence, Yulara, Australia, August 2016

Hunting for Auroral Emission from Exoplanets - 2 talks
Christene Lynch, Astronomer in Residence, Yulara, Australia, August 2016

Journey through the Universe: the Milky Way and beyond - 2 talks
Vanessa Moss, Astronomer in Residence, Yulara, Australia, August 2016

The Martian and life on Mars
Brad Tucker, Bega, Australia, August 2016

Time travel
Katie Mack, Melbourne International Film Festival, Melbourne, Australia, August 2016

What is Time and What is the Universe?
Brad Tucker, Canberra, Australia, August 2016

Black holes and supercomputers - 3 talks
Edoardo Tescari, Astronomer in Residence, Yulara, Australia, September 2016

Dark matter
Katie Mack, AstroLight Festival, Melbourne, Australia, September 2016

Explosions and collisions in space
Brad Tucker, Mount Stromlo Observatory, Australia, September 2016

Past, present, and future of Mount Stromlo
Brad Tucker, ANU History Learning Community, Canberra, Australia, September 2016

Revealing ultracool dwarf magnetic activity through multi-frequency radio observations
Christene Lynch, Research Week of UWA, University of Western Australia, Australia, September 2016

The Universe in a computer: a review of numerical simulations - 2 talks
Weiguang Cui, Astronomer in Residence, Yulara, Australia, September 2016

Turning science fiction into reality
Brad Tucker, Rotary Canberra Sunrise, Canberra, Australia, September 2016

Astronomy for Fun - Introduction to and historical astronomy
Brad Tucker, Mount Stromlo Observatory, Australia, October 2016

Astronomy for Fun - The life of stars
Brad Tucker, Mount Stromlo Observatory, Australia, October 2016

Astronomy for Fun - The solar system and planets
Brad Tucker, Mount Stromlo Observatory, Australia, October 2016

Creative knowledge 2016
Brad Tucker, Mount Stromlo Observatory, Australia, October 2016

Explosions and collisions in space
Brad Tucker, Mount Stromlo Observatory, Australia, October 2016

How do we measure distances in the Universe?
Anais Möller, Astronomer in Residence, Yulara, Australia, October 2016

Looking for the earliest galaxies with the Hubble Space Telescope
Stephanie Bernard, Astronomer in Residence, Yulara, Australia, October 2016

Past, present, and future of Mount Stromlo
Brad Tucker, Mount Stromlo Observatory, Australia, October 2016

Public Talk
Bryan Gaensler, York University's 2nd International Ada Lovelace Day Lecture at the Bergeron Centre for Engineering Excellence, Toronto, Canada, October 2016

Supermassive black holes: friend or foe?
Julie Banfield, Peterborough, Canada, October 2016

The longest journey - is interstellar travel possible? - 2 talks
Dan Taranu, Astronomer in Residence, Yulara, Australia, October 2016

Active Galactic Nuclei: the bright edge of a black hole? - 2 talks
Anthea King, Astronomer in Residence, Yulara, Australia, November 2016

Ad hominem - from priest to cosmologist
Brad Tucker, Canberra, Australia, November 2016

An evening with Lisa Randall, 3 nights
Tamara Davis & Samuel Hinton, Melbourne, Sydney and Brisbane, Australia, November 2016

Astronomy for Fun - Astrobiology
Brad Tucker, Mount Stromlo Observatory, Australia, November 2016

Astronomy for Fun - Cosmology
Brad Tucker, Canberra, Australia, November 2016

Astronomy for Fun - Galaxies
Brad Tucker, Canberra, Australia, November 2016

How do we measure distances in the Universe?
Anais Möller, Astronomer in Residence, Yulara, Australia, November 2016

Illuminating the dark ages of the universe
Rachel Webster, Allison-Levick Memorial Lecture, Melbourne, Australia, November 2016

Merging white dwarfs as Type Ia supernova progenitors
Ashley Ruiter, Melbourne, Australia, November 2016

Superluminous supernovae: the future of beacons of the past
Chris Curtin, Astronomer in Residence, Yulara, Australia, November 2016

The accelerating universe
Brian Schmidt, Bloomington, USA, November 2016

Outreach tips and tricks
Brad Tucker, Stromlo Student Seminars, Mount Stromlo Observatory, Australia, December 2016

Public Talks
Tamara Davis, Large Hadron Collider exhibition, University of Queensland, Brisbane, Australia, December 2016

INTERNATIONAL VISITORS TO CAASTRO IN 2016

Mohammad Akhlaghi
Tohoku University, Japan

Krzysztof Belczynski
University of Warsaw, Poland

Andrew Cameron
University of St Andrews, UK

Emma Chapman
Imperial College, London, UK

Steve Croft
University of California, Berkeley, USA

Roger Davies
Oxford University, UK

Alistair Edge
Durham University, UK

Sara Ellison
University of Victoria, Canada

Bjorn Emonts
National Institute for Aerospace Technology, Astrobiology Centre, Madrid, Spain, Spain

Parviz Ghavamian
Towson University, USA

Fabio Governato
University of Washington, USA

John Horst
San Diego State University, USA

Garth Illingworth
University of California, Santa Cruz, USA

David Kaplan
University of Wisconsin-Milwaukee, USA

Ross Knapman
Durham University, UK

Cedric Lacey
Durham University, UK

Claudio Linares
Durham University, UK

Adrian Lucy
Columbia University, New York, USA

Aaron Ludlow
Durham University, UK

Sebastian Ohlmann
Heidelberg Institute for Theoretical Studies, Germany

Stefan Oslowski
Bielefeld University, Germany, Poland

Rüdiger Pakmor
Heidelberg Institute for Theoretical Studies, Germany

John Peacock
University of Edinburgh, Scotland

Friedrich Röpke
Heidelberg Institute for Theoretical Studies, Germany

Graziano Rossi
Sejong University, South Korea

Alfonso Aragon-Salamance
Nottingham University, United Kingdom

Douglas Scott
University of British Columbia, Canada

Tracy Slatyer
Massachusetts Institute of Technology, USA

Willem van Straten
Auckland University of Technology, New Zealand, New Zealand

Martin Stringer
Instituto de Astrofisica de Canarias, Spain

Joe Swiggum
University of Wisconsin-Milwaukee, USA

Catarina Tiburz
University of Bielefeld, Germany, Germany

Michael Tremme
University of Washington, USA

Evangelia Tremou
Michigan State University, USA

Jon Willis
University of Victoria, Canada

Visitor Profile

Every 6 months, CAASTRO has a competitive funding call for Visitors to CAASTRO. Many of the visitors on this page are funded through this scheme.

Dr Evangelia Tremou is a researcher at Michigan State University in the USA. She works on transient sources, and in 2016 visited CAASTRO in Sydney for two weeks to learn how to use the pipeline developed for VAST (the survey for Variables and Slow Transients), which will run on the Australian SKA Pathfinder. Her initial goal was to determine which of 72 candidates, obtained with the Very Large Array radio telescope in the course of the CHILES survey, was real. CHILES is the COSMOS H I Large Extragalactic Survey: transients are not its primary target, but it is finding them in the course of producing H I images. CAASTRO members Paul Hancock, Martin Bell and Shivani Bhandari helped Tremou install and run the pipeline, and she managed to process most of her data during her stay in Sydney.

VISITS TO OVERSEAS LABORATORIES AND FACILITIES IN 2016

Caitlin Adams
International Center of Interdisciplinary Science Education (ICISE), Quy Nhon, Vietnam

Igor Andreoni
Harvard University, USA

Igor Andreoni
Johns Hopkins University, USA

Jacobo Asorey
Cambridge University, UK

Jacobo Asorey
Southampton University, UK

Matthew Bailes
Stellenbosch Institute for Advanced Study, South Africa

Stephanie Bernard
Aspen Centre for Physics, USA

Stephanie Bernard
Leiden Observatory, Leiden University, The Netherlands

Stephanie Bernard
University of California, Davis, USA

Stephanie Bernard
W. M. Keck Observatory, Hawaii - 2 trips, USA

Ramesh Bhat
Raman Research Institute, Bangalore, India

Christopher Blake
Aspen Centre for Physics, USA

Manisha Caleb
ASTRON, The Netherlands

Manisha Caleb
Astronomical Observatory of Cagliari, Italy

Manisha Caleb
Manchester University, UK

Manisha Caleb
Max Planck Institute for Radio Astronomy, Germany

Manisha Caleb
West Virginia University, USA

Joseph Callingham
ASTRON, The Netherlands

Joseph Callingham
University of Cape Town, South Africa

Rajan Chhetri
California Institute of Technology, USA

Matthew Colless
Texas A&M University, USA

Jeff Cooke
California Institute of Technology, USA

Jeff Cooke
Space Science Telescope Institute, USA

Jeff Cooke
University of California, Irvine, USA

Jeff Cooke
University of California, Riverside, USA

Christopher Curtin
Harvard University, USA

Christopher Curtin
Johns Hopkins University, USA

Tamara Davis
Cambridge University, UK

Tamara Davis
Southampton University, UK

Marcin Glowacki
Dartmouth College, USA

Kate Gunn
Suzhou Centre - University of Sydney, China

Sam Hinton
Cambridge University, UK

Sam Hinton
Lawrence Berkeley National Laboratory, USA

Sam Hinton
Southampton University, UK

Cullan Howlett
International Center of Interdisciplinary Science Education (ICISE), Quy Nhon, Vietnam

Cullan Howlett
University of Portsmouth, UK

Fabian Jankowski
Jodrell Bank Observatory, UK

Fabian Jankowski
Max Planck Institute for Radio Astronomy, Germany

Christopher Jordan
Cambridge University, UK

Anna Kapinska
ETH Zurich, Switzerland

Anna Kapinska
Max Planck Institut fur Extraterrestrial Physics, Germany

Hansik Kim
Aspen Centre for Physics, USA

Hansik Kim
Korea Institute for Advanced Study, Seoul, South Korea

Claudia Lagos
European Southern Observatory, Germany

Emil Lenc
California Institute of Technology, USA

Christene Lynch
California Institute of Technology, USA

Christene Lynch
Giant Metrewave Radio Telescope, India

Christene Lynch
Pune University, India

Christene Lynch
University of Wisconsin, USA

Edward Macaulay
University of Portsmouth, UK

Katie Mack
African Institute for Mathematical Sciences, Rwanda

Katie Mack
American Museum of Natural History, USA

Katie Mack
Aspen Centre for Physics, USA

Katie Mack
California Institute of Technology, USA

Katie Mack
Harvard University, USA

Katie Mack
Jet Propulsion Laboratory (NASA), USA

Katie Mack
Massachusetts Institute of Technology, USA

Katie Mack
University of Colorado, USA

Rebecca McElroy
Durham University, UK

Rebecca McElroy
European Southern Observatory, Chile

Ben McKinley
California Institute of Technology, USA

Martin Meyer
University of Cape Town, South Africa

Bradley Meyers
California Institute of Technology, USA

Bradley Meyers
New Mexico Institute of Mining and Technology, USA

Bradley Meyers
University of New Mexico, USA

Anais Möller
Carnegie Mellon University, USA

Anais Möller
European Southern Observatory, Chile

Anais Möller
Lawrence Berkeley National Laboratory, USA

Anais Möller
Stanford Linear Accelerator (SLAC), USA

Anais Möller
University of Chicago, USA

Jeremy Mould
International Center of Interdisciplinary Science Education (ICISE), Quy Nhon, Vietnam

Fiona H Panther
Heidelberg Institute for Theoretical Studies (HITS), Germany

Fiona H Panther
Max Planck Institiut fur Kernphysik, Germany

Fiona H Panther
Max Planck Institut fur Extraterrestrial Physics, Germany

Aditya Parthasarathy
Auckland University of Technology, New Zealand

Bart Pindor
Cambridge University, UK

Bart Pindor
Hartree Centre, Science & Technology Facilities Council, UK

Bart Pindor
Imperial College London, UK

Bart Pindor
Oxford University , UK

Mahsa Rahimi
California Institute of Technology, USA

Mahsa Rahimi
Penn State University, USA

Mahsa Rahimi
University of California, Los Angeles, USA

Mayuri S.Rao
Indian Institute of Science, India

Mayuri S.Rao
Raman Research Institute, Bangalore, India

Ashley Ruiter
Bishop's University, Canada

Ashley Ruiter
Heidelberg Institute for Theoretical Studies (HITS) , Germany

Ashley Ruiter
Munich Institute for Astro- and Particle Physics, Germany

Elaine Sadler
Suzhou Centre - University of Sydney, China

Elaine Sadler
European Southern Observatory, Germany

Elaine Sadler
Max-Planck Institute for Astrophysics, Germany

Elaine Sadler
University of Manchester, UK

Elaine Sadler
SKA Headquarters, UK

Diane Salim
National Astronomical Observatory of Japan, Japan

Adam Schaefer
Max Planck Institut fur Extraterrestrial Physics, Germany

Brian Schmidt
Beijing Ancient Observatory, China

Brian Schmidt
Centro Quesadhip Ruak, Dili, Timor-Leste

Brian Schmidt
European Southern Observatory, Chile

Brian Schmidt
Indiana University, USA

Brian Schmidt
Netherlands School of Astronomy, The Netherlands

Brian Schmidt
University of Amsterdam, The Netherlands

Brian Schmidt
University of Groningen, The Netherlands

Brian Schmidt
University of Leiden, The Netherlands

Brian Schmidt
University of Nijmegen, The Netherlands

Nic Scott
Kapteyn Institute for Astronomy, Groningen, The Netherlands

Ivo Seitenzahl
Heidelberg Institute for Theoretical Studies (HITS) , Germany

Lister Staveley-Smith
ASTRON, The Netherlands

Lister Staveley-Smith
European Southern Observatory, Germany

Lister Staveley-Smith
Jodrell Bank Observatory, UK

Lister Staveley-Smith
South African Astronomical Observatory, South Africa

Lister Staveley-Smith
Suzhou Centre - University of Sydney, China

Lister Staveley-Smith
University of Cape Town, South Africa

Marcin Sokolowski
Raman Research Institute, Bangalore, India

Dan Taranu
Oxford University, UK

Dan Taranu
University of Leiden, The Netherlands

Dan Taranu
University of Portsmouth, UK

Dan Taranu
University of Toronto, Canada

Edoardo Tescari
Faculdad de Ciencias Espaciales, Universidad Nacional Autónoma de Honduras (UNAH), Honduras

Edoardo Tescari
Instituto de Astronomía, Universidad Nacional Autónoma de México, Mexico

Cathryn Trott
California Institute of Technology, USA

Cathryn Trott
Munich Institute for Astro- and Particle Physics, Germany

Cathryn Trott
Sexten Centre for Astrophysics, Italy

Brad Tucker
European Southern Observatory, Chile

Brad Tucker
Google X, USA

Brad Tucker
Lawrence Berkeley National Laboratory, USA

Brad Tucker
NASA Ames Research Centre, USA

Brad Tucker
Space Telescope Science Institute, USA

Brad Tucker
Stanford Linear Accelerator (SLAC), USA

Brad Tucker
University of California, Berkeley, USA

Brad Tucker
University of California, Davis, USA

Brad Tucker
University of Maryland, USA

Vivek Venkatraman
Auckland University of Technology, New Zealand

Vivek Venkatraman
California Institute of Technology, USA

Mia Walker
National Instruments, Austin, USA

Randall Wayth
California Institute of Technology, USA

Rachel Webster
Aspen Centre for Physics, USA

Rachel Webster
Imperial College London, UK

Rachel Webster
Leiden University, The Netherlands

Laura Wolz
École Polytechnique Fédérale de Lausanne, Switzerland

Laura Wolz
Imperial College London, UK

Laura Wolz
Mullard Space Science Laboratory, University Cambridge London, UK

Laura Wolz
Suzhou Centre - University of Sydney, China

Stuart Wyithe
Aspen Centre for Physics, USA

Stuart Wyithe
Canadian Space Agency, Canada

Stuart Wyithe
Kavli Institute, Peking University, China

Stuart Wyithe
Munich Institute for Astro- and Particle Physics, Germany

Stuart Wyithe
Suzhou Centre - University of Sydney - 2 trips, China

Mengyao Xue
Shanghai Astronomical Observatory, China

Bonnie Zhang
European Southern Observatory, Chile

Bonnie Zhang
Southampton University, UK

WORKSHOPS

CAASTRO hosted a number of interesting, well-attended and stimulating workshops during 2016.

Diving into the Dark: Bridging Cosmological Theory and Observation 17–22 July 2016, Cairns, Queensland

The major science conference *Diving into the Dark* drew a fantastic group of over 60 cosmologists from around the world to Cairns to talk about the dark side of the Universe. The specific focus of the conference was to bring observers and theorists together to design better ways to test theories of dark energy and dark matter. The diverse participants included observers mapping the distribution and velocities of galaxies, others using supernovae to trace the expansion history of the universe, some measuring gravitational lensing, and yet others trying to do dark-matter detection directly with ground-based experiments. These observers were brought together with theorists who try to find theoretical explanations for dark energy and dark matter, and simulators who make detailed predictions from those theories of what the distribution of galaxies should look like, and how that distribution should change over time

The invited and contributed talks, given by exciting, complementary speakers, were all excellent. Invited speakers included Chris Blake, Josh Frieman, Austin Joyce, Konrad Kuijken, Dan Scolnic, Douglas Scott, Rita Tojeiro, and Hans Winther. We even managed to get some crossover in speakers with the International Astronomical Union's symposium, *The Multi-Messenger Astrophysics of the Galactic Centre,* which was being held up the road in Palm Cove at the same time as *Diving into the Dark*. Rarely would the Cairns area have seen such a concentration of professional astrophysicists!

The program included ample time for self-organised sessions, in which the participants suggested topics and gathered groups of interested researchers to discuss them. Some groups used these sessions to brainstorm new types of observations, others used then to try to group-solve problems in analysis, and yet others used them as an opportunity to meet with collaborators from around the world, to progress papers already in the pipeline.

These open slots in the schedule were highlights of the conference, many participants thought. Yet another highlight was a trip to Green Island to explore the Great Barrier Reef, made during a long open session on Wednesday afternoon. This was especially enjoyed by participants who were making their first visit to Australia.

The conference ran smoothly thanks to the excellent work of the CAASTRO administration team and our superb CAASTRO student volunteers. Our students had the chance to chair conference sessions, and for several of them it was the first time they had met the authors of the papers they had been working with. All in all it was a very successful week, both a great learning experience for our members and a great demonstration to the community of the strength of CAASTRO's research program.

Diving into the Dark conference
Credit: Josh Calcino

The 2nd Australia-China Workshop attendees in Suzhou, China
Credit: Dr Lin Li

1st Australia–China ACAMAR workshop: 5–7 April 2016, Perth, Western Australia

The inaugural Australia–China Workshop on Astrophysics, organised by the Australia–China Consortium for Astrophysical Research (ACAMAR), was held at the Rendezvous Hotel in Scarborough in Perth from 5–7 April 2016. This was an exciting and well-attended event, with over 80 people taking part in sessions on Antarctic astronomy, gravitational waves, radio astronomy, instrumentation and big-data challenges. The workshop provided an excellent opportunity to meet with our Chinese colleagues to strengthen existing research collaborations and plan new ones. It was particularly interesting to see the rapid progress being made on the Chinese 500-m radio telescope, FAST, which was opened later in the year.

2nd OzSKA Workshop: 8 April 2016, Perth, Western Australia

The second annual OzSKA meeting was held in Perth on 8 April 2016 at the Rendezvous Hotel, Scarborough, directly following the ACAMAR workshop held on 5–7 April at the same venue.

The main purpose of this one-day meeting was to update the Australian astronomical community about recent progress within the SKA project: it covered the development of key science and working group activities, how to participate, key upcoming dates, and progress towards the realisation of scientific operations on SKA1. The program was a mixture of invited talks, contributed talks and discussion, and consisted of a session on SKA politics, summaries of SKA science from members of the various SKA Science Working Groups, and a session on SKA infrastructure. The meeting concluded with a 45-minute discussion hosted by panellists Ron Ekers, Sarah Pearce, Peter Hall and Tyler Bourke on the upcoming technical challenges confronting the SKA

The meeting attracted 61 formal participants (22 of them female). They included David Luchetti and Jerry Skinner from the Australian SKA office; Claire Patterson from the Department of the Premier and Cabinet (Government of Western Australia); Simon Aarons from the Office of Science; Tyler Bourke from the SKA Observatory Office; and two participants from China, Professor Xuelie Chen (National Astronomical Observatories, Chinese Academy of Sciences) and Dr Mingmin Chi (Fudan University).

The organising committee consisted of Jean-Pierre Macquart, James Miller-Jones, Martin Meyer, Kate Gunn and Kylie Williams, and the meeting was jointly sponsored by ICRAR and CAASTRO.

2nd Australia–China ACAMAR workshop 5–7 December 2016, Suzhou, China

ACAMAR held its second joint China–Australia Workshop in Suzhou during 5–7 December 2016. About 90 people attended the meeting, 27 of whom were Australians. The welcome drinks and dinner were held at the University of Sydney's new Suzhou Centre, and we are very grateful for the sponsorship that the University of Sydney provided. Both the Chinese and Australian participants commented that it was good to know that the University of Sydney has a presence in China, and to have the opportunity to see it.

The scientific program emphasised FAST, the SKA and its pathfinders, pulsars, big data, and Antarctica. Time was devoted to breakout discussions to foster further collaboration; this will be repeated at future meetings in an enhanced form. The collaboration goes from strength to strength, and the third ACAMAR Workshop has been scheduled for Tasmania in September 2017.

The ACAMAR 2017 China SKA PhD scholarships have started to roll out to CAASTRO universities plus the University of Tasmania. In addition, a Chinese proposal for a combined PhD scholarship and postdoctoral scheme has been approved by the Chinese Academy of Sciences. ACAMAR expects to progress this in 2017.

The Australian Consul-General opened the 2nd Australia-China Workshop in Suzhou, China.
Credit: Dr Lin Li

The inaugural Sydney Astrofest
Credit: Debra Gooley

The 50th Anniversary ASA Meeting
Credit: ASA

First Sydney Astrofest draws 2000 people 30 July 2016, University of Sydney

Stargazing events are not uncommon, but how often do they come with a great line-up of speakers, activities for kids, a slate of exhibitors and a travelling planetarium? That's what the University offered on Saturday 30 July at Sydney Astrofest. As far as we know, this was the first event of its kind to be held south of Sydney Harbour. The promise of a free night of family fun lured 2000 people to campus.

Events took place in and around the Charles Perkins Centre, next to Oval no. 2. That afternoon the University rugby team was battling it out with Warringah in the first semi-final for the Shute Shield, so amateur astronomers were setting up their telescopes to the crowd's happy cheers. (Sydney won, so the rejoicing carried on into the night.)

The astronomy-keen rolled in from 4pm, instantly forming a queue for planetarium tickets (which sold out within an hour). They then stormed the lecture theatre for the official opening by Joss Bland-Hawthorn (University of Sydney). That was followed by the first talk, by cosmologist Alan Duffy (Swinburne University): no dry spiel this, but a romp through space science as depicted in the movies. By the time Alan had finished it was dark, and while many people settled down in the theatre for a night of great talks, others formed lines to look through the eight telescopes on site at Mars, Saturn, Jupiter and the odd nebula. Inside in the warmth kids were busy building space stations and aliens out of LEGO and concocting telescopes out of toilet rolls, while their elders checked out goodies on the stalls, from liquid-nitrogen demos to virtual-reality goggles. After all that activity had fed the mind, the Lions Club Sausage Sizzle was there to feed the body too – and raise funds for the Starlight Foundation charity in the process.

Sydney Astrofest was organised by CAASTRO and well supported by the School of Physics. In particular, thanks are due to Joss Bland-Hawthorn and to Tara Murphy, Vanessa Moss and Joseph Callingham, three of the night's eight speakers; and to the other wonderful volunteers, without whom the event wouldn't have happened. CAASTRO's Debra Gooley and Jenny Lynch bore the brunt of organising the event, helped by Wiebke Ebeling, Helen Sim, Kylie Williams and CAASTRO's Chief Operating Officer, Kate Gunn. The many exhibitors and sponsors gave the event great support, with Sydney Observatory and Celestron, both of which donated prizes, deserving special mention.

2016 ASA Annual Scientific Meeting 3–8 July, University of Sydney

The 2016 Annual Scientific Meeting of the Astronomical Society of Australia (ASA) was held during 3–8 July at the University of Sydney. It marked the 50th anniversary of the ASA's formation. The meeting was returning to its roots, because the first ASA meeting was held in a chemistry lecture theatre on the Sydney campus from 30 November to 2 December 1966. This year's meeting attracted over 265 participants.

Opened by the Chief Scientist Dr Alan Finkel, the meeting consisted of 27 science sessions and seven special sessions. The welcome reception was held at Sydney Observatory and the conference dinner took place at Doltone House restaurant in Darling Harbour. This year the first Rainbow Astronomy Dinner was held for those who identify as LGBTI+, their allies, and anyone else who wanted to attend. To assist participants attending the conference with their children, we provided professional care for infants and children aged up to five years.

The special feature of this meeting was a time capsule, curated by CAASTRO member Vanessa Moss and consisting of various artefacts stored in a seismic- and water-resistant box. It will be opened at the ASA Meeting of 2066.

ASA Diversity in Astronomy 2016 Workshop 27–29 June 2016, University of Melbourne

The annual Diversity in Astronomy (previously Women in Astronomy) Workshop was held at the School of Physics at the University of Melbourne over two days in June 2016. CAASTRO co-hosted a lecture and reception with the Women in Science Parkville Precinct (WISSP) and the Astronomical Society of Australia (ASA) on the opening night. Leonie Walsh, the Victorian Lead Scientist, gave the keynote address.

