
ICRAR
International
Centre for
Radio
Astronomy
Research
Volume 4
2015–2016
4

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ICRAR International Centre for Radio Astronomy Research

Curtin University

THE UNIVERSITY OF WESTERN AUSTRALIA

GOVERNMENT OF WESTERN AUSTRALIA

'Boab star trails' – Ancient Boab trees and the southern stars, East Kimberley, Western Australia. Photographer: Wayne Riley.

Foreword

Chair of the ICRAR Board, Dr Ken Michael.

Much has been achieved in the past two years through the International Centre of Radio Astronomy Research, ICRAR, which is a successful partnership of Curtin University, The University of Western Australia and the Western Australian Government.

It consistently receives recognition, at both the national and international levels, in respect to radio astronomy research and its application in support of the Square Kilometre Array project.

The relationship with the SKA Project Office remains strong and in March 2017 the SKA Organisation Board met in Perth, with the opportunity afforded to ICRAR representatives to meet with them. It is clear that research developments in science, engineering and data intensive astronomy by ICRAR have a direct impact on the SKA Project, as is evident through the attraction of key professionals and researchers to ICRAR.

The current five year plan of ICRAR is now in its final stages of development and the Centre has seen wide ranging expansion of areas of development during this time, strengthening the ties with the SKA project even further in respect to research outcomes and associated applications.

It is also timely to develop ICRAR III, building on the work to date and articulating how the SKA project will be supported as it moves into its next phase of development. ICRAR continues to be ranked highly internationally and the relationship between its partners facilitates development which embraces research qualities and close links with industry.

I would like to take this opportunity to thank the ICRAR partners, members of the Board, the Executive Director, Professor Peter Quinn, and his executive team, the staff of ICRAR and all those who have supported ICRAR in achieving the notable developments to date in support of the SKA project.

Hon Dr Ken Michael AC FTSE
Chair of the ICRAR Board

Farewell... Dr Bernard Bowen & Professor Peter Hall

It is with gratitude and respect that this Year Book sees ICRAR farewell Dr Bernard Bowen and Professor Peter Hall, who have had a profound influence on the organisation ICRAR is today.

L to R: Professor Steven Tingay, Dr Bernard Bowen and Professor Peter Hall.

Professor Peter Hall showing the Premier of Western Australia Colin Barnett an SKA-low "Christmas tree" antenna. L to R: Professor Peter Quinn, Colin Barnett MLA, Professor Peter Hall.

Former Chair of the ICRAR Board, Dr Bernard Bowen.

A plaque detailing the naming of minor planet Bernardbowen gifted to Dr Bernard Bowen in 2015.

Dr Bowen was instrumental in the establishment of ICRAR in 2009 as a joint venture between Curtin University and The University of Western Australia. Renowned as one of the country's finest science administrators, he was the inaugural chair of the ICRAR Board and set the way the Board functions.

Dr Bowen oversaw the growth of ICRAR, including the transition from ICRAR I to ICRAR II, and helped to bring part of the Square Kilometre Array telescope to Western Australia. The ICRAR Board is now chaired by former WA Governor Dr Ken Michael.

Professor Hall was ICRAR's first director of engineering, taking the helm from the organisation's launch in 2009. He led the engineering program from Day 1, making decisions that would ultimately guide the team to the international success and visibility it enjoys today. Professor Hall's vision and expertise helped to position ICRAR as a leading engineering contributor to both the MWA telescope and the SKA. He retired at the end of 2016.

The contributions of Dr Bowen and Professor Hall will continue to resonate in the years to come and ICRAR thanks them for their tireless efforts.

SKA project update

The SKA is arguably the world's largest science project, with the low frequency part of the telescope alone set to have more than a quarter of a million antennas facing the sky. Since the beginning of the pre-construction program in 2013, there have been two important parallel efforts for the project: the first is to set up an intergovernmental organisation (IGO); and the second is to define what will be built and how much it will cost.

This artists rendition of the SKA-mid dishes in Africa shows how they may eventually look when completed. The 15m wide dish telescopes, will provide the SKA with some of its highest resolution imaging capability, working towards the upper range of radio frequencies which the SKA will cover. Credit: SKA Organisation

Eleven international teams, called consortia, are tasked with designing a critical element of the project, with each consortium composed of partners who are leaders in their fields.

An aerial view of Jodrell Bank Observatory and the headquarters of the SKA Organisation, in the United Kingdom.

Currently the SKA is a UK company limited by guarantee, with partners and a board of directors. As an international IGO, the SKA would instead exist as a treaty-level organisation founded by an agreement between governments. IGOs can usually transfer money, things and people between countries without any taxes or other impediments to movement. Both the European Southern Observatory and CERN operate as IGOs, and this collaboration fuelling structure allows them a lot of flexibility in the way they do business.

The process of setting up the SKA as an IGO started in 2014 and the documentation for this process is now in place. It is hoped that the SKA will officially be an IGO before the end of 2017, with headquarters in Manchester and ten or more countries as official signatories.

At the same time, a huge amount of work has gone into efforts to define and cost the telescope. This is happening through 11 international consortia, each charged with designing a different part of the SKA. All of the consortia have now passed the preliminary design review stage of their piece of the telescope, and we have the first vision of the design of SKA-low and SKA-mid—what they might look like, how big they will be and what technologies they will carry.

Unfortunately transformational projects are not without their challenges. The cost of what was designed was more than 900 million Euros, against a budget of only 650 million Euros. The original plans were to see three parts to the SKA; SKA-low (in Western Australia), SKA-mid (in South Africa) and SKA-survey (an outgrowth of ASKAP in Western Australia). In early 2015, the tough decision was made to cut SKA-survey from the final plans, changing the capabilities of the telescope to fit inside the budget.

This difficult rebaselining decision has been accepted as necessary and people are working to refine the design of the two remaining parts of the SKA. However recently it again became clear that the design was too expensive, that the aspirations were too big. It was realised that the SKA may need to be even more serious about rebaselining, and call on the community to contribute more to the project. It is likely the SKA will depend much more on some of the systems built for the precursors, perhaps with elements of the MWA, LOFAR, MeerKAT or ASKAP used for SKA-low and SKA-mid.

It is an important crunch time for the project and an evolving story. The SKA has made it through similar challenges before and will get through them again, and the final design may not be far off. It is hoped that contracts to build SKA-low and SKA-mid will be issued in 2018 or 2019, achieving the right cost and the lofty science goals of the transformational project.

Members of ICRAR's Engineering team working with colleagues from the National Institute for Astrophysics in Italy to install antennas for the Aperture Array Verification System test platform at the future SKA site in Western Australia.

1

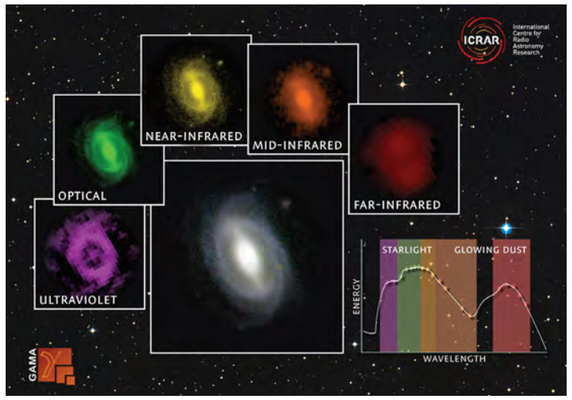
THE BEGINNING

Looking back and looking forward

ICRAR has grown from the roots put down in its first five years, and continued to develop its strengths in science, engineering and data intensive astronomy. The second five years of ICRAR—known as ICRAR II—was formally launched in July 2014, and 2015 and 2016 have seen the organisation flourish as its staff and students have operated 'full steam ahead'.

In astronomy, ICRAR has broadened from a primary focus on radio astronomy to expand into other areas. The Centre has recognised its great strength in multi-wavelength astronomy, studying the infrared sky, the optical sky, the ultraviolet sky and even higher energies like X-rays, along with radio. By synthesising all these observations into one clear picture, we can gain a greater understanding of how the Universe works.

At the heart of this new and growing area of multi-wavelength astronomy is the GAMA project, an international consortium led at ICRAR to gather data from different wavelengths. This information is welded together to develop a comprehensive picture of the contents of the cosmos, and to increase our understanding of the evolution of the Universe.



A galaxy from the GAMA survey observed at different wavelengths, from the far ultraviolet to the far infrared. The inset graph shows how much energy is being generated at the different wavelengths.

Some of the dipoles that form part of the Murchison Widefield Array (MWA) radio telescope, located at the Murchison Radio-astronomy Observatory in outback Western Australia.

One of the 36 antennas of the CSIRO Australian SKA Pathfinder (ASKAP) radio telescope located at the Murchison Radio-astronomy Observatory.

ICRAR's Executive Director, Professor Peter Quinn.

Another growing area of science in ICRAR II is simulations and theoretical astronomy. The Centre has developed a great strength in being able to use large computers to model individual galaxies, clusters of galaxies and even the entire Universe. This modelling can show us how galaxies have grown over time—both the parts we can see (the stars) and the parts we can't see (the dark matter).

These synthetic, or 'mock' Universes, are also great training grounds for observers. Astronomers can use the simulations to develop strategies and techniques for finding new objects, to perfect designs for surveys of the sky and to analyse what they find. The simulations team has grown in partnership with other ICRAR scientists surveying the sky with radio and optical telescopes.

Engineering remains a hugely important discipline for ICRAR to be able to contribute to the deployment and prototyping of technologies. ICRAR II has seen the Centre's relationship with the SKA project develop very strongly, with pre-construction contracts initiated in 2013. In particular, ICRAR has been very active in the development of the low-frequency receiving system for SKA-low, working on the Murchison Radio-astronomy Observatory (MRO) site in Western Australia. Similarly, ICRAR's Data Intensive Astronomy program, previously known as ICT, has also been leading a major and challenging piece of work for the SKA—designing the science data processor systems.

Both of these significant contributions to the SKA have matured in the last year, and both were successful in passing their preliminary design reviews. This marks a great milestone for ICRAR, with the Centre making a direct and major contribution to the effort to design and realise the SKA.

Now, halfway through ICRAR II, the Centre is striving to achieve the goals set out in its current five-year plan.

i. ICRAR will continue to use the teams developed in its early years to do great science with the SKA precursors here in Australia. ICRAR has on its doorstep the very successful Murchison Widefield Array (MWA), and is about to begin early science with the Australian SKA Pathfinder (ASKAP). Survey science teams at ICRAR will be spearheading scientific leadership, discoveries and publications with the SKA precursors.

ii. ICRAR will continue to focus on delivering everything promised to the SKA project, completing the first phase of pre-construction and welding the Centre to the SKA project as a valuable partner.

iii. ICRAR will prepare the way for the next stage of its life—ICRAR III. The concepts of ICRAR III were defined in 2016, and the Centre will continue to detail what this next phase will be like and how it will be achieved in the era of SKA construction and operations.

Governance and Management

Governing Board as at 31 Dec 2016

Dr Ken Michael	Chair. Appointed July 2016.
Mr Graham McHarrie	Independent member. Appointed February 2009.
Professor Ron Ekers	Independent member. Appointed November 2012.
Professor Chris Moran	Nominated member. Appointed August 2016.
Professor Robyn Owens	Nominated member. Appointed November 2012.
Dr Tom Hatton	Independent member. Appointed July 2014.
Ms Fiona Roche	Nominated member. Appointed September 2015.
Ms Erica Smyth	Independent member. Appointed July 2016.
Dr David Williams	Nominated member. Appointed July 2015.

Past Board Members 2015-16

Dr Bernard Bowen	Chair. February 2009 – June 2016.
Professor Tom Spurling	Nominated member. February 2009 – June 2015.
Ms Jennifer McGrath	Nominated member. December 2014 – August 2015.
Professor Graeme Wright	Nominated member. May 2012 – June 2016.

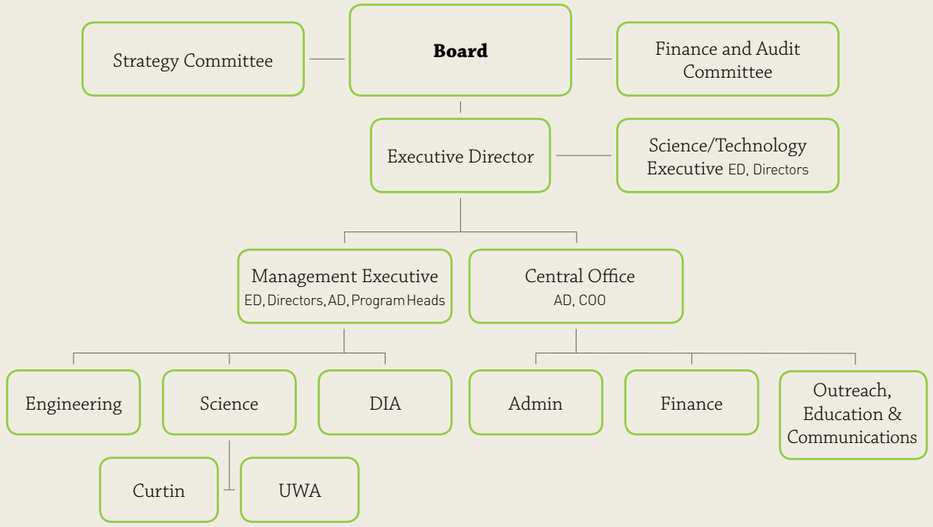
Finance and Audit Committee as at 31 Dec 2016

Mr Graham McHarrie	Chair from June 2010.
Mr Mark Woffenden	Member from June 2010.
Dr Tom Hatton	Member from August 2014
Mr Charlie Thorne	Nominated member from November 2015.
Mr Ian Loftus	Nominated member from November 2016.

Executive Team as at 31 Dec 2016

Professor Peter Quinn	Executive Director and Chief Executive Officer.
Professor Peter Hall	Director for Engineering.
Dr Renu Sharma	Associate Director and Chief Operating Officer.
Professor Lister Staveley-Smith	Director of Science at ICRAR-UWA.
Professor Carole Jackson	Director of Science at ICRAR-Curtin.
Professor Andreas Wicenec	Head of Data Intensive Astronomy at ICRAR-UWA.

ICRAR Organisational Structure



Cumulative Value of External Grants Won by ICRAR

Finances

ICRAR began its second phase in July 2014 with a $26 million investment from the WA State Government and a commensurate endowment from two joint venture partners; Curtin University and The University of Western Australia. These partners have committed additional in-kind contributions totalling $75 million.

From September 2009 to December 2016, ICRAR has leveraged this core funding to win grants totalling $65.2 million.

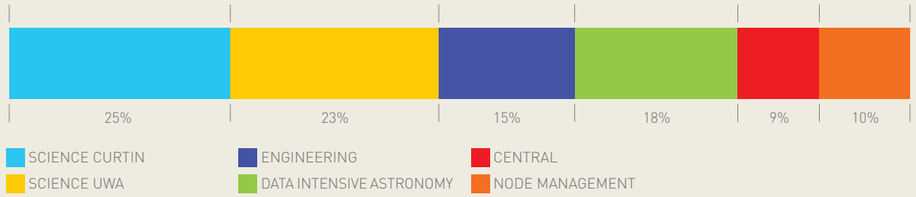
International Excellence

ICRAR is a successful, world-class collaborative organisation. It is recognised internationally for its excellence in science, engineering and technological research.

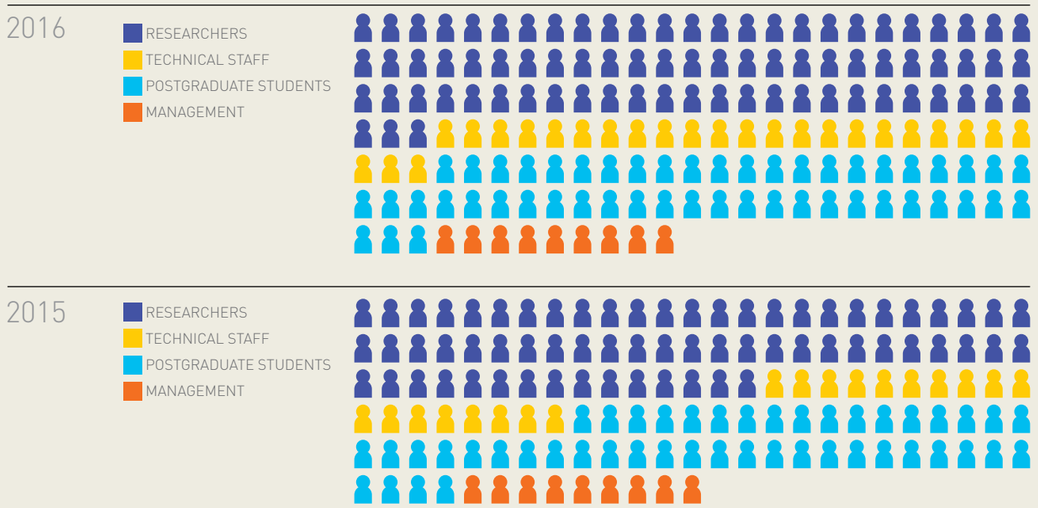
Staff Profile

Year	2015	2016
Researchers	65	78
Technical Staff	18	25
Postgraduate Students	46	50
Management	9	9

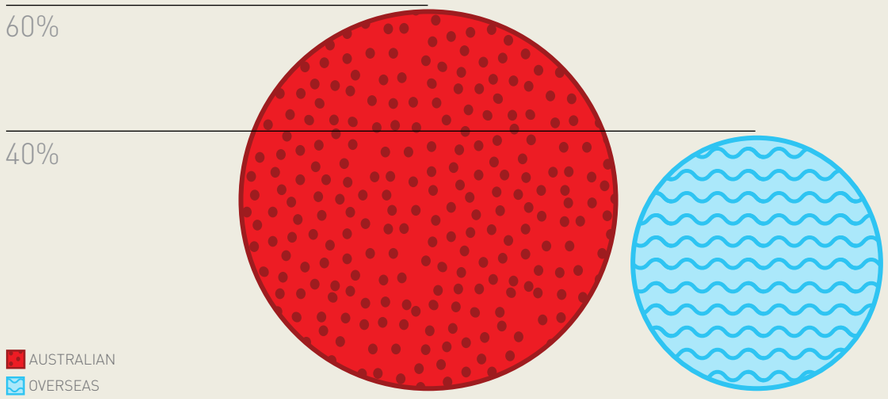
Budget 2014 to 2021



ICRAR Staff Profile

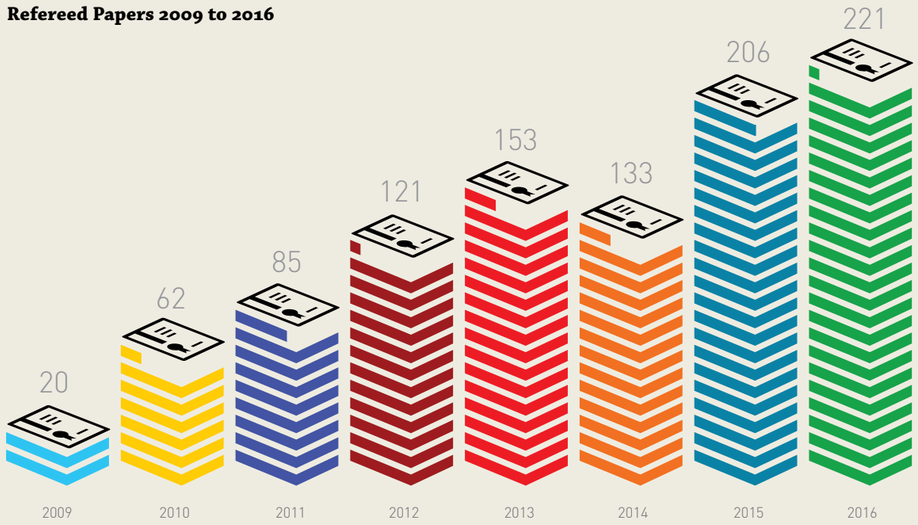


Postgraduate Students

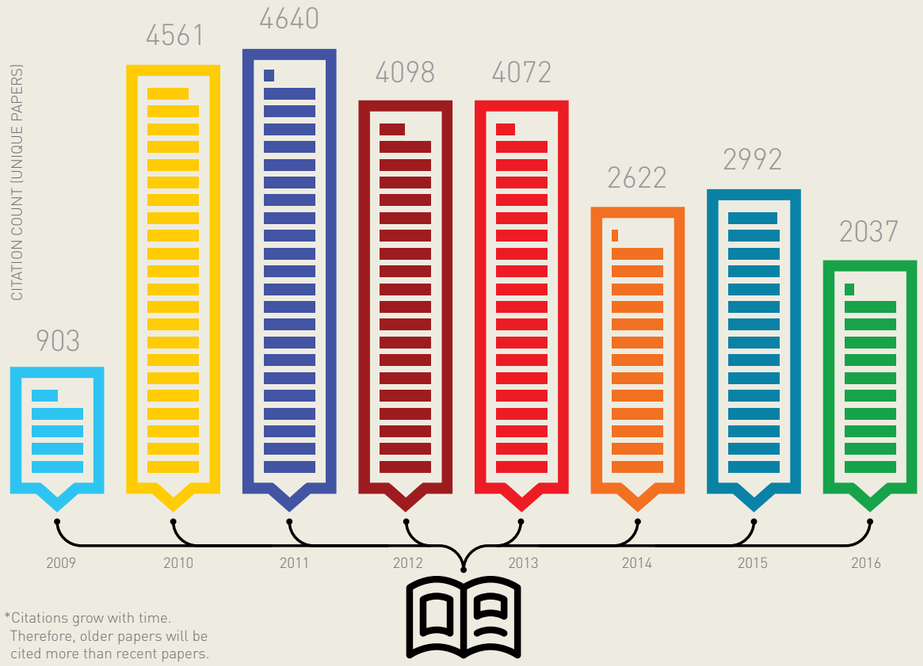


Over the past seven years, more than 1,000 national and international visitors from academia, government and industry have visited ICRAR's headquarters in Perth, Western Australia. During this time, ICRAR's researchers have published more than 1,000 refereed articles, achieved over 23,000 citations and secured more than $65 million in competitive funding.

Refereed Papers 2009 to 2016



Citations for ICRAR authored publications*



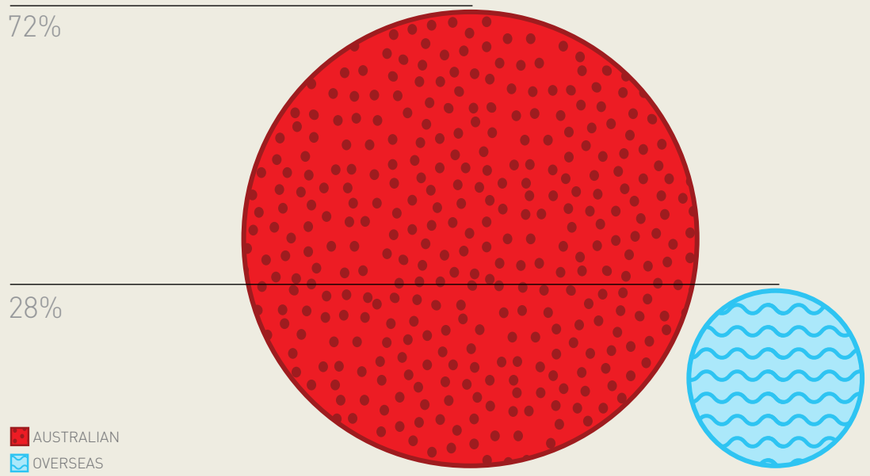
*Citations grow with time. Therefore, older papers will be cited more than recent papers.

ICRAR incorporates an effective industry engagement program with local, national and international partners such as Balance Utility, Systemic, ThoughtWorks, Data Direct Networks, Amazon, Intel, IBM, Cisco, Raytheon, Kaelus and many others. ICRAR plays an important strategic role in numerous global organisations with senior staff membership on a number of national and international boards, committees and working groups.

