2013–2014

ICRAR | 2013–2014

ICRAR
International Centre for Radio Astronomy Research

Volume 3
2013–2014

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ICRAR
YEARBOOK
2013-2014

International Centre for Radio Astronomy Research
www.icrar.org
info@icrar.org

ICRAR is a joint venture between Curtin University and The University of Western Australia with strong support from the Western Australian and Australian governments.

Printed and bound in Australia

Written and edited by Michelle Wheeler, Pete Wheeler & Kirsten Gottschalk.
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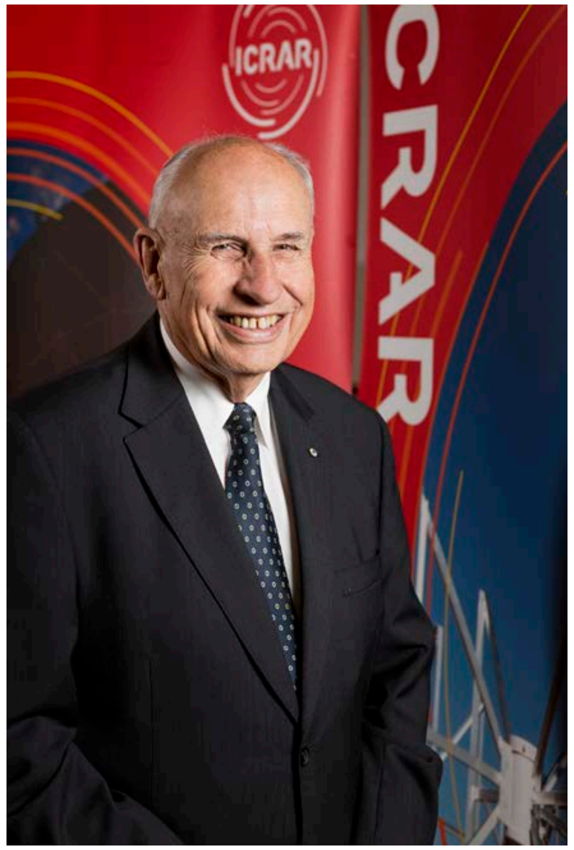

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1. Dr Bernard Bowen, Chair of the International Centre for Radio Astronomy Research

Foreword

The International Centre for Radio Astronomy Research, or ICRAR as it is widely known nationally and internationally, is a successful partnership between Curtin University, The University of Western Australia and the Western Australian Government.

This, the third instalment of our biennial 'Year Book', aims to provide the reader with an engaging overview of ICRAR's recent activities in the fields of science, engineering, data intensive astronomy and outreach.

In just five years ICRAR has become a prestigious centre of research excellence, recognised by an independent committee as one of the top five university-based radio astronomy research centres in the world. This success has led to further support from the State Government and our two university partners, with funding that will carry ICRAR through to the end of the decade.

ICRAR has developed signature research themes in science, engineering and data intensive astronomy. These key areas have attracted professionals to the Centre from around the world, both as staff members and as transient visiting researchers.

Internationally, the interface between ICRAR and the Square Kilometre Array project office is strong and will continue to grow as we head towards building the low frequency parts of the telescope in the Western Australian outback in the coming years.

Connecting with the broader community, communicating scientific research and promoting interest and participation in science, astronomy and engineering is an important part of ICRAR's work. In the past five years ICRAR's science communicators, researchers and postgraduate students have delivered outreach and education activities in Western Australia, interstate and overseas, interacting with more than 80,000 members of the public, school students and teachers.

I take this opportunity through the publication of the Year Book to thank all members of the ICRAR Board, its Executive Director, Professor Peter Quinn, his executive team and all those who contribute so much to ICRAR through their professional advice, attention to detail and the on-going development of ICRAR as an important Centre for the State and the two universities.

Bernard Bowen AM FTSE
Chair of the ICRAR Board

1991 THE IDEA FOR THE SKA IS CONCEIVED.
2006 SOUTH AFRICA AND AUSTRALIA ARE SHORTLISTED TO HOST THE SKA. BOTH COUNTRIES BEGIN BUILDING INFRASTRUCTURE.
2012 THE DECISION IS MADE TO BUILD PARTS OF THE SKA IN BOTH SOUTH AFRICA AND AUSTRALIA.
2013-18 PRE-CONSTRUCTION AND DESIGN PHASE.
2015 JODRELL BANK OBSERVATORY IN THE UK IS CHOSEN AS SKA'S GLOBAL HEADQUARTERS.
2018 CONSTRUCTION OF PHASE ONE STARTS IN WA (100,000 'DIPOLE' ANTENNAS) AND SOUTH AFRICA (200 'DISH' ANTENNAS). PLANNING FOR PHASE TWO BEGINS.
2021 EARLY SCIENCE AND OBSERVATIONS ARE PRODUCED BY THE FIRST PARTS OF THE TELESCOPE.
2023 PHASE ONE IS COMPLETE. CONSTRUCTION FOR PHASE TWO BEGINS.
2030 SKA IS COMPLETE AND FULLY OPERATIONAL.

SKA Project Update

The Square Kilometre Array (SKA) will be the biggest and most capable radio telescope ever built. It will expand our understanding of the Universe and drive technological development worldwide.

Future generations will recognise this project as an engineering and scientific marvel of the 21st century, but two decades ago, at the end of the 20th century, the telescope was little more than the ambitious aspiration of a visionary group of radio astronomers.

Now, after many years of sustained effort from scientists, engineers, politicians and industry colleagues, we're on the cusp of an international effort to build the world's biggest radio telescope.

Already, SKA precursor radio telescopes are on the ground and producing science from both the Australian and African sites. The Murchison Widefield Array (MWA) and the Australian SKA Pathfinder (ASKAP) are located in outback Western Australia, and MeerKAT, in South Africa's Karoo Desert.

After an extremely rigorous process lasting almost two years, the first phase of the project has been defined and agreed upon by the international project members. For Phase 1 of the SKA, approximately 10 per cent of the final array, 200 fifteen metre diameter parabolic 'dish' antennas will be built in South Africa and more than 100,000 low frequency 'dipole' antennas in Australia.

Through these two complementary technologies of dishes and dipoles, the SKA will allow astronomers to address a broad range of exciting science, such as observing pulsars and black holes to detect the gravitational waves predicted by Einstein, testing gravity, and looking for signatures of life elsewhere in the galaxy.

From here on, the project will move at a rapid pace. In 2016 and 2017, prototypes for the different antenna types will be deployed and tested at both sites, with the results used to inform the final design and specifications for the actual SKA antennas.

From 2018 to 2025 the first wave of SKA antennas will begin to sweep out across remote landscapes on both sides of the Indian Ocean. Then, as Phase 1 is commissioned and comes on line, planning will already be underway to roll out the remaining 90 per cent of the telescope, with full operations achieved by 2030.

2. The UWA node of ICRAR

THE BEGINNING

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Looking back and looking forward

ICRAR's first five years from 2009 to 2014 have been a time of tremendous growth and excitement.

The commitment and talent of ICRAR's astronomers, engineers and data scientists has seen the Centre rise rapidly to become one of the top five university-based radio astronomy research centres in the world.

The Centre has developed into a world-class organisation with more than 140 staff and students from around the world, from leading researchers to PhD candidates and undergraduate students.

ICRAR was instrumental in bringing part of the Square Kilometre Array, arguably the world's largest science project, to Western Australia.

The site decision in May 2012 was followed by news in 2013 that ICRAR was part of three successful consortia bidding for the SKA design work, further cementing the Centre's role as a strong member of the SKA project.

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ICRAR was launched in 2009 with $20 million in funding from the WA State Government, $4 million for every year of operations.

Five years on and a report by Deloitte Access Economics found that ICRAR was worth approximately $17.5 million to the WA economy in 2013-14 alone, a more than four-fold return on investment in that year.

Between 2009 and 2014, ICRAR's researchers had almost 600 peer-reviewed publications—more than two a week.

More than 80% of these publications were in high-profile journals as measured by the Journal Impact Factor.

The Centre secured 91 grants worth $42.8 million, and had 12 papers published in the highly prestigious journals Nature and Science.

The incredible output is showing no signs of stopping. ICRAR's astrophysicists are discovering more about the Universe every day, studying black holes, galaxies and dark matter, and looking back in time for signals from the beginning of the Universe.

The $50 million Murchison Widefield Array (MWA) was commissioned in 2013 and the science results from this telescope are now flowing thick and fast.

ICRAR's research engineers are working on early designs for the Square Kilometre Array and have already built and deployed a prototype at the Murchison Radio-astronomy Observatory in Western Australia's remote Mid West.

Our Data Intensive Astronomy team are doing ground-breaking research into managing huge volumes of information and changing the way we will think about big data.

Along the way, ICRAR has been collaborating with some of the world's most prestigious institutions, including Oxford University, Cambridge University, the University of California, Massachusetts Institute of Technology, the Chinese Academy of Sciences and NASA.

The Centre has also attracted innovative industry partners such as Intel, Cisco and Amazon.

All this has been achieved alongside a significant contribution to the Western Australian community through outreach and education.

In its first five years, ICRAR hosted or supported more than 350 community events promoting science, astronomy and the Square Kilometre Array.

More than 80,000 people have attended these public programs, with almost a third of the audience in schools.

In August 2013, ICRAR was awarded $26 million in State Government funding and $26 million from Curtin University and The University of Western Australia for the next five years.

Having achieved its two main goals for its first five years—to see the SKA come to Western Australia and to be given a key role in the design of the telescope—ICRAR is now looking to the future.

For the next five years, the Centre will focus on doing great science with the SKA precursors (the MWA and the Australian SKA Pathfinder) and assisting with the deployment of the first part of the telescope in the Murchison region.

ICRAR will also work towards a long-term future that will see it become the Australian regional SKA science and engineering centre for the telescope's more than 50-year lifetime.

3. PhD Candidate, Tom Russell.

4. Associate Director, Dr Renu Sharma.

5. Professor Peter Quinn & SKA Director General Phil Diamond with Indigenous Elders, Walter Eatts, Doolan-Leisha Eatts & their grandson Samuel Eatts at the SKA Engineering Conference's 'sundowner' event in Fremantle.

6. WA Premier Colin Barnett during a visit to ICRAR.

7. Professor Lister Staveley-Smith.

8. UWA Vice-Chancellor, Professor Paul Johnson.

9. A visit by the Japanese Consul General Mr Koichi Funayama (right), Consul Hideo Shinozuka (middle) and ICRAR's Professor Andreas Wicenec (left).

10. ICRAR Board Chair Dr Bernard Bowen (middle) with ICRAR Directors Professor Steven Tingay (left) and Professor Peter Hall (right).

Visiting Committee highlights ICRAR's strengths

In 2014, ICRAR was reviewed by a Visiting Committee made up of astronomy leaders from around the world.

The committee, chaired by Nobel Prize winner Professor Brain Schmidt, met in Perth from May 13-16 and toured both nodes of ICRAR, located at Curtin University and The University of Western Australia.

The committee interviewed members of the ICRAR executive, staff and students, as well as key stakeholders from Curtin, UWA, CSIRO and the Square Kilometre Array (SKA) Organisation.

The Visiting Committee found that ICRAR's strengths included scientific leadership, scientific research, engineering leadership and expertise, and computational expertise.

'ICRAR has quickly emerged as a new major organisation with broad recognition and respect on the world stage,' the committee's report said.

'This recognition and respect comes from its broad world-class science program that includes aspects of observational astronomy, simulation and instrumentation.'

'ICRAR has also emerged as a major contributor to SKA development, taking on programs not dissimilar in scale to CSIRO, and well beyond any other Australian organisation, thereby firmly establishing the organisation as part of the world-wide SKA community.'

> *"ICRAR has created a world-class astronomy presence in Western Australia in less than a decade, a feat whose impressiveness is hard to overstate."*
> *Visiting Committee, May 2014*

The committee also said ICRAR had quickly established itself as a place attractive to top young researchers to undertake their astronomical research.

'ICRAR, with its critical mass of expertise, varied programs, and generous funding for travel, training and collaboration, is doing an excellent job of developing the human capital of the organisation,' the report said.

Visiting committee members

Professor Paul Alexander
Head of Astrophysics, Cambridge, and UK Board Member of SKA
Dr Tony Beasley
Director, USA's National Radio Astronomy Observatory
Professor Elaine Sadler
University of Sydney
Professor Brian Schmidt
Australian National University (Chair)
Dr Marco de Vos
Managing Director, Netherlands Institute for Radio Astronomy – ASTRON

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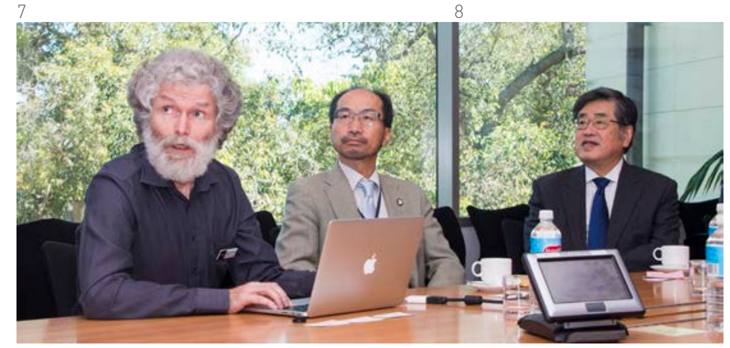

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Governance and Management

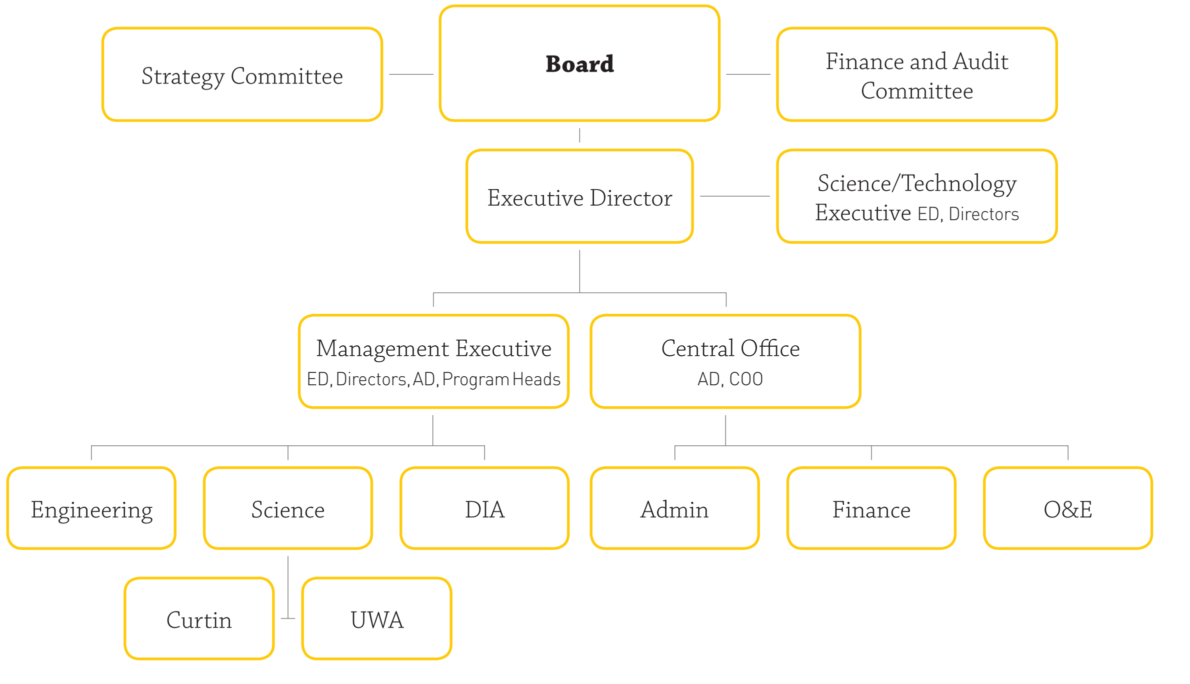
Governing Board as at 31 Dec 2014	
Dr Bernard Bowen	Chair. Appointed February 2009.
Professor Tom Spurling	Nominated member (CSIRO). Appointed February 2009.
Mr Graham McHarrie	Independent member. Appointed February 2009.
Professor Ron Ekers	Independent member. Appointed November 2012.
Professor Graeme Wright	Nominated member (Curtin University). Appointed May 2012.
Professor Robyn Owens	Nominated member (The University of Western Australia). Appointed November 2012.
Dr Tom Hatton	Independent member. Appointed June 2014.
Ms Jennifer McGrath	Nominated member (Office of Science, Department of Premier and Cabinet). Appointed December 2014.

Past Board Members 2013-2014	
Ms Michelle Reynolds	Nominated member (Office of Science, Department of Premier and Cabinet). February 2014 – November 2014.
Professor Lyn Beazley	Independent member. February 2009 – June 2014.
Mr Philip Jenkins	Nominated member (Department of Commerce). February 2009 – June 2014.
Mrs Kerry Sanderson	Independent member. June 2013 – October 2014.
Dr Vanessa Guthrie	Independent member. February 2011 – March 2013.

Finance and Audit Committee as at 31 Dec 2014	
Mr Graham McHarrie	Chair from June 2010
Mr Mark Woffenden	Member from June 2010
Dr Tom Hatton	Member from August 2014
Mr Joe Valenti	Nominated member (Curtin University)
Mr Ashwin Raj	Nominated member (Government of Western Australia)

Executive Team (Science and Technology Executive and Management Executive) as at 31 Dec 2014	
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 for Science at UWA
Professor Steven Tingay	Director for Science at Curtin University
Professor Andreas Wicenec	Head of Data Intensive Astronomy

ICRAR Organisational Structure



Finances

For operations between 2009 and 2014, ICRAR received $14 million of cash investment and more than $60 million in in-kind contributions from the joint venture partners – Curtin University and The University of Western Australia. From the State Government, ICRAR received significant support via a funding grant of $20 million. ICRAR used this 'core funding' to leverage and win 91 competitive grants and fellowships totalling $42.8 million over five years. This includes Federal Government grants for two SKA pre-construction programs, resulting in WA's participation in the design and prototyping of the Square Kilometre Array.

From ICRAR I to ICRAR II

In 2013 the State Government announced a further $26 million for ICRAR, for the period 2014 to 2019, leading to an equal funding commitment from the joint venture universities.

The following year, 2014, was a transitional year for the Centre, with ICRAR closing out the first five years of operations and beginning its next phase. Long term planning for ICRAR's future also began, with objectives aligned with the progress of the SKA project, both globally and in Western Australia.

A snapshot of ICRAR's planned budget for the next five years is shown below.

Performance, equity and inclusivity

ICRAR has emerged as a highly successful collaborative and productive organisation, recognised internationally for excellence in science, engineering and technological research. In 2014 our 'family' grew to 140 staff and PhD students, with more than 650 national and international visitors from academia, government and industry visiting the Centre over the past five years.

In our first five years our researchers published almost 600 refereed articles in academic journals, receiving more than 9,000 citations and helping to secure more than $42.8 million in competitive funding.

During this time ICRAR organised nearly 300 seminars and has been involved in more than 60 collaborative projects with top ranking institutions such as Oxford University, Cambridge University, University of California, Massachusetts Institute of Technology, the Chinese Academy of Sciences and NASA.

> * *In 2014 an independent review of ICRAR was conducted by Deloitte Access Economics to identify the outcomes generated by ICRAR for Western Australia and to define specific outcomes for the Centre for 2014 to 2019. This review described ICRAR as "among the top five university-based radio astronomy research institutions in the world."*

This achievement is due to the high quality of staff and students recruited by the Centre nationally and internationally.

ICRAR has an effective industry engagement program with local, national and international industry partners such as Balance Utility, Systemics, ThoughtWorks, Data Direct Networks, Amazon, Intel, IBM, Cisco, Raytheon, Kaelus and many others.

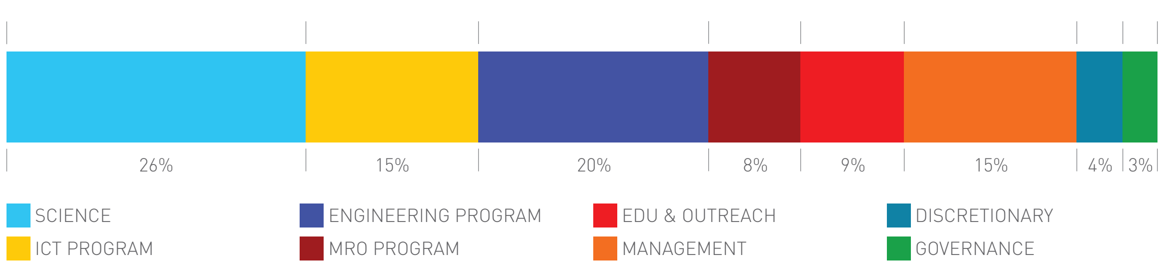
The Centre has also played an important strategic role in several global forums with senior staff contributing to many national and international boards, committees and working groups.

ICRAR proactively supports the principles of equity, diversity, inclusivity and a healthy work life balance. The Centre annually sponsors the Astronomical Society of Australia (ASA) Women in Astronomy Workshop and hosted the ASA workshop "Pathways to Success" in 2013.

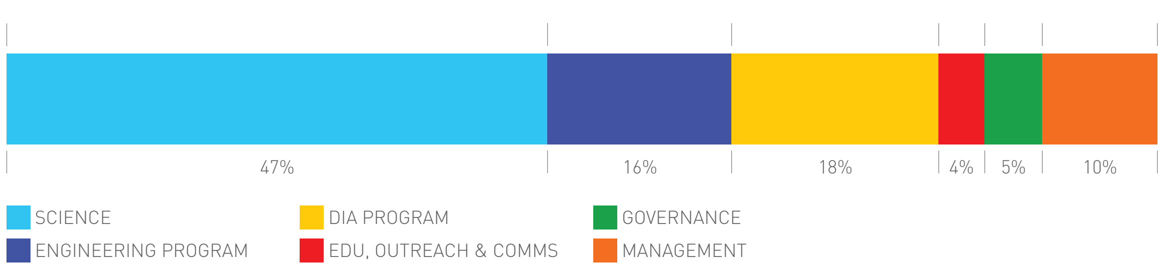
In 2014 ICRAR launched a Visiting Fellowship for Senior Women in Astronomy with both nodes awarded the ASA Pleiades Bronze Award in recognition of these efforts.

Everyone at ICRAR works hard to make the Centre an exciting, interesting and welcoming place to work and visit. After five years of success, we're looking forward to what the next five will bring.

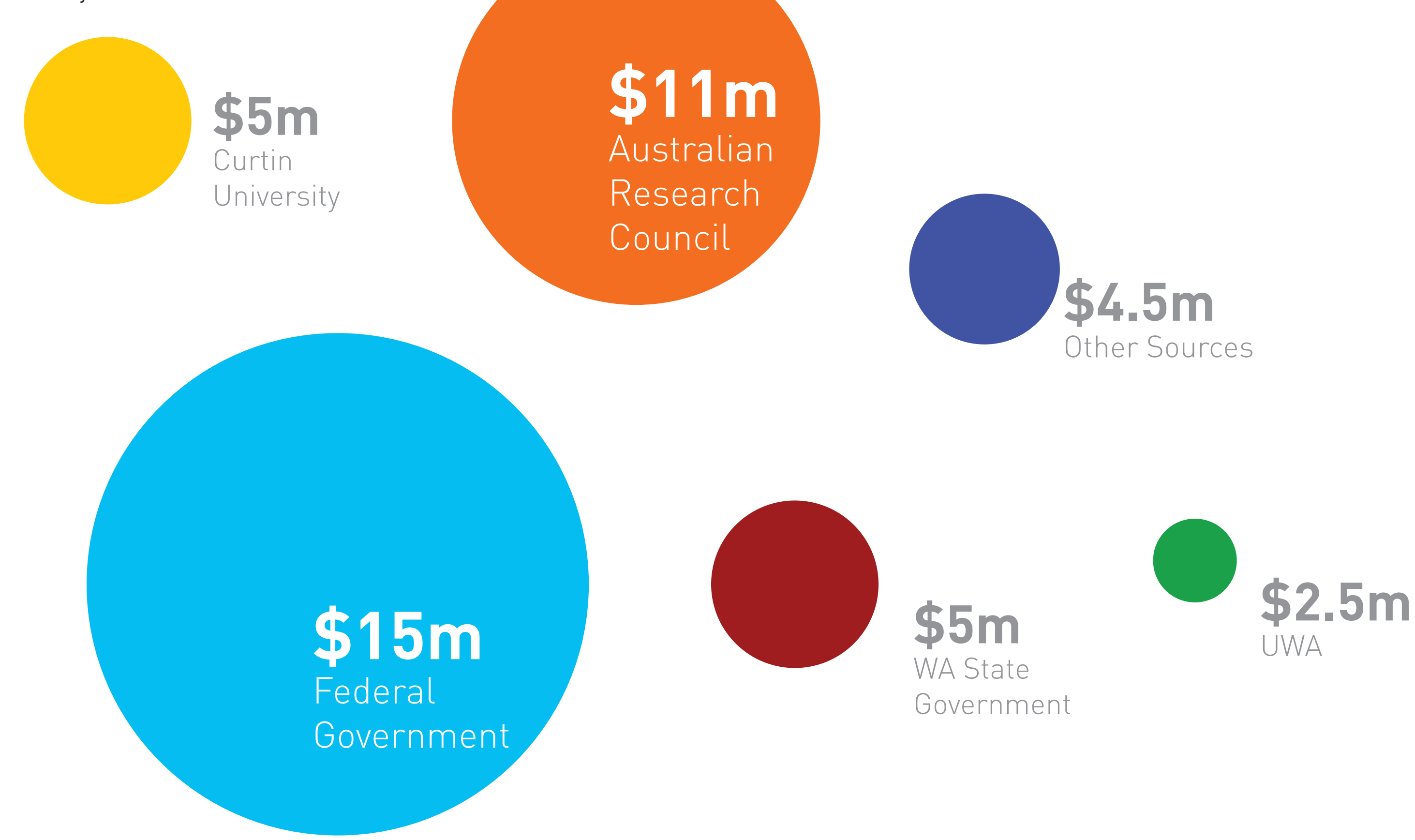
ICRAR Programmatic Expenditure 2009–2014



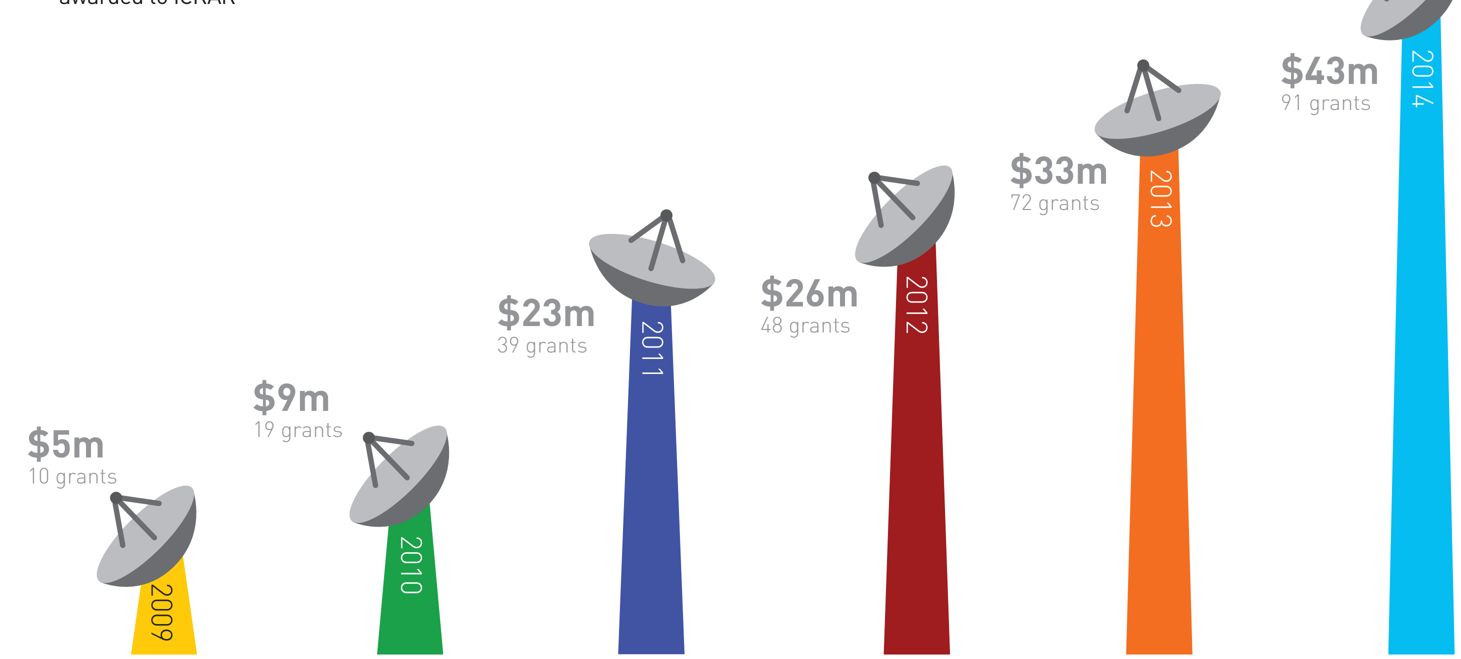
ICRAR Projected Programmatic Expenditure 2014–2019



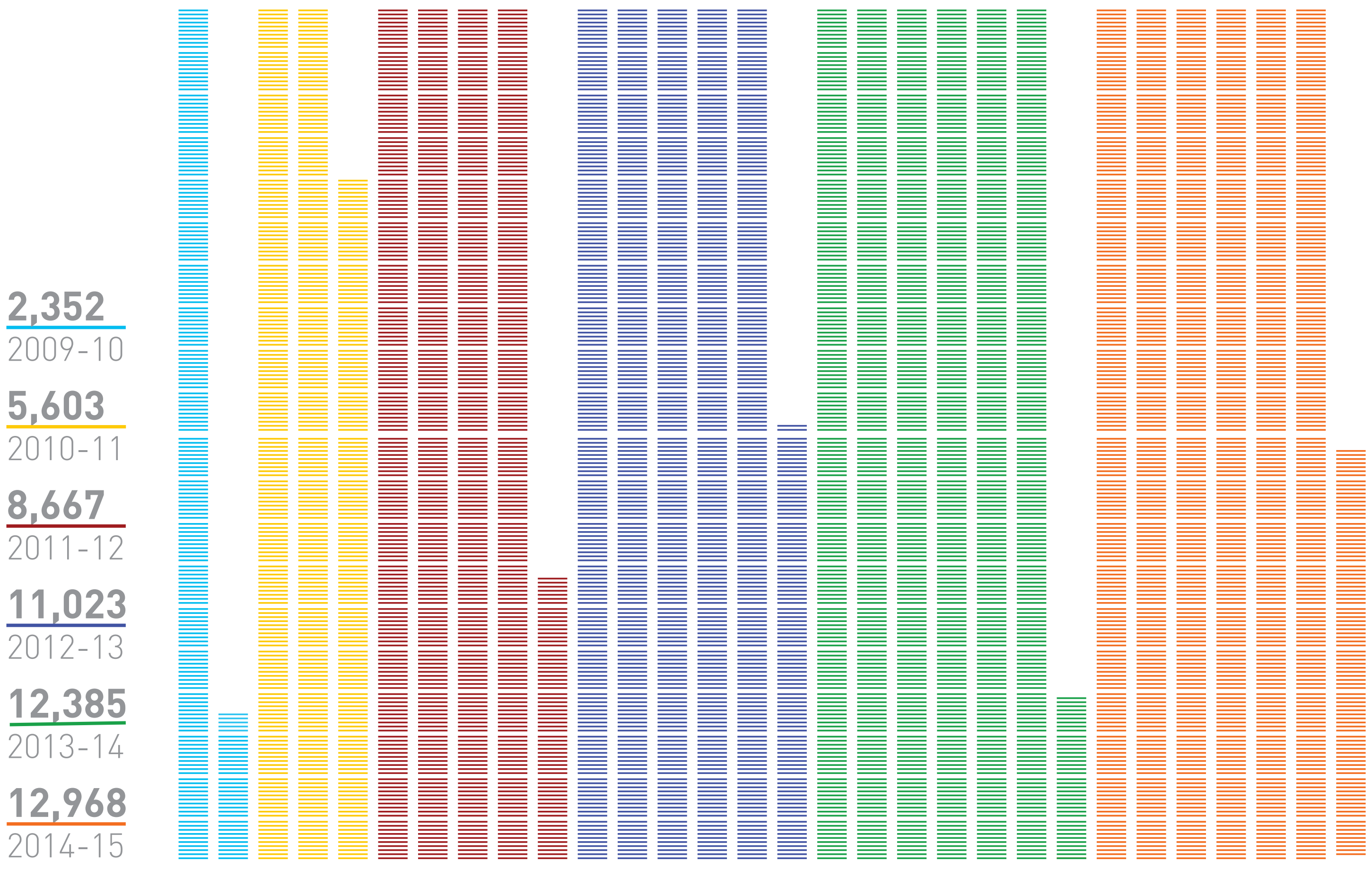
Additional research grants won by ICRAR



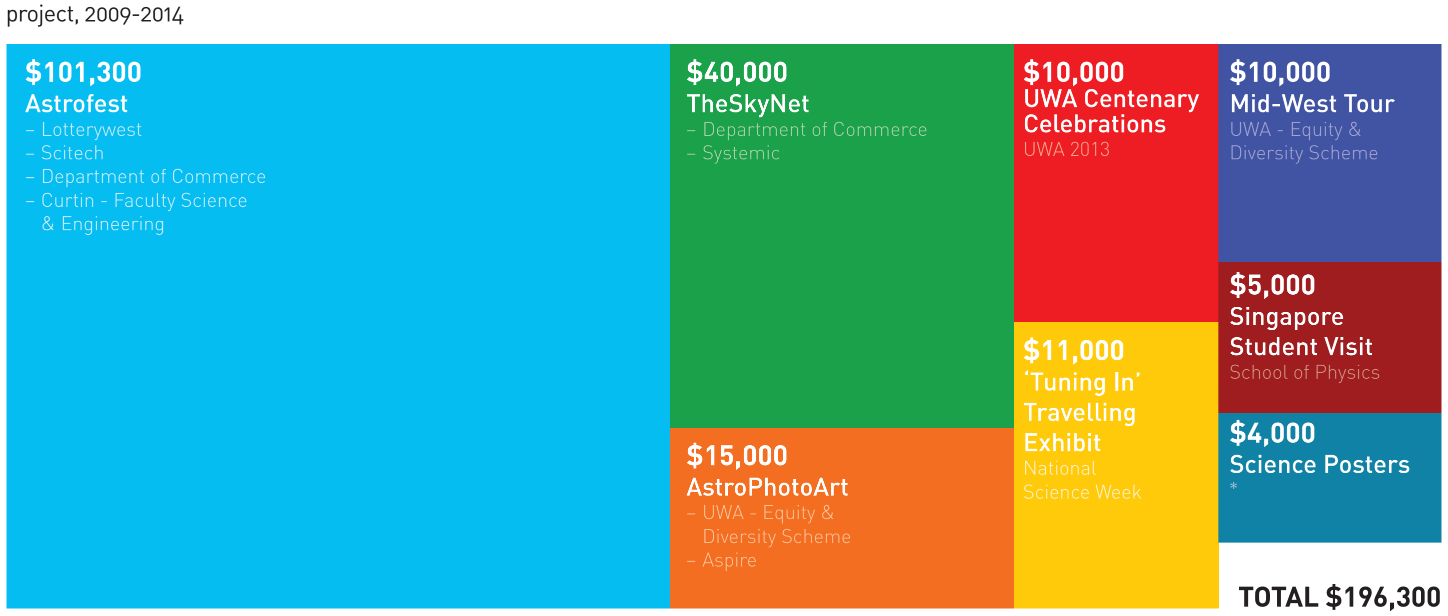
Value of Research Grants and the cumulative number awarded to ICRAR



Cumulative number of citations to published, refereed journal papers as of 30 June 2015.

