CIRA
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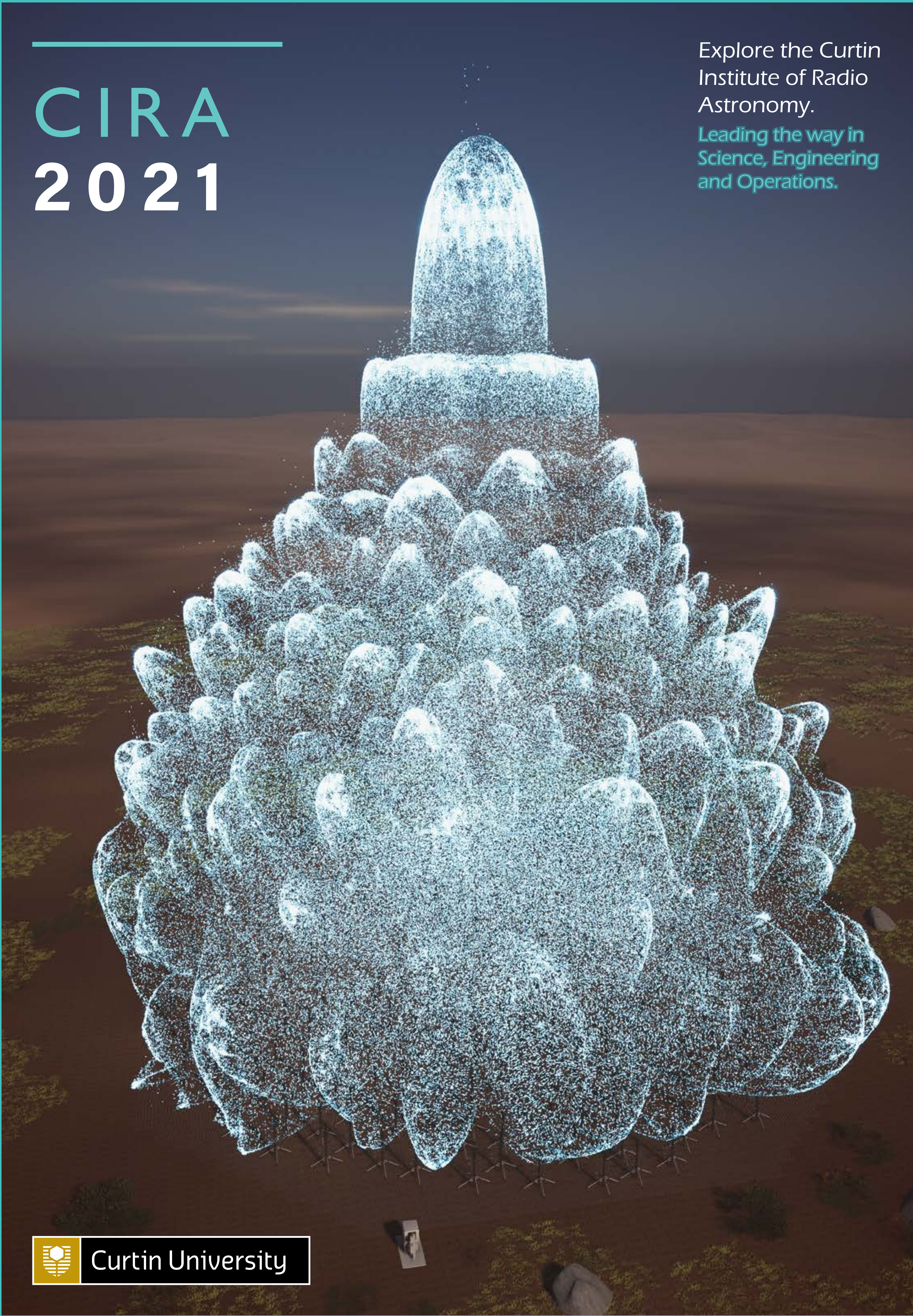

Curtin University

SUMMARY

IMAGE CREDIT LEFT & FAR RIGHT: AdobeStock

This annual report covers the calendar year 2021.

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COVER IMAGE:
Visualised SKA-Low Station Beam Pattern at 80 MHz in logarithmic scale obtained using full-wave electromagnetic simulation
IMAGE CREDIT: Scott Bell/Daniel Ung

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EXECUTIVE DIRECTOR'S REPORT

Professor Steven Tingay
CIRA Executive Director

As always, it is a pleasure to commend to you the Annual Report for the Curtin Institute for Radio Astronomy (CIRA).

The 2021 report is packed with highlights from our Science, Engineering, and Operations programs, with plenty of great photos of the team in action, and accounts of our many education and outreach activities.

Up front, I want to thank and congratulate the team that compiled this annual report, led by Chamila Thrum. It is a significant piece of work, but really important work, to document and summarise the success and achievements of CIRA's people.