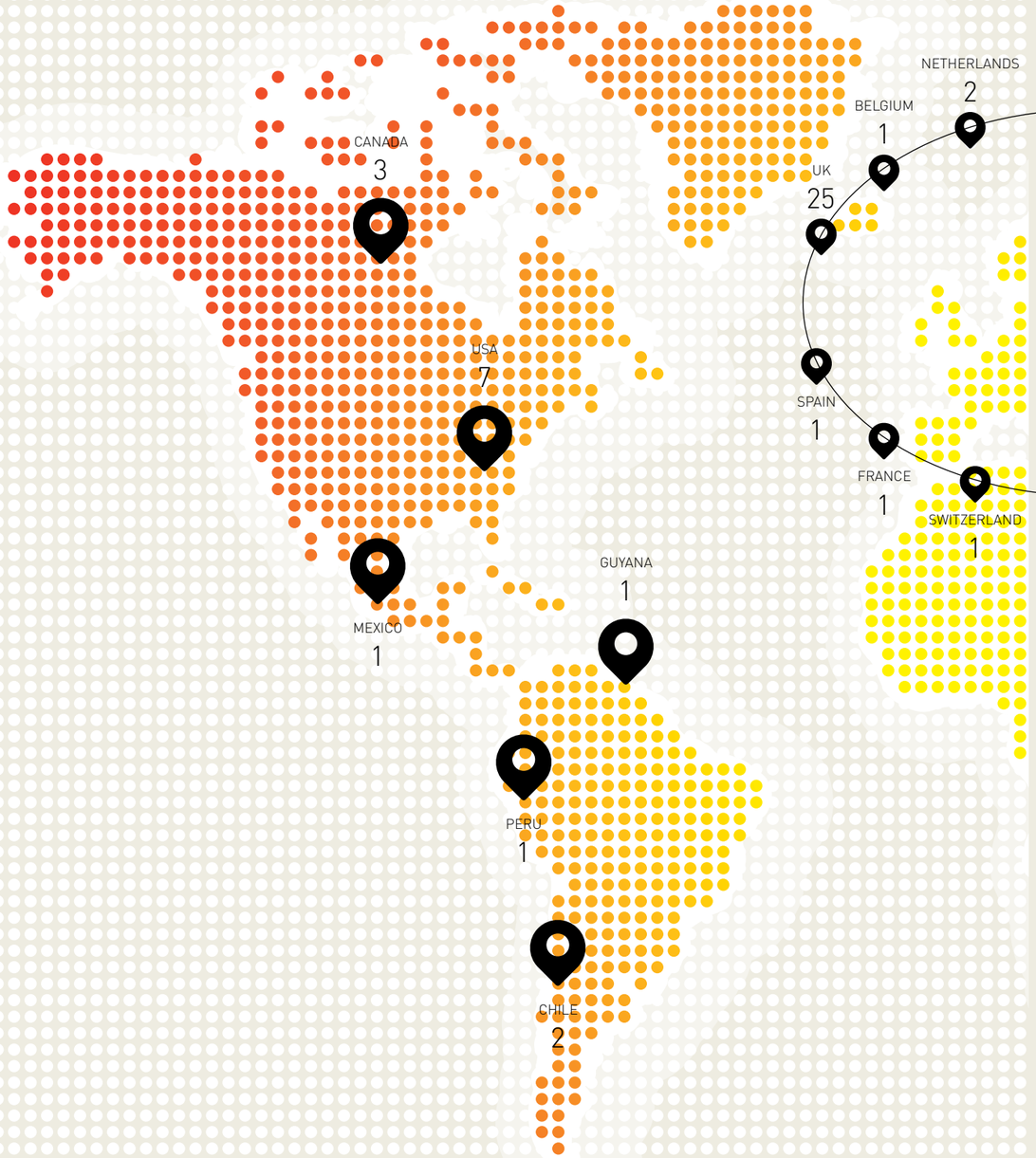
During the past 7 years, ICRAR researchers have been granted access to over 25 national and international research facilities including telescopes and super computer facilities. Securing more than 9,500 hours of professional telescope time and 13 million CPU hours, this represents an estimated value of over $5 million.

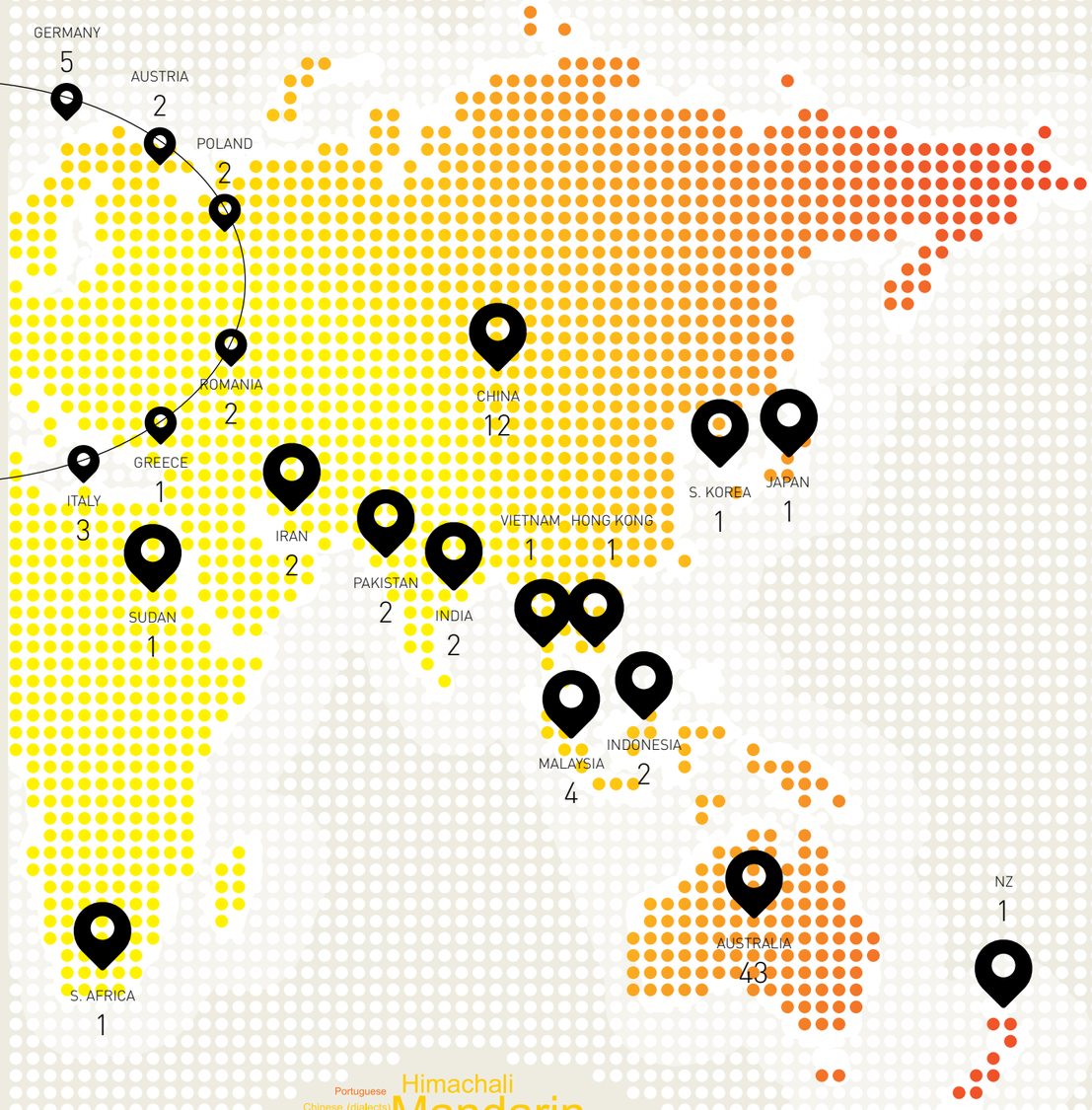
International collaborative agreements and memorandums of understanding have been developed with the National Astronomy Research Institute Thailand, Shanghai Astronomical Observatory China, the Large Synoptic Survey Telescope, Think Bottom Up and Nyriad. Three quarters of the Square Kilometre Array pre-construction industry partners are Australian, with the majority of these based in Western Australia.

SKA Pre-Construction Industry Partners



An International Centre:
ICRAR staff by country of birth





A 'word cloud' showing the cultural and language distribution at ICRAR

Top 5 most spoken languages at ICRAR

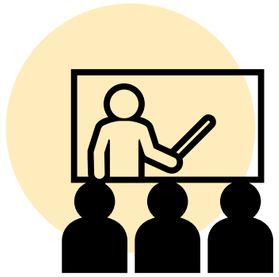
1	English
2	French
3	German
4	Mandarin
5	Spanish

Location by Jivan
from the Noun Project

A 'word cloud' showing how our staff describe working at ICRAR

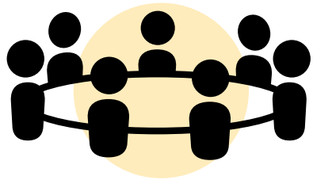
ICRAR's supportive research environment

ICRAR organises a range of activities at both Curtin and UWA to bring staff and students together and encourage collaboration across disciplines.



Induction

With the majority of people recruited internationally, staff and students are assisted with relocation support, temporary accommodation and a detailed induction.



Research group meetings

Research groups conduct their own team meetings to discuss research projects and bring the team together for updates.

Weekly seminars

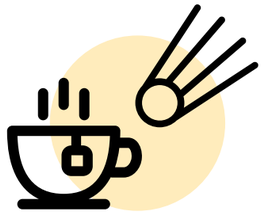
Held on Tuesdays and Thursdays at both ICRAR-Curtin and ICRAR-UWA. Talks are given by visitors, local staff or experts from other institutions, and are open to the public.

Journal club

Weekly journal clubs are held at ICRAR-Curtin and at ICRAR-UWA. These provide an opportunity for researchers to come together and discuss journal articles.

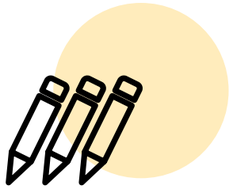
All Hands meetings

All Hands meetings are conducted twice a year after ICRAR Board meetings to update staff and students on important matters, and to enable them to meet members of ICRAR's Board.



Astro morning tea

Every Wednesday at ICRAR-UWA. This weekly one-hour hit of interesting scientific information is also used to highlight funding opportunities and student work.



Write club

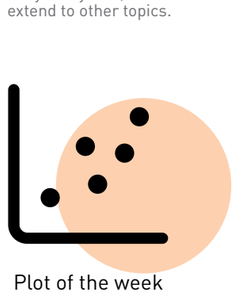
Every Monday at ICRAR-UWA and every Wednesday at ICRAR-Curtin, this provides a few hours of dedicated time to get together and write.

de Laeter Colloquium

This monthly colloquium series aims to enhance collaboration between the two ICRAR nodes, CSIRO and high-profile centres of astronomical research around the world.

PyClub

This is a weekly forum at ICRAR-Curtin for staff and students to get together to discuss tips, tricks and issues in the computing space. As the name suggests, it is focused mainly on Python, but can extend to other topics.



Plot of the week

Every Friday at ICRAR-UWA students get together to discuss research results and ask questions.

Staff committees

A development committee, based at ICRAR-Curtin, and a diversity, equality and inclusion committee, based at ICRAR-UWA, meet quarterly to improve staff wellbeing. The committees' remits include race, gender, inclusivity, unconscious bias and development.

Shared spaces

Both ICRAR-Curtin and ICRAR-UWA have tearoom facilities and outdoor spaces.

Student presentation day

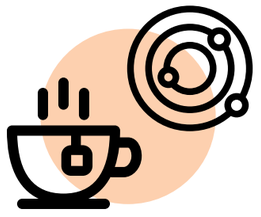
All ICRAR staff and students are invited to come together once a year for talks from PhD and Masters students. A separate presentation day is held for summer interns.

Friday morning tea

Held every Friday at ICRAR-UWA, this social and informative morning tea often showcases international food. As part of our commitment to cultural inclusion, the ICRAR-Curtin development committee also runs occasional morning teas to mark specific cultural events.

ICRAR-Con

A three-day retreat for all staff and students held annually in the first week of September, including a mix of talks and social activities. Previous events have been held at Seashells Resort Mandurah and Rottnest Island.



Radio galaxy morning tea

Radio galaxy morning tea is held at 10am each Thursday, rotating between ICRAR-Curtin, ICRAR-UWA and CSIRO-Perth. The aim of this morning tea is to facilitate an informal discussion on the latest research in radio astronomy and/or galaxy evolution science. This cross-institutional discussion group helps foster further research collaboration between the three institutes.

Visiting fellowship for senior women in astronomy

A three-month fellowship that sees a senior female researcher share her journey with other women in astronomy. The recipient imparts stories and specific strategies to young students and staff, to help more women reach higher levels in academia.

Credits: Teaching by B Farias, Meet by Sergey Demushkin, Magazine Reading by Andrey Vasiliev, Pencils by Creative Stall, Tea by Kaylen, Galaxy by Vladimir Belochkin, Comet by Ilaria Bernareggi, Code by Dmitrij, Public Speaker by Darrin Loeliger, Class by David, Cooperation by Matias Porta Lezcano, Meeting by Claire Jones, Coworking by Gregor Cresnar, Presentation by Gregor Cresnar, Scatter Plot by Allen, Cinema by Abdo, Women Population by Deepak, Heart by Piger, People by Magicon. All from the Noun Project.

Partnerships and Collaborations

As ICRAR prepares for a major role in the international regional centre network for the SKA, the organisation is working more and more with our Asian neighbours. In recent years ICRAR has forged agreements with astronomical communities in Thailand and China, creating mutually beneficial links that help increase the astronomical vitality of the region.

ICRAR has a particularly close relationship with China, thanks to the Australia-China Consortium for Astrophysical Research (ACAMAR), with many Chinese students coming to study at ICRAR through to the Chinese scholarship scheme, postdoctoral fellows and collaborations around the FAST telescope. This relationship is growing rapidly and will continue to be a major part of ICRAR in the future, with China and Australia working very closely together on a regional centre concept for the Asia-Pacific region.

The signing of an MOU between ICRAR and the National Astronomical Research Institute of Thailand to develop high performance computing infrastructure in the country and establish a Thai VLBI Network.

The Five-hundred-metre Aperture Spherical Telescope (FAST) in the southwestern province of Guizhou. Credit: Prof. Andreas Wicenec/ICRAR.

In preparation for bringing SKA science to the Asian region, ICRAR is looking to expand its regional partnerships even further, with strong relationships with Indonesia, Singapore and Korea a priority for the near future.

ICRAR has also forged strong relationships with industry, working with companies big and small. ICRAR has always worked closely with companies interested in being involved in the SKA in Australia and New Zealand, including IBM, SGI, Cisco, Intel, Amazon, Systemic and Nyriad.

But in recent years ICRAR has also made a decision to look sideways at relationships it can have with companies outside of the SKA. Many companies are interested in the technologies ICRAR is developing and how they might be relevant to other industries, particularly in the minerals, energy and exploration sector. Astronomers are explorers of the sky so it makes sense to help the explorers of the Earth to do what they do, and ICRAR has already begun projects with Chevron, BHP Billiton, Think Bottom Up and Rio Tinto.

An artist's impression of the galaxies found in the 'Zone of Avoidance' behind the Milky Way. This scene has been created using the actual positional data of the new galaxies and randomly populating the region with galaxies of different sizes, types and colours.

2

SCIENCE

Science Overview

ICRAR's astronomers are uncovering the secrets of our Universe through radio astronomy, multi-wavelength studies and computer simulations.

One of many recent highlights for ICRAR has been the publication of the GaLactic and Extragalactic All-sky MWA, or 'GLEAM' survey, which showed what the Universe would look like if human eyes were sensitive to radio waves. This survey of 300,000 galaxies, using the Murchison Widefield Array telescope in remote Western Australia, was the first radio survey to image the sky in such amazing technicolour. This large-scale, high-resolution survey of the radio sky observed at frequencies from 70 to 230 MHz, studying radio waves that had been travelling through space—some for billions of years. Its publication generated headlines around the world and a GLEAM sky image was one of Nature Magazine's top 10 science images for 2016.

ICRAR also leads the Galaxy And Mass Assembly (GAMA) survey—another study of 300,000 galaxies. This survey looks at different sources to GLEAM and compiles observations across many different wavelengths to build up a picture of the cosmos. GAMA focuses on studying the evolution of mass, energy and structure, and now has the leading measurements on the stellar mass content of the Universe. In combination with the COSMOS and 3D-HST surveys, it has resulted in a complete understanding of the build-up of stellar mass and the evolution of energy over all of time.

Black hole research is another very strong area for ICRAR, with an outstanding group of astrophysicists studying the inflow and outflow of material around black holes of all masses. The group's work over the past two years has resulted in several publications in high-impact journals, including Science and Nature.

Another big discovery was the finding of hundreds of galaxies hidden behind the Milky Way. This major study uncovered 883 galaxies, a third of which had never been seen before, and shed light on a mysterious gravitational anomaly dubbed the Great Attractor.

The Centre has been very strong internationally in pushing developments in the field of angular momentum, and how it relates to the shape and spin of galaxies. We've always known that some galaxies are 'flat' while others are 'fat' but until now it's been difficult to explain why. Through simulations and observations we're slowly realising the importance of angular momentum in explaining why these galaxies look so different.

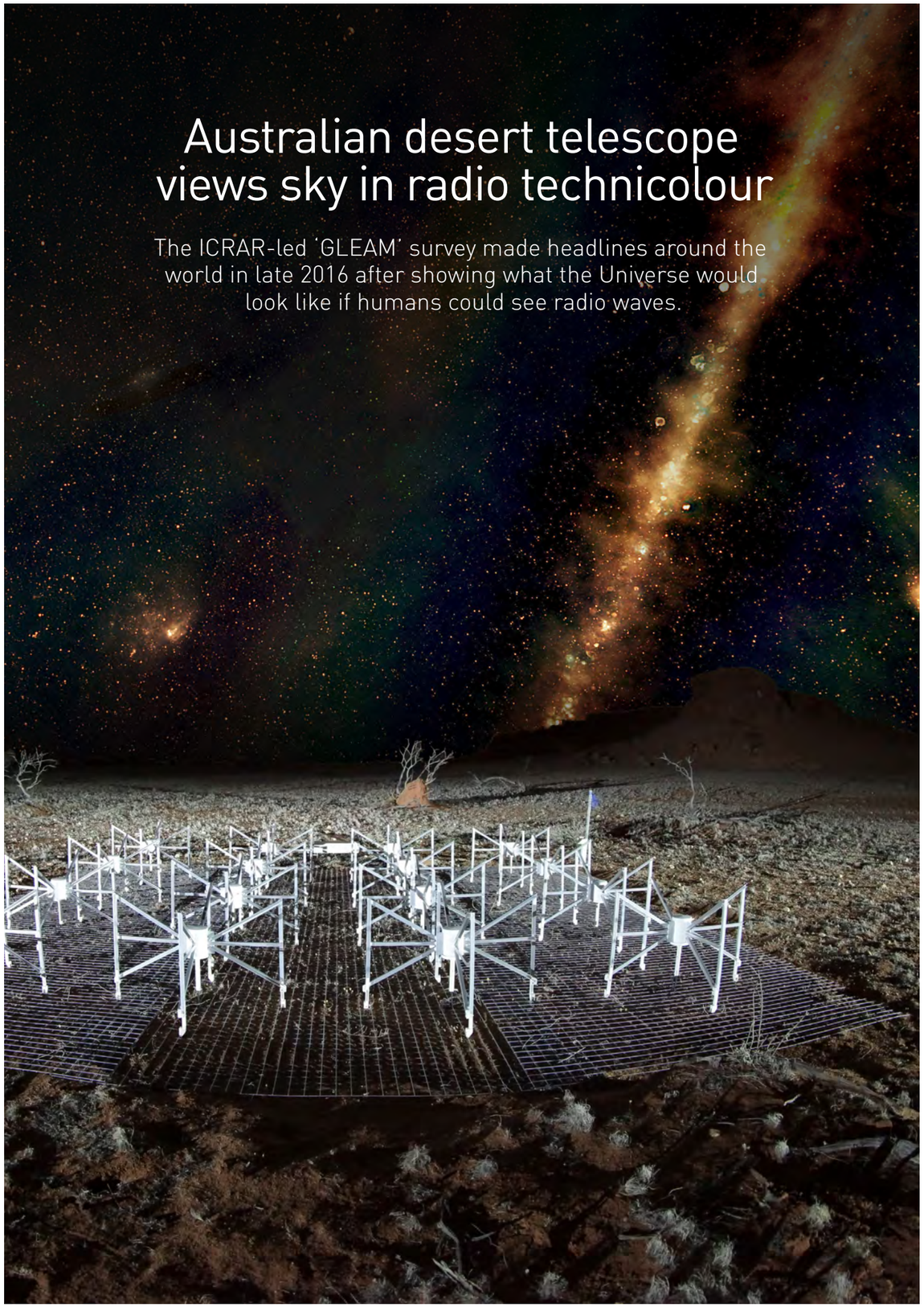
ICRAR also has some fantastic astronomers working with simulations, who build model Universes in computers. These simulations can be used to explain the properties, orbits and evolution of galaxies, and the group has done very good work recently on galaxy clusters and dwarf galaxies.

At the same time the Centre's observational researchers have made some interesting discoveries with the SAMI galaxy survey, which uses a new prototype instrument on the Anglo-Australian Telescope to study galaxy evolution, angular momentum and star formation. There has also been success with studies of cosmology and galaxy distances using the 6dF and 2MTF galaxy surveys on the Australian Astronomical Observatory's UK Schmidt Telescope, the Green Bank Telescope in the US and the Parkes radio telescope. And, work is underway to study the first results coming from the surveys conducted with CSIRO's Australian SKA Pathfinder (ASKAP).

The Centre's astrophysicists are discovering more about some of the Universe's most mysterious objects—pulsars. These rapidly rotating neutron stars are the remnants of massive stars that exploded as supernovae. They emit beams of radio waves, which we can detect on Earth as 'pulses' as the stars turn. ICRAR researchers are also at the forefront of research into fast radio bursts—a new and exciting area of astronomy studying events in the Universe in which incredible amounts of energy are unleashed in only a few milliseconds.

ICRAR's scientists are working on experiments to search for faint signals from the Epoch of Reionization, a time very early in the history of the Universe when the first stars and galaxies began to appear. These signals are incredibly difficult to detect but by understanding the necessary instrumentation and foreground source effects, it is hoped ICRAR can pave the way for the SKA to discover more about this incredible time in the life of the Universe.

Finally, astronomers are starting to use the second phase of the MWA and plan for the third, based on the expertise gained so far. This leading edge telescope will continue to drive key science in areas including the Epoch of Reionization, transients, pulsars and extragalactic science in the years to come.



Australian desert telescope views sky in radio technicolour

The ICRAR-led 'GLEAM' survey made headlines around the world in late 2016 after showing what the Universe would look like if humans could see radio waves.

The GaLactic and Extragalactic All-sky MWA, or 'GLEAM', survey produced a catalogue of 300,000 galaxies observed by the Murchison Widefield Array (MWA) telescope.

Articles, images and videos of the GLEAM survey were published by more than 300 news outlets worldwide including the New York Times, National Geographic, ABC News, Channel 10, the Sydney Morning Herald, the Daily Mail, the Huffington Post and Australian Geographic.

ICRAR early career research fellow Dr Natasha Hurley-Walker said GLEAM was the first radio survey to image the sky in such amazing technicolour. "The human eye sees by comparing brightness in three different primary colours—red, green and blue," she said. "GLEAM does rather better than that, viewing the sky in 20 primary colours. That's much better than we humans can manage, and it even beats the very best in the animal kingdom, the mantis shrimp, which can see 12 different primary colours."

GLEAM is a large-scale, high-resolution survey of the radio sky observed at frequencies from 70 to 230 MHz, using radio waves that have been travelling through space—some for billions of years. The survey is being used by astronomers at ICRAR and around the world to unlock some of the secrets of the Universe.

"Our team is using this survey to find out what happens when clusters of galaxies collide," Dr Hurley-Walker said. "We're also able to see the remnants of explosions from the most ancient stars in our galaxy, and find the first and last gasps of supermassive black holes."

MWA director Associate Professor Randall Wayth said GLEAM was one of the biggest radio surveys of the sky ever assembled. "The area surveyed is enormous," he said. "Large sky surveys like this are extremely valuable to scientists and they're used across many areas of astrophysics, often in ways the original researchers could never have imagined."

The $50 million MWA radio telescope is located deep in the West Australian outback, at a remote site north-east of Geraldton. A consortium of 13 partner institutions from four countries (Australia, USA, India and New Zealand) financed the original development, construction, commissioning and operations of the facility, and since commencing operations in mid 2013 the consortium has grown to include new partners from Canada and Japan.

Associate Professor Wayth said it was realised in the early days of the MWA that the galactic and extra-galactic science teams using the telescope all wanted to observe different sources in the sky. "It was easier to just survey the entire sky, produce a catalogue of all of the information and then allow everyone to use that catalogue and all the images," he said. "GLEAM is a large, international team and it is a big amount of work, but now the data has been published to the world anyone can use it to discover more about our Universe."

Associate Professor Wayth said GLEAM was a big highlight for ICRAR and a significant legacy data product from the MWA. He said the unusual frequency range allowed astronomers to do some very interesting astrophysics with the data.

"It's really quite valuable, and has already been used by a whole bunch of different people for different science projects," Associate Professor Wayth said. "We're solving the puzzle of what these sources are actually doing."

The MWA was the first of the three SKA precursors to be completed. Finishing the GLEAM survey with the telescope is a big step on the path to SKA-low, the low frequency part of the international radio telescope to be built in Australia in the coming years.