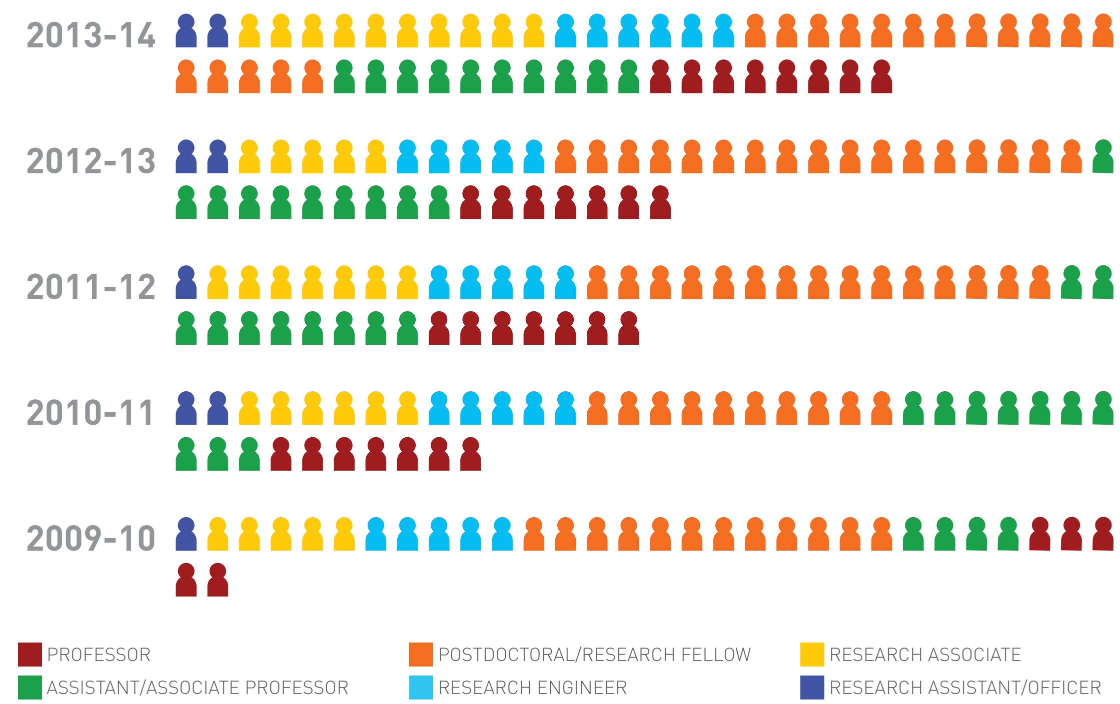


Non-research grants secured by ICRAR by project, 2009-2014

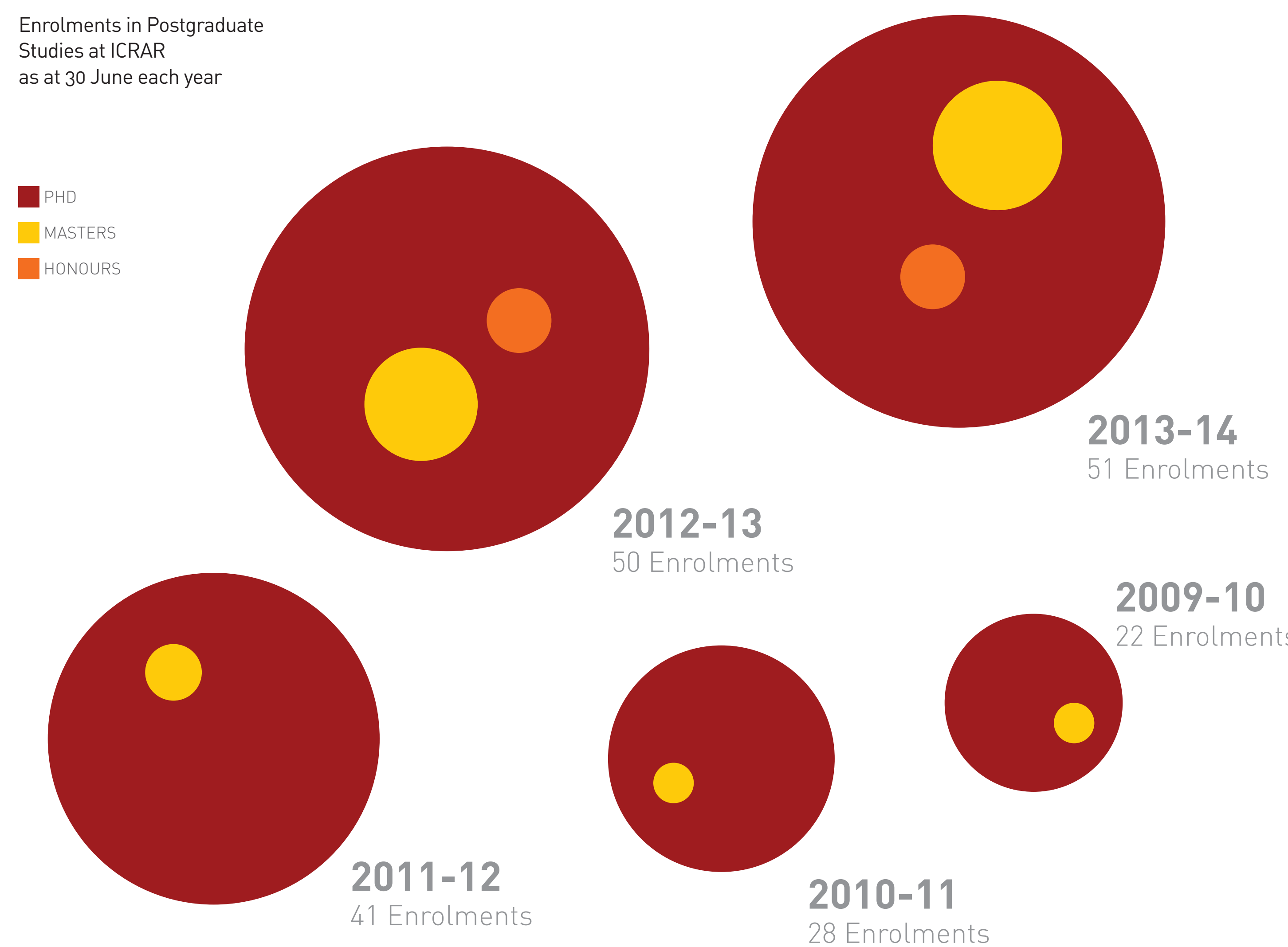


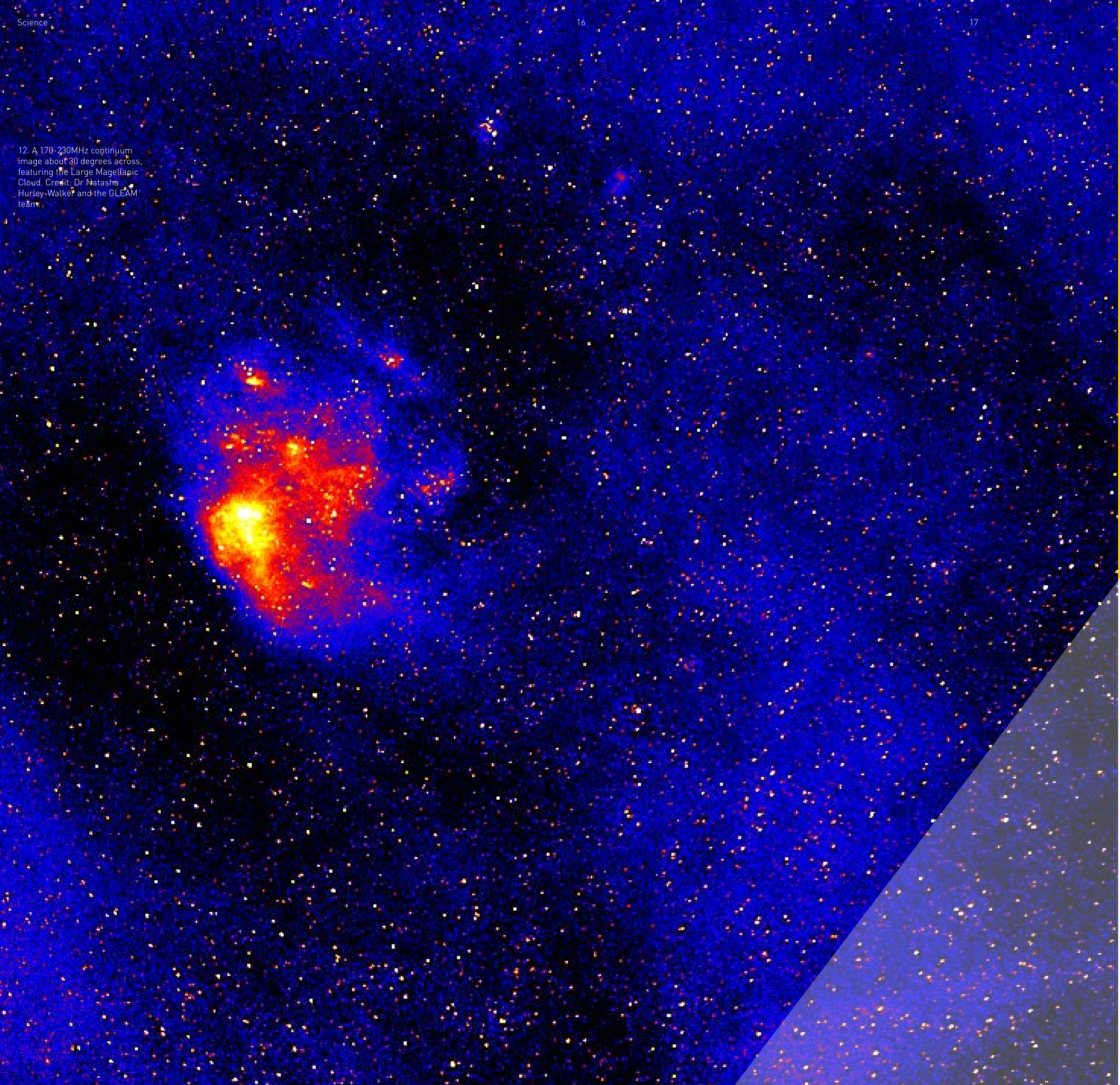
*National Science Week co. CoE Plant Energy Biology

Number of dedicated research staff employed by ICRAR



Enrolments in Postgraduate Studies at ICRAR as at 30 June each year





12. A 170-230MHz continuum image about 30 degrees across, featuring the Large Magellanic Cloud. Credit: Dr Natasha Hurley-Walker and the GLEAM team.

SCIENCE

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Science Overview

ICRAR's astronomers have gone from strength to strength in recent years as they look deeper into space and learn more about the incredible Universe around us.

The last two years have seen a dramatic growth in the Centre's ability to process and publish data from the GAMA survey, a study of about 300,000 galaxies on the Anglo-Australian Telescope in New South Wales.

It has been an exciting time because of ICRAR's involvement in the CHILES collaboration, a survey on the Karl G. Jansky Very Large Array telescope in the United States, led by Columbia University.

This survey is producing huge quantities of data and paving the way for similar but much deeper science with the Square Kilometre Array's precursors, the Australian SKA Pathfinder and MeerKAT.

The last few years have also seen the launch of the $80M Pawsey Supercomputing Centre and the Murchison Widefield Array (MWA) on ICRAR's doorstep.

In particular, observations for the GLEAM survey conducted with the MWA are complete and ICRAR scientists are now analysing the data and beginning to publish some exciting papers from this research.

The MWA has also accumulated about 1000 hours of data in the search for signals from the Epoch of Reionisation, a time in the early Universe about 13 billion years ago when the first stars and galaxies were born, and the Centre has already published excellent research on signal estimation from this work.

ICRAR's astronomers are discovering more about how galaxies evolve through simulations, and the theoretical physics team is working feverishly on predicting the gas content of galaxies at different redshifts and trying to understand feedback and galaxy formation processes.

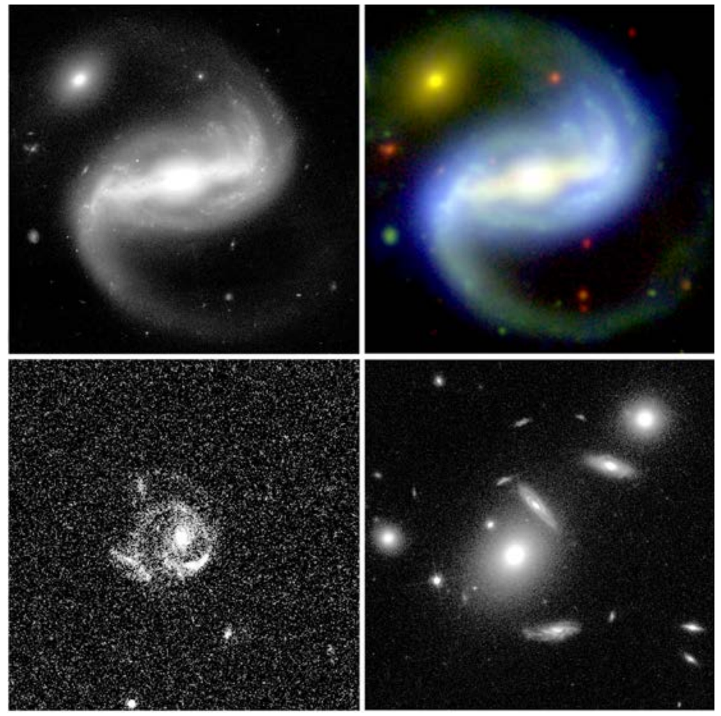
The Centre has done ground-breaking studies on the development of angular momentum in galaxies, helping us understand how they get their spin and what effect this has on their shape. Flat galaxies, for instance, have acquired a lot of angular momentum.

Finally, the last few years have allowed ICRAR to make several breakthroughs in understanding peculiar velocities in galaxies and better understand the large-scale distribution of dark matter in the nearby Universe, using observations from telescopes across the planet, including the Parkes Radio Telescope and UK Schmidt Telescope in Australia, Green Bank Telescope in the United States and the Arecibo Observatory in Puerto Rico.

In every sense, ICRAR is a truly global research centre, attracting top scientists from around the world and collaborating with top ranking institutions including Oxford University, Cambridge University, the University of California and NASA.

In the coming years the Centre is set to leverage its proximity to the Murchison Radio-astronomy Observatory—the radio-quiet site that is home to the Murchison Widefield Array, the Australian SKA Pathfinder and the future SKA-low—as well as the Pawsey Supercomputing Centre to understand more about our Universe.

With new telescopes on the way that are more powerful and more sensitive than ever, there is no limit to what we could discover.



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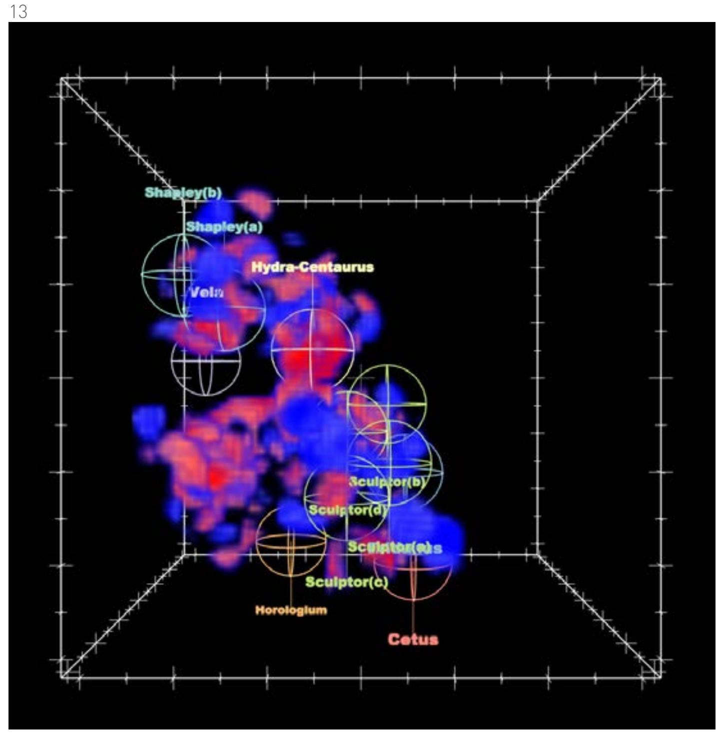

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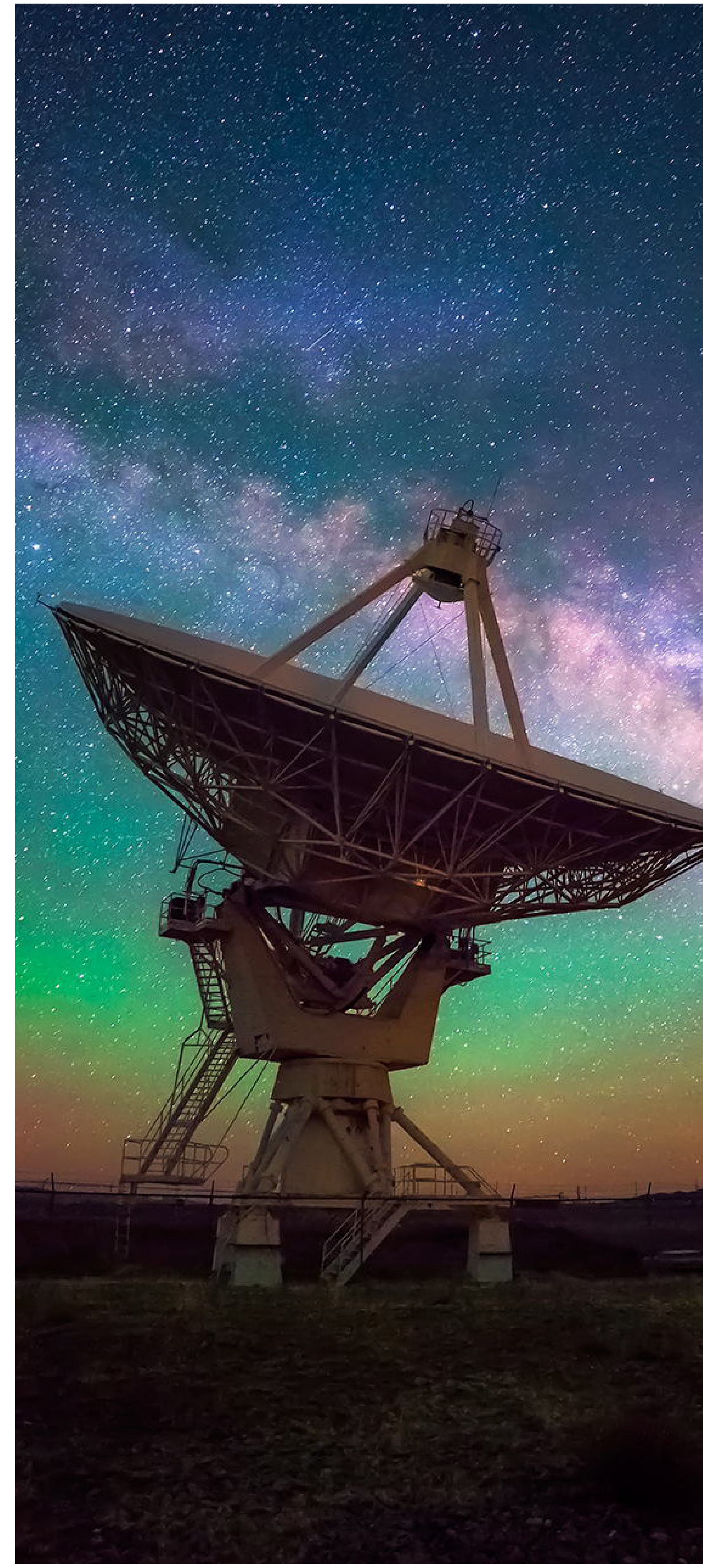
13. Examples of sources in the COSMOS region produced using the GAMA cut-out tool.

14. A 3-dimensional map of galaxy motions as observed by the 6dF Galaxy Survey.

15. An antenna of the Very Large Array in New Mexico. Credit: Knate Myers.



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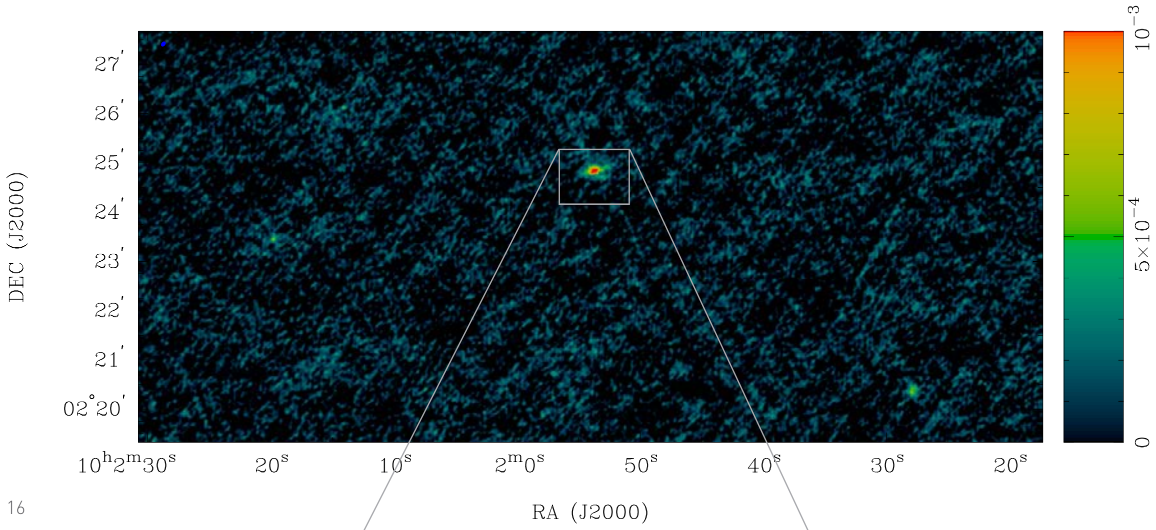
CHILES

CHILES turns up the heat on deep space discoveries. Throughout the Universe, one element—hydrogen—is more abundant than any other.

Radio astronomers are particularly interested in looking at neutral hydrogen, or HI (pronounced H-one), because it is the building block for all the stars and galaxies we see in the sky.

If you want to understand galaxy evolution, you need to know where the HI is coming from and how it interacts, both within a galaxy and between a galaxy and its environment.

ICRAR is part of an international team conducting the deepest survey ever undertaken in the HI, known as CHILES—or the COSMOS HI Large Extragalactic Survey—which uses observations from the Karl G. Jansky Very Large Array telescope in New Mexico, in the southern United States.



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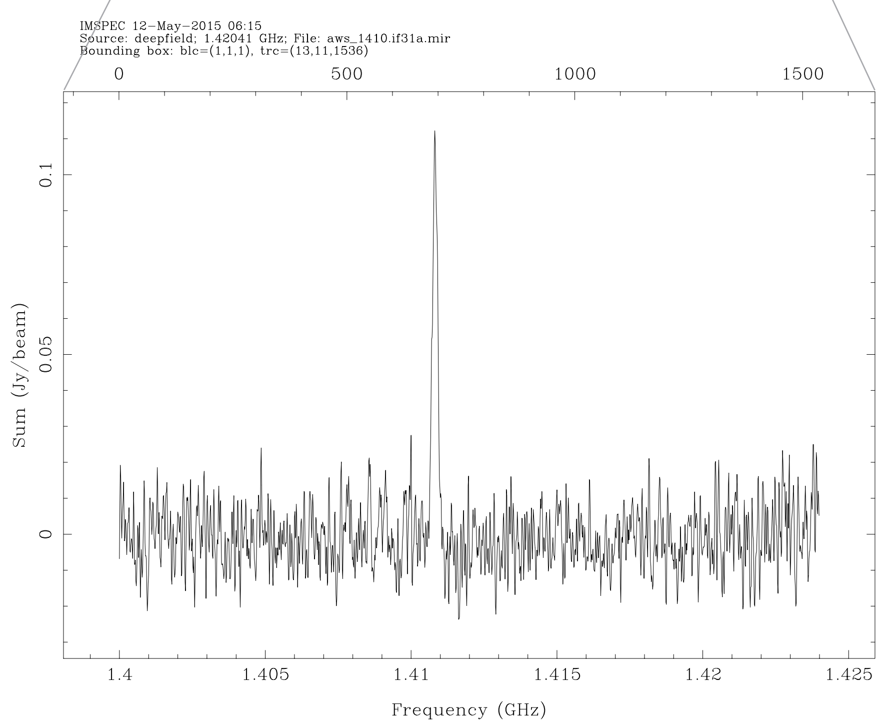

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16, 17. Shown is the hydrogen line emission from a single galaxy in an image cube made in a highly distributed fashion with Amazon Web Services (AWS) Cloud-based computing.

The top image is the view of the galaxy on the sky, below the spectra shows the integrated flux across the galaxy as a function of frequency (in GHz) showing the emission is limited to a fraction of a MHz. The redshift allows us to calculate the distance to this galaxy to be 30 Mpc.

Using the AWS computing allows us to access highly-flexible, demand-driven, cost-effective processing power for data intensive astronomy applications. We can use the flexibility of a cloud to tune the hardware applied to the problem to deliver the best performance per dollar.

This survey is a huge international collaboration led by Columbia University and involves more than 30 researchers from Australia, Europe, Asia, the US, South America and South Africa.

CHILES will look at galaxies close to our own Milky Way (known as the local Universe) and will also study neutral hydrogen emission from galaxies deep in space, peering back almost five billion years in time.

> *"For the first time, astronomers will be able to resolve these galaxies to the point where they can see the environment they live in (whether they are embedded in a galaxy group or isolated on their own) and how this relates to the amount of HI, allowing us to find out if galaxies evolve differently depending on what is around them."*
> ***Dr Attila Popping***

Observing further back in lookback time than ever before comes with its fair share of challenges.

Every one of CHILES' 1000 hours of observing produces some 100GB of raw data—far more than can be easily managed on a laptop—so just processing and reducing the sheer amount of information generated is a massive test for the science team.

From the telescope in New Mexico, the first part of the data reduction is done in the US and then the data is transferred to Perth, where ICRAR researchers Attila Popping, Martin Meyer and Andreas Wicenec have created special algorithms to process the massive amount of data.

CHILES will observe the same area of the sky for all 1000 hours, which can't be done in one continuous block and is instead split up into observing sessions of a few hours.

ICRAR's role is to combine the data from these different observing sessions into one extremely sensitive set and to image the survey, or take the raw data and convert it into something scientists can use, like a data cube.

The project involves much more data than most astronomers are used to dealing with and ICRAR has been processing it with the Pawsey Supercomputing Centre, and exploring it using Amazon Web Services, a cloud-based computing service.

The research team also faces technical challenges such as radio frequency interference caused by things like mobile phones, satellites, TV signals and aeroplanes.

This interference needs to be cleaned out of the data, a task that is made more difficult because CHILES operates over a very large frequency range and there is a lot of variation in the type of interference experienced at different frequencies.

Learning to deal with the challenges CHILES poses is very important for the astronomy community because CHILES acts as a pilot project for future surveys on next generation telescopes such as the Square Kilometre Array (SKA) and Australian SKA Pathfinder (ASKAP).

As much as models and simulations are useful to have, the experience gained by solving these problems with real data, and doing real science, is going to be highly sought after as these next generation telescopes come on line.

So far CHILES has completed a pilot phase of about 60 hours of observing, after which the team spent time trying to make sense of the data and prove they could deal with such large volumes of information.

The full 1000-hour survey is now underway, with about 180 hours of observing completed in 2014 and 270 hours planned for 2015.

The project is an excellent data set to combine with other surveys at different wavelengths, such as optical or ultraviolet surveys, to study the relationship between what we see at other wavelengths and the amount of gas in galaxies.

While it is still early days for CHILES, with each step we are understanding more about how to work with big data and improve our reduction and processing techniques, in order to make the most exciting discoveries in the years to come.

RESEARCHER PROFILE
Dr Ivy Wong
Super Science Fellow

Dr Ivy Wong's research can be distilled to one simple question; how do galaxies start and stop forming stars?

Ivy studies material spewing from supermassive black holes in distant galaxies, and looks at what happens to the gas galaxies need to survive.

> *"I want to know what triggers star formation within individual galaxies."*
> *Dr Ivy Wong*

"Is it nature? Is it nurture? Does the galaxy care what environment it lives in in the grand scheme of where it is in the Universe?"

"When does a galaxy decide to grow a supermassive black hole and how does that happen?"

Dr Wong uses data from instruments like the Parkes radio telescope in regional New South Wales and NASA's Galaxy Evolution Explorer satellite, and is also involved in the science commissioning for the Australian SKA Pathfinder (ASKAP) telescope.

She is the project scientist for Radio Galaxy Zoo, a citizen science initiative that has seen volunteers search more than a million images of the sky and identify more than 50,000 objects likely to be jets from black holes.

Dr Wong says the rate of scientific output is much quicker than ever before and the next big discoveries will come from radio astronomy.

"Working at ICRAR puts me closer to the action with the ramp up of next- generation surveys such as WALLABY, EMU and DINGO, all of which use the ASKAP telescope in Western Australia," she says.