This year's event explored many issues around diversity, especially gender diversity in the workplace. Lara Rafferty (RMIT) led a workshop on sexuality that highlighted the issues facing transgender people and how institutions can respond to them.

Professor Rachel Webster presents at the Diversity in Astronomy Workshop
Credit: Nouf

ASKAP 2016 Chair Lisa Harvey-Smith
Credit: CSIRO

Sarah Brough (ASA and CAASTRO member) led a discussion on ASA initiatives, in particular the Pleiades Awards, which are driving much of the change in our industry. There was also a focus on the personal stories of our fellow astronomers, which covered topics as diverse as parenthood, transgender challenges, culture and ethnicity, and family-friendly workplace practices from a father's point of view. Doug Hilton (Walter and Eliza Hall Institute) provided an insight into the situation in medical research, telling us about the family-friendly and career-break support he has incorporated at the institutional level.

The program also included lots of opportunity to explore ideas of teamwork, other cultures and mindfulness in a more practical way, as well as the chance to meet other delegates in a social setting. Resident artist Briony Barr directed us through her artwork, 'Drawing with Complexity'. Delegates had an opportunity to encounter more teamwork with the African drumming group, which lead us through drumming and dance routines. There was also a quick workshop in 'drawing for mindfulness' using an art form called Zentangle.

Follow-up of Wide-Area X-ray Surveys Workshop
27–29 April 2016, Ringberg Castle, Bavaria, Germany

CAASTRO held its first joint workshop with the Max Planck Institute for Extraterrestrial Physics (MPE), *Follow-up of Wide-Area X-ray surveys*, as part of our eROSITA collaboration. The German eRosita instrument, to be carried on a Russian satellite, will perform a sensitive X-ray imaging survey of the whole sky and is expected to detect large numbers of galaxy clusters and millions of active galactic nuclei. Workshop participants discussed scientific opportunities opened up by the synergy between eROSITA and existing or upcoming wide-area surveys, with an emphasis on multi-object spectroscopy and southern hemisphere programs. MPE is one of CAASTRO's international partner organisations, and this workshop was a strong demonstration of our commitment to this collaboration.

ASKAP 2016: The Future of Radio Astronomy Surveys
6–10 June 2016, University of Sydney

The user community of CSIRO's Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope gathered in Sydney in June for *ASKAP 2016: The Future of Radio Astronomy Surveys*, a conference organised by CSIRO with generous support from location host, CAASTRO, and sponsors, the International Centre for Radio Astronomy Research and Astronomy Australia Limited.

Over 130 astronomers, telescope-commissioning experts and data scientists from 16 countries gathered to plan key aspects of ASKAP science surveys and discuss how best to conduct these large surveys and exploit the complex data sets they will generate. The event showcased a mix of plenary lectures, short cutting-edge science results from ASKAP and ASKAP-related surveys, in-depth interactive discussions and hands-on workshops.

A large part of the program was devoted to looking ahead to a world in which ASKAP will be fully operational. There were presentations on surveys at other wavelengths that will complement ASKAP, and astronomers from other large survey instruments lent their expertise to discussions on strategies for data sharing between large astronomical surveys.

The final day of ASKAP 2016 was devoted to one of the most interesting technical challenges for ASKAP and other SKA precursors, namely the novel exploitation and visualisation of large data sets. It wasn't just talk: attendees got 'hands-on' with Virtual Observatory tools and the CSIRO ASKAP Science Data Archive (CASDA).

ASKAP 2016 was a warm, friendly affair with a great deal of camaraderie and good humour evident. Participants even held a minute's silence for ASKAP's test array, BETA, which was decommissioned not long before the conference.

CAASTRO Annual Scientific Conference, Hobart
Credit: Dilyar Barat

The Changing Face of Galaxies: Uncovering Transformational Physics 19–23 September 2016, Wrest Point, Hobart, Tasmania

CAASTRO Annual Scientific Conference

One hundred and forty astronomers, from 12 countries, met at Wrest Point Conference and Events Centre in Hobart in September to discuss *The Changing Face of Galaxies: Uncovering Transformational Physics*. The conference covered 70 talks and 58 posters over five days. The focus was on understanding how galaxies seen at high redshift have transformed into the galaxies we see today.

Central to tackling this question is our ability to observe and simulate galaxies in new ways. New projects using spatially resolved optical spectroscopy are shedding light on a broad range of physical processes; observations at radio frequencies are opening up a new window on the gas content in galaxies; large-scale multi-wavelength surveys are providing coverage of galaxies over their entire spectral energy distribution. Galaxy simulations have also advanced dramatically in the last few years: there have been big steps in large-scale hydrodynamic simulations, with new views on feedback and the construction of realistic disk galaxies. Our focus at the conference was to bring together these different lines of evidence to discover which processes drive the transformations we see in the galaxy population.

The conference began with Marcella Corollo (ETH Zurich) showing us how the rise of bulges and the fading of disks lead to the declining star-formation rate in the local Universe. There were a number of talks on high-redshift kinematic measurements, including those by Emily Wisnoiski (Max Planck Institute for Extraterrestrial Physics) and Martin Bureau (Oxford University); as well as new simulations Paul Torrey (MIT), Jorge Moreno (Harvard University), Chris Power (University of Western Australia), Rob Crain (Liverpool John Moores University) and others; and the power of integral-field observations, as demonstrated by the SAMI survey and other major surveys.

The conference organisers strove for speakers balanced in gender and at different stages of their careers. One approach we took to achieve this was a blind ranking of submitted talk proposals: the science organising committee saw only the talk title and abstract, not the name or any other identifying information for the speaker, when they ranked the talks. We felt that this gave us a broad and balanced program. Among the participants as a whole we had 36 per cent women and 64 per cent men: the balance was also good for the scientific organising committee (50/50), session chairs (56/44), invited speakers (47/53) and contributed talks (30/68).

On the first afternoon we ran a *poster trivia quiz,* where all the attendees were organised into teams and tried to answer questions based on the content of the posters presented at the conference. Everyone enjoyed getting to know one another and looking over the posters. This is certainly something we would do again at other conferences with large numbers of posters.

The conference dinner was held at the Museum of Old and New Art (MONA), located within the Moorilla winery on the Berriedale peninsula in Hobart. After a ferry ride at sunset, delegates were treated to a private tour of the museum followed by a two-course dinner. Another highlight of the week was a 'ghost tour' of Port Arthur where delegates were treated to spooky tales and an unusual view of the historic site.

Karen Masters and Chris Power wrapped up the conference with a comprehensive review, reminding us of the important questions that we still need to answer.

CAASTRO annual retreat, Busselton Western Australia
Credit: CAASTRO

ANNUAL RETREAT

28–30 November 2016

Busselton, population 36,000, is a seaside tourist town 220 km south of Perth, Western Australia. During 28–30 November this year the population swelled a little further, as over 100 CAASTRO members descended on the Abbey Beach Resort just south of the town for their annual retreat. Being a nationally distributed organisation, CAASTRO finds it valuable to bring its members together each year to strengthen their existing connections with each other and build new ones.

Annual retreats are always a time to look both back and ahead: back to the year's achievements and ahead to the future. Chief among the achievements were the successes of established, ongoing surveys: the SAMI Galaxy Survey, OzDES, Radio Galaxy Zoo, SkyMapper's projects, and the searches for fast radio bursts and pulsars with the Molonglo and Parkes telescopes. CAASTRO's publication rate has risen in line with this activity. Stuart Wyithe, leader of the Evolving Universe theme, pointed out in his address to the meeting that his theme had produced 44 papers in the first 11 months of 2016, twice the number it had published in the equivalent period in 2015.

Looking forward, we can expect another scientifically productive year in 2017 as the big projects continue to produce results. But there is also the excitement of seeing CAASTRO's successors, CAASTRO-3D and OzGrav, start up in 2017. A number of projects, such as the MWA's Epoch of Reionisation survey, the FLASH survey on the Australian SKA Pathfinder, and work with SAMI, will continue under the banner of CAASTRO-3D. So too will CAASTRO's successful outreach programs, *CAASTRO in the Classroom* and the *Uluru Astronomer in Residence*. Some CAASTRO astronomers will find opportunities with the forthcoming Square Kilometre Array radio telescope: at the retreat, Curtin Node Leader Carole Jackson outlined the progress of this project and noted that two of the new Australian SKA Fellowships had been awarded to CAASTRO's Martin Meyer and Attila Popping.

The retreat's scientific talks covered the big projects already mentioned, and much more. Several speakers presented ways to tackle the problem of foregrounds in Epoch of Reionisation experiments. James Allison (CSIRO), a member of the FLASH team, gave a detailed run-down of the gaps in our understanding of the history of neutral hydrogen (HI) in the Universe and our prospects for detecting HI in absorption. (This talk was judged to be the best of the meeting.) Bonnie Zhang (Australian National University) described an exciting new publication procedure: presenting a paper 'blind' – that is, with only the method described, and the actual numerical result obscured, to ensure that the method was assessed in an unbiased way. Honours student Dougal Dobie (University of Sydney) presented his involvement with ATESE, a search for extreme examples of radio 'twinkling' (scintillation), which has found the longest-lasting case known, an event that ran for well over a year. Fiona Panther (Australian National University) suggested intriguing implications (not yet published) of her work on a particular type of supernova. Paul Geil (University of Melbourne) spoke about DRAGONS, a simulation project that calculates the observables of high-redshift galaxies: with the confidence of a theorist, he proclaimed that we should be able to detect the Epoch of Reionisation out to a redshift of 10. In a more back-to-basics approach, PhD student Jack Line (University of Melbourne) discussed fundamental aspects of interferometry, generating much discussion, while Willem van Straten (Swinburne University) addressed how to explain the orthogonal polarisations seen in pulsar pulses, a question first raised in 1969.

The invited talks by international speakers complemented the members' talks. Emma Chapman (University College London) spoke about procedures developed to mitigate Galactic foregrounds in observations made with LOFAR (Europe's Low-Frequency Array), while Claudio Llinares (Durham University) presented 'alternative', less-usual tests for distinguishing between different theories of gravity.

Our third external speaker, Professor Robyn Owens (Deputy Vice-Chancellor, University of Western Australia) had been invited to talk about diversity: she broadened her theme to argue for the value of workplaces encouraging not just more diverse people but also more diverse thinking, something that would enlarge the range of possible solutions considered, and so give us a better chance to solve problems.

As always at CAASTRO retreats, there were networking sessions (a lunch for students and a breakfast for postdocs), and hands-on sessions (one to guide students in writing papers and, for those further on in their careers, a masterclass on writing papers for Nature). There were morning walks and bike rides. And of course there was the CAASTRO Special Activity, which this year included climbing for the vigorous and trampolining for all (the photos from which can be used for blackmail for years to come).

It's remarkable how much you can pack into three days. This was a very enjoyable meeting, attended by almost all CAASTRO members. Its success was due, once again, to the efforts of the CAASTRO Executive, the A-team and, particularly, Kylie Williams.

EDUCATION & OUTREACH

CAASTRO Education and Outreach has always aimed to be national, despite the challenge of being distributed across seven Australian universities plus domestic and international partners. The portfolio is more than the sum of its parts, and was designed to create novel, meaningful and innovative additions to the wonderful outreach initiatives already pursued by the astronomy community. Nearing the end of CAASTRO's funding lifetime, we have driven a number of our major legacy projects towards completion.

Thinking and delivering big

Title scene of CAASTRO planetarium show
Credit: John Goldsmith

We are very pleased to have this year completed three of our biggest projects, projects that will serve the CAASTRO brand and astronomy engagement for many years to come. Across the three projects, we attract audiences of all ages.

Our planetarium show *Capturing the Cosmos* was launched on 21 March 2016, with a main event at Scienceworks in Melbourne and a satellite event at Scitech in Perth. This production was jointly led by Dr Wiebke Ebeling (CAASTRO) and Dr Tanya Hill (Museum Victoria) and features current research within CAASTRO, namely supernova cosmology with SkyMapper and Epoch of Reionisation studies with the Murchison Widefield Array (MWA). Thanks to stunning animations, superb live filming, and narration by Australian actor and Academy Award winner Geoffrey Rush, this show has received much praise. In the first months of distribution to fixed and mobile planetaria throughout Australia, around 50,000 visitors, including thousands of school students, saw the full-dome version of *Capturing the Cosmos*. International licensing begins in 2017. Museum Victoria completed the flat-screen version of the show in July 2016: we immediately used this in our Uluru partnership, running screenings as part of the Uluru Astronomy Weekend and the Astronomer in Residence program.

Later in the year, we took delight in receiving the CAASTRO wall calendar, *Bright Stars,* from the printers. This beautifully designed resource is much more than a calendar: it contains an introduction to CAASTRO, our research and our vision for astronomy outreach, and the personal profiles of ten of our 'Bright Stars': CAASTRO members at different stages of their careers. These features are combined with a perennial calendar that marks significant dates in astronomy research and space exploration. Distribution to Australian high schools has commenced, and the calendar will also be offered at public events for a gold coin donation (which will go towards a local outreach program). The project was designed to encourage many thousands of young people to study STEMM subjects, and is a collaboration between Dr Wiebke Ebeling (CAASTRO) and Jacinta den Besten (Telescopes in Schools). It was also a mentoring project in itself, with Perth-based junior science communicator Jessica Scholle working on it as an intern.

CAASTRO's perennial calendar for high schools
Credit: CAASTRO

First glimpse of CAASTRO's upcoming comic book
Credit: CAASTRO

A very fitting end to this very productive year in the Education and Outreach portfolio was marked by the completion of script and artwork for CAASTRO's comic book, "The Cosmic Adventures of Alice and Bob", which reaches out to our youngest audience yet. Celebrating the essence of CAASTRO – big questions and innovative solutions – in a very entertaining and engaging way, the book tells the fictional story of two friends striving to get to their hockey finals and the real stories of scientific discoveries that only happened thanks to curiosity, perseverance and ambition. The book was a collaboration between the CAASTRO working group, led by Dr Wiebke Ebeling (Curtin University) and assisted by CAASTRO School Education Officer Jenny Lynch (University of Sydney) and CAASTRO Chief Investigator Christian Wolf (Australian National University), and Perth-based science communicators Cristy Burne (a children's book author) and Aska (an illustrator). It will be published under Curtin University copyright and launched at Perth Astrofest on 18 March 2017 as the keynote of the event. Free online teaching notes will also be made available to allow teachers to fully appreciate the abundance of references and hidden clues throughout the book. All Australian primary and combined schools will receive free copies, and will also be able to order class sets.

School engagement with more breadth and depth

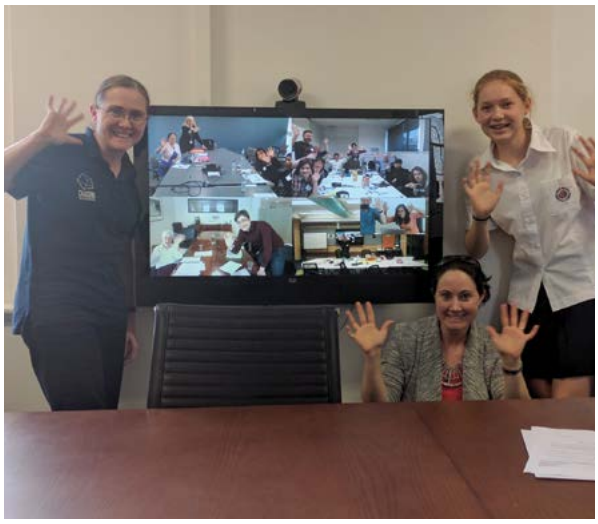
Our school seminar program, *CAASTRO in the Classroom*, has now been guided by CAASTRO School Education Officer Jenny Lynch (University of Sydney) for more than a year, and has gone from strength to strength. In addition to ten video-conferencing sessions delivered by researchers at various CAASTRO nodes, the program also featured as part of 12 science teachers' conferences and professional-development workshops across Australia. Video recordings of the sessions, now available on the CAASTRO YouTube channel, allow the resource to be re-used. Key to the program's great success in 2016 was the use of other modes of delivery in addition to videoconferencing. We ran two exceptionally popular live YouTube events, "Why study Physics?" (by Vanessa Moss) and "Awesome Astronomy" (by Scott Croom), and three one-to-one conversations between a school and a researcher, delivered via Skype. Both formats made *CAASTRO in the Classroom* a truly national program that at last reaches students in all Australian states and territories. The program's impact was further boosted this year by three science teachers, who helped to develop classroom resources that complement the 'live' aspect of the program.

Screening of 'Capturing the Cosmos' at Ayers Rock Resort
Credit: Marija Stankovic

Joint ASELL/CAASTRO teachers' training workshop at Perth
Credit: Jenny Lynch

Uluru 'Astronomer in Residence' Natalia Sommer at CAASTRO's stall in the town square
Credit: Nathaniel Butterworth

In October, CAASTRO seized the opportunity to partner up with fellow AMSPP grant recipient Advancing Science by Enhancing Learning in Laboratories (ASELL) to deliver a half-day training workshop for small groups of high-school science teachers and their students in Sydney, Canberra, Melbourne, Perth and Armidale. The workshop included videoconferencing sessions about the two programs, the science curriculum and pedagogy, as well as hands-on activities for the participants, facilitated by a local CAASTRO member. The contents and format of this unique collaboration were well received by participants.



Joint ASELL/CAASTRO teachers' training workshop at Sydney
Credit: Jenny Lynch

Public outreach in cities and the outback

CAASTRO had a presence in three astronomy-themed public celebrations this year: the well-seasoned Perth Astrofest in March; the inaugural Sydney Astrofest (of which CAASTRO was the main organiser) in July; and Melbourne's second Astronomy and Light Festival in September. Every one of these drew record crowds, namely 5,000 visitors in Perth, 2,000 visitors in Sydney and 2,000 visitors in Melbourne. Each featured information stalls, science talks and shows, solar and night sky observing and family-friendly activities, and at each CAASTRO members had a lot of interaction with the public audience of all ages and talked about their research, our science goals, our other initiatives and about careers in astrophysics. The Sydney event's success has laid the foundation for it to become an annual event, jointly organised by CAASTRO and the University of Sydney Science Faculty.

Our partnership with Voyages Indigenous Tourism Australia once again delivered quality outreach to visitors of the Ayers Rock Resort in Yulara, through our Astronomer in Residence and Uluru Astronomy Weekend programs. Between March and November 2016, 18 CAASTRO members took up their fortnight-long residencies at the resort, talked about CAASTRO research and added their astronomy knowledge to the stargazing events. After we received the flat-screen version of our planetarium show *Capturing the Cosmos*, from mid-August we modified the weekly seminar

Four of our speakers at Sydney Astrofest: (Left – right) Alan Duffy (Swinburne), Lisa Harvey-Smith (CSIRO), Joseph Callingham (University of Sydney), David Malin (Australian Astronomical Observatory).
Credit: Jacinta Den Besten

1) Welcome speech by Wiebke Ebeling at launch of planetarium show ***Credit: John Goldsmith***

2) Tamara Davis on stage with Lisa Randall ***Credit: Think Inc.***

3) Sam Hinton at Brisbane opening gig of the Think Inc. event ***Credit: Phil Kent***

about CAASTRO to become a daily screening of the show. Once a week the screening is followed by a Q&A session with our researcher. This event, now located at the resort's Wintjiri Arts and Museum area, has attracted healthy numbers of visitors.

In November we partnered with Think Inc. to host US American particle physicist Professor Lisa Randall on a tour of Brisbane, Melbourne and Sydney. Our sponsorship deal allowed us to nominate the Australian host of the tour, our "Dark Theme" leader Tamara Davis (University of Queensland), and to have CAASTRO PhD student Sam Hinton (University of Queensland) appear at the opening event in Brisbane. We recorded a video interview with Davis and Randall in which they answered questions from Year 12 students and science teachers from Brisbane Girls Grammar School.

Spreading the word and sharing our passion

CAASTRO research enjoys an overwhelmingly positive response from the media and the public. In 2016 we published 12 press releases about our research outputs and other significant news: they generated excellent coverage in national and international media, online and print – well over 250 articles. Our press release for research by CAASTRO PhD student Joe Callingham (University of Sydney) on supernova remnant 1987A was accompanied by a CAASTRO video press release production, created by Education and Outreach Manager Dr Wiebke Ebeling (Curtin University): this received over 6,000 views in a few months. The joint CAASTRO–ESO press release for PhD student Rebecca McElroy (University of Sydney) and her discovery of the 'changing-look' galaxy Markarian 1018 was another great success, leading to Rebecca being invited to give interviews on ABC News 24 and on several radio stations. Many other CAASTRO members communicated their science in radio interviews, TV appearances, podcasts and short video segments.

Remaining true to our conviction that not only selected highlights should be publicised, we kept up our efforts in creating short, semi-technical research stories for all CAASTRO-led papers. Working with the first author of each piece of work, Dr Ebeling published 20 research stories on the CAASTRO website and compiled them into the sixth edition of the CAASTRO Reader's Digest. These booklets have found a particularly keen audience in astronomy high-school programs, amateur astronomy societies and university senior management, and demonstrate CAASTRO's productivity and the continuous, incremental advances that characterise science.

Tools for successful careers

This year we carried on our tradition of organising a professional training program for our members in conjunction with our Annual Retreat, but trialled a new format. We offered four separate half-day modules that participants could choose and combine, based on their interests and time constraints. The workshops were hosted on Curtin University campus over two days and covered leadership, creative thinking (de Bono's concepts), conflict management, and 'open science'. The external facilitators had been thoroughly briefed on what it means to work in scientific research and what the key stepping stones and hurdles are, in particular for young academics, to make sure that examples were specific and relevant. The new format and the workshop contents were well received by around the participants, of whom there were about 20 per module.

Assisting the CAASTRO Student and Post-Doctoral Committees with the production of a new resource, CAASTRO Education and Outreach Manager Dr Wiebke Ebeling (Curtin University) created a presentation template about careers. This presentation contains information and advice on all aspects of academic life and the decision-making processes that can help guide a person onto a successful career path. The intention is for this resource to not only be of use to our members, for their preparation of resumes and grant proposals, but also to be a template for presentations at career-themed events at CAASTRO node locations, to both internal (CAASTRO) and external audiences.

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.

CAASTRO LOCATIONS

The MWA signpost, located at the centre of the array.
Credit: Marianne Annereau

2016 ICRAR members *Credit: ICRAR*

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, Carole Jackson at 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.

EDUCATE

CAASTRO Curtin University team members

Curtin University

CAASTRO AT CURTIN UNIVERSITY

The Curtin Institute of Radio Astronomy is a partner in the International Centre for Radio Astronomy Research (ICRAR) and the managing organisation of the Murchison Widefield Array (MWA). Research at CAASTRO's Curtin node focuses on the Evolving and Dynamic themes; Curtin is also the headquarters for CAASTRO Education and Outreach. This year the node had 19 members. There was one staff change during the year, when Dr Marcin Sokolowski was seconded to work on Curtin's SKA developments. CAASTRO Associate Investigator Dr Randall Wayth continued in the role of MWA Director. Curtin engineering intern Ms Mia Walker contributed strongly to CAASTRO-related activities also during the year as well as undertaking MWA technical duties. The Curtin node hosted the international MWA Project Meeting in June.

In the Evolving Universe research theme, CAASTRO members at Curtin contributed advances in instrumentation, observations and theory throughout 2016.

The BIGHORNS conical log-spiral antenna is now permanently deployed at the Murchison Radio-astronomy Observatory (MRO) and continues to yield all-sky, low-frequency radio spectra, valuable for studying the impact of the ionosphere on our ability to detect the global Epoch of Reionisation (EoR) signal. BIGHORNS data are also being used to develop a predictive model for when unusual atmospheric conditions may allow distant radio-frequency interference to propagate to the MRO, and, in conjunction with the MWA and Desert Fireball Network, to help identify and remove radio-frequency interference generated by aircraft.

This year saw the publication of the GLEAM (GaLactic and Extragalactic All-sky MWA) survey's catalogue of 300,000 sources across the whole southern extragalactic sky (page 11). Authors on the paper included CAASTRO members Callingham, Hancock, Kapinska, Morgan, Wayth, Murphy, Bell, Gaensler, Lenc, Procopio, Staveley-Smith, Briggs, Tingay and Webster. The significant publicity around this paper highlighted the MWA's coverage of a contiguous, broad frequency range (72–231 MHz) and the GLEAM survey's uniqueness in being sensitive to radio emission from both compact and diffuse radio sources up to tens of degrees in angular size.

Christopher Jordan modelled the ionosphere and diffuse emission foreground for the EoR detection and developed a quantitative metric to quickly assess the quality of data.

Cathryn Trott processed 30 hours of MWA EoR data with the Cosmological HI Power Spectrum estimator (CHIPS) and published these deepest limits on the EoR signal from the MWA. She also published work describing the benefits of wavelet analysis for EoR foreground mitigation and exploring the evolution of signal through redshift.

Steven Murray generated foreground statistical models for the EoR sky, based on the latest estimates of the broad differential source count from MWA and other deep observations, and has developed a general formalism for understanding the signature of any foreground clustering on the EoR power spectrum. The group aims to use the MWA hexagonal subarrays and MWA-AAVS hybrid arrays for data calibration and EoR science, and are developing a suite of data quality metrics to refine the optimal data used for EoR science.

Ronniy Joseph commenced as a new PhD student. He will explore the information available for calibration and EoR science when using hybrid arrays.

The Curtin node's contribution to the Dynamic Universe theme comes largely from working with MWA data, but there is also significant work done on fast radio bursts, transients in general, and other phenomena.

We took on three new CAASTRO PhD students this year: Mengyao Xue, Bradley Meyers, and Samuel McSweeney. All are co-supervised by CAASTRO Associate Investigator Ramesh Bhat and CAASTRO Postdoc Steven Tremblay, and all will use MWA data for their dissertation.