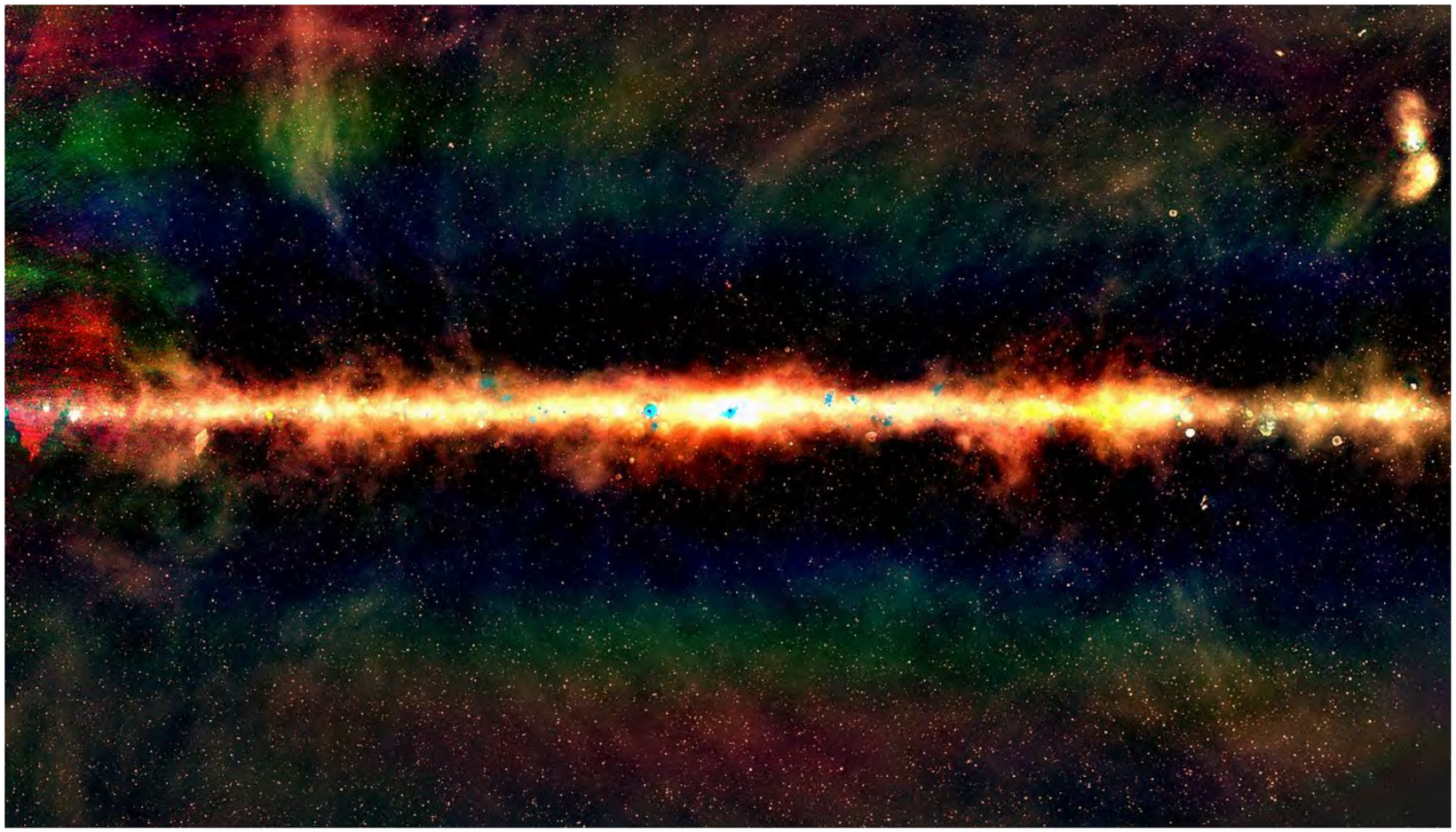
"It's a significant achievement for the MWA telescope and the team of researchers that have worked on the GLEAM survey," Associate Professor Wayth said. "The survey gives us a glimpse of the Universe that SKA-low will be probing once it's built. By mapping the sky in this way we can help fine-tune the design for the SKA and prepare for even deeper observations into the distant Universe."

The GLEAM team has created a 'Gleamoscope' web app to allow people to view the Milky Way in wavelengths from gamma ray to X-ray, visible light, far-infrared, microwaves and radio waves. The app can be viewed online at gleamoscope.icrar.org or found on Google Play for Android phones and tablets.

Natasha Hurley-Walker's TED talk 'How radio telescopes show us unseen galaxies' is available on the TED website, where it has been viewed almost half a million times.

2015-2016 Achievement

A GLEAM sky image was one of Nature Magazine's top ten science images of the year for 2016.



p23: A 'radio colour' view of the sky above a 'tile' of the Murchison Widefield Array radio telescope, located in outback Western Australia. The Milky Way is visible as a band across the sky and the dots beyond are some of the 300,000 galaxies observed by the telescope for the GLEAM survey. Credit: Radio image by Natasha Hurley-Walker (ICRAR/Curtin) and the GLEAM Team. MWA tile and landscape by Dr John Goldsmith / Celestial Visions.

The GLEAM view of the centre of the Milky Way, in radio colour. Red indicates the lowest frequencies, green indicates the middle frequencies and blue the highest frequencies. Each dot is a galaxy, with around 300,000 radio galaxies observed as part of the GLEAM survey. Credit: Natasha Hurley-Walker (Curtin / ICRAR) and the GLEAM Team.

ICRAR's Dr Natasha Hurley-Walker, lead researcher for the GLEAM survey project.

"Jellyfish galaxies could help unlock a language we're trying to understand—the language of how the Universe formed and evolved."

Researcher Profile

Dr Luca Cortese
Senior Research Fellow

When it comes to galaxies, Dr Luca Cortese likes the odd one out.

He famously discovered 'jellyfish' galaxies—strange and unusual galaxies with long strings of gas and stars trailing behind.

"As a young postdoc I started focusing on what we were calling at that time Rosetta Stone galaxies," Luca said.

These galaxies could help unlock a language we're trying to understand—the language of how the Universe formed and evolved.

"They're very weird, very peculiar objects, you find one out of thousands," Luca said.

"These galaxies are very, very photogenic, they are just beautiful, you can stare at the images for hours.

"And then because they are so rare sometimes you have a glimpse of a physical process that afterwards you realise might be common in galaxies."

Jellyfish galaxies, for instance, have been shown to represent a short but crucial snapshot in the evolution of cluster galaxies.

Growing up in Milan, Luca thought he might one day travel the world as an architect, designing buildings like the Sydney Opera House.

Instead it was the lure of the SKA telescope and discovering more about the Universe that saw him swap his glamorous hometown for sunny Perth.

Luca studies "the physics of the engine" or how pristine gas clouds are transformed into stars, dust and metals to create the variety of galaxies we see today.

He works with large statistical samples of galaxies to determine the evolutionary path of the average galaxy and, at the same time, unveil the most unusual ones.

He was attracted to ICRAR by the synergy between SKA-related science and multi-wavelength astronomy.

"It's still quite unique to find a research institute where both areas are pretty much world class," he said.

Luca loves that his work is very dynamic and gives him the ability to interact with many different groups.

"Even if I'm not involved, just having a sneak preview of different projects and what different people are working on is really exciting," he said.

Luca can regularly be heard on the radio giving interviews about astronomy, in both English and in his native Italian.

"We believe there's a supermassive black hole at the centre of every galaxy and I'm interested in the ones where there's material falling onto that black hole."

Researcher Profile

Dr Sarah White
Research Associate

When Dr Sarah White arrived at ICRAR, fresh from a PhD at the University of Oxford, she had one early request.

Could she visit the remote outback site earmarked for Western Australian's part of the SKA?

The next month Sarah found herself in the red dirt of the Murchison Radio-astronomy Observatory, replacing low-noise amplifiers for the MWA telescope.

"It was quite an adventure," she said.

"You're so far from civilisation, with the nearest hospital being 1.5 hours' flight away if you get bitten by a spider or snake."

One day the team was making mini gazebos to shelter the receivers from the Sun when a storm appeared on the horizon.

"It was a race against the clock to get all the gazebos up, get in the car and get back to the on-site cabin before the lightning struck," Sarah said.

"That was probably one of my most exciting days in astronomy."

Now Sarah is using the MWA telescope to research active galaxies.

"We believe there's a supermassive black hole at the centre of every galaxy and I'm interested in the ones where there's material falling onto that black hole," she said.

"These objects can tell us more about the way galaxies evolve, and radio emission allows us to trace their black hole activity and the galaxy's star formation."

Sarah was first introduced to radio astronomy at the University of Cambridge and hasn't looked back since.

For her PhD she studied distant, optically-bright, active galaxies—known as 'quasars'—with faint radio emission.

"In these objects I found that black hole activity is dominating the radio emission, which goes against the previous assumption that star formation dominates," Sarah said.

"This is important as telescopes like the SKA will detect millions of these 'radio-quiet' quasars for the first time."

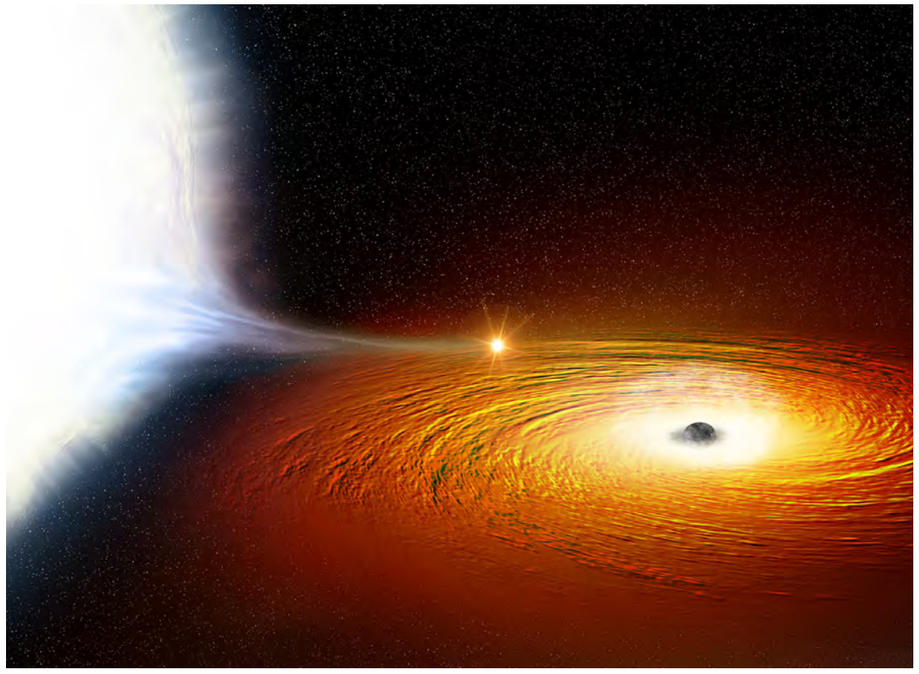
Sarah loves this area of research and has always loved Australia.

"I grew up watching Neighbours, Finding Nemo and Round the Twist," she said. "And at ICRAR everyone's just super friendly—it's like a family."

The Science of Black Holes

Since Albert Einstein first predicted their existence with his general theory of relativity, black holes have fascinated and baffled astronomers and the general public alike. ICRAR is home to one of the world's best research groups studying black holes, and every year the group is able to uncover more secrets of these elusive light-sucking regions of space.

This artist's impression depicts a rapidly spinning supermassive black hole surrounded by an accretion disc. This thin disc of rotating material consists of the leftovers of a Sun-like star which was ripped apart by the tidal forces of the black hole. Shocks in the colliding debris as well as heat generated in accretion led to a burst of light, resembling a supernova explosion. Credit: ESO, ESA/ Hubble, M. Kornmesser.



An artist's impression of a white dwarf star (left) in orbit around a black hole and so close that much of its material is being pulled away. There is a hotspot where the gas from the white dwarf hits the disc of matter swirling around the black hole. The black hole itself is surrounded by a cloud of ionised gas, which contains large amounts of oxygen. Credit: X-ray: NASA/CXC/University of Alberta/A.Bahramian et al.; Illustration: NASA/CXC/M.Weiss.

ICRAR-Curtin acting science director Associate Professor James Miller-Jones said a lot of the research relies on having observations from different wavelengths, including optical, radio and X-ray emissions. "If we want to understand the connection between what's flowing into a black hole and what's coming out, we need to look across the electromagnetic spectrum," he said.

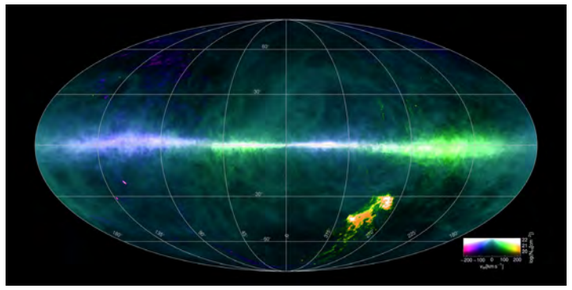
Most of the group's work looks at powerful jets of radiation and particles that shoot out of black holes at close to the speed of light, and how they relate to the infalling matter in the accretion flow. They also study winds, massive but slow-moving outflows being blown off the accretion disk around black holes.

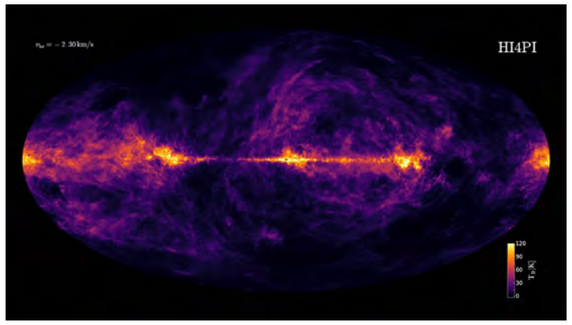
One of the team's most influential findings was the discovery in 2015 of jets from a hungry black hole swallowing a star in a nearby galaxy. This extreme event was one of only about 20 occasions when a supermassive black hole at the centre of a galaxy has been seen to actually rip apart and consume a star. It was the first time scientists had been able to see both a disk of material falling into a black hole and a jet in a system of this kind, and helped to confirm physicists' theories about the nature of black holes. The work was published in the journal Science.

Almost a year later, ICRAR's black hole experts published another startling discovery. They argued that an event previously thought to be the brightest supernova ever seen was in fact another black hole, this time spinning very rapidly, ripping apart a star that came too close. In the process, the star was "spaghettified" and shocks in the colliding debris as well as heat generated by accretion led to a burst of light. This gave the event the appearance of a very bright supernova explosion, even though the star would not have become a supernova on its own as it did not have enough mass. The research appeared in the first edition of Nature Astronomy.

The Milky Way and Beyond

What did the Milky Way look like billions of years ago? How did our Sun and other stars like it form? And what objects might be hiding nearby, obscured by the cloud that is our own galaxy? These are some of the questions keeping ICRAR's galaxy researchers awake at night as they endeavour to discover more about our own Milky Way.





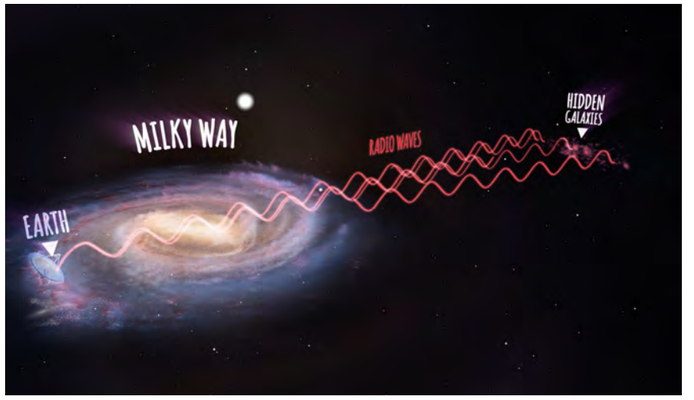
This HI4PI map was produced using data from the 100 metre Max-Planck radio telescope in Effelsberg, Germany and the 64 metre CSIRO radio telescope in Parkes, Australia. The image colours reflect gas at differing velocities. The plane of the Milky Way runs horizontally across the middle of the image. The Magellanic Clouds can be seen at the lower right. Image credit: Benjamin Winkel and the HI4PI collaboration.

An image showing the HI 21-cm line emission of neutral atomic hydrogen of the Milky Way galaxy and the neighbouring galaxies, like the Andromeda galaxy and the Magellanic Clouds, both visible in the lower half of the panel. It has been derived from observational data of the 100-m Effelsberg radio telescope operated by the Max-Planck-Institut fV°r Radioastronomie/Germany and the CSIRO's 64-m radio telescope at Parkes/Australia. Credit: Benjamin Winkel for the HI4PI collaboration.

In 2016, ICRAR-led research discovered galaxies hidden behind the Milky Way, shedding light on a mysterious gravitational anomaly dubbed the Great Attractor. Using CSIRO's Parkes radio telescope equipped with an innovative receiver, an international team of scientists were able to see through the stars and dust of the Milky Way, into a previously unexplored region of space. The discovery may help to explain the Great Attractor region, which appears to be drawing the Milky Way and hundreds of thousands of other galaxies towards it with a gravitational force equivalent to a million billion Suns.

ICRAR-UWA science director and lead author Professor Lister Staveley-Smith said the team found 883 galaxies, a third of which had never been seen before.

"The Milky Way is very beautiful of course and it's very interesting to study our own galaxy but it completely blocks out the view of the more distant galaxies behind it," he said.



An image showing the location of the galaxies discovered in the 'Zone of Avoidance'. Until now this region of space has remained hidden from view because of the gas and dust of the Milky Way which blocks light at optical wavelengths from reaching telescopes on Earth.

ICRAR is also involved in HI4PI, an exciting project that sees the fusion of two surveys to create a giant map of the gas in the Milky Way. Postdoctoral research fellow Dr Steven Janowiecki said HI4PI covers the entire sky, looking in every direction from Earth at what the gas is doing in our galaxy and beyond.

"For thousands of years we've had really good surveys of stars—stars are easy to measure with our eyes—but if you want to measure what makes the stars, the gas, then you need big radio telescopes to do it," he said. "With more recent telescopes we can see in higher resolution... lots of little faint clumps, clouds and tendrils of gas."

Dr Janowiecki first started working with radio observations that would become part of HI4PI a decade ago, as a summer intern at the US National Radio Astronomy Observatory in West Virginia. He went on to do graduate studies in dwarf galaxies and star formation, and only recently returned to radio astronomy.

Dr Janowiecki said the Milky Way is like a windscreen we have to look through in order to see other galaxies in the outside Universe. "It's enveloping us in this fog and you have to remove that if you want to see what's beyond us," he said.

"My Dad bought me a telescope when I was pretty young and that became a fascination for me."

Researcher Profile

Dr Barbara Catinella
Senior Research Fellow

Dr Barbara Catinella's research involves uncovering secrets about the lives and deaths of galaxies.

Barbara studies the role of gas in galaxies and is an expert in surveys of neutral hydrogen, the fuel from which new stars are formed.

"Those kinds of surveys teach you about galaxy evolution," she said.

"So how gas is consumed by galaxies when they make stars, how gas is released through various mechanisms... the life of a galaxy is really to do with the gas cycle."

Before joining ICRAR in 2015, Barbara had already followed her passion for astronomy around the world.

The Italian researcher did a PhD at Cornell University in the US and a postdoc at Arecibo Observatory in Puerto Rico, before spending six years in Germany at the Max Planck Institute for Astrophysics and two years at Melbourne's Swinburne University.

She was drawn to Western Australia by the role that ICRAR has in the SKA Pathfinders.

"That's exactly the kind of science that I love to do, so for me it's been a fantastic opportunity," Barbara said.

"It's the right place to be for me. The environment is extremely friendly and it's a beautiful campus."

Barbara has always wanted to be an astronomer, growing up in a house filled with books about science and astronomy.

"My Dad bought me a telescope when I was pretty young and that became a fascination for me," she said.

Today Barbara's research relies not just on radio telescopes but on ultraviolet data from satellites and optical ground-based telescopes as well.

"Understanding galaxies is really about understanding the multi-wavelength picture," she said.

"I find the problems that we're working on in radio astronomy right now are absolutely fascinating."

Researcher Profile

Dr Ryan Shannon
Research Fellow

Dr Ryan Shannon's research sees him scouring the cosmos for one of the Universe's most mysterious objects—pulsars.

Pulsars are rapidly rotating neutron stars, the remnants of massive stars that exploded as supernovae.

They emit beams of radio waves, which we can detect on Earth as 'pulses' of radio waves as the stars turn.

Some pulsars are ultra-stable and are the Universe's best natural clocks.

Ryan said pulsars provide a great physical laboratory for tests of fundamental physics.

"We're trying to open up a new way to look at the Universe," he said.

One of Ryan's research projects is searching for gravitational waves, most likely from pairs of supermassive black holes in the middle of galaxies.

"Because the centres of galaxies are so obscured in electromagnetic radiation and black holes are so close together, it's very difficult to see them in any other way," he said.

"We're able to peer into galaxies and see what's going on in the centre where all the action is."

Another project is using the ASKAP telescope to search for fast radio bursts, unexplained pulses from very distant galaxies billions of light years away.

Ryan has always been interested in science but it wasn't until his first year at university that an astronomy course captured his imagination.

"I found the problems that we were solving in astronomy so interesting... just the vastness of space and the scales of things really connected with me at that point," he said.

Today Ryan splits his time between ICRAR and CSIRO Astronomy and Space Science, bringing the two groups together.

"I get to work with so many interesting people," he said.

"And I find the problems that we're working on in radio astronomy right now are absolutely fascinating."

"It seems like every day there's a new challenge and a new discovery to be made... it's really quite exciting."

Cosmic suntans, colliding galaxies and a dying Universe

However you look at it, the discoveries made using the Galaxy and Mass Assembly (GAMA) survey are impressive. The survey made headlines in 2015 when it was used to show that when two different sized galaxies are about to smash together, the larger galaxy stops the smaller one making new stars.

A month later GAMA was used to measure the energy generated within a large portion of space more precisely than ever before, discovering that it's only half what it was two billion years ago and fading. Or in other words—the Universe is slowly dying. Then in 2016, the same survey was able to show that ten trillionths of your suntan comes from beyond our galaxy.

But GAMA is about much more than generating headlines. ICRAR astrophysicist Dr Luke Davies described how the survey of 300,000 galaxies brings together data from different telescopes around the world. "It's initially based around observations with the Anglo-Australian Telescope in Siding Spring, where we measure the spectrum of light from galaxies and use it to work out the distances to them," he said.

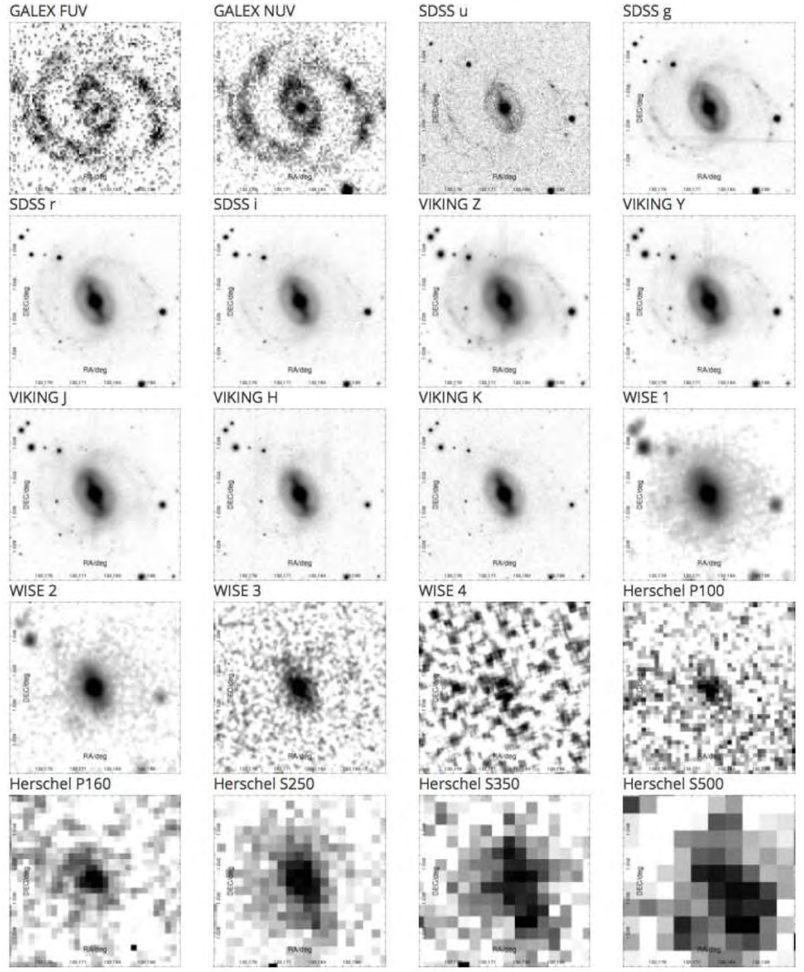
"We then have, for these volumes of space, a large three-dimensional map of the Universe. We bring in lots of data from other telescopes, taking images from the ultraviolet, the optical you can see with your eyes, the near infrared, the far infrared... all the way through to radio wavelengths."

Dr Davies said building this massive multi-wavelength database allows astronomers to examine the different physical properties of galaxies. "We can work out things like how many stars the galaxies have in them, how many new stars they're now forming each year, how much dust they contain and many other things," he said. "Then we try and look at the various factors that affect all of these different properties, such as where a galaxy lives in the Universe."

GAMA is the culmination of a decade of work by scientists around the world, and most research with the survey is now done out of ICRAR. Other highlights for 2015 and 2016 include ICRAR PhD graduate Dr Angus Wright's measurements of the properties of light emitted from all 300,000 galaxies and Dr Davies' work on calculating star formation rates.

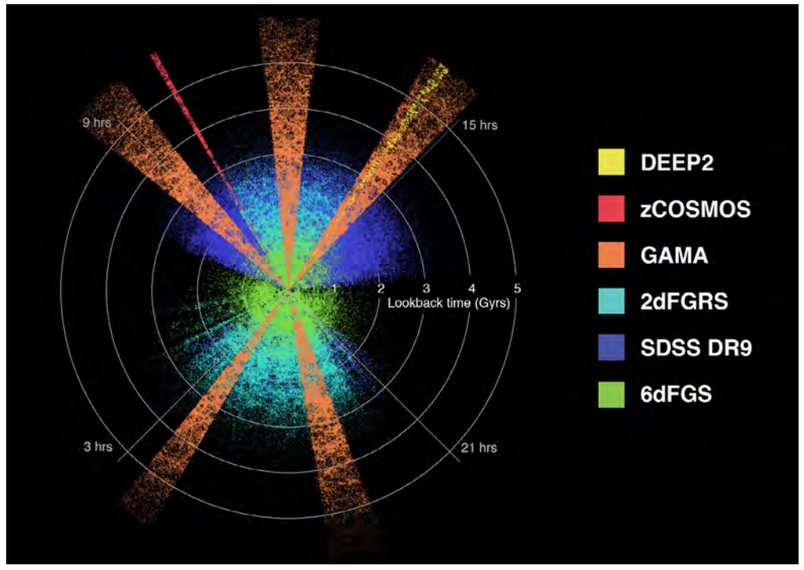
The research that showed the Universe is dying, led by ICRAR's Professor Simon Driver, coincided with a huge release of all of the photometric data from the survey, allowing the wider astronomical community to undertake cutting-edge science with the GAMA data. ICRAR senior research fellow Aaron Robotham also wrote a new piece of software that measures the components of a galaxy better than ever before.