"It is very exciting to think that we are discovering more of the Universe faster than ever before."

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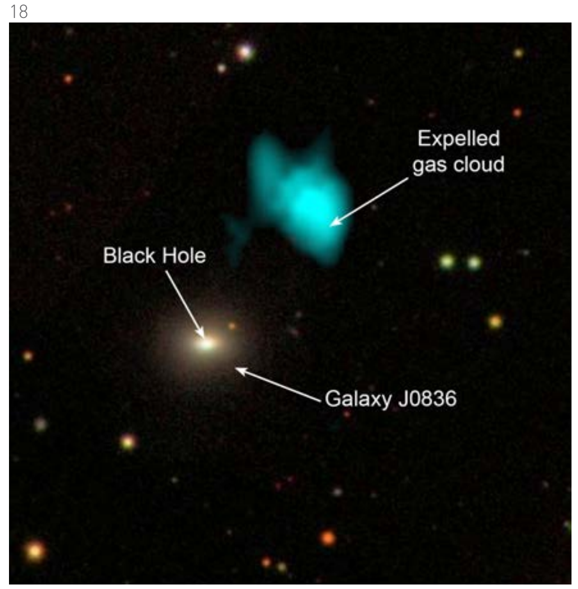

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18. Dr Ivy Wong.

19. An image showing galaxy J0836, the approximate location of a black hole residing at the galaxy's core, and an expelled gas reservoir.

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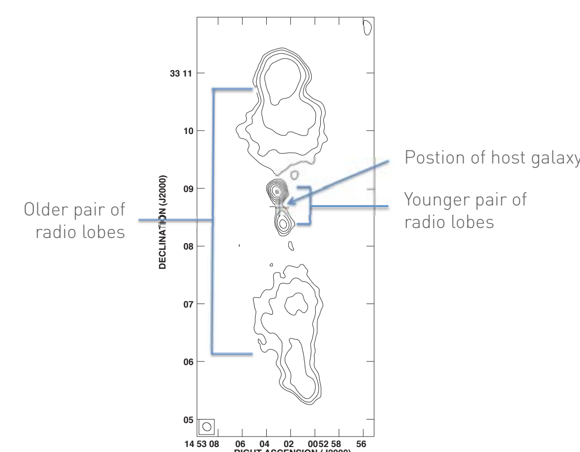

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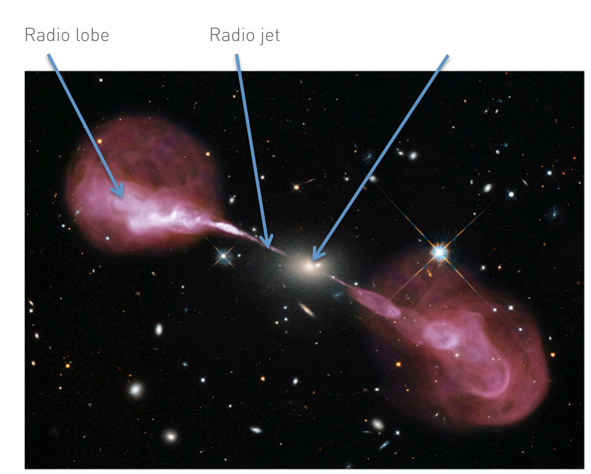

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RESEARCHER PROFILE
Dr Tom Franzen
Postdoctoral Researcher

> * *When the next generation of revolutionary new radio telescopes come online in the coming decades, talented young researchers like Tom Franzen are set to be at the forefront of new discoveries that are yet be imagined.*

Tom is an expert in extragalactic science and uses radio astronomy surveys to study radio galaxy populations.

For reasons not entirely understood, supermassive black holes at the centres of galaxies sometimes spew out jets of energetic particles, and the jets produce enormous lobes of radio emission that expand over time. These lobes are one of the two major components of a radio galaxy that Tom looks for, along with the Active Galactic Nucleus (AGN).

By combining data from high and low frequency radio surveys, Tom is able to observe both of these components and find out more about what triggers jet activity, and how this might relate to star formation.

Tom moved to ICRAR from CSIRO in April 2014 and is already making use of data from the Murchison Widefield Array (MWA), exploiting overlaps with other radio, optical and infrared surveys to extract as much information as possible about the nature and evolution of galaxies.

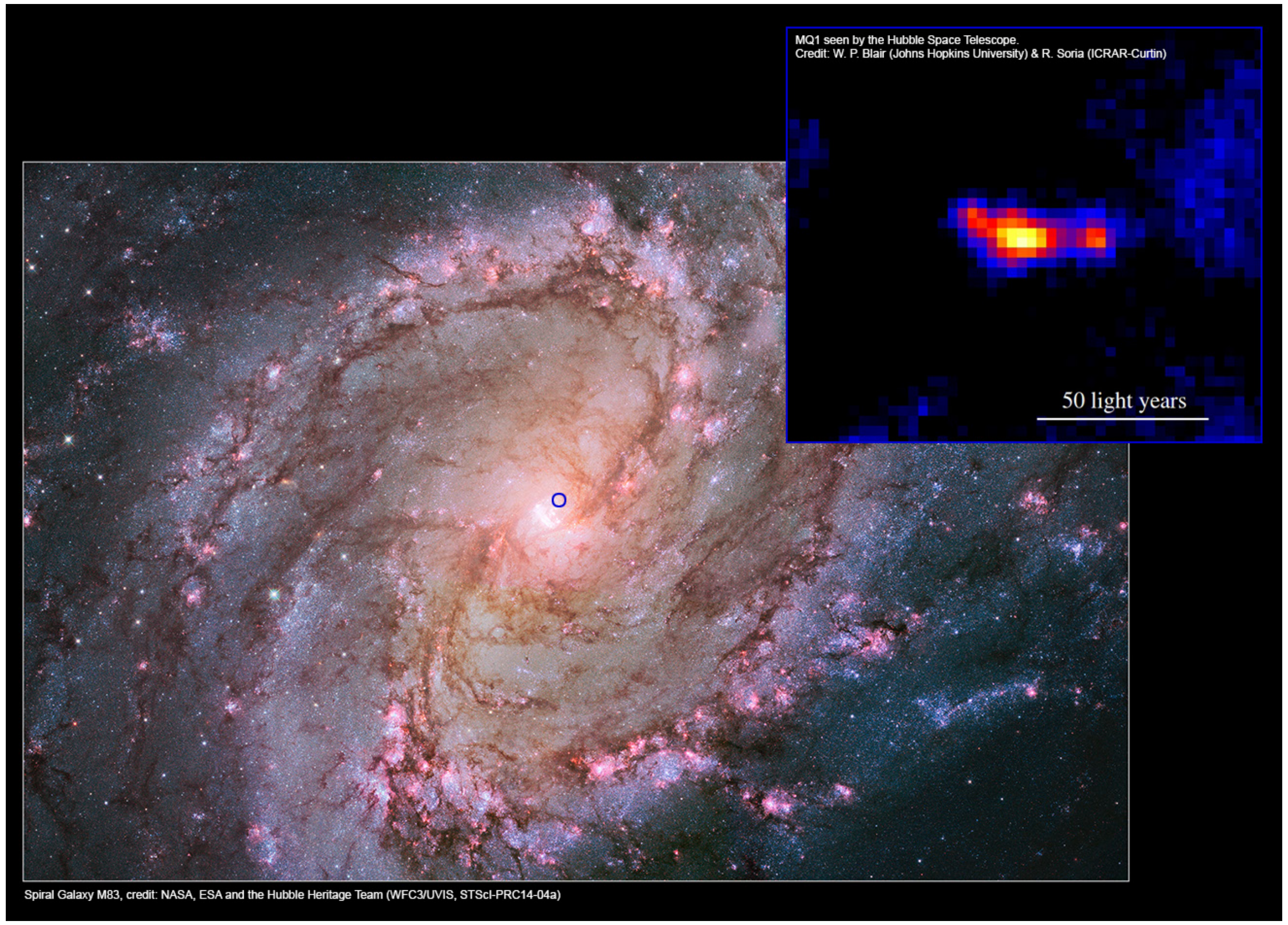
"I think it's really fantastic to have all this MWA data which is now coming out from these surveys," he says. "There's so much you can do with it… it's a very exciting time."

"If you can build up samples of sources where you can get information about both what's happening on short-time scales, the recent active galactic nucleus activity, and evidence of previous activity, which you can see in the radio lobes, that can provide important new information about how radio galaxies evolve," he says.

20. Dr Tom Franzen.

21. Double-double radio galaxy J1453+3308, as imaged by the Giant Metrewave Radio Telescope (GMRT) in India, reproduced from Konar et al. (2006)

22. A false colour image of radio galaxy 3C348: Optical in white/yellow, radio in red. Credit: NASA, ESA, S. Baum, C. O'Dea, R. Perley, W. Cotton and the Hubble Heritage Team.



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23. Nearby spiral galaxy M83 and the MQ1 system with jets, as seen by the Hubble Space Telescope. The blue circle marks the position of the MQ1 system in the galaxy (see inset). Credit: M83 - NASA, ESA and the Hubble Heritage Team (WFC3/UVIS, STScI-PRC14-04a). MQ1 inset - W. P. Blair (Johns Hopkins University) & R. Soria (ICRAR/Curtin).

24. Located 300 million light years away in the constellation Coma Berenices, these colliding galaxies have been nicknamed "The Mice" because of the long tails of stars and gas emanating from each galaxy. Credit: NASA, Holland Ford (JHU), the ACS Science Team and ESA.

ACHIEVEMENT

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Astrophysicist James Miller-Jones won a 2014 WA Young Tall Poppy Scientist of the Year award for his work on black hole jets.

The Science of Black Holes

ICRAR's accretion physics group continues to ignite imaginations around the world as they discover more about one of the greatest mysteries in the Universe—black holes.

In early 2014, members of the team published a paper in Science on the discovery of a new "fast and furious" black hole in the nearby galaxy M83.

The black hole is only about 100km across—very small by cosmic standards—but has powerful jets that have blown a bubble in the black hole's surroundings.

The bubble of hot gas is heated by two jets just outside the black hole, powerfully shooting out energy in opposite directions and acting like cosmic sandblasters pushing out on the surrounding gas.

A couple of months later, the team were involved in the observation of a gamma-ray burst, a bright flash of light emitted by a dying star collapsing to a black hole.

They observed the light to be highly polarised, suggesting it was corkscrewing around in a spiral motion.

This finding gives insight into an event that happened almost 11 billion years ago and was published in the journal Nature.

Then in October 2014, members of the group were involved in another Nature paper about the discovery of a black hole that is consuming gas from a nearby star 10 times faster than previously thought possible.

The black hole lies on the outskirts of the galaxy NGC7793, about 12 million light years from Earth, and is at least a million times brighter than the Sun.

The researchers calculated that the black hole is ingesting a weight equivalent to 100 billion billion hot dogs every minute.

Galactic cannibals gain weight by eating smaller neighbours

ICRAR researchers made international headlines in September 2014 when they discovered massive galaxies in the Universe have stopped making their own stars and are instead snacking on nearby galaxies.

The astronomers looked at more than 22,000 galaxies and found that while smaller galaxies were very efficient at creating stars from gas, the most massive galaxies were much less efficient at star formation.

They produced hardly any new stars themselves, and instead grew by eating other galaxies.

Dr Aaron Robotham, who led the research, found that our own Milky Way is at a tipping point and is expected to now grow mainly by eating smaller galaxies, rather than by collecting gas.

The Milky Way is going to consume two nearby dwarf galaxies, the Large and Small Magellanic Clouds, in about four billion years but will eventually get its comeuppance when it merges with the nearby Andromeda Galaxy in about five billion years.

The reason star formation slows down in really massive galaxies is thought to be because of extreme feedback events in a very bright region at the centre of a galaxy known as an Active Galactic Nucleus (AGN).

The topic is much debated but a popular mechanism is where the AGN basically cooks the gas and prevents it from cooling down to form stars.

Almost all of the data for the research was collected with the Anglo-Australian Telescope in New South Wales as part of the Galaxy And Mass Assembly (GAMA) survey, led by ICRAR Professor Simon Driver.

The GAMA survey involves more than 90 scientists and took seven years to complete.

Dr Robotham's study, published in the Monthly Notices of the Royal Astronomical Society, is one of more than 75 publications to have come from the work so far and at least another 100 are in progress.

Carbon monoxide predicts 'red and dead' future for gas guzzler galaxy

An ICRAR astronomer studying the carbon monoxide in a galaxy more than 12 billion light years from Earth discovered that it's running out of gas, quite literally, and headed for a 'red and dead' future.

The galaxy, known as ALESS65, was observed by the Atacama Large Millimeter Array in 2011 and is one of less than 20 known very distant galaxies to contain carbon monoxide.

Dr Minh Huynh and her team used the Australia Telescope Compact Array radio telescope in New South Wales to work out how much carbon monoxide they could see in ALESS65 and extrapolated that out into how much fuel the galaxy has left to make new stars.

Our galaxy, the Milky Way, has about five billion years before it runs out of fuel and becomes 'red and dead' but ALESS65 is a gas guzzler and only has tens of millions of years left—a very short lifespan in astronomical terms.

The research was published in July 2014 in the Monthly Notices of the Royal Astronomical Society.

The team will now turn their attentions to the search for carbon monoxide in another galaxy near to ALESS65, named ALESS61.

Even though here on Earth carbon monoxide is a deadly gas that can cause suffocation, in galaxies it plays an important role in the lifecycle of stars.

Finding and studying carbon monoxide in more galaxies will tell us even more about how stars formed in the early days of the Universe and help solve the mystery of far away 'red and dead' galaxies.

Dark matter in the Milky Way

Astrophysicist Prajwal Kafle made waves around the world when his research revealed there is half as much dark matter in the Milky Way than previously thought.

Dr Kafle probed the edge of the Milky Way, looking closely, for the first time, at the fringes of the galaxy about 5 million trillion kilometres from Earth. He discovered that the weight of dark matter in the Milky Way is 800 000 000 000 (or 8×10^{11}) times the mass of the Sun.

Dark matter cannot be seen with telescopes but we know the mysterious substance exists because of its gravitational influence on visible matter. "Stars, dust, you and me, all the things that we see, only make up about 4 per cent of the entire Universe," Dr Kafle said. "About 25 per cent is dark matter and the rest is dark energy, and in the Milky Way, what we can see only makes up a tenth of the galaxy, the rest is dark matter."

Dr Kafle, who is originally from Nepal, made the calculation using a robust technique developed by British astronomer James Jeans in 1915—decades before the discovery of dark matter. His measurement was published in October 2014, and helps to solve a mystery that has been haunting theorists for almost two decades. "The current idea of galaxy formation and evolution, called the Lambda Cold Dark Matter theory, predicts that there should be a handful of big satellite galaxies around the Milky Way that are visible with the naked eye, but we don't see them," Dr Kafle said.

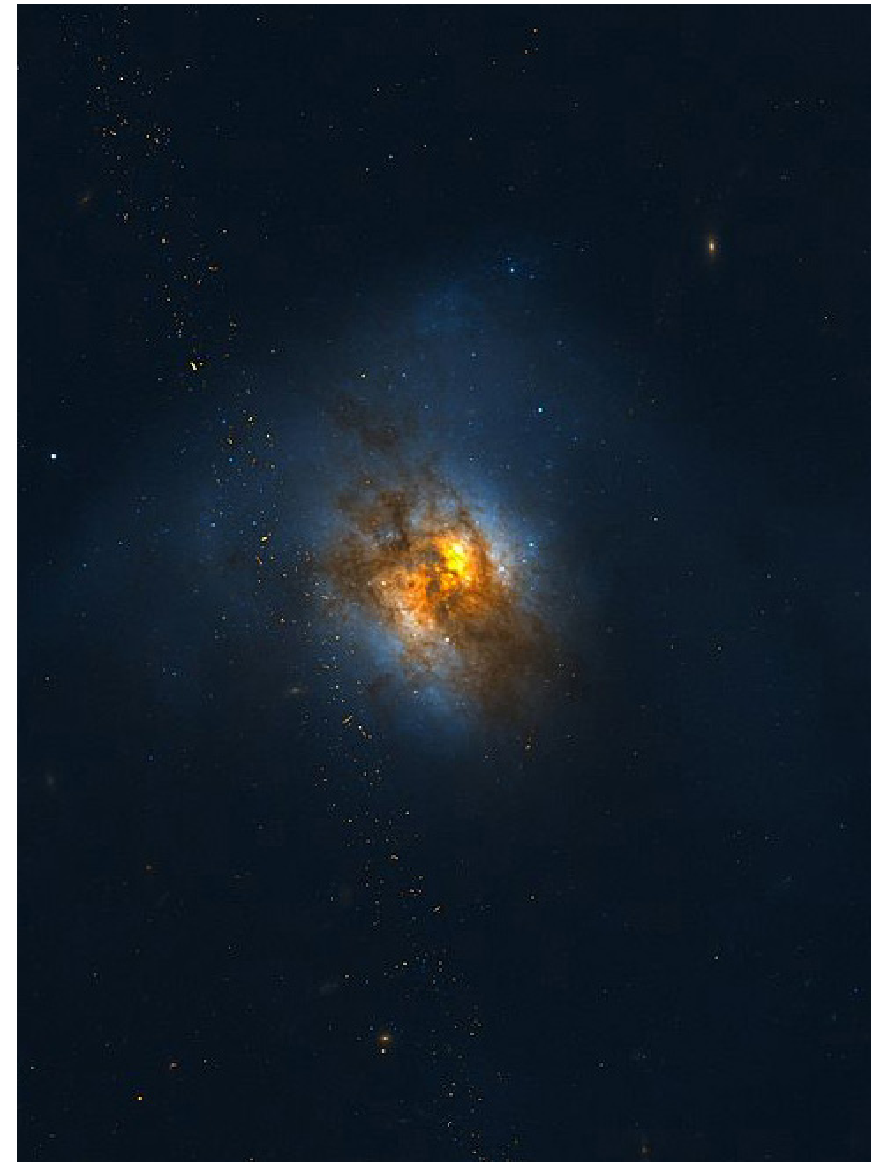
> *"When you use our measurement of the mass of the dark matter the theory predicts that there should only be three satellite galaxies out there, which is exactly what we see; the Large Magellanic Cloud, the Small Magellanic Cloud and the Sagittarius Dwarf Galaxy."* Dr Prajwal Kafle

25. A nearby 'Ultraluminous Infrared Galaxy' similar to what ALESS65 would look like if it were closer to Earth. Credit: NASA, ESA, and the Hubble Team.

26. NGC5044, a 'red and dead' galaxy like ALESS65 will become in about 25 million years, after running out of fuel. Credit: X-ray: NASA/CXC/Stanford Univ/N. Werner et al; Optical: DSS).

27. Radio waves emitted from ALESS65 as observed by the Australia Telescope Compact Array. Credit: Huynh et al.

28. Artist's impression of the Milky Way and its dark matter halo (shown in blue, but in reality invisible). Credit: ESO/L. Calçada.



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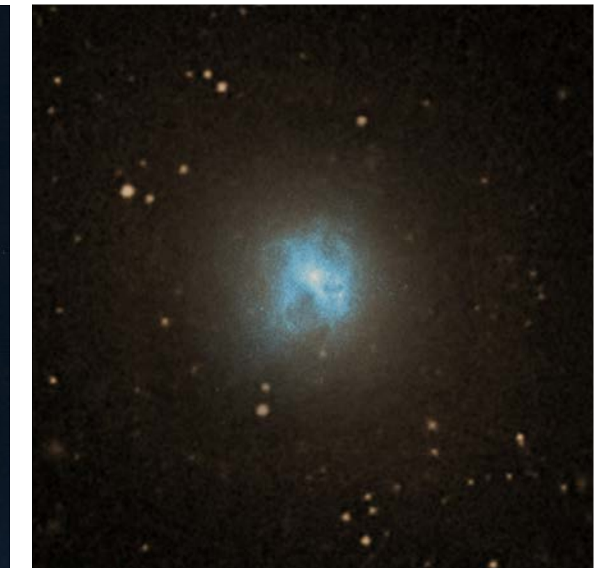

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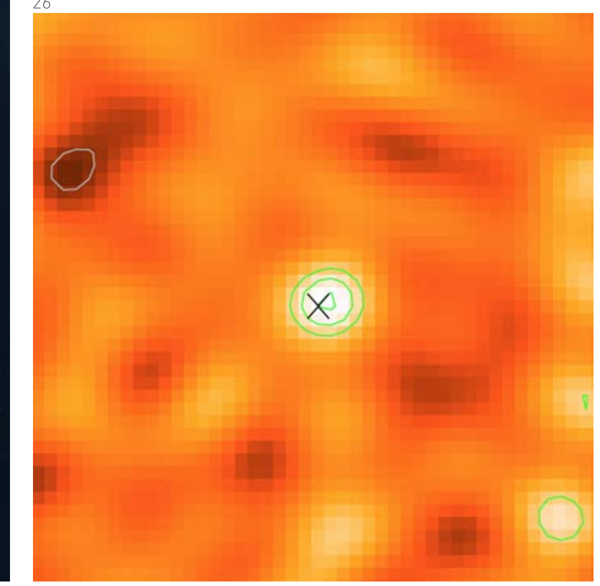

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Smashing galaxies together in a super-computer

One of the research areas that most captures people's imagination does not involve telescopes, observations or looking at the night sky at all.

ICRAR has a talented group of simulations experts who make giant sections of virtual universes inside computers to understand the enormous cosmic web of dark matter and see what happens when galaxies smash into each other.

They try to replicate what the real Universe looks like inside a computer to help us understand how we got to be the way we are today.

The team, led by Professor Chris Power, can build galaxies to spec, adding dark matter, stars and gas to models of places such as our own Milky Way and the nearby Andromeda Galaxy.

They apply the effect of gravity to replicate how the galaxies move, and run simulations billions of years into the future to see what will happen.

The researchers also run cosmological simulations to track how galaxies formed in the early Universe.

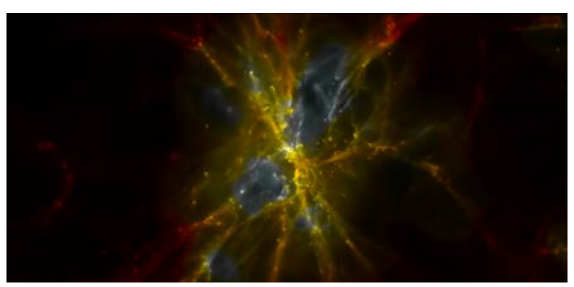
They start with the cosmic microwave background, the oldest light we can see.

Initially there is almost no structure, just gas and dark matter, with ripples where there is slightly more mass in some places and less in others.

The team is able to set up these ripples in a computer and work out how they would act under the influence of gravity, running the computer program forward to the stars and galaxies that we see today, almost 14 billion years after the Big Bang.

This extremely visual science has a very broad appeal, even for people with a limited science background, and the team's visualisations have appeared in countless media articles.

> *These visualisations have attracted hundreds of thousands of views on social media and in 2014 they were used to create a planetarium show, which sold out in Perth and has attracted the interest of other planetarium operators around the country, with the possibility of the show travelling to other states.*



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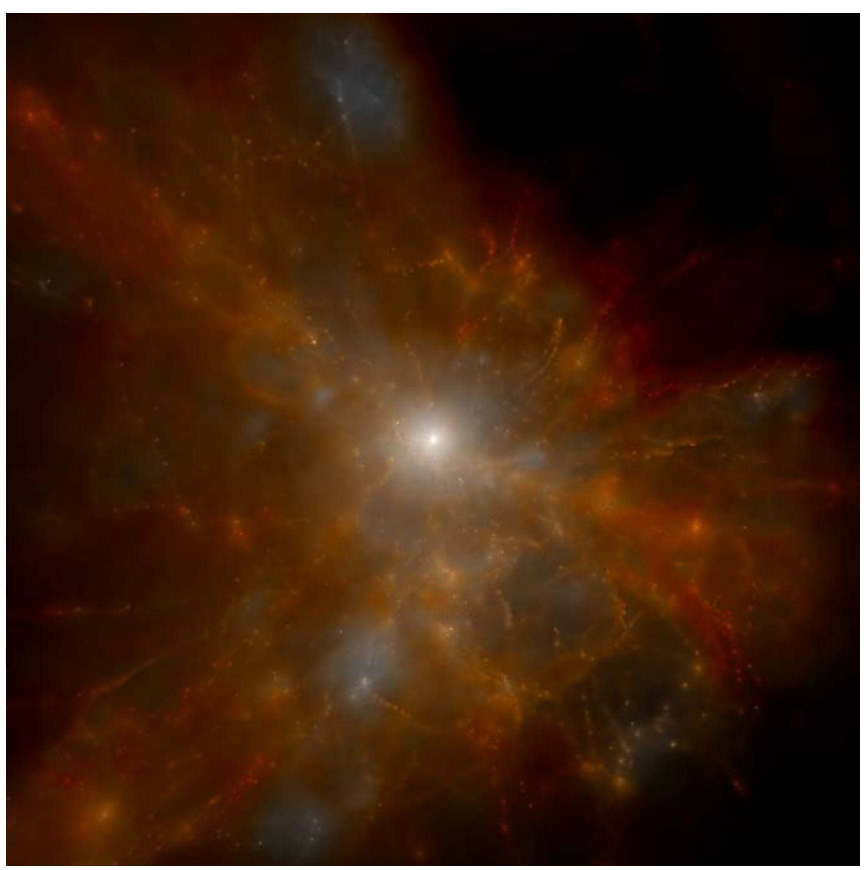

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29. A view of a Milky Way-like galaxy embedded in a gaseous cosmic web approximately 3 million light years across.

30. A collision between two Milky Way-like galaxies with a bridge of gas drawn out by gravitational tides connecting them.

31. A close encounter between two Milky Way-like galaxies as they begin to merge.

32. A close-up of a Milky Way-like galaxy, showing complex web-like gas distribution feeding the galaxy.

Credit 29-32: These simulated images have been created by Professor Chris Power and Dr Rick Newton.

33. An artist's impression of the RadioAstron Observatory in orbit.

34. Galaxy 0716 +714 at radio wavelengths as observed by RadioAstron.

Russian space telescope RadioAstron probes the Universe

When the world's largest orbiting space telescope—the Russian RadioAstron—needed help processing data, ICRAR was there to lend a hand.

The Centre is one of only a handful of facilities in the world capable of managing the data from the telescope, which is helping to make discoveries about the structure of galaxies, star formation, black holes, dark matter and interstellar space.

RadioAstron was launched in 2011 and works with telescopes on the ground to observe objects in our Universe from two places thousands of kilometres apart.

This technique, known as Very Long Baseline Interferometry, gives us extremely high resolution data, and RadioAstron has produced the highest resolution images of any object in all of astronomy—much, much better for example than images from the Hubble Space Telescope.

> *"What RadioAstron can do better than any other instrument is observe objects that are very small and very bright, such as jets coming from supermassive black holes at the centre of galaxies."*
> *Dr Cormac Reynolds*

RadioAstron has an eccentric orbit that takes it from within one Earth diameter of us to about 30 Earth diameters away, almost to the Moon.

Combining the data from this and the telescopes on the ground is hugely complex.

You need access to a supercomputer running a correlator and expertise in Very Long Baseline Interferometry, capabilities ICRAR has in abundance thanks to their work routinely linking telescopes in Australia, New Zealand and South Africa.

The Centre joins only three other facilities in the world, located in Germany, the Netherlands and Russia, in having the supercomputing resources and expertise to be able to do this processing work.

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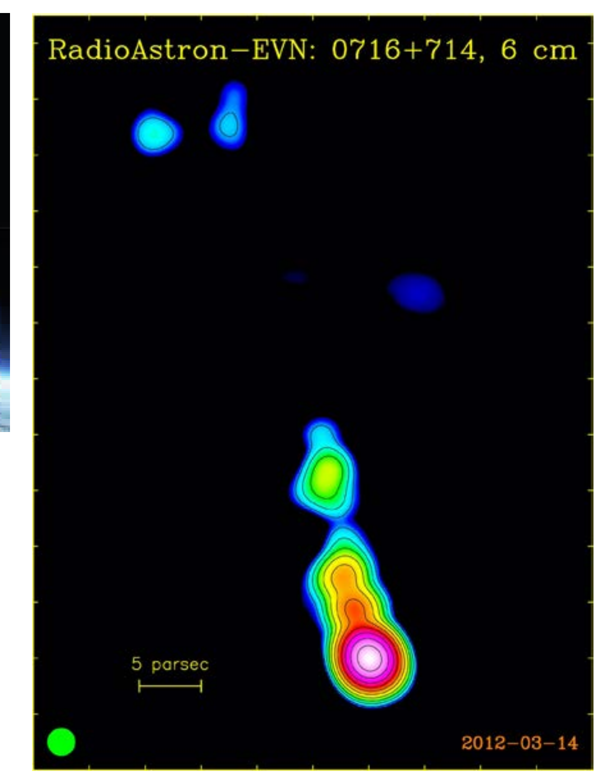

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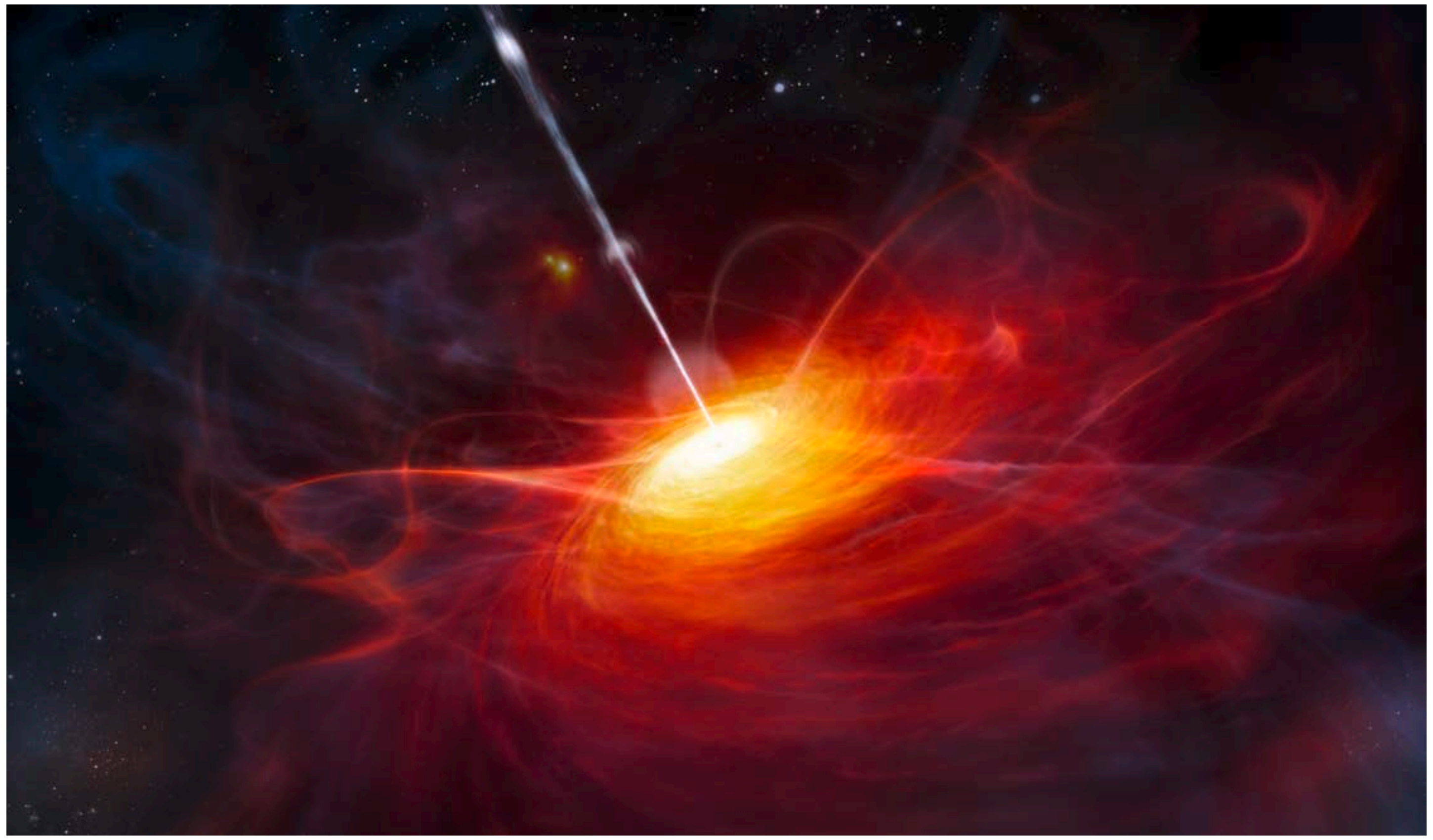

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Interstellar medium acts as galaxy's own telescope

Look up at the sky tonight and you'll see that stars twinkle but the planets do not.