Over the course of 2021, CIRA staff and students published amazing research in the world's top journals, won prestigious fellowships and grant funding, and won prizes and accolades for their work. I hesitate to call out highlights here, as there are so many, but the Directors of Science, Engineering, and Operations have summarised our highlights well in their reports, and the following pages are packed with detailed descriptions.

I remain in awe of our people, who approach their work, be it in research, administration, teaching, or technical support, with energy and a passion for what they are doing. CIRA is a very well resourced research institute, for sure, but considering the range of activities CIRA is involved in, from the International Centre for Radio Astronomy Research Joint Venture with The University of Western Australia, to operating the Murchison Widefield Array, to playing a fundamental role in technology development for the Square Kilometre Array, and our wide-ranging work with the Industry and Defence sectors, CIRA's outputs are impressive relative to the inputs.

For example, I had occasion at the end of 2021 to reflect on CIRA's performance. As a benchmark I chose an organisation (I won't name) that I consider the world's leading astrophysics research institution and I chose the metric of Nature and Science papers as an indicator of performance. This organisation is ~50 years old, has a staff of approximately 850, and an annual budget of approximately $A160M. Since 2007 (when CIRA was established), they have authored and co-authored just over 200 papers in Nature and Science.

By comparison, CIRA started in 2007 with a single member of staff and has grown to approximately 80 staff. Since 2007, CIRA's total budget has been $A125M and, in that time, CIRA has authored or co-authored 23 papers in Nature and Science. More than 50% of CIRA's total published research has been in the last five years.

So, pound-for-pound, CIRA outperforms my chosen benchmark by a factor of up to two on this metric, which is impressive. I believe that this is a function of our smart choice of research and the way we go about it, as a purposeful multi-disciplinary exercise. That was the rationale on which CIRA was established in 2007. And it is clearly the result of being able to support smart and motivated people and resource our priorities. I include our PhD and Masters students in these statements, as in many ways they are the engine room of CIRA's programs.

Looking forward, with the Murchison Widefield Array producing outstanding science, the Square Kilometre Array entering its construction phase, and CIRA's increasing diversification of work with different industry sectors, the next few years are looking busy and exciting. I'm looking forward to seeing what our outstanding group of people will achieve in the environment of opportunity during this period.

Finally, as always, I would like to thank the members of the CIRA Executive Team for their support and work over the course of 2021, that is: Prof. James Miller-Jones, Director of Science; Prof. David Davidson, Director of Engineering; Ms Tina Salisbury, CIRA Business Manager; and Mr Tom Booler, Director of Operations.