An infographic created to support a GAMA media release about the amount of photons from the distant Universe that contribute to the average suntan.



A galaxy from the GAMA survey observed at 20 different wavelengths from the far ultraviolet to the far infrared. Credit: ICRAR / GAMA.

The distribution of galaxies as mapped by various Australian, US and European survey teams. In total we have mapped the locations of over 4 million galaxies that can be used to study the evolution of mass, energy and structure in the Universe over the past few billion years. Credit ICRAR / GAMA.



Students working in the anechoic chamber at Curtin University to test radio frequency interference.

3

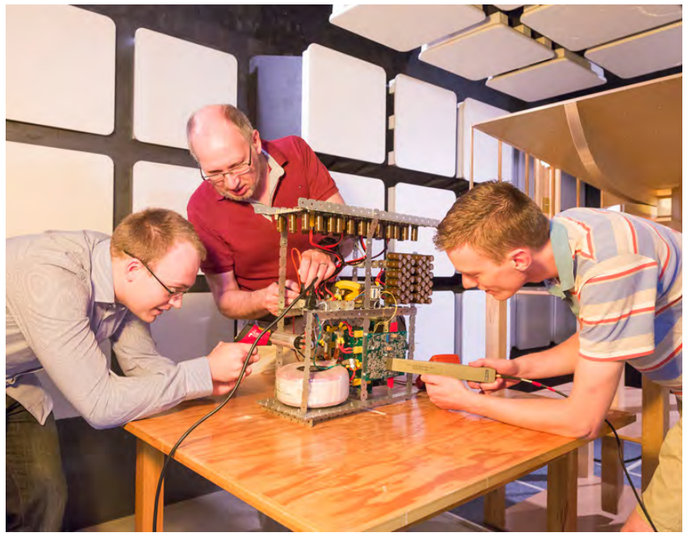
ENGINEERING

Engineering overview

The engineering team at ICRAR is working to research, develop and test new technology for radio astronomy in the 21st century.

The Centre has taken a leading role in delivering high-impact engineering solutions for the SKA, through deploying and operating instrumentation for the Murchison Widefield Array (MWA) and SKA test arrays. ICRAR's engineers work closely with government and industry to solve the formidable challenges of realising a mega-science project on the scale of the SKA.

ICRAR is a member of the SKA pre-construction consortium charged with designing the antennas, on board amplifiers and local processing for SKA-low. This group—known as the Aperture Array Design and Construction (AADC) consortium—is bringing the SKA to life with a vision for the low frequency part of the SKA, called SKA-low.



ICRAR PhD Candidate James Buchan, Lawrence Borle from ICRAR Industry partner Balance Utility Solutions and Tom van Nunen, ICRAR engineering intern from the Netherlands prepare a power supply destined for inclusion in the SKA-low verification platform.

Electrical engineering and computing student, Shane Overington, working in the ICRAR electronic laboratory to diagnose and repair a faulty MWA data transmission printed circuit board.

Members of the engineering team working with colleagues from the National Institute for Astrophysics in Italy to install antennas for the Aperture Array Verification System test platform.

The Centre's high-level engineering expertise and proximity to the SKA site has seen ICRAR play an integral role in testing elements of the design on the ground in the remote Murchison region. This includes the system-level testing and verification of early prototypes of the Christmas tree-like antennas, known as SKALAs, that will dot the landscape when the SKA comes to fruition. With ICRAR in this integral role, the consortium was able to meet an important milestone when it passed the preliminary design review phase with flying colours.

The engineering team has also been working with industry to map out the logistics and detailed planning needed for the eventual roll out of the SKA. This work is hugely important to the success of the project, given the unprecedented challenge of deploying 130,000 antennas in a remote desert region. Through these industry links, ICRAR has established the feasibility of the SKA in Western Australia and helped pave the way for the telescope's construction.

At the same time, ICRAR's engineers have been perfecting the day-to-day operations of the MWA telescope, a precursor to the SKA. Since the MWA became operational in mid-2013, the team has learnt a lot about operating and maintaining a telescope and its associated infrastructure on such an isolated site. The group has refined a routine of visiting the MWA for short stints of maintenance and upgrade work, rather than needing staff permanently based in the Murchison.

Another highlight was the start of the second phase of the MWA in mid-2016, which saw the telescope grow from 128 to 200 tiles. The extra 72 tiles became operational in October, and in 2017 an additional 56 tiles are set to be positioned out on very long baselines to double the diameter of the array.

To date, ICRAR remains the only institution internationally to routinely use an SKA precursor telescope as part of the path to the SKA. The tireless work of its engineering team has ensured the Centre is well positioned to be a major contributor to the effort to build the SKA when construction contracts are issued, potentially as early as 2018 or 2019.

On the path to SKA-low

When the SKA was first conceived in the early 1990s, no one had any idea where the ambitious international project would be located or what it would look like. But after years of hard work from the ICRAR engineering team and their collaborators around the world, the SKA is starting to come to life.

We now have a vision for the low frequency part of the SKA, known as SKA-low. Early prototypes tested by ICRAR on-site consist of Christmas tree-like antennas—or SKALAs as the design is officially known. The antennas will be clustered together in SKA stations that will dot the landscape in WA's remote Murchison.

ICRAR has been contributing to the design of the SKA as a member of the Aperture Array Design and Construction (AADC) consortium, a group charged with designing the antennas, on board amplifiers and local processing for SKA-low. In parallel with a high-level system engineering process led by the international SKA office, ICRAR has been working to test elements of the design on the ground in the Murchison. This next step in the prototyping and verification process will see the Aperture Array Verification System 1 (AAVS1) built near the future SKA site in 2017.

"At this point, the system engineering focus is on generating detailed design documentation," said ICRAR Associate Professor Randall Wayth. "While this is an essential part of the process, we would also prefer to have something on the ground that is actually working. In our experience, early prototyping and verification have been invaluable."

The prototype system will consist of four stations, including one full station that will be 35m in diameter with 256 prototype SKALA antennas, and operate as a 'proper' SKA-low station. "It's the real thing," Associate Professor Wayth said. "The electronics, the signal transport and the parts of the system that digitise and form beams—make all these little antennas work as one big antenna—that is all the proposed SKA-low system."

AAVS1 is being hosted within the MWA, allowing it to piggyback on the infrastructure set up for the existing telescope in a relationship Associate Professor Wayth believes is mutually beneficial. "We'll integrate the signals from the two telescopes so we can use them together because that will be much more powerful than using AAVS1 alone," he said.

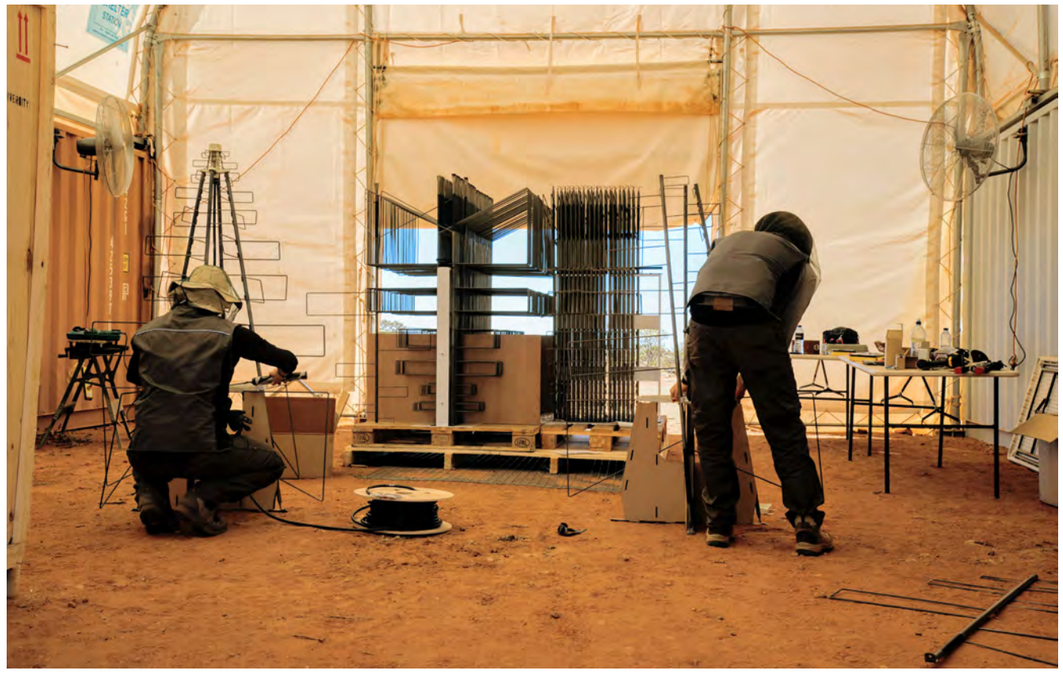
Ultimately the first phase of SKA-low will consist of a whopping 512 stations, each with 256 antennas, for a total of 131,072 antennas. "It's a big project, all of the production needs to be high volume," Associate Professor Wayth said. "Even just deploying and building the antennas will be quite a challenge. That's part of the reason we're building AAVS1, to actually find out how long it takes to build, assemble and install everything. When you're paying people to do this it all adds up quite quickly, and if the installation of the antennas turns out to be a significant part of the cost then that's an issue."

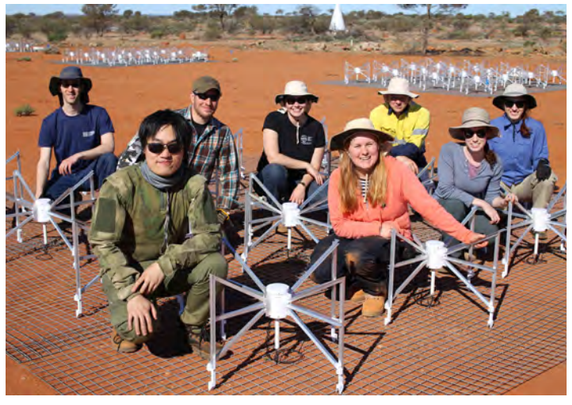
Being able to tie down cost estimates of all of the different components of the system, even for seemingly mundane things like actually installing them on the ground, is hugely important for the success of the SKA. It is this practical experience building both the MWA and AAVS1—from preparing the ground to wiring up power and optical fibre—that has led to the AADC consortium being able to provide some of the most robust cost estimates of any group to the SKA.

ICRAR assistant director of engineering operations Tom Booler said ICRAR's main role was initially around the system-level testing and verification of the SKA antennas. But the organisation's proximity to the site has seen ICRAR take on a lot of the logistical work and detailed planning around the roll out of the telescope. "One thing that's been at the fore much more than we anticipated is the deploying of 130,000 antennas in the desert, how we install and connect them up," Mr Booler said. "While we understand the nuts and bolts of deploying antennas, the magnitude is unprecedented."

The closest comparable exercise is the installation of large, remote solar farms, and ICRAR partnered with defence contractor Raytheon Australia to learn from these massive solar energy projects. ICRAR also worked on deployment planning with Geraldton-based contractor GCo Electrical, and delivered flexible costings to the international SKA office.

"That report was very, very well received by the SKA office because it recognised that the SKA was going to continue to change," Mr Booler said. "It's designed to be decision-support information rather than a fixed plan and can be chopped and changed depending on the bigger context. In an area that we didn't anticipate being in when we started pre-construction, we've had a really big impact."





PREVIOUS PAGE

Making preparations for the Aperture Array Verification System test platform at the Murchison Radio-astronomy Observatory.

THIS PAGE

Engineering Support Technician Luke Horsley working on an antenna for the Aperture Array Verification System test platform on site at the Murchison Radio-astronomy Observatory.

Associate Professor Wayth said it has been a big couple of years for the design consortium and he hopes that seeing AAVS1 in place will help build excitement and momentum for the SKA. "It will be really nice to see AAVS1 come together because a lot of people have put in a lot of years to get to this point," he said. "And having something real on the ground that is producing real data and making some images will be a big shot in the arm for SKA in general and especially SKA-low."

2015-2016 Achievement

The Aperture Array Design Construction consortium designing the antennas, on board amplifiers and local processing for SKA-low passed the all-important preliminary design review with flying colours.

Part of a "Christmas tree" antenna belonging to the Aperture Array Verification System test platform.

L to R Pieter Benthem (ASTRON). Prof. Carole Jackson (ICRAR-Curtin), Paul Akhurst, Tom Booler (ICRAR-Curtin).

The assembly area for the Aperture Array Verification System test platform at the Murchison Radio-astronomy Observatory (MRO).

Part of the AAVS test platform comprising of "Christmas tree" antennas at the MRO in outback Western Australia.

Members of the engineering team working on a receiver for the Aperture Array Verification Systemt test platform at the MRO.

PhD students from Brown University and Washington University sit with the ICRAR team at one of the new MWA tiles.

"In a way I'm fortunate because I have the astrophysics and radio astronomy background, and the engineering and technical background... so I have had a foot in both camps since the beginning of the MWA."

Researcher Profile

Associate Professor Randall Wayth
MWA Director

You won't see Associate Professor Randall Wayth wandering around ICRAR in a suit and tie too often.

The down-to-earth director of the MWA telescope is far more likely to be found in a T-shirt getting his hands dirty with the design, building and scientific work of the telescope.

Randall took on the role in December 2015 after years of involvement with the MWA, as a postdoctoral researcher, staff scientist, and later, as the telescope's commissioning scientist.

But it has been far from a standard career trajectory,

Randall completed an undergraduate degree in electrical engineering and computer science, and worked in industry as a software consultant for five years before turning to astronomy.

He undertook a PhD in astrophysics at the University of Melbourne and then a postdoctoral position at the Harvard-Smithsonian Center for Astrophysics before returning to Australia to join ICRAR.

"I started off more as a scientist and then was hired into the engineering faculty," Randall said.

"In a way I'm fortunate because I have the astrophysics and radio astronomy background, and the engineering and technical background.

"And so, for better or for worse, I have had a foot in both camps since the beginning of the MWA."

While seeing the perspective of both the engineers and scientists has its benefits, it can also make it difficult to juggle all the tasks that need to be done.

But it's this mix of things that gets Randall out of bed in the morning.

"With everything going on, it's great seeing projects to fruition," he said.

"These days when I go up to site it's often with visitors, so it's really nice to have the opportunity to show off all of the work we've done."

"A lot of the emphasis with the MWA is on the science but there's so much involved in actually getting that data."

Researcher Profile

Mia Walker
Instrument Support Engineer

When Mia Walker sits back and looks at the big picture, her job is pretty awesome.

She regularly gets to go to the Australian outback to fix a telescope.

"The main purpose of my job is to support the MWA operations team to keep the telescope up and running," she said.

"We also look into ways to expand the telescope—so research and design into expansion prototype tools—and see how we can improve things on the engineering side in the future."

The role model who inspired Mia to become an engineer was an unconventional one.

"Honestly? I grew up watching Stargate SG-1 and I wanted to be just like Samantha Carter," she said.

"She was so cool, she was so smart, she had an answer for everything and she could fix everything.

"I just wanted to be really useful in a real sense, in a mechanical sense."

Mia came to ICRAR with a double degree in both Physics and Electronic and Communication Engineering.

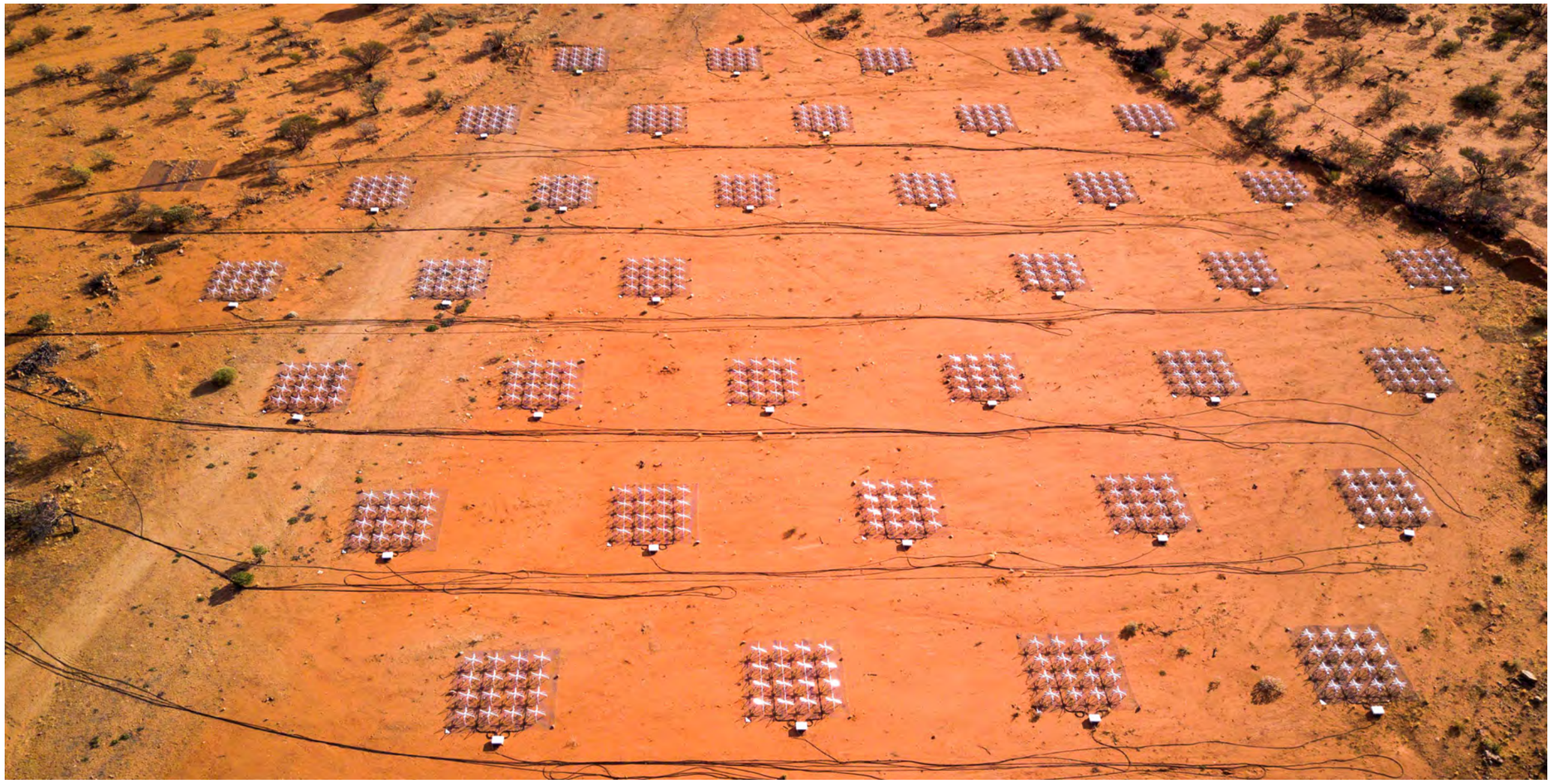
Her engineering honours saw her build a mini telescope from dongles used to tune into radio stations on computers.

And she did a final year physics project studying X-ray data from an exploding binary star system.

But while she likes to think she can see where both astronomers and engineers are coming from, there's no denying where her heart lies.

"A lot of the emphasis with the MWA is on the science but there's so much involved in actually getting that data," Mia said.

"The engineering that goes into building the telescope, running the telescope, making sure it spits out the data that the astronomers all want... I find that way more important."



An aerial view of some of the new tiles recently installed for the Murchison Widefield Array.

Instrument Support Engineer Mia Walker (left) and Engineering Graduate Intern Kim Steele working on the Murchison Widefield Array radio telescope.

Outback telescope comes of age

It is hard to believe the Murchison Widefield Array (MWA) telescope, in the remote West Australian outback, is less than four years old. The MWA became operational in mid-2013 and has already shown what the Universe would look like if humans could see radio waves, followed up on the discovery of gravitational waves and attracted funding for an expansion that doubled the size of the telescope.

"It has ramped up pretty quickly, partly because we had a prototyping period where a lot of the software and understanding came together early on," said MWA director Associate Professor Randall Wayth. "That allowed the science teams to be productive from the very first day of operations."

The MWA has four general science programs—the epoch of reionization, galaxy science, time domain astrophysics and space weather. "All of those science programs have really been making good headway," Associate Professor Wayth said. "We've had a pretty constant output of publications, which is really good for everyone, especially the collaboration."

One of the biggest highlights has been the GLEAM survey, a catalogue of 300,000 galaxies observed by the MWA that made headlines worldwide when it was released in 2016. The MWA was also the first radio telescope in the world to respond to a call to hunt down the source of a gravity wave detection, after the waves were discovered last year. The telescope was first on sky and the only radio telescope to have large coverage of the potential source area of the event.

ICRAR assistant director of engineering operations Tom Booler said the team had learnt a lot about the business of keeping a telescope like the MWA running day-to-day. "We've learnt a lot about maintaining an instrument like this on a remote site," he said. "We've learnt about the routine of being on site for a short duration, about what does and doesn't need maintenance regularly, what's going to fail, what's not going to fail and therefore what we should have sitting on the shelf. All those nitty gritty nuts and bolts and operational engineering considerations, which are all really important for the SKA given the MWA's role as a precursor."

The maturity of the MWA—from design and engineering to data management and science output—has seen the project attract new partners. The collaboration has grown from 15 institutions in four countries to 20 institutions in six countries, including China and Japan.

And in 2015, the project's success was recognised with the award of a Linkage, Infrastructure, Equipment and Facilities (LIEF) grant to expand the telescope. "This expansion has only been possible because of the early success of the instrument and continuing enthusiasm of the radio astronomy community for ongoing support of the telescope," Mr Booler said.

The start of this second phase in mid-2016 saw the MWA grow from 128 to 200 tiles. These extra 72 tiles, which became operational in October, are arranged in regular hexagonal patterns. In 2017, an additional 56 tiles are set to be positioned out on very long baselines to double the diameter of the array.

2015-2016 Achievement

The MWA was awarded LIEF funding in 2015 for the expansion of the project. The subsequent rollout of this second phase in 2016 doubled the size of the telescope.

2015-2016 Achievement

The MWA won the 2015 Thomson-Reuters Citation Award in space science category and was a finalist in the 2016 Eureka Prizes in category of international scientific collaboration.

"Building the MWA has been a great advantage in doing scientific work—I really appreciate having that engineering knowledge as well as the scientific knowledge."

Kim Steele
Engineering Graduate Intern

During her astronomy degree, it seems Kim Steele couldn't stay away from ICRAR.

The former Curtin University student did a summer internship with the Centre in her second year, and when a chance to help build the MWA telescope came up in her third year she jumped at the opportunity.

Kim went on to do her honours at ICRAR, before scoring a job working to maintain the telescope she helped build as a student.

"I spend a lot of time on site [at the Murchison Radio-astronomy Observatory] just doing whatever needs to be done up there," she said.

"So maintenance of all the bits and pieces... I see which dipoles, which tiles and which receivers have failed and go out and replace the components."

As one of only four people regularly visiting the remote MWA site, Kim is the project's resident shutterbug.

She documents the work on site, and captures images for presentations and scientific papers.

Kim is also working on the Engineering Development Array (EDA), a scratch pad that lets ICRAR researchers test new engineering technologies.

Kim said she loves working in the remote Murchison region.

"It's kind of away from everything but also up on site with the telescope," she said.

"I love getting away and having a hand in making something, and I love taking pictures."

"Building the MWA has been a great advantage in doing scientific work—I really appreciate having that engineering knowledge as well as the scientific knowledge."

"The more I can help them do their job, the more research gets done and the more amazing things are discovered."

Greg Sleap
MWA Data Manager

Combining his IT expertise with his passion for astronomy is a dream come true for Greg Sleap.

As the data manager for the MWA telescope, Greg is responsible for maintaining the day-to-day operations of the telescope's data archive, and making sure the observations are available to scientists.

"I love not having a repetitive job and I love the fact that every day is different," he said.

"I've met a lot of really cool astronomers from all over the world, and it's good to know that the work I do helps them go and make discoveries.

"The more I can help them do their job, the more research gets done and the more amazing things are discovered."

Greg has been fascinated by astronomy since he was a child, and emailed ICRAR about job openings years before his current position was created.

He came to ICRAR from the private sector with expertise in system administration, database design, software development, business intelligence and analytics.

Greg's previous experience traversed the mining industry, telecommunications and consulting.

But nothing could have prepared him for working on the MWA.

"It's been a big learning curve... getting to understand the telescope and how the data archive works has been really cool," he said.

"I love the fact that there's a new challenge every day and I'm learning every day.

"Being part of the MWA project is a dream come true because everything we do is learning lessons that will feed into the low frequency portion of SKA."

A field-deployable prototype of UWA's frequency synchronisation system in use in South Africa.

David Gozzard and a KAT-7 'dish' antenna at South Africa's SKA site.