Bhat and Tremblay began a collaboration with the German LOFAR group led by Verbiest (University of Bielefeld), to enable comparison between MWA and LOFAR data for both verification and scientific gains. Bielefeld early-career researchers Oslowski and Tiburzi were at Curtin on extended visits as part of this joint venture.

In the area of fast radio bursts (FRBs), a major highlight was the publication, in *Nature* early in the year, of a paper reporting on the putative host galaxy of FRB 150418: for this, MWA and Parkes data provided the first broadband spectral-index constraint on FRB emission. A new collaboration has been initiated with the Indian group based at the Indian Institute of Technology Kharagpur, and the National Centre for Radio Astrophysics, on efforts relating to gearing up the Ooty widefield array for FRB searches. Jean-Pierre Macquart has continued his work on the detection and interpretation of fast radio bursts, and has taken up the reins as co-Principal Investigator of the ASKAP CRAFT survey, which is poised to detect and localise these elusive events in large numbers.

Paul Hancock, in collaboration with CAASTRO members Martin Bell and Tara Murphy (University of Sydney), published a variability analysis of archival data from the Australia Telescope Compact Array that was made using the VAST pipeline. CAASTRO Associate investigator Jean-Pierre Macquart, in collaboration with Emil Lenc and CAASTRO Advisory Board member Ron Ekers, developed a new approach to finding pulsars: it takes advantage of the fact that, because they are compact sources, interstellar scintillation imprints time-variable, fine-scale structure in their spectra. This will be a computationally-cheap means of searching for pulsars with widefield interferometers.

CAASTRO Associate investigator John Morgan supervised two short-term CAASTRO postdocs, Balwinder Singh Arora and Rajan Chhetri, for half of 2016. Arora, building on his PhD work, produced a software package that ingests publicly available data from GPS (and GLONASS) ground-stations, pre-processes the data in an automated fashion, and provides a summary of the ionospheric activity relevant to radio astronomers for the desired time and location. Arora has now moved to GeoScience Australia but CAASTRO will be able to continue to make use of this software package.

Chhetri, Morgan and Ekers have worked on the phenomenon of interplanetary scintillation (IPS), the scattering of radio signals by charged particles flowing off the Sun. The phenomenon causes compact sources to 'twinkle' (scintillate) at radio wavelength. The MWA is extremely well suited to making IPS observations, and can survey for compact sources at low frequency with unprecedented depth and breadth. Along with CAASTRO Director Elaine Sadler, Chhetri, Morgan and Ekers are investigating the nature of compact radio sources newly discovered this way. Morgan is also investigating the use of MWA IPS observations to improve space-weather modelling and forecasting, working with many international collaborators.

Curtin has carriage of the CAASTRO Education and Outreach portfolio under the management of Dr Wiebke Ebeling. Major outreach projects, including a planetarium show, a wall calendar and a comic book, were completed this year or progressed for completion in early 2017 (details, page 87). Research and outreach activities by Curtin members were highlighted in four (out of 11) press releases and four (out of 20) news stories published by CAASTRO, in collaboration with national and international partners. In March, CAASTRO had once again a presence at Astrofest, at Curtin Stadium, where Dr Ebeling was joined by CAASTRO PhD students Bradley Meyers and Mengyao Xue, CAASTRO research staff members Dr Marcin Sokolowski and Dr Chris Jordan, and Node Leader Professor Carole Jackson. In July, CAASTRO PhD student Sam McSweeney participated in the *Astronomer in Residence* outreach program at Ayers Rock Resort in July. In October, the Curtin node was one of the five national training venues for high-school science teachers and students as part of CAASTRO's collaboration with the ASELL program (Advancing Science by Enhancing Learning in the Laboratory). In early December Curtin hosted a two-day professional development event for CAASTRO members.

Professor Carole Jackson

CAASTRO Node Leader

Theme: Evolving

Jackson is a current WA Premier's Fellow. She is a key participant in the GLEAM survey (page 11), has had a long-term involvement in the technical and scientific developments for the Square Kilometre Array (SKA) radio telescope, and has also been involved in early science with the Australian SKA Pathfinder (ASKAP). Jackson's research interests lie in active galactic nuclei and populations of powerful radio sources, particularly in mapping their distribution with respect to Epoch of Reionisation foregrounds. During 2016 she continued to chair the Science Advisory Committee for the peak Australasian body concerned with the SKA, the Australian and New Zealand SKA Coordination Committee, and was highly involved in discussions around the design of the SKA and Australian strategy relating to it. In early 2017 Jackson will resign from her roles as Chief Investigator and Node Leader to take up the position of Scientific and General Director of the Netherlands Institute for Radio Astronomy, ASTRON.

Mr Balwinder Arora

CAASTRO Researcher

Theme: Evolving

Arora has been working on ionospheric corrections. Building on his PhD work, he has produced a software package that ingests publicly available data from GPS and GLONASS ground-stations, pre-processes the data in an automated fashion, and provides a summary of the ionospheric activity – useful information for an astronomer to have before observing or processing large data files.

Dr Ramesh Bhat

CAASTRO Associate Investigator

Theme: Dynamic

Bhat continues to work in the areas of pulsars and Fast Radio Bursts. A significant part of his research this year involved using the MWA for pulsar science, including studying pulsar emission physics and using pulsars as probes of the interstellar medium: these could be major niche areas of the MWA, given its low-frequency advantages. The study of millisecond pulsars, especially those important for pulsar timing-array experiments, is rapidly emerging as an important activity; the MWA's potential was vividly demonstrated by the discovery of scintillation arcs in J0437–4715, a result that was published in the Astrophysical Journal early this year. Bhat is currently supervising three Curtin PhD candidates, on research projects that exploit MWA's newly-developed pulsar capabilities. He has also facilitated the MWA's participation in the high-profile SUPERB project, which is searching for pulsars and fast radio bursts (FRBs).

Dr Rajan Chhetri

CAASTRO Research Staff

Theme: Evolving

Chhetri joined CAASTRO in 2016. He is working on using interplanetary scintillation (IPS) to identify sub-arcsecond compact structures in radio-source populations at low radio frequencies: in particular, he is using IPS observations made with the MWA to identify active galactic nuclei (AGN) at low radio frequencies. This new work complements his past study of compact AGN at high radio frequencies and regions of electromagnetic spectrum (optical, infrared, X-ray and gamma-ray). Using new insights into AGN gained from low radio frequencies, he is making a multiwavelength study of compact AGN to understand their evolution across cosmic time.

Dr Wiebke Ebeling

CAASTRO Education and Outreach Manager

Theme: Education and Outreach

In 2016 Ebeling's work was focused on the delivery of key legacy projects in CAASTRO's Education and Outreach portfolio. The planetarium show *Capturing the Cosmos* was launched nationally on 21 March, with Ebeling hosting the satellite launch event at Scitech in Perth. The *Bright Stars* wall calendar was completed, ready for distribution to high schools, amateur astronomy societies and the public in 2017. The CAASTRO children's comic, *The Cosmic Adventures of Alice & Bob,* was progressed to final artwork, well on track for its launch at Perth Astrofest on 18 March 2017. In addition to these major projects, Ebeling continued to publish science news stories for CAASTRO social media and the *Reader's Digest*, worked on 11 media releases, led video productions and facilitated the Early Career Researcher training. As Chair of the Post-Doctoral Committee she organised the committee meetings and drove the preparation of resources for CAASTRO members.

Dr Paul Hancock

CAASTRO Affiliate

Theme: Dynamic

Hancock has taken the idea of image stacking and applied it to transient radio phenomena to provide insights into the nature of Type Ia supernovae and long gamma-ray bursts. He is one of the main contributors to the VAST pipeline, an analysis and visualisation tool designed to detect and classify variable and transient radio sources from the latest generation of radio surveys. Hancock is currently using the VAST pipeline to process data from the MWA in order to detect various signatures of variability. One such signature is the scintillation of distant galaxies that occurs as their light passes through the interstellar medium of the Milky Way.

Dr Christopher Jordan

CAASTRO Affiliate

Theme: Evolving

Jordan works in the Epoch of Reionisation (EoR) group at Curtin university. In 2016, he analysed a large amount of MWA data to characterise ionospheric behaviour: this contributes to planning for the SKA. In 2017 he will work to gain an even better understanding of ionospheric behaviour, as well as investigating more EoR-related topics with the MWA. His PhD, completed in 2015, was on high-mass star formation; he continues to contribute to Australian star-formation studies, and to a search for regions of ionised hydrogen in our Galaxy, important for understanding its large-scale structure.

Mr Ronniy Joseph

CAASTRO PhD Student

Theme: Evolving

In October 2016 Joseph commenced his PhD under supervision of Trott and Wayth, after which he joined CAASTRO as part of the Evolving Universe theme. His project focuses on the use of non-traditional radio interferometers to probe the weak signals from the Epoch of Reionisation (EoR). He will study the use and benefits of combining antennas from different arrays, particularly whether this provides information not available from traditional arrays. In late 2016 he started working on the impact of deviations from redundancy for calibration of the Murchison Widefield Array (MWA).

Dr Jean-Pierre Macquart

CAASTRO Associate Investigator

Theme: Dynamic

This year Macquart has worked on the properties of scintillating AGN and pulsars, as a means of understanding the nature of anomalous turbulence in the interstellar medium of our Galaxy. He also started work with CAASTRO Advisory Board member Ron Ekers and fellow CAASTRO members Morgan and Chhetri on developing techniques that use interplanetary scintillation to probe compact sources and to detect new pulsars with the MWA. He is continuing to work on detecting FRBs with the CRAFT survey and unravelling the mystery of their origin.

Mr Samuel McSweeney

CAASTRO PhD Student

Theme: Dynamic

McSweeney started his PhD at Curtin this year, under the supervision of Bhat and Tremblay (both at Curtin) and Avinash Deshpande (Raman Research Institute, India). He investigates the radio emission mechanism of pulsars by studying the sub-pulse drifting behaviour that some pulsars exhibit. His first first-author paper was recently accepted for publication.

Mr Bradley Meyers

CAASTRO PhD Student

Theme: Dynamic

Meyers' research interests are primarily in pulsar emission physics and interstellar propagation effects, especially at low frequencies. Meyer joined CAASTRO in early 2016 to work with Tremblay and Bhat at Curtin University on his PhD project, investigating sporadic emission phenomena from pulsars using the MWA Voltage Capture System. To date he has studied Crab giant pulses, using simultaneous observations with the MWA and Parkes to characterise giant-pulse spectral behaviour and energetics; in future he will investigate other kinds of sporadically emitting pulsars, such as nulling pulsars and Rotating Radio Transients, to find links between the populations. Meyers is the Curtin representative on the CAASTRO student committee.

Dr Steven Murray

CAASTRO Research Staff

Theme: Evolving

Murray is a postdoc working with the MWA Epoch of Reionisation (EoR) team. His work involves developing sophisticated statistical models of the plethora of radio sources that lie between us and the EoR, obscuring and distorting it. In particular, he has developed an analytic description of how the cosmological structure of the foreground sources interferes with the EoR signal. Alongside this work he also contributes to other projects, including characterisations of the ionosphere in the context of EoR observations and using halo modelling techniques to understand the biasing of HI sources.

Dr Marcin Sokolowski

CAASTRO Research Staff

Theme: Evolving

In 2016 Sokolowski was seconded to work on Curtin's SKA developments (mainly Engineering Development Array and MWA beam modelling). However, he continued to support BIGHORNS data acquisition. In 2016 he used BIGHORNS data to study the long-distance propagation of radio-frequency interference (mainly digital TV and FM radio) to the Murchison Radio-astronomy Observatory caused by tropospheric ducting. This work was presented at an IEEE conference and published in its proceedings. The BIGHORNS data were also used in conjunction with Desert Fireball Network to study statistics of signals from distant sources of interference that were reflected off aircraft, satellites and meteor trails.

Ms Kimberly Steele

CAASTRO Affiliate

Themes: Evolving, Dynamic, Education and Outreach

In March this year Steele joined the engineering team at Curtin full-time as an Engineering Graduate Intern, working on the Murchison Widefield Array. Her tasks includes managing digital media and documenting activity onsite; working with Randall Wayth and Marcin Sokolowski on Curtin's Engineering Development Array for the SKA; and Education and Outreach activities where possible. Steele is a returning CAASTRO member, having completed her Honours project with CAASTRO at Curtin in 2014.

Dr Steven Tremblay

CAASTRO Research Staff

Theme: Dynamic

Tremblay has continued to lead the Murchison Widefield Array's (MWA) Voltage Capture System (VCS) group. A significant portion of his effort in 2016 was focused on making the coherent beamforming capabilities as robust and easy to use as possible. This year he also published an analysis of two dozen Compact Symmetric Objects: these are radio galaxies, less than a kiloparsec end to end and probably young, that provide unique insight into the early stages of galaxy evolution. In addition, he joined the CAASTRO Gender Action Committee.

Dr Cathryn Trott

CAASTRO Associate Investigator

Themes: Dynamic, Evolving

Trott's work in the Evolving Universe theme has focused on processing Epoch of Reionisation (EoR) data from the MWA. She is also leading efforts to understand the impact of foreground contamination on EoR estimation. She has derived a framework for understanding the impact of ionospheric activity on EoR power spectra, and has published work exploring the benefits of wavelet analysis for studying signal evolution. This year she played a large role in shaping the EoR experiment for the SKA, working as part of the Science Working Group Board, and contributing to the design and specifications of the telescope. Trott is also a member of the Dynamic Universe theme, and here she contributes across a range of projects: for instance, predicting the rate at which the MWA and SKA-Low will detect fast radio bursts, and understanding the statistical properties of high-time-resolution data in order to detect signals more efficiently. She also plays active roles in the SKA Science and Engineering Advisory Committee and several SKA Resolution Teams.

Ms Mia Walker

CAASTRO Affiliate

Themes: Evolving, Dynamic, Education and Outreach

This year Walker joined the Murchison Widefield Array (MWA) operations team at Curtin. Her work includes the research, design and implementation of new equipment that will be used in the expansion of the MWA telescope. She was involved in the reconfiguration of the array into closely packed hexagonal stations, an arrangement that offers the best opportunities for detecting the Epoch of Reionisation.

Associate Professor Randall Wayth

CAASTRO Associate Investigator

Theme: Evolving

Wayth is a member of the Curtin University Department of Electrical and Computer Engineering and has both engineering and science interests in astrophysics. He took on the MWA Director role in 2016 and also manages the CAASTRO-supported BIGHORNS Epoch of Reionisation Global Signal project. Wayth co-supervises one CAASTRO PhD student working in the Evolving Universe theme. He has continued as Project Scientist within the SKA-Low Aperture Array Design and Construction (AADC) consortium, a role that he took up in 2015. Wayth works with several CAASTRO members on the MWA's GLEAM survey and Epoch of Reionisation key science program.

Ms Mengyao Xue

CAASTRO PhD Student

Theme: Dynamic

Xue started her PhD studies in Nov 2015 and joined CAASTRO in early 2016: she is supervised by Bhat, Tremblay, and Ord. She has been carrying out a low-frequency census of southern pulsars with the MWA. Her work is mainly based on the archival high-time-resolution data generated by the MWA Voltage Capture System (VCS) since 2014. She has also started to work on the polarimetric observations of pulsars made with the VCS.

Ms Xiang Zhang

CAASTRO PhD Student

Theme: Dynamic

Zhang is a PhD student who joined CAASTRO in September 2016. She works with Wayth and Hancock on a project to detect radio emissions from fireballs. In this, she searches for intrinsic radio emission from fireballs with the Murchison Widefield Array radio telescope and compares the results with data from the Desert Fireball Network.

CAASTRO UWA team members

THE UNIVERSITY OF WESTERN AUSTRALIA

CAASTRO AT THE UNIVERSITY OF WESTERN AUSTRALIA

The UWA node of CAASTRO has grown considerably in recent years and now has around 26 staff and students. The node is housed in the Ken and Julie Michael Building at the edge of the main campus, and its researchers work alongside colleagues at the International Centre for Radio Astronomy Research (ICRAR). The node has a direct link to the Pawsey Supercomputer network, which gives ready access to high-bandwidth data reduction and simulation facilities.

Work at the UWA node is focused on the Dark and Evolving themes. Research highlights for those two areas follow.

- The 2MASS Tully-Fisher (2MTF) survey was formally completed this year. We published a study of velocity field cosmography from the survey and made an analysis of the velocity power spectrum. A new PhD candidate has begun a study of the combined 6dFGSv and 2MTF samples.
- UWA and University of Sydney researchers have studied modified dark-energy models and the signatures they leave on the topology of the density field and cosmic voids.
- We have computed mock galaxy surveys, to measure the growth rate of cosmic structure and test general relativity in current (6dFGSv and 2MTF) surveys. Working with colleagues at the University of Queensland and Durham University in the UK, we have generated a wider set of modified gravity models and mock galaxy data (Simulations Of Non-standard Gravity, SONG), to calculate the inferred growth function from galaxy surveys.
- We have worked further on SURFS (Synthetic UniveRses For Surveys), a simulation set for following the evolution of galaxies from $z = 24$ to today. The final data set will have millions of synthetic galaxies that can be followed across cosmic time, linking observables to galaxy-formation physics.
- We published five papers on state-of-the-art hydrodynamical simulations of galaxy clusters, exploring different treatments of star formation and supermassive black hole growth. These studies clearly show how current galaxy-formation models suffer from 'fine tuning', and that differences in the predicted galaxy cluster are present in the wider galaxy population outside the cluster.
- We concluded a major study of the low-frequency radio halo of nearby starburst galaxy NGC 253 that used data from the Murchison Widefield Array's GLEAM and EOR surveys. This study has been submitted for publication.
- The first results from the WALLABY survey, which is to be carried out with the Australian SKA Pathfinder (ASKAP), were obtained with the ASKAP-12 early science array. CAASTRO, CSIRO and ICRAR researchers have all contributed to analysing the data.
- A new open-source code has been developed that rapidly fits brightness profiles to galaxy images. It is being applied to deep, high-quality images of SAMI galaxies from the KiDS survey.
- We have simulated gas-rich mergers of galaxies in groups and have found that, if the energy output from active black holes is lacking, these mergers create too many stars near the centers of massive elliptical galaxies.

In other highlights:

Obreschkow and Wong won WA Young Tall Poppy Awards, which recognise outstanding achievements in both research and science communication

Obreschkow's short science video, *Cosmic Eye*, has been viewed more than 150 million times

Power was awarded a University of Western Australia mid-career researcher prize.

Summary of future goals

- Combine the 2MTF and 6dFGSv data sets to explore large-scale structure and motions (bulk flow and velocity power spectrum) over larger distances than previously possible.
- Obtain and process ASKAP early science data from the DINGO and WALLABY HI surveys.
- Use the SURFS simulations to explore a variety of topics in galaxy formation, angular momentum build-up and satellite evolution, and further increase its resolution.
- Explore modified-gravity simulations and identify observables capable of distinguishing between modified cosmologies and the current concordance cosmology.
- Drive cutting-edge theoretical research on galactic angular momentum and cosmic large-scale structure. In connection with the first topic, submit a proposal for a meeting at the IAU General Assembly in 2018.

Professor Lister Staveley-Smith

CAASTRO Node Leader
Theme: Evolving and Dark

Staveley-Smith is UWA node leader and CAASTRO Deputy Director. He co-supervises three CAASTRO PhD students. In 2016 he facilitated a number of activities within the Australia-China ACAMAR collaboration, co-organising the inaugural workshops in Perth and Suzhou and overseeing a new ACAMAR scholarship scheme. He also helped the Executives of CAASTRO and CAASTRO-3D make appointments and other transition arrangements. Staveley-Smith's CAASTRO research activities this year included obtaining science results from the now-completed MWA GLEAM and 2MTF HI/NIR surveys and being involved in early science observations for the WALLABY survey.

Mr Kamran Ali

CAASTRO PhD Student
Theme: Dark

Ali, under the supervision of Danail Obreschkow, has dedicated most of his time to looking at statistical measures other than matter power spectrum, to constrain the warm dark matter model.

Mr Rodrigo Adolfo Cañas Vazquez

CAASTRO PhD Student
Theme: Evolving

Cañas Vazquez is a first year PhD student supervised by UWA node members Lagos, Power, Welker, and Elahi. He uses numerical simulations to understand the formation and evolution of galaxies, particularly those we can observe at the present time. For his PhD project, Cañas Vazquez will work with state-of-the-art cosmological simulations of galaxy formation to compare the properties of simulated galaxies with the ones observed in the universe. He will use mainly the Horizon-AGN simulation to study the co-evolution of galaxies and AGN, but will also work with the EAGLE and Illustris simulations.

Dr Weiguang Cui

CAASTRO Affiliate
Theme: Evolving and Dark

Cui uses cosmological simulations to study how massive clusters of galaxies and the cosmic web of filaments and voids are formed, and how they can be used to test our theories of galaxy formation and gravity. As part of the nIFTy galaxy cluster comparison, an international collaboration of galaxy formation modellers and simulators, Cui has led a comprehensive analysis of the internal structure of a galaxy cluster modelled with multiple leading astrophysical hydrodynamics codes, and has shown that the key differences between different simulations can be traced to different assumptions in how stars and black holes deposit their energy into the surroundings. Cui has also used a statistical sample of simulated clusters to investigate how reliably observational measures of cluster properties (e.g. the location of a cluster's centre or its dynamical state) recover the 'true' values, and has shown that measurements based on the stellar component are a more robust tracer than other measurements.

Dr Pascal Elahi

CAASTRO Affiliate
Themes: Evolving and Dark

Elahi is a computational astrophysicist studying cosmic structure in multiple cosmologies, dark-matter haloes, galaxy evolution and the physics of galaxy formation. He joined CAASTRO this year as an affiliate in the Evolving and Dark themes. Elahi's recent work has focused on developing tools for N-body simulations, studying the evolution of dark matter haloes across cosmic time, and investigating the lives of subhaloes/satellite galaxies; he has also worked on identifying the observational signatures of cosmological models that use modified dark matter, dark energy and gravity. Elahi is involved in several major research projects, such as the ICRAR-based SURFS (Synthetic UniveRses For Surveys) and the international nIFTy Cosmology collaboration.

Mr Guido Granda Muñoz

CAASTRO PhD Student
Theme: Evolving

Granda Muñoz is a first year PhD student supervised by UWA node members Lagos, Power, and Elahi. He is interested in galaxy formation and evolution and cosmology. Granda Muñoz comes to CAASTRO from the University of Innsbruck, Austria, as part of the Astromundus Master program. He is currently studying a fundamental distribution in the Universe, the velocity function, by comparing predictions of the Lambda-CDM cosmological model with observations of the distribution of galaxies per unit volume and per circular velocity interval. This research will help to clarify how well the currently accepted cosmological models, and their alternatives, match observational results.

Ms Katherine Harborne

CAASTRO PhD Student
Theme: Evolving

Harborne joined CAASTRO late in 2016. Her research, supervised by Power, focuses on studying feedback in dwarf galaxies using hydrodynamical simulations.

The research is motivated by the 'missing satellites' problem: Harborne hopes to produce better models of how dwarf galaxies evolve, to explain why current CDM simulations generate more sub-halos than we observe. As part of her PhD research, Harborne will also create mock catalogues that can be used with the SAMI Galaxy Survey.

Dr Cullan Howlett

CAASTRO Postdoctoral Researcher
Theme: Dark

Howlett joined CAASTRO at UWA in October 2015 and is active within the Dark theme. In 2016 he published forecasts of the tests of gravity that will be achievable with the WALLABY and TAIPAN surveys; he also led the cosmological analysis of data from the completed 2MTF survey. Howlett is co-chair of the large-scale-structure working group in the TAIPAN survey, which starts commissioning in Q1 2017. From August 2016 to January 2017 he was a member of the executive board for TAIPAN.

Dr Minh Huynh

CAASTRO Associate Investigator
Theme: Evolving

Huynh is a Senior Research Fellow at UWA. In November 2016 she became a Senior Data Scientist at CSIRO, jointly employed by ICRAR/UWA. Previously, from 2010 to 2013, she was the Deputy International Project Scientist for the Square Kilometre Array. Huynh studies galaxy formation and evolution, using sensitive multiwavelength data from ground and space-based observatories. She is currently using data from the Australia Telescope Compact Array to identify radio sources in some well-studied fields of the MWA's GLEAM survey. This will pave the way for future science that draws on both MWA observations and the EMU survey carried out with the Australian SKA Pathfinder.

Dr Anna Kapínska

CAASTRO Postdoctoral Researcher
Theme: Evolving

Kapínska is one of the core team members of the Galactic and Extragalactic All-Sky MWA (GLEAM) survey, which has now made its first public data release. Within the MWA collaboration, Kapínska is a member of the Radio Galaxies, Clusters and Cosmic Web GEG Science Team, focusing predominantly on radio galaxies and large-scale feedback from active galactic nuclei (AGN): she investigates radio galaxies with the use of radio data and semi-analytical models. In addition, she is a member of the science team for the citizen-science project Radio Galaxy Zoo. Kapínska has devised a pilot study on radio-loud AGN radio sources for the upcoming EMU (Evolutionary Map of the Universe) survey, which is to be carried out with CSIRO's Australian SKA Pathfinder telescope (ASKAP). Since 2014 she has also been the Project Manager for EMU, and looks forward to ASKAP early science data being delivered in 2017.

Ms Katharine Kelley

CAASTRO PhD Student
Theme: Dark

Kelley joined CAASTRO in 2015 as a member of the Dark theme. Her doctoral research principally relates to understanding and modelling QCD axion interactions, with a view to using radio telescopes as a tool for detecting dark matter. QCD axions have long been considered a strong candidate for cold dark matter, with mass, couplings and abundance that could account for a significant component of the dark-matter density. Exploiting the experimental techniques first published by Sikivie in 1982, she is modelling the expected all-sky signal 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, has explored relevant physical processes such as black-hole accretion and galaxy co-evolution, and has modelled the interstellar medium, star formation, 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 (awarded by the European Astronomical Society for the best PhD in Europe in the area of theoretical astrophysics). This year she was made a Distinguished Fellow of UWA's Institute for Advanced Studies.