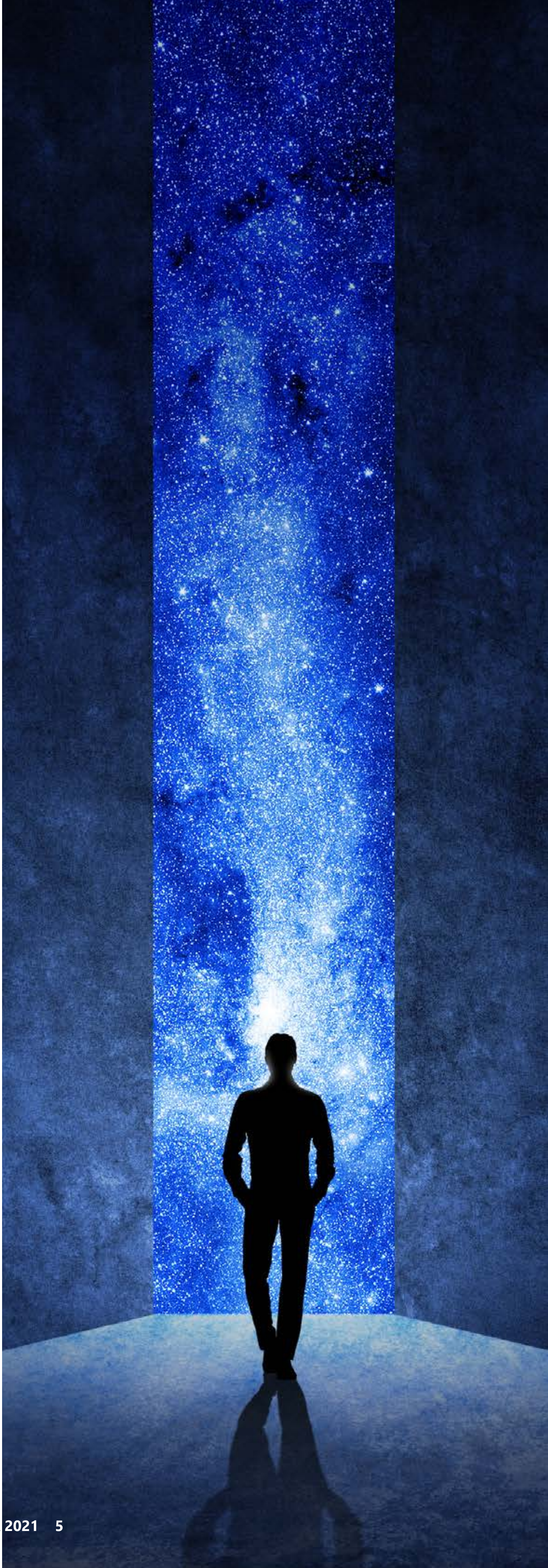


IMAGE CREDIT LEFT: ICRAR/Curtin

MURCHISON WIDEFIELD ARRAY DIRECTORS REPORT

Professor Steven Tingay
CIRA MWA Director

This is my first MWA Director report for a while, as I'm back in the role after some years. First, I'd like to thank the two previous MWA Directors for their hard work while in the role, keeping the MWA at the forefront of international radio astronomy. Associate Professor Randall Wayth and Professor Melanie Johnston-Hollitt oversaw the Phase II expansion of the MWA and the funding required to replace the MWA correlator.

Now that Melanie has moved on to another role at Curtin, Director of the Curtin Institute for Computation, I'm back in the role of MWA Director from 2021.

Calendar year 2021 saw a number of scientific highlights from the MWA. Just to name a few, Natasha Hurley-Walker et al. discovered a radio transient with an unusually slow period, research accepted for publication in Nature (published in January 2022). Ben McKinley et al. had their extensive observations of Centaurus A accepted for publication in Nature Astronomy (published in January 2022). And PhD student Nick Swainston led the long-awaited discovery of the first new pulsar with the MWA via the SMART survey.

Also, across all the MWA science programs, from heliospheric and ionospheric science to the Epoch of Reionisation, great gains have been made. Publications using MWA data continue to be very highly cited by the international astronomy community.

The most significant technical work over the course of 2021 was the bulk of the development for the new MWA correlator, MWAX. MWAX was deployed in early 2022 and a full description belongs in next year's annual report. Additionally, significant work has been undertaken in the form of ongoing maintenance and repair, including a major program to replace many of the aging coax cables that support the MWA tiles. This work should be complete by the end of 2022.

On the MWA Board front, 2021 has been an active year. A large part of the year was occupied by the Board making preparation for the Phase III MWA. Phase III includes the MWAX correlator, but also includes a major upgrade of the MWA's aging receiver systems, that have been operational in the challenging conditions of the Murchison since 2012. The MWA Board and partner countries have committed to Phase III, with the non-Australian members committing $A3.5M toward Phase III over the period 2023 – 2028.

As the current Australian MWA operations funding commitment concludes in 2023, the final part of the Phase III puzzle is a renewal of this funding from the Australian Government. I expect, over the course of 2022, to conclude these discussions and be able to chart a path for the MWA during 2023 – 2028, with significantly upgraded capabilities and the ability to further capitalise on the enormous scientific opportunities that have developed over the last decade.

Although the year did not usher in the desired return to pre-pandemic activities, 2021 saw the CIRA Science team continue to adjust to the new normality. After a year of online research and teaching, our staff and students settled into new, and more flexible, working patterns. Against a backdrop of remote teaching, online conferences and recruitment challenges, interrupted by the occasional sharp lockdown, the group has continued to deliver on its core responsibilities in research, teaching and engagement. I'm particularly mindful of the stresses that this has placed on staff and students alike, whether from the increased workload, the isolation from friends and family interstate or overseas, or the sheer uncertainty being faced across the sector. I'm grateful to the entire group for their efforts over the past year, and extremely proud of what has been achieved.

Professor James Miller-Jones
CIRA Science Director

In the research space, the CIRA Science team's productivity continued unabated, with 120 peer-reviewed publications in the calendar year, including a lead-author paper in the prestigious journal Science. Many of the research highlights are showcased in the following pages, and it has been fantastic to see a number of our long-term research threads start to hit their stride, including the first discoveries by the MWA of both pulsars and radio transient sources.

It was particularly pleasing to see the outstanding research achievements of the group being recognised externally, with Cath Trott winning the Australian Academy of Science's Nancy Millis Medal for outstanding mid-career researchers. On the international stage, the CRAFT group (Jean-Pierre Macquart, Clancy James, Wayne Arcus and Freya North-Hickey) were part of the team awarded the prestigious Newcomb Cleveland Prize by the American Association for the Advancement of Science, for the most outstanding paper published in the journal Science. Staff and students have also been recognised at the annual awards ceremony for the ASTRO-3D ARC Centre of Excellence, and internally at the Curtin Research and Engagement Awards. I warmly congratulate all who were recognised in these various fora.

The impact of the research work carried out at CIRA is also evident in the media attention it has garnered. The four high-profile media releases over the course of the year generated over 600 articles worldwide, with a cumulative audience of over 3 million people. In addition, our staff and students have provided media commentary on topical astronomy stories, and volunteered their time at numerous outreach events, from school visits to the rescheduled Astrofest event or the popular Virtual Reality documentary "Beyond the Milky Way". Such outreach work is great fun, extremely rewarding, and constitutes an important part of our role as scientists. I would like to express my sincere thanks to all those who regularly give up their time to promote astronomy to the general public.