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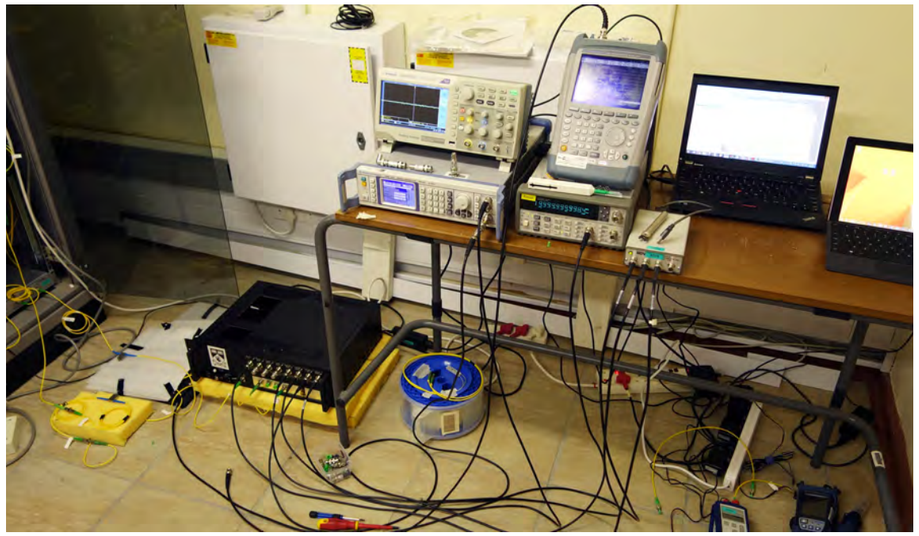
Sascha Schediwy (left) and David Gozzard in front of the frequency synchronisation system.

David Gozzard and a MeerKAT 'dish' antenna at South Africa's SKA site.



WA innovation keeps SKA antennas in time

How do you synchronise observations from thousands of SKA antennas separated by hundreds of kilometres in the WA outback?

ICRAR researcher Dr Sascha Schediwy and UWA PhD student David Gozzard worked with a team of researchers to build a 'frequency synchronisation system' for the SKA, which will help messages from a centrally located atomic clock reach the antennas and keep them in time.

The prototype system was built in partnership with the SKA Signal and Data Transport consortium, who are in charge of developing the signal and data network for the international project.

Lead designer Dr Schediwy said tests of the system show it performs between 100 and 1,000 times better than required for the SKA.

"The SKA telescope is designed to be synchronised using ultra-stable frequency signals that are transmitted on optical fibre from a centrally-located atomic clock to each of the telescope's thousands of individual antennas," he said.

"As mechanical stresses and thermal changes acting on the fibre degrade the stability of the transmitted signals, the SKA requires an active frequency synchronisation system to maintain coherence across the array."

The prototype SKA frequency synchronisation system continuously measures the changes in the fibre link and applies a correction in real-time.

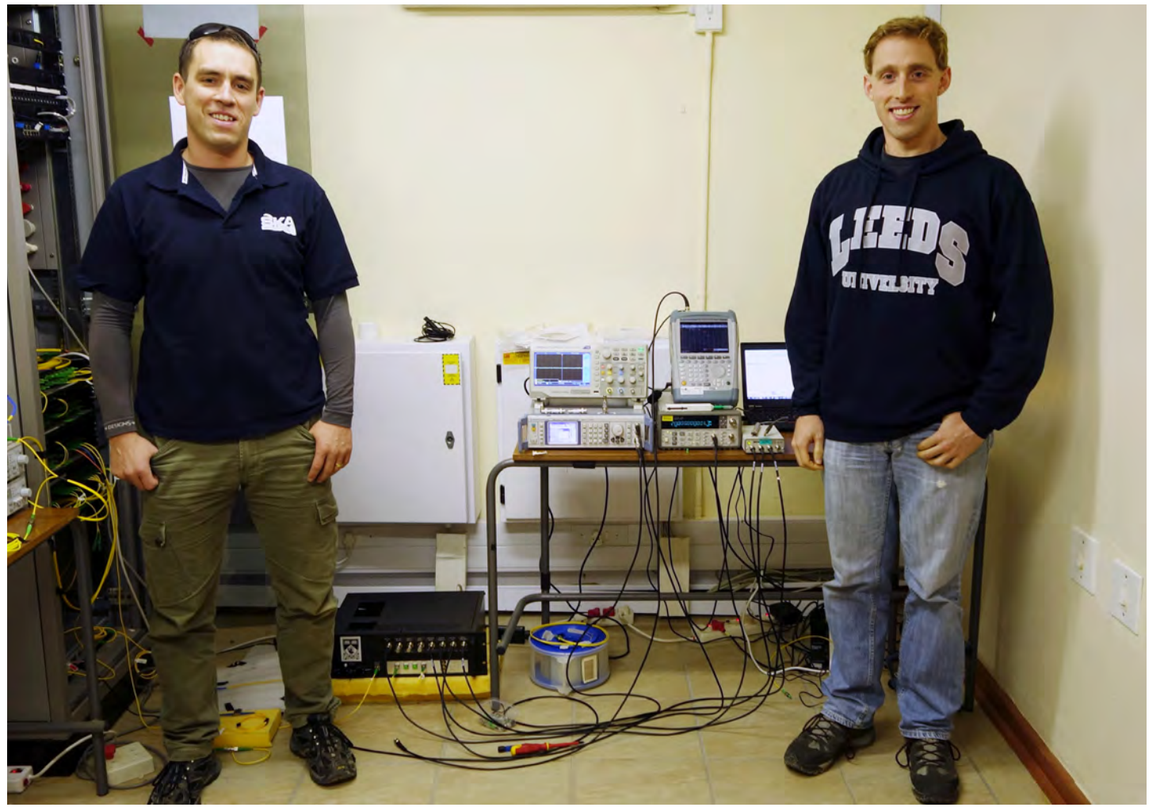
It reduces fluctuations to no more than one part in ten trillion over a 1-second period.

"A clock relying on a signal of that stability would only gain or lose a second after 300,000 years," Dr Schediwy said.

Australian SKA project director David Luchetti said the extreme accuracy of this technology could have all sorts of applications beyond discovering stars and galaxies from the early Universe.

"Astronomy is constantly pushing the boundaries in fields like precision timing, imaging and big data management, leading to new technologies like more advanced medical imaging," he said.

"At the time of invention, we often don't fully appreciate the extent to which these technologies can change lives and boost the economy."



Dave Pallot, Associate Professor Chen Wu and Professor Andreas Wicenec from ICRAR's Data Intensive Astronomy Team.

4

DATA INTENSIVE ASTRONOMY

DIA Overview

ICRAR's Data Intensive Astronomy team continues to go from strength to strength as they imagine solutions for unimaginable volumes of data.

The group is part of a prestigious international collaboration designing the Science Data Processor, or 'brain' of the SKA telescope. Together they will create the computing hardware platforms, software and algorithms needed to process data from the correlator, and turn it into a form that can be used by astronomers.

ICRAR is responsible for a part of the Science Data Processor known as the execution framework, which will need to run up to 100 million tasks in just a few hours as it processes the data coming from the telescope. The team has created a prototype execution framework called DALiuGE, and successfully run it on everything from a laptop to the world's second largest supercomputer, Tianhe-2. The Science Data Processor has officially passed the preliminary design review stage of the SKA pre-construction work, paving the way for its use for the final telescope.

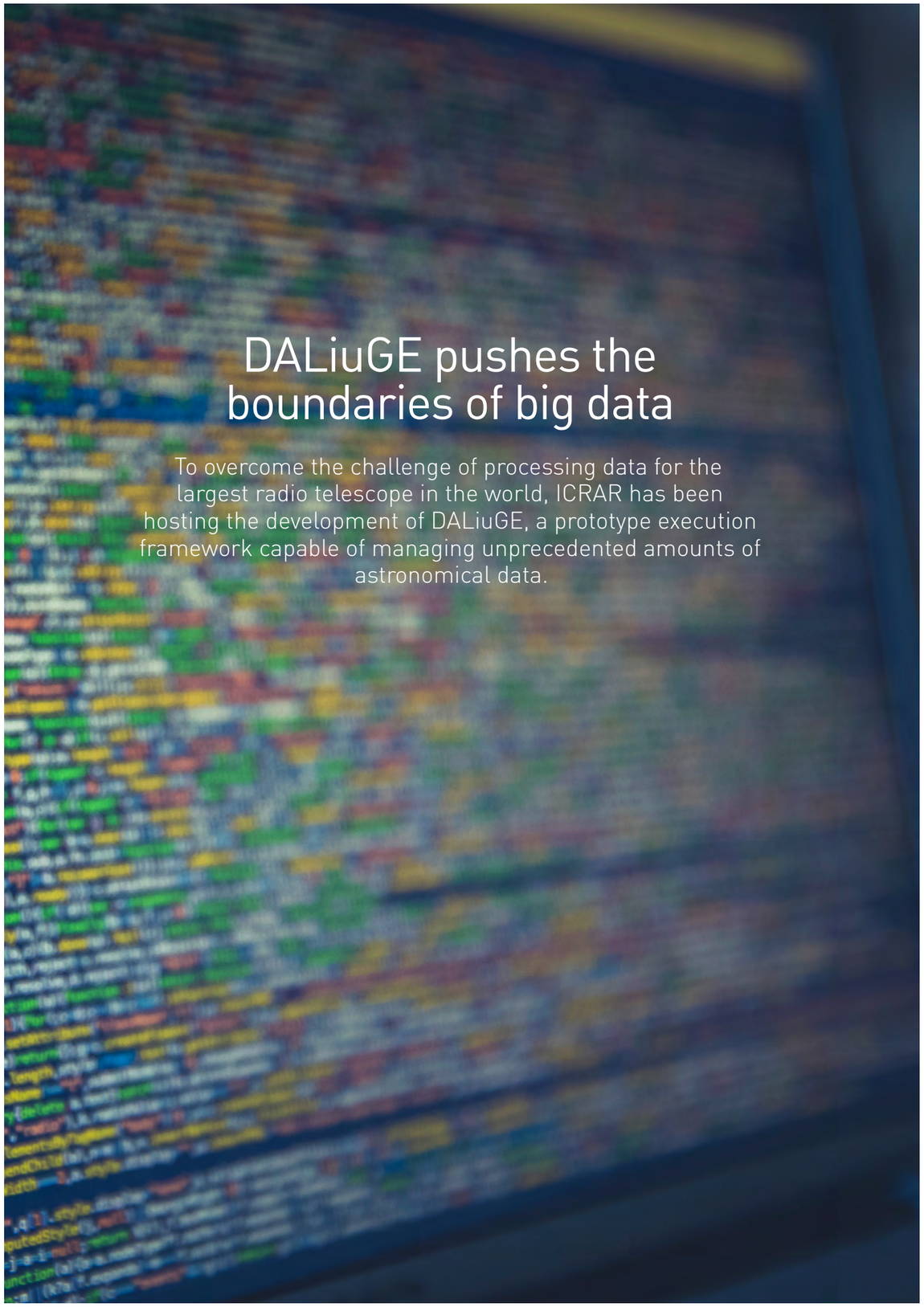
DALiuGE has also been harnessed for the Data Intensive Astronomy team's work in science survey support, which sees the group applying their expertise to existing astronomy projects. One of the most successful projects has been the use of the framework to process data from the COSMOS HI Large Extragalactic Survey (CHILES) on the Very Large Array of the National Radio Astronomy Observatory in the US. This survey saw an international team of scientists push the limits of radio astronomy to detect a faint signal emitted by hydrogen gas in a galaxy more than five billion light years away—almost double the previous record and a meagre indication of what's actually possible.

The DALiuGE framework has also been successfully scaled to process data rates equivalent to those expected to come from the SKA. These simulations first take a model of the sky and turn it into what would be expected to come from the correlator of the SKA—essentially going backwards. DALiuGE is then employed to recreate the image.

The Data Intensive Astronomy team is also supporting the data archive for the Murchison Widefield Array (MWA) telescope, an SKA precursor. The group manages the hardware and software both on site in the remote Murchison region and at the Pawsey Supercomputing Centre in Perth, where the data is stored. This archive is at 13 petabytes and steadily growing, with the telescope collecting more data every day.

The MWA is due to receive an upgrade that will result in the telescope producing four times more data than it is at the moment, and ICRAR's data specialists are working on a compression algorithm that will capture the data on site. The algorithm is expected to compress the data to a factor of between 1.8 and 2.3.

Finally, the team works to support in-house computing and storage systems to support astronomers and engineers in their research. Data experts are embedded into science teams at ICRAR, where they might tweak a bit of code, fix a bottleneck or professionalise a piece of software, all to discover more about our Universe.



DALiuGE pushes the boundaries of big data

To overcome the challenge of processing data for the largest radio telescope in the world, ICRAR has been hosting the development of DALiuGE, a prototype execution framework capable of managing unprecedented amounts of astronomical data.

The DALiuGE framework enables researchers to run up to 100 million tasks in just a few hours using thousands of compute nodes with minimal overheads. The goal is to spend as little time as possible managing the process and as much time as possible reducing the data.

ICRAR's head of Data Intensive Astronomy Professor Andreas Wicenec said DALiuGE is designed to process data in an asynchronous way. "What that means is every single task is running independently, so there's no central control of the whole thing," he said. "We have a central distribution at the beginning and some monitoring going on but there is no central control. That's very different from existing frameworks."

While other big data programs such as Spark are controlled by some form of central hub, the DALiuGE framework sees the data look after itself. It kicks off in one spot and then it just goes, like a giant domino challenge. "If you take those dominoes, you might have branching in one place," Professor Wicenec said. "Maybe there are a few steps in the beginning, then you split it up and then you have all these chains going on in parallel and completely independently, and all of them are going as fast as they can go."

One of the dominoes chains could stop for some reason, such as because it's too far away. "Then we can actually deal with that and say, 'Okay, well do we really need that much data'," Professor Wicenec said. "Because sometimes it doesn't matter too much if we lose some part of the reduction. We can decide. There's a threshold up to which we can go on or just stop the whole process at that point."

While other big data programs such as Spark are controlled by some form of central hub, the DALiuGE framework sees the data look after itself.

Essentially DALiuGE is making data 'active'. When a piece of data is ready, it automatically kicks off the next task that needs to be completed. "That's why it's completely independent of those other domino branches," Professor Wicenec said. "There's nothing controlling it. That's the difference to many of the other frameworks.

DALiuGE is, of course, ultimately being designed for the SKA. But the system has already been used for processing large astronomical datasets in existing radio astronomy projects. In 2016, as part of a collaboration between ICRAR and Shanghai Observatory, the framework was deployed on Tianhe-2, a supercomputer capable of performing quadrillions of calculations per second across 16,000 computer nodes, making it the second fastest in the world at the time.

Excitingly, Professory Wicenec said DALiuGE can be used on any large data set, even outside of astronomy. "There's nothing astronomical in there at all, that's the beauty of it," he said. "It's a completely generic framework and we've already used it for other things. It's really about getting the right algorithms in place—once that's done we can put whatever we like in there."

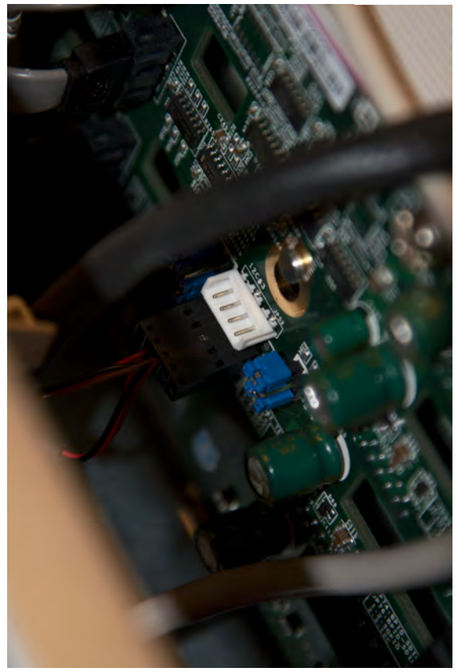
One project the team discussed is the sensor network, or control network, of a deep water pipeline. "All these sensors are checking and monitoring the health of the pipeline itself," Professor Wicenec said. "It's really just a sensor network, which in a way is very similar to a radio telescope, especially an interferometer, because that's a sensor network at the end of the day as well, it's just producing a lot more data."

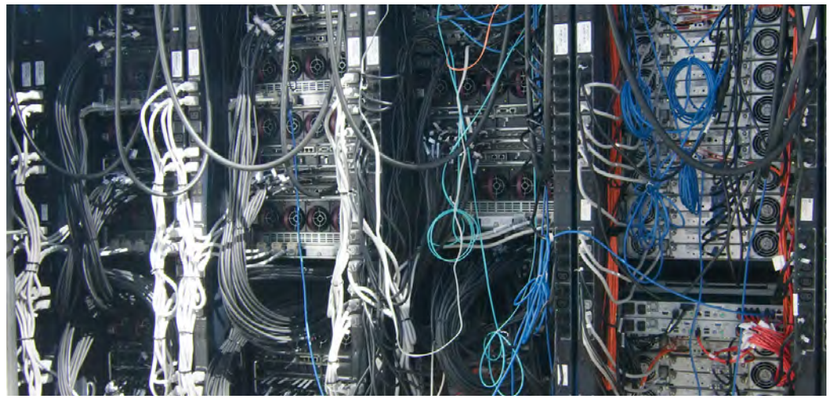
And more data is fine, with the DALiuGE framework designed to scale according to the amount of information coming in. The program has been run on everything from a laptop to one of the biggest supercomputers in the world.

A deep water pipeline, for instance, uses very complex data with many, many sensors, each outputting several different measurements. The goal is to be able to plug in new algorithms and 'data mine' the information coming in, to see what impacts different factors have. "If they see, for instance, some storm coming up, what's the effect on the pipeline," Professor Wicenec said. "There's a lot of potential in the data."

With the system running successfully and tested on projects big and small, the next step is to make DALiuGE more user-friendly. Right now the framework is a prototype, and end users need support to run it. But with all the pieces in place, the research team is working to polish the system for end users.

Essentially the program is making data 'active'. When a piece of data has finished processing, it automatically kicks off the next task that needs to be completed.



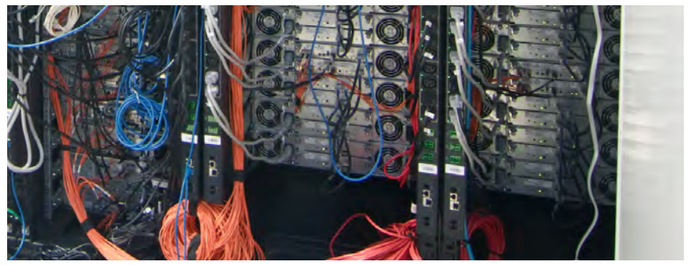


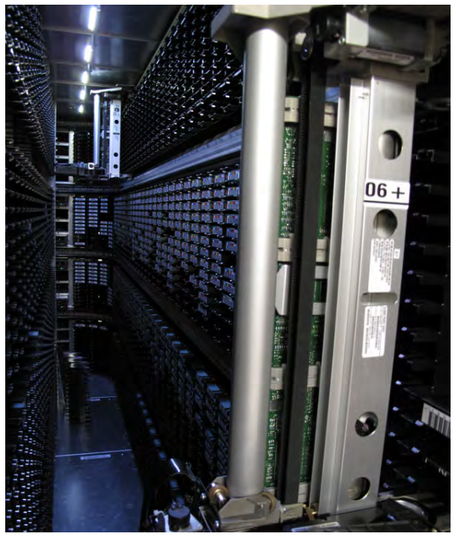
Computer components.

Inside the central control building at the Murchison Radio-astronomy Observatory.

The backend of the EPIC cluster unveils a truly impressive amount of cables for power, networking and intercommunication.

A slot robotic tape library.





After his time with the European Space Agency and European Southern Observatory, Markus Dolensky is no stranger to big astronomical projects.

Key Staff Profile

Markus Dolensky
Technical Leader

After his time with the European Space Agency and European Southern Observatory, Markus Dolensky is no stranger to big astronomical projects.

The computer scientist specialises in archive support for astronomy data centres, and has turned his project management skills to endeavours in both industry and the world's premier astronomy research institutions.

He has worked as a software engineer on both ground and space missions, including six years developing the calibration pipelines and archives for the Hubble Space Telescope.

Today, Markus is the technical leader for ICRAR's Data Intensive Astronomy group.

The role sees him in charge of the preservation system design, or the big storage system, for the SKA telescope.

"We're working together with our industry partners to stay abreast of evolving technology," Markus said.

"The software development needs to start before the computer hardware becomes available, for the simple fact that we need the latest, most power-efficient hardware.

"We need to factor in future performance enhancements and come up with software solutions which will be current at the time of procurement.

"We're trying to minimise risk when making design trade-offs and come up with a future-proof concept."

Markus is originally from Austria, and in his spare time translates the Jonathan's Space Report—a log of all manned and unmanned space launches—from English to German.

He hasn't looked back since moving to Perth to work on the SKA.

"The work environment and working conditions are excellent here," Markus said. "There is never a boring day."

"I really enjoy teaching primary kids, where their minds are excited and they still think science is cool."

Special Profile

Kevin Vinsen
DIA Expert

COSMOS COMPUTING SEES STUDENTS REACH FOR THE STARS

Primary schools can't get enough of data intensive astronomy expert Kevin Vinsen, whose musings on astronomy, computing and artificial intelligence are in hot demand from students.

Kevin is no stranger to captivating a room full of people.

He has given TEDx talks and interviewed Apple co-founder Steve Wozniak on stage in front of a live audience.

But working with schools has seen Kevin turn his hand to perhaps his toughest—and most important—audience yet.

"I really enjoy teaching primary kids, where their minds are excited and they still think science is cool," he said.

"And at the end of the day, to get people into science you've got to get them early."

Kevin has helped develop a Cosmic Computing program that sees students act out the roles of different computer parts to learn how a machine works.

The students pretend to be a computer's central processing unit, disk drive, display and arithmetic logic unit.

They work together in groups of four to create a picture.

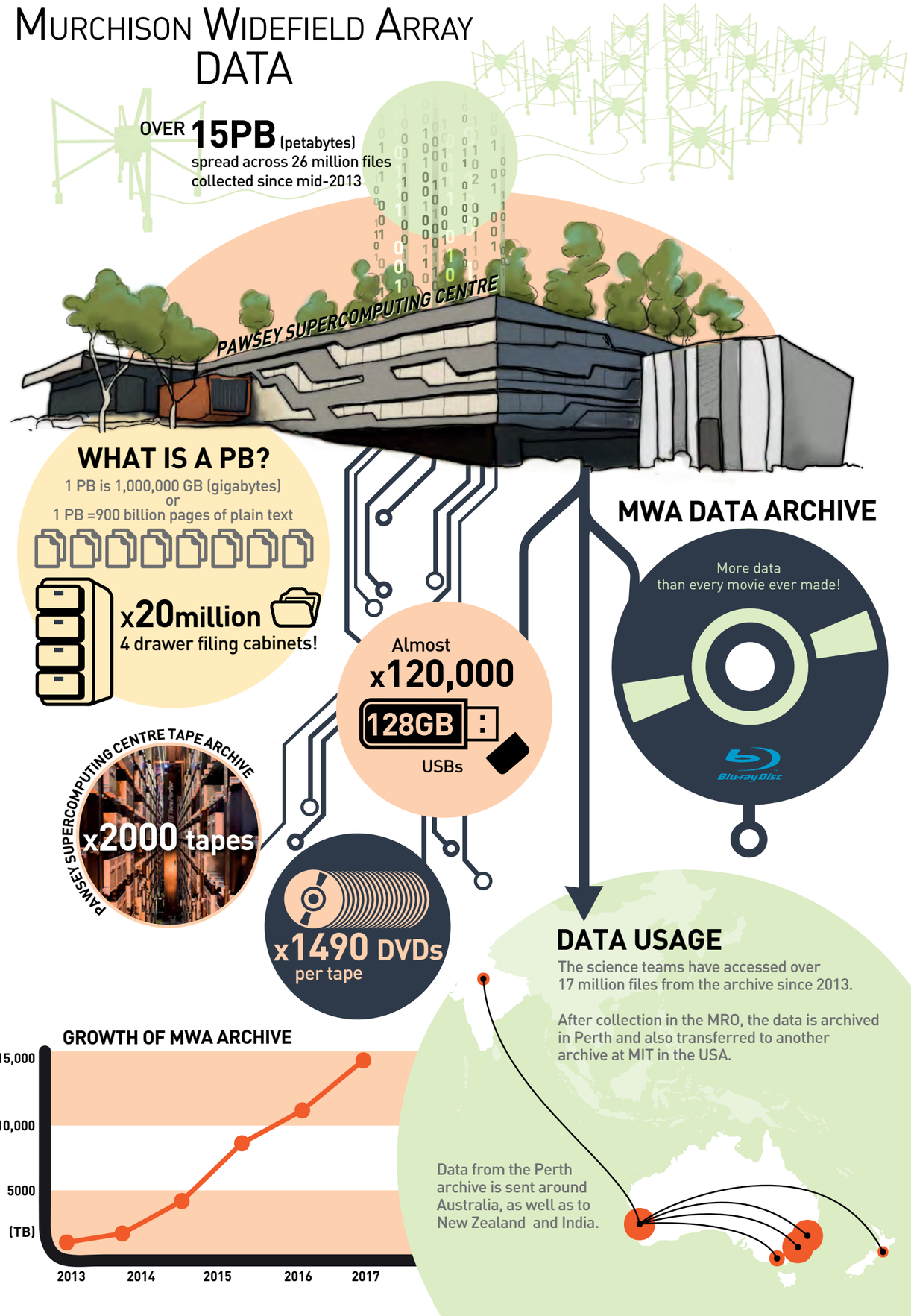
"The kids start to understand how the computer really works, and what's happening under the hood," Kevin said.

ICRAR has also invested in a set of Piper kits, which allow students to build a real computer and learn how to build simple electronics using MineCraft.

And Kevin is using a program known as Jupyter to teach kids to code in Python.

So far Kevin has worked with schools in Dalkeith, Byford, Ellenbrook, Halls Creek, Derby and Willetton.

The Cosmos Computing resources will also be made available to students overseas, following requests from schools in Canada and India.



Perth tech company helps build computing platform of the future

When a connection in the Netherlands pointed ICRAR at Perth software developers Think Bottom Up, head of Data Intensive Astronomy Professor Andreas Wicenec knew there must be something worth following up. Professor Wicenec tracked down the small Perth company and found they had a unique and innovative database engine that could be harnessed for big data work.