Mr Lincheng Li

CAASTRO PhD Student
Theme: Evolving

Li is a joint PhD student from National Astronomical Observatories, Chinese Academy of Sciences. He has studied for his degree for two years in China and will continue at UWA for another two years (2016–2018). During his studies in China, Li investigated the environmental effect on the neutral hydrogen content in galaxies. At ICRAR-UWA he is working on the H I intensity-mapping project led by Staveley-Smith.

Dr Martin Meyer

CAASTRO Associate Investigator
Theme: Evolving

Meyer's research focuses on H I (neutral hydrogen) surveys and the role played by hydrogen gas in the formation and evolution of galaxies. He leads DINGO, a project that will take deep HI observations with the Australian SKA Pathfinder to understand how the H I content of the Universe has evolved over the past four billion years. In the lead-up to this project, Meyer is working on the CHILES deep H I survey being carried out with the VLA, as well as wide-field H I stacking experiments in the GAMA G09 field also being observed with this facility. Meyer is current co-chair of the H I galaxy science working group for the SKA.

Mr Scott Meyer

CAASTRO PhD Student
Theme: Evolving and Dark

Meyer has investigated the application of H I stacking to measuring Tully-Fisher parameters for galaxies that have no detectable H I emission, and has shown technique is promising for studying low-mass or high-redshift galaxies. Meyer undertook this work with his UWA supervisors, (Martin) Meyer, Obreschkow and Staveley-Smith. His research used data from the S-cubed simulations, HIPASS and 6dFGS, and could be extended to high-redshift datasets such as CHILES.

Dr Danail Obreschkow

CAASTRO Associate Investigator
Theme: Evolving and Dark

This year Obreschkow worked in the Evolving and Dark science themes. His key focus within Evolving is galactic angular momentum. To advance this topic, late in the year Obreschkow appointed a new post-doc, Liang Wang, on a large ARC Discovery Project grant shared with Karl Glazebrook (Swinburne University). Obreschkow is the primary supervisor of CAASTRO post-doc Dan Taranu, who is modelling galaxies observed by the SAMI survey, and co-supervises CAASTRO PhD student Scott Meyer, who is working on H I line stacking. Within the Dark theme, Obreschkow's main interest is the analysis of cosmic large-scale structure, especially higher-order spatial correlations. He is supervising CAASTRO PhD student Kamran Ali to work on this topic. Obreschkow has obtained $20k collaboration support that will enable Ali to spend two months in Switzerland and the UK for this project in early 2017.

Dr Se-Heon Oh

CAASTRO Postdoctoral Researcher
Theme: Evolving

Oh has focused 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 (ASKAP) telescope, Oh has developed a software package for the kinematic analysis of resolved galaxies. The new software, 2DBAT, is based on Bayesian MCMC analysis: it can perform robust and systematic analysis of the dynamics of an unprecedented number of galaxies in a fully automated manner, removing the previous subjectivity in the analysis. In conjunction with Obreschkow, Oh co-supervised Masters student Kirsty Butler for her project on measuring the baryonic angular momentum in dwarf galaxies. Butler successfully completed this and obtained her Masters degree from UWA in August 2016. She published her results in ApJ Letters and was nominated for the Astronomical Society of Australia's Bok prize. Oh moved to a tenured position in radio astronomy at the Korea Astronomy and Space Science Institute in August 2016.

Ms Clare Peter

CAASTRO Administrator

Peter provides administrative support, and coordinates reporting and financials for the UWA node. She works alongside the ICRAR-UWA administration team.

Dr Attila Popping

CAASTRO Postdoctoral Researcher
Theme: Evolving

Popping's research interests lie in galaxy evolution, the neutral hydrogen content of galaxies in particular. He leads IMAGINE, a Legacy project of the Australia Telescope Compact Array: this is an investigation of the extended environment of galaxies, aimed at improving our understanding of galaxies interact with the surrounding intergalactic medium. He is an active contributor to the DINGO and WALLABY surveys being made with the Australian SKA Pathfinder (ASKAP) telescope and was member of ACES, the ASKAP Commissioning and Early Science team. Popping is working on several experiments involving H I stacking and plans to use stacking techniques to do early science with ASKAP. He is also a core member of the CHILES survey, a large project on the VLA in the USA to investigate neutral hydrogen gas at intermediate and high redshifts.

Professor Chris Power

CAASTRO Associate Investigator
Theme: Evolving

Power's CAASTRO work in 2016 focused on two main areas. One was the detailed analysis of simulated massive galaxy clusters, run as part of the nIFTy galaxy cluster comparison, which has led to the publication of five papers so far. Power has been working on predictions for the thermodynamical structure of the outskirts of galaxy clusters and their consistency across different codes; how they are influenced by substructure and the cluster's position within the larger scale cosmic web; and the nature of the emission future radio surveys might detect from the warm intergalactic medium. Power's second area of focus was the use of N-body models of disc galaxies to understand how observational kinematic measurements made with integral-field spectrographs such as SAMI relate to the true underlying kinematics measured directly from the model. Power is working on this topic with CAASTRO PhD student Ms Kate Harborne, who is investigating it as part of her thesis.

Mr Fei Qin

CAASTRO PhD Student
Theme: Dark

Qin's PhD thesis is based on testing the cosmology model with bulk-flow measurements. The bulk-flow velocity is the weighted mean value of the peculiar velocities of galaxies and arises from the mass-density contrast of the Universe at various scales. Qin is estimating the bulk flow velocity with a data set drawn from the 2MTF and 6dFGSv surveys, using a log-normal peculiar velocity estimator together with the minimum variance method and the maximum likelihood method.

Mr Tristan Reynolds

CAASTRO Pre-PhD Student
Theme: Evolving

Reynolds' pre-PhD project is using data from observations taken with the CSIRO-designed phased-array feed (PAF) that was mounted on the Parkes radio telescope this year. Reynolds first Parkes PAF observations of the Large Magellanic Cloud to verify that the data-reduction pipeline worked correctly. He then reduced observations taken of the GAMA G23 field to perform H I stacking of GAMA galaxies with faint or null H I detections. This work will lead into Reynolds' PhD research with Staveley-Smith of carrying out H I stacking using data from the WALLABY survey on ASKAP. He will begin this project in 2017.

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. His main project at present is an H I intensity-mapping experiment using the Parkes radio telescope. In 2016, Rhee conducted a pilot HI intensity-mapping observations using a new phased-array feed (PAF), developed for the Effelsberg 100-m telescope by CSIRO but installed on Parkes for testing prior to shipping. The PAF system gave Parkes a wider field-of-view and bandwidth, speeding up the intensity-mapping observations. During the commissioning of the system, Rhee tested the spectral-line observation mode, observing calibrators and taking H I spectra of nearby galaxies and intensity-mapping data.

Mr Khaled Said

CAASTRO PhD Student
Theme: Dark

Said is currently a joint PhD candidate at the University of Cape Town and the University of Western Australia. His PhD thesis is aimed at exploring the density distribution and dynamics of galaxies in the Zone of Avoidance (ZOA). He has already published the requirements to achieve such a goal: a calibrated and unbiased Tully-Fisher relation to be used as the global template relation; 21-cm observations of spiral galaxies in the ZOA, from which to extract the redshift and the rotational velocity of galaxies; and deep NIR imaging of the H I sources, to measure the apparent magnitude of each galaxy. Said is currently using these NIR and H I data with the recently calibrated Tully-Fisher relation to derive distances and peculiar velocities for inclined spiral galaxies in the southern Zone of Avoidance. He will submit his thesis in February 2017.

Mr Paul Scott-Taylor

CAASTRO PhD Student
Theme: Evolving and Dark

Scott-Taylor investigated the formation and evolution of galaxies through radio-continuum emission from star-forming galaxies. His work focused on the development of new semi-analytic models for the continuum emission. Scott-Taylor withdrew from his PhD in 2016.

Dr Dan Taranu

CAASTRO Postdoctoral Researcher
Theme: Evolving

Taranu is a member of the SAMI Galaxy Survey team. He has developed code to build realistic 3D models of spiral galaxies that include the main components of spirals: a thin disk of rotating stars, a compact, spherical stellar bulge, and a spherical halo of invisible dark matter. By adjusting the properties of each component, Taranu can make the models fully reproduce the motions of stars in galaxies as observed by the SAMI spectrograph, which gives a way to measure the sizes and masses of each component more precisely. Taranu has also run dozens of sophisticated supercomputer simulations of collisions of spiral galaxies in groups. Such dramatic galaxy mergers are thought to have created the most massive elliptical galaxies in the nearby universe, some of which have been observed with SAMI. Taranu co-supervised Masters student Lesley Maddox (with Obreschkow, her principal supervisor) on the topic of simultaneously modelling H I emission lines and SAMI IFU maps. Maddox successfully completed this project and obtained her Masters degree from UWA in August 2016.

Dr Charlotte Welker

CAASTRO Affiliate
Theme: Evolving

Welker is a Research Associate and Jim Buckee Fellow at ICRAR/UWA. She works on hydrodynamic, cosmological and zoom simulations, mostly using the AMR code RAMSES. Welker's main research interest is the interplay between the cosmic web on large scales and galaxy evolution. She is particularly interested in how the filamentary pattern of the cosmic web funnels the gas inflows and infalling satellites down to the core of haloes, greatly affecting the advection of angular momentum that ultimately shapes galaxies. Welker was recently granted 1.45 million CPU hours on Australian supercomputers to simulate highly resolved groups and clusters. Using these, she can investigate the fate of the gas in more detail, and produce fine morphometric bulge/disc decompositions that can be compared with results from the SAMI survey.

Dr O. Ivy Wong

CAASTRO Affiliate
Theme: Evolving

Wong works 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 will use the new radio telescopes located in Western Australia, the Murchison Widefield Array and the Australian SKA Pathfinder (ASKAP), to help her answer some of these questions. Wong co-leads Radio Galaxy Zoo (with Dr Julie Banfield, ANU), an online citizen-science project aimed at cross-matching radio jets with the host galaxies from which the jets emanate. Wong has also joined the ASKAP spectral-line early science processing team to examine early-science data that has been taken for the WALLABY survey.

CAASTRO University of Sydney team members

THE UNIVERSITY OF SYDNEY

CAASTRO AT THE UNIVERSITY OF SYDNEY

The CAASTRO Sydney node is co-located with the Sydney Institute for Astronomy (SIfA) within the University of Sydney's School of Physics. 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 2016 CAASTRO's Sydney node moved back from the University's Redfern annex to the main University campus. It is now located in the Physics building.

This year there were 32 CAASTRO team members at the Sydney node, including 12 students. The research activities at this node mainly fall within the Evolving and Dynamic themes.

In the Evolving Universe theme, our major activities for 2016 (and the Sydney node researchers involved in them) were:

- 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, covering both isolated galaxies and those in groups and clusters. The SAMI instrument uses a novel 'hexabundle' technology jointly developed by Sydney and the AAO (Australian Astronomical Observatory). The survey continues to make excellent progress. The Sydney node researchers taking part were Bland-Hawthorn, Bloom, Bryant, Croom, Fogarty, McElroy, Richards, Sadler, Schaefer and Scott
- 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 involved Callingham, Lenc, Murphy and Sadler
- 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, as part of the ASKAP FLASH survey. Glowacki, Mahony, Moss, Reeves and Sadler were involved.

In the Dynamic Universe theme, our main activities were:

- working on two ambitious new radio transient surveys. We analysed data from the MWA transient survey and continued to prepare for the Variables and Slow Transients (VAST) survey, which is to be made with the Australian SKA Pathfinder. This year we focused particularly on searching for time-dependent radio emission from stars and planets, and investigating and developing novel techniques (including variance imaging) for detecting pulsars. The researchers involved were Dobie, Lynch, Musaeva, Murphy, Ward and Zic
- Searches for Fast Radio Bursts with the upgraded Molonglo radio telescope (UTMOST), in collaboration with CAASTRO CI Matthew Bailes and colleagues at the Swinburne node. Campbell-Wilson, Murphy and Green participated.

Our visitors this year included Professor Sarah Ellison (University of Victoria, Canada), Dr Steve Croft (University of California Berkeley), Dr David Kaplan (University of Wisconsin) and Professor Alistair Edge (Durham University), as well as many researchers from other CAASTRO nodes who visited us for Busy Weeks and workshops. Many CAASTRO staff helped with the organisation of the 50th-anniversary meeting of the Astronomical Society of Australia, held at the University of Sydney in July 2016, and we also organised the workshop "A Celebration: Bruce Slee and 70 Years of Radio Astronomy" at the University in August.

Our 2016 science highlights from the Evolving Universe theme included the award of the Astronomical Society of Australia's inaugural Peter McGregor Prize to the SAMI team. This award recognized "the impressive development of the 'hexabundle' technology that has been the primary enabler for the SAMI instrument, representing a significant leap in capability for multi-object spectroscopy". Rebecca McElroy's paper on the galaxy Markarian 1018 identified it as a rare 'changing look' AGN (active galactic nucleus) in which broad optical emission lines have appeared and disappeared on timescales of years to decades. Such objects can provide unique clues about the processes through which gas is accreted onto the central black holes in massive galaxies. Joseph Callingham completed his catalogue and analysis of peaked-spectrum radio sources in the MWA GLEAM survey. These objects are believed to represent the earliest stages in the life of a radio galaxy, and Joe's work has more than doubled the number of known peaked-spectrum sources (details, page 14). Emil Lenc published a pioneering study of three-dimensional magnetised structures within our local region of the Milky Way, based on the analysis of polarimetric observations with the MWA.

In the Dynamic Universe theme, highlights included Christene Lynch's paper on radio emission from ultra-cool white dwarf stars (which showed that many of these stars can generate and sustain strong magnetic fields) and the first new detections of fast radio bursts from the Molonglo radio telescope (UTMOST). The first direct detection of gravitational waves was announced in February 2016: Tara Murphy and colleagues were actively involved in the search for radio counterparts of the gravitational-wave signal, taking advantage of the wide-field imaging capabilities of the MWA and the Australian SKA Pathfinder.

One of our main education and outreach activities continues to be the *CAASTRO in the Classroom* program, and our School Education Officer Jenny Lynch continues to do an outstanding job of streaming talks and discussion sessions with CAASTRO astronomers to high schools across Australia. The program has been larger than ever this year, with over 2000 students joining some of the live-stream presentations. Several Sydney node researchers and students again travelled to Uluru to take part in CAASTRO's 'Astronomer in Residence' program at the Voyages resort. We also held the first Sydney Astrofest at the University of Sydney in July 2016, and it was a very successful and well-attended event.

The University of Sydney hosts CAASTRO's main administrative office, which in 2016 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 Public Relations). 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. The team organised two major international conferences in 2016, along with our Annual Retreat and a range of smaller workshops.

Professor Elaine Sadler

CAASTRO Chief Investigator
CAASTRO Director and Sydney Node Leader

Theme: Evolving

Sadler is working with Allison (CSIRO), Mahony, Moss, Reeves and Glowacki and other members of the FLASH (First Large Absorption Survey in HI) team to study HI absorption in galaxies out to redshift $z = 1$. For this work they are using new tools and techniques developed for the forthcoming FLASH survey, which will be carried out with the Australian SKA Pathfinder (ASKAP) telescope at the Murchison Radio-astronomy Observatory. In 2016 the team's members continued their analysis of data obtained with the first six dishes of ASKAP, and began a new set of observations with a 12-antenna system as ASKAP entered its Early Science phase. Results from this work were presented at several national and international astronomy meetings. Sadler has also worked with Curtin CAASTRO researcher Rajan Chhetri to investigate using MWA measurements of interplanetary scintillation as a way to identify the most compact low-frequency radio sources in the southern sky. These objects will be particularly interesting targets for the FLASH survey.

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. Bland-Hawthorn's particular interest is to understand the evolution of galaxies in the context of their environment. He is a member of the GASKAP survey team that targets gas in the Galactic halo, and a member of the GAMA and CALIFA galaxy survey teams. Bland-Hawthorn is an ARC Australian Laureate Fellow.

Ms Jessica Bloom

CAASTRO PhD Student
Themes: Evolving, Dark

Bloom's focus is understanding the role of events such as mergers in galaxy evolution. She has used tools developed to identify perturbed galaxies and study the relationships between kinematic asymmetry, stellar mass and star formation; she has demonstrated that kinematic asymmetry is inversely proportional to stellar mass and is linked to an increased concentration of star formation. She plans to 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's key projects centre on using the dynamics of stars and gas, as measured by the SAMI Galaxy Survey, to identify how gas gets into galaxies to build up mass and make galaxies look the way they do in different formation environments. Bryant is on the SAMI Galaxy Survey Executive team, chairs the Target Selection workgroup, is SAMI Instrument Scientist and runs the observations with the SAMI instrument at the Anglo-Australian Telescope. Bryant is also the Project Scientist for the Hector instrument, SAMI's successor: Hector will be able to take spectra of more than ten times as many galaxies. As Project Scientist, Bryant links astronomers and instrument teams. She is also continuing to work on astronomical instrumentation, developing new astrophotonic optical-fibre imaging bundles for Hector.

Mr Joseph Callingham

CAASTRO Theme: Evolving
CAASTRO Postgraduate Student

Callingham has been working on spectral modelling of young radio galaxies using data from the MWA and ATCA. He has helped produce the all-sky survey of the MWA, a study of the accuracy of the low-frequency flux scale for the southern hemisphere, and a new catalogue of young radio galaxies; he has also investigated the circumstellar environment of Supernova 1987A at low radio frequencies. In 2017 he will begin work at ASTRON as a postdoctoral fellow.

Mr Duncan Campbell-Wilson

CAASTRO Affiliate
Theme: Dynamic

Campbell-Wilson has successfully developed a new radio receiver for the Molonglo radio telescope using integrated radio components, field programmable gate arrays and fibre optics. In the process, he identified a number of subtle difficulties in operating digital technologies next to very sensitive astronomical receiving equipment and began implementing the engineering solutions. He also revamped a number of critical systems in the telescope infrastructure with newer technology. DRAO in Canada has tested Campbell-Wilson's new, well-matched wideband antenna and developed it further for radio astronomy.

Professor Scott Croom

CAASTRO Chief Investigator
Theme: Evolving

Croom is leading the SAMI Galaxy Survey, a project to carry out spatially resolved spectroscopy on thousands of galaxies, using the Sydney–AAO Multi-object Integral-field spectrograph (SAMI) on the Anglo-Australian Telescope. In 2016 the SAMI Galaxy Survey continued apace: it has now observed over 1,800 galaxies. Among the exciting new results published this year were the connections between angular momentum and optical morphology, the role of galaxy interactions in clusters, identification of galaxy-scale winds and accurate measurements of the star-formation rate. In 2017 we can look forward to even more science from SAMI, including investigations of the role of environment in determining star formation and dynamics in galaxies, the distribution of young and old stars in galaxies, and the role of groups and clusters in shutting down star formation. 2017 will also see the next public data release from SAMI.

Mr Dougal Dobie

CAASTRO Student (Honours)

Theme: Dynamic

Dobie has been working with data from the Australia Telescope Compact Array, searching for Extreme Scattering Events (ESEs): these are lensing effects caused by large clouds of plasma. In the course of his Honours thesis, supervised by Tara Murphy and Keith Bannister (CSIRO), Dobie detected many interesting variable sources, including the longest-lasting ESE known. In 2017 Dobie will begin his PhD, again supervised by Murphy, working on the VAST (Variables And Slow Transients) survey being carried out with the Australia Telescope SKA Pathfinder.

Mr Marcin Glowacki

CAASTRO PhD Student

Theme: Evolving

Glowacki is part of the FLASH (First Large Absorption Survey in HI) team working with the Australian SKA Pathfinder. The aim of FLASH is to search for cool, star-forming material in the early Universe ($0.4 < z < 1.0$) by means of HI 21-cm absorption, and so 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 HI 21-cm absorption with the Australian Telescope Compact Array (ATCA), using a sample of AT20G-selected (Australia Telescope 20-GHz survey) compact radio galaxies.

Ms Debra Gooley

CAASTRO Finance Officer

Gooley helps CAASTRO to achieve its goals and objectives by coordinating and managing the KPI (key performance indicator) and financial reports required for its primary funding body, the Australian Research Council (ARC).

Professor Anne Green

CAASTRO Affiliate

Themes: Dynamic and Evolving

Green is a collaborator on a project with CAASTRO's Swinburne Node to upgrade the capabilities of the Molonglo Telescope, converting it to a multi-tasking detector of transient sources. This project, UTMOST, was launched in December 2015 to coincide with the 50th Anniversary of the opening of the telescope. In 2016 Green's science focused on searches for transient sources at cosmological distances and deep imaging of radio relics and halos around massive galaxies.

Ms Kate Gunn

CAASTRO Chief Operating Officer

Gunn has been CAASTRO's Chief Operating Officer for six years. A start-up specialist with a wealth of business and University experience, she has 25 y ears in management and a background in the commercialisation of University intellectual property.

Ms Helen Keys

CAASTRO Executive Assistant

Keys joined CAASTRO in 2015 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 (SEG). During 2016 Keys co-ordinated arrangements for the Walter Stibbs and Hunstead Lecture Series, and facilitated meetings of CAASTRO Advisory Board, Executive, and various events on behalf of CAASTRO.

Dr Emil Lenc

CAASTRO Postdoctoral Researcher

Theme: Evolving

Lenc joined the Slow Transients group at the University of Sydney in 2016. His research focuses on exploring new search techniques for transients and pulsar-like objects in Murchison Widefield Array (MWA) data. This builds on earlier research he undertook in the Evolving theme, in which he developed tools for MWA polarimetry and difference imaging. Lenc plans to continue exploring these techniques and apply them to existing survey data to search for pulsars, exoplanets and flare stars.

Ms Jing Li

CAASTRO Honours Student
Theme: Evolving

Li has been working with the data from SAMI Galaxy Survey to measure the star-formation rates (SFRs) of galaxies in clusters. She is comparing these SFRs with those measured by radio and infrared surveys, to investigate how the radio-SFR correlation varies with environment. Li began her Honours project in mid 2016 and is supervised by Julia Bryant.

Dr Christene Lynch

CAASTRO Postdoctoral Researcher
Theme: Dynamic

This year Lynch continued her work with 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 used the Murchison Widefield Array (MWA) to detect faint, polarised flares from the star UV Ceti. This work illustrated the importance of using polarised imaging to detect faint sources in MWA observations. She also completed an MWA observing campaign of the Upper Scorpius Association, placing the first limits on radio emission from young exoplanet systems. In 2017 Lynch will continue her search for radio emission from low-mass stars with a 100-hour survey of nearby, magnetically active M-dwarf stars.

Ms Jenny Lynch

CAASTRO School Education Officer

An experienced science communicator and project manager, Lynch is responsible for running the outreach program *CAASTRO in the Classroom*. She has a background in medical physics and over 16 years' experience working in science and science communication. With support from the Commonwealth Government through the Australian Maths and Science Partnerships Program (AMSPP), *CAASTRO in the Classroom* was expanded in 2016 to reach a national audience through videoconferencing and live streaming sessions for schools. This year Lynch worked with experienced science teachers to develop classroom resources and deliver professional-development workshops for teachers.

Dr Elizabeth Mahony

CAASTRO Postdoctoral Researcher
Theme: Evolving

In 2016 Mahony continued working on the upcoming First Large Absorption Survey in HI (FLASH) survey, along with fellow CAASTRO members Sadler, Allison, Moss and Glowacki. Using commissioning data, Mahony has detected HI absorption in a number of bright radio galaxies, providing insight into the fuelling mechanisms at play in active galactic nuclei. She has also been testing data pipelines and compiling multiwavelength datasets, to prepare for a larger, blind survey for HI absorption that will be carried out with the Australian SKA Pathfinder during its Early Science phase.

Ms Rebecca McElroy

CAASTRO PhD student
Theme: Evolving

McElroy works on integral-field spectroscopy of active galaxies. She is a member of the SAMI Galaxy Survey, helped with SAMI observations, and has worked to combine her AGN dataset and the SAMI sample in a new comparison paper.

Dr Vanessa Moss

CAASTRO Postdoctoral Researcher
Theme: Evolving

Moss joined the First Large Absorption Survey in HI (FLASH) team in mid-2014. Her focus is on the galactic ecosystems of both intervening and associated absorbing systems, with an emphasis on their multiwavelength footprints. She was the primary observer for the FLASH team when it used the six-antenna BETA array of the Australian SKA Pathfinder during 2015–2106 to make observations towards more than 100 galaxies. Moss is currently leading the analysis of an X-ray sample she developed to study the connection between HI and X-ray absorption. In 2016 she also represented CAASTRO in science communication and outreach activities, including Science Meets Parliament and the CAASTRO Astronomer in Residence program at Uluru.

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 (at gigahertz frequencies) and exoplanets and flare stars (at low frequencies). In addition, she 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 2017 Murphy will be conducting the first radio transients surveys with the Australian SKA Pathfinder (ASKAP) telescope, and using the Murchison Widefield Array and ASKAP telescopes to search for electromagnetic counterparts to gravitational-wave events.

Ms Aina Musaeva

CAASTRO PhD student
Theme: Evolving

In 2016 Musaeva authored two peer-reviewed papers for publication in the Monthly Notices of the Royal Astronomical Society. She is currently writing up her PhD thesis.

Ms Sarah Reeves

CAASTRO PhD Student
Theme: Evolving

Reeves submitted her PhD thesis, "21-cm emission and absorption in nearby gas-rich galaxies", in February 2016. She is now working at the Powerhouse Musuem in Sydney.