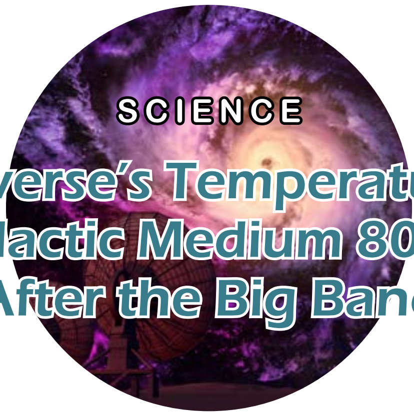
I am particularly grateful to all our staff and students who take on teaching duties, whether through coursework delivery or project student supervision. Our staff teach into 11 different coursework units within the Physics and Astronomy discipline, from first year to Honours level. We have supervised students in three different Physics project units, as well as Capstone projects within the Computing discipline and Honours and Masters-level students within the Mathematics and Statistics discipline. It is great to see CIRA staff engaging right across the School.

IMAGE CREDIT: AdobeStock

Pleasingly, our postgraduate student cohort has continued to expand. Our significant RTP success in 2021, taken together with several externally-funded studentships, will soon give us the largest student cohort at CIRA to date. Our students have achieved great success, with Tyrone O'Doherty winning a prestigious Forrest scholarship, a number of our 5 HDR completions in 2021 going on to postdoctoral positions in Australia or overseas, and two winning iPREP WA internships.

As ever, there were a number of staff movements in 2021, despite the difficulties in getting new staff members to WA. Forrest Fellow Nichole Barry and ASTRO-3D members Anshu Gupta and Ridhima Nunhokee all joined the Epoch of Reionisation team, and Marcin Glowacki arrived to join the CRAFT group. We farewelled Melanie Johnston-Hollitt, Paul Hancock, Guillaume Drouart and Amanda Wilber, and wish them all the best going forward. Ramesh Bhat and Clancy James joined the continuing staff cohort, Cath Trott was promoted to Professor, and Gemma Anderson to Senior Lecturer, and I extend them all my congratulations.

In closing, I'd like to thank the entire CIRA Science team for their hard work over the past year, and congratulate them on their achievements. With WA beginning to adjust to a new post-pandemic "normal" in 2022, we are all keen to reconnect with colleagues, family and friends as the year progresses. We look forward to welcoming a sizeable new cohort of talented students, as well as several new staff members over the coming year. On the research front, the upgrade to the MWA correlator should enable new and impactful science. In the medium term, the influx of new SKA staff to WA, and the newly-funded Australian Science Regional Centre promise significant new opportunities for collaboration, and hint at exciting times ahead.



Taking the Universe's Temperature: Constraints on the Intergalactic Medium 800 Million Years After the Big Bang

CATHRYN TROTT
Associate Professor

The Epoch of Reionisation (EoR) remains one of the least explored eras in the history of the Universe. In this time, between 200 million and 1 billion years after the Big Bang, the first stars and galaxies formed and illuminated the cosmos. Their remnants produced enough energetic light to then re-ionise the neutral hydrogen gas that filled the cosmos in the intergalactic space, and comprised 75% of the normal matter in the Universe. Little is known about the structure of the hydrogen gas during this early time, making it difficult to tailor our experiments to detect its signature, but measuring the temperature of the gas over time can provide insights into the first stars and galaxies.

As an alternative to undertaking blind experiments with no knowledge of the expected signal, we can use other tracers of the structure of the early Universe to guide what we might expect to see by looking for the gas. By matching observations from different tracers to those made with our radiotelescopes, we can gain more insights into the structure and temperature of the intergalactic gas.

Lyman-alpha emitting galaxies (LAEs) have bright emission from hydrogen embedded within the star forming regions of the galaxy. They are observed with optical and ultraviolet telescopes, and have been detected within the Universe's first billion years. The locations of LAEs at the end of the EoR are expected to correlate with regions of re-ionised hydrogen, because LAEs are not visible if they are surrounded by neutral hydrogen gas. Mapping the neutral hydrogen around regions with known LAEs therefore offers an avenue to constrain the temperature of the Universe within the EoR by providing an expectation for the spatial distribution of the neutral gas.

We used 12 hours of data observed with the Murchison Widefield Array to constrain the temperature of the intergalactic hydrogen gas around 58 LAEs that had been detected with the Subaru Hypersuprime Cam on the Japanese Subaru 10m telescope, in a period 800 million years after the Big Bang. We used the known LAE locations as a template for how the gas should appear to a radiotelescope, and then tested our data for that pattern (Figure 1 shows such a template). By comparing the real data with simulations for what we expect to observe with different temperatures of gas, we were able to show with high confidence that the intergalactic gas is colder than 30K in this region of the Universe. Figure 2 shows the recovery of the template signal as a function of sky location using realistic simulations of the sky and telescope.

This is the first application of this technique to reionisation data, and a unique approach to measuring the temperature of the gas. Deeper measurements can start to exclude some current models of the evolution of the early Universe.