This is because the Earth's atmosphere acts as a tool to resolve objects in the night sky.

It is the equivalent to having a telescope with a 20cm mirror, about the size of a good-quality amateur scope.

But what if you could apply this effect to the entire Universe?

ICRAR astrophysicist Jean-Pierre Macquart is using the "atmosphere of our galaxy"—the interstellar medium—to look at objects in more detail than ever before.

This interstellar medium is the matter that lies between the stars in our galaxy, from which new stars form and to which the dead remnants of stars return at the end of their lives.

Dr Macquart is studying turbulence within the interstellar medium and how it can be used as a tool to study objects in the background.

Where the Earth's atmosphere gives us the equivalent of a 20cm telescope, looking at objects through the interstellar medium is equivalent to having a free telescope with a diameter more than 10 times the distance between the Earth and the Sun.

It allows Dr Macquart and his colleagues to achieve resolutions five orders of magnitude better than any other technique.

Using the interstellar medium, Dr Macquart is able to study objects in unprecedented detail and probe physics that could not be tackled otherwise.

The technique is particularly good for studying quasars (the emission regions near supermassive black holes) and exploring long-standing mysteries such as how pulsars emit radio waves.

35. This artist's impression shows how ULAS J1120+0641, a very distant quasar powered by a black hole with a mass two billion times that of the Sun, may have looked just 770 million years after the Big Bang. Credit: ESO/M. Kornmesser.

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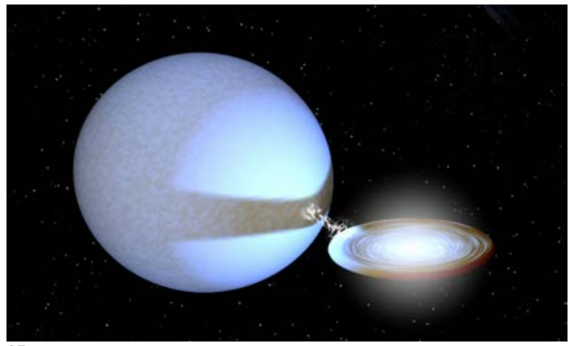

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36. PhD Student, Tom Russell.

37. A rendering of Black Hole P13 on the outskirts of galaxy NGC7793, about 12 million light years from Earth.

38. Tom Russell working with high school students.

STUDENT HIGHLIGHT
Tom Russell
PhD Student

Thesis: The connection between inflow and outflow around accreting stellar mass black holes.

Tom Russell's research into black holes is shaping our understanding of one of the biggest mysteries of the Universe.

He is studying the relationship between in-falling and out-flowing material around black holes to determine how the out-flowing jets are launched and how they change over time.

Tom is also helping to discover how supermassive black holes at the centre of large galaxies evolved.

> * *By studying less massive black holes in small galaxies with conditions similar to the early Universe, Tom is able to discover how supermassive black holes initially formed and grew.*

Tom says he has really enjoyed his PhD, and has received amazing support not only from his supervisors but from ICRAR as a whole.

"The support's been fantastic from ICRAR," he says.

"They've sent me to a few places around the world and there's lots of expertise around.

"You can ask people about many different aspects of astronomy, not just radio astronomy, so if I ever encounter problems there's a plethora of people around who I can ask for help."

Since starting his PhD three years ago, Tom has already published six peer-reviewed papers, including three as the lead author.

His research has generated significant interest from around the world and he has given invited lectures at prestigious institutions including the University of Oxford, Harvard University, the University of Amsterdam and the University of Michigan.

Tom is passionate about sharing his work and is also heavily involved in ICRAR's outreach program.

"Being able to just go out and talk to schools and kids and the general public makes it exciting," he says.

"You're not just sitting at a screen all the time, you're going out and people are getting excited about what you're doing, and that makes you excited as well."

39. A field of MWA dipole antennas.

MURCHISON WIDEFIELD ARRAY

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MWA Today

The Murchison Widefield Array unlocks mysteries of the Universe. In the heart of Western Australia's remote Murchison region, the ancient landscape is dotted with squares of spider-like structures facing the sky.

This powerful telescope—the Murchison Widefield Array (MWA)—is quietly surveying hundreds of thousands of galaxies, keeping watch on our Sun and peering back in time to watch the birth of the first stars and galaxies.

It has been a journey of almost a decade to reach this point, with construction of the radio telescope completed at the end of 2012 and commissioning by mid 2013.

The observations are now flowing thick and fast, with the instrument collecting more than four petabytes of data since it became operational.

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40. The core of the Murchison Widefield Array, captured using a camera mounted on a drone.

41. Dutch Ambassadorial visit to the Murchison Radio-astronomy Observatory.

42. Dutch Ambassadorial visit. Left to right: Professor Peter Hall (ICRAR/Curtin), Ambassador Mrs Annemieke Ruigrok, (Netherlands Embassy, Canberra), Professor Deborah Terry (Curtin University Vice-Chancellor) and His Excellency Mr Sem Fabrizi, Ambassador of the EU Delegation to Australasia.

The MWA is a low-frequency (80-300 MHz) telescope and its wide field of view means it can quickly survey huge areas of the sky.

Already the $50 million international project, headed up by Professor Steven Tingay, is making discoveries nobody ever expected.

"All the science results are starting to roll out in earnest now," Professor Tingay says.

"It's an amazing feeling for the team to have all pulled together, delivered the instrument and now to see it doing science, and doing science that wasn't expected when we did the planning… it's incredibly satisfying overall."

More than 25 papers have been published in the telescope's short life and another 30 are in the pipeline for the next year or so.

Among the most exciting experiments is the search 13 billion years back in time for faint signals from the birth of the first stars and galaxies after the Big Bang.

This period of time, known as the Epoch of Reionisation, is incredibly difficult to detect but the MWA is a forerunner in the international race to be the first to uncover these elusive signals from the early Universe.

> *"It's an epoch in the Universe that's never been probed before, so this is uncharted territory."*
> *Professor Steven Tingay*

"The MWA has a big program to uncover that signal—it's going to take some time but the early results are really promising."

The MWA is also helping us learn more about our planet. It is collecting observations of the ionosphere, a part of the upper atmosphere just 100km above the surface of the Earth that has been ionised by solar radiation.

The ionosphere distorts the radio waves the MWA receives, and while this distortion is somewhat of a nuisance for the telescope, it is allowing scientists to examine the structure and evolution of the ionosphere on a scale never studied before.

Slightly further out, the MWA is also being used to study the Sun and space weather in the Solar System.

The project receives funding from the US Air Force to monitor solar flares, particularly large eruptions called coronal mass ejections, which travel outwards from the Sun and occasionally hit the Earth.

These coronal mass ejections can cause all sorts of damage to power grids, satellites and communication networks, and the MWA is being used as an early warning system for the flares as they approach the Earth.

But the MWA is looking much further than our own Solar System.

The telescope is observing the Milky Way and hundreds of thousands of other galaxies in the most comprehensive survey of the sky ever undertaken at low frequencies.

"This is an all-sky set of observations that looks at every radio source in the sky that we can from the Southern Hemisphere," Professor Tingay says.

"We'll end up with a catalogue of something like half a million objects, which is unprecedented at low frequencies."

Although the MWA is a powerful telescope in its own right, it is laying the groundwork for what is arguably the biggest science project on the planet, the Square Kilometre Array (SKA).

This multi-billion dollar project is set to be built in Western Australia and South Africa, with the Australian part of the project sitting alongside the MWA in the remote Murchison region.

Building the MWA has given ICRAR's researchers a huge head start in acquiring the skills and wisdom needed to make the SKA a reality.

While the telescope is the result of a collaboration between 15 highly prestigious institutions, including MIT and Harvard, ICRAR's experience on the ground in the Murchison is already proving invaluable.

The Centre's engineers have overcome the challenges associated with constructing such an advanced instrument in a remote area with limited infrastructure.

The data scientists have learnt how to process the huge volumes of information coming from the telescope, and transport that data first to Perth and then around the world.

ICRAR's young astrophysicists have cut their teeth on the observations from the MWA in preparation for the revolutionary jump in sensitivity that the SKA will bring.

The low frequency part of the SKA alone, known as SKA-low, will be 50 times larger than the MWA.

This huge jump in science capability and the associated challenges in data management are going to require everything ICRAR's researchers have learned so far and more.

It is impossible to tell what new discoveries about our Universe the MWA and SKA will bring, but one thing is certain—it is a hugely exciting time to be in radio astronomy.

ACHIEVEMENT

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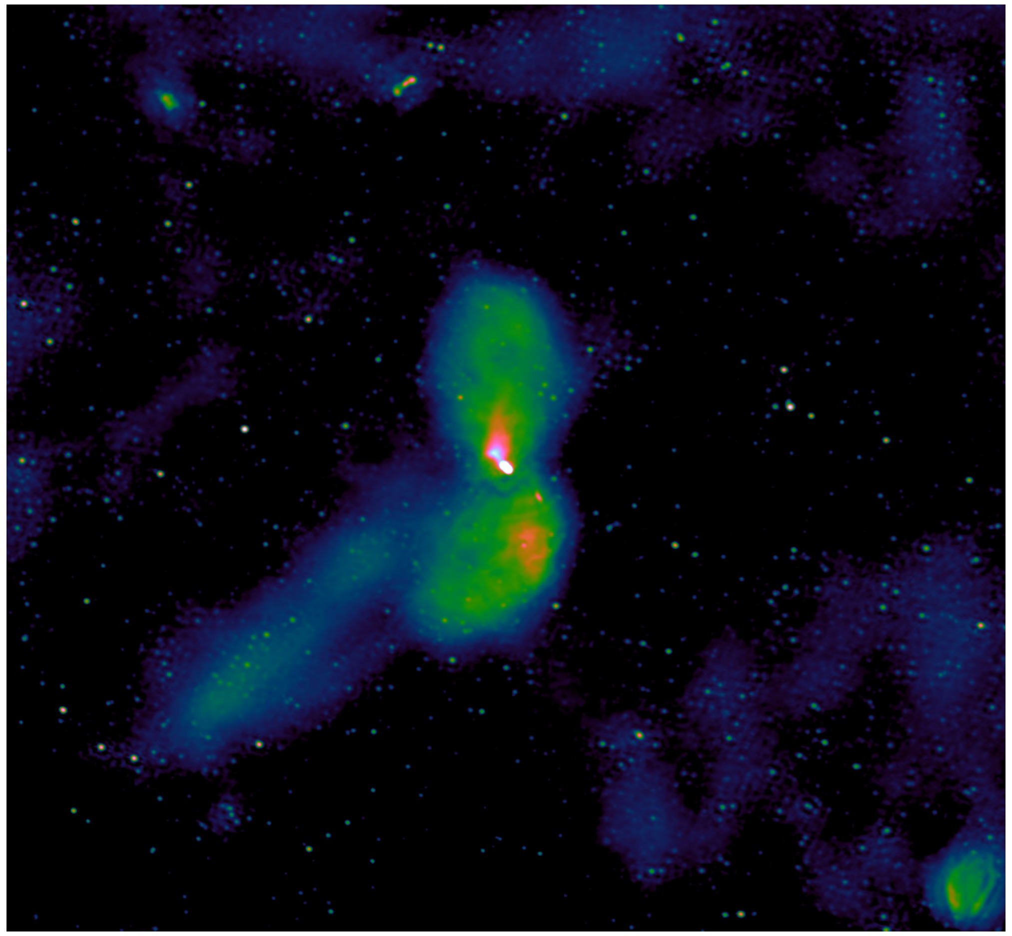
The $50 million Murchison Widefield Array (MWA) telescope was brought into full science operations mode in the middle of 2013.



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43. The giant radio galaxy Centaurus A as imaged by the MWA at 155 MHz. Credit: Dr Randall Wayth, ICRAR.

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RESEARCHER PROFILE

Professor Carole Jackson

Professor of Radio Astronomy and WA Fellow

After 18 years involvement with the development of the multi-billion dollar telescope, there's not much Professor Carole Jackson does not know about the Square Kilometre Array.

Carole was lured to Perth in 2013 with the award of a prestigious WA Fellowship and has made a strong addition to the ICRAR leadership team.

She brings more than 25 years experience in both industry and research, and has particular interests in radio-loud active galactic nuclei, technology development and industry partnerships.

Prior to joining ICRAR, Carole spent 10 years at CSIRO, where she led the design and commissioning of the 36 dish antennas that make up the Australian SKA Pathfinder (ASKAP).

She led the formation of the international SKA Dish Consortium, a group comprising members from South Africa, the UK, China, Canada, Italy and Sweden, including a number of major industry partners.

Carole says the most exciting aspect of moving to ICRAR has been the opportunity to rekindle her own astronomical research, applying her expertise in the evolution of active galactic nuclei to observations flowing from telescopes such as the Murchison Widefield Array.

> *"Over the next few years there's going to be a wealth of new results from these new low frequency surveys."*
> *Professor Carole Jackson*

Carole loves the discovery aspect of her work, obtaining insights into the workings of the Universe such as how galaxies that were once so powerful seem to have faded away.

"The other side I see is how you can build big groups, and watch those teams really producing great work," she says.

"It is all about recruiting the right people and then allowing them to go do what they're really good at."

44. Professor Carole Jackson.

The Data Deluge

Every second, the Murchison Widefield Array (MWA) telescope produces a staggering 3.2 Gigabits of data.

ICRAR's Data Intensive Astronomy team has been able to reduce, archive, package and send this data to the other side of the world at roughly the same rate it is produced by the telescope, the first trial of transcontinental real time data flow for a Square Kilometre Array precursor.

From the telescope's home in the desert, radio signals are collected from the sky and enter a receiver and then a correlator, which reduces the amount of data to about 400MB/s.

The data goes to an online archive and is sent via Geraldton to the Pawsey Supercomputing Centre in Perth, some 800km away, where it is immediately archived on a combination of hard disks and tape libraries.

Given its data rate, this archive system does not significantly reduce the data so it must be moved regularly to supercomputer clusters (such as the Fornax cluster at The University of Western Australia) for reduction and further processing.

In these clusters the data goes through a calibration and imaging process and is turned into images, the first stage at which the data can be used for science.

These images are distributed to researchers in Perth and Sydney, across the Indian Ocean to the Raman Research Institute in India and across the Pacific Ocean to New Zealand and Massachusetts Institute of Technology in the United States.

With so much data in play, the biggest challenge isn't even being able to process the data, it is simply moving it around and converting it to different formats.

Up to 80 per cent of the time needed to process the data can be taken up by converting it into a format suitable for efficient processing.

45. Supercomputer racks inside the Control Building of the Murchison Radio-astronomy Observatory, where signals from the MWA arrive before being sent on to the Pawsey centre in Perth via Geraldton.

Gaming the Sky

ICRAR researchers working on early designs for the Square Kilometre Array (SKA) are testing video game graphics cards to process observations from the multi-billion dollar telescope.

GPU graphics cards power the ultra-fast, ultra-realistic graphics for modern computer games but, with a little help from industry partners, ICRAR is utilising them in the Central Signal Processor (CSP) of the SKA.

The CSP is the element of the SKA that talks directly to the telescopes, or the part that first takes the signals from the sky and turns them into something that is ready for complex processing.

The samples come off the telescope like noise from a TV aerial and the CSP is the 'glue' taking the signals from the antennas to the science data processor.

The processes that happen here are very simple but have to be done extremely quickly to keep up with the rate of data coming from the telescope.

The CSP is one of three SKA 'work packages', or groups working together to trial early designs for the telescope, that ICRAR is involved in.

The CSP work package is managed by Canada's National Research Council and includes Oxford University, ASTRON in the Netherlands and the National Centre for Radio Astrophysics in India, as well as industry partners Cisco Systems, who are responsible for the networking, and NVIDIA, who make the graphics cards.

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

ENGINEERING

4

Engineering Overview

ICRAR's world-class engineering team are playing a leading role in the end-to-end design, construction, data processing and science extraction for the Square Kilometre Array (SKA).

The group specialises in antenna design, electromagnetic compatibility and radio-frequency systems, and is made up of people from both industry and academia, with a mix of PhD-level research engineers and professionals from industry focussed on and adept at getting systems on the ground.

This talented group proved themselves in 2012 with the successful deployment and commissioning of the Murchison Widefield Array (MWA), the first SKA precursor instrument to be fully operational for science.

The same year also saw the team deploy AAVS0.5, an SKA verification system consisting of 16 SKA-style elements integrated into the MWA signal processing chain. The AAVS0.5 was a critical factor in definitively demonstrating the feasibility and utility of the low-frequency element of the SKA in the Murchison.

These two projects—the MWA and AAVS0.5—are now providing important insights to the design of the Low Frequency Aperture Array (LFAA) which is the signal collecting element of the SKA-low telescope that will be built in Australia.

ICRAR is doing this work as part of a consortium of prestigious organisations including the Netherlands Institute for Radio Astronomy (ASTRON), the Italian National Institute for Astrophysics (INAF), Oxford University and Cambridge University—collectively referred to as the Aperture Array Design and Construction (AADC) Consortium.

The AADC Consortium is charged with design of the LFAA element of the SKA-low telescope including the Christmas tree-like antennas, amplifiers and local monitoring, control and processing.

The engineering team is also involved in the consortium responsible for the Central Signal Processor (CSP) design work package. The CSP is the element of the SKA that will prepare the signals collected by the hundreds of thousands of antennas for processing by a supercomputer.

The CSP Consortium is managed by Canada's National Research Council and includes Oxford University, ASTRON and the National Centre for Radio Astrophysics in India, as well as a number of industry partners including Cisco Systems and NVIDIA.

With their track record of on-the-ground successes, ICRAR's engineering team is set to play a crucial role in steering the SKA during the pre-construction design phase that is underway and runs through to 2016.

The current focus of the ICRAR engineering team is AAVS1, a scaled-up 400-antenna version of AAVS0.5. AAVS1 will include a 256-antenna station, which represents the smallest unit of collecting area and basic building block of the LFAA.

ICRAR's principal responsibilities are for the onsite integration and characterisation of the AAVS1, and its operation in support of the LFAA team's requirements and design verification activities. AAVS1 is scheduled to be deployed on the MRO from late 2015.

Although the ICRAR engineering team has been structured and developed primarily to position ICRAR to play a major role in the SKA, a variety of other activities flow from or contribute to the main effort.

Chief among these is the ongoing maintenance and development of the MWA, which has direct relevance to ICRAR's LFAA mandate.

Other activities include the development and commissioning of new astronomical instrumentation such as the BIGHORNS system, an experiment designed to search for the global signature of the birth of the first stars and galaxies in the Universe.

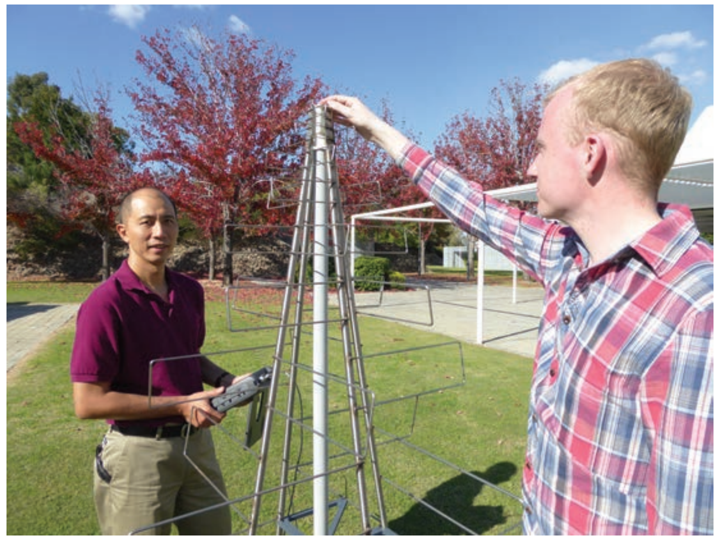
However, its design and the manner in which it is operated mean that BIGHORNS is also an excellent monitor of the radio-frequency environment at the MRO site and the data it generates is of keen interest to the LFAA team and other site users.

The engineering team has also leveraged their unique circumstances—proximity to the MRO, access to low-frequency instrumentation and expertise gleaned from MWA and AAVS0.5—to develop new techniques in antenna metrology and polarimetry.

47. Dr Adrian Sutinjo and Rene Baelemans, a student intern from the Technical University of Eindhoven, testing an "SKA Log-periodic Antenna" (SKALA) prototype designed by Cambridge University.

48. Dr Budi Juswardy from ICRAR assembling one of the 16 AAVS0.5 SKALA antennas at the MRO. Credit: A. Sutinjo.

49. An artist's impression of the Australian SKA Low Frequency Aperture Array.



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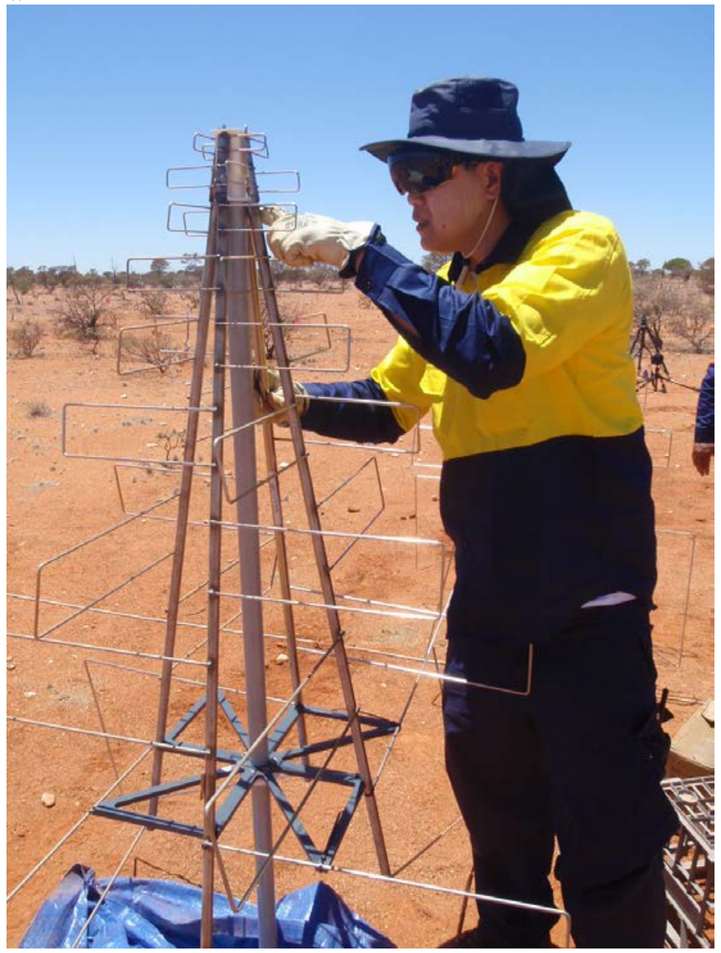

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SKA-low

Like explorers creating maps of new places they discover, astronomers create maps of the Universe featuring stars and black holes in distant galaxies.

Just as maps of the Earth have layers—think street view or satellite view on Google Maps—so too do maps of the cosmos.

The different layers of the cosmos are explored using a variety of instruments, designed to view different parts of the electromagnetic spectrum and characteristic wavelengths.

Space is most often viewed at optical wavelengths—that is, at the point in the electromagnetic spectrum that is made up of the light we can see with our eyes.

The Universe can also be viewed at many other wavelengths that are invisible to the naked eye such as at radio, infrared and X-ray wavelengths.

Each layer reveals different things about the Universe and when they are considered together, they provide us with insights that could not be gleaned from viewing the individual layers in isolation.

The Square Kilometre Array (SKA) will be a radio telescope, meaning it will probe the Universe using the part of the electromagnetic spectrum made up of radio waves.

The main part of the SKA telescope to be built in Australia is known as SKA-low, so called because it will collect low frequency radio waves—from 50MHz to at least 350MHz.

Scientists use radio waves at these low frequencies to look out to the edge of the Universe in their efforts to understand what happened in the period of time immediately after the 'Big Bang'.

ICRAR is playing a leading role in the design of SKA-low. The Centre is part of a consortium of universities and research institutes engaged in the design of the Low-Frequency Aperture Array (LFAA)—the part of SKA-low system that will be deployed in Australia to collect the low-frequency radio waves emanating from space.

SKA-low will be located at the Murchison Radio-astronomy Observatory in Western Australia's Mid West region.

This remote area is the perfect place to build a radio telescope because it is very sparsely populated—just 110 people live in a shire half the size of Tasmania.

This remoteness and low population density mean that the site is not affected by radio frequency interference from everyday technologies like mobile phones, TVs, radio stations and aeroplanes that would otherwise drown out the faint radio signals from space that the telescope is designed to collect.

SKA-low will consist of more than 130,000 wide bandwidth antennas.

Three quarters of the antennas—which stand approximately person height, have no moving parts and are shaped like a Christmas tree—will be tightly packed within a 3km radius core area, with the remaining collecting area distributed on three spiral arms that extend out to a radius of approximately 50km.

With stationary antennas, SKA-low will be an all-electronic telescope.

Different parts of the sky will be explored by manipulating the signals the antennas receive rather than by physically steering the antennas to face in different directions.

Engineers and scientists will employ advanced signal processing and computing techniques to produce a variety of views of the Universe.

The utility of SKA-low will increase over time as these signal processing and computing techniques evolve and improve.

The LFAA is one of three SKA design consortia in which ICRAR is involved.

50-52. An artist's impression of the low frequency portion of the Square Kilometre Array (SKA-low) to be constructed in Australia. Credit: Swinburne Astronomy Productions/ ICRAR/U. Cambridge/ASTRON.

ICRAR is partnered with ten prestigious institutions from around the world—including the Netherlands Institute for Radio Astronomy (ASTRON), the Italian National Institute for Astrophysics (INAF), Oxford University and Cambridge University—to design the LFAA.

The consortium is responsible for designing the Christmas tree-like antennas, amplifiers and local monitoring, control and processing for SKA-low.

Prototyping and verification are critical elements of the SKA design process and ICRAR leads this critical task within the LFAA Team.

As part of this program of work ICRAR and its partners are developing a series of SKA verification systems known as the Aperture Array Verification System (AAVS).

The first version of the AAVS, AAVS0.5, was deployed at the MRO in 2012. AAVS0.5 consists of 16 SKA-low Antennas (SKALA) configured to utilise the signal processing chain of the Murchison Widefield Array (MWA) with which it is co-located.

Thanks in large measure to ICRAR engineers and scientists AAVS0.5 has been a highly productive system, enabling a number of preliminary measurements and characterisations to be made, and uncovering a variety of design and integration issues for consideration in resolution through the detailed design process.

The team are now working on a much larger 400-SKALA system, AAVS1, which will include one full-size SKA station of 256 antennas and three smaller stations.

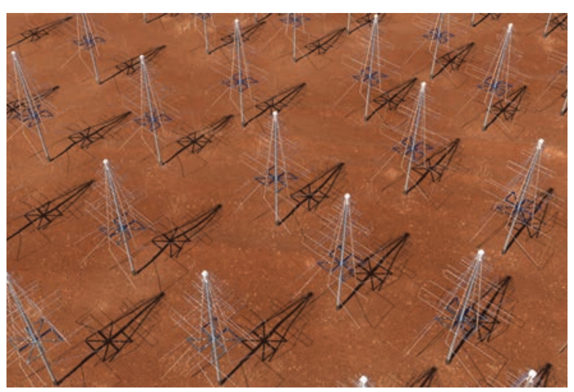
AAVS1 will be constructed from late 2015 and will play a critical role in verifying that the LFAA design satisfies SKA's performance requirements.

A significant challenge facing the LFAA team is the sheer scale of the instrument. There are few precedents for the deployment and installation of thousands of antennas to demanding positional and orientation specifications.

ICRAR leads the activity to investigate and plan the deployment of the LFAA and the engineering team involved in the project are drawing on their unique expertise and experience developed through constructing, commissioning and now operating the MWA at the MRO.

Working on the MWA and AAVS0.5 at the MRO has given the ICRAR engineering team end-to-end system understanding and insights few, if any, other groups involved in SKA preconstruction activities can match.

This means that ICRAR is uniquely placed to make high impact contributions to the design, construction and commissioning of the SKA-low telescope in the coming years.



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ACHIEVEMENT

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A 16-antenna prototype known as AAVS0.5 was deployed, linked to the existing Murchison Widefield Array and its data processed by ICRAR researchers.

RESEARCHER PROFILE
Dr Adrian Sutinjo
Senior Research Fellow

It sounds like a challenge that would intimidate even the most talented engineers; building a telescope in a remote desert region, on a scale never seen before, that could one day generate more data in a single day than current global internet traffic.

But for Adrian Sutinjo, solving problems to pave the way for the Square Kilometre Array (SKA) is absolutely the best part of his job.

"I like how easy it is to find problems that have not really received attention," he says.

"In a lot of areas of research you have to dig quite deep to find problems. Here the problems are all around you and you have a hard time keeping up with the rate at which they come up… it's exciting."

Adrian originally trained as a radio engineer and worked in industry for seven years before returning to university to complete a PhD in antennas and electromagnetics.

Today, the down-to-earth researcher leads the prototyping and verification task for the Aperture Array Verification System for SKA-low.

> *"In 2014, our team completed the characterisation of a 16-element prototype in the Murchison region, which was deployed, linked to the existing Murchison Widefield Array and the data processed by ICRAR researchers."* Dr Adrian Sutinjo

The highly successful project was the first verification system on site and uncovered a number of issues to be solved in preparation for the start of construction.

The team are now working on a much larger 256-element prototype, which is expected to be the same size as a full SKA station and will represent one part in several hundred of the final SKA.

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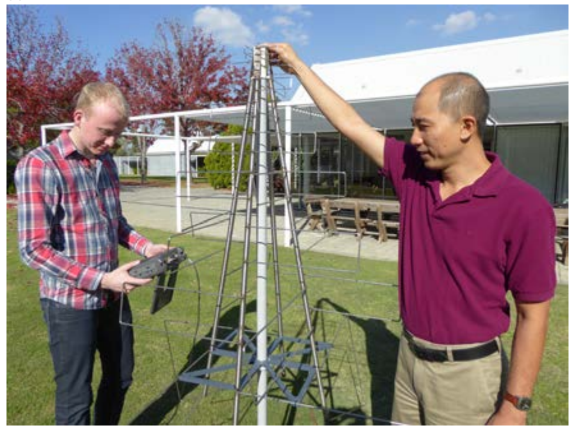

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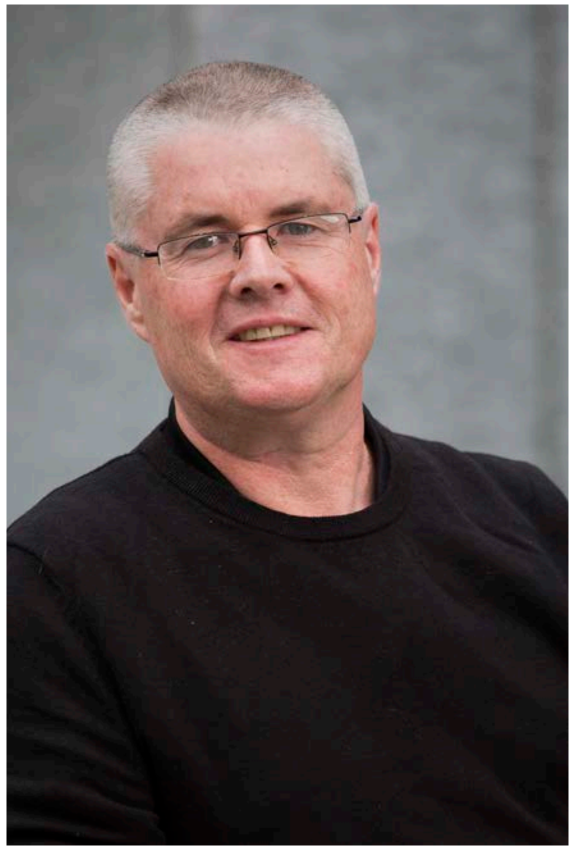
53. Dr Adrian Sutinjo.

54. Dr Adrian Sutinjo and Rene Baelemans, a student intern from the Technical University of Eindhoven, testing an "SKA Log-periodic Antenna" (SKALA) prototype designed by Cambridge University.



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55. David Kenney.

56. RF characterisation of a conical log-spiral reference antenna designed and built by ICRAR Engineering.

KEY STAFF PROFILE
David Kenney
Senior Technical Officer

It is not every day you get to spend time in a state-of-the-art laboratory where prototypes are being built for what is arguably the world's largest science project.