Mr Samuel Richards

CAASTRO PhD Student
Theme: Evolving

In 2016 Richards completed his PhD thesis, "Advancements in multi-object integral-field spectroscopy". This thesis is the culmination of Richards' many years work on the Sydney-AAO Multi-object Integral-field spectrograph (SAMI), detailing its instrumental development and astronomical progress.

Dr Richard Scalzo

CAASTRO Affiliate
Theme: Dark, Dynamic

In late 2015 Scalzo moved to a new research position at the University of Sydney's Centre for Translational Data Science, but he has remained involved with CAASTRO as an Affiliate. He is continuing his research on Type Ia supernovae, developing hierarchical Bayesian models to provide the largest and most accurate available suite of bolometric light curves to date. With several other CAASTRO members (Gunn, Hinton, Möller, Murray, Zhang), Scalzo participated in the 2016 Atlassian *ShipIt* hackathon, where CAASTRO's team placed fifth in a field of more than 200 teams.

Mr Adam Schaefer

CAASTRO Postgraduate Student
Theme: Evolving

Schaefer is a postgraduate student working within the Evolving Universe theme. He has been a member of CAASTRO since 2013. Schaefer uses 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

Scott is a University of Sydney Postdoctoral Research Fellow and CAASTRO affiliate. His research focuses on understanding the processes of galaxy assembly through the use of spatially resolved spectroscopy. In 2016 Scott led the analysis of stellar populations within the SAMI Galaxy Survey, and continued to study the nature of dwarf elliptical galaxies with the SAMI instrument.

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 2016 she coordinated the publicity for the inaugural Sydney Astrofest, which attracted around 2000 people.

Ms Charlotte Ward

CAASTRO Student (Honours)
Theme: Dynamic

In 2016 Ward focused on time-domain radio astronomy, particularly the automated detection of fast radio bursts and other transients from Parkes telescope survey data. To address the difficulties of identifying single pulses in large datasets, and the need to identify fast radio bursts in time for multiwavelength follow-up, she has been working on machine-learning techniques for detecting these events. Ward's previous work has included using pulsars to study refractive scintillation in the ISM and studying radio emission from ultra-cool dwarfs.

Ms Kylie Williams

CAASTRO Events and Communications Officer

Williams coordinates the regular CAASTRO newsletter and organises various events hosted by CAASTRO around Australia. In 2016 she organised or assisted with a record 16 meetings, including the 50th ASA Meeting in Sydney, the CAASTRO annual retreat in Busselton, WA, and two international conferences, "Diving into the Dark" in Cairns and "The Changing Face of Galaxies" in Hobart.

Mr Andrew Zic

CAASTRO Student (Honours)
Theme: Dynamic

Zic is interested in investigating radio transients, and techniques to detect them. As part of his honours project, he implemented statistical techniques to detect the diffractive interstellar scintillation of pulsars using data from the Murchison Widefield Array. These techniques can be used as an alternative search method for pulsars, which overcomes some limitations of traditional search methods. His upcoming PhD thesis will focus on characterising the population of radio-loud flare stars, and placing constraints on the physical mechanisms responsible for the radio emission.

CAASTRO University of Melbourne team members

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 a track record of excellence in observational and theoretical cosmology, areas which provide the basis for our contributions to CAASTRO.

Evolving Universe theme

CAASTRO researchers at the University of Melbourne work primarily within the Evolving Universe theme, which Professor Stuart Wyithe leads. Within this theme, they are largely focused on Epoch of Reionisation (EoR) science.

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, Kim and Wyithe published a paper showing the statistical relationship between ionising luminosity and megaparsec-scale overdensity, using detailed models of galaxy formation. They then used a Monte-Carlo technique to apply this relationship to reionisation of the intergalactic medium within large-volume dark-matter simulations. The resulting simulations can be used to address the contribution of very-large-scale clustering of galaxies to the structure of reionisation. Imaging this structure during the Epoch of Reionisation is a key goal for the Square Kilometre Array.

By the end of 2016, the Epoch of Reionisation (EoR) team within the MWA Collaboration had observed a total of about 2200 hours in three EoR fields, generating about three terabytes of data. The team has developed two software calibration and analysis pipelines, one essentially based in the US and the other a collaboration between Melbourne and Curtin Universities. Jacobs *et al*. (2016) this year published a major paper comparing the outputs between the different pipelines and establishing the protocols for verification of the pipeline outputs. CAASTRO researchers Pindor and Procopio made major contributions to this effort. The next significant phase of the data analysis was planned, and implementation commenced. In collaboration with Cathryn Trott from Curtin University, Pindor was also involved in developing the Cosmological H I Power Spectrum Estimator (CHIPS), an algorithm developed and implemented with data from the Murchison Widefield Array. Applying CHIPS to three hours of EoR data, we set a 2σ upper limit on the EoR dimensionless power spectrum.

CAASTRO PhD student Stephanie Bernard discovered galaxy candidates during the EoR ($z\sim10$) in archival Hubble Space Telescope (HST) data from the Brightest of Reionizing Galaxies (BORG[z8]) Survey. The Wide Field Camera 3 (WFC3) on the Hubble Space Telescope had previously made it possible to search for galaxies at $z\sim8–11$ (500–700 Myr after the Big Bang). To continue quantifying the number density of the most luminous galaxies at the earliest epoch observable with HST, Stephanie searched for $z\sim10$ galaxies and identified six candidates. Three of the sources, including the two brightest, are in a single WFC3 pointing: this suggests significant clustering, which is expected from bright galaxies at $z\sim10$. The study highlights that $z\sim10$ searches can yield a small number of candidates.

High redshift galaxies were also studied theoretically. In 2016 CAASTRO student Antonios Katsianis completed his PhD and published the final two papers associated with it. The first of these papers looked at the evolution of the star-formation rate function (SFRF) and cosmic star-formation rate density (CSFRD) of galaxies at $z\sim1–4$. Katsianis focused on the role of feedback from active galactic nuclei (AGN) and supernovae in form of galactic winds, and found that the key factor for reproducing the evolution of the observed SFRF and CSFRD at $z\sim1–4$ is the presence of a feedback mechanism that is prominent at high redshifts ($z>4$) but which becomes less efficient with time. In a second paper Katsianis investigated the relation between the star-formation rate and the stellar mass of galaxies at $z\sim1–4$. Examining the evolution of the relation, he found that simulations could produce results consistent with observations that use spectral energy distribution techniques to estimate star-formation

rates, dust corrections, and stellar masses, but that they were not able to reproduce results obtained by combining only UV and IR luminosities (UV + IR). Thus, surveys that preferentially select star-forming galaxies typically predict a larger median or average star-formation rate at a fixed stellar mass than mass-selected samples and hydrodynamic simulations.

Intensity mapping of the neutral hydrogen (H I) is a new observational tool with which to efficiently map the large-scale structure over wide redshift ranges. CAASTRO researcher Laura Wolz presented a new cleaning technique, using independent component analysis, to remove foreground emission, and developed a Fourier-based optimal estimator to compute the temperature power spectrum of the intensity maps and cross-correlation with the galaxy survey data. The new technique generates cross-correlation measurements between WiggleZ galaxies and H I data taken with the Green Bank Telescope that are similar to those obtained by the Singular Value Decomposition (SVD) method, and confirms that foreground subtraction with the new technique preserves the 21-cm signal of interest.

Dark Universe theme

In 2016 Mack, in collaboration with Wyithe, continued to investigate the impact of energy released from self-annihilating dark matter (DM), by calculating the heating of gas in the intergalactic medium surrounding the small, high-redshift DM haloes thought to host the first stars. The main results were that the injected energy from DM suppresses accretion onto 10^5–10^6 $M_\odot$ haloes at redshifts above 20, increasing the Jeans mass in early haloes into which primordial gas would otherwise accrete. This indicates that DM annihilation could delay the formation of the first galaxies.

Other Highlights

The Melbourne node continued to make strong contributions in outreach, public, and professional education activities throughout 2016.

Key events included the March launch of Melbourne Planetarium's new show *Capturing the Cosmos*, a collaboration between CAASTRO and Scienceworks; hosting of the national *Diversity in Astronomy* workshop in June; and Professor Rachel Webster's November delivery of the *Allison Levick Memorial Lecture*, a free public lecture on 'Illuminating the Dark Ages of the Universe'. Further afield, Procopio, Bernard, King and Tescari represented Melbourne as the *Astronomer in Residence* at the Ayers Rock Resort in the Northern Territory (NT). In August, Professor Rachel Webster made her annual pilgrimage to the NT as one of four guest astronomers at the annual *Uluru Astronomy Weekend*, further strengthening the ties between CAASTRO and the NT community.

As in past years, numerous secondary school students engaged with CAASTRO as part of the *Telescopes in Schools* initiative and via the University of Melbourne's Year Ten work-experience program, which now includes an observing night to which parents are invited.

Future goals

2017 promises to be another very exciting year for CAASTRO research at Melbourne, with further results addressing the two of the biggest questions posed in the Evolving theme. We look forward to highlights that include:

- publication of the deepest limits from the Murchison Widefield Array experiment to detect the Epoch of Reionisation, with a theoretical analysis based on the simulations developed during the first five years of CAASTRO
- application of our simulated intensity maps to data taken as part of CAASTRO's Parkes HI intensity-mapping program
- publication of results from our program to simulate the material ejected by winds from SAMI galaxies
- publication of calculations of how decaying dark matter modified gas and galaxy formation around the earliest galaxies.

Professor Stuart Wyithe

CAASTRO Node Leader
Themes: Evolving, Dark

In 2016 Wyithe worked on new programs to model the cross-correlation between HI and optically detected galaxies (which will be applied to the CAASTRO intensity-mapping experiment) and on hydrodynamic simulations of SAMI galaxies. In 2017 Wyithe will cease to be a CAASTRO CI and take up his role as Deputy Director for CAASTRO-3D. He will be succeeded as Node Leader by Professor Rachel Webster.

Professor Rachel Webster

CAASTRO Chief Investigator
Theme: Evolving

Webster's primary focus has been on the continuing development of the Murchison Widefield Array pipeline to analyse the substantial Epoch of Reionisation (EoR) dataset and, now, how the pipeline will be supported in the long-term. She is also working with Japanese colleagues on a new aspect to the project, the cross-correlation of the EoR H I signal with the high-redshift population of Lyman-alpha galaxies.

Ms Stephanie Bernard

CAASTRO PhD Student
Themes: Dynamic, Evolving

Bernard's PhD project is looking at bright galaxies during the Epoch of Reionisation. In 2016 she led the analysis of new Brightest of Reionizing Galaxies (BoRG) survey data, taken with the Hubble Space Telescope, and identified a large sample of new galaxy candidates from only 500 million years after the Big Bang. Bernard also led a program using the Spitzer Space Telescope to follow up these galaxies, and was the first Australian PhD student to be awarded time on this telescope. These new data allow for a more confident determination of the number of bright galaxies during the Epoch of Reionisation.

Dr Catherine de Burgh-Day

CAASTRO PhD student
Theme: Dark

De Burgh-Day was awarded her doctorate at the end of January 2016 and went to her preferred first job as a 'Software Testing Lead: Numerical Modelling', at the Melbourne headquarters of the Bureau of Meteorology. De Burgh-Day's thesis on the Direct Shear Mapping technique was recognised by her joint award of the Royal Society of Victoria Young Scientist Research Prize for the Physical Sciences at the end of 2015.

Ms Jacinta den Besten

CAASTRO Affiliate
Theme: Education and Outreach

2016 was a busy year for den Besten. First up was the opening night (and day) for the new planetarium show *Capturing the Cosmos*, a collaboration between CAASTRO and Scienceworks. The launch included a live interview session with schools across Victoria. Den Besten was also involved in the organisation of the inaugural Sydney Astrofest, held at the University of Sydney in July, and the AstroLight (Astronomy and Light) festival, which returned to Scienceworks in September (with CAASTRO again as the main sponsor). Both events showcased Australian astronomy through talks, displays and activities and had in excess of 2000 visitors each. Den Besten continued to manage the Year 10 work-experience program and the high-school astronomy outreach program, 'Telescopes in Schools'. In October, den Besten also assisted Lynch with the Melbourne presentation of the 'Learning through Inquiry' professional development workshop in partnership with ASELL. Finally, the *Bright Stars* calendar was published at the end of the year, a joint project with Ebeling to promote astronomy careers to high-school students through the profiles of young CAASTRO astrophysicists.

Ms Kim Dorrell

CAASTRO Executive Officer

In 2016 Dorrell continued her role as node administrator, ensuring the integration of the Centre's procedures and activities with the University's overarching structures, while assisting with various events such as the June *Diversity in Astronomy* workshop hosted at The University of Melbourne and September's week-long *Changing Face of Galaxies* conference in Hobart. She also continued her work as Secretary to the Project Steering Committee of the Stawell Underground Physics Laboratory (SUPL).

Dr Paul Geil

CAASTRO Affiliate
Theme: Evolving

Geil works as a postdoctoral fellow under Wyithe's Laureate Fellowship at the University of Melbourne. As a member of the DRAGONS project he undertakes research into the Epoch of Reionisation, in particular the formation and evolution of the first galaxies and their impact on the intergalactic medium and how observable these effects are. He brings to CAASTRO expertise in the simulation of radio interferometric observations, applicable to the Murchison Widefield Array and Square Kilometre Array, and so can help bridge the gap between the numerical simulation of the first galaxies and low-frequency observations.

Dr Hansik Kim

CAASTRO Affiliate
Theme: Evolving

In 2016 Kim examined the importance of low-H I-mass galaxies for the H I intensities predicted to be found by upcoming neutral hydrogen surveys. In this study, Kim showed that a dark-matter halo mass resolution better than $\sim 10^{10} h^{-1}\ M_{\odot}$ at redshifts higher than 0.5 is required for converged 21-cm brightness-temperature fluctuations. Kim also investigated the importance of star-formation laws to our understanding of galaxy formation and evolution at high redshift.

Dr Anthea King

CAASTRO Affiliate
Theme: Dark, Evolving

King was formerly a CAASTRO student based at the University of Queensland working with the OzDES team; she is now employed as a postdoctoral researcher, working under Professor Webster. She continues her involvement with OzDES and is helping to perform reverberation mapping with the sample of active galactic nuclei (AGN) from OzDES. King's expertise is predominantly in AGN science and cosmological parameter-fitting using geometric probes of the Universe's expansion. Her main research interests lie in understanding AGN structure and how we can apply this information to make more accurate mass estimates and standard candle measurements. Her CAASTRO project involves modelling the structure of AGN using photoionisation and microlensing, and straddles the Dark and Evolving themes.

Mr Jack Line

CAASTRO PhD student
Theme: Evolving

In 2016 Line developed new software, MAJICK, a test bed for interferometric simulations and imaging techniques, especially for Epoch of Reionisation experiments. Line also continued to work within the Murchison Widefield Array collaboration on various projects, using his cross-matching software PUMA. Line will submit his PhD thesis in early 2017.

Dr Katherine Mack

CAASTRO Affiliate, Postdoctoral Researcher
Theme: Evolving, Dark

In 2016 Mack transitioned from her ARC Discovery Early Career Researcher Award (DECRA) to a joint CAASTRO-CoEPP Postdoctoral Research Fellowship in Theoretical Cosmology. Previously, Mack held a Postdoctoral Fellowship from the STFC at the University of Cambridge in the Kavli Institute for Cosmology/Institute of Astronomy. She received her PhD in astrophysics at Princeton University and her undergraduate degree in physics at Caltech. Mack's research has mainly been in particle physics, cosmology and theoretical astrophysics. Her current interests include early-universe physics, dark matter, the Epoch of Reionisation, Big Bang relics, compact objects and supermassive black holes.

Dr Ben McKinley

CAASTRO Affiliate
Theme: Evolving

In 2016 McKinley commenced a DECRA fellowship and has transitioned to being an Affiliate member of CAASTRO. His work is now focused on detecting

the global, redshifted 21-cm signal from the Epoch of Reionisation using the Murchison Widefield Array (MWA) telescope and a novel technique involving lunar occultations of the sky. He has also continued to co-supervise CAASTRO student Jarryd Rasti in a project to measure the beam patterns of individual MWA tiles. McKinley has also worked on observations of our nearest neighbouring radio galaxy, Centaurus A, which continues to provide surprising new insights into radio-galaxy evolution.

Ms Sinem Ozbilgen

CAASTRO PhD student
Theme: Dark

Ozbilgen is working to tighten the Tully-Fisher relation (TFR). It is known that the slope of the TFR changes with the morphological type: Ozbilgen is investigating this as a third parameter that could reduce the scatter. She is also investigating whether the ratio of velocity dispersion to circular velocity, or a combination of the velocity dispersion and circular velocity, could be the third parameter. For this work she is using both observations and data from the EAGLE simulation.

Dr Bart Pindor

CAASTRO Postdoctoral Researcher
Theme: Evolving

Pindor works on the Murchison Widefield Array (MWA) Epoch of Reionisation (EoR) experiment. In 2016 he continued to lead the processing of the EoR observations and worked on applying lessons learned from the MWA to the design of the Square Kilometre Array EoR experiment. In collaboration with Cathryn Trott from Curtin University, Pindor was also involved in development of the Cosmological H I Power Spectrum Estimator (CHIPS), an algorithm developed and implemented with data from the MWA.

Dr Pietro Procopio

CAASTRO Postdoctoral Researcher
Theme: Evolving

By the end of 2016, the Epoch of Reionisation team within the Murchison Widefield Array collaboration had developed two software calibration and analysis pipelines, one essentially based in the US and the other a collaboration between Melbourne and Curtin Universities. The team then compared the outputs between the different pipelines and established the protocols for verification of the pipeline outputs. Researchers Pindor and Procopio made major contributions to this effort. When his CAASTRO contract completed ended in July 2016, Procopio moved to a new role as Statistics Programmer and Analyst in the School of Population and Global Health at the University of Melbourne.

Ms Mahsa Rahimi

CAASTRO PhD student
Theme: Evolving

This year Rahimi processed about 30 hours of data from one Epoch of Reionisation (EoR) field observed with the Murchison Widefield Array, and used these data to place a statistical limit on the cosmological H I power at high redshift (which she published). She is now processing data from another field, to set a new limit. Rahimi also worked on foreground simulations to be used in other EoR experiments, and on a new technique for mitigating foreground contamination in EoR fields.

Mr Jarryd Rasti

CAASTRO Masters student
Theme: Evolving

Rasti's project is designed to measure the beam patterns of the tiles of the Murchison Widefield Array (MWA), using downlink transmissions from low-Earth-orbit satellites such as Orbcomm, and make power-ratio measurements for each tile. Orbcomm satellites pass frequently over the MWA site, meaning that many measurements can be made; the frequent passes also reduce the problem of flux and polarisation varying over time. The project involves calculating satellite trajectories to identify high altitude passes and analysing the data detected on site.

Mrs Jennifer Riding

CAASTRO PhD student
Theme: Evolving

Riding's PhD is focused on finding methods to remove bright complex sources such as radio galaxies and nebulae from Epoch of Reionisation data. This work has been delayed because she took up a position at Siding Spring Observatory in northwest NSW in early 2016. In 2017 she plans to quantify her work in source subtraction in the power spectrum and write up her final thesis.

Dr Edoardo Tescari

CAASTRO Postdoctoral Researcher
Theme: Evolving

Throughout 2016 Tescari continued to work on a SAMI project to study galactic outflows at low redshift by means of hydrodynamic simulations. He has developed and extensively tested a pipeline to analyse EAGLE simulations that extracts cubes of a given size around galaxies with particular properties. For his SAMI–EAGLE project on galactic outflows, Tescari has been collaborating with Wyithe, Cortese, Power, Ho and the SAMI and EAGLE teams. These researchers have found that the outflowing activity of unperturbed disc galaxies correlates with stellar mass and the surface density of star formation. The same team is now working with Lisa Kewley's group at the Australian National University on resolved gas-phase metallicities. Tescari is also co-supervising CAASTRO PhD student Angela Garcia (Swinburne University) on a project to study the Epoch of Reionisation with metal absorption lines.

Dr Laura Wolz

CAASTRO Postdoctoral Researcher
Theme: Evolving

This year Wolz continued her work studying cosmology and galaxy evolution using H I intensity mapping. She also started new projects to explore the possibility of indirectly measuring the HI mass of optically detected galaxies by cross-correlating their positions with HI intensity-mapping data. Wolz has continued her work on data reduction and cosmological analysis for the Parkes intensity-mapping project. She has also been involved in intensity-mapping projects within the Square Kilometre Array project, with a specific focus on the Australian SKA Pathfinder. Wolz has been awarded an ARC DECRA fellowship to develop methods for intensity-mapping experiments: she will take this up at the University of Melbourne in 2017.

CAASTRO Swinburne University of Technology team members

CAASTRO AT SWINBURNE UNIVERSITY OF TECHNOLOGY

The Swinburne node has three Chief Investigators (Professors Chris Blake, Jeremy Mould and Matthew Bailes), eight Affiliate Investigators, four postdoctoral researchers and 11 students. Bailes leads both the Swinburne node and CAASTRO's Dynamic theme.

Node members have pursued several major radio astronomy projects this year.

- At the Parkes 64-m telescope researchers in the Dynamic theme have been undertaking a series of major surveys of the dynamic radio sky. Bailes initially led the High Time Resolution Universe project, which used a new suite of digital filterbanks to perform 64 microsecond snapshots of the radio sky across 1024 frequency channels in all 13 beams of the Parkes multibeam receiver. With CAASTRO support, his team led the development of a real-time radio-pulse detector using GPU technologies and a near-real-time data pipeline for processing pulsar surveys. The HTRU data is still being searched for interesting objects.
- The Molonglo radio telescope had been upgraded in recent years but lacked a digital correlator, which prevented CAASTRO scientists from exploiting its large collecting area for radio surveys. Swinburne, Sydney and ANU worked with CSIRO to develop a new digital-correlator system that used GPUs. This system ran for most of the 2016 calendar year.
- Former CAASTRO postdoc Evan Keane has been leading the Survey for Pulsars and Extragalactic Radio Bursts (SUPERB) on the Parkes telescope. The SUPERB team has a number of CAASTRO members.

These project produced some remarkable discoveries this year. The SUPERB survey detected an FRB in real time: this was tracked by other telescopes within two hours of being found. The discovery was reported in a Nature paper by Keane *et al.* (2016), with a follow-up by Johnston *et al.* (2016). At first it was believed that the FRB was associated with a fading radio afterglow, but subsequent observations suggested that there may have been a chance coincidence with a variable AGN. Regardless of the confidence we can now place in the association, the SUPERB survey has shown the worth of a real-time detector in helping to place limits on FRB behaviour at other wavelengths.

The SUPERB survey also discovered the slowest known radio pulsar, by detecting its single pulses in a nine-minute pointing. The team is continuing to time this object to see if it is a high-field or old pulsar. New signal-processing techniques developed by CAASTRO Masters student Vincent Morello were extremely effective in distinguishing the pulsar's signal from radio-frequency interference.

Andrew Cameron, a PhD student at the Max Planck Institute for Radioastronomy, has been working with Professor Bailes and Partner Investigator Michael Kramer on searching the southern galactic plane for pulsars (page 26). This is an incredibly computationally demanding task and makes use of the CAASTRO CPU allocation on the NCI national facility. The project has now discovered almost 100 pulsars. One of these is in a very tight orbit and is the most relativistic pulsar system ever discovered: it will be of great interest to gravitational-wave hunters. Details should be published in 2017.

In optical astronomy, the Swinburne node leads the DECamERON project, which has published two papers this year.

In 2017 Professor Bailes will be leaving CAASTRO to look at the Universe in a very different way, using gravitational waves: he will be Director of the new ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav). His experience on the CAASTRO Executive and as a Theme leader were crucial in leading a successful campaign for a new Centre of Excellence, and he hopes that CAASTRO's two successors, CAASTRO 3-D and OzGrav, will maintain a close

relationship – for instance, by running joint workshops for their early-career researchers in computing, data-processing techniques and career development. Dr Adam Deller will be nominated to replace Bailes as a Chief Investigator at the Swinburne node and conclude the radio projects in train.

Professor Matthew Bailes

CAASTRO Node Leader
Theme: Dynamic

In 2016 Bailes continued as leader of the Dynamic theme in CAASTRO, overseeing efforts with the Parkes and Molonglo telescopes to discover pulsars and fast radio bursts (FRBs). These searches led to a number of publications, including one paper in Nature and another in Science, co-authored with CAASTRO collaborators at the Max Planck Institute for Radioastronomy and others. The Nature paper described a fast radio burst that was followed by a brightening of a radio AGN: whether or not they were connected remains an open question. Former CAASTRO postdoc Vikram Ravi (Caltech) co-led another project that discovered an extraordinarily bright FRB. The FRB was near on the sky to a pulsar (a Galactic object), and yet its rotation measure was almost identical, indicating that the intergalactic medium along the line of sight was largely unmagnetised (page 16). In addition, CAASTRO Dynamic-theme scientists published five new FRBs discovered in the Parkes telescope's high-latitude survey, in a paper led by David Champion (MPIfR). Background work completed within CAASTRO brought the Molonglo telescope to life and CAASTRO student Manisha Caleb discovered three FRBs with it in 2016.

This year Bailes led a successful bid for a new ARC Centre of Excellence, of which he will be the Director. The new Centre (the ARC Centre of Excellence for Gravitational Wave Discovery, OzGrav) will begin operations in 2017.