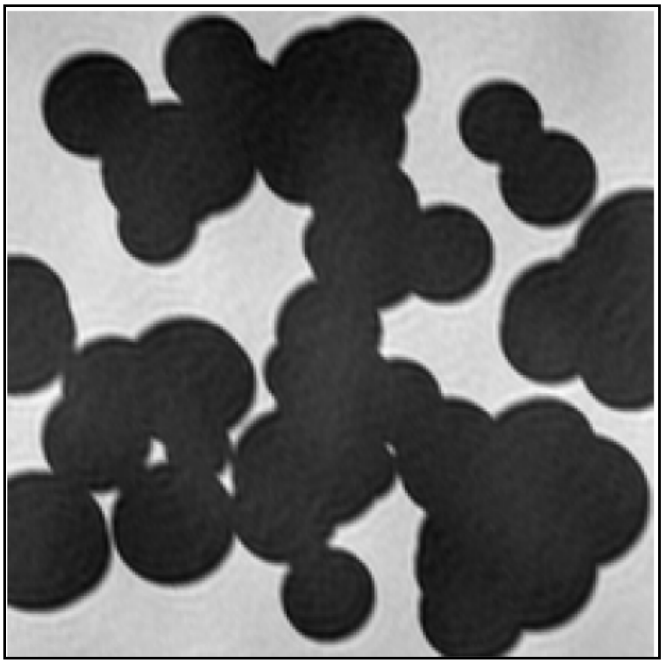


IMAGE ABOVE: Figure 1: Template signal expected to be observed by the Murchison Widefield Array telescope for intergalactic gas of a specific temperature (reproduced from Trott et al, 2021, MNRAS, 507, 772, doi 10.1093/mnras/stab2235).

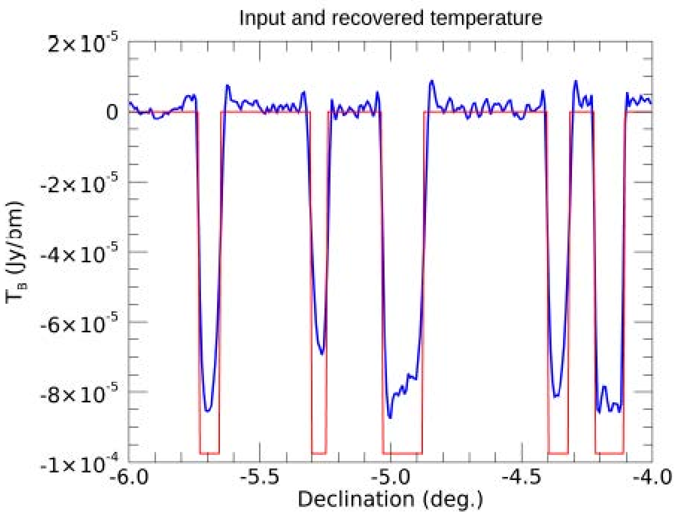


IMAGE ABOVE: Figure 2: Simulated (red) and recovered (blue) temperature as a function of sky location for simulations of the intergalactic gas (reproduced from Trott et al, 2021, MNRAS, 507, 772, doi 10.1093/mnras/stab2235)..

A New Type of Repeating Radio Transient

NATASHA HURLEY-WALKER
Senior Lecturer & ARC Future Fellow

The GaLactic and Extragalactic All-sky MWA eXtended (GLEAM-X) survey (page 20) is an ambitious attempt to make a deep image of the entire southern radio sky across the frequencies measured by the Murchison Widefield Array. When you build a deep survey, you need to revisit the sky multiple times. So in 2020, I suggested to an Honours student, Tyrone O'Doherty, that we could run a project looking at the differences between observations, and see if we can find anything that changes: a search for radio transients. Co-supervised by myself and Dr Paul Hancock (now at the Curtin Institute for Computation), over 2020 Tyrone transformed a snippet of code and a few terabytes of GLEAM-X data into a huge search for transients, exploring thousands of square degrees of our Galaxy. Quite to everyone's surprise, amidst many spurious features, he found one very bright candidate that seemed to pass every test we could throw at it. It was there one month, but gone the next! Named after the survey it was found in, and its location on the sky, we dubbed it GLEAM-X J162759.5-523504.3.

In 2021 I started looking into what this strange object could be. Radio transients are a big focus of research in CIRA (Page 14) so I expected it to be a known class of object. I quickly discovered that this object wasn't just changing month-to-month; it was changing minute-to-minute! For the first three months of 2018, this source switched on for up to a minute, then off again, and repeated this every eighteen minutes, a periodicity that had never been seen before in any radio-bright object. And this source was very bright. When it was on, it outshone all the other radio sources in our thousand square degree field-of-view!