"The technology behind it is very interesting," he said. "We thought we'd need something like this, especially for the DALiuGE framework, so we talked to them and decided to do a small project with the company to test the waters."

This proof-of-concept work was a small image reconstruction—similar to a 3D sliding tile puzzle. The successful study gave ICRAR all the information it needed to engage Think Bottom Up to work on a much bigger project for astronomy computing framework DALiuGE.

That second project is doing what's called data life cycle management. Unlike typical databases such as Microsoft SQL Server or Oracle DB, which rely on a central engine, Think Bottom Up's product is a completely distributed database and is 'eventually consistent'.

"If you want to have a fully distributed system, it can't be immediately consistent," Professor Wicenec said. "So if you change some information on one server, the same information will not immediately be changed on the other servers in the system, but only after a short amount of time. Our application, as well as many other applications, can live with such a situation, if it gets consistent eventually. It's a really, really good product and the people in the company are technically absolutely outstanding."

Supercomputing for Thailand

ICRAR's big data experts are helping to build supercomputing expertise in Thailand with support from a Department and Foreign Affairs and Trade grant. Astronomy is the top science education area in Thai schools and the country plans to build a small, distributed radio telescope.

Led by the National Astronomical Research Institute of Thailand (NARIT), the project requires expertise not only in radio astronomy but in capturing, storing and processing the huge amounts of data the telescope will collect.

In 2016, ICRAR signed a Memorandum of Understanding with NARIT to help build up high performance computing skills in our regional neighbour. The arrangement has seen Thai researchers visit ICRAR for a series of introductions and lectures on a wide range of topics in computing and data management. The researchers then returned to Thailand to disseminate what they had learnt. A further three days of courses is being planned for 2017 to support Thailand in building up the required supercomputing expertise and infrastructure.

ICRAR's head of Data Intensive Astronomy Professor Andreas Wicenec said Thailand also had great optical astronomers, with a strong robotic telescope network. "One of the systems they're interested in is our data management system NGAS, so we're teaching them how to use that and they'll deploy it for collecting all the data and managing those robotic telescopes," he said. "They're building that up very fast. The other thing they are really, really strong in is outreach and education, they've got a program running to distribute Dobsonian telescopes all across Thailand."

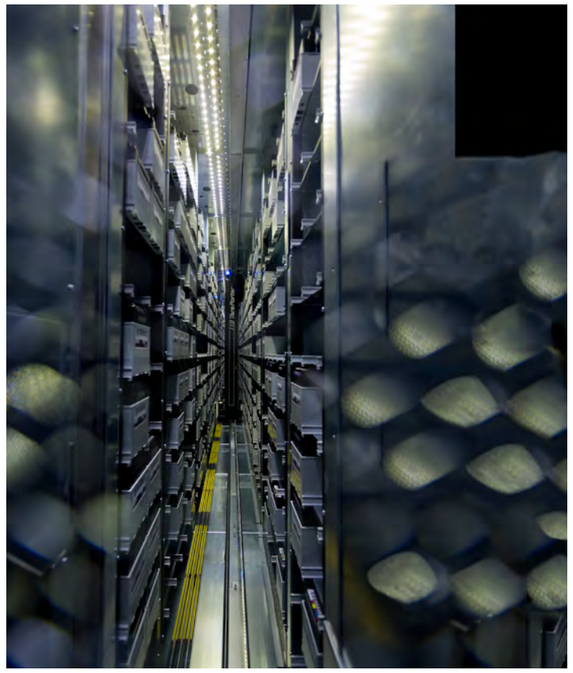
The signing of an MOU between ICRAR and the National Astronomical Research Institute of Thailand to develop high performance computing infrastructure in the country and establish a Thai VLBI Network.

Making big science possible through big data solutions

ICRAR has implemented a scheme that embeds big data experts in science teams to help astronomers get the most out of the observations they're collecting. Known as the survey science support project, the scheme is using big data expertise to enable some of the most exciting science in the world today.

"What we're essentially doing is asking our science teams for bottlenecks or things they don't have yet," said Professor Andreas Wicenec, ICRAR's director of Data Intensive Astronomy. "One way we can help is to improve the little modules that are out there. We are trying to take the code and see, well, 'how can we do this better'?"

It could be a matter of professionalising the software altogether or just executing things in a different way. ICRAR data intensive astronomy expert Kevin Vinsen, for instance, was able to help the GAMA project cut down the time to process a set of galaxies at the Pawsey Supercomputing Centre from three months to three hours. ICRAR software engineer Rodrigo Tobar Carrizo put his mind to another key tool for GAMA—Profit—making it modular, expandable and fast.



ICRAR's supercomputing experts are also enabling scientists to manage the masses of data they're collecting. "If you have one data set from more than one observation, it's not too hard," said Professor Wicenec. "But if you suddenly have 1,000 hours of observations collected over three years then it's a completely different story. Doing that in an ad hoc way just breaks the whole thing. You will never really finish and the science coming of that is probably far from what you could get out of it."

A tape library at the Pawsey Supercomputing Centre in Perth.

The Pawsey Supercomputing Centre in Perth.

Dr Jason Wang and Professor Andreas Wicenec visiting Shanghai University to discuss the use of NGAS data management infrastructure for FAST, the largest single dish radio telescope in the world.

"Studying at ICRAR has been one of the best decisions I have made in my life so far."

Student Highlight

Dr Jason Wang
Research Associate, Oak Ridge National Laboratory, US

A PhD at ICRAR parachuted Dr Jason Wang into a postdoctoral position in scientific data management.

Jason submitted his thesis in July 2016 and is now based at Oak Ridge National Laboratory in the US.

"I'm using what I learned at ICRAR for tackling astronomical data problems to solve data storage and input/output problems for the wider scientific community," he said.

Jason's PhD research was in the input/output challenges and management of extremely large parallel data streams.

He designed a system to address some of the unique data challenges of the SKA telescope and introduced cutting-edge techniques for storing data at minimal cost.

Jason's heritage also saw him heavily involved in ICRAR's collaborations in China, and at one stage he was asked to present to the US Ambassador to Australia.

Jason said studying at ICRAR was an opportunity to pursue a lifelong interest in astronomy.

"I don't know why, but as soon as I could read, most of the books I read were about astronomy," he said.

"Later for some reason I didn't choose astronomy as my major but went for computer science instead.

"So working at ICRAR and being involved in the SKA project was really a precious opportunity for me to realise my childhood dream."

Jason said the most joyful part of working at ICRAR was the opportunity to regularly talk face-to-face with top people in both astronomy and computational science.

"Studying at ICRAR has been one of the best decisions I have made in my life so far," he said.

ICRAR Outreach staff setting up for a guerrilla astronomy in in Geraldton. Credit: Kim Steele

5

OUTREACH, EDUCATION & COMMUNICATIONS

Overview

Connecting with the community to communicate our research and promote the importance of science and education is a core part of ICRAR's work.

Each year, our researchers and postgraduate students, supported by a team of professional science communicators, deliver a plethora of outreach and education programs across Western Australia and beyond.

So far, since the Centre launched in late 2009, more than 125,000 people have directly interacted with our outreach programs, with hundreds of thousands more connecting with us through a growing online presence.

Our media releases put the work of our researchers in front of a global audience, leading to thousands of news articles, read by millions of people, each year.

ICRAR has achieved this level of success through the passion, creativity and excitement our researchers and science communicators bring to their work, and through the collaborative relationships we have built with likeminded organisations and individuals working in the outreach and education space.

In this section you'll read about just some of our flagship programs and get a sense for the important outcomes it generates for ICRAR, the universities that underpin the Centre and the State of Western Australia.

Taking the stars on tour with Astrofest

ICRAR has been working with colleagues and partners to bring the wonder of the night sky to towns and communities throughout Western Australia.

Approaching its tenth year, Astrofest has become a staple in Perth's astronomical calendar, leading to events in regional WA and beyond, with Sydney and Melbourne holding annual Astrofests based on the Perth model.

Perth Astrofest

March 2015 and 2016

Astrofest is an educational and vibrant celebration of astronomy and space, coordinated and led by ICRAR on behalf of Astronomy WA—a collective of Western Australian outreach, education and astronomy organisations.

Attracting more than 4,000 people each year, Astrofest entertains and educates visitors from the youngest of kids through to seasoned astronomy veterans. Some of the largest privately owned telescopes in Australia come out to join more than 40 others, including radio and solar telescopes, giving viewers a taste of the Universe and its sights. Always the highlight of the event, the telescopes are operated by their owners, giving Astrofest attendees the opportunity to learn about the different kinds of telescopes available to suit almost any budget.

Astrofest also has a huge range of indoor and outdoor activities on offer, including:

- An astrophotography competition and exhibition showcasing amazing West Australian talent
- Laser guided tours of the night sky
- Make your own Lego SKA antenna
- Guest astronomy speakers from ICRAR, CAASTRO and CSIRO
- Hands on activities and giveaways for young and young-at-heart
- Exhibitor stalls from almost every astronomy organisation in Western Australia

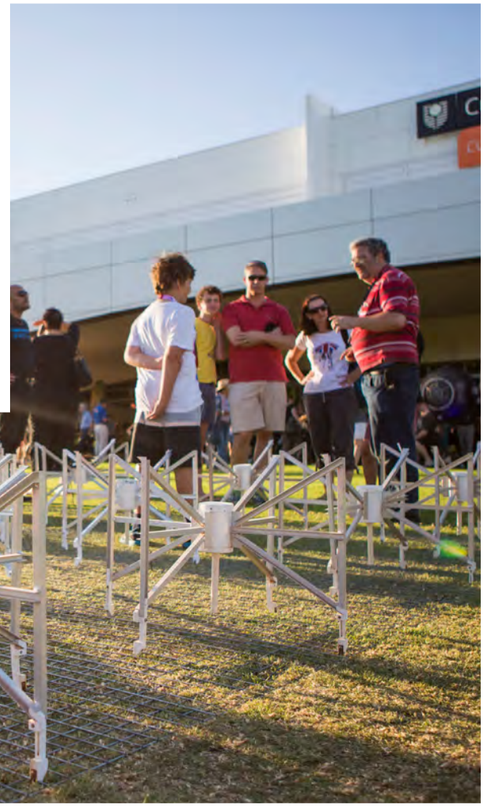
After the Perth event, the stunning astrophotography exhibition travels the state throughout the year, showing in Geraldton at the WA Museum, York and other venues in Perth, further spreading the impact of Astrofest.

Left: Water powered rockets—always a highlight at Perth Astrofest

Below: Ridgefield Astrofest visitors ready to enjoy the night sky through an ICRAR 'Dobsonian' telescope.

Right: Lego telescopes under construction at the Perth Astrofest.

Right: MWA "bowtie" antennas at Perth Astrofest.



Below: Looking through WA's largest privately owned telescope at Perth Astrofest.

Mount Magnet Astrofest

May 2015 and 2016

Now also an annual staple on the calendar, the skies at Mount Magnet never fail to delight. The entire community makes a weekend of it, celebrating their region's strengths with the three-day 'Astro Rocks Fest', featuring the Astrofest on Saturday night.

The weekend's activities bring people to town from around the region (and as far afield as Perth and the South West) to share in the amazing dark sky above Mount Magnet. In addition, astronomy themed art is shown at the local Indigenous art gallery and the region's history is celebrated with a full weekend schedule of events.

ICRAR coordinates the Astrofest evening with help from our colleagues at the Gravity Discovery Centre Observatory, Astronomy Education Services and the Astronomy Group of WA (AGWA). With up to 15 telescopes out on the oval, inflatable planetaria thanks to Scitech and 'comet' launches from the Fireballs in the Sky team, it's a night of educational fun for all ages.

Ridgefield Astrofest

September 2016

A first for ICRAR in 2016, the Ridgefield Astrofest took advantage of the UWA Future Farm located near Pingelly. Designed as an event to give back to the local community and to complement the biennial agricultural field day held on the property, Ridgefield Astrofest saw almost 300 visitors come out to view the Astrofest astrophotography display, hear about the local Pingelly observatory (now retired) and check out the stunning night sky through multiple telescopes.

Kalgoorlie Mini Astrofest

May 2016

Another first for ICRAR was an evening event out in the Goldfields at the Kalgoorlie Mini Astrofest. Supported with a Perth Astrofest seed grant, the event was led by the local science engagement group and featured telescopes from the Perth Observatory and ICRAR, laser guided tours of the night sky and a talk on the SKA to entertain visitors.

Over 200 locals came out to spend the evening under the stars, proving the appetite for astronomy in the region—the local coordinators are planning two more astronomy events in 2017 to satisfy this appetite!

Dandaragan Mini Astrofest

December 2016

Another recipient of a Perth Astrofest seed grant, Dandaragan Mini Astrofest saw the local community get together for an evening of astronomy talks, nibbles and telescopes at the community hall.

Melbourne Astronomy and Light Festival

August 2015 and September 2016

A large Astrofest based on the Perth model, the Melbourne Astronomy and Light Festival sees scores of people come out to Scienceworks and the Planetarium for a fun night with all the science they can handle. ICRAR provided advice and support for the inaugural event in 2015, and was glad to see the success follow on to another event in 2016.

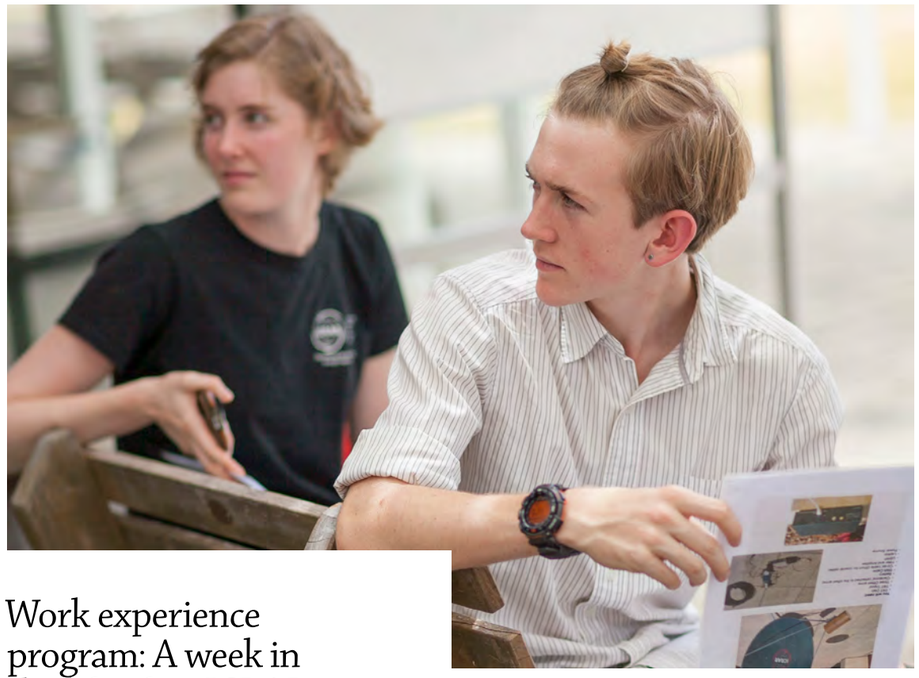
Sydney Astrofest

July 2016

The second in a series of large Astrofests that have sprung up based on the Perth event, Sydney Astrofest is managed by CAASTRO, of which ICRAR is a member organisation. Through the close connection between CAASTRO and ICRAR, the CAASTRO team have been involved in the Perth Astrofest for many years, and have put on an engaging evening over in Sydney for all to enjoy. ICRAR was in attendance, presenting the SKA and our work in WA to a new audience over in Sydney.

A further Sydney Astrofest is planned in 2017 to continue the trend of successful Astrofests across Australia.

ICRAR work experience student Cole Bannister learns about the operation of a radio telescope at ICRAR-Curtin.



Work experience program: A week in the life of an ICRAR researcher

Every year, select secondary students spend a week at ICRAR as part of our formal work experience program. Year 10's and 11's from schools surrounding Perth visit both ICRAR nodes and experience as many aspects of ICRAR's research as possible.

Students spend each day with a mix of researchers, learning about the day-to-day work of our astronomers, computing specialists and engineers, as well as contributing to ICRAR's outreach programs. They also have the opportunity to participate in any special events on that week, and are part of our weekly activities including Journal Club, Astro Morning Tea and Radio Galaxy Morning Tea.

ICRAR's work experience program is a popular choice for students, and a place is only granted after a competitive selection process, which ensures only the keenest future astronomers, engineers and data intensive astronomers receive a place.

Since it began in 2010, 52 students have spent time with us, most following our standard work experience program across both nodes of ICRAR.

The majority of our past work experience students have gone on to study in astronomy and related fields:

- Andrew Jamieson (2011), ICRAR studentship student in 2015 and graduating 2017 from Engineering/ Science from ANU.
- Aiden Sobey (2011), currently studying Engineering and Maths at UWA.
- Danielle Broughton (2011), member of the Australian Synchronised Ice Skating team competing at the World Championships in Colorado in early 2017, and graduated with a diploma in Medical Imaging from Curtin in early 2017.
- Samuel Warnock (2011), graduated in Computer Science from Murdoch University in 2014 and now works as a software developer in Perth.
- Michael Ponds (2011), studied Physics at University College London, and now is at UWA for a PhD working as part of the LIGO collaboration.
- Sasha Whittle (2011), currently studying a combined Bachelor of Science and Bachelor of Fine Arts at ANU, with study in astronomy included.
- Jennifer Hardwick (2011), currently studying Astronomy and Astrophysics at UWA (final year).
- Patrick Ryan (2011), studying Science/Engineering at Curtin University.
- Madeleine McKenzie (2012), studying Physics at UWA.
- Piraya Quach-Thanissorn (2012), currently studying a Bachelor's Degree in Mechatronics, Robotics, and Automation Engineering at the University of Melbourne. Training manager at RoboGirls, helping encourage girls into STEM subjects. She is also involved in the Melbourne Space Program, helping to design experiments and equipment for space.
- Lachlan Bunney (2013), studying Physics at UWA.
- Ryan Shaw (2013), studying Engineering.
- Holly Pennington (2013), studying Physics at UWA.
- Ben Stone (2014), studying Physics at UWA.
- Nicholas Walters (2014), studying Software Engineering at UWA.

Students from Iona Presentation College Perth visiting the SPIRIT observatories with their science teacher Katrina Prendergast and coordinator of the SPIRIT program, Paul Luckas.

Iona students get into the SPIRIT of astronomy

Year 9 and 10 students at Iona Presentation College have jumped head first into astronomy at ICRAR, using the robotic SPIRIT telescope to conduct real research.

The 44 girls, who are part of an extension science program at the school, spent a semester taking photographs of the heavens as part of a pilot astronomy immersion project.

The Iona students used the SPIRIT telescope to observe variable stars—stars that change brightness—and created light curves based on their observations. They then submitted their work to the American Association of Variable Star Observers, who verified the data before publishing it for use by the astronomy community around the world.

ICRAR's SPIRIT program has two rooftop telescopes at UWA, both of which can be controlled remotely from anywhere in the world. This facility allows schools to access the same tools used by researchers and astronomers to observe and collect astronomical data, using just an Internet browser. Every year the telescopes are used by hundreds of students from dozens of schools all over Western Australia and beyond.

SPIRIT program manager Paul Luckas said SPIRIT allowed school students to do real astronomy, and submit their work to professional journals. The Iona students' research has also featured in publications including Australian Sky and Telescope and the Variable Stars South monthly circular. "This is students doing genuine science," Mr Luckas said. "In fact, some of the students are now coming to ICRAR because of it. We've had three or four of them wanting to study astrophysics at ICRAR because they used SPIRIT in Year 9 and 10. And that's one of our goals."

Iona student Victoria Wong, for instance, applied for extraordinary work experience at ICRAR during the school holidays after taking part in the SPIRIT immersion program. The Year 11 student is set to be mentored by an astrophysicist ahead of her aim to study astronomy at UWA in 2019.

Mr Luckas said that as a free Internet telescope initiative for education and research, SPIRIT was unique in Australia . "To the extent that ICRAR is living on the cutting-edge of science it's also on the cutting-edge of outreach," he said. "We not only provide access to the telescopes but we provide the education packages, and we go out to schools." SPIRIT is also being used by a growing number of undergraduate and postgraduate university students at UWA and Curtin for research projects.

Mr Luckas said the Iona teachers reported that astronomy was the girls' favourite science subject. The SPIRIT immersion pilot is now set to be extended to John XXIII College in 2017, with other schools asking for the program to be rolled out more widely.

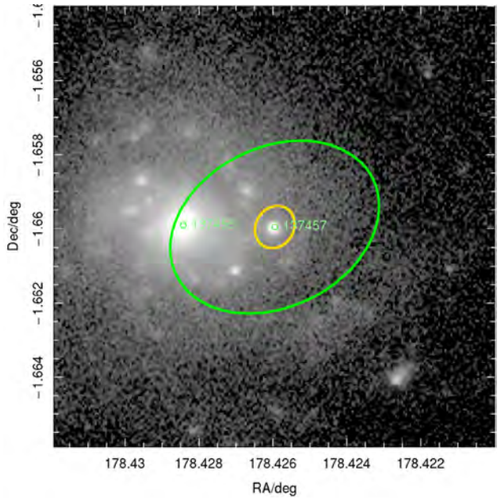
Citizen scientists take on the Universe

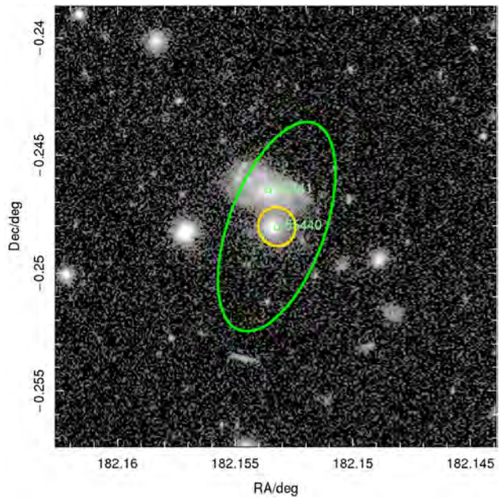
Since 2011 ICRAR has created programs that allow everyday citizens to assist in the scientific process and become involved in astronomical research. Currently, three main citizen science projects are running with ICRAR's involvement: Galaxy Explorer, Radio Galaxy Zoo and our original program, theSkyNet.

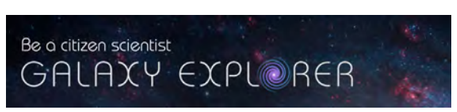
Galaxy Explorer
galaxyexplorer.net.au

Galaxy Explorer's citizen scientists have successfully helped ICRAR's astronomers classify and measure the properties of more than 200,000 galaxies since National Science Week 2015. Developed by ABC Science, Galaxy Explorer has provided data being used by graduate level astronomers working for the GAMA survey, led from ICRAR-UWA.

Since early 2016 we have had a dedicated postgraduate research student analysing the outputs from Galaxy Explorer, merging the galaxy sizes with other catalogues we have available. The overall improvement has been remarkable, with some very complex regions of the sky now successfully split into distinct sources, helping astronomers create a detailed atlas of the sky.







Radio Galaxy Zoo
radio.galaxyzoo.org

Black holes are found at the centre of most, if not all, galaxies. The bigger the galaxy, the bigger the black hole and the more sensational the effect it can have on the host galaxy. These supermassive black holes drag in nearby material, growing to billions of times the mass of the Sun and occasionally producing spectacular jets of material travelling nearly as fast as the speed of light. These jets often can't be seen in visible light but can be detected by radio telescopes. Astronomers need help to find these jets and match them to the galaxy that hosts them, which is where citizen scientists come in.

Co-led by Dr Ivy Wong at ICRAR-UWA, Radio Galaxy Zoo asks citizen scientists to analyse images of galaxies with radio jets. After marking the jets, citizen scientists then identify the accompanying galactic source in infrared, allowing researchers to spot supermassive black holes.

Astronomers have a good understanding of how small black holes—those that are several to tens of times more massive than our Sun—are formed. The picture is less clear for the supermassive black holes found in the centre of galaxies.

In order to better understand how these black holes form and evolve over time, astronomers need to observe many of them at different stages of their lifecycle. To do this, they need to find them first, which is the objective of Radio Galaxy Zoo.

theSkyNet

theSkyNet.org

A little different than the standard citizen science project, theSkyNet uses your spare computing power during down times to help ICRAR researchers process astronomy data. Complementing the activities of Galaxy Explorer, theSkyNet is helping astronomers to discover the properties of hundreds of thousands of galaxies and to develop automated ways of finding interesting sources in large volumes of radio data.

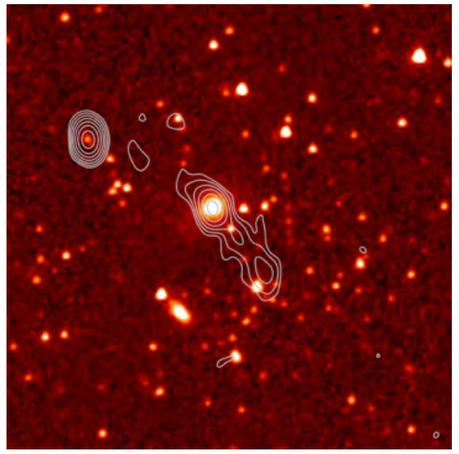
"TheSkyNet" is the first distributed computing project based in Australia and was launched in September 2011. Since the project's launch theSkyNet has been recognised for its ability to produce real research outcomes for ICRAR astronomers and collaborators whilst also being an innovative and effective method to engage the public in science through astronomy.