Unless of course you're David Kenney, one of the go-to guys for all things related to the ICRAR engineering laboratory where ideas for the multi-billion dollar Square Kilometre Array (SKA) telescope come to life.

This cutting-edge facility is located at Curtin University and allows engineers to build and test components before they are deployed in the field, acting as an interface between ideas and the real world.

The laboratory houses world-class technology in radio-frequency test and measurement equipment, antenna design systems and low-noise microwave engineering, some of which are the only systems of their kind in Australia.

A big part of David's job is supporting research engineers and students working in the facility as they build and test technology being considered for the SKA.

> *"The resources in the lab are really quite impressive and it's a privilege to be able to use this high end gear."*
> *David Kenney*

David also plays a leading role in the development, field deployment and validation of preconstruction systems for the SKA, and has made several trips to the Murchison region where the telescope will eventually be built.

Before coming to ICRAR, David worked in industry as a design engineer, looking at projects including the detection of explosives, narcotics and weapons for aviation security.

He says he loves the hands on nature of his role at ICRAR and the chance to learn new things.

"There's a lot of new stuff to learn here and there are a lot of clever people," David says.

Earth's Ionosphere

Deep space search yields discoveries close to home.

Astronomy often leads to discoveries no one could have imagined at the start of the research. CSIRO, for instance, famously invented WiFi during a radio astronomy project.

At ICRAR, the search for a faint signal from the early Universe has led to discoveries about a part of the upper atmosphere just 100km above the surface of the Earth, known as the ionosphere.

Astronomer Marcin Sokolowski began looking at the ionosphere while using an experiment called BIGHORNS to search for the signal from the Epoch of Reionisation, a time that saw the birth of the first stars and galaxies in our Universe.

The signal from the Epoch of Reionisation is extremely faint and the ionosphere was distorting the radio waves BIGHORNS receives.

This distortion is somewhat of a nuisance for the instrument but it is allowing Dr Sokolowski and his colleagues to examine the properties of the ionosphere—and what they are finding is that it changes considerably from one day to another.

The ionosphere is made up of ions and free electrons so if, for instance, the Sun is more active, or there are more cosmic rays hitting the atmosphere at a particular time, the rate of ionisation will increase.

This change in ionisation has a significant impact on how the ionosphere absorbs, emits and refracts the radio waves astrophysicists are searching for.

The ionosphere is affecting another project as well—the Murchison Widefield Array—which aims to statistically detect the signal from the Epoch of Reionisation.

Only by calibrating the telescope to remove the unwanted effects of the ionosphere will we be able to detect this very faint signal from the early Universe.

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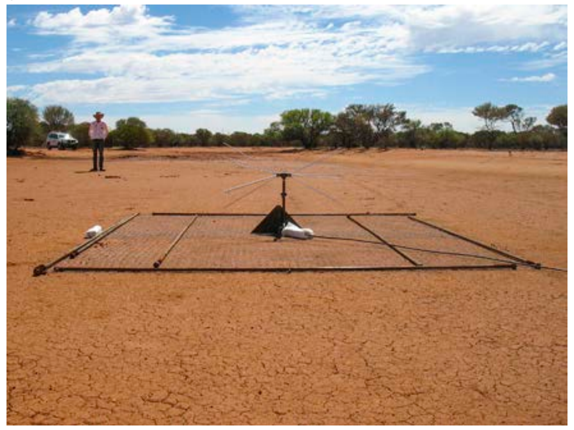

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57. Dr Marcin Sokowlowski and Dr Randall Wayth installing the BIGHORNS cone antenna at the Murchison Radio-astronomy Observatory.

58. BIGHORNS deployment at Wondinong Station near Mt Magnet with a portable biconical antenna.

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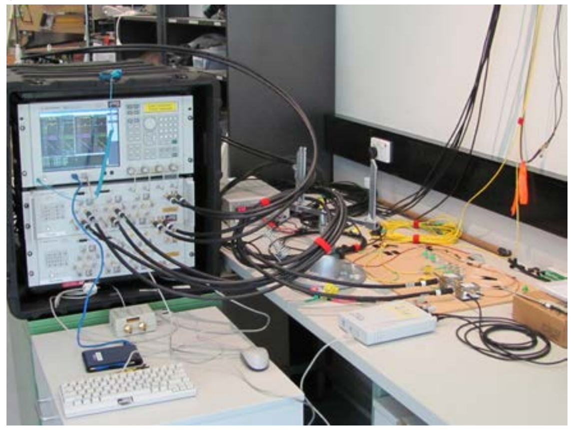

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59. James Buchan.

60. The Electronics Laboratory at ICRAR/Curtin.

61. An anechoic chamber.

STUDENT HIGHLIGHT
James Buchan
PhD Student

At a time early in his PhD when many students are focused on trawling through the literature, James Buchan is already thinking about his design for a low-interference inverter for the Square Kilometre Array (SKA).

Radio telescopes need to be in radio-quiet areas where there is limited interference from everyday technologies like mobile phones, TV and radio stations.

The Murchison Radio-astronomy Observatory, where the Square Kilometre Array (SKA) is set to be built, is perfect for this, with just 110 people living in a shire half the size of Tasmania.

But it is also important to make sure electromagnetic interference is not introduced from components of the telescope itself—and this is where James' research comes in.

James completed his honours in electrical engineering through ICRAR in 2014, working on electromagnetic interference suppression techniques for an early SKA prototype known as AAVS0.5.

He spent time working with renewable energy company Balance Utility Solutions before coming back to finish what he started, and do a PhD based around the next stage of the SKA design process, AAVS1.0.

> *"The project that we're working on involves designing and prototyping a solar hybrid stand-alone power system that will supply energy to the antennas."*

"The power system will contain a commercially available inverter, which is expected to generate electromagnetic interference requiring suppression technologies such as filtering and shielding"

"If this inverter generates too much electromagnetic interference and fails to meet electromagnetic compatibility standards for the SKA, we will have to come up with a new design for one that doesn't interfere with the antennas "

James' PhD is jointly supervised by ICRAR and the Curtin Department of Electrical and Computing Engineering, and James says he wanted to do research in radio astronomy because the SKA is such a large-scale and well-known project.

"I thought it would give me a great foot in the door in terms of radio astronomy engineering and electrical engineering in general," he says.

"Undertaking a PhD research project provides me a chance to work on a really innovative and challenging project and it potentially leads into a really exciting future career."

The Epoch of Reionisation– keeping it quiet

Watching the birth of the first stars and galaxies.

All over the world, astrophysicists are in a race to peel away 13 billion years of cosmic time and uncover faint signals from the birth of the first stars and galaxies.

This period in the early history of the Universe is known as the Epoch of Reionisation—a time roughly a billion years after the Big Bang when the light and radiation from the first stars and galaxies spread out and reionised the hydrogen in the Universe.

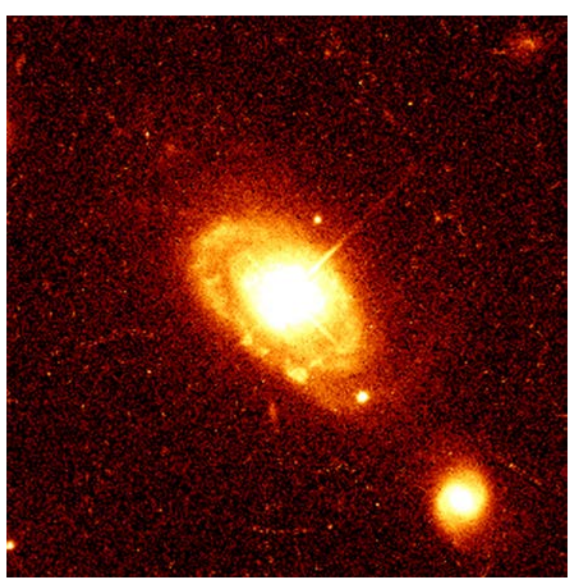
The signal from this time, sometimes called "cosmic dawn", is very faint and incredibly difficult to detect.

But ICRAR is at the forefront of the international mission to find out more about this mysterious period in the early Universe thanks to the unique BIGHORNS experiment and the Murchison Widefield Array (MWA).

BIGHORNS is a simple experiment that aims to detect the average of the signal from the Epoch of Reionisation across the entire sky.

This portable, battery-powered experiment uses a single antenna to search deep into space for the elusive signals.

In 2013 and 2014, BIGHORNS was deployed in radio quiet locations around Western Australia with stints at Eyre Bird Observatory in the middle of the Nullarbor, at Wondinong Station east of Mt Magnet and at Muresk, some 70km north-east of Perth.



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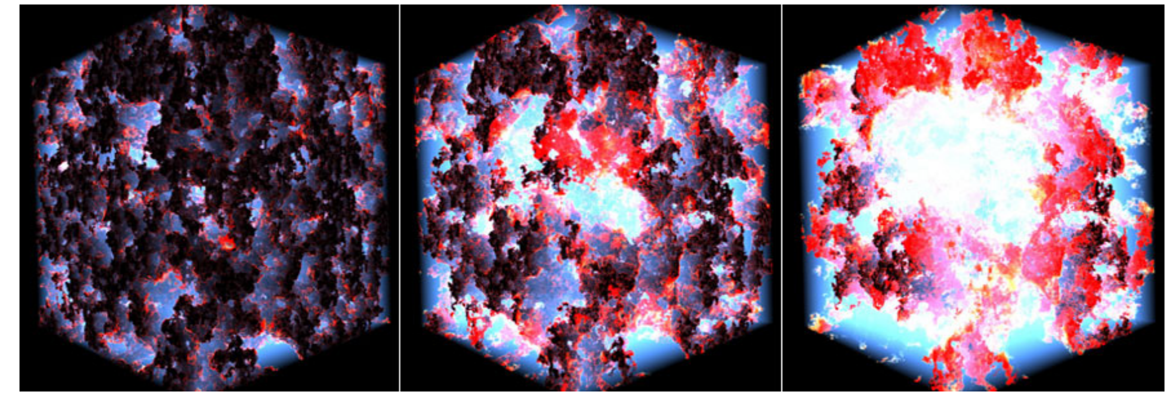
62. Quasar PG 0052+251 and its host galaxy as observed by the Hubble Space Telescope. Image courtesy STScI.

63. A Conical Log-Spiral Reference Antenna at the Murchison Radio-astronomy Observatory.

64. A portion of space 1 billion light years across depicted in three moments of a reionisation simulation. Dark colours indicate cold neutral gas, while red to blue to white indicates increasingly hot ionised gas. The bubbles form small but expand and merge. Image courtesy of Marcelo Alvarez, Ralf Kaehler and Tom Abel.



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In October 2014, the experiment found a more permanent home at the Murchison Radio-astronomy Observatory, a radio-quiet location set to be the future site of the low frequency antennas of the Square Kilometre Array (SKA).

BIGHORNS now sits alongside the MWA, which is also being used to detect the Epoch of Reionisation.

Where BIGHORNS looks at the global average of the signal from all parts of the sky, the MWA looks on a smaller scale at the signal coming from particular patches of the sky, staring at these patches (or fields) for hundreds or thousands of hours.

Within these fields there are thousands of " foreground sources"—radio galaxies, quasars and other objects that produce radio waves.

But the signal from the Epoch of Reionisation is behind the foreground sources, and spread across the sky.

To find the signals from the early Universe with BIGHORNS or the MWA, the research team needs to understand and remove the foreground sources through very precise calibration of the instrument, which begins in the design stage and ends with data post-processing that uses sophisticated statistical techniques to separate the foreground at different times and frequencies.

The level of sensitivity from the MWA is one step closer to the SKA, which, when built, will be sensitive enough to image chunks of the Universe and look even closer at regions of ionised hydrogen.

Being able to successfully detect the signal from the Epoch of Reionisation would help theoretical physicists to confirm or disprove various models of the Universe.

It would help us discover when the hydrogen became ionised, how long it took and whether stars, galaxies or black holes were responsible for this massive change in the early Universe.

And while the signal from the Epoch of Reionisation so far remains elusive, early results from BIGHORNS and the MWA are very promising.

ICRAR's scientists and engineers are constantly improving the instruments to remove background interference and tune them in to the signals from the Epoch of Reionisation.

Through this onion peeling exercise we are learning more every day about radio frequency interference in the Murchison, a part of the Earth's atmosphere known as the ionosphere and our own Sun, all while we get ever closer to finding out more about the very beginnings of the Universe.

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65. 2014 ICRAR-iVEC Summer Studentship students Sarah Nelson and Mitchell Chiew joining in on a school visit to ICRAR.

SUMMER STUDENTSHIPS

5

Summer Studentships Program

ICRAR's various studentship programs have seen 54 students join us for up to ten weeks since ICRAR's beginning in 2009. Students worked with our staff on projects across astronomy, engineering and high performance computing, gaining valuable experience for their future careers.

Our summer studentship program has grown in status and reach since the first cohort completed their studentships in early 2010, and we now regularly receive more than a quarter of our applications from interstate and New Zealand.

This highly competitive program only accepts one in five students that apply, and includes support for the student's living and travel expenses for their time at ICRAR.


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66. ICRAR-iVEC Summer Studentship students.

67. 2014 Summer Studentship student Ben Courtney-Barrer helps a high school student triangulate the location of a meteorite during a 'Fireballs in the Sky' activity.

68. 2014 Summer Studentship student (and now an ICRAR Masters student) Kirsty Butler and work experience student Cole Bannister using ICRAR's Tiny Radio Telescope to measure the temperature of the Sun's corona.

Each year eight students are selected; four for the ICRAR studentship program, and four additional students join us in the ICRAR-Pawsey Centre (formerly iVEC) program for projects with a computational focus. ICRAR staff also support students who enter through Curtin and UWA faculty programs that have an interest in astronomy.

Participants have ranged from first year undergraduate students through to students at the end of their first degree, with the main target group being students in their third and fourth year who are ready to make decisions about their post-undergraduate future.

As well as their project work with supervisors from throughout ICRAR, our studentship students also immerse themselves in ICRAR life, joining in on social events and research group activities such as journal club and colloquia, building their network to help in their future endeavours.

The program has been very successful thus far, with many students continuing on to PhDs at an ICRAR node, and many more still continuing their association with ICRAR in other ways (see the 'Honour Roll' alongside).

The opportunities available to ICRAR's studentship students are often unique among astronomy programs, with some of our students working at the SKA site in the Murchison, travelling across the Nullabor to help deploy equipment and working with the Outreach and Education team for annual summer schools and student visits.

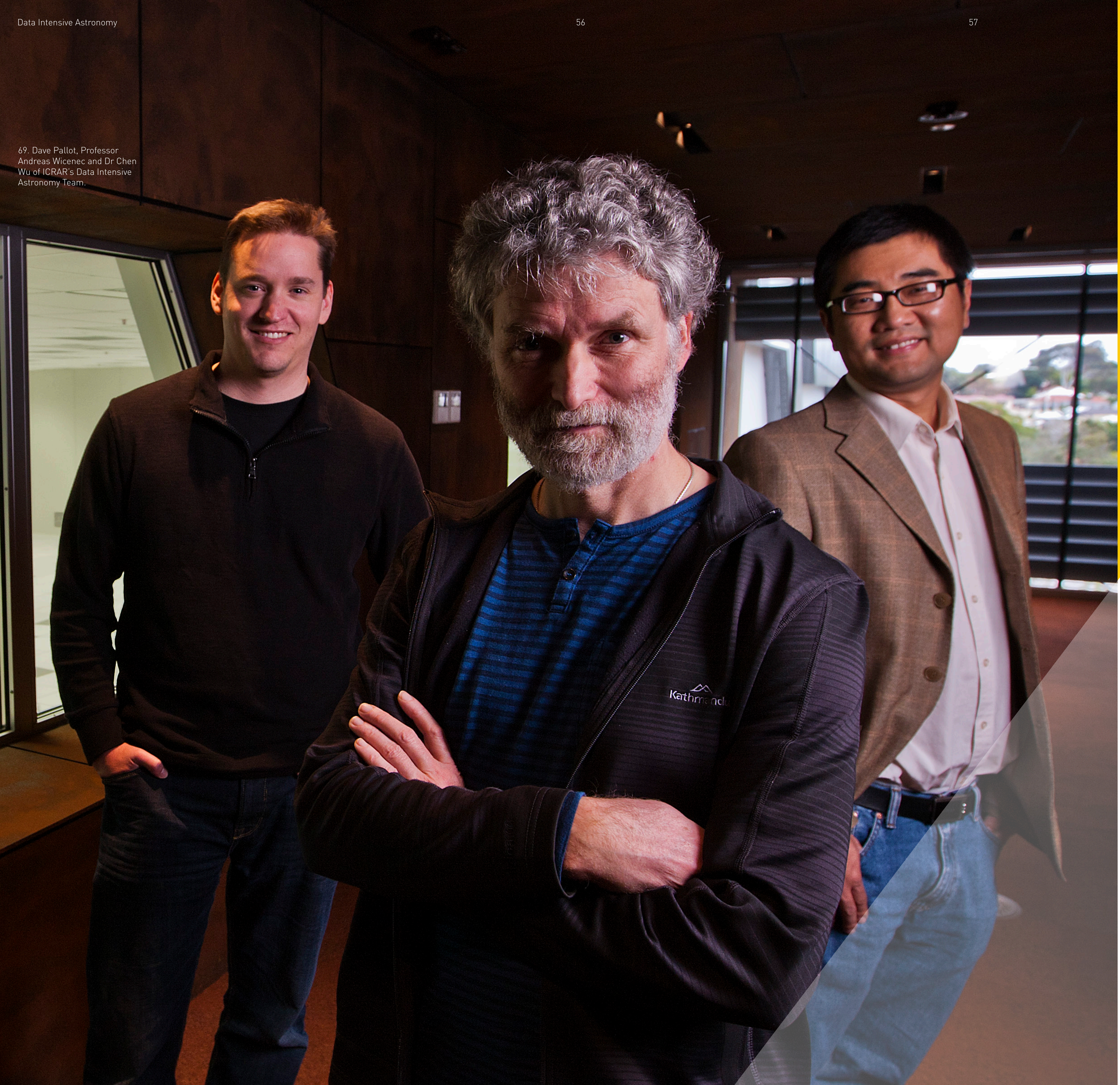
Our students are also offered mentoring and advice about their future in astronomy and related fields by experienced ICRAR staff and postgraduate students, and are exposed to non-academic career options in data science, industry and other fields, providing a well rounded experience of future options in astronomy.

For the next five years of ICRAR we plan to continue to expand the opportunities available within our studentship program, including the opportunities that will arise as SKA construction draws closer. ICRAR is committed to helping foster the skills of Australia and New Zealand's next generation of astronomers, engineers and data intensive astronomy specialists through our studentship programs.

ICRAR Summer Studentship Program Honour Roll

The students listed below have continued their association with ICRAR following the completion of their studentships, and as many more studentship students complete their undergraduate degrees this list will continue to grow.

Student	Where are they now...
Morag Scrimgeour 2010	Completed her PhD in 2013 at ICRAR/UWA.
Daniel Beard 2010	Worked part time at ICRAR for a semester following a studentship.
Monique Hollick 2010	Studied Science Communication at UWA and joined us for a science communication internship in 2014.
Steven Murray 2012	Currently a PhD student at ICRAR/UWA.
Sarah Bruzzese 2012	Currently a PhD student at ICRAR/UWA.
Stephen Andrews 2012	Currently a PhD student at ICRAR/UWA.
Teresa Slaven-Blair 2012	Completing honours in astronomy at Curtin University.
Jarrod Ramsdale 2013	Completed an honours degree in astronomy at Curtin last year.
Sammy McSweeney 2014	Completing an honours year in astronomy at Curtin this year.
Krystal Cook 2014	Completing a Masters in Astronomy at ICRAR/UWA.
Ryan Urquhart 2014	Currently a PhD student at ICRAR/Curtin.
JT Malarecki 2014	Currently a PhD student at ICRAR/UWA.
Morgan Lewis 2014	Now a published author in astronomy. When his studentship work was included in a paper by ICRAR/Curtin researcher Dr Sokolowski, Morgan was listed as a co-author of the paper.
Benjamin Courtney-Barrer and Andrew Jamieson 2015	Both are working with UWA Physics staff for their honours projects at the Australian National University in 2015.
Kirsty Butler 2015	Commenced a Masters in Astronomy at ICRAR/UWA.



69. Dave Pallot, Professor Andreas Wicenec and Dr Chen Wu of ICRAR's Data Intensive Astronomy Team.

DATA INTENSIVE ASTRONOMY

6

Data Intensive Astronomy Overview

ICRAR's Data Intensive Astronomy group is producing leading edge solutions for unimaginable volumes of information and data.

The team is leading international efforts to manage the data deluge from the Square Kilometre Array (SKA) telescope, which, when built, will produce 100 times more data than the world's internet traffic in 2010.

Transporting, processing and storing this extraordinary quantity of data will require incredible computer power and the SKA will be supported by a supercomputer capable of more than 100 petaflops (one hundred thousand, million, million floating point operations) per second, three times more powerful than the world's top supercomputer in 2013.

ACHIEVEMENT

∗ The MWA archive is controlling almost 10 million individual data files adding up to more than 6 Petabytes (1 PB = 1,000,000 GB)... and counting.

To meet the challenge of dealing with this amount of information, ICRAR's Data Intensive Astronomy team come from both industry and academia and have a broad range of expertise from computer science to radio astronomy, technical project management, systems engineering and systems modelling.

In 2013 and 2014, the group has focused on designing the data layer for the science data processor—the 'brain' of the SKA—as part of a prestigious collaboration led by Cambridge University.

ICRAR is contributing about 30 per cent of the manpower to this project, which is a hugely important step in being able to make incredible discoveries with the SKA.

The opening of the Pawsey Supercomputing Centre in late 2013 has given ICRAR access to world leading super computing facilities on our doorstep in Perth.

ICRAR is the prime user of this facility, which houses several powerful supercomputers including one known as Magnus that is capable of performing a million billion calculations simultaneously every second.

Magnus debuted at number 41 in the list of the world's top 500 supercomputers in 2014, making it the most advanced scientific supercomputer in the Southern Hemisphere at the time.

At the same time as designing crucial pieces of the puzzle for the SKA, ICRAR's Data Intensive Astronomy team is supporting existing precursor projects such as the Murchison Widefield Array (MWA), which the Centre developed the data archive system for.

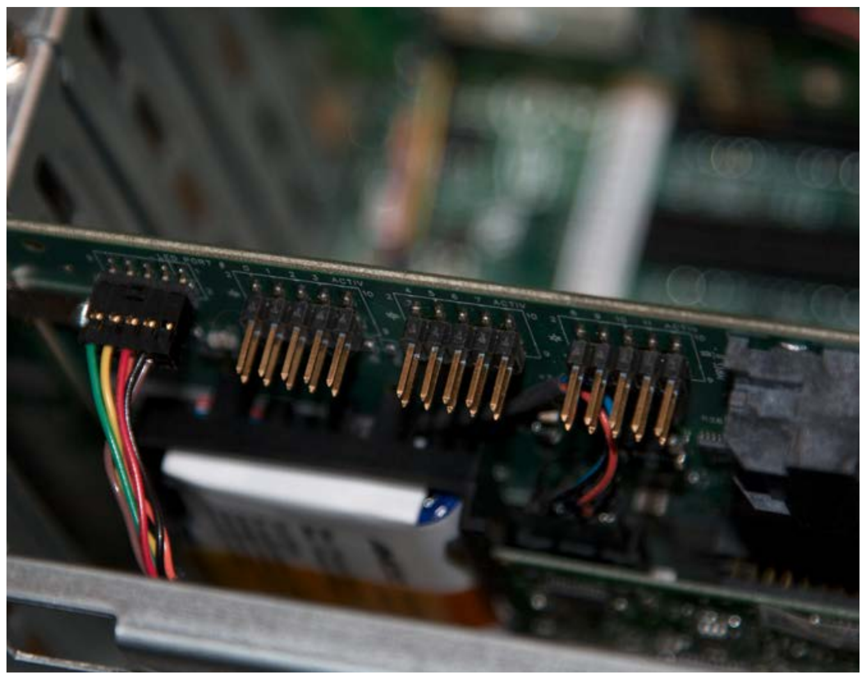
They are also working to support big survey science projects like GLEAM, conducted with the MWA, and the CHILES survey, which uses data collected by the Jansky Very Large Array radio astronomy observatory in the United States. CHILES is a huge survey that is producing data very similar to that which is expected to come from the Australian SKA Pathfinder and the SKA. CHILES data is also being used to further develop theSkyNet, a citizen science initiative that links thousands of computers around the world to simulate a powerful supercomputer.

These projects are allowing the Data Intensive Astronomy team to try out ideas such as cloud computing and prototype data management systems using real observations, experience that puts them among the best in the world at dealing with big data from radio telescopes.

70. Computer components.

71. A view inside the 6500 slot robotic tape library operated by iVEC's Pawsey Centre.

72. Part of the 'Central Nervous System' of a supercomputer.



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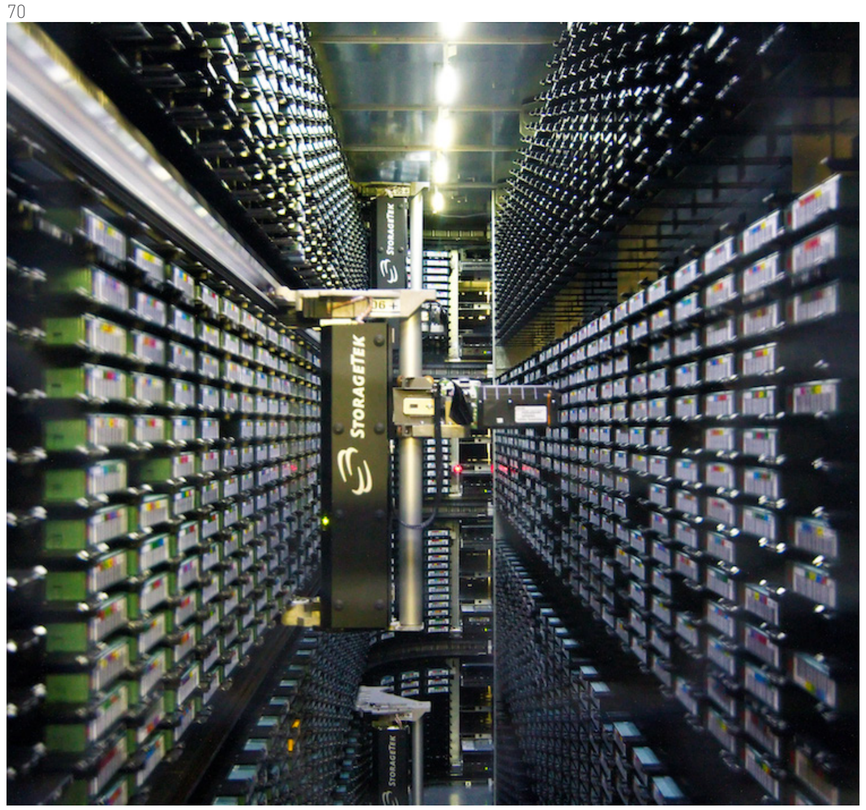

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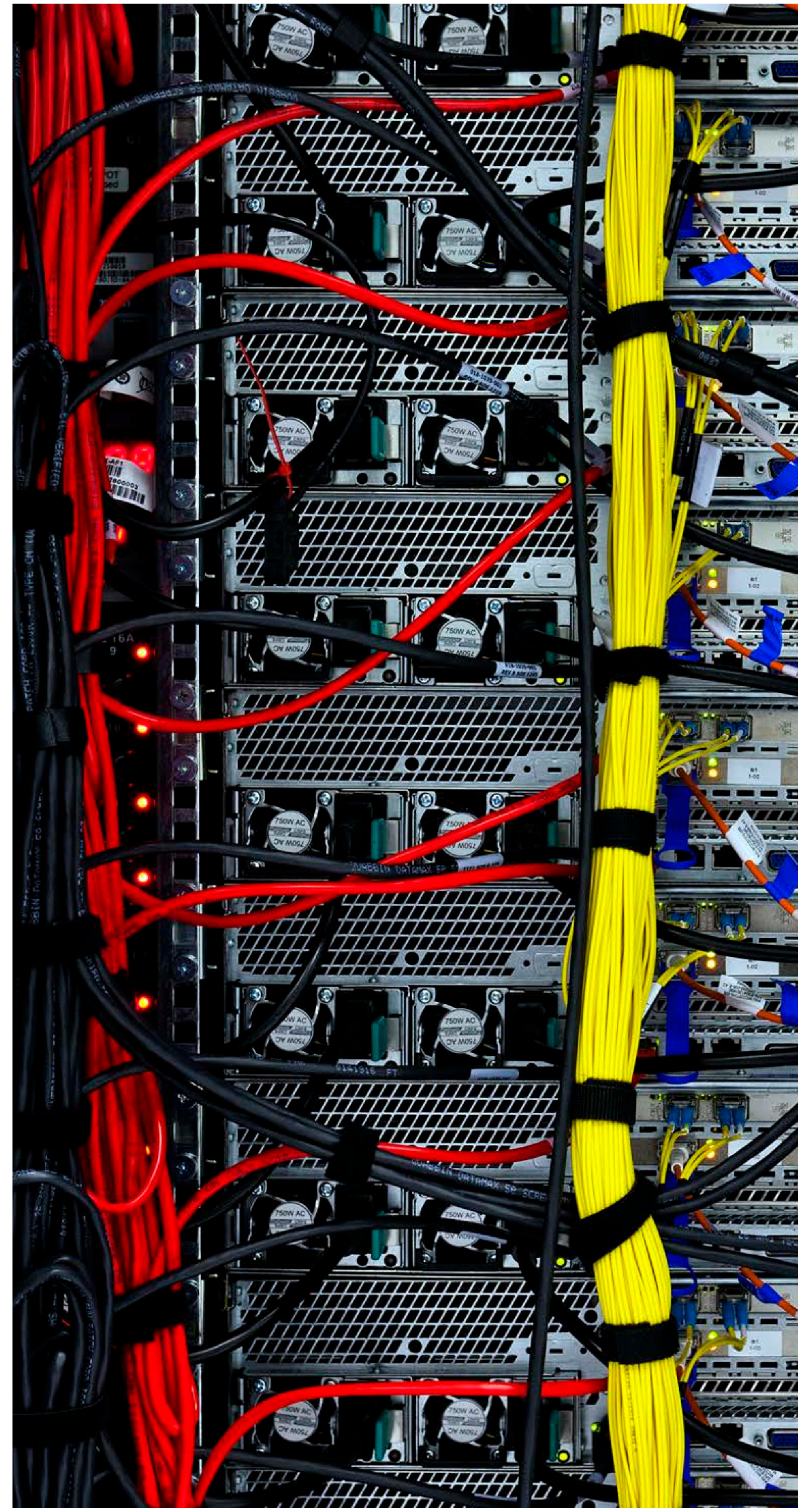

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Building the 'brain' of the SKA

When the Square Kilometre Array (SKA) is turned on, it will immediately start collecting huge amounts of radio signals coming from stars and galaxies in the distant Universe.

The low frequency part of the SKA alone is set to have more than a quarter of a million antennas facing the sky, collectively producing terabytes of data every second.

With so many antennas producing such sensitive observations, there has to be a point where the data is calibrated, processed and archived—the 'brain' of the SKA.

This brain is called the Science Data Processor and it will filter out interference and turn the data into a form that can be accessed by astronomers around the world.

This hugely important step in being able to make incredible discoveries with the SKA is one that ICRAR's Data Intensive Astronomy team is taking a leading role in designing.

From the telescope's home in remote outback Australia and South Africa, the observations of the sky will initially come in like TV signals.

They will be sent to a dedicated computer on site known as the Central Signal Processor, where the raw data will be reduced ready to be sent to high-performance computing centres.

In Australia this means an 800km trip down a long fibre link to the Pawsey Supercomputing Centre in Perth and in South Africa the data will be transported to Cape Town.

It is here that the Science Data Processor (SDP) comes into play.

The data is calibrated to remove unwanted radio frequency interference or 'noise' caused by things like mobile phones, satellites, TV signals and aeroplanes.

The SDP bridges the gap between the telescope and the science by turning the data into products, such as multi-wavelength image cubes, that can then be used by astronomers to make discoveries.

At the same time it will also search the observations of the sky for sources that vary in time.

These processes are independent of each other and some will happen concurrently, all in close to real time.

The challenge is huge because the data rates coming off the telescope are enormous—more than the entire global internet traffic for 2010 each day.

The Science Data Processor is one of three SKA 'work packages', or groups working together to develop the final design for the telescope, that ICRAR is involved in.