Fortunately CIRA is exactly the right place to find experts at solving cosmic mysteries. From correcting the arrival time of the pulses for the motion of the Earth around the Sun, to rapidly following up the source with X-ray observations; from figuring out how to measure the polarisation of the radio waves, to working through the possibilities of what the source could be: with a little help from collaborators at CSIRO and SHAO, we had it covered. The leading contender for the nature of the source is an "ultra-long period magnetar", which had been predicted by theorists to exist, but had never before been observed. By mid-2021 we had pulled together a paper in record time, and submitted it to Nature.

Published in January 2022, the discovery has provoked an enormous storm of public enthusiasm across the world. More than 3,000 articles across over 100 countries have been published, reaching at least 13 million people, while Tyrone and I have interviewed over 50 times across TV, music, podcasts, and print. The video explainer I put together with the help of the ICRAR outreach team reached the top 1% of videos viewed on Vimeo, and Tyrone and I have received messages from all over the world about the discovery. Importantly, the paper has provoked enormous interest in the scientific community, with theorists offering new ideas as to the origin of the radio emission, and observers across the world creating new programmes to search for this new class of objects. This includes here in CIRA, where I am now leading a new programme to monitor the Galaxy with the MWA. On detection, we plan to immediately follow up these sources with multiple radio and space telescopes, and solve this new cosmic mystery.

Article

A radio transient with unusually slow periodic emission

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Check for updates

N. Hurley-Walker[1✉], X. Zhang[2,3], A. Bahramian[1], S. J. McSweeney[1], T. N. O'Doherty[1], P. J. Hancock[1], J. S. Morgan[1], G. E. Anderson[1], G. H. Heald[2] & T. J. Galvin[1]

The high-frequency radio sky is bursting with synchrotron transients from massive stellar explosions and accretion events, but the low-frequency radio sky has, so far, been quiet beyond the Galactic pulsar population and the long-term scintillation of active galactic nuclei. The low-frequency band, however, is sensitive to exotic coherent and polarized radio-emission processes, such as electron-cyclotron maser

ARTICLE IMAGE CREDIT: Nature Journal 2021

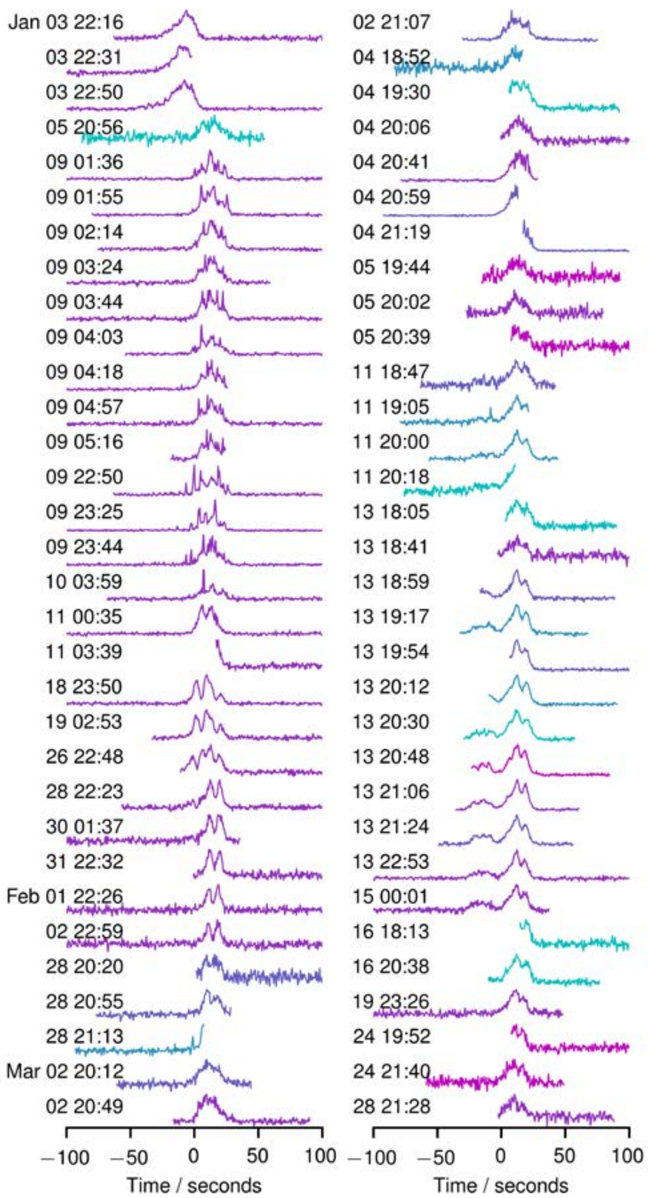


IMAGE LEFT:
64 of the 71 detected pulses from GLEAM-X J162759.5-523504.3, lined up by its measured period of 1091 seconds, and corrected for the motion of the Earth around the Sun and other effects. The colour of the profiles indicates the frequency: low frequencies around 80 MHz are shown in cyan, transforming to magenta for high frequencies around 220 MHz. Credit: Hurley-Walker et al. (2022)