Professor Chris Blake

CAASTRO Chief Investigator
Theme: Dark

Blake and his research group have continued their efforts to test the nature of gravitational physics on cosmic scales by combining different cosmological probes such as large-scale structure, the peculiar velocities of galaxies, and gravitational lensing. During 2016 the group led the cosmological analysis of the Kilo-Degree Survey (KiDS), as part of its role in that project: the KiDS data set is currently the best available for studies of weak gravitational lensing. The group also completed observations for the 2-degree Field Lensing Survey, which has generated a spectroscopic data set overlapping that of KiDS, allowing detection of multiple gravitational signatures of lensing and velocities. Finally, the group pioneered two new techniques for testing gravity: one using joint analyses of peculiar-velocity and galaxy-redshift surveys and another using the cross-correlation between galaxies and the galaxy-free regions called voids.

Professor Jeremy Mould

CAASTRO Chief Investigator
Theme: Dark

During 2016 Mould worked on several projects: co-adding spectra from the OzDES survey, writing a paper on supernova hosts and radio galaxies, and (with a former CAASTRO postdoc) measuring the initial mass function of galaxies from infrared spectra. He also assisted with the Taipan survey, which is designed to measure the Hubble Constant to within one per cent and to improve the mass map of the local Universe. Mould is the Chair of the Project Steering Committee for the Stawell Underground Physics Lab. The Lab's first experiment is the southern hemisphere component of SABRE, an experiment designed to directly detect dark matter.

Dr Ixandra Achitouv

CAASTRO Postdoctoral Researcher
Theme: Dark

Achitouv joined CAASTRO in 2014 as a postdoctoral fellow and became Theme Scientist for the Dark theme in 2015. Her research focuses on developing analytical models to describe the large-scale structures of the Universe (such as cosmic voids or clusters of galaxies). In 2016 she worked on predicting the profile of voids in non-standard cosmologies. She has also probed general relativity by measuring the growth rate of cosmic structure within voids identified in data from the 6dF Galaxy Survey.

Ms Caitlin Adams

CAASTRO PhD Student
Theme: Dark

Adams is a second year PhD student working with Blake, Achitouv and Parkinson. This year she developed a new approach for testing the cosmological model at low redshift, and has applied this to peculiar velocities and galaxy positions from the 6dF Galaxy Survey. Her analysis uses the fact that both observables trace the underlying matter distribution: this shared information can reveal more about how gravity behaves on cosmological scales. Adams plans to test alternative cosmological models with her approach, and hopes to shed more light on the cause of the Universe's accelerated expansion

Mr Igor Andreoni

CAASTRO PhD Student
Theme: Dynamic

Andreoni is a PhD candidate at Swinburne supervised by Cooke, Bailes and Ryder (Australian Astronomical Observatory). His interests include the detection and science of transient events, the multi-wavelength follow up of fast radio bursts and 'multi-messenger' studies to search for electromagnetic counterparts to gravitational-wave signals. The research project in which he is most involved, *Deeper, Wider, Faster* (page 25), aims to explore the fast transient Universe (that is, changes on timescales from seconds to hours) with simultaneous observations with radio, optical, UV, X-ray and gamma-ray telescopes.

Andreoni's work focuses on the acquisition of optical data with DECam (the Dark Energy Camera in operation at CTIO in Chile), the real-time analysis of these data, and the study of the detected transients.

Dr Ewan Barr

CAASTRO Affiliate
Theme: Dynamic

Barr was employed for development of the Square Kilometre Array project. He assisted Vincent Morello with his Masters thesis on searching for pulsars, and with the SUPERB survey for pulsars and fast radio bursts with the Parkes telescope.

Ms Shivani Bhandari

CAASTRO PhD Student
Theme: Dynamic

Bhandari's work revolves around searching for and localising fast radio bursts (FRBs), a relatively new class of transient radio source. She is involved in two large collaborations: the High Time Resolution Universe (HTRU) survey, legacy survey done with the Parkes telescope, and the Search for Pulsars and Extragalactic Bursts (SUPERB), an ongoing survey for pulsars and FRBs in real time, also being done with Parkes. Bhandari's work involves looking for bright single pulses in HTRU low-latitude data and leading the multiwavelength follow-up for bursts discovered by SUPERB. Bhandari is a part of the UTMOST commissioning team, which is making radio images with the Molonglo radio telescope. She is also involved with two surveys planned for the Australian SKA Pathfinder telescope: VAST, a survey for variable and slow transients, and CRAFT, which is looking for fast transients, including fast radio bursts.

Mr Alex Codoreanu

CAASTRO PhD Student
Theme: Evolving

Codoreanu is working on understanding the enrichment and ionisation of metals towards the end of the Epoch of Reionisation by identifying absorption features in the spectra of quasars present in the first billion years of the Universe. He has made the first measurement on the amount of Mg II present when the Universe was just one billion years old, and his follow-up work will investigate the metallicity of these absorbers. This year he participated in the *CAASTRO in the Classroom* program and gave two colloquia.

Dr Jeff Cooke

CAASTRO Associate Investigator
Themes: Evolving, Dynamic

Cooke's research spans both the Dynamic and Evolving themes. In the Dynamic theme, he has pioneered the detection and study of high redshift ($z > 2$) supernovae, and has discovered events that took place when the Universe was just 10–20 per cent of its current age. Such observations could help us detect both the first generation of stars that formed after the Big Bang and a long-theorised type of supernova called pair-instability supernovae. Cooke leads also leads an innovative program to catch and study the fastest bursts in the Universe (of seconds to minutes duration): the multiwavelength *Deeper, Wider, Faster* program (page 25). In the Evolving theme, Cooke leads work to detect and characterise galaxies in the early Universe and understand their contribution to the Epoch of Reionisation. He has also has developed techniques to study absorption-line systems at both low and high redshifts.

Mr Chris Curtin

CAASTRO PhD Student
Themes: Evolving, Dynamic

In 2016 Curtin finished reductions on two key fields of the u-SUDSS, a program to study the highest-redshift superluminous supernovae, and was awarded time on the Dark Energy Camera (DECam) in Chile to observe a third field. He selected candidate objects from one of the first SUDSS fields he had observed and, with a program awarded to Cooke, was able to collect Keck spectra on three of them. The spectra are still being reduced, but these candidates look to be among the highest-redshift supernovae ever observed near peak brightness.

Dr Alan Duffy

CAASTRO Affiliate

Themes: Evolving, Dark

This year Duffy created and published 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 also created an online pipeline to image the local Universe and probe the nature of the intergalactic medium: this was developed as part of the Theoretical Astrophysical Observatory (TAO), a tool with which researchers can construct virtual Universes. Duffy continues as a Chief Investigator of the first southern-hemisphere deployment of the SABRE dark-matter detection experiment, which will be run at the Stawell Underground Physics Laboratory in Victorial.

Dr Chris Flynn

CAASTRO Postdoctoral Researcher
Theme: Dynamic

Over the last 18 months Flynn has co-led (with Matthew Bailes) the transformation of the Molonglo radio telescope into UTMOST, a machine for finding pulsars and fast radio bursts. By 2016 the telescope had been brought to sufficient sensitivity to discover three fast radio bursts (FRBs) (page 14). Only one other FRB was discovered anywhere this year, so Molonglo's three were a standout achievement. The results showed that FRBs are at least 10,000 km distant from Earth and cannot be some local radio phenomenon. By year's end the UTMOST team had increased the instrument's sensitivity by improving its spectral resolution almost tenfold – an advance long planned and now achieved. In collaboration with ARC Future Fellow Dr Adam Deller, the team is also starting to refit the telescope's unused north-south

arm (page 27). This will hugely improve UTMOST's resolution in a north-south direction, which in turn will boost its ability to localise FRBs.

Ms Luz Angela Garcia

CAASTRO PhD Student
Theme: Evolving

Garcia started her PhD in February 2014 at Swinburne under the supervision of Ryan-Weber, Tescari and Wyithe. She is studying the Epoch of Reionisation, using hydrodynamical simulations to derive theoretical constrains on the end of this era and investigate different scenarios. Specifically, she is investigating the evolution of some metal absorption-line features in the spectra of high redshift quasars (C II and C IV, among others). She is also attempting to recover information about the content of neutral hydrogen at high redshift ($z<6$).

Professor Karl Glazebrook

CAASTRO Affiliate
Theme: Dark

Glazebrook published 22 refereed papers in 2016. The most notable were: the work by his student, George Bekiaris, who published the first GPU accelerated code for fitting galaxy kinematic models to 3D data cubes; a paper in the very first issue of Nature Astronomy on gas reservoirs in Milky Way ancestors; the publication of all the data from the ZFOURGE imaging survey of high-redshift galaxies; the first series of papers on the follow-up ZFIRE survey done with Keck; and a new mathematical relation to explain the neutral hydrogen content of nearby galaxies. At the end of 2016 Glazebrook was elected to the Board of Directors of Astronomy Australia Ltd.

Mr Andrew Jameson

CAASTRO Affiliate
Theme: Dynamic

Jameson is experienced in software development, systems administration, high-performance computing and data management. He has substantial expertise in the design and implementation of radio-astronomy instrumentation for single-pixel feeds and interferometers, and has worked on systems deployed at the Parkes, Molonglo and MeerKAT telescopes and on pre-construction design for the Square Kilometre Array. He is continuing to work 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 deployed the pulsar-timing instrument at MeerKAT and worked with Flynn to extend the functionality of Molonglo's correlator and beamformer.

Mr Fabian Jankowski

CAASTRO PhD Student
Theme: Dynamic

In 2016 Jankowski designed and implemented a dynamic telescope observation scheduler for UTMOST that has greatly increased the telescope's observing efficiency. He takes part in monitoring more than 330 radio pulsars and has discovered ten pulsar glitches so far. He has also studied the spectral properties of more than 400 radio pulsars, using data he obtained with the Parkes telescope.

Mr Andrew Johnson

CAASTRO Postdoctoral Researcher
Theme: Dark

This year Johnson was awarded his PhD for his thesis, "Searching for departures from the standard model of cosmology". He also published the final paper from his thesis: it described a new approach to calibrating the source–redshift distribution in deep galaxy-imaging surveys, which is a key challenge to realising the scientific potential of weak gravitational lensing. Johnson is now employed as a data scientist in industry.

Dr Shahab Joudaki

Postdoctoral Researcher
Theme: Dark

Joudaki has co-led the cosmological analysis of weak gravitational lensing measurements from the Kilo Degree Survey. He has also developed a cosmology-fitting pipeline to self-consistently analyse measurements from overlapping lensing and spectroscopic surveys. He is applying this pipeline to the overlap of the Kilo Degree Survey, the 2-degree Field Lensing Survey and the Baryon Oscillation Spectroscopic Survey, to test gravity on cosmic scales.

Mr Vivek Venkatraman Krishnan

CAASTRO PhD Student
Theme: Dynamic

Krishnan's main focus in 2016 was to set up a new observing mode at the UTMOST telescope that allows observers to make repeated, rapid surveys of the Galactic plane searching for both one-off and periodic transient events while also timing the pulsars in the survey pointings. The pipeline for this has been developed and is currently being tested. Krishnan also investigated how the measurements of post-Keplerian parameters for relativistic binary pulsars compare with the predictions of general relativity and alternatives, such as scalar-tensor theories of gravity. He is now working on how the observations of the pulsar J1141–6545 can be used to test the validity of these theories.

Ms Susan Lester

Node Administrator

Lester continues to manage the administrative, financial and reporting functions for the CAASTRO team at Swinburne. With the awarding of the OzGrav ARC project to Matthew Bailes in late 2016, Jeremy Mould has now become the Node Leader for Swinburne until the end of 2017, requiring a change in reporting lines for Lester and others.

Mr Vincent Morello

CAASTRO PhD Student
Theme: Dynamic

Morello has been focusing on pulsar searching and the application of machine learning to radio-astronomy data, under the supervision of van Straten and Barr at Swinburne. He recently submitted his MSc thesis, "Discovering pulsars with Machine Learning", which presented a highly accurate algorithm for pulsar identification in current and future large-scale surveys and reported the discovery of 26 new pulsars. Morello is currently investigating algorithms to mitigate radio-frequency interference and developing search software to discover the most slowly spinning pulsars in the Galaxy.

Mr Aditya Parthasarathy

PhD Student
Theme: Dynamic

Parthasarathy is a PhD candidate at Swinburne, supervised by Bailes, van Straten and Oslowski. His interests lie in achieving the highest precision in pulsar timing through robust statistical techniques. Parthasarathy is involved in the Parkes Pulsar Timing Array (PPTA) collaboration and is interested in studying profile variability in radio pulsars. His work in the past year has been focused on developing a generalised template-matching algorithm that accounts for jitter/self-noise in observations of bright millisecond pulsars. He is also a part of the UTMOST commissioning team and has contributed towards developing the automatic scheduling and observing system at Molonglo.

Ms Kathryn Plant

Research Assistant
Theme: Dark

Plant is a pre-PhD student working on a one-year project in the pulsar/fast radio burst group at Swinburne, building firmware for a new digital receiver for the Molonglo telescope. She is interested in how new instrumentation can address the challenges of detecting and localising FRBs. Her current project focuses on FPGA (field-programmable gate array) programming to acquire spectra at high frequency resolution and high time resolution. She is now testing the digital receiver she programmed at Molonglo.

Associate Professor Emma Ryan-Weber

CAASTRO Associate Investigator
Theme: Evolving

Ryan-Weber's research in 2016 continued to focus on metal absorption-line systems in the high redshift Universe. She gave two invited talks at conferences on this subject in Heidelberg and Berlin. Ryan-Weber is supervising two Swinburne PhD students on this project. Garcia is collaborating with Tescari and Wyithe on simulating metal absorption-line systems, while Codoreanu is working on high signal-to-noise ratio spectra of redshift-6 quasars to search for intervening metal lines, in particular Mg II, from redshift two to six.

Dr Willem van Straten

CAASTRO Affiliate
Theme: Dynamic

Van Straten is an expert on radio polarimetry and digital signal processing, and he is currently leading the development of the pulsar timing instrument for the Square Kilometre Array. He supervises CAASTRO students on pulsar and fast-radio-burst projects, and he was the principal coordinating supervisor for Petroff and Morello. Van Straten has recently developed a novel statistical framework for analysing the polarisation of signals that fluctuate on short timescales, such as the single-pulse emission from pulsars, rotating radio transients and fast radio bursts.

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. 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.

Ding Yan

Commissioning Engineer, Molonglo

This year Ding Yang helped develop the Molonglo telescope's analogue, mechanical and radio-frequency systems to improve the telescope's ability to monitor pulsars, search for fast transients and make maps of the radio sky.

CAASTRO ANU team members

Australian National University

CAASTRO AT THE AUSTRALIAN NATIONAL UNIVERSITY

The Australian National University's node of CAASTRO has 24 researchers, ranging from the undergraduate to the Professorial level. They do research across CAASTRO's three themes: observations and modelling of transients; the characterisation of dark energy and dark matter through cosmological surveys; and optical and radio observations aimed at understanding the evolving Universe.

Within the Dark Universe theme, Anais Möller, Natalia Sommer, Brad Tucker and Bonnie Zhang actively participate in the OzDES survey (page 29) and its analysis, helping with observations and analysis of cosmological implications, superluminous supernovae, and quasar reverberation mapping. Möller leads the SkyMapper telescope's transient survey, which has already identified over 30 Type Ia supernovae, plus a number of unusual events. The supernova group has several papers in train.

A variety of work has been done in the Dynamic Universe theme. Using the upgraded Molonglo telescope, UTMOST, Manisha Caleb has made the first interferometric detections of fast radio bursts (FRBs), one of the most tantalising mysteries of the last decade. They are millisecond duration radio bursts of unknown origin, and being now placed beyond the ~10,000 km Fresnel limit of the telescope, their origin is unambiguously cosmic. Ashley Ruiter has continued to work on understanding formation pathways of thermonuclear supernovae, transients and black hole binary mergers, and gave invited talks at international meetings. Fiona Panther has worked with her, Ivo Seitenzahl and others on a new hypothesis for the origin of antimatter streaming out of inner parts of the Milky Way, suggesting that merging white dwarf stars be responsible. Ivo Seitenzahl has continued his work on 3D thermonuclear supernova explosion models, using CAASTRO allocation for supercomputing time on raijin, an NCI (National Computational Infrastructure) facility. His delayed-detonation model is now used in the gravitational-wave sensitivity calculator at the University of Cambridge, UK.

In the Evolving Universe theme, Matthew Colless has been working with Francesco D'Eugenio, Dilyar Barat and Tania Barone on galaxy data from the SAMI survey. They have found new scaling relations between the mass of a galaxy and its dynamical properties that are tighter, more general, and more physically meaningful than previous ones. They have also measured a correlation between the stellar population in galaxies and its dynamical properties and have found, intriguingly, that stellar population parameters correlate more strongly with the depth of a galaxy's gravitational potential than with its mass. This suggests that the evolution of the stellar population is determined by the escape velocity of gas that is retained for subsequent generations of star formation. Julie Banfield has engaged the public with a citizen-science project, Radio Galaxy Zoo, to help understand how radio galaxies evolve over cosmic time. The project's participants have discovered a number of extremely large radio galaxies that probably would not otherwise have been found in archival data.

Christopher Onken and Christian Wolf have advanced the legacy of the SkyMapper telescope, its public Southern Sky Survey. An Early Data Release was published in 2016: this has triggered a flurry of analysis that will lead to publications in 2017. Christian Wolf has worked with Jacob Golding on a new imaging diagnostic for mapping changes in a galaxy's recent star formation, which will be an attractive addition to a SkyMapper atlas of 10,000 nearest galaxies.

A number of new members joined the ANU node this year, including PhD student Natalia Sommer; undergraduate students Matthew Alger, Tania Barone, Jacob Golding, Mason Ng, and Georgina Taylor; and Administrator Susanne Meinen. We had to say goodbye to Fang Yuan (now at Geoscience Australia, Canberra).

Professor Brian Schmidt resigned as Node leader as he took on the position as Vice-Chancellor of the ANU. Administrator Denise Sturgess left to support him in his new role.

CAASTRO at ANU led the re-development of the Visitor Centres at Mount Stromlo and Siding Spring Observatory, which now showcase the science being done at these sites with SkyMapper and Radio Galaxy Zoo. During the past year, Brad Tucker and his outreach team have hosted over 5,000 people at Mount Stromlo, both the general public and school students, for stargazing events and talks.

In 2017 we 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 continue on the analysis of SAMI data, and SkyMapper will release its first full-hemisphere dataset and see its optical images combined with Early Science data from the Australian SKA Pathfinder.

Dr Christian Wolf

CAASTRO Node Leader
Theme: Evolving, Dynamic, Dark

Wolf has worked for 20 years on photometric redshift and statistical classification techniques and pioneered high-precision photometric redshifts and their application to quasars. He has led the COMBO-17 multiband survey, which explored the evolution of galaxies and quasars over most of cosmic time, and the measurement of 30,000 galaxy redshifts in the 2dFLenS Survey, which will help extract high-quality photometric redshifts from the SkyMapper survey. He is now exploring Active Learning algorithms to design training sets of maximal value for minimal cost. Wolf's research interests include galaxy evolution and the decline of star formation in spiral galaxies; he has a particular focus on improving measurements of star-formation rates in the infrared and radio domains. He also works on dust extinction in the Milky Way and external galaxies, and on AGN variability.

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: he will compare the radio and optical surveys in the analysis of the velocity field and explore implications for cosmological models. Colless 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. He 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.

Professor Brian Schmidt

CAASTRO Chief Investigator
Theme: Evolving, Dynamic, Dark

From 1 January 2016 Schmidt became the Australian National University's 12th Vice-Chancellor. He continues to be involved in CAASTRO, remaining a Chief Investigator and helping to supervise a graduate student in the Dark Universe theme, and chairing the Gender Action Committee.

Schmidt continues to make many public appearances both in Australia and internationally. This year he appeared at the World Science Festival in Brisbane, spoke at the World Economic Forum in Davos and the World Economic Forum New Champions event in Dalian, was a featured speaker at the STARMUS III Festival in the Canary Islands and the European Open Science Forum in Manchester, and also presented at the Supernovae through the Ages Conference on Rapa Nui.

Mr Matthew Alger

CAASTRO Honours student
Theme: Dynamic

In 2016 Alger completed his Honours thesis, which was on the topic of applying machine learning to cross-match optical and radio sources. He is currently working with Christian Wolf to develop a public legacy software library for applying active learning algorithms to astrophysics.

Dr Julie Banfield

CAASTRO Postdoctoral Fellow
Theme: Evolving

Banfield's research is centred on 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 PhD student
Theme: Dark, Evolving

In 2016 Barat began his PhD in Astronomy at the ANU under the supervision of Professor Matthew Colless. Barat continues to work closely with the SAMI Galaxy Survey. His research focuses on optimising galaxy scaling relations and using them as distance probe to measurement cosmological parameters. Barat is also a member of the Taipan survey, for which he will be mapping the matter distribution in the local Universe from the peculiar-velocity survey, one of its sub-projects.

Ms Tania Barone

CAASTRO Honours student
Theme: Dark, Evolving

Barone completed her Honours degree at the Australian National University, under the supervision of Professor Matthew Colless. Her thesis involved using data from the SAMI Galaxy Survey to investigate the relation between the stellar population of early-type galaxies (ETGs) and their structure and dynamics. After completing her thesis she continued further investigations of the trends found in her Honours work.

Professor Frank Briggs

CAASTRO Affiliate
Theme: 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.

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 using the upgraded Molonglo Observatory Synthesis Telescope near Canberra. Caleb and team made the first interferometric detections of FRBs in 2016, *placing their origin beyond the ~10,000 km Fresnel limit of the telescope*, and so ruling out local sources of interference as a possible origin.

Dr Francesco D'Eugenio

CAASTRO Postdoctoral Fellow
Theme: Dark, Evolving

D'Eugenio is working on the SAMI Scaling Relations, including the Fundamental Plane, dynamical modelling of the early-type galaxies in the SAMI sample and de-projected angular momentum. He is also studying galaxy evolution at intermediate redshift and the classification of galaxies into slow and fast rotators.

Mr Jacob Golding

CAASTRO undergraduate student
Theme: Evolving

Golding joined CAASTRO this year. He has worked with Christian Wolf on a CAASTRO pre-PhD project: investigating SkyMapper's ability to produce spatial maps of recent changes in the star formation within nearby galaxies, using its bespoke filter set.

Ms Susanne Meinen

CAASTRO Administrator

Meinen has worked as CAASTRO Node Administrator at the Australian National University's Mount Stromlo Observatory since May 2016. She provides administrative support to the team.

Dr Anais Möller

CAASTRO Postdoctoral Fellow
Theme: Dark, Dynamic

Möller's research interests focus on type Ia supernova (SN Ia) cosmology and machine learning. She is working in both high-redshift SN Ia surveys, such as SNLS and DES, and the low-redshift survey at SkyMapper. She is currently leading the SkyMapper Transient Survey (which is designed to generate an untargeted sample of SN Ia to obtain the low-z cosmology anchor) and also coordinating observations to detect optical counterparts of gravitational-wave events, fast radio bursts, and other optical transients. In high-redshift SN Ia surveys, Möller is currently working on selection biases and photometric classification of supernovae. As a member of the OzDES team, Möller is also working on spectroscopy of both supernovae and their host galaxies; she is also part of the team preparing the cosmology analysis for the spectroscopic sample of DES (the Dark Energy Survey).

Mr Mason Ng

CAASTRO Pre_PhD student
Theme: Dynamic

Over the summer of 2016–17, Ng worked with Christian Wolf and Christopher Onken as a Pre-PhD student. His project involved employing machine-learning methods to improve the quality of images obtained by SkyMapper.

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. 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. Her CAASTRO research involves improving our understanding of peculiar sub-luminous thermonuclear supernovae. In particular, she aims to measure the ages of the stellar populations that give rise to supernovae like SN1991bg, the largest subclass of SNe Ia. This will give insight into the possible progenitors of these cosmic explosions and lead to a better understanding of why the rate at which they occur changes across cosmic time. Panther is also investigating whether these events might be the origin of the mysterious positrons in the Milky Way.

Dr Ashley Ruiter

CAASTRO Postdoctoral Fellow
Theme: Dynamic

Ruiter works in binary star evolution modelling to understand the formation of interacting stars that give rise to explosive phenomena and compact objects. She is interested in transient sources such as supernovae, RCrB stars, accretion-induced-collapse neutron stars, and binary stars that can be used as verification sources for gravitational-wave detectors. Ruiter uses theoretical methods to uncover the evolutionary channels that lead to their formation, predict their birth rates, and constrain their birth sites and ages.

Ms 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 2016 Salim led work to create a method of predicting distributions for gas column densities from data of the SAMI Galaxy Survey and a multi-freefall description of star formation. In her Honours year in 2017 she will extend these studies to explore any discrepancies between star-formation theories.

Ms Mayuri Sathyanarayana Rao

CAASTRO PhD student
Theme: Evolving

Rao is in the third 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. She is investigating spectral distortions of the Cosmic Microwave Background (CMB), particularly those arising from the epoch of recombination through reionisation. Rao is now developing a prototype element of an array to detect these and other cosmological distortions of the CMB. Her focus is on the high-level system design and integration, calibration techniques and system analysis.

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 oxygen-rich and Balmer-dominated supernova remnants in the Magellanic Clouds.

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 2024. Within CAASTRO Sharp is a leader of the SAMI Galaxy Survey data-analysis group. For the OzDES supernova survey project, 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 Natalia Eiré Sommer

CAASTRO PhD student
Theme: Dark

Sommer finished her Master's degree in June 2016 and began her PhD in August. In the former she investigated the possibility of performing reverberation mapping with active galactic nuclei in bulk, using data from the DES and OzDES surveys. She is continuing this work in her PhD, and will look to apply the theory she has developed to real measurements.

Ms Georgina Taylor

CAASTRO pre-PhD student
Theme: Dynamic

Taylor is working over the summer with the SkyMapper Transient Search team at the Australian National University. Her work involves simulating supernova light curves and bandpasses needed for the transient search, and analysing how combining data from the Kepler Extra-Galactic Survey and SkyMapper can improve cosmological distance measurements.