The work package is led by Cambridge University and involves a suite of prestigious institutions and industry partners including Oxford University, ASTRON in the Netherlands and Amazon.

Within this impressive collaboration, ICRAR is responsible for the part of the SDP known as the data layer—the part that binds everything together along the pipeline the data is sent through.

The data layer controls what happens to the data from the time it comes in on the fibre cable to the final product delivered to the scientists.

The SDP design ICRAR is creating is referred to as 'data-driven', which means the data itself is an active program that will kick off the applications needed to process it.

You can think of this like a Word document. At the moment you would start Word and then open the document afterwards but ICRAR is looking to turn that around.

A data-driven system would be like having the document first, and the document knowing that it needs to be edited and opening Word.

While Word does not know what you want to write, we do know what needs to happen to the SKA data every step of the way, so the data can actually run the whole process without the need for human interaction.

As well as creating the framework for the data pipeline, ICRAR is also responsible for moving the data around. One of the big challenges here is in having cost effective storage so the information can be archived for many years.

This area is highly dynamic and it is expected that storage hardware will get cheaper and many of the technologies we use today will change considerably over the course of the SKA's 50-year lifetime.


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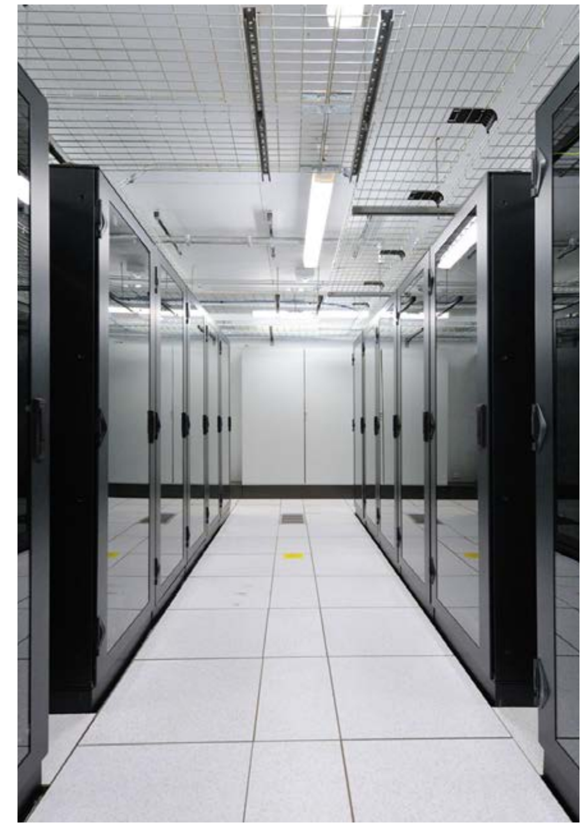
But the software should not change too much at all—many of the pipeline modules we use at the moment were written in the 1970s and 1980s—so it is important to design a system that can be adapted to technology changes.

With such a large and diverse project to complete, it makes sense that ICRAR's Data Intensive Astronomy group has a diverse team that includes radio astronomers, software developers and seasoned experts who have worked on big industry projects who can help deliver the complex, robust architecture required.

Most of the team are split between working on the Science Data Processor and science support for existing projects, allowing them to test out ideas on real-world data being produced now by surveys such as CHILES, on the Karl G. Jansky Very Large Array telescope in the United States, and GLEAM, on the Murchison Widefield Array.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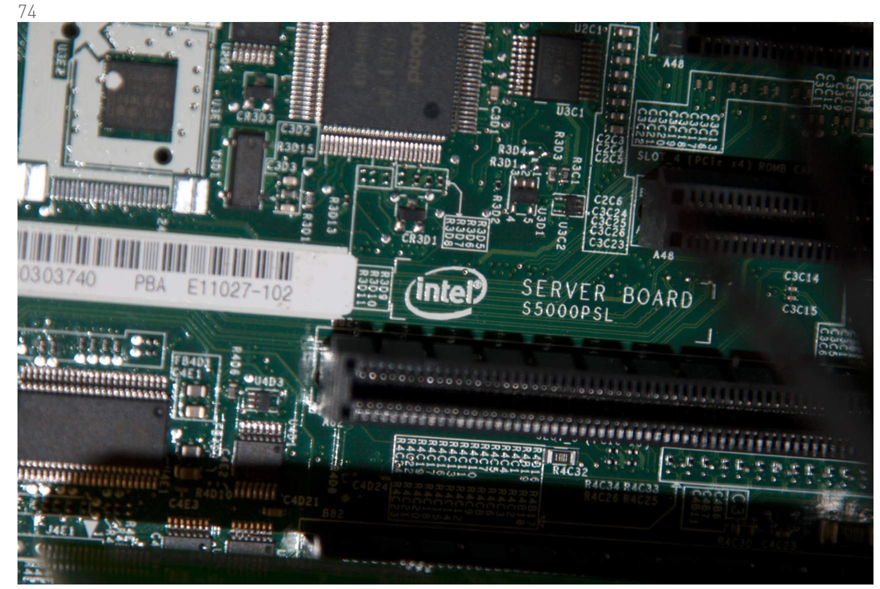

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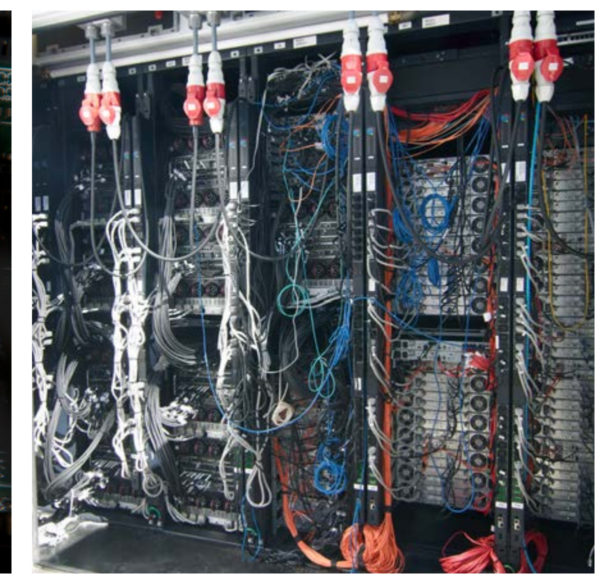
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73. An aerial view of part of the Australian SKA Pathfinder and the Control Building for the Murchison Radio-astronomy Observatory (MRO).

74. Supercomputer racks inside the MRO's Control Building.

75. A server board and components.

76. The backend of a supercomputer.

77. Professor Andreas Wicenec, head of ICRAR's Data Intensive Astronomy team.

78. Inside the Control Building of the MRO.

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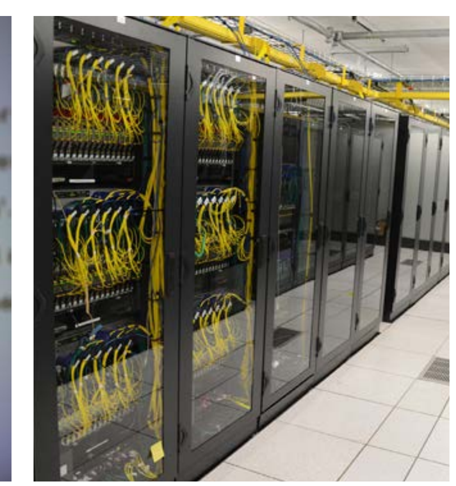
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RESEARCHER PROFILE
Kevin Vinsen
Senior Research Fellow

After almost 10 years as the chief software engineer for one of Australia's leading defence contractor Thales, Kevin Vinsen knew it was time for a change.

But it was a part-time role helping out in the early days of ICRAR that rekindled his passion for computing and prompted him to give up his job managing more than 360 engineers to work in astronomy.

"I had so much fun I decided to take a pay cut to come to ICRAR," he says. "I wish I'd done it years ago—I'm back doing the type of things I love."

Now, Kevin is helping to make discoveries about our Universe by managing the incredible amounts of data that will be produced by next generation radio telescopes.

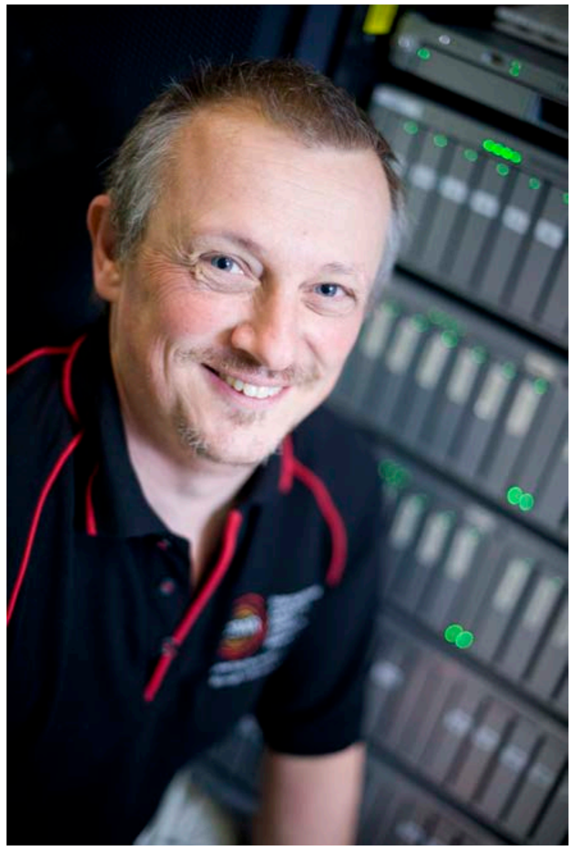
He works with a consortium of 21 organisations worldwide, led by Cambridge University, on the Science Data Processor for the multi-billion dollar Square Kilometre Array (SKA).

> *"The data rates involved are expected to exceed global internet traffic."*
> *Kevin Vinsen*

Kevin produced the software engineering and configuration management plans for the Science Data Processor consortium in a process known as the Preliminary Design Review.

He provides data support for two huge galaxy surveys called GAMA and CHILES and is the project scientist for theSkyNet, a citizen science initiative that links thousands of computers around the world to simulate a powerful supercomputer.

"I'm a kid in a toy shop," Kevin says. "I can do the techie stuff that I love and the team is fantastic… we just get on and do awesome stuff."



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79. Kevin Vinsen.

80. Perth's Pawsey Supercomputing Centre.

Pawsey Supercomputing Centre opens on ICRAR's doorstep

The $80 million Pawsey Supercomputing Centre is now open for business, giving ICRAR access to one of the world's largest supercomputers on their doorstep in Perth.

The powerful Magnus supercomputer housed at the Centre is capable of performing a million billion calculations simultaneously every second, and debuted at number 41 in the list of the world's top 500 supercomputers in 2014.

This made it the most advanced scientific supercomputer in the Southern Hemisphere at the time.

Another powerful supercomputer at the Centre—Galaxy—contains the same amount of memory as 6400 DVDs and is dedicated to radio astronomy research.

Even the name of the Centre comes from pioneering Australian radio astronomer Dr Joe Pawsey.

The Pawsey Supercomputing Centre was officially launched in 2013 but ICRAR was given early access to the facility, becoming Pawsey's first large-scale customer.

ICRAR has been using the facility to process and archive data from the Murchison Widefield Array (MWA) since the telescope became operational in mid-2013, with the data being stored on a combination of hard disks and tape archive.

The Pawsey Supercomputing Centre has also been earmarked as the future location of the science data processor for the Square Kilometre Array when the telescope is built.

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Collaborating with the big guys

With big data set to be one of the largest computing challenges of the coming decades, it's no surprise ICRAR's work in Data Intensive Astronomy is attracting the attention of leading technology companies from around the world.

These big players in the world of computing and information technology include corporations such as Amazon, Intel, IBM, Cisco Systems and Raytheon—all sharing an interest in managing the kind of data rates that next generation telescopes like the Square Kilometre Array (SKA) will produce.

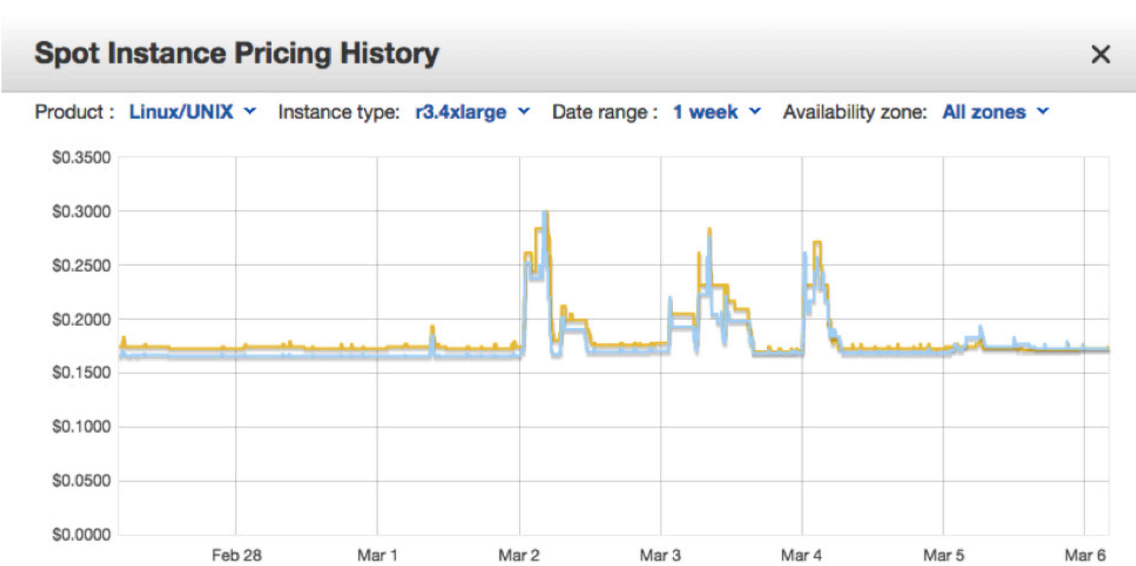
> * *In the past five years, ICRAR has engaged in more than 60 varied collaborative projects, 21 of them with industry.*

Cisco Systems and NVIDIA, for instance, have been contracted to help design the Central Signal Processor for the SKA, while global IT consulting firm ThoughtWorks has allowed its staff to help ICRAR in between projects for clients—time known within the company as being "on the beach".

Technology giant Amazon came on board initially to help with theSkyNet, an ICRAR-led citizen science initiative that links thousands of computers around the world to simulate a powerful supercomputer.

Now ICRAR is looking to use Amazon's cloud computing services to process, store and distribute data from the CHILES survey, a deep space survey conducted on the Jansky Very Large Array telescope in the United States.

Using Amazon's cloud would allow researchers all over the world to access observations from the telescope, rather than the traditional approach of storing all the data at a single supercomputer in one place.



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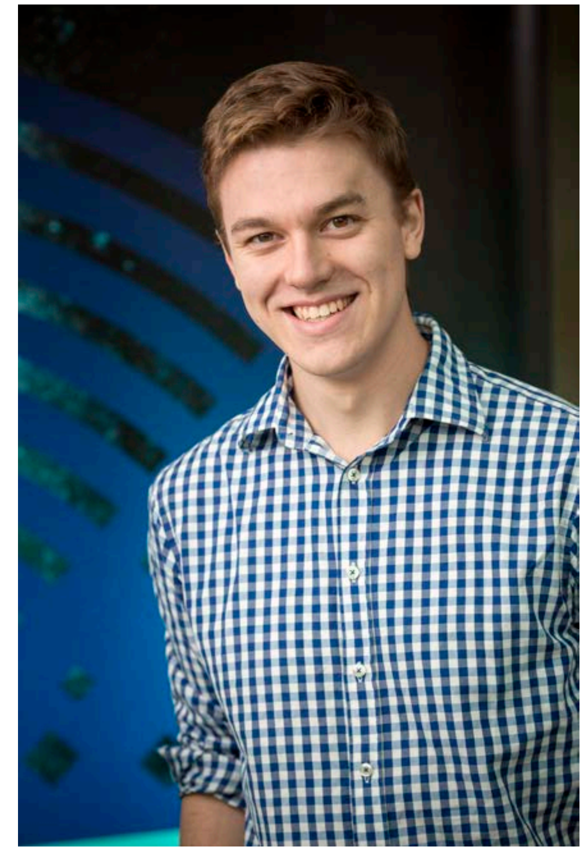
81. A graph showing the cost of the Amazon Web Services cloud computing platform for Australia and the significant effects on market price caused by processing the CHILES data.



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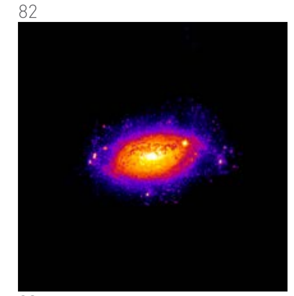

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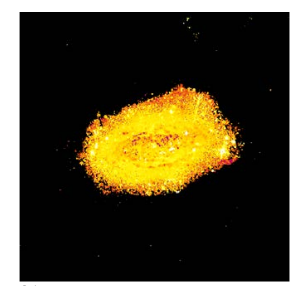

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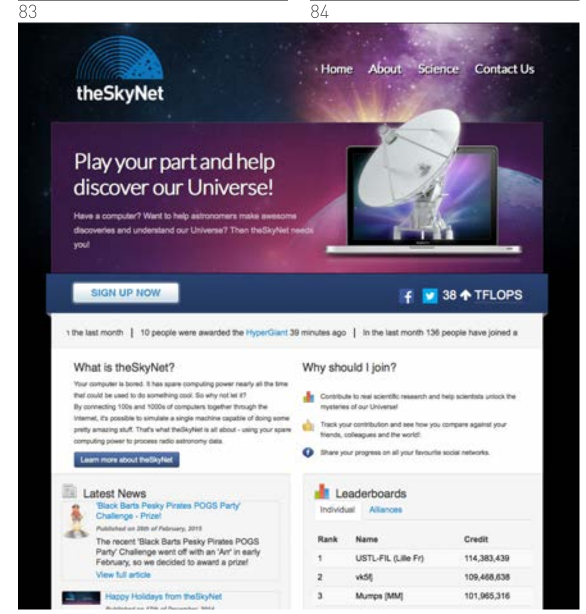

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STUDENT HIGHLIGHT
Ryan Bunney
Summer Student

For Ryan Bunney, the chance to work on theSkyNet, a citizen science initiative that links thousands of computers around the world to simulate a powerful supercomputer, was a dream come true.

Ryan undertook a winter internship with ICRAR in 2014 and implemented the celestial source finder Duchamp on the BOINC volunteer computing platform, work that means volunteers now have another set of observations to process and can contribute even more to discoveries in radio astronomy.

> *It was really good fun, it was a good learning experience and a fairly steep learning curve initially."*
> *Ryan Bunney*

"It was good for me personally because I picked up a lot of skills... when I attack a uni problem now it's a lot easier."

Ryan enjoyed the project so much he returned to ICRAR as a summer student to finish what he started, and now works part-time on theSkyNet,

The University of Western Australia computer science student hopes to one day complete his honours followed by a PhD in data intensive astronomy.

Ryan says being able to work on theSkyNet was "just the coolest opportunity".

"This project's great because it has a good community orientation and we can engage with volunteer scientists in a way that we wouldn't have been able to do previously," he says.

"But also, it's a stepping stone into bigger data projects, which is a fascinating field and is absolutely the big computing area in the next 10 or 15 years.

"And obviously being able to work on the SKA, which is such a great scientific area of work in general, in a computing field—it's a marriage of the best of both worlds."

82. Ryan Bunney.

83-84. Results from theSkyNet POGS project showing the star formation rate and the amount of dust in a distant galaxy, calculated by volunteer computing power.

85. www.theskynet.org


86. An audience gathers for a live presentation from ICRAR researchers at Scitech's Planetarium.

OUTREACH AND EDUCATION

7

Outreach Overview

Connecting with the broader community, promoting uptake and participation in science and communicating our research is an integral part of ICRAR's work.

Our researchers represent some of the best minds on the planet, brought together to work at the new frontier of science that is radio astronomy and the large scale telescopes being built in outback Western Australia.

Nepal, Switzerland, Germany, Italy, Spain, England, Ireland, Scotland, Wales, China, Vietnam, India, Russia, Korea, South Africa, the USA— the list of where our researchers come from goes on and on.

Each year these researchers and our postgraduate students, supported by a small team of professional science communicators, give back to the community through a plethora of outreach and education programs throughout the State and beyond.

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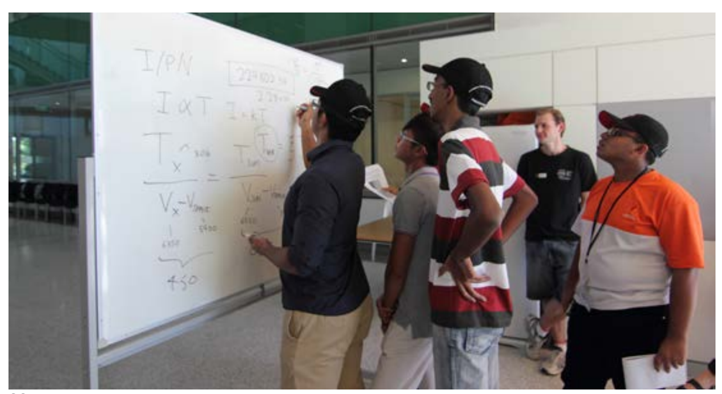
Whether it's the person on the street, the teacher in the classroom or the student about to head off to university, our public lectures, community observing events, school programs, and extensive online presence help us to reach people, wherever they are and however they prefer to engage.

In our first five years, more than 80,000 people have interacted directly with ICRAR outreach programs, with hundreds of thousands more connecting with us through our growing online presence.

Our media releases, and a commitment to communicating only the best research stories that capture the imagination of our audiences, has generated thousands of articles and a potential global readership in the millions.

ICRAR has achieved this level of outreach success because of the passion, creativity and level of excitement our researchers and science communicators bring to their work, and through the collaborative relationships we've been able to establish with like-minded organisations and individuals working in this important domain.

In everything we do, we strive to maintain an extremely high level of quality and take the road less travelled through a creative and innovative approach. In this section you'll read about some of our flagship programs and see how we target and engage a whole range of audiences in a variety of ways.



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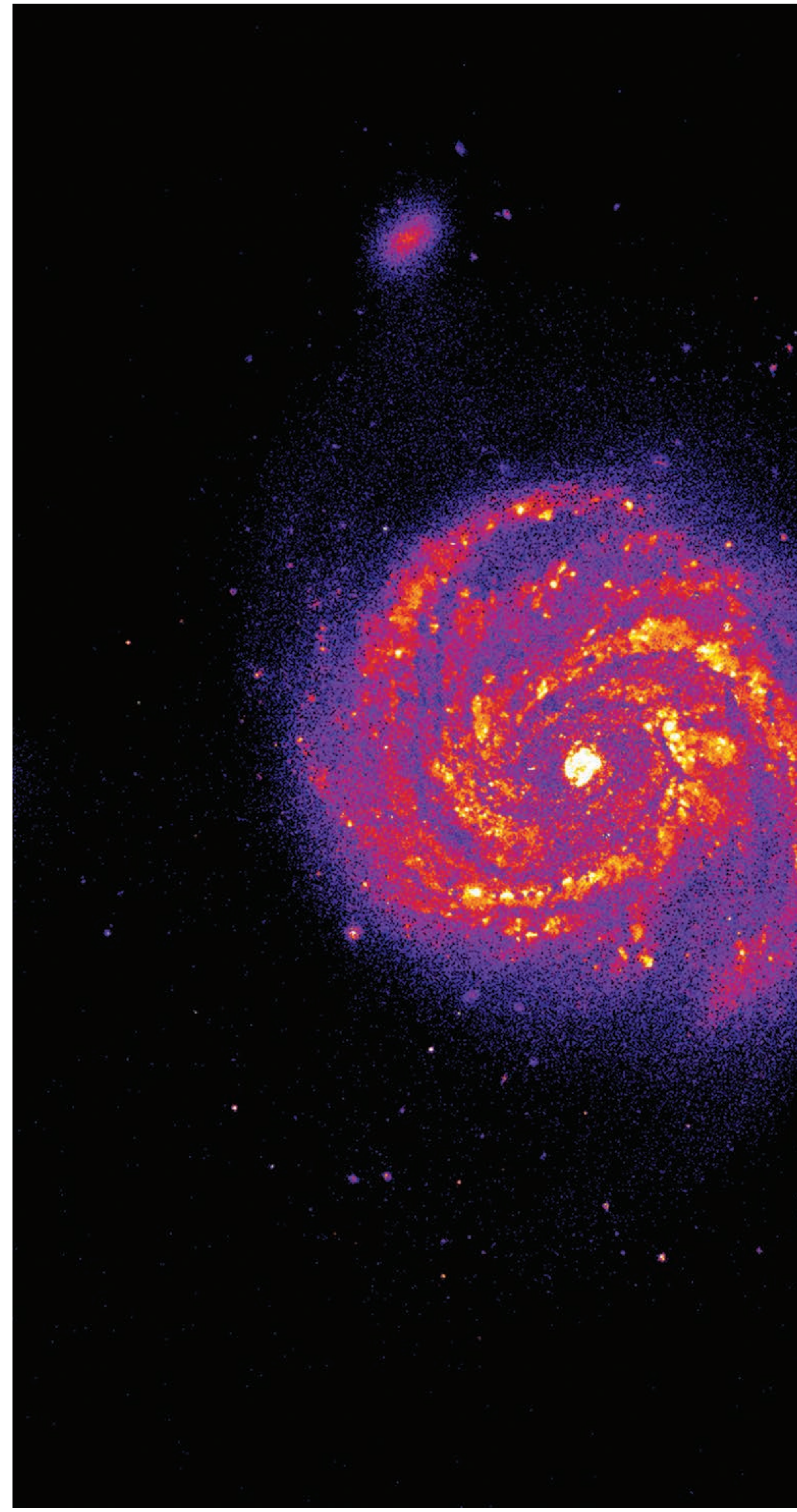
87. 2014 ICRAR-iVEC Summer student Ben Courtner-Barrer helps a visiting high school student build ICRAR's Tiny Radio Telescope.

88. ICRAR PhD student Scott Meyer helps visiting high school students from Singapore calculate the temperature of the Sun's corona.

89. Stunning spiral galaxy M100 shows off its star formation rate in this results image from theSkyNet, processed by over 1000 volunteer computers.



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theSkyNet

Your computer is bored. It has spare computing power nearly all the time that could be used to do something awesome. So why not let it?

By connecting 100s and 1000s of computers together through the Internet, it's possible to simulate a single machine capable of doing some pretty amazing stuff. That's what theSkyNet is about - using your spare computing power to process astronomy data.

At any given time, day or night, almost 30,000 computers around the world are contributing to ICRAR's 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 70 and 100 TFLOPs of compute power, or just shy of a top 500 supercomputer.

Since the project's launch in 2011, theSkyNet has been recognised for its ability to produce real research outcomes for astronomers, whilst also being an innovative and effective method to engage the public in astronomy. Almost 26,000 people have processed data for theSkyNet, with more than 65,000 people signed up to the website.

TheSkyNet is a platform capable of processing data for many projects at once. Our current primary project, theSkyNet POGS, combines data from telescopes GALEX, Pan-STARRS1 and WISE to generate a multi-wavelength galaxy atlas for the nearby Universe. From this, the project will calculate physical parameters such as star formation rate, stellar mass of the galaxy, dust attenuation and total dust mass of a galaxy, on a pixel-by-pixel basis using spectral energy distribution fitting techniques. TheSkyNet POGS is a collaboration with Johns Hopkins University in the United States.

Our original project, theSkyNet SourceFinder, is helping refine sourcefinding methods for the large flow of data expected from the next generation of radio telescopes (ASKAP and the SKA) using various existing algorithms, such as Duchamp. TheSkyNet SourceFinder is currently paused as it is being redeveloped, with an expected relaunch in September 2015.

TheSkyNet Volunteers

TheSkyNet's audience is passionate about astronomy and keen to be involved in research. TheSkyNet gives them that opportunity but also provides front-line access to ICRAR astronomers and their knowledge through the website's forums and helpdesk.

Volunteers are presented with the results they helped to create through their theSkyNet.org user account and are rewarded for their contributions with credits. Credits determine a member's position on the leader boards and in turn trigger digital trophies to mark milestones in a volunteer's processing.

The digital trophies are themed around important numbers for astronomy, computing and geek culture, providing another avenue for the promotion of astronomy and related research.

TheSkyNet website also has a number of interactive features, the most exciting of which are the member initiated challenges. These challenges encourage volunteers to compete with each other in a variety of ways, from raw processing speed, to most improved over a set period of time. This promotes increased participation in the project and greater interaction between our members, and is the most active part of theSkyNet's website.

Volunteers on theSkyNet POGS 'collect' galaxies they have helped process and can map their real locations in a simulated night sky using our plug-in for Stellarium, a popular and freely available planetarium software package.

TheSkyNet also engages its audience through social media (Facebook and Twitter), eNewsletters that detail achievements and the science conducted on the platform and our forums where volunteers can interact with the research team.

Impact and reach of theSkyNet

TheSkyNet promotes Australian astronomy to the world. It is the first distributed computing project based in Australia on 'BOINC', the platform originally created for the famous project SETI@home.

Since its launch the project has continued to go from strength to strength, achieving several significant milestones. We now have more than 6,000 people actively contributing at any moment, and at times we have achieved more than 100 TFLOPs in processing power.

In addition, theSkyNet POGS is the 11th most active project on BOINC and its 4th most active project that doesn't process using GPUs, a highly competitive position amongst more than 50 active BOINC projects. So far the POGS project has processed more than 90,000 galaxies, a task that would take the 500th most powerful supercomputer in the world about 250 days to complete, an outstanding achievement for such a young project.

TheSkyNet's audience is primarily in the United Kingdom and the United States, with a loyal and growing base in Australia. We are exporting Australian science to the world and increasing the exposure of leading-edge local work on large-scale surveys and next generation radio telescopes.

TheSkyNet is hosted using cloud infrastructure purchased from Amazon Web Services who recently contributed $250,000 to the Square Kilometre Array, a direct impact of their connection to ICRAR and introduction to the project via theSkyNet.

TheSkyNet has significant reach globally and within Australia and the flexibility of its online format has allowed it to continue growing. At the current rate of growth theSkyNet will approach 100,000 members signed up to the website by the end of 2015.

Third Birthday

To celebrate theSkyNet's 3rd birthday in September 2014, a mosaic of all the galaxies processed by theSkyNet POGS so far was created, resulting in a stunning gigapixel image, well worth exploring in detail online at http://www.gigapan.com/gigapans/162657.

The image contains over 60,000 galaxies and results calculated by theSkyNet POGS volunteers. The main image of the mosaic is the star formation rate of galaxy M100, as calculated by theSkyNet volunteers.

theSkyNet

SourceFinder

POGS

90-91. Two examples of digital trophies awarded to theSkyNet volunteers.

92. A galaxy mosaic using results from theSkyNet's first three years made for the initiatives 3rd anniversary in 2014. Over 60,000 galaxies are used in the image, which shows the star formation rate of galaxy M100.

93-95. The results images that theSkyNet volunteers see when they log in to theSkyNet.org. The grey lines on the image show where their computer has helped process on the galaxy and its surrounds.