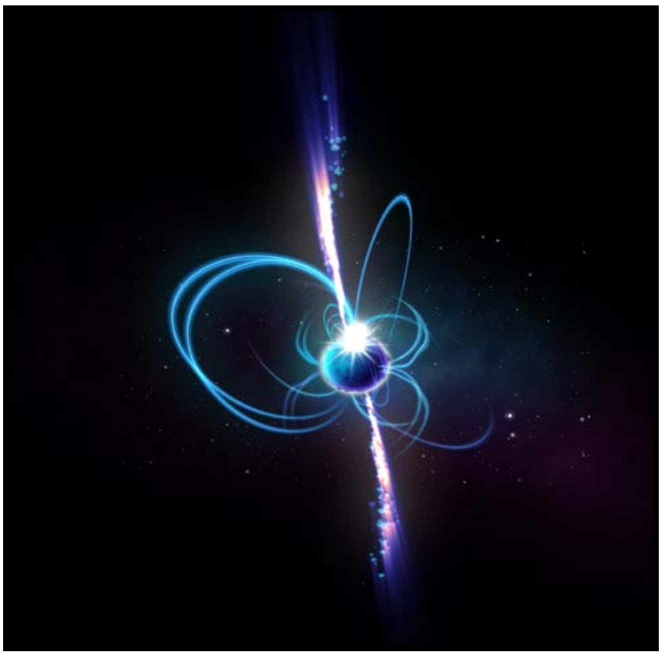


IMAGE RIGHT MAGNETAR
An artist's impression of a magnetar. Magnetars are extremely magnetic neutron stars, some of which sometimes produce radio emission. Known magnetars rotate every few seconds, but theoretically "ultra-long period magnetars" could rotate much more slowly, perhaps explaining the pulses seen from GLEAM-X J162759.5-523504.3.
IMAGE CREDIT: ICRAR

Towards the First Sample of Powerful Radio Galaxies Within the Epoch of Reionisation

JESS BRODERICK
Senior Research fellow

GUILLAUME DROUART
Research Associate

NICK SEYMOUR
Senior Lecturer

TIM GALVIN
Associate Lecturer

How do black holes grow so quickly in the early Universe? The high-redshift radio galaxy (HzRG) group aims to understand how 'monster' black holes with masses a billion times that of the Sun can exist less than one billion years after the Big Bang.

This is not much time for them to grow so massive, implying large 'seed' black holes or extreme astrophysics yet to be observed. Powerful radio galaxies have long been beacons of active supermassive black holes, but none have been discovered yet at a redshift $z > 6$ (0.93 billion years after the Big Bang). We have continued to make great progress over the last 12 months in our search for these elusive objects, with three first-author publications (Drouart et al. 2021, PASA, 38, 49; Seymour et al. 2022, PASA, 39, 16; Broderick et al. 2022, PASA, in press; arXiv:2204.08490) and several accepted observing proposals.

Following our successful pilot study (Drouart et al. 2020, PASA, 37, 26) using the Murchison Widefield Array (MWA) GLEAM survey, we obtained near-infrared imaging and spectroscopic observations of the most exciting radio galaxy from the pilot, GLEAM J0917−0012, with WFC3 onboard the Hubble Space Telescope (Seymour et al. 2022). Originally thought to be at $z = 10.15$ from faint spectroscopic features (Drouart et al. 2020), i.e. well within the Epoch of Reionisation (EoR; $z > 6.5$) when the first stars and galaxies formed in the Universe, follow-up observations with both the JVLA and ALMA did not support this interpretation (Drouart et al. 2021).

Given the extreme faintness of the host of this radio galaxy, we then sought follow-up with Hubble. We detect the host galaxy in our two deep F098M (0.98 μm) and F105W (1.05 μm) images (Fig. 1); it is about 50 per cent brighter in the second band, which suggests a very red colour or continuum spectral break.

The spectroscopic observations with the G102 grism reveal a single weak line at 1.12 μm (Fig. 2). To help identify this line, we utilised several photometric redshift fitting techniques, details of which can be found in Seymour et al. (2022). The results from this fitting do not conclusively identify what the line could be, although two possibilities are Ly-α at $z = 8.21$ or [OII] at $z = 2.01$. Further observations are still required to unambiguously determine the redshift of this intriguing candidate ultra-high-redshift radio galaxy.

In addition to the above study with Hubble, we refined the low-frequency radio spectral curvature selection technique used in the pilot project to identify 51 new HzRG candidates from GLEAM in the region covered by the 1200 deg2 VIKING near-infrared survey.

Our GLEAM–VIKING HzRG candidate sample is now defined in Broderick et al. (2022). Taking advantage of Australia's strategic partnership with the European Southern Observatory (ESO), we were awarded time with HAWK-I on the Very Large Telescope (VLT) from 2021 October – 2022 March (PI Broderick) to obtain deep near-infrared K-band (2.15 μm) images of our new sample, which by selection are not detected in VIKING.