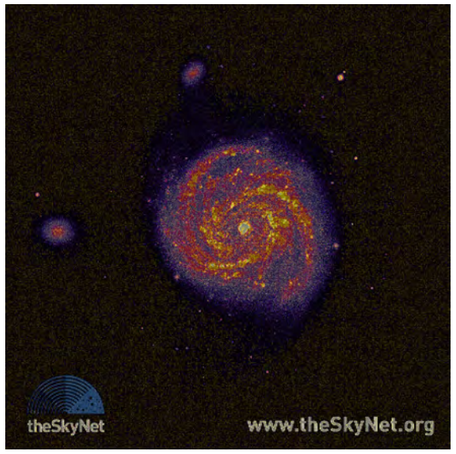
At any given time, day or night, almost 20,000 computers around the world are contributing to theSkyNet initiative. This adds up to a distributed network capable of performing more than one million processing tasks per week, placing theSkyNet on par with a supercomputer with between 60 and 100 TFLOPs of compute power, or just shy of a top 500 supercomputer. More than 54,000 people have processed data for theSkyNet, with more than 60,000 people signed up to the website.

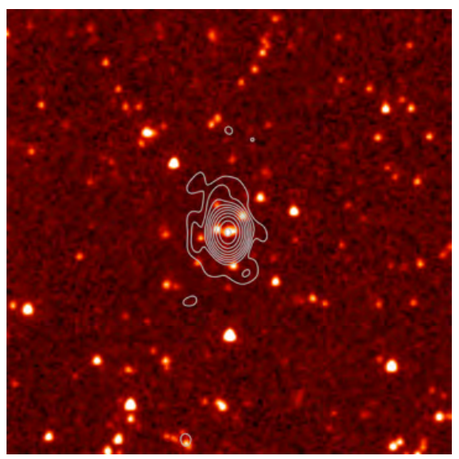
Left: Great improvements were made by Galaxy Explorer's citizen scientists. The green aperture is computer generated, whereas the yellow aperture is created by citizen scientists, showing how much accuracy is gained when humans are involved.

Right: Radio contours and IR images of Radio Galaxy Zoo galaxies, ready for matching.

Right: The star formation rate of M81 as calculated by theSkyNet POGS. This image is a mosaic of the thousands of galaxies processed by theSkyNet.







GALAXY ZOO RADIO

theSkyNet

TheSkyNet Quick Stats

WEBSITE VISITS
830,000+ unique visits to theSkyNet website since launch from 181 countries.

PROCESSING POWER
15/5/2014: A peak processing power of 106 TFLOPs was achieved.

- Equivalent to 366 modern Intel Core i7 processors, worth approximately $249,000 (not including running costs).

Total BOINC credit awarded is almost 14.6 billion credits, equivalent to:

- Almost 6 billion TFLOPs.
- 24 hours on the world's fastest computer.
- A high-performance desktop for 600 years.

Radio Galaxy Zoo Quick Stats

- 12,000+ citizen scientists at work
- More than 1.9 Million classifications complete
- 95,000+ radio source components classified
- Up to 40,000 radio galaxies analysed!

'The Pulpit' – Overlooking the coastal cliffs of West Cape Howe National Park. Photographer: Luke Hetherington.

'Orion's sword' – Orion's sword is an astronomical asterism in the constellation Orion. The sword sits inside the Orion Molecular Cloud Complex, a large group of bright nebulae, dark clouds, and young stars in the Orion constellation. The cloud is between 1,500 and 1,600 lightyears away, and hundreds of light-years across. This image shows M43, NGC 1982, NGC 1977, M42 (Great Nebula in Orion), NGC 1976, NGC 1975, NGC 1981, NGC 1973. Photographer: Paul Storey.

'Bungle Bungles Milky Way' – The Bungle Bungles (Purnululu National Park) provides a superb location to experience the Milky Way. Purnululu is located in the East Kimberley of Western Australia and its distinctive landscape is internationally famous, an extraordinary experience for visitors. Photographer: Wayne Riley.

Connecting through astrophotography

In a world of increasing light pollution and decreasing dark skies, one of Western Australia's greatest natural assets is a breath taking night sky, and one of the best ways to experience it without having to travel to every part of the State is through the Astrofest astrophotography exhibition.

Curated by ICRAR PhD graduate Dr John Goldsmith, this annual exhibition has been a core component of Perth's Astrofest since ICRAR began coordinating the event in 2009. The exhibition celebrates and showcases a wealth of superb astronomical imagery captured by Western Australian talent—who, over the years of the exhibition, are now among the best in the world.

Thousands of people view the exhibition in Perth before it travels to other parts of the State and venues such the WA Museum in Geraldton, York Town Hall, the University of Western Australia, and some of the towns that hold regional Astrofests.

The exhibition presents a diverse range of astronomical imaging, including deep-space images, photographs of the Sun and Moon and wide-field views of the night sky, as well as astronomical landscape images. It allows people of all ages to experience, enjoy and connect with the Western Australian night sky in all its wonder as seen from every corner of this amazing part of the world.

In the media

Both 2015 and 2016 were extraordinary years for ICRAR in the media, with thousands of articles about the Centre's discoveries published in more than 70 countries. Each of the two years saw more than 2000 stories mentioning ICRAR, which collectively attracted a global readership in the millions.

ICRAR's astronomers, engineers and big data specialists were interviewed frequently on radio and television, both about their own research and providing expert commentary on trending issues. The Centre's work appeared on BBC News, Fox News, MSN, Yahoo!, the Daily Mail, ABC News, the Sydney Morning Herald, the Age, Reuters, the Huffington Post, Smithsonian, the Examiner, Discovery News, the Sunday Times, the West Australian, Channel Ten, Catalyst, Nine News, the Australian, SBS and Sky News, just to name a few.

ICRAR's research featured alongside two NASA stories in a yearly wrap-up of world astronomy news on Triple J, and was also listed as one of the top 100 stories of the year by Discover magazine. These stories all helped to raise the profile of ICRAR and increase interest in radio astronomy and science around the world.

The exceptional level of media coverage over this time has been driven by a combination of the exciting research outcomes generated at ICRAR, the distribution of engaging media releases and a reputation for great stories. The Centre is careful to send out well-written releases supported by high quality multimedia assets in the form of imagery and/or video content. ICRAR distributed 10 media releases in 2015 and 13 in 2016. The most successful of these releases, as judged by the number of stories they generated, are shown opposite.

ICRAR's outreach team has worked hard to cultivate relationships with individual journalists and media organisations over time. They also run media training, social media and presentation skills workshops to support researchers in sharing their science. In 2015, this included training in media skills and interview techniques with a journalist from The West Australian and a newsreader and producer from Channel Nine.

The Centre has developed a growing reputation for researchers who are experienced and skilled in dealing with the media, and willing to make time to respond quickly to media enquiries from around the world.

TOP THREE MEDIA RELEASES

1

Scientists measure slow death of the Universe (900+ articles)

August 11, 2015

An international team of astronomers studying 200,000 galaxies has measured the energy generated within a large portion of space more precisely than ever before, discovering that it's only half what it was 2 billion years ago and fading – the Universe is slowly dying.

2

Scientists discover hidden galaxies behind the Milky Way (300+ articles)

February 10, 2016

Hundreds of hidden nearby galaxies have been studied for the first time, shedding light on a mysterious gravitational anomaly dubbed the Great Attractor.

3

Australian desert telescope views the sky in radio technicolour (200+ articles)

October 26, 2016

A telescope located deep in the West Australian outback has shown what the Universe would look like if human eyes could see radio waves.

Where are they now?

At ICRAR, we pride ourselves on the opportunities available to our students across astronomy, engineering and data intensive astronomy.

'Re-connect' – Stars mirrored in perfectly still water. Photographer: Jordan Gardner.

When you study at ICRAR you have the experience and support of two universities behind you, as well as the wealth of knowledge provided by over 100 researchers that form our Centre.

ICRAR's graduate students have gone on to positions in both industry and astronomy around the globe. Featured in this section is a selection of our recent past students and where their studies with ICRAR have taken them.

Dr Sarah Bruzzese

PhD Graduate, Year Completed 2015

CURRENT POSITION

Dr Bruzzese completed her PhD on star formation in the outer regions of galaxies at ICRAR-UWA in 2015. Heavily involved in ICRAR's outreach and education program, Sarah's passion lay with sparking a love of science in the next generation, and so she went on to complete her secondary teaching qualification. Sarah now teaches Physics to high school students at St Hilda's Anglican School for Girls.

Kirsty Butler

MSc Graduate, Year Completed 2016

CURRENT POSITION

After completing her Masters study with ICRAR-UWA in 2016, Kirsty has accepted a PhD position at the University of Leiden, The Netherlands in galaxy kinematics. Kirsty will be looking at feedback and outflows from luminous galaxies.

Dr Chittawan Choeysakul

PhD Graduate, Year Completed 2015

CURRENT POSITION

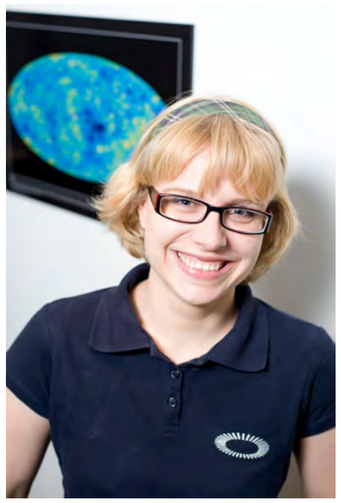
Dr Chittawan Choeysakul graduated from ICRAR-Curtin in 2015 after working on electromagnetic emission and electromagnetic compatibility in the Radio Astronomy Engineering group. Following graduation, Chittawan returned to the Royal Thai Navy to work as an aide to the chief of staff, as well as working as a research scientist on naval projects. Chittawan is now completing further naval training, as well as continuing his research efforts within the navy.

Laura Hoppmann

PhD (Submitted)

CURRENT POSITION

During her time at ICRAR-UWA, Laura worked on deep studies of the Universe at radio wavelengths. After submitting her thesis, Laura has now taken up a research scientist position with the Big Data Analytics Group at the Max Planck Society, Max Planck Digital Library.



Dr Rebecca Lange
PhD Graduate, Year Completed 2016

CURRENT POSITION
Before coming to ICRAR, Rebecca worked as a research assistant in the scientific imaging for archaeology and art conservation group at Nottingham Trent University, UK, using imaging and data techniques not dissimilar to astronomy work! During her time at ICRAR-UWA, Dr Lange completed her doctorate on the growth of galaxies and their components in the local environment. Upon completion Dr Lange made her way back into data science and now works at Curtin University, as a CIC computational specialist for the faculty of humanities, assisting other researchers with their data and computational needs. She is also a member of the Astronomy Data and Computing Services (ADACS) initiative and helps teach astronomers the computational skills needed in the era of big telescopes and big data.

Dr Steven Murray
PhD Graduate, Year Completed 2015

CURRENT POSITION
After graduating with his doctorate from ICRAR's UWA node, Dr Murray took the long trip across the river to ICRAR-Curtin for his first postdoctoral position. Steven now works as part of the Epoch of Reionisation (EoR) group on statistical foreground models for the EoR, hoping to detect this extremely faint signal from the very early Universe.

Dr Tom Russell
PhD Graduate, Year Completed 2016

CURRENT POSITION
During his time at ICRAR-Curtin, Tom worked as part of the Accretion Physics group studying black hole physics and was named 'Young Scientist of the Year' in 2015 by the WA Premier. After graduating from his PhD in 2016, Dr Russell took up a position as a Veni Postdoctoral Research Fellow at the Anton Pannekoek Institute for Astronomy, University of Amsterdam, The Netherlands.

Dr Jason Wang
PhD Graduate, Year Completed 2016

CURRENT POSITION
Dr Wang joined ICRAR-UWA in 2011 as a Masters student with ICRAR's Data Intensive Astronomy team. Working on data problems for the Square Kilometre Array, Jason was hooked, and began his PhD soon after completing his masters study. Through some of his PhD work with ICRAR, Jason connected with the Oak Ridge National Laboratory in Tennessee, USA, where he took up a Research Associate position upon graduation from The University of Western Australia.

Dr Angus Wright
PhD Graduate, Year Completed 2016

CURRENT POSITION
Dr Wright worked in the Multiwavelength And Spectroscopic Surveys group at ICRAR-UWA, using multi-band photometry and HI surveys to constrain the galactic baryonic mass function. After graduating with his doctorate in 2016, Angus took up a position at the University of Bonn, Germany in The Argelander-Institut für Astronomie (AIfA), working as part of their Cosmology and Weak Lensing group.

Dr Cameron Yozin-Smith
PhD Graduate, Year Completed 2016

CURRENT POSITION
Working in simulated worlds, Cameron spent his PhD studies tracing the evolution of our dwarf galaxy neighbours using numerical models. After graduating in 2016, Dr Yozin took up a Victoria University Canada Postdoctoral Fellowship in Near-field Cosmology with Professor Julio Navarro at the University of Victoria, Canada.

6

STAFF & STUDENTS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1

Kamran Ali, ICRAR-UWA
PhD Candidate, January '15
Information Content of Cosmic Structure.

2

Dr Gemma Anderson, ICRAR-Curtin
Research Associate, September '15
Rapid-response radio follow-up of high-energy transients, including: accreting sources, gamma-ray bursts, supernovae and flare stars.

3

Stephen Andrews, ICRAR-UWA
PhD Candidate, February '14
Measuring and Modelling the Extragalactic Background Light using the GAMA survey.

4

Wayne Arcus, ICRAR-Curtin
PhD Candidate, June '16
Fast Radio Bursts as Cosmic Probes.

5

Dr Balwinder Singh Arora, ICRAR-Curtin
PhD Graduate, October '12 - September '16
Ionospheric Modeling for low frequency radioastronomy.

6

Fiona Audcent-Ross, ICRAR-UWA
PhD Candidate, March '13
Star Formation in the Local Universe.

7

Dr Robert Bassett, ICRAR-UWA
Research Associate, February '16 - February '17
Galaxy formation and evolution; Gas accretion; N-body simulations versus observations.

8

Alex Beckley, ICRAR-UWA
TheSkyNet Programmer, December '12 - January '16
High performance distributed computing; Citizen Science and the role this can play in big data; Science Communication.

9

Professor Kenji Bekki, ICRAR-UWA
Research Professor, January '10
Galaxy formation and evolution; origin of globular clusters; Magellanic Clouds.

10

Dr Ramesh Bhat, ICRAR-Curtin
Senior Research Fellow, June '12
Observational pulsar astronomy including pulsar scintillation; Surveys for pulsars and fast radio bursts and their follow ups; Pulsar timing arrays for the detection of gravitational waves; Binary-pulsar timing, astrometry and the theories of gravity.

11

Dr Hayley Bignall, ICRAR-Curtin
Senior Research Officer, September '09 - September '15
Time domain astrophysics; VLBI; Interstellar scattering; Variability of AGN.

12

Tom Booler, ICRAR-Curtin
Director, Engineering (Acting), February '11
Program management.


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13

Mark Boulton, ICRAR-UWA
Senior Systems Engineering/IT Manager, March '12
Server/Infrastructure design/maintenance/support; Systems Engineering; Software design and coding.

14

Dr Toby Brown, ICRAR-UWA
PhD Graduate, October '15 - May '16
Revealing the Gas Cycle of Galaxies.

15

Dr Sarah Bruzzese, ICRAR-UWA
PhD Graduate, March '12 - February '16
Star formation in the outer disks of nearby galaxies NGC 2915 and M83.

16

James Buchan, ICRAR-Curtin
PhD Candidate, March '15
Photovoltaic-Battery Power Systems for the Square Kilometre Array Radio Telescope Considering Electromagnetic Compatibility Characterisation.

17

Andrew Butler, ICRAR-UWA
PhD Candidate, January '15
Measuring AGN Feedback: Black Hole Kinetic Luminosity Outputs in the HERG and LERG Paradigm.

18

Kirsty Butler, ICRAR-UWA
Student - Masters, February '15 - July '16
Angular Momentum of Dwarf Galaxies.

19

Rodrigo Canas, ICRAR-UWA
PhD Candidate, May '16
Understanding the Galaxy-AGN connection and its evolution through cosmic time using numerical simulations.

20

Dr Barbara Catinella, ICRAR-UWA
ARC Future Fellow, September '15
Extragalactic HI surveys; Environmental effects on galaxy evolution; Galaxy scaling relations.

21

Qingxiang Chen, ICRAR-UWA
PhD Candidate, October '15
Neutral hydrogen via spectral stacking.

22

Dr Rajan Chhetri, ICRAR-Curtin
Research Associate (CAASTRO), April '16
Active galactic nuclei; Multi-wavelength study of radio populations; Radio interferometry techniques; Widefield interplanetary scintillation.

23

Dr Chittawan Choeysakul, ICRAR-Curtin
PhD Graduate, July '11 - February '16
Characterisation of a Reverberation Chamber Model for Electromagnetic Emission Measurements.

24

Evelyn Clune, ICRAR-Curtin
Administrative Officer, October '15
Administration.


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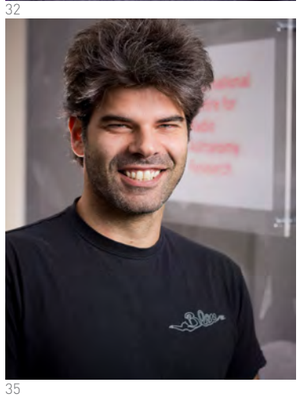
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25

Krystal Cook, ICRAR-UWA
Masters Graduate, March '14 - September '15
Radio Recombination Lines Using the MWA.

26

Ian Cooper, ICRAR-UWA
Project Manager, March '13 - February '17
SKA Science Data Processor Project Management.

27

Dr Luca Cortese, ICRAR-UWA
Senior Research Fellow, September '15
Extragalactic astronomy; Galaxy Evolution; Gas and star formation cycle in galaxies.

28

Brian Crosse, ICRAR-Curtin
Instrumentation and Commissioning Engineer, January '11
Low Frequency Radio Astronomy Engineering.

29

Dr Weiguang Cui, ICRAR-UWA
Research Associate, November '13 - November '16
Cosmology simulations (N-body/Hydro) and large scale structures; Modified gravity and Dark Energy simulations; Galaxy groups and clusters.

30

Dr Peter Curran, ICRAR-Curtin
Senior Research Fellow, August '12 - February '16
High-energy astronomy and accretion onto black holes. It was with heavy hearts that we said goodbye to our friend and colleague Dr Peter Curran who passed away in February, 2016. In recognition of Peter's contribution to ICRAR-Curtin's work in the accretion physics program, Curtin University has created the Peter Curran Memorial Fellowship for Radio Astronomy Research at ICRAR-Curtin in his honour.

31

Dylan Cusack-Pacquelet, ICRAR-UWA
Student - Masters, February '16,

32

Jacqueline Da Gama, ICRAR-UWA
Finance Manager, August '15
Responsible for all financial matters relating to all ICRAR grants; Providing finance related advice to Centre staff in the matters of accounting, budgeting, and management reporting; Ensuring compliance with all financial and accounts requirements.

33

Brenda Dagnall, ICRAR-UWA
Executive Assistant, June '16 - March '17
Executive Assistance to Professor Peter Quinn; Administration.

34

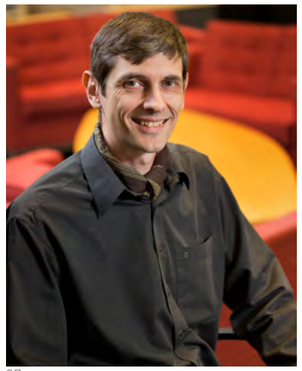
Dr Luke Davies, ICRAR-UWA
WAVES Project Scientist, October '13
Galaxy evolution; Muliwavelength surveys; Star formation; Galaxy interactions.

35

Dr Foivos Diakogiannis, ICRAR-UWA
Research Associate, July '14 - June '17
Theoretical and computational Galactic Dynamics; Galactic archaeology; Mass modelling; Evolutionary Algorithms.

36

Dr Richard Dodson, ICRAR-UWA
Senior Research Fellow, September '09
Data Intensive and Astronomical Methods for the Square Kilometre Array; Calibration of interferometers at low and high frequencies; Time domain astronomy with interferometers.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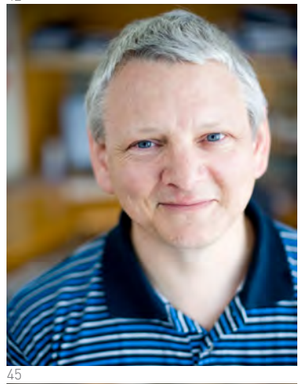
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37

Markus Dolensky, ICRAR-UWA
Technical Leader, January '14
Technical project management; Scientific data processing systems.

38

Professor Simon Driver, ICRAR-UWA
Research Winthrop Professor, April '11
Evolution of mass; Evolution of energy; Evolution of structure.

39

Dr Guillaume Drouart, ICRAR-Curtin
Research Associate, November '15
Black hole and galaxy evolution at the edge of the Universe.

40

Geoff Duniam, ICRAR-UWA
Student - Masters, March '14
Big Data in Radio Astronomy.

41

Angela Dunleavy, ICRAR-Curtin
Administrative Coordinator, June '12
Administration.

42

Dr Wiebke Ebeling, ICRAR-Curtin
CAASTRO Education and Outreach Manager, July '11
Science Communication: science news stories, media releases; Science Education: video productions, hands-on tools; Science Outreach: displays, visualisations, publications.

43

Ahmed Elagali, ICRAR-UWA
PhD Candidate, May '16
Studies of Interacting Galaxies & the Environmental Effects on Their Evolution.

44

Dr Pascal Elahi, ICRAR-UWA
Research Associate, April '16
Numerical Astrophysics; Galaxy Formation; Cosmology.

45

David Emrich, ICRAR-Curtin
Engineer - Radio Astronomy Instrumentation, September '09
Radio Astronomy Engineering.

46

Dr Bi-Qing For, ICRAR-UWA
Research Associate, August '11
Stellar evolution; HI surveys; Galaxy evolution and formation; Multiwavelength studies of the Magellanic System.

47

Sam Foster, ICRAR-UWA
Citizen Science Project Officer (theSkyNet), November '14
High performance distributed computing; BOINC infrastructure.

48

Dr Thomas Franzen, ICRAR-Curtin
Postdoctoral Researcher, April '14
Extragalactic continuum radio surveys; Population and evolutionary studies of radio galaxies.


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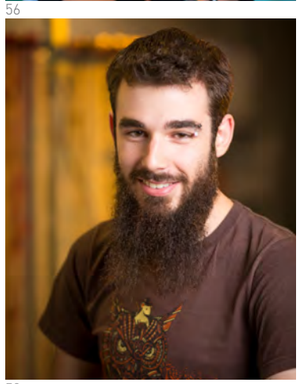
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49

Jonah Gannon, ICRAR-UWA
Student - Masters, July '16
Developing the StarFox Telescope for Deep Sky Imaging.

50

Morgan Goodman, ICRAR-Curtin
Student - Masters, August '16
Formation and evolution of dwarf galaxies with different types.

51

Kirsten Gottschalk, ICRAR-UWA
Astronomy Ambassador, January '10
Online communication and social media; Media liaison; Science Writing; Graphic and web design; Event Management; Work Experience and Studentship Student Support; as well as resources and events for schools.

52

David Gozzard, ICRAR-UWA
PhD Candidate, February '14
Stabilized transfer of time and frequency for space science applications.

53

Guido Granda, ICRAR-UWA
PhD Candidate, May '16 - March '17
Synthetic Universes of the Radio Sky.

54

Professor Peter Hall, ICRAR-Curtin
Director, Engineering/Professor Emeritus, September '09
Radio astronomy engineering; Square Kilometre Array design and verification; Engineering education.

55

Dr Paul Hancock, ICRAR-Curtin
Early Career Research Fellow, September '13
Low frequency radio variability; Fireballs and meteors; Software and methods to support astronomy.

56

Kate Harborne, ICRAR-UWA
PhD Candidate, October '16
The study of feedback processes in dwarf galaxies.

57

Benjamin Henderson, ICRAR-UWA
Masters Graduate, March '14 - January '16
Search for high-z dropouts in the GAMA mutli-wavelength database.

58

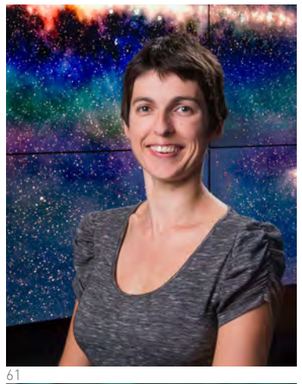
David Herne, ICRAR-Curtin
PhD Candidate, March '06 - June '16
The Australian Mid-latitude Continental Ionosphere with Respect to Low-frequency Radio Astronomy.

59

Luke Horsley, ICRAR-Curtin
Engineering Support Technician, August '15
Fieldwork logistics and engineering support.

60

Dr Cullan Howlett, ICRAR-UWA
Research Associate (CAASTRO), October '15
Large galaxy surveys; Cosmology; Large scale structure.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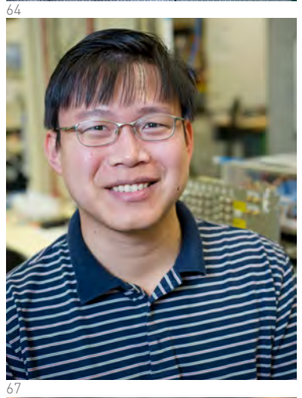
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Dr Natasha Hurley-Walker, ICRAR-Curtin
Early Career Research Fellow, August '11
Radio astronomy; Astronomical surveys; Supernova remnants; Galaxy clusters; Radio galaxies.

62

Dr Minh Huynh, ICRAR-UWA
Research Associate Professor, September '10
Galaxy evolution; Active galactic nuclei; Radio surveys.

63

Professor Carole Jackson, ICRAR-Curtin
Director, Science (Curtin), August '13
Extragalactic radio source evolution; Technologies for radio astronomy; Industry engagement strategies & large projects.