Dr Brad Tucker

CAASTRO Postdoctoral Fellow
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 SNe to learn about their physics and progenitors. Tucker is working on a variety of supernova surveys including the SkyMapper Supernova Survey, OzDES, ESSENCE and the Carnegie Supernova Project; he also leads the Kepler Extra-Galactic Survey, a NASA Kepler K2 key project to search for supernovae, other extragalactic transient objects, and black holes. Tucker does a lot of astronomy outreach, frequently speaking to school groups and the general public about astronomy, and has regular segments on radio and television.

Dr Fang Yuan

CAASTRO Postdoctoral Researcher
Theme: Dynamic

Yuan was a member of the SkyMapper transient team and the OzDES team until her departure from the ANU in August. Her main science interest lies in understanding a diverse range of stellar explosions. She studies supernovae, gamma-ray bursts, fast radio bursts and gravitational-wave events.

Ms Bonnie Zhang

CAASTRO PhD student
Themes: Dark, Dynamic

Zhang is a third-year PhD student studying observational cosmology. Her research is on using Type Ia supernovae to measure the cosmic distance scale, including precise analysis of supernova systematics. Her work spans the nearby and high-redshift Universe, from measurements of the Hubble constant from low-redshift SNe to studies of cosmic acceleration and dark energy at higher redshifts. She is part of both the SkyMapper team and the OzDES collaboration, and involved in analyses of supernova light curves discovered in the SkyMapper Transient Survey at low redshift, and the Dark Energy Survey at high redshift.

CAASTRO University of Queensland team members

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

CAASTRO AT THE UNIVERSITY OF QUEENSLAND

A CAASTRO node was formed at the University of Queensland in 2014: it consists of four research staff, one postdoc and half a dozen students. In 2016 we welcomed a new postdoc, Jacobo Asorey, to the group and farewelled Edward Macaulay, who has gone on to a new postdoc position at Portsmouth University in England.

We achieved some exciting results in the Dark Universe theme this year. Samuel Hinton led the paper measuring the 2D baryon acoustic oscillation signal of galaxies in WiggleZ, splitting the signal along the line of sight from that perpendicular to the line of sight. This represents the final cosmology paper we expect from the WiggleZ survey; there will also be a final data paper, led by Michael Drinkwater. In addition, we continued to investigate physical effects, arising from inhomogeneities in the Universe, that could potentially bias cosmological results: Per Andersen published a paper showing that sparsely sampled peculiar-velocity surveys would tend to overestimate the magnitude of bulk flows, while Joshua Calcino tested supernova data for the presence of a local density fluctuation that could bias cosmological results.

The OzDES team made rapid progress this year, submitting discoveries of interesting objects for publication and contributing to some wider Dark Energy Survey (DES) papers. We published a plethora of papers: the discovery of a Type I superluminous supernova (Smith *et al.* 2016); the discovery of a $z = 0.65$ post-starburst broad absorption line quasar (Mudd *et al.* 2016); the paper describing the MARZ software (Hinton *et al.* 2016); the RedMaPPer Galaxy Cluster Catalog (Rykoff *et al.* 2016); a paper on redMaGiC galaxies (Rozo *et al.* 2016); a paper giving the redshift distribution of galaxies in the DES early data's shear catalogue (Bonnett *et al.* 2016); and a key DES paper giving an overview of all of the science beyond dark energy that DES will accomplish (Dark Energy Survey Collaboration 2016). Edward Macaulay completed his work demonstrating how to using the dispersion about the Hubble diagram to measure lensing of supernovae, which will soon be applied to DES catalogues. Finally, Tamara Davis and David Parkinson co-authored a chapter for the *Supernova Handbook*, "Characterising Dark Energy through supernovae".

For his Honours thesis project Daniel Muthukrishna created a new code for analysing supernova spectra. His project, "DASH: Deep Learning for the Automated Spectral Classification of Transient Astronomical Objects", was supervised by David Parkinson (UQ) and Brad Tucker (ANU). The code uses machine-learning techniques, the Google TensorFlow package, to identify the type and age of supernova based on spectra (details, page 28). The code is already being used by the OzDES team to analyse supernova spectra from the Anglo-Australian Telescope, and other international supernova groups have shown great interest in it. The project won the GBST prize for the Best Software Project at the University of Queensland, and the Institute of Electrical and Electronics Engineers prize for the best student thesis in Queensland. Daniel was also awarded an Australia Gemini Studentship, which allowed him to spend ten weeks during the (southern hemisphere) summer of 2016–2017 working with the Gemini researchers in Chile.

In the Dark theory project, David Parkinson and Jacob Seiler (David's previous Honours student, who graduated in 2015) published a paper that used large-scale simulations to estimate the magnitude of the bulk flow under a theory of gravity different from the standard general theory of relativity. In this project, Parkinson and Seiler simulated the redshift and sky distribution of the 2MASS Tully-Fisher (2MTF) survey and compared them with bulk-flow measurements from that survey.

In the Evolving Universe theme, Simon Deeley completed extra analysis on his Honours project topic and submitted the work for publication. He showed that the density-morphology relation (that there is a higher fraction of elliptical galaxies in dense environments) does not just apply to the densest environments of

galaxy clusters, but varies continuously from low-mass galaxy groups up to clusters. With CAASTRO support he collaborated with Daniel Cunnama (University of the Western Cape) to use simulations to predict the merger rates in the group environments. They showed that the observed density-morphology relation is entirely consistent with predictions that the transformation is driven by galaxy mergers.

Michael Drinkwater led several UQ undergraduate students in the analysis of gas outflows measured by the SAMI Galaxy Survey. They have detected significant outflows, revealed by 'blue wings' in oxygen emission lines, and their aim is to determine if these outflows are driven by star formation or the energy input from active nuclei in these galaxies.

In the Dynamic Universe theme, Holger Baumgardt and his collaborators from Harvard University have been analysing the accelerations of millisecond pulsars in the globular cluster 47 Tucanae. Comparing the observed accelerations of these pulsars with N-body simulations, they found clear evidence for the presence of a compact concentration of ~1500 solar masses in the cluster centre, most likely in the form of a massive black hole. This discovery opens up a new pathway to search for massive black holes. Baumgardt and his team are now extending their search to other globular clusters, such as Terzan 5 and M28, that host large populations of millisecond pulsars

We had a number of exciting events during 2016. Brisbane hosted the World Science Festival: this was the first time it was held outside New York. In connection with this, we had many exciting visitors extend their stay and visit UQ including Paul Davies (author of "Quantum Fields in Curved Space"), Josh Frieman (director of the Dark Energy Survey), and George Musser (editor of Scientific American). We also had Douglas Scott (Planck, University of British Columbia) visited for two weeks as a CAASTRO visitor. There is clearly a huge appetite in Queensland for public talks and science shows, as evidenced by the resounding success of the World Science Festival (over 150,000 visitors passed through the museum in four days, and over 80 per cent of shows were completely sold out, easily packing 600-person auditoriums). It was an exciting year for outreach in general, with group members appearing on television several times: in the ABC's Q&A program, a BBC documentary, the children's show SCOPE, Channel 7 news, and even Lateline. Node leader Davis also made a three-city speaking tour with Professor Lisa Randall, a theoretical physicist from Harvard (details, page 87).

Of course one of the major highlights of 2016 was the Dark theme workshop, *Diving into the Dark*, which we held in Cairns in northern Queensland. We were able to entice many of the field leaders to this conference and designed a program with ample time for interaction and collaboration. It was a great success, with very high quality talks and fruitful interactions (details, page 78).

Professor Tamara Davis

CAASTRO Node Leader
CAASTRO Chief Investigator
Theme: Dark

Davis studies gravity, dark energy, and black holes using supernovae, large-scale structure, and active galactic nuclei. Her main current focus is the Dark Energy Survey (DES), which is a five-year survey measuring approximately 30 million galaxies. DES has already discovered several thousand supernovae, and is monitoring almost 800 active galaxies to measure how the masses of supermassive black holes have evolved over the last 12 billion years. Davis's 2016 outreach activities included many public talks, radio interviews, and TV appearances, including a panel discussion on the ABC's Q&A, a speaking tour with theoretical physicist Lisa Randall, an episode for the kids show SCOPE, a comedy science show "Science Says!", and a well-shared article for The Conversation, "Relax, the universe is still accelerating".

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 of galaxies (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 Jacobo Asorey

CAASTRO Postdoctoral Researcher
Theme: Dark

Asorey is a postdoctoral research fellow, working with Tamara Davis. His research interests lie in testing cosmological models by studying the expansion and growth histories of the Universe, using the large-scale structure maps obtained from extragalactic surveys such as DES and OzDES. Asorey obtained his PhD in Physics in 2013 at the Universitat Autonoma de Barcelona, where he studied large-scale structure using angular cross-correlations. He was a postdoctoral researcher from 2013 to 2016 at the University of Illinois at Urbana-Champaign, where he investigated the effect of photometric redshifts on clustering.

Dr Holger Baumgardt

CAASTRO Affiliate
Theme: Dynamic

Baumgardt's focus is on direct collisions between white dwarfs as a possible cause of Type Ia supernovae. In 2015 he and a student worked on calculating collision rates between single white dwarfs in various globular clusters; more recently, he has made

simulations that investigate the role of stellar binaries in these collisions.

Mr Joshua Calcino

CAASTRO PhD Student
Theme: Dark

Calcino is studying for his Honours degree under the supervision of Tamara Davis. His research focus lies in cosmology, but he has a strong interest in all areas of astronomy.

Mr Simon Deeley

CAASTRO Honours Student
Theme: Evolving

Deeley is an Honours student, working under the supervision of Michael Drinkwater. He began his Honours project by looking at how the fraction of elliptical galaxies varies across groups of different masses, using data from the Galaxy and Mass Assembly (GAMA) survey. He then compared these results with merger simulations, finding that galaxy mergers appear to be the dominant driver of galaxy evolution in these environments.

Professor Michael Drinkwater

CAASTRO Associate Investigator
Theme: Evolving

Drinkwater's research focus is on the origin and evolution of galaxies. He is using observations from the SAMI Galaxy Survey to determine the role of black holes in driving high-velocity outflows in galaxies. With Simon Deeley, he recently demonstrated a strong correlation between galaxy mergers and the formation of elliptical galaxies in galaxy groups.

Mr Samuel Hinton

CAASTRO PhD Student
Theme: Dark

Samuel Hinton is a PhD student. In his undergraduate software and physics theses, Samuel developed the redshifting code *Marz* and performed an analysis of the 2D BAO (baryon acoustic oscillation) signal in order to constrain cosmology. Having worked with the OzDES team previously, Samuel is now looking into a fully Bayesian approach to supernova cosmology. In 2017 Samuel intends to delve further into Bayesian analysis, take on a technical role in the development of the TAIPAN project in addition to his work with OzDES, and complete as many side projects as possible.

Mr Harry Hobson

CAASTRO Honours Student
Theme: Dark

Harry Hobson is studying for his Honours degree under the supervision of Tamara Davis. Using the DES/OzDES reverberation-mapping dataset, he is investigating the emission-line properties of active galactic nuclei and how these properties affect mass estimates made using reverberation mapping.

Mr Daniel Muthukrishna

CAASTRO Honours Student
Theme: Dark

In 2016 Muthukrishna completed his Honours degree in physics and engineering at the University of Queensland. His main focus is cosmology, and he has done some work on analysing the acceleration history of the universe with supernova and BAO (baryon acoustic oscillation) data. More recently, however, he has worked with the Australian sector of the Dark Energy Survey, OzDES. In particular, he has developed DASH, a machine-learning program to quickly and accurately classify supernova spectra obtained by OzDES (details, page 28).

Dr David Parkinson

CAASTRO Associate Investigator
Theme: Dark

Parkinson heads the Theory and Simulations project within CAASTRO. He has been leading research into testing theories of modified gravity, which have been proposed as an alternative explanation for the accelerated expansion of the universe; his work has focused on using measurements of the large-scale structure of the universe to test these models. He has also developed theoretical predictions and numerical simulations for the formation of structure under alternative theories of gravity.

Parkinson is leading the cosmology analysis of the EMU (Evolutionary Map of the Universe) wide-area radio survey, which will be conducted on the Australian Square Kilometre Array Pathfinder (ASKAP) telescope. He is also an executive team member and observer for the 2dFLens survey, which will combine spectroscopic measurements of the redshift-space distortions with weak gravitational lensing to direct test our theory of gravity on cosmological scales.

Ms Merryn Taylor

CAASTRO Honours Student
Theme: Dark

Merryn completed her Honours thesis this year under the supervision of Tamara Davis, looking at the weak gravitational lensing of Type Ia supernovae.

Ms Candy Wu

CAASTRO Administrator

Wu joined the CAASTRO UQ node in March 2014. She had previously worked in finance and human resources for six years for the School of Mathematics and Physics and the School of Business at the University of Queensland. Wu provides financial and administrative support to the CAASTRO members at the university and is responsible for reconciling financial data against the CAASTRO budget.

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, Molonglo, and the Pawsey Supercomputing Centre. 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.

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 soon play, 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 support-astronomer 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's primary research activities within CAASTRO fall under the Evolving Universe theme, although some aspects of his work overlap with activities in 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.

Commonwealth Scientific and Industrial Research Organisation

Dr Simon Johnston
CAASTRO Partner Investigator

Dr Johnston was Head of Astrophysics for CSIRO Astronomy and Space Science until November 2016. 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.

Dr George Heald
CAASTRO Partner Investigator

Dr Heald leads the newly formed CSIRO Astronomy and Space Science (CASS) Astrophysics team in Perth, which is based at the Australian Resources Research Centre next to the Pawsey Supercomputing Centre. His research interests include how galaxies' gas content and magnetic fields affect star formation. Dr Heald has extensive experience in designing and performing all-sky imaging surveys at low radio frequencies. He co-leads the ASKAP POSSUM survey, an investigation of cosmic magnetic fields; is a core member of the Cosmic Magnetism Science Working Group for the SKA; and serves on the Executive Board of the Murchison Widefield Array.

Professor Ray Norris
CAASTRO Partner Investigator

Professor Norris is an emeritus fellow at CSIRO and is 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. Norris is also a Professor, undertaking research, at Western Sydney University.

Dr James Allison
CAASTRO Affiliate

Dr Allison is an Affiliate in CAASTRO and is a member of the ASKAP FLASH survey, which probes the distribution and evolution of atomic hydrogen (HI) to high redshifts. His current research focusses on using HI absorption lines to study the role of neutral gas in fuelling active galactic nuclei and the subsequent feedback on the host galaxy. Dr Allison also served on the CAASTRO Gender Action Committee in 2016.

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 conducting surveys for radio transients; 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 principle investigator of the Murchison Widefield Array Transients Survey (MWATS), which will 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.

California Institute of Technology, USA

Professor Shri Kulkarni
CAASTRO Partner Investigator

Professor Kulkarni's research interests fall within CAASTRO's 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 gamma-ray bursts and software correlation and instrumentation development applicable to the Square Kilometre Array. Kulkarni is one of the originators of the Palomar Transient Factory (PTF), a northern-hemisphere counterpart 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. Professor Kulkarni also has 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 contributed to CAASTRO's Dark Universe theme until 2016, when he resigned because of a change in role. Pain was the Director of LPNHE, a large physics research grouping that carries out a broad range of high-energy and particle-physics experiments. As French lead investigator of the Supernova Legacy Survey (SNLS) project, Pain is using type Ia supernovae to measure the acceleration of the universe. Pain and his team at LPNHE actively participated in the SkyMapper supernova survey, taking leading roles in the calibration and precision photometric analysis of the supernova data.

Dr Nicolas Regnault
CAASTRO Partner Investigator

Dr Regnault replaced Dr Pain as a CAASTRO Partner Investigator during 2016. His team worked on the preparation and the design of the SkyMapper supernovae survey, and he has been involved in the spectroscopic follow-up of the first SNe discovered by SkyMapper, through CAASTRO's participation in the PESSTO program. He has worked on the recalibration and refurbishing of the SkyDICE light source, and has assisted the SkyMapper team with the photometry and photometric calibration of the SkyMapper SN Ia light curves.

University of Toronto, Canada

Professor Bryan Gaensler
CAASTRO Partner Investigator

Professor Gaensler is the Director of the Dunlap Institute at the University of Toronto. In 2016 he worked on wide-field survey data from the Murchison Widefield Array, which he used to search for the synchrotron cosmic web and to study a new sample of peaked-spectrum radio galaxies. In 2017 he will work on early-science observations made 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 is in the CAASTRO Evolving Universe theme, and his current research lies in using spectral distortions in the cosmic microwave background as a diagnostic of the cosmic baryon evolution in the Universe. The research develops methods and instrumentation for all-sky measurements of the radio background, at centimetre and longer wavelengths, for detecting global spectral-distortion signals from cosmological reionisation and recombination. The research work of Subrahmanyan and his colleagues at the Raman Research Institute with the Murchison Widefield Array is primarily in efforts to detect the Epoch of Reionisation.

University of Oxford

Professor Roger Davies
CAASTRO Partner Investigator

Professor Roger Davies is Philip Wetton Professor of Astrophysics and Director of the Centre for Astrophysical Surveys at Oxford University. Within CAASTRO, Davies's contributions are 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 for researchers from all CAASTRO nodes. In 2016 CAASTRO members used eight million CPU hours on NCI facilities.

ASSOCIATED ORGANISATIONS

Italian National Institute for Astrophysics (INAF)

Professor Steven Tingay
CAASTRO Affiliate

Professor Tingay is currently Director of the Institute of Radioastronomy at the Italian National Institute for Astrophysics (INAF), as well as Head of Section II (Radioastronomy) within the INAF Science Directorate (responsible for the coordination of the Italian national radio-astronomy program, including Italy's involvement in the SKA). Tingay holds these positions while on secondment from Curtin University. As a CAASTRO Affiliate, Tingay continues collaborations with CAASTRO staff and students he started as a CAASTRO Chief Investigator, primarily on research projects being carried out with the Murchison Widefield Array (MWA) in Western Australia.

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 Deputy Vice-Chancellor (Enterprise) at the University of New South Wales. 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 the Australian SKA Pathfinder, 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 at the University of Nottingham and an Associate Investigator in CAASTRO. His research interests fall under the Evolving Universe theme, focusing on numerical simulations of the intergalactic medium and the epoch of reionisation.

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 studying the peculiar-velocity field of the local Universe with the data from the 2MASS Tully-Fisher Survey. His research interests are HI 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 Keane is a CAASTRO Affiliate. His role is in the Dynamic Universe Theme, where he works mainly in the areas of pulsars and fast radio bursts. Dr Keane is a Project Scientist with the SKA Organisation, based at Jodrell Bank in the UK. There he is contributing to the design of the telescope and its science programme. He is also Partner Investigator of the Survey for Pulsars and Extragalactic Radio Bursts (SUPERB) at Parkes. Through his visiting role at Swinburne he supervises three CAASTRO PhD students and is involved with the UTMOST project.

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 HI): this survey, to run on the Australian SKA Pathfinder, will research the reservoir of star-forming gas in the distant Universe.

CAASTRO COLLABORATIONS

This year CAASTRO team members have been involved in a number of Australian and international collaborations. 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, is due to be launched in 2018. 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 Australian widefield facilities such as ASKAP, MWA, Molonglo, Parkes, ATCA, SkyMapper, AAT and TAIPAN. The agreement applies to 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 of 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.

ACAMAR: the Australia-ChinA Consortium for Astrophysical Research

Institutions: Purple Mountain Observatory of the Chinese Academy of Sciences (Nanjing, China), National Astronomical Observatories of the Chinese Academy of Sciences (NAOC), CAASTRO

ACAMAR is 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. ACAMAR maximises the scientific return on investments in astronomy infrastructure, particularly by helping the two countries to cooperate in running telescopes based in Australia, Antarctica 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.

SkyMapper

Institutions: Australian National University, CAASTRO, Monash University, Australian Astronomical Observatory, University of Sydney

SkyMapper is a 1.35-metre telescope with a 5.7 deg^2 imager, located near Coonabarabran, New South Wales, and owned and operated by the Research School of Astronomy and Astrophysics at the Australian National University. CAASTRO secured a $1.16m ARC Linkage Infrastructure Equipment and Facilities (LIEF) grant to secure membership of the SkyMapper consortium for all Australian astronomers during 2014–2019. This funding 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, University of Sydney, University of Western Australia, Western Sydney University

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, Taipan and Funnelweb. The Taipan survey of one and a half million galaxies will begin observations in 2017. It is aimed at:

- measuring the Hubble constant, H_0, with a precision of one per cent
- measuring the bulk motion of galaxies, to better understand dark energy
- linking the star-formation and gas-fuelling properties of galaxies, to understand galaxy evolution. (This will be done in conjunction with the WALLABY radio survey, made with the Australian SKA Pathfinder,)

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
- provide a robust input sample for the next-generation planet-finding satellite observatory, TESS.

While the scientific goals of the TAIPAN facility and surveys are closely aligned with CAASTRO goals, these projects are not currently receiving any CAASTRO funding.

OzDES

Institutions: Australian Astronomical Observatory, Australian National University, University of Queensland, 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 (SN Ia) 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 slated to begin full scientific operations around 2020. In 2016 the Australian Astronomical Observatory and CAASTRO worked together to engage the whole Australian astronomy community in this project.

Murchison Widefield Array

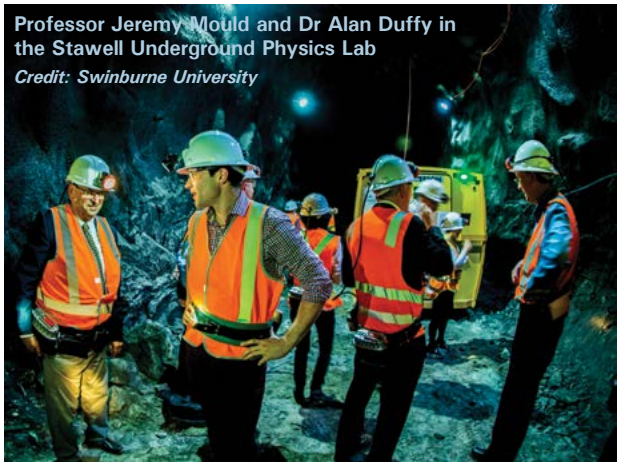
Institutions: University of Melbourne, Australian National University, University of Sydney, Curtin University, University of Western Australia, Swinburne, CSIRO, Massachusetts Institute of Technology, Harvard-Smithsonian Center for Astrophysics, University of Washington, Arizona State University, Brown University, University of Toronto, University of Wisconsin–Milwaukee, Raman Research Institute

CAASTRO members make key contributions to 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 radio signals from neutral hydrogen at the Epoch of Reionisation. In 2016 the MWA was expanded, with 72 new antenna tiles installed in two sets of regular hexagons. These new antennas are specifically to improve the sensitivity of the MWA for the EoR power spectrum experiment.

Stawell Underground Physics Lab

Institutions: University of Melbourne, Swinburne University of Technology, University of Adelaide, Australian National University, Australian Nuclear Science and Technology Organisation.

The design for the Stawell Underground Physics Lab (SUPL) began in 2015 and construction is expected to start in July 2017. Called SABRE (Sodium iodide with Active Background Rejection), the detection experiment – the first direct-detection experiment for dark matter in the Southern Hemisphere – is being developed by a consortium of institutions from Australia, the Italian National Institute of Nuclear Physics (INFN) and Princeton University. 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.



Professor Jeremy Mould and Dr Alan Duffy in the Stawell Underground Physics Lab
Credit: Swinburne University

Outreach collaborations

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. We also held our third *Uluru Astronomy Weekend*, as part of National Science week: at this event, 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 two-year collaboration with Museum Victoria (MV) for the production of a planetarium show. The show was launched in early 2016, with CAASTRO and the team at Melbourne Planetarium presenting CAASTRO research results and real datasets for events at several Australian and overseas locations. It has now been seen by more than 50,000 people.