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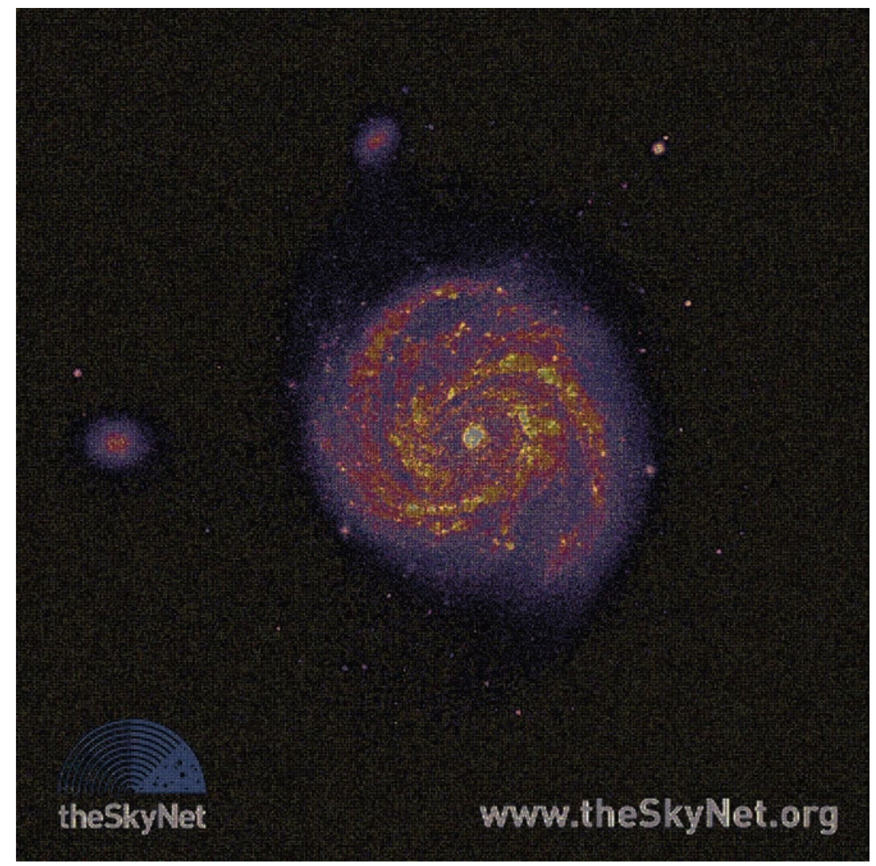

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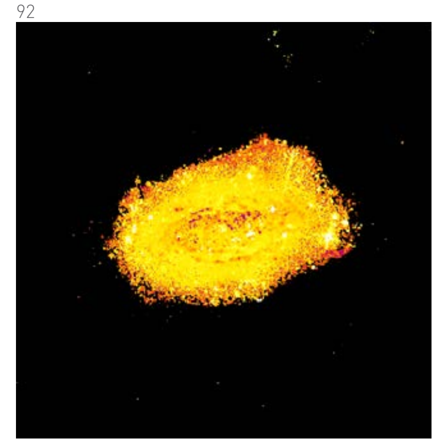

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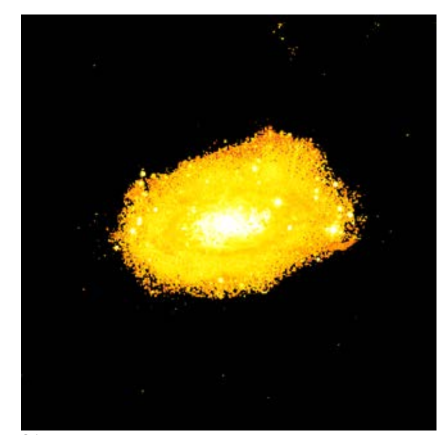

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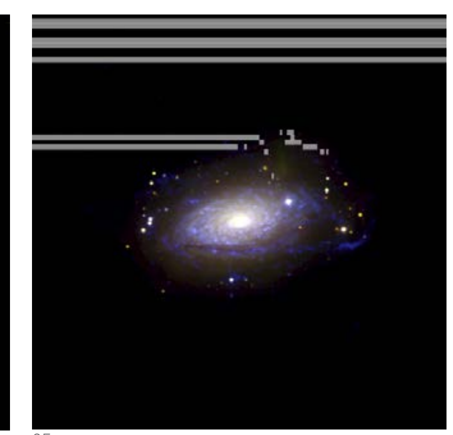

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theSkyNet QUICK STATS

Website visits

- More than 730,000 unique visits to theSkyNet website have occurred since launch.
- There have been nearly 3,600,000 page views from people in 171 countries.

Processing power

- A peak processing power of 106 TFLOPS on theSkyNet POGS was achieved on the 15th of May, 2014. This is equivalent to 366 modern Intel Core i7 5930K processors, which would cost approximately $249,000 to purchase (not including other hardware, power, and cooling etc.).

The total BOINC credit awarded since the start of theSkyNet POGS is more than 6,898,000,000 credits, equivalent to:

- 2,999,500,000 TFLOP's.
- The world's fastest computer (33,862.7 TFLOPS) for 24 hours.
- The 500th best computer (133 TFLOPS) for 261 days.
- A high-performance desktop (0.3TFLOPS) for 317 years.

SPIRIT telescope puts focus on high school discoveries

It is not just the researchers making incredible discoveries at ICRAR.

School and university students are making real contributions to science without having to leave their classrooms thanks to the unique SPIRIT program.

SPIRIT gives teachers and students access to the same tools used by professional astronomers to observe and collect astronomical data.

Participants use a web browser to remotely access two research-grade robotic telescopes, known as SPIRIT I and SPIRIT II, through the internet.

The telescopes are located on a roof at UWA and students can control them to take images of distant astronomical objects or even schedule automated data acquisition for sophisticated research projects.

ICRAR, the UWA Physics Department and SPICE launched SPIRIT in 2010, and the hugely successful program has inspired hundreds of budding astronomers over the last five years.

In 2013 and 2014 alone, more than 450 teachers and students attended professional learning workshops to discover how to use the state-of-the-art robotic telescopes.

SPIRIT is in high demand from local university students using the telescopes for astrophysics projects as well as high school students from around the State, many of whom are taking part in academic extension programs.

Both SPIRIT I and SPIRIT II are often booked solid by multiple users for weeks at a time, with all observing opportunities from dusk until dawn taken.

Astronomy is one of the last areas of science where amateurs can make new discoveries and SPIRIT gives participants the opportunity to do genuinely important scientific research.

High school students have used the telescopes to undertake precise observations of minor planets for submission to the Minor Planet Centre at Harvard University.

These results appear in professional publications that provide credit for student observations and analysis.

Other student projects have included supernovae surveys and photometric studies of stars and clusters.

> * *Students can use SPIRIT to make observations from their classrooms at school or even from the comfort of home using their own computer.*

Giving people the chance to be involved in real research in this way is making a genuine impact on the students and their choices in upper high school and beyond.

One example is former Mount Lawley Senior High School student Gur Ashish Singh Bhatia, who took part in a SPIRIT pilot program as a Year 10 student.

Gur opted to use SPIRIT again for a Year 12 project and is now studying third year astrophysics at UWA, where he is once more making use of the robotic telescopes.

He credits the SPIRIT program with his decision to study physics at university.

SPIRIT is unique in Australia as the country's only educational robotic telescope outreach initiative.

Worldwide it remains one of only a handful of successful web-enabled outreach telescopes with remote, real time operation.

96. The Trifid Nebula (M20) as imaged by one of the two SPIRIT telescopes.

97. Former Vice-Chancellor of UWA, Professor Alan Robson, Hon Dr Elizabeth Constable MLA and Paul Luckas at the launch of the SPIRIT II telescope.

98. Students from Mt Lawley Senior High School attending a SPIRIT Minor Planet workshop.


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99. A young child looking through a telescope for the first time at the Mt Magnet 'Astro Rocks Fest'.

100. PhD student Mehmet Alpaslan working with students from Meekatharra District High School.

101. A student from Halls Creek District High School after seeing the Sun (safely) through one of ICRAR's outreach telescopes.

Outback Outreach

Western Australia's size, with communities separated by hundreds, or in some cases, thousands of kilometres of outback, creates a significant geographical challenge for organisations seeking to engage with those living in towns and communities in regional and remote areas.

But, by working with others - something ICRAR does in both research and outreach - these challenges can be overcome to some extent. A collaborative approach maximises impact, minimises cost, avoids duplication of effort and can lead to a mutually beneficial relationship with others.

During the last two years ICRAR outreach has continued to engage with communities right around the State, with our most significant collaborative tours being those that visited the Mid West and Kimberley regions. The organisations involved in both were ICRAR, Aspire UWA, Scitech, SPICE and UWA's School of Indigenous Studies.

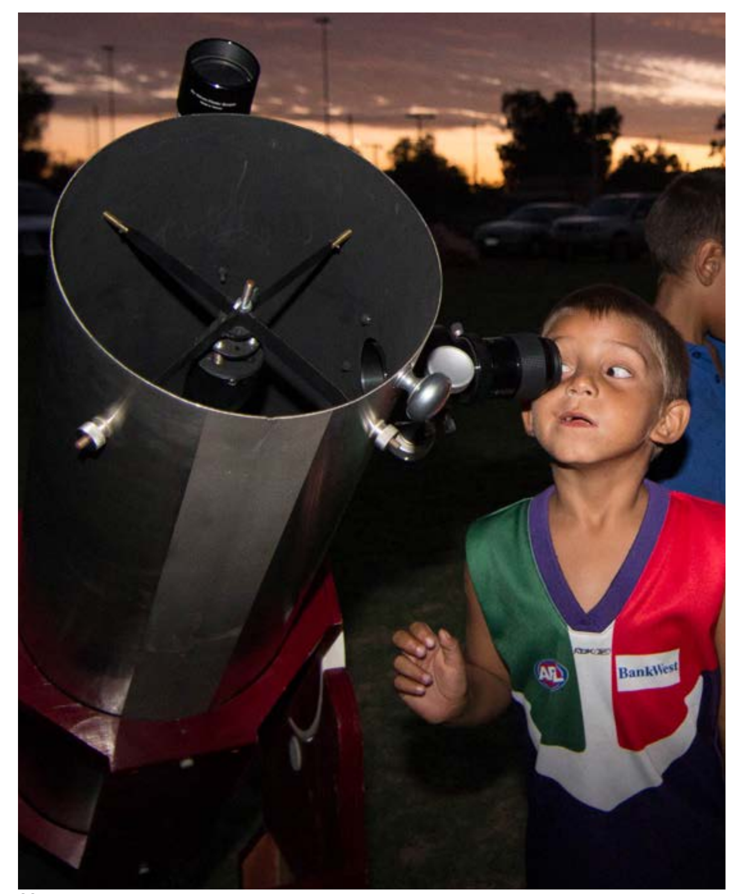
In the Mid West we visited Morawa, Meekatharra, Mt Magnet, Pia Wadjarri, Kalbarri and Jurien Bay, and in the Kimberley it was the faraway communities of Kununurra, Wyndham, Halls Creek and Fitzroy Crossing.

The programs we delivered involved students from Kindy right through to Year 12 engaging in one or more activities. Students observed the Sun using special solar telescopes, learned about the composition and evolution of galaxies through science and maths problems, undertook simple scientific investigations based around water rocket launches and found out about big science projects happening in WA, like the Square Kilometre Array.

In the evenings our team would set up telescopes on the local oval and invite people from the community to come and explore their night sky with us. Most had never looked through a telescope before, and guided by our expert staff they saw and learned about objects like the Moon, Jupiter, the Jewel Box, the Orion Nebula, Omega Centauri and more.

Whilst astronomy provided the underlying theme for these programs and experiences, another of our objectives was to engage students in a broader conversation about the benefits of a tertiary education and the options and support available to them if they decided to go on to university.

Research has shown that a principal determining factor for participation in higher learning is the extent to which education is valued and promoted within the family and community. So, by engaging school students, educators and also the wider community through our programs, we promote the benefits and opportunities that education has the potential to bring to everyone in that community.



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Astro Art

Until recently, photographing the night sky was a domain accessible only to experienced photographers with the money and knowhow to operate expensive and complex equipment.

But, with advances in technology, the equipment to image the sky and get amazing results quite quickly has become increasingly affordable, accessible and user-friendly.

Since ICRAR launched in the International Year of Astronomy in 2009, the Centre has actively fostered a Western Australian community of photographers who use the heavens as their canvas and in so doing, share the awe-inspiring Western Australian night sky and landscape with local and overseas audiences.

Each year, Dr John Goldsmith, a graduate of the ICRAR PhD program and an expert in Indigenous knowledge of the night sky, has curated and brought together the work of local astrophotographers to be exhibited at the Perth Astrofest and some of the regional Astrofest events that have now begun to emerge.

Six years on, and this initiative has led to a wealth of extraordinary talent in Western Australia, who are producing some of the best work in the world.

Drawing on this success and our experience using astrophotography as a way of opening up science and astronomy to new audiences, over the past 18 months ICRAR has been trialling the 'AstroPhotoArt' program for schools.

Deciding to work intensively with small groups of students from low socio-economic areas, we designed a program targeting Year 9 and 10 students that included 10 hours of contact time during the school day (to limit the potential impact on other studies) plus at least two sessions for night time imaging.

Through this program our hope was that students who might not ordinarily engage or participate in science would do so if presented with an opportunity to learn new skills, use high tech equipment and learn about photography, image processing and composition.

So far we've trialled this program with students from one regional school (Derby DHS) and one metropolitan school (Lockridge SHS), with some amazing results.

Having participated in this program:

- More than half of the students thought they were now better at doing science.
- Most students said their understanding of astronomy had improved a lot.
- All students indicated that their understanding of science had improved between a little and a lot.
- Approximately half of the students indicated they were more likely to study science at university than they had been before the program.

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Work Experience Program

Since 2010 ICRAR has hosted 33 high school students from around Perth (and even interstate) for some hands on experience in astronomy, engineering and computer science.

The ICRAR program isn't the standard 'photocopying and coffee making' experience of cliché, instead our researchers work hard to make an engaging, informative and fun program for visiting students.

Instead of spending the week on a single project and in only one area of ICRAR, students split their time between the two ICRAR nodes, experiencing both Curtin and UWA. Additionally, students have mini 'research sessions' with as many different researchers as possible, so they can get a taste for all the areas ICRAR is involved in.

Entry into our work experience program is competitive, with an intensive screening process to make sure we only accept students with a true passion for astronomy. This means many of our students have gone on to keep up a connection with ICRAR and volunteer at many of our public events, such as the annual Astrofest.

Some of our first work experience students are now starting to enter university, and we're looking forward to seeing many more of them start their path through tertiary education in coming years.

102. An image of the Milky Way and a light painted tree captured by Parniyan Pakniyat of Lockridge SHS, who participated in ICRAR's AstroPhotoArt program.

103. A long exposure showing head torch trails during an AstroPhotoArt session near Gingin Observatory.

104. 2014 Astrofest Astrophotography Exhibition winner 'Cosmic Balance' by talented local Perth astrophotographer Michael Goh.

105. The Orion Nebula captured by photographer Dr Shaun Ridley near Gingin Observatory.

106. Work experience student, Madeline McKenzie.

107. Work experience student, Benjamin Stone.

In their own words

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"When I applied to do a week of work experience at ICRAR, I could never have believed what a pivotal role it would play in determining the career I wanted to pursue. I had always enjoyed learning about astronomy, but that week provided me with various examples of what I could do with my life and the passion and determination required to achieve it. I cherish the memories from that week and will never forget how generous the researchers were with their time and how welcoming and supportive everyone was. Thank you for giving me the incredible opportunity of participating in your work experience program." Madeleine McKenzie, 2012. Madeleine is now studying Physics at UWA.

107

"It was honestly a really incredible experience and I'm so glad I was given the opportunity to talk with some leading researchers and pioneers in astrophysics. I think if you're interested in physics, and have hopes to one day take part in research perhaps in the field of astronomy, you should definitely reach out to ICRAR, you won't be disappointed." Benjamin Stone, 2014. Ben is now studying Physics at UWA.

As part of their time at ICRAR, some of our students also write a blog of their experiences, sharing what they have learnt and what a work experience week with us is like. They are all available on the ICRAR website: www.ICRAR.org/education/work_experience

National Science Week 2014

Every year ICRAR is proud to play a part in the Nation's celebration of science, National Science Week. This continued with our significant outreach presence for National Science Week 2014 in August. ICRAR staff and students saw almost 1,300 school students (combined over primary and secondary levels) and were involved in the 'Perth Science Festival', attended by an estimated 10,000 people.

We held eight 'Ask an Astronomer' sessions in Primary schools within Perth, where a young ICRAR astronomer spent time in the classroom talking about their work and answering all the students' questions about space and astronomy.

Staff members also visited 7 high schools to give talks on their research and the Square Kilometre Array, encouraging over 750 students in years 8 to 12 to consider science and engineering as a university option.

ICRAR also donated nine 'Universe in a Box' kits to primary schools in and around Perth. These kits were purchased from the EU Universe Awareness program and contained many activities and resources for primary school teachers to use in their classrooms.

The Perth Science Festival saw ICRAR staff and students sharing their love for astronomy with an enthusiastic public, and helping Perth's future scientists discover constellations through a 'Make your own Stargazer' activity, assisted by astronomers from CSIRO. The festival was held in the Cultural Centre of Perth and was the official WA launch of National Science Week.

In addition to the in-person outreach activities within Perth, ICRAR also had a large presence on social media during the week, with two daily themed posts, an astronomy image in the morning and a staff profile in the afternoon.

Astronomy images included the first data from the SKA-low verification system in the Murchison, pictures of deep space objects taken by local astrophotographers as well as a stunning timelapse video of Australian landscapes at night.

Some of these posts also went out through the official SKA Telescope social media accounts to thousands of followers.

In total, it's estimated than an audience of over 20,000 people were involved in ICRAR's National Science Week outreach activities globally, including social media followers and in person encounters.

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108. Future scientists getting their first taste of astronomy at the Perth Science Festival.

109-110. Students at Ardross Primary School in Perth exploring the Solar System with their 'Universe in a Box' kit, donated to the school by ICRAR during National Science Week.

111. Families flocked to the stargazer stall at the Perth Science Festival to get hands-on with astronomy.

112-113. Visitors to the Perth Science Festival during National Science Week making 'stargazers' to learn more about the constellations.

114. A family observing the Sun (safely) at Perth Science Festival.

Astrofest Update

Perth continues to host Australia's largest annual astronomy festival, Astrofest, a vibrant celebration of astronomy and Western Australian science.

Astrofest attracts more than 4,000 people each year and features fun and engaging activities for people from all walks of life. Optical and radio telescopes, including some of the largest in the State, are available throughout the evening to give festival-goers a fascinating look at some of the wonders of the Universe.

A huge range of other interactive activities are also on offer, including:

- Guided 'tours' of the night sky
- Astrophotography competition and displays
- Scitech science shows
- Make your own Lego SKA antenna
- Guest speakers
- Hands-on activities for people of all ages

115

115. Inside Astrofest at Curtin Stadium.

116. Astrofest visitors enjoying the work of local astrophotographers.

117. A member of the public observing the sky through ICRAR's computerised outreach telescope.

118. Star Wars characters investigating a model of an SKA-low antenna.

119. Dr Natasha Hurley-Walker presenting to an enormous Astrofest audience.

120. A young Astrofest visitor exploring the sky through one of ICRAR's outreach scopes.

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Every year Astrofest is coordinated by ICRAR on behalf of Astronomy WA, a collective of astronomy outreach and education organisations from throughout Western Australia.

The ongoing success of Perth's Astrofest was acknowledged in 2014 when it was one of three finalists in the WA Premier's Science Awards, Science Engagement Initiative of the Year category.

> *In addition to Perth's Astrofest, there are currently three regional Astrofests held regularly in Carnarvon, Mount Magnet and Murchison Shire, all with support from members of Astronomy WA and the Perth Astrofest team.*

The Perth Astrofest is currently going through a consolidation and stocktake period, with an external consultant working on a review and strategic plan for Astrofest's future. The review will lay out a future path for a sustainable Astrofest that can continue to grow and service the Perth community, and ICRAR is playing a leading role in the review process.

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Where are they now?

At ICRAR we take our responsibility to the next generation of astronomers, engineers and high performance computing professionals seriously.

Our students receive not only an excellent education, but also extensive support from across both of ICRAR's nodes. We're very proud that our past students are now contributing to the astronomical community around the world. Featured in this section is a selection of our past students and where their studies with ICRAR have taken them.

121. PhD Graduate Dr Jacinta Delhaize just before she left ICRAR for a new challenge at the University of Zagreb in Croatia.

122. PhD Graduate, Dr Mehmet Alpaslan.

123. PhD Graduate, Dr Florian Beutler.

124. PhD Graduate, Dr Tim Colegate.

125. PhD Graduate, Dr Phil Crosby.

Dr Mehmet Alpaslan
PhD Graduate
Year Completed 2014
Current Position Postdoctoral Fellow - NASA Ames Research Center

Dr Alpaslan worked with the Galaxy and Mass Assembly (GAMA) team at ICRAR during the course of his PhD, including many observing trips to the Anglo Australian Telescope in NSW. His published work includes the discovery of 'tendrils' within the extensive GAMA survey, a new structure of galaxies in the Cosmic Web. Mehmet is now working at the NASA Ames Research Center near San Francisco continuing his PhD research and studying how galaxies in filaments evolve differently to those that exist in the voids of the Cosmic Web.

Dr Florian Beutler
PhD Graduate
Year Completed 2013
Current Position Postdoctoral Researcher - Physics Divisions, Lawrence Berkeley National Laboratory

Dr Beutler calculated a highly accurate value for the Hubble Constant during his PhD at ICRAR using a new method based on the measurement of Baryon Acoustic Oscillations, gathering him global media coverage and his first publication. Since then Florian has moved on to the Lawrence Berkeley National Laboratory in the United States and is currently working on the BOSS survey, where he uses redshift-space distortions to test General Relativity on cosmic scales.

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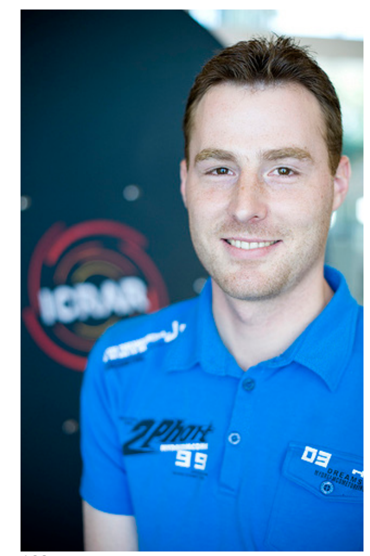

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Dr Tim Colegate
PhD Graduate
Year Completed 2013
Current Position Postdoctoral Researcher - International Centre for Radio Astronomy Research, Curtin University

Dr Colegate was working on the design of the Square Kilometre Array during his PhD at ICRAR, specifically investigating how the SKA could explore varying cosmic events, called 'transients', and spent time working with the SKA team in Cambridge. Tim now continues his work at ICRAR, this time as an employee, using the MWA to measure and test prototype low-frequency aperture array antenna systems for the SKA.

Dr Phil Crosby
PhD Graduate
Year Completed 2013
Current Position Assistant Director, Western Australia - CSIRO Astronomy & Space Science

Dr Crosby studied how to improve the success of mega science projects, like the SKA, for his PhD with ICRAR, and continues to put his research to excellent use as Assistant Director, WA in CSIRO's Astronomy and Space Science division. Phil is very involved in the international SKA effort through his role at CSIRO and maintains close ties with ICRAR.

Dr Jacinta Delhaize
PhD Graduate
Year Completed 2014
Current Position Postdoctoral Researcher - University of Zagreb

Dr Delhaize refined an innovative method for viewing the hydrogen gas in distant galaxies, 'stacking', during her studies at ICRAR and also spent time observing with the iconic Parkes radio telescope in NSW. She was also an active participant in the ICRAR outreach program, something she's continued in her new role at the University of Zagreb in Croatia. Jacinta has not only started a fledgling outreach operation, she's also continuing her research into galaxy evolution by using large radio continuum surveys.

Dr Toby Potter
PhD Graduate
Year Completed 2013
Current Position Research Associate - Centre for Petroleum Geoscience and CO_2 Sequestration

Dr Potter's work on modelling iconic Supernova 1987A earned him his PhD at ICRAR, as well as multiple publications, including two first-author. Toby is now working in the Centre for Petroleum Geoscience and CO_2 Sequestration at The University of Western Australia, continuing his simulation work.

126. PhD Graduate, Dr Jacinta Delhaize.
127. PhD Graduate, Dr Toby Potter.
128. PhD Graduate, Dr Hayden Rampadarath.
129. PhD Graduate, Dr Morag Scrimgeour.


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Dr Hayden Rampadarath
PhD Graduate
Year Completed 2014
Current Position Postdoctoral Fellow - University of Manchester

Dr Rampadarath worked on wide-field VLBI observations during his time at ICRAR, including how we could use existing VLBI data in the Search for Extraterrestrial Intelligence! After an initial Postdoctoral position at the University of Southampton, Hayden has now returned to Manchester to work on how to create images from the SKA and research the cores of nearby galaxies with radio interferometry.

Dr Morag Scrimgeour
PhD Graduate
Year Completed 2013
Current Position Data Scientist - Square, San Francisco

Dr Scrimgeour completed her PhD research using the WiggleZ survey of the Universe, confirming that the Universe at very large scales is evenly distributed, something that Einstein's equations rely on. Her outstanding thesis won the 2015 Charlene Heisler Prize for best astronomy PhD in Australia. and after working at the University of Waterloo as a postdoctoral researcher, Morag has now transitioned into a data scientist role at Sparked.com, a start-up company in San Francisco, where she applies statistical modelling to predict customer behaviour.


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STUDENT HIGHLIGHT
Lewis Teixeira
Physics Undergraduate

Our enthusiastic students from both Curtin University and The University of Western Australia heavily support ICRAR's Outreach, Education and Communications team in sharing the Centre's research. Our PhD, Masters and Undergraduate students spend time in schools and the community sharing their passion for science, and are always visible at outreach events.

> * *Our students hone their communications skills with some of the toughest audiences out there (kindergarten students, and moody teenagers!) and come away with many tools that will hold them in good stead in their future careers.*

One such student is Lewis Teixeira, a final year undergraduate in the physics program at UWA. We first met Lewis when he was in high school, and took part in an opportunity with ICRAR to meet astronaut Andy Thomas and speak to astronauts on board the International Space Station.

Lewis, originally from Hamilton Hill, was inspired by his experience and decided to enrol at UWA the next year.

Ever since, Lewis has been heavily involved in campus life, as an Aspire UWA Program mentor for high school students, member of the UWA Physics outreach program and as an invaluable part of the ICRAR Astrofest volunteer team. Lewis is also loving his new role as a lab demonstrator and tutor to first year physics and mathematics classes.

Lewis's passion for outreach is apparent if you are ever lucky enough to meet him, and he counts his outreach involvement as part of his success at university.

"I love giving back to the community, and when I'm out there doing outreach it's clear every little opportunity we create goes a long way in raising interest for science and technology," says Lewis.

Lewis also volunteers at his old high school, helping the later year students with their physics and maths skills.

Lewis's infectious enthusiasm is a quality mirrored in many of the students involved with ICRAR outreach, and we count ourselves very lucky to have such a wealth of talent to draw upon and help share ICRAR's work with the community.

130. Physics undergraduate student, Lewis Teixeira.
131. Lewis working with high school students in a fun water rockets themed investigation.

132. ICRAR staff attending the inaugural ICRAR-con on Rottnest.

STAFF AND STUDENTS

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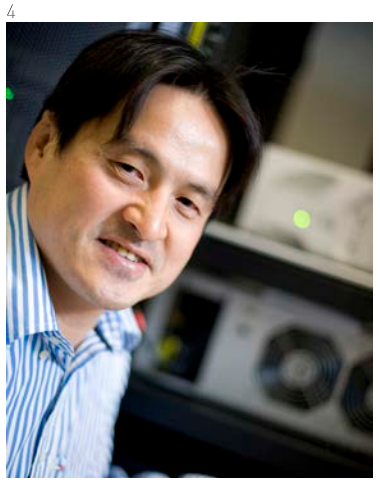
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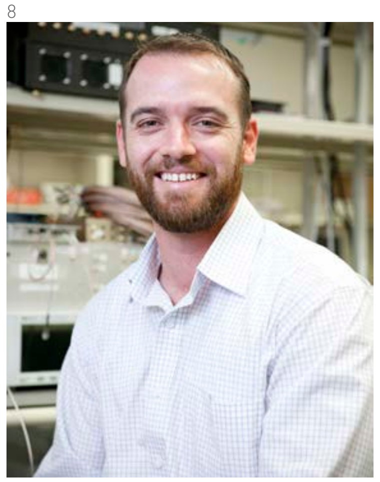
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Dr Mehmet Alpaslan, ICRAR-UWA
PhD Graduate, Oct-11 to Sep-13
The cosmic web unravelled: a study of filmamentary structure in the Galaxy and Mass Assembly survey.

2

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

3

Fiona Audcent-Ross, ICRAR-UWA
PhD Candidate, Mar-13
Star formation demographics in HI selected galaxies.

4

Laurens Bakker, ICRAR-Curtin
Research Engineer, Jun-14
Radio astronomy engineering; Prototyping of radio astronomy instrumentation; System design; RF engineering; Electromagnetic Compatibility.

5

Arora Balwinder Singh, ICRAR-Curtin
PhD Candidate, Oct-12
Ionosphere Faraday Rotation, its Estimation and Mitigation for Radio Astronomy Applications.

6

Alex Beckley, ICRAR-UWA
TheSkyNet Web Programmer/Analyst , Dec-12
High performance distributed computing; Citizen Science and the role this can play in big data; Science Communication.

7

Prof Kenji Bekki, ICRAR-UWA
Professor, Jan-10
Computational study of galaxy formation and evolution; Globular clusters; Cosmic evolution of dust, the Magellanic Clouds, and the origin of life.

8

Dr Ramesh Bhat, ICRAR-Curtin
Senior Research Fellow, Jun-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.

9

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

10

Robin Boddington, ICRAR-Curtin
Aboriginal Liaison Officer, Oct-09 to Oct-13

11

Tom Booler, ICRAR-Curtin
Program Manager, MRO Projects, Feb-11
Project planning and management.

12

Mark Boulton, ICRAR-UWA
Senior Systems Engineering/IT Manager, Mar-12
Data Intensive Astronomy/Computing; Scalable Distributed Processing; Scalable Distributed Storage; System Architecture/Engineering.


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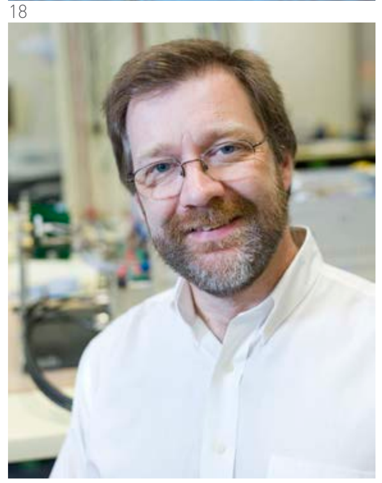
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Emily Bromfield, ICRAR-Curtin
Administrative Assistant, Apr-14 to Apr-15

14

Sarah Bruzzese, ICRAR-UWA
PhD Candidate, Mar-12
Star formation in the outer disks of nearby galaxies.

15

Dr Alessio Checcucci, ICRAR-UWA
Research Associate , Oct-11 to Jul-14

16

Commander Choeysakul Chittawan, ICRAR-Curtin
PhD Candidate, Jul-11
Small Reverberation Chambers for Radio Frequency Emission Measurements: a Radio Astronomy Feasibility Study.

17

Dr Nathan Clarke, ICRAR-Curtin
Research Engineer, Apr-10 to May-14

18

Dr Tim Colegate, ICRAR-Curtin
Postdoctoral Researcher, Sep-09
Antenna and array measurements using radio telescopes; Calibration of low-frequency aperture array antennas in the southern sky; Design of low-frequency aperture array prototypes for the SKA.

19

Krystal Cook, ICRAR-UWA
Student - Masters, Mar-14
Radio Recombination Lines Using the MWA.

20

Ian Cooper, ICRAR-UWA
Project Manager, Mar-13
The Project Management of the Science Data Processor (SDP) using an Agile project management methodology integrated with a traditional Waterfall approach, in order to achieve an optimal utilisation of the international consortium's diverse expertise.

21

Brian Crosse, ICRAR-Curtin
MWA Software Manager, Jan-11
The Murchison Widefield Array hardware and software. Information Systems integration; High Performance and 'Big Data' processing techniques.

22

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

23

Dr Peter Curran, ICRAR-Curtin
Senior Research Fellow, Aug-12
High-energy astronomy and accretion onto black holes.

24

Dr Luke Davies, ICRAR-UWA
Research Associate, Oct-13
Galaxy Evolution in large spectroscopic surveys. Primarily focused on the build-up of stellar mass through both star-formation and mergers.


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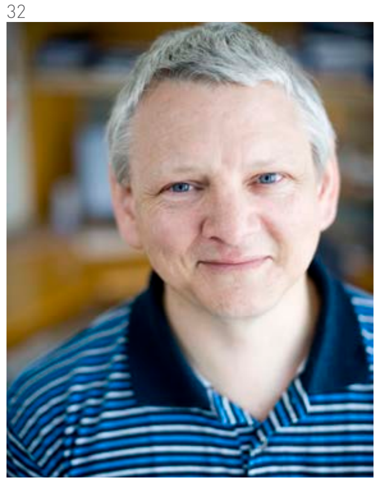
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25
Lara Delacour, ICRAR-UWA
IP Manager, Sep-12
Facilitator of university research and commercialisation activities.