64

Dr Steven Janowiecki, ICRAR-UWA
Postdoctoral Research Fellow, September '15
Galaxy Evolution and Star Formation; Optical and Radio Observations.

65

Dr Christopher Jordan, ICRAR-Curtin
Research Associate, October '15
Epoch of reionisation; Ionospheric science; High mass star formation.

66

Ronniy Joseph, ICRAR-Curtin
PhD Candidate, October '16
Probing the Epoch of Reionization with Non-Traditional Hybrid Arrays.

67

Dr Budi Juswardy, ICRAR-Curtin
Research Engineer, January '11
Radio Frequency Systems; Electronic Circuit Design; Reliability and Risk Assessment; Power Systems.

68

Dr Prajwal Kafle, ICRAR-UWA
Research Associate, May '14
Formation and evolution of galaxies, in particular Milky Way-like galaxies.

69

Dr Anna Kapinska, ICRAR-UWA
Research Associate (CAASTRO), August '13
Radio galaxies; Relativistic jets; AGN feedback; Radio continuum surveys.

70

Katharine Kelley, ICRAR-UWA
PhD Candidate, June '14
A Radio Astronomy Search for Axion Dark Matter.

71

David Kenney, ICRAR-Curtin
Senior Technical Officer, April '14
Support the ICRAR radio astronomy engineering laboratory; Leading role in the development, deployment and validation of SKA pre-construction systems; Design, prototype and test radio astronomy instrumentation; Support engineering projects undertaken by staff and students.

72

Dr Franz Kirsten, ICRAR-Curtin
Research Associate, October '14
Pulsar scintillometry; Pulsar astrometry; Astrometry of compact object; Radio interferometry.


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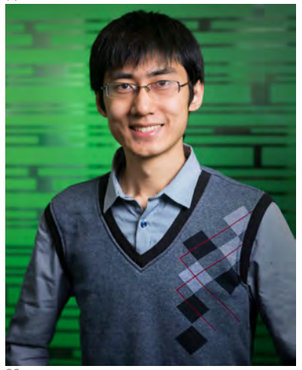
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73

Dr Slava Kitaeff, ICRAR-UWA
Senior research Fellow, May '11
Big data; Algorithms; Software; Universe(s).

74

Kathy Kok, ICRAR-UWA
Finance Manager, January '10 - July '15
Financial Management.

75

Soheil Koushan, ICRAR-UWA
PhD Candidate, March '16
Measuring the Cosmic Optical Background Light using the WAVES Input Catalogue.

76

Dr Claudia Lagos, ICRAR-UWA
ARC Early Career Researcher, May '15
Galaxy formation in cosmological simulations.

77

Dr Rebecca Lange, ICRAR-UWA
PhD Graduate, June '12 - July '16
Understanding the physical growth of galaxies and their components - A local perspective.

78

Lincheng Li, ICRAR-UWA
PhD Candidate, November '16
Intensity Mapping, a New Technique to Study the Evolution of the Universe.

79

Hanson Ling, ICRAR-UWA
Student - Masters, February '16
Dynamic Evolution of Binary Black Holes.

80

Boyang Liu, ICRAR-UWA
PhD Candidate, February '16
Early ASKAP Science: Cold Atomic Gas and Molecular Hydrogen Formation in the Magellanic Clouds.

81

Paul Luckas, ICRAR-UWA
SPIRIT Program Manager, March '16
Robotic telescopes in Education.

82

Dr Damien Macpherson, ICRAR-UWA
PhD Graduate, February '12 - January '17
Optimal strategies for detecting the first stars: the biggest explosions in the Universe.

83

Dr Jean-Pierre Macquart, ICRAR-Curtin
Senior Research Fellow, September '09
Scintillation and Wave Propagation Theory; The Interstellar and Intergalactic Medium; Radio Transients; Pulsars; The Galactic Centre.

84

Lesley Maddox, ICRAR-UWA
Masters Graduate, March '15 - August '16
Kinematic Modelling of Galaxies.


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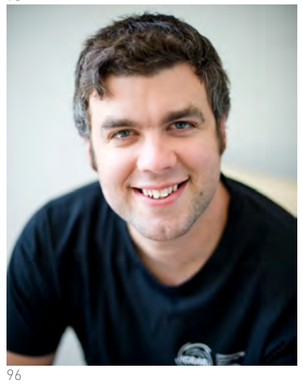
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85

JT Malarecki, ICRAR-UWA
PhD Candidate, March '15
Organisation and exploration of very large imagery data in the SKA.

86

Dr Jurek Malarecki, ICRAR-UWA
PhD Graduate, January '11
The Warm-Hot Intergalactic Medium.

87

Liz Mannering, ICRAR-UWA
Web Developer & Outreach Assistant, May '15
Front-end web developer working on the AAO node of the All-Sky Virtual Observatory (ASVO) project, connecting researchers to a wealth of theoretical and observational data from telescopes across the globe; Designing and building online astronomy outreach tools.

88

Yolandie McDade, ICRAR-UWA
Executive Assistant, May '11
Executive Assistance to Professor Peter Quinn; Administration.

89

Sam McSweeney, ICRAR-Curtin
PhD Candidate, March '16
Investigating Emission Mechanisms by Mapping Pulsar Magnetospheres in Three Dimensions.

90

Professor Gerhardt Meurer, ICRAR-UWA
Research Winthrop Professor, January '10
Galaxies: star formation and evolution.

91

Dr Martin Meyer, ICRAR-UWA
Senior Research Fellow, September '09
HI surveys; Galaxy formation and evolution.

92

Scott Meyer, ICRAR-UWA
PhD Candidate, February '12
Investigating the Tully-Fisher relation and galaxy kinematics through neutral Hydrogen spectral line stacking techniques.

93

Bradley Meyers, ICRAR-Curtin
PhD Candidate, February '16
Investigating the Links between Radio Pulsar Populations that display Intermittent Emission Phenomena at Low Frequencies.

94

Dr James Miller-Jones, ICRAR-Curtin
Director, Science (Curtin), Acting, July '10
X-ray binaries; Jets; Accretion physics; Radio transients.

95

Dr Amanda Moffett, ICRAR-UWA
Research Associate, October '13 - October '16
Galaxy evolution, specifically understanding the processes that set up and change galaxy morphology over time; The effects of large-scale structure on evolution.

96

Dr John Morgan, ICRAR-Curtin
Research Fellow, May '10
Extra-galactic science with the MWA; Solar science with the MWA; VLBI and interferometry; Education and outreach.


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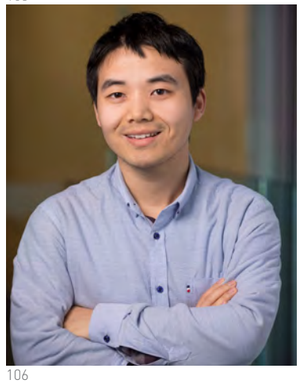
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97

Steven Murray, ICRAR-Curtin
PhD Graduate and Research Associate (CAASTRO), April '12
Epoch of Reionisation; Large Scale Structure; Astrostatistics.

98

Rakesh Nath, ICRAR-Curtin
PhD Candidate, October '14 - August '15
Estimating the neutral hydrogen signal from the Epoch of Reionisation using low-frequency radio interferometers.

99

Tracey O'Keefe, ICRAR-UWA
Administrative Officer, April '14
Administration; HR; General Finance.

100

Dr Danail Obreschkow, ICRAR-UWA
Research Associate Professor, October '11
Galaxy evolution theory; Cosmology; Hydrodynamics.

101

Dr Se-Heon Oh, ICRAR-UWA
Research Fellow, May '11 - September '16
Galaxy dynamics; Dark matter in galaxies; HI galaxy surveys (VLA THINGS/LITTLE THINGS, ASKAP WALLABY/DINGO, MeerKAT MHONGOOSE).

102

Dr Steven Ord, ICRAR-Curtin
Senior Research Fellow, February '11 - December '15
High time resolution radio astronomy research; Pulsars; Central signal processing for the SKA.

103

Samuel Oronsaye, ICRAR-Curtin
Masters Graduate, August '12 - July '16
Studies of the Crab Giant pulses with the Murchison Widefield Array.

104

Dr Shantanu Padhi, ICRAR-Curtin
Research Engineer, June '10 - June '15
Antennas/EM Simulations; Optimisations.

105

Dave Pallot, ICRAR-UWA
Software Engineer and Administrator, January '15
Software Engineering; Survey Science Support Engineering; IT Administration.

106

Hengxing Pan, ICRAR-UWA
PhD Candidate, December '16
Analysing large-scale galaxy bias.

107

Clare Peter, ICRAR-UWA
Administration Officer (CAASTRO), August '13
CAASTRO Administration and Finance.

108

Dr Richard Plotkin, ICRAR-Curtin
Senior Research Fellow - Peter Curran Memorial Fellow, November '15
Black Hole Accretion; Relativistic Jets; Multiwavelength Observations.


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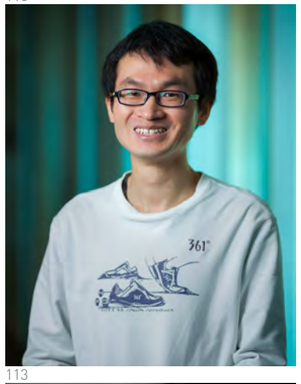
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Dr Attila Popping, ICRAR-UWA
Research Fellow (CAASTRO), November '10
Galaxy Evolution; Neutral Hydrogen Surveys; Neutral Hydrogen in the Intergalactic Medium.

110

Rhys Poulton, ICRAR-UWA
PhD Candidate, September '16
Studying the orbits and interactions of satellite galaxies in the next generation of surveys and simulations.

111

A/Prof Chris Power, ICRAR-UWA
Research Professor & ARC Future Fellow, March '11
Galaxy Formation and Evolution; Dark Matter; Scientific High Performance Computing.

112

Hai-Hua Qiao, ICRAR-Curtin
PhD Candidate, October '14
Accurate OH maser positions from SPLASH: Understanding the origins of OH masers with an unbiased survey.

113

Fei Qin, ICRAR-UWA
PhD Candidate, November '15
Bulk flow and peculiar velocity.

114

Professor Peter Quinn, ICRAR-UWA
Executive Director, September '09
Galaxy formation and evolution; Dark matter; Computational cosmology and data intensive astronomy.

115

Lisa Randell, ICRAR-UWA
Administrative Assistant, July '14
Administration; Reception; Purchasing; Visitor Travel/ Accommodation.

116

Dr Cormac Reynolds, ICRAR-Curtin
Senior Research Fellow, September '09 - September '15
Studies of Active Galactic Nuclei (AGN), principally through high angular resolution radio astronomy; The Interstellar Medium.

117

Dr Jonghwan Rhee, ICRAR-UWA
Research Associate (CAASTRO), June '14
HI surveys; 21-cm cosmology.

118

Dr Maria Rioja, ICRAR-UWA
Research Fellow, September '09
Interferometric observations, imaging, and high precision astrometry; Development of Calibration techniques; Studies of AGNs, star forming regions, evolved stars; SKA.

119

Dr Aaron Robotham, ICRAR-UWA
Senior Research Fellow, January '13
Galaxy Evolution; Dark Matter; Large Scale Structure.

120

Gregory Rowbotham, ICRAR-UWA
Cosmos Consultant, March '16
Outreach, Education and Communication.


121


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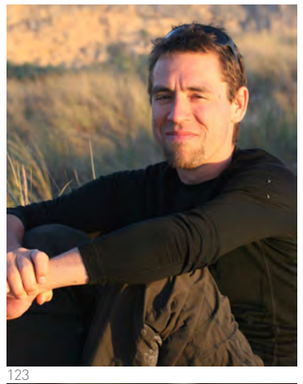
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121

Dr Thomas Russell, ICRAR-Curtin
PhD Graduate, March '12 - October '15
The connection between inflow and outflow around accreting stellar mass black holes.

122

Tina Salisbury, ICRAR-Curtin
Operations Coordinator, January '10
Finance and Administration.

123

Dr Sascha Schediwy, ICRAR-UWA
Research Fellow, February '14
Phase synchronisation of the SKA telescope; Laser timing links for space science applications; Phased array technologies.

124

Dr Franz Schlagenhaufer, ICRAR-Curtin
Research Engineer, March '10
Electromagnetic Compatibility; Electromagnetic measurements; Electromagnetic simulations.

125

Dr Paul Scott-Taylor, ICRAR-UWA
PhD Candidate, May '13 - November '16
Advanced computing of simulated galaxies in the SKA era.

126

Dr Nick Seymour, ICRAR-Curtin
Senior Lecturer, July '14
Active Galactic Nuclei; Galaxy Evolution; Multi-wavelength Surveys.

127

Dr Ryan Shannon, ICRAR-Curtin
Research Fellow, June '15
Observations of pulsars; Searches for fast radio bursts; Searches for gravitational waves.

128

Dr Renu Sharma, ICRAR-UWA
Associate Director, Chief Operating Officer, September '09
ICRAR management, planning, execution, compliance, and reporting; Creating and supporting an enabling and inclusive culture at ICRAR; Supporting ICRAR governance and helping plan for the long term sustainable future of ICRAR.

129

Austin Shen, ICRAR-UWA
Student - Masters, March '16
Earth's tidal energy resource: from geophysics to astrophysics.

130

Greg Sleap, ICRAR-Curtin
MWA Data Manager, June '16
MWA Data Archive; Software Engineering.

131

Dr Charlotte Sobey, ICRAR-Curtin
Research Associate, February '16
Observing pulsars using Square Kilometre Array precursors and pathfinders to investigate astrophysical magnetic fields.

132

Dr Marcin Sokolowski, ICRAR-Curtin
Postdoctoral Fellow (CAASTRO), January '12
Radio-astronomy instrumentation (Engineering Development Array); MWA beam modelling; Global Epoch of Reionisation experiment (BIGHORNS); Data quality control and calibration; Monitoring of RFI environment at the MRO; Software for control and real time data analysis of widefield optical robotic telescopes.


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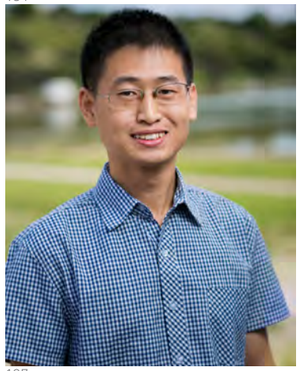
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133

Dr Roberto Soria, ICRAR-Curtin
Senior Research Fellow, March '11
Accretion onto compact objects; X-ray properties of galaxies; Outflows and jets.

134

A/Prof Chris Springob, ICRAR-UWA
Research Assistant Professor, September '12 - December '15
The peculiar velocities of galaxies as measured by redshift-independent distance indicators.

135

Professor Lister Staveley-Smith, ICRAR-UWA
Director, Science (UWA), September '09
Radio Astronomy.

136

Kim Steele, ICRAR-Curtin
Engineering Graduate Intern, March '16
Engineering Development Array data analysis; Murchison Widefield Array maintenance; Media archive admin and maintenance.

137

Hongquan Su, ICRAR-Curtin
PhD Candidate, September '14
Mapping the Galaxy in 3D using observations of HII region absorption with the MWA.

138

Dr Adrian Sutinjo, ICRAR-Curtin
Senior Lecturer, January '12
Electromagnetics; Antenna & radio engineering; Radio astronomy instrumentation.

139

Dr Dan Taranu, ICRAR-UWA
Research Associate (CAASTRO), December '14
Galaxy evolution; Numerical simulations; Dynamical modelling.

140

Jonathan Tickner, ICRAR-Curtin
Senior Technical Officer, March '10
Electronic engineering; Mechanical fabrication; Logistics; Lab mangement.

141

Professor Steven Tingay, ICRAR-Curtin
John Curtin Distinguished Professor, September '09
Development of science, engineering, and computing for the SKA and its precursors, in particular the Murchison Widefield Array.

142

Rodrigo Tobar Carrizo, ICRAR-UWA
Software Engineer, May '15
Software design, development and optimization; Distributed and control systems; Databases and storage.

143

Chenoa Tremblay, ICRAR-Curtin
PhD Candidate, April '15
The First Spectral Line Survey of Orion and the Galactic Centre at 100-300 MHz.

144

Dr Steven Tremblay, ICRAR-Curtin
Postdoctoral Fellow (CAASTRO), September '11
Fast Radio Transients; Pulsars; Young Radio Galaxies.


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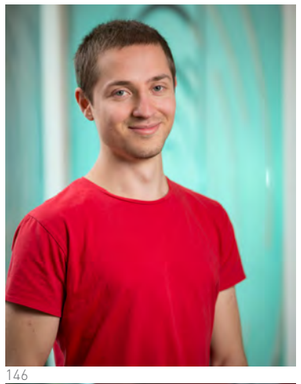
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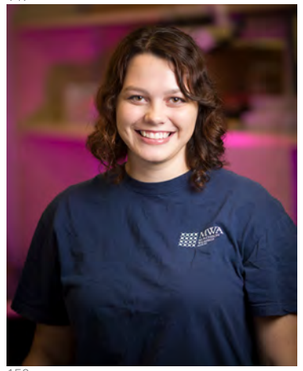
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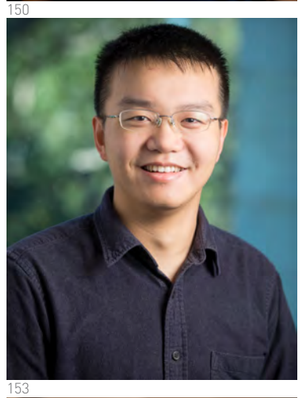
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145

Dr Cathryn Trott, ICRAR-Curtin
Senior Research Fellow and ARC DECRA Fellow, February '11
Signal processing theory; Epoch of Reionisation.

146

Vlad Tudor, ICRAR-Curtin
PhD Candidate, January '15
Quiescent stellar-mass black holes in globular clusters.

147

Daniel Ung, ICRAR-Curtin
Support Engineer, Aperture Array, January '15
Electromagnetic simulation of aperture arrays.

148

Ryan Urquhart, ICRAR-Curtin
PhD Candidate, February '15
Exploring regimes of super-Eddington accretion in black hole binaries.

149

Kevin Vinsen, ICRAR-UWA
Research Associate Professor, July '10
Data Intensity Astronomy; Galaxy Morphology; Machine Learning.

150

Mia Walker, ICRAR-Curtin
Instrument Support Engineer, February '16
Research and development of radio astronomy equipment; Commissioning and repair of equipment on-site; Outreach and education.

151

Dr Andrew Walsh, ICRAR-Curtin
Senior Research Fellow, January '13 - January '17
Masers; Star formation; Galactic surveys.

152

Dr Jason Wang, ICRAR-UWA
PhD Graduate, January '11 - July '16
A Data Optimized I/O Middleware for Accessing Heterogeneous Storage Hierarchies in High Performance Computing and Cloud Environments.

153

Dr Liang Wang, ICRAR-UWA
Research Associate, September '16
Galaxy formation simulation.

154

Adam Watts, ICRAR-UWA
Student - Masters, March '16
Main sequence luminosity functions constraints on the IMF from HST observations of nearby galaxies.

155

A/Prof Randall Wayth, ICRAR-Curtin
MWA Director, Research Associate Professor, September '09
Low frequency radio astronomy; Radio astronomy engineering; Epoch of Reionisation science.

156

Dr Charlotte Welker, ICRAR-UWA
Jim Buckee Fellow in Astrophysics, November '15
Galaxy evolution, large scale structures, and hydrodynamic simulations.


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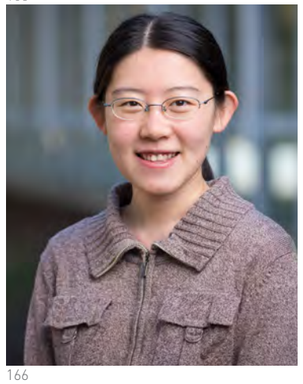
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157

Dr Tobias Westmeier, ICRAR-UWA
Research Fellow, October '10
High-velocity clouds around the Milky Way and nearby galaxies; The Magellanic Stream; Evolution and interaction of galaxies in different environments; Detection and parametisation of galaxies in HI; Large HI surveys with SKA precursors.

158

Pete Wheeler, ICRAR-UWA
Outreach, Education and Communications Manager, September '09
Outreach, Education & Communications.

159

Dr Sarah White, ICRAR-Curtin
Research Associate, October '15
Using multi-wavelength surveys to study galaxy evolution; Investigating the radio emission from active galactic nuclei.

160

Professor Andreas Wicenec, ICRAR-UWA
Head, Data Intensive Astronomy, August '10
Data Intensive Astronomy; Stellar Astrophysics and Astrometry.

161

Andrew Williams, ICRAR-Curtin
MWA Monitor and Control Engineer, June '13
MWA operations; Instrumentation control.

162

Alex Williamson, ICRAR-UWA
Masters Graduate, March '15 - July '16
A Search for Large HI Gas Streams in the Local Volume.


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163

Dr O. Ivy Wong, ICRAR-UWA
Research Fellow, March '14
Physical processes of star formation & galaxy evolution. Growth of supermassive black holes. Multiwavelength observations (X-rays, UV, optical, IR, radio); All-sky radio surveys (HI and continuum); Citizen science (Radio Galaxy Zoo).

164

Dr Angus Wright, ICRAR-UWA
PhD Graduate, March '13 - September '16
Using Multi-band Photometry and HI Surveys to Estimate the Galactic Baryonic Mass Function.

165

Dr Chen Wu, ICRAR-UWA
Senior Research Fellow, March '11
Data intensive astronomy; Dataflow optimisation; High performance computing and machine intelligence.

166

Mengyao Xue, ICRAR-Curtin
PhD Candidate, November '15
Southern Pulsar Census and Polarimetric Studies with the MWA.

167

QingZeng Yan, ICRAR-Curtin
PhD Candidate, November '15
Molecular Clouds in the Milky Way.

168

Matthew Young, ICRAR-UWA
Astronomy & Astrophysics Course Coordinator, September '09
Coordination of the Astronomy and Astrophysics Coursework; Teaching; Outreach.

169

Cameron Yozin-Smith, ICRAR-UWA
PhD Graduate, March '12 - February '16
The environmental processing of late-type dwarf galaxies.

170

Xiang Zhang, ICRAR-Curtin
PhD Candidate, November '15
Detecting radio emission from meteors with the MWA.

'Sugerloaf Rock little world' – Sugarloaf Rock illuminated by the first quarter Moon. Photographer: Grahame Kelaher.

7

END MATTER

On the horizon

Although ICRAR II will run until July 2019, the Centre has already begun planning for ICRAR III.

This exciting time sees the organisation in preparation mode, creating new research program outlines and business cases to support the renewal and long-term vision of the Centre. It is a time of a lot of work, and a time when ICRAR is asking its partners to make a commitment to its future.

In 2016, ICRAR was fortunate to receive letters from the Vice Chancellors of both Curtin University and The University of Western Australia agreeing that ICRAR is a long-term entity important to the two universities. They see ICRAR as a continuing source of research outcomes, papers and grants, and an integral part of where both universities want to go as international research and teaching institutions. The Premier and WA Minister for Science also made a commitment that ICRAR was the long-term vehicle for the State to draw benefit from the SKA project, and encouraged ICRAR to begin developing the case for more resources for the future.

A panorama of the night sky over Guilderton Lighthouse featuring the central galactic plane and the Large & Small Magellanic Clouds. Courtesy of astrophotographer, Trevor Dobson.

Where ICRAR I relied primarily on Curtin and UWA for strategy and direction, ICRAR II developed into a three-way partnership between the two universities and the WA State Government. ICRAR III may expand the partnership even further, and the organisation is looking for new partners to come in and support ICRAR into the future. The reasons why ICRAR exists are long-term given the 50-year plus lifetime of the SKA. To receive continuing returns during the life of the SKA project and observatory, ICRAR's partners recognise there is a need to make long-term commitments. As such, ICRAR III has a very long-term vision, and the Centre will be asking its partners for a ten-year funding window rather than five.

The partnership could also extend to include the Australian Federal Government, which has offered ICRAR a lot of support in the past through individual grants. ICRAR can help the Australian Government achieve significant returns on its SKA investment in much the same way as it currently helps the WA State Government achieve returns for WA. In particular, ICRAR is well placed to ensure the desired Federal returns in areas outside of international research, such as STEM and big data innovations.

At its heart, ICRAR will also be a strong science and technology organisation focused on research and development, and the core business of ICRAR III will be the same as ICRAR I and II. However there may be other things ICRAR III will do that are quite different. It could, for instance, deliver services paid for by the SKA project or the government. In addition to doing its own research and development work, ICRAR could do contract work for others, with these services supporting ICRAR's long-term future and a sustainable bottom line. The skills ICRAR has developed as an organisation means it could also leverage opportunities to do things outside of the SKA, radio astronomy or even astronomy.

ICRAR will be here long-term to make sure the WA and Australian governments receive long-term benefit from the SKA. Beyond five or ten-year funding cycles, ICRAR remains the best platform for that return.

ICRAR III will also be needed by the SKA. The project has indicated that it will need things from the community in order to maximise scientific return, in much the same way as the Large Hadron Collider has drawn on its community for many years. That facility was able to discover the Higgs Boson only because it had both a machine that could run the experiment and a community of scientists with the computers and know-how to analyse the data and produce a result. The SKA is likely to be the same. It will have telescopes in WA and South Africa and will need its community of scientists with computers, know-how and technologies working together to discover more about our Universe.

ICRAR YEARBOOK
2015–2016

International Centre for
Radio Astronomy Research
www.icrar.org
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Design by HartBlack

International Centre for Radio Astronomy Research

Curtin University

THE UNIVERSITY OF WESTERN AUSTRALIA

GOVERNMENT OF WESTERN AUSTRALIA