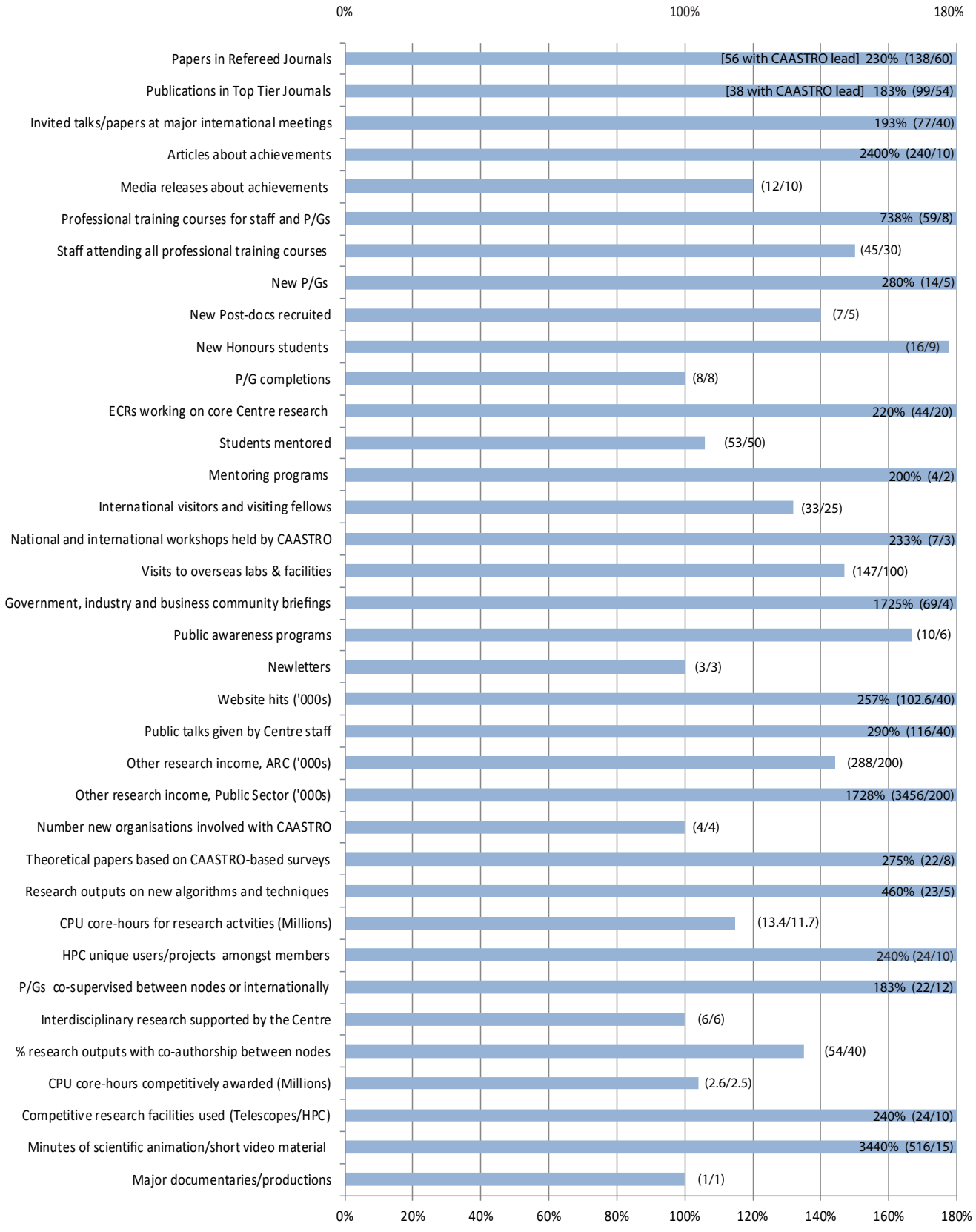
CAASTRO Education and Outreach has worked closely with the MV Astronomy and Space Sciences team to create educational resources, both hands-on and digital, that tie in with both the show and the Australian curriculum.

Science writing for younger audiences

CAASTRO Education and Outreach has worked with freelance science-communication professionals in Perth to create the *Bright Stars* school calendar and a comic book, "The cosmic adventures of Alice and Bob". *Bright Stars* features the personal profiles of our researchers and their advice to high-school students, which we hope will spark their interest in astronomy. The calendar was produced in collaboration with CAASTRO's outreach partner *Telescopes in Schools* and is being distributed to Australian high schools as a free resource. The comic book will be launched in March 2017: it too will be distributed for free, to Australian primary and combined schools.

KPI DASHBOARD

January – December 2016



* 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 2016

INCOME

	2011	2012	2013	2014	2015	2016	ACTUAL	2017	ESTIMATED
ARC Income	$3,000,000	$2,800,000	$3,100,000	$3,100,000	$3,100,000	ARC Income	$2,800,000	ARC Income	$2,700,000
ARC Indexation	$47,431	$153,527	$295,786	$398,406	$461,065	ARC Indexation	$471,130	ARC Indexation	$577,912
Node Contributions	$912,272	$1,039,569	$842,002	$1,206,663	$997,980	Node Contributions[⌘]	$1,059,247	Node Contributions	$973,937
Other Grants		$750,000	$1,264,437						
Other	$747,294	$13,685	$28,206	$296,930	$301,210	Other *	$152,457	Other	$17,000
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 Actual Income**	**$4,482,834**	**Total Estimated Income**	**$4,268,849**
Carry Forward	$-	$2,930,552	$2,967,985	$3,037,571	$3,456,823	Carry Forward	$3,184,858	Carry Forward	$2,736,186
Total Funds Available	**$5,106,997**	**$6,937,333**	**$7,583,979**	**$9,304,007**	**$8,317,078**	**Total Funds Available**	**$7,667,692**	**Total Estimated Funds Available**	**$7,005,035**

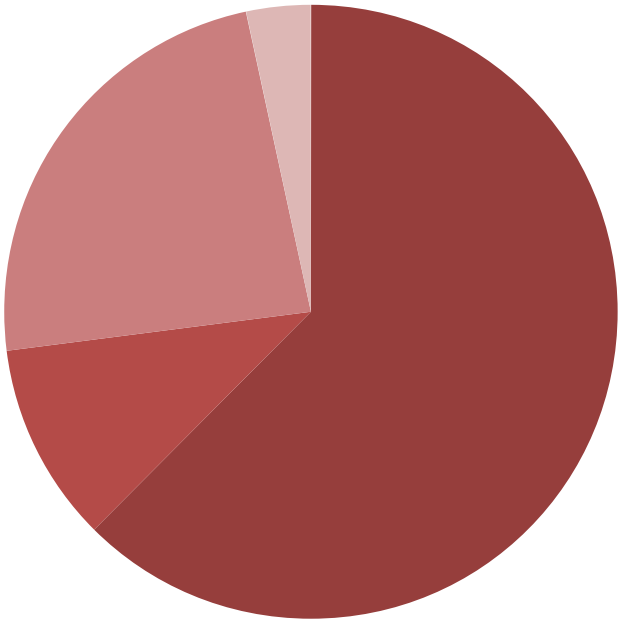
*Other income includes CAASTRO workshop income/sponsorship, Secondments (CSIRO, AAO), reimbursement from TAIPAIN project
[¥] Includes NSW SLF Grant Part II, DIISR Travel Grants and LIEF Grant won by UWA
[⌘] ANU contributed remaining 2015 funds of $84,215 in Jan 2016

EXPENDITURE

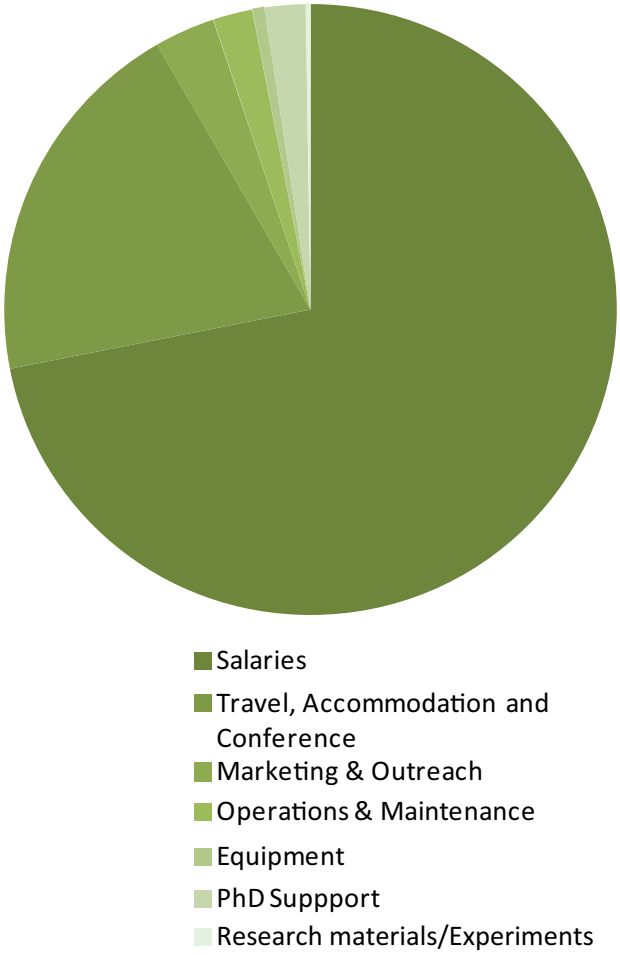
	2011	2012	2013	2014	2015	2016	ACTUAL	2017	ESTIMATED
Salaries	$1,467,096	$2,807,859	$2,875,061	$3,320,256	$3,874,054	Salaries	$3,708,004	Salaries	$3,716,907
Travel, Accommodation and Conference	$363,516	$503,587	$778,788	$810,779	$831,743	Travel, Accommodation and Conference	$1,018,045	Travel, Accommodation and Conference	$814,000
Marketing & Outreach	$124,914	$139,732	$20,336	$92,675	$133,937	Marketing & Outreach	$165,440	Marketing & Outreach	$75,000
Operations & Maintenance	$103,342	$81,706	$56,535	$124,237	$66,916	Operations & Maintenance	$108,392	Operations & Maintenance	$44,900
Equipment	$102,993	$145,790	-$59,721	$29,891	$24,157	Equipment	$32,674	Equipment	$30,000
PhD Support	$5,709	$101,763	$126,522	$201,402	$182,211	PhD Suppport	$111,613	PhD Suppport	$123,000
Research materials/ Experiments	$8,874	$188,911	$5,766	$3,507	$19,202	Research materials/ Experiments	$13,266	Research materials/ Experiments	$-
Corrections			-$6,879			Adjustments for Grants[#]	-$225,928		
2013 Grants **			$750,000	$1,264,437					
Total Expenditure	**$2,176,445**	**$3,969,348**	**$4,546,408**	**$5,847,184**	**$5,132,220**	**Total Actual Expenditure**	**$4,931,506**	**Total Estimated Expenditure**	**$4,803,807**
Balance	$2,930,552	$2,967,985	$3,037,571	$3,456,823	$3,184,858	Actual balance	$2,736,186	Estimated balance	$2,201,228

** LIEF, SIEF & AMSPP Grants have been reported as fully expensed in 2014, although LIEF Grant to be spent over 5 years, SIEF Grant to be spent over 36 months and AMSPP Grant to be spent over 2 years.
[#] Credit for non-ARC salary expenses – Collaborations

2016 INCOME



2016 EXPENDITURE



CAASTRO IN-KIND REPORT JANUARY - DECEMBER 2016	
University of Sydney	$442,287
University of Western Australia	$266,082
University of Melbourne	$269,970
Swinburne University of Technology	$541,373
Australian National University	$298,349
Curtin University of Technology	$362,285
CSIRO	$2,970,629
Anglo-Australian Observatory	$1,192,950
Max Planck Institute for Radio Astronomy	$146,696
California Institute of Technology	$134,673
The University of Oxford	$53,792
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 Nucleaire et de Hautes Energies	$160,088
National Computational Infrastructure	$1,000,000
Raman Research Institute	$200,000
University of Queensland	$123,977
Voyages Indigenous Tourism	$50,000
Total In-Kind Contributions	**$8,670,059**

GRANTS WON BY CAASTRO MEMBERS IN 2016

ARC Centre of Excellence
ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions.
This Centre aims to answer fundamental questions in astrophysics including the origin of matter and the periodic table of elements, and the origin of ionisation in the Universe. It intends to use Australian three-dimensional technology to transform our understanding of the Universe. It will unify world-leading Australian optical and radio surveys with theoretical simulations and new e-Science techniques for Peta-scale data sets. The Centre will also nurture young scientific leaders and make high-school students interested in STEM sciences through education and outreach programmes. It is expected the research will propel Australia to the forefront of astronomical research for the coming decade while capitalising on innovative instrumentation.
CE170100013
$33,400,000
Chief Investigator: Lisa Kewley
Other CAASTRO investigators: Stuart Wyithe; Elaine Sadler; Lister Staveley-Smith; Karl Glazebrook; Carole Jackson; Jonathan Bland-Hawthorn; Cathryn Trott; Rachel Webster; Matthew Colless; Scott Croom; Emma Ryan-Weber; Christopher Power; Warrick Couch; Roger Davies; Bryan Gaensler; and Andrew Hopkins

ARC Centre of Excellence
ARC Centre of Excellence for Gravitational Wave Discovery.
This Centre aims to explore the historic first detections of gravitational waves to understand the extreme physics of black holes and warped spacetime, and inspire the next generation of Australian scientists and engineers. This Centre will coalesce research activities into a focussed national programme whose discoveries are intended to experimentally validate Einstein's General Theory of Relativity and educate the public about the wonders of Einstein's Universe.
CE170100004
$31,300,000
Chief Investigator: Matthew Bailes
Other CAASTRO investigators: Jeff Cooke, Warrick Couch, Shrinivas Kulkarni, and Michael Kramer

ARC Discovery Early Career Researcher Award
Intensity mapping cosmology with radio telescopes.
This project aims to develop a versatile infra-structure for the data analysis of existing observations and future data. Cosmology using intensity mapping of hydrogen with radio telescopes is a key science area for the anticipated Square Kilometre Array. The results of available datasets will constrain the expansion rate of the Universe and the laws of gravity about 7 billion years ago, inaccessible by other observations. New techniques will improve the synergies between optical and radio data by measuring the gas content of optical galaxies. This is expected to advance knowledge of how the galaxy evolves.
DE170100356
$360,000
Chief Investigator: Laura Wolz

ARC Discovery Project
The major transformation mechanism of disk galaxies.
This project aims to discover how lenticular (S0) galaxies formed, which has been a problem since they were first introduced as a possible transition between elliptical and spiral galaxies over 80 years ago.
DP170102344
$389,500
Chief Investigator: Kenji Bekki
CAASTRO investigators: Warrick Couch & Michael Drinkwater

ARC LIEF
Full scale detector system for dark matter.
This project aims to complete a detector system to detect dark matter via nuclear recoil in the Stawell Underground Physics Laboratory (SUPL).
LE170100162
$415,000
Chief Investigator: Elisabetta Barberio
CAASTRO investigators: Jeremy Mould, Alan Duffy

ARC LIEF
Hector-1: Unravelling how galaxies evolve.
This project aims to deliver the first part of Hector, an instrument that can produce three-dimensional (3D) images of 60,000 galaxies in 5 years. This cosmological survey of the local universe is expected to reveal how galaxies, including the Milky Way, evolve and build up their spin with cosmic time. Spin-off technologies could have important industrial applications outside astronomy.
LE170100242
$400,000
Chief Investigator: Joss Bland-Hawthorn
Other CAASTRO investigators: Warrick Couch, Scott Croom, Julia Bryant

ARC LIEF
Semiconductor laser for adaptive optics in astronomy and space awareness.
This project aims to create a laser system for use as a laser guide star.
LE170100004
$502,453
Chief Investigator: Celine d'Orgeville
CAASTRO investigator: Robert Sharp

ARC LIEF
The Cherenkov Telescope Array - Production phase.
This project aims to ensure Australia's contribution to the five-year production phase of the Cherenkov Telescope Array (CTA), a very high energy gamma-ray astronomy instrument that is expected to transform both high energy astrophysics and astro-particle physics.
LE170100104
$1,390,000
Chief Investigator: Gavin Rowell
CAASTRO investigator: Anne Green

Other Public Sector
Australia and Germany Joint Research Cooperation Scheme - Pulsar hunting with fast folding algorithms
$25,000
Chief Investigator: Michael Kramer

Other Public Sector
University of Sydney Flexible Initiatives Fund, Worldwide Universities Network - HI Workshops
$3,000
Chief Investigator: Lister Staveley Smith

Other Public Sector
University of Sydney and the China Studies Centre - Conference Fund 2016
$10,000
Chief Investigator: Elaine Sadler

Other Public Sector
Women in STEM and Entrepreneurship Award, Department of Industry, Innovation and Science
$250,000
Chief Investigator: Kate Gunn

CAASTRO PEOPLE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CAASTRO Executive

1. Elaine Sadler (Director)
2. Lister Staveley-Smith (Deputy Director)
3. Matthew Bailes (Dynamic theme leader)
4. Tamara Davis (Dark theme leader)
5. Kate Gunn (Chief Operating Officer)
6. Carole Jackson
7. Christian Wolf
8. Stuart Wyithe (Evolving theme leader)

Chief Investigators

9. Chris Blake
10. Matthew Colless
11. Scott Croom
12. Jeremy Mould
13. Tara Murphy
14. Brian Schmidt
15. Rachel Webster


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Partner Investigators

16. Lindsay Botton
17. Warrick Couch
18. Roger Davies
19. Xiaohui Fan
20. Carlos Frenk
21. Bryan Gaensler
22. George Heald
23. Andrew Hopkins
24. Simon Johnston
25. Michael Kramer
26. Shri Kulkarni
27. Ray Norris
28. Reynald Pain
29. Ue-Li Pen
30. Nicolas Regnault
31. Mara Salvato
32. Ravi Subrahmanyan


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Associate Investigators

33. Ramesh Bhat
34. Joss Bland-Hawthorn
35. Jamie Bolton
36. Jeff Cooke
37. Michael Drinkwater
38. Claudia Lagos
39. Chris Lidman
40. Jean-Pierre Macquart
41. Martin Meyer
42. John Morgan
43. Danail Obreschkow
44. Christopher Onken
45. Stephen Ord
46. Chris Power
47. Ashley Ruiter
48. Emma Ryan-Weber
49. Ivo Seitenzahl
50. Robert Sharp


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51. Stuart Sim
52. Cathryn Trott
53. Randall Wayth

CAASTRO Research Staff


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54. Ixandra Achitouv
55. Balwinder Singh Arora
56. Jacobo Asorey
57. Julie Banfield
58. Julia Bryant
59. Seo-Won Chang
60. Rajan Chhetri
61. Francesco D'Eugenio
62. Lisa Fogarty
63. Cullan Howlett
64. Andrew Johnson
65. Shahab Joudaki
66. Anna Kapinska
67. Emil Lenc
68. Christine Lynch


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69. Anais Möller
70. Edward Macauley
71. Katherine Mack
72. Elizabeth Mahony
73. Vanessa Moss
74. Steven Murray
75. Se-Heon Oh
76. Bart Pindor
77. Kathryn Plant
78. Attila Popping
79. Pietro Procopio
80. Jonghwan Rhee
81. Marcin Sokolowski
82. Dan Taranu
83. Edoardo Tescari
84. Steven Tremblay
85. Brad Tucker
86. Laura Wolz
87. Ding Yan
88. Fang Yuan

CAASTRO
Professional Staff

89. Jacinta den Besten (Outreach, U. Melbourne)
90. Kim Dorrell (Executive Officer, U. Melbourne)
91. Angela Dunleavy (Administrative Coordinator, Curtin U)
92. Wiebke Ebeling (Education & Outreach Manager, Curtin U)
93. Debra Gooley (Finance Officer, U. Sydney)
94. Helen Keys (Executive Assistant to Director U. Sydney)
95. Sue Lester (Administrator, Swinburne)
96. Jenny Lynch (School Education Officer, University of Sydney)
97. Susanne Meinen (Administration Officer, ANU)
98. Clare Peter (Administrative Officer, UWA)
99. Helen Sim (Public Relations Officer, U. Sydney)
100. Kylie Williams (Events & Communications, U. Sydney)
101. Candy Wu (Administration Officer, U. QLD)

Not pictured

Tina Sallis (Operations Coordinator, Curtin U)


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CAASTRO Affiliates

102. James Allen
103. James Allison
104. Keith Bannister
105. Ewan Barr
106. Holger Baumgardt
107. Brian Boyle
108. Frank Briggs
109. Sarah Brough
110. Duncan Campbell-Wilson
111. Weiguang Cui
112. Stephen Curran
113. Alan Duffy
114. Pascal Elahi
115. Paul Geil
116. Karl Glazebrook
117. Anne Green
118. Paul Hancock
119. Tao Hong


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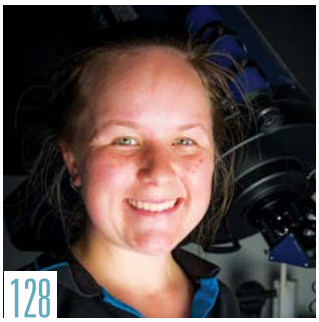
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120. Andrew Jameson
121. Christopher Jordan
122. Evan Keane
123. Hansik Kim
124. Anthea King
125. Greg Madsen
126. Daniel Mitchell
127. Signe Riemer-Sørensen
128. Kimberly Steele
129. Edward Taylor
130. Steven Tingay
131. Syed Ashraf Uddin
132. Willem van Straten
133. Mia Walker
134. Charlotte Welker
135. Oiwei Ivy Wong


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CAASTRO Students

136. Caitlin Adams
137. Matthew Alger
138. Kamran Ali
139. Per Andersen
140. Igor Andreoni
141. Dilyar Barat
142. Tania Barone
143. Stephanie Bernard
144. Shivani Bhandari
145. Jessica Bloom
146. Joshua Calcino
147. Manisha Caleb
148. Joe Callingham
149. Roderigo Canas Vazquez
150. Alexandru Codoreanu
151. Christopher Curtin
152. Simon Deeley
153. Dougal Dobie


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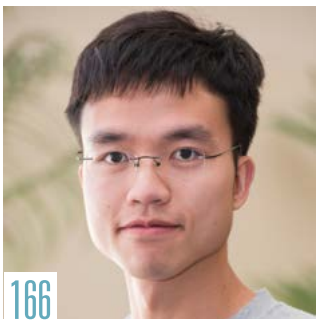
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154. Luz Angela Garcia Penaloza
155. Marcin Glowacki
156. Jacob Golding
157. Guido Granda Munoz
158. Katherine Harborne
159. Samuel Hinton
160. Harry Hobson
161. Fabian Jankowski
162. Ronniy Joseph
163. Katharine Kelly
164. Sarah Leslie
165. Jing Li
166. Lincheng Li
167. Jack Line
168. Rebecca McElroy
169. Samuel McSweeney
170. Scott Meyer
171. Bradley Meyers


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172. Vincent Morello
173. Aina Musaeva
174. Daniel Muthukrishna
175. Sinem Ozbilgen
176. Fiona Panther
177. Aditya Parathasarathy Madapusi
178. Mahsa Rahimi
179. Jarryd Rasti
180. Sarah Reeves
181. Tristan Reynolds
182. Samuel Richards
183. Jennifer Riding
184. Fei Qin
185. Khaled Said
186. Diane Salim
187. Mayuri Sathyanarayana Rao
188. Adam Schaefer
189. Henning Schmitz


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190. Paul Scott-Taylor
191. Natalia Eiré Sommer
192. Georgina Taylor
193. Merryn Taylor
194. Sarah Thomson
195. Matthew Varidel
196. Vivek Venkatraman
197. Charlotte Ward
198. Alexander Williamson
199. Mengyao Xue
200. Bonnie Zhang
201. Xiang Zhang
202. Andrew Zic


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Not pictured

Garima Chauhan
Wei Chieh (Mason) Ng
Jacob Seiler

GLOSSARY

ACRONYM	DESCRIPTION	DEFINITION
2MTF	Project	2MASS Tully-Fisher
6dFGS	Project	6-degree Field Galaxy Survey
AAL	Organisation	Astronomy Australia Ltd
AAT	Facility	Anglo-Australian Telescope
ASELL	Organisation	Advancing Science by Enhancing Learning in Laboratories
ATCA	Facility	Australia Telescope Compact Array
AGN	Object	Active Galactic Nuclei
ASKAP	Facility	Australian Square Kilometre Array Pathfinder
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
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 Burst
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
GRB	Object	Gamma-Ray Burst
HECTOR	Project	Follow-on IFU after SAMI
HIPASS	Project	HI 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
MOST	Facility	Molonglo Observatory Synthesis Telescope
MWA	Facility	Murchison Widefield Array
NCI	Facility	National Computational Infrastructure
NRAO	Facility	National Radio Astronomy Observatory, USA
NVSS	Project	NRAO VLA Sky Survey
OzDES	Project	Australian Dark Energy Survey
PESSTO	Project	Public ESO Spectroscopic Survey of Transient Objects

ACRONYM	DESCRIPTION	DEFINITION
PHISCC	Conference Committee	SKA Pathfinders HI Survey Coordination Committee
RFI	Term	Radio Frequency Interference
SAMI	Project	Sydney–AAO Multi-object Integral-field spectrograph
SKA	Facility	Square Kilometre Array
SNe Ia	Object	Supernovae Ia
S-PASS	Project	S-band Polarisation All Sky Survey
SRG	Facility	Spektrum-Rötgen-Gamma, Russian satellite
TAIPAN	Facility	Transforming Astronomical Imaging surveys through Polychromatic Analysis of Nebulae
UKST	Facility	UK Schmidt Telescope
UTMOST	Facility	An upgrade of the Molonglo Observatory Synthesis Telescope
VAST	Project	Variable and Slow Transients
VLA	Facility	Very Large Array
WALLABY	Project	Widefield ASKAP L-Band Legacy All-sky Blind SurveY
WiggleZ	Project	A large-scale galaxy redshift survey
WSRT	Facility	Westerbork Synthesis Radio Telescope

ULURU ASTRONOMER IN RESIDENCE

Natalia Eiré Sommer, CAASTRO Astronomer in Residence in the Town Square

Credit: Nathaniel Butterworth

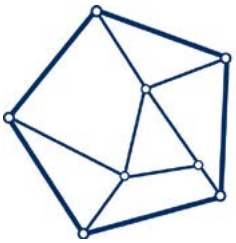
What is it like being the astronomer in residence for CAASTRO at Uluru? 'Great' doesn't begin to cover it. It's so beautiful there, such great people working in the small SkyTalker department, with so much passion, and such an amazing night sky. As astrophysicists, we tend to spend way more time looking into a computer screen than into the night, and to us, stars and galaxies are represented by numbers, rather points and smears in the sky. During the stay at Uluru you get to right that wrong, even if only for a couple of weeks.

I have loved spending several hours each day talking to interested people. Let's face it; space is awesome, and everyone knows it! People have been keen to come to my public talks, to learn about how black holes work, and to let me explain to them how various stars end their lives. They have loved me pointing out the clusters of stars we are pointing our telescopes at, and having me explain what exactly they are seeing through the eyepiece. And as for me, I have loved helping them out, providing them with the knowledge they are looking for.

Natalia Eiré Sommer
CAASTRO Astronomer in Residence, 2016

The Uluru night sky

Credit: Natalia Eiré Sommer



CAASTRO

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