26
Dr Jacinta Delhaize, ICRAR-UWA
PhD Graduate, Sep-09 to May-14
Studies of galaxy evolution using stacking techniques.

27
Dr Foivos Diakogiannis, ICRAR-UWA
Research Associate, Jul-14
Galactic Archeology; Galactic Dynamics.

28
Joseph Diamond, ICRAR-UWA
Outreach & Education Assistant, May-14 to Aug-14

29
Dr Richard Dodson, ICRAR-UWA
Research Fellow, Sep-09
Surveys with SKA and the pathfinders; New Methods for Radio Astronomy; New observations which are made possible by consequence of these new methods.

30
Markus Dolensky, ICRAR-UWA
Technical Leader, Jan-14
Scientific data processing systems; Data-intensive computing; Technical project management.

31
Prof Simon Driver, ICRAR-UWA
Research Professor, Apr-11
The evolution of mass, energy and structure from the epoch of re-ionisation (~13 billion years ago) to the present day.

32
Geoff Duniam, ICRAR-UWA
Student - Masters, Mar-14
Big Data Architecture in Radio Astronomy: The SkyNet and SKA.

33
Angela Dunleavy, ICRAR-Curtin
Administration Coordinator , Jun-12
Administration.

34
Dr Wiebke Ebeling, ICRAR-Curtin
Education and Outreach Coordinator (CAASTRO), Jul-11
Science Communication, Outreach & Training; CAASTRO Science Press Releases; CAASTRO Social Media; Professional Development for Staff and Students; School Engagement; Public Outreach.

35
David Emrich, ICRAR-Curtin
MWA Hardware Manager, Sep-09
The Murchison Widefield Array Hardware and low-level software; Logistics and planning remote fieldwork operations; Amateur backyard astronomy and public outreach.

36
Robert Finnegan, ICRAR-UWA
Student - Masters, Feb-13 to Nov-14
Galactic morphological provenance, evolution.


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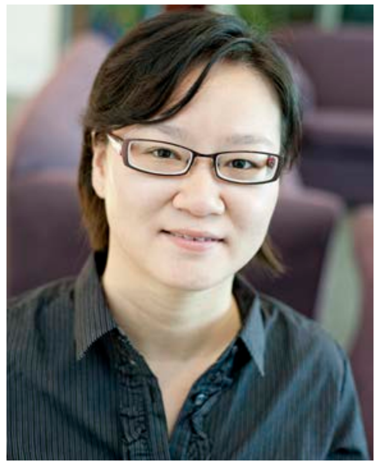
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Dr John Flexman, ICRAR-Curtin
Research Officer, Feb-11 to Feb-15

38
Dr Bi-Qing For, ICRAR-UWA
Research Associate, Aug-11
Galaxy evolution and formation; The Magellanic Clouds; Multiwavelength astronomy; HI surveys.

39
Courtney Fowler, ICRAR-UWA
Executive Assistant, Nov-13 to Apr-14

40
Dr Thomas Franzen, ICRAR-Curtin
Postdoctoral Researcher, Apr-14
Radio continuum surveys; Radio galaxy populations and evolution.

41
Hatsune Furui, ICRAR-UWA
Student - Masters, Mar-14
Extended Ultraviolet Disks in HI selected galaxies.

42
Dr Derek Gertsmann, ICRAR-UWA
PhD Graduate, Jun-10 to Sep-13
Ultra-scale visualisation with adaptive resource management for data intensive scientific research.

43
Dr Leith Godfrey, ICRAR-Curtin
Research Fellow, May-10 to May-13

44
Dr John Goldsmith, ICRAR-Curtin
PhD Graduate, Jul-09 to Feb-15
Cosmos, Culture and Landscape: Documenting, Learning and Sharing Aboriginal Astronomical Knowledge in Contemporary Society.

45
Leanne Goodsell, ICRAR-UWA
Administrative Assistant, Nov-10 to Jun-14

46
Kirsten Gottschalk, ICRAR-UWA
Astronomy Ambassador, Jan-10
Online communication and social media; Media releases, media liaison, and science writing; Graphic and web design; Event management, work experience students, studentship support, as well as resources and events for schools.

47
Dr Thushara Gunaratne, ICRAR-Curtin
Postdoctoral Research Associate, Aug-13 to Jan-14

48
Prof Peter Hall, ICRAR-Curtin
Director, Engineering , Sep-09
The ICRAR Engineering Program; SKA_LOW science and pre-construction activities; Astronomical instrumentation; Time domain astronomy, including pulsars and fast radio bursts; Engineering education and outreach; Astronomy, industry and innovation links.


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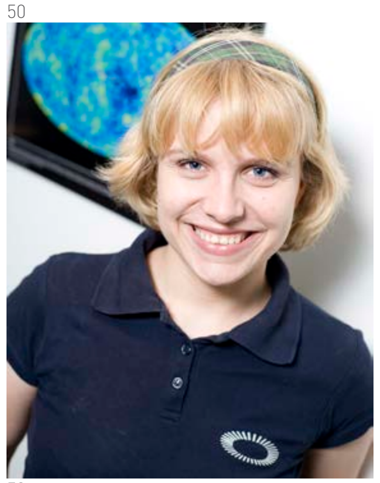
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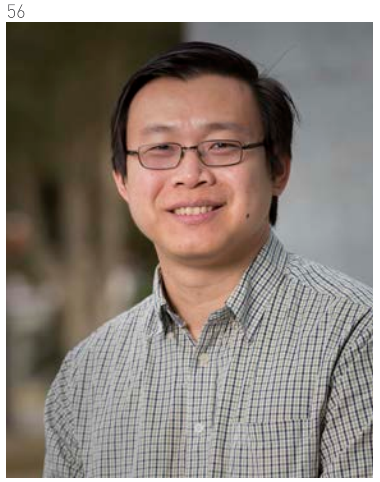
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Dr Paul Hancock, ICRAR-Curtin
Early Career Research Fellow, Sep-13
Gamma-ray bursts; Type Ia Sne; Radio transients; Radio variability; Radio continuum surveys.

50
Benjamin Henderson, ICRAR-UWA
Student - Masters, Mar-14
Galaxy And Mass Assembly (GAMA): Spectral Energy Distributions and Galaxy Parameters of GAMA-II with MAGPHYS.

51
David Herne, ICRAR-Curtin
PhD Candidate, Sep-09
The Australian Mid-latitude Continental Ionosphere in Respect of Low-frequency Radio Astronomy.

52
Dr Shaun Hooper, ICRAR-UWA
PhD Graduate, Sep-09 to Dec-13
Low-Latency Detection of Gravitational Waves for Electromagnetic Follow-up.

53
Dr Laura Hoppmann, ICRAR-UWA
PhD Graduate, Jan-11 to Dec-14
Deep studies of the universe at 21 cm.

54
Dr Natasha Hurley-Walker, ICRAR-Curtin
Super Science Fellow , Aug-11
Radio sky surveys; Commissioning radio interferometers; Supernova remnants; Galaxy clusters; Relic radio galaxies.

55
Dr Minh Huynh, ICRAR-UWA
Senior Research Fellow, Sep-10
Galaxy evolution; Radio continuum surveys.

56
Mathieu Isidro, ICRAR-UWA
Project Officer, Jul-13 to Oct-13

57
Prof Carole Jackson, ICRAR-Curtin
WA Fellow, Aug-13
Radio galaxy and quasar populations; Unification schemes and cosmic evolution; Developing successful industry engagement strategies to benefit astronomy; Design and build of new telescopes; SKA technologies and science.

58
Aziz Jiwani, ICRAR-Curtin
Student - Masters, Sep-09 to May-14
Conical Spiral Antennas for the Square Kilometre Array - A Feasibility Study.

59
Dr Budi Juswardy , ICRAR-Curtin
Research Engineer, Jan-11
Radio-frequency circuit and system design; Power systems; Optical communication.

60
Dr Prajwal Kafle, ICRAR-UWA
Research Associate, May-14
Formation and evolution of galaxies, in-particular Milky Way-like galaxies.


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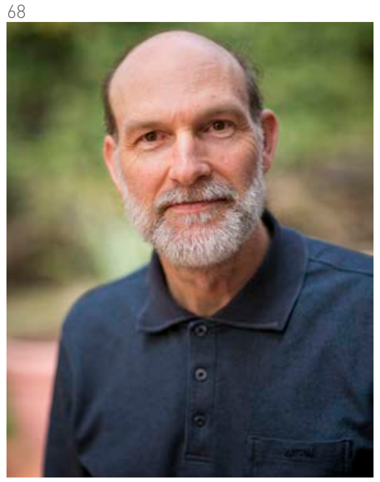
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72

61

Dr Anna Kapinska, ICRAR-UWA
Research Associate (CAASTRO), Aug-13
Extragalactic radio astronomy; Radio galaxies. Relativistic jets; Supermassive black holes; Low frequency radio interferometry (MWA, LOFAR, SKA).

62

Katharine Kelley, ICRAR-UWA
PhD Candidate, Jun-14
A Radio Astronomy search for Axionic Dark Matter.

63

Rachel Kennedy, ICRAR-Curtin
Administrative Assistant, Jul-11 to Jan-13

64

David Kenney, ICRAR-Curtin
Senior Technical Officer, Apr-14
Electronic design and RF systems; Test and measurement/Data processing; IT and Networking.

65

Dr Franz Kirsten, ICRAR-Curtin
Research Associate, Oct-14
High angular resolution observations of pulsars with very long baseline interferometry.

66

Dr Slava Kitaeff, ICRAR-UWA
Senior Research Fellow, May-11
Software; Radio astronomy instrumentation; Spectroscopy.

67

Kathy Kok, ICRAR-UWA
Finance Manager, Jan-10
Financial Management.

68

Dr Nadia Kudryavtseva, ICRAR-Curtin
Super Science Fellow , Dec-10 to May-14

69

Rebecca Lange, ICRAR-UWA
PhD Candidate, Jun-12
Understanding the physical growth of galaxies and their components over the past 5 billion years.

70

Katie Lau, ICRAR-UWA
Administration Officer (CAASTRO), Apr-11 to Apr-13

71

Chris Lord, ICRAR-Curtin
Student - Masters, Sep-09 to Aug-14
A Low Frequency Array of Simple Radio Telescopes for the Detection of Solar X-Ray and Radio Flares and the Study of the Ionosphere.

72

Paul Luckas, ICRAR-UWA
Student - Masters, Feb-10 to May-13
The design deployment and use of internet accessible robotic telescopes for student research projects.


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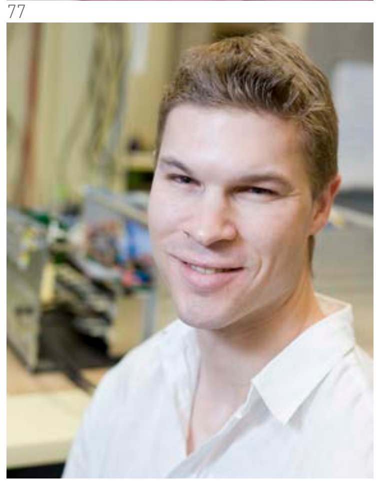
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81


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84

73

Damien Macpherson, ICRAR-UWA
PhD Candidate, Feb-12
Optimal strategies for detecting the first stars by their Gamma-Ray Bursts: the biggest explosions in the Universe.

74

Dr Jean-Pierre Macquart, ICRAR-Curtin
Senior Research Fellow, Sep-09
Astrophysical Transients; Turbulence, Magnetic Fields and Scattering in the Interstellar and Intergalactic Medium; The Galactic Centre; High brightness temperature emission in AGN.

75

Jurek Malarecki, ICRAR-UWA
PhD Candidate, Jan-11
The Warm-Hot Intergalactic Medium.

76

Yolandie McDade, ICRAR-UWA
Executive Assistant, May-11
Administration.

77

Prof Gerhardt Meurer, ICRAR-UWA
Research Professor, Jan-10
Leader of the Survey of Ionisation in Neutral Gas Galaxies and its sister Survey of Ultraviolet emission in Neutral Gas Galaxies; Galaxy evolution via star formation; Gas in galaxies, dark matter, and galaxy dynamics.

78

Dr Martin Meyer, ICRAR-UWA
Senior Research Fellow, Sep-09
HI surveys; Galaxy formation and evolution; Large-scale structure; Galaxy scaling relations; Stellar cluster dissolution.

79

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

80

Dr James Miller-Jones, ICRAR-Curtin
Senior Lecturer, Jul-10
Accretion and jet physics, using observations of stellar-mass black holes, neutron stars or white dwarfs, to understand the connection between inflow and outflow around accreting compact objects.

81

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

82

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.

83

Mehran Mossammaparast, ICRAR-Curtin
Student - Masters, May-11 to Aug-14
A Radiometric Receiver for Measuring Red-Shifted 21cm Emission from the Epoch of Reionisation.

84

Steven Murray, ICRAR-UWA
PhD Candidate, Apr-12
Tools and Statistics for Dark Matter Haloes.


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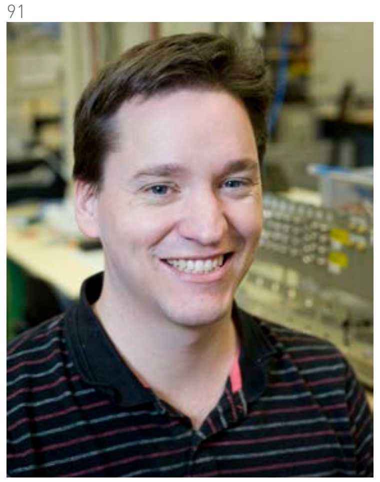
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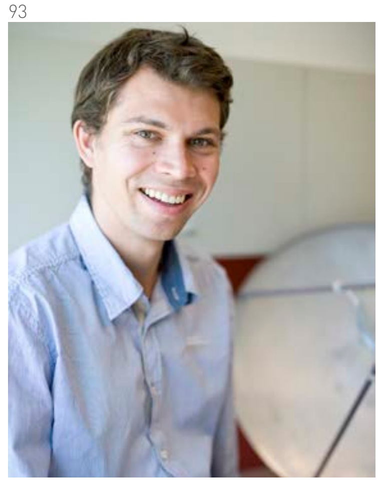
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85
Rakesh Nath, ICRAR-Curtin
PhD Candidate, Oct-14
Estimating the neutral hydrogen signal from the Epoch of Reionisation using low-frequency radio interferometers.

86
Dr Richard Newton, ICRAR-UWA
Jim Buckee Fellow in Astrophysics, Nov-13 to Nov-14

87
Tracey O'Keefe, ICRAR-UWA
Administrative Officer, Apr-14
Administration.

88
Dr Danail Obreschkow, ICRAR-UWA
Senior Research Fellow, Oct-11
Galaxy Evolution and Cosmology.

89
Dr Se-Heon Oh, ICRAR-UWA
Research Fellow, May-11
Galaxy dynamics; Dark matter in galaxies; HI galaxy survey (VLA THINGS/LITTLE THINGS, ASKAP WALLABY/DINGO, MeerKAT MHONGOOSE).

90
Dr Stephen Ord, ICRAR-Curtin
Senior Research Fellow, Feb-11
High time resolution radio astronomy research; Pulsars; Central Signal Processing for the Square Kilometre Array.

91
Samuel Oronsaye, ICRAR-Curtin
PhD Candidate, Aug-12
Working on pulsars with the MWA.

92
Dr Shantanu Padhi, ICRAR-Curtin
Research Engineer, Jun-10
Antennas/EM Simulation; Optimizations.

93
Divya Palaniswamy, ICRAR-Curtin
Student - Masters, Jun-11 to Feb-14
The High Resolution Dynamic Radio Sky.

94
Dave Pallot, ICRAR-UWA
Software Engineer and Administrator (DIA), Jan-15
Parallel and Concurrent Computing; Machine Learning; Network Architectures and Security Systems.

95
Clare Peter, ICRAR-UWA
Administration Officer, Aug-13
Administration.

96
Dr Attila Popping, ICRAR-UWA
Research Fellow, Nov-11
HI surveys; Galaxy Evolution; Intergalactic medium and the Cosmic Web; HI stacking; New radio telescopes, especially ASKAP and the SKA.


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97

A/Prof Chris Power, ICRAR-UWA
Future Fellow, Mar-11
Dark matter; Galaxy formation modelling; Supercomputer simulations.

98

HaiHua Qiao, ICRAR-Curtin
PhD Candidate, Oct-14
Accurate OH maser positions from SPLASH.

99

Prof Peter Quinn, ICRAR-UWA
Executive Director, Sep-09
Dark matter halo structure and dynamics - cosmological formation and dynamical probes; Nature of Dark Matter - microlensing and particle candidate searches, Axionic Dark Matter; Galaxy interactions - satellite systems, disk interactions and mergers.

100

Dr Hayden Rampadarath, ICRAR-Curtin
PhD Graduate, Aug-10 to Dec-13
Applications of Wide-Field VLBI.

101

Lisa Randell, ICRAR-UWA
Administrative Assistant, Jul-14
Administration.

102

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

103

Dr Jonghwan Rhee, ICRAR-UWA
Research Associate, Jun-14
Galaxy formation and Evolution; HI gas evolution & HI survey; 21 cm cosmology; Radio Astronomy Techniques and Instruments; Parallel computing.

104

Dr Maria Rioja, ICRAR-UWA
Research Fellow, Sep-09
High precision astrometric measurements of AGN core-shifts, parallactic distances, and proper motions; Development of calibration techniques to enable astrometric measurements at the highest and lowest frequencies with next generation instruments.

105

A/Prof Aaron Robotham, ICRAR-UWA
Senior Research Fellow, Jan-13
Extra-galactic astronomy, focussing on galaxy evolution and the role of local environment.

106

Thomas Russell, ICRAR-Curtin
PhD Candidate, Mar-12
The connection between inflow and outflow around accreting stellar mass black holes.

107

Tina Sallis, ICRAR-Curtin
Finance Manager, Jan-10
Finance.

108

Dr Franz Schlagenhaufer, ICRAR-Curtin
Research Engineer, Mar-10
Electromagnetic interference (EMI) analysis of radio astronomy equipment; EMI testing and measurement procedures; Application of commercial EMI tools to radio astronomy equipment.


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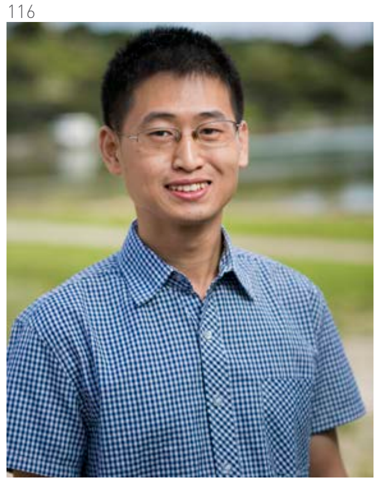
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109

Dr Paul Scott-Taylor, ICRAR-UWA
PhD Candidate, May-13
Advanced Computing of Simulated Galaxies in the SKA era.

110

Dr Morag Scrimgeour, ICRAR-UWA
PhD Graduate, Apr-10 to Apr-14
Cosmology with Large-scale Structure and Galaxy Flows.

111

Dr Nick Seymour, ICRAR-Curtin
Senior Lecturer, Jul-14
Galaxy evolution: star formation history of the Universe; The co-evolution of super-massive black holes and their host galaxies; Deep surveys (particularly radio); Powerful AGN (radio-loud/radio-quiet, obscured/unobscured).

112

Dr Renu Sharma, ICRAR-UWA
Associate Director and Chief Operating Officer, Sep-09
Enable ICRAR to become a sustainable organisation with long term future; Ensure ICRAR to be a flexible, efficient, effective, supportive and innovative organisation with transparency in all its operations; Create a culture that enables all staff and students to succeed.

113

Jackie Soady, ICRAR-Curtin
Administrative Assistant, Jun-13 to Dec-13

114

Dr Marcin Sokolowski, ICRAR-Curtin
Postdoctoral Researcher (CAASTRO), Jan-12
Global Epoch of Reionisation experiments (BIGHORNS); Calibration of instruments; Robotic telescopes; Optical transients and counterparts of Gamma ray-bursts (GRBs).

115

Dr Roberto Soria, ICRAR-Curtin
Senior Research Fellow, Mar-11
Black hole accretion and outflows; Microquasar jets; Ultraluminous X-ray sources; Populations of X-ray binaries in nearby galaxies.

116

A/Prof Christopher Springob, ICRAR-UWA
Research Assistant Professor, Sep-12
The peculiar velocities of galaxies as measured by redshift-independent distance indicators.

117

Prof Lister Staveley-Smith, ICRAR-UWA
Director, Science (UWA), Sep-09
Galaxies and cosmology; Supernova remnants; Surveys; Neutral hydrogen; The Magellanic Clouds; Radio astronomy and the SKA.

118

Roselina Stone, ICRAR-Curtin
Administrative Assistant, Aug-12 to Aug-14

119

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

120

Dr Adrian Sutinjo, ICRAR-Curtin
Senior Lecturer, Jan-12
Electromagnetics; Antennas; Radio electronics; Radio astronomy engineering.


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121
Dr Dan Taranu, ICRAR-UWA
Research Associate (CAASTRO), Dec-14
Galaxy formation and evolution.
N-body simulations.

122
Dr Omar Tibolla, ICRAR-Curtin
Research Fellow, Nov-13 to Apr-14

123
Jonathan Tickner, ICRAR-Curtin
Senior Technical Officer, Mar-10
Technical support.

124
Prof Steven Tingay, ICRAR-Curtin
Director, Science (Curtin), Sep-09
The Murchison Widefield Array.

125
Rita Tomic, ICRAR-Curtin
Administrative Assistant, Nov-13 to Feb-14

126
Dr Steven Tremblay, ICRAR-Curtin
Postdoctoral Research Fellow (CAASTRO), Sep-11
Low frequency and high time resolution radio astronomy; Pulsars; FRBs; RRATs, Radio Galaxies; VLBI; Polarimetry.

127
Dr Cathryn Trott, ICRAR-Curtin
ARC DECRA Research Fellow, Feb-11
Signal processing theory; Epoch of Reionisation; Radio transient; Signal estimation and detection.

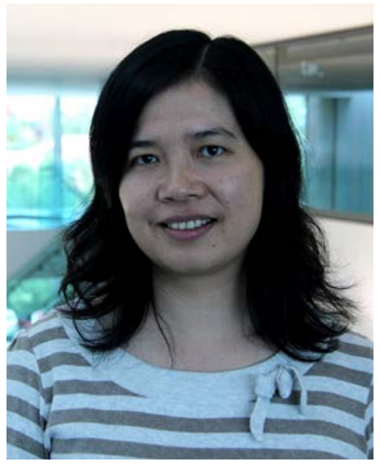
128
Kevin Vinsen, ICRAR-UWA
Senior Research Fellow, Jul-10
Data Intensive Astronomy; Spectral Energy Distribution; TheSkyNet; High Performance Computing; Large Scale Surveys; Galaxy Classification; Machine Learning.

129
Dr Andrew Walsh, ICRAR-Curtin
Senior Research Fellow, Jan-13
High Mass Star Formation; Masers; Galactic Plane surveys; Radio spectral line emission and absorption; The Centre of the Milky Way.

130
Jason Wang, ICRAR-UWA
PhD Candidate, Jan-11
A data optimised I/O middle ware and API for applications to access heterogenous storage hierarchies in HPC and cloud environments.

131
Mark Waterson, ICRAR-Curtin
Research Engineer, Nov-09 to Mar-14

132
Dr Randall Wayth, ICRAR-Curtin
Senior Researcher, Sep-09
MWA GLEAM survey science; MWA and SKA_LOW EOR science; SKA_LOW advanced data processing.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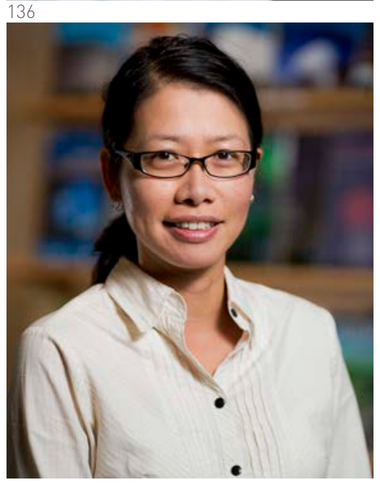
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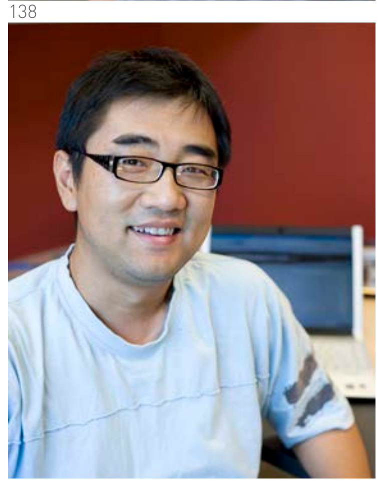
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133

Dr Linqing Wen, ICRAR-UWA
Research Associate Professor , Sep-09 to Dec-13

134

Dr Stefan Westerlund, ICRAR-UWA
PhD Graduate, Mar-10 to Mar-15
A parallel source finder framework and Gaussian filter implementation for large radio astronomy spectroscopic data using high performance computing.

135

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

136

Pete Wheeler, ICRAR-UWA
Outreach, Education & Communications Manager, Sep-09
Outreach, Education & Communications.

137

Prof Andreas Wicenec, ICRAR-UWA
Senior Principal Research Fellow, Aug-10
Data Intensive Astronomy; SKA Data Management; Scalable High Performance Computing; Globally distributed storage systems; High precision astrometry and photometry (GAIA, Hipparcos).

138

Dr Andrew Williams, ICRAR-Curtin
MWA Monitor and Control Engineer, Jun-13
Instrument control and scientific programming; Murchison Widefield Array (MWA) software; Background is optical astronomy: gravitational microlensing, image processing.

139

Dr Ivy Wong, ICRAR-UWA
Super Science Fellow, Mar-14
Using massive HI surveys and multiwavelength observations to study the physical processes driving and stopping star formation in nearby (3 - 200Mpc) galaxies.

140

Angus Wright, ICRAR-UWA
PhD Candidate, Mar-13
Using Multi-band Photometry and HI Surveys to Estimate the Universal Baryonic Mass Function.

141

Dr Chen Wu, ICRAR-UWA
Senior Research Fellow, Mar-11
Data-intensive astronomy; Scalable dataflow systems; Data management systems; Workload profiling. Distributed systems including Cloud, HPC, and Clusters.

142

Matthew Young, ICRAR-UWA
Astronomy & Astrophysics Course Coordinator, Jan-14
Pulsars, Pulsar evolution and Pulsar astrophysics; Models of the radio-emission mechanism; Education and developing and implementing evidence-based approaches to teaching; Flipped classrooms and outreach.

143

Cameron Yozin-Smith, ICRAR-UWA
PhD Candidate, Mar-12
Tracing the chemodynamical evolution of dwarf satellite galaxies, with CUDA-accelerated numerical methods.

144

Dr Giovanna Zanardo, ICRAR-UWA
PhD Graduate, Feb-10 to Apr-15
Radio evolution of the remnant of supernova SN1987A.

133. The Sun behind some Boab trees near Derby in WA's remote Kimberley region.

NEXT

9

On the horizon

Having achieved its two main goals for its first five years—to see the Square Kilometre Array (SKA) come to Western Australia and to be given a key role in the design of the telescope—ICRAR is now looking to the future.

For the next five years, the Centre will focus on doing great science with the SKA precursors (the Murchison Widefield Array and the Australian SKA Pathfinder) and assisting with the deployment of the first parts of SKA-low in the Murchison region.

ICRAR is working towards a long-term future that will see it become the Australian regional SKA science and engineering centre for the telescope's more than 50-year lifetime.

The Centre has worked hard to build up a team of talented scientists, who hold leadership positions in radio, optical and infrared astronomy projects, both in Australia and internationally.

ICRAR is in the box seat to reap the rewards from the Murchison Widefield Array (MWA), which was commissioned in mid 2013.

The observations are now flowing thick and fast from this small but powerful telescope and the Centre is ready to capitalise on the excellent science results being generated.

Within the next five years, the Australian SKA Pathfinder (ASKAP) will also ramp up and ICRAR is poised to make groundbreaking discoveries with the telescope.

In theoretical and computational science, ICRAR is well placed thanks to the opening of the Pawsey Supercomputing Centre in 2013 and a strong computational astrophysics team.

Across the board, ICRAR is leading internationally when it comes to putting infrastructure on the ground.

The Centre has developed a very strong and capable engineering team who have all the skills necessary to help in the prototyping, verification and deployment of the SKA.

Having proven themselves on the MWA, this team is in the strongest position of any group to meet the engineering challenges the low frequency array of the SKA will bring.

Managing huge volumes of information will be vital for next generation telescopes and ICRAR's Data Intensive Astronomy team is changing the way we think about big data.

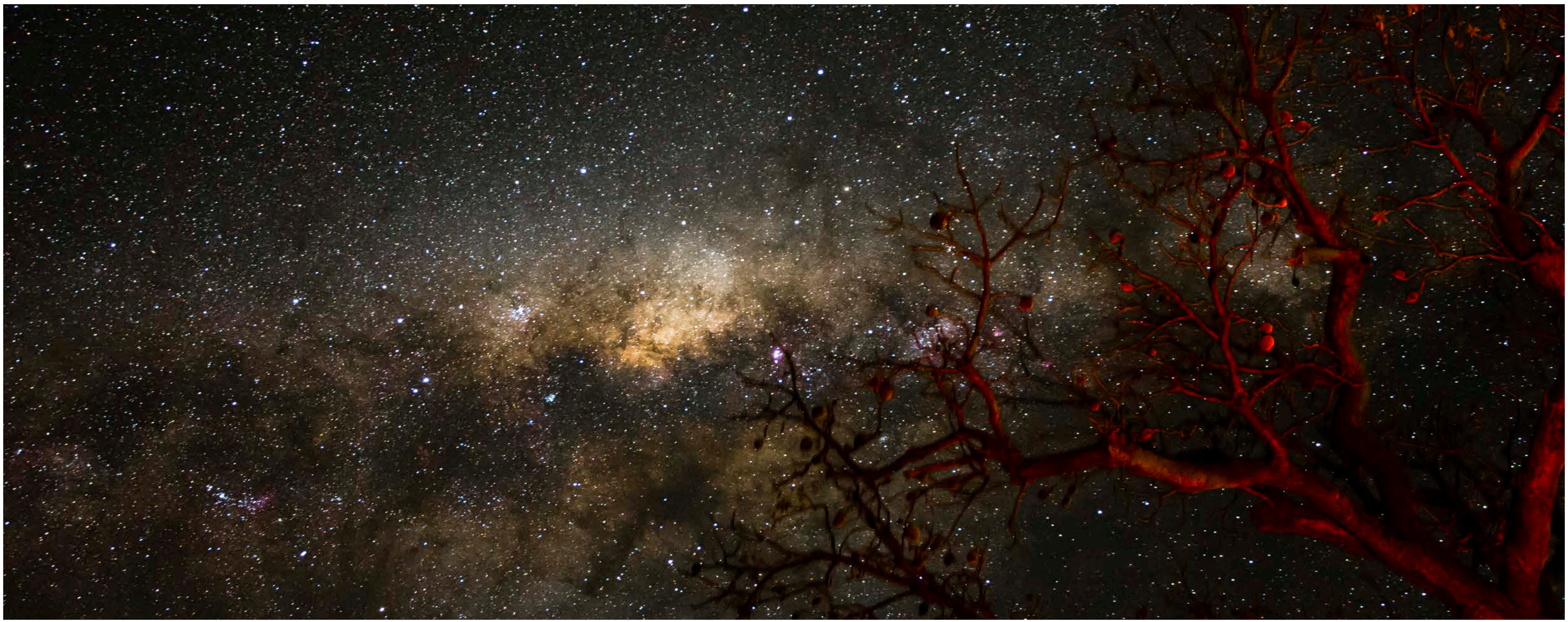
The team's experience designing and developing the data flow and management system for the MWA has been invaluable as they begin to design the data systems for the SKA.

ICRAR also strongly believes in giving back to WA and to the universities and community that help to fund the Centre's research.

The Centre is increasing the profile of the State internationally and training young scientists, engineers and data specialists for the future.

At the same time the technology and big data research being conducted at ICRAR could help solve real problems for WA businesses, such as those in the minerals and energy industry.

ICRAR's outreach team will continue to work with WA teachers, students and people in the street to excite them about careers in science, the SKA and astronomy, while the world's largest science project is built on their doorstep.



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134. The Milky Way and a Kimberley Boab, captured during ICRAR's 'AstroPhotoArt' program in Derby.

International Centre for
Radio Astronomy Research
www.icrar.org
info@icrar.org

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ICRAR YEARBOOK 2013-2014