From the HAWK-I observations, there are 14 sources of particular interest with host galaxy magnitudes $K > 23$ [AB]: 5 with host detections, and 9 with host non-detections as deep as $K > 24$ [5σ; AB]. An example is shown in Fig. 3. Given both the radio properties and the very faint host galaxy magnitudes, there is the exciting possibility that at least some of these 14 sources could be at ultra high redshift and within the EoR, as indeed might be the case for GLEAM J0917−0012 above. Even finding a single powerful radio galaxy within the EoR would enable highly valuable constraints to be placed on the physical conditions in the early Universe, for example from redshifted 21-cm neutral hydrogen (HI) studies with the MWA or the Square Kilometre Array (SKA) – and there is the potential to build a statistical sample of powerful radio galaxies within the EoR from the target list!

We have proposed for time on ALMA to determine the spectroscopic redshift of each of these high-priority targets. Stay tuned!

FIGURE 1

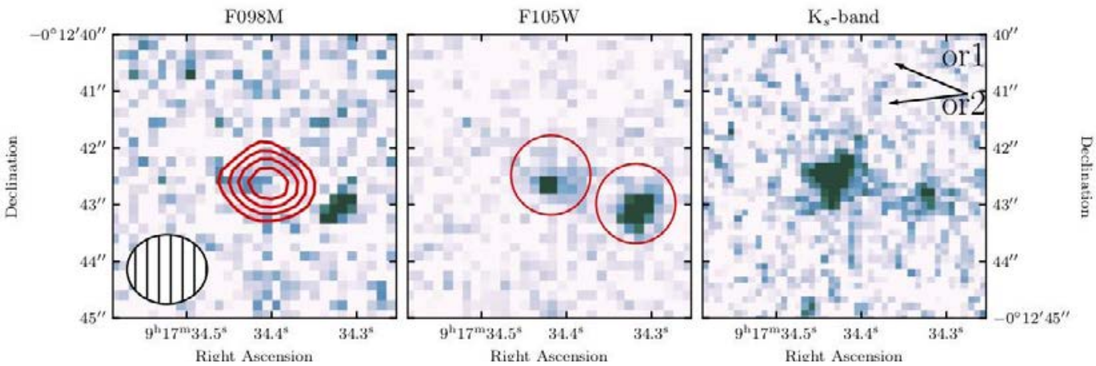


Fig. 1: Greyscale F098M, F105W and K-band images of the host of GLEAM J0917−0012 (centre of each panel) and a companion galaxy (to the west). Overlaid on the F098M image in red are high-resolution ALMA 100-GHz contours, with the ALMA synthesised beam shown in the lower left of the panel. The contours are (3, 4, 5, 6) x 10 µJy beam−1, the root mean square (RMS) noise of the ALMA image. The two circles in the middle panel indicate the host and the companion. The host galaxy shows a compact near-infrared morphology with a size of about 0.25 arcsec, and with faint extension to the west. The arrows in the third panel indicate the dispersion directions of each orientation of the grism. Image credit: Seymour et al. (2022).

FIGURE 2

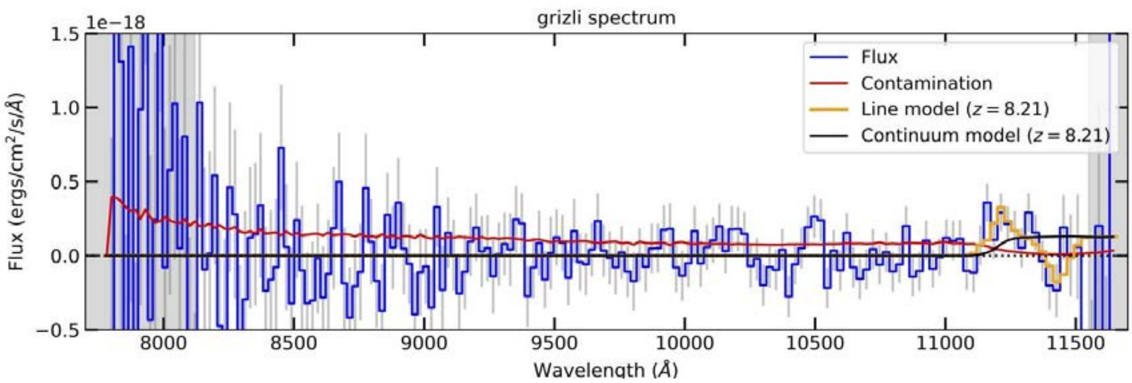


Fig. 2: The Hubble Space Telescope spectrum of GLEAM J0917−0012. The estimated contamination from other sources, indicated in red, is subtracted. Grey shaded regions indicate where the transmission of the G102 grism drops below 10 per cent. The spectrum is consistent with a very low or zero flux density across most of the wavelength range. A feature at 1.12 µm is seen, albeit at a signal-to-noise ratio of about 3. Overlaid are the continuum (black) and line (orange) model templates, which are most consistent with other constraints from the analysis of this source. This solution at z = 8.21 shows the Ly-α line in emission and the NV line in absorption. Follow-up observations are required to confirm this result. Image credit: Seymour et al. (2022).

FIGURE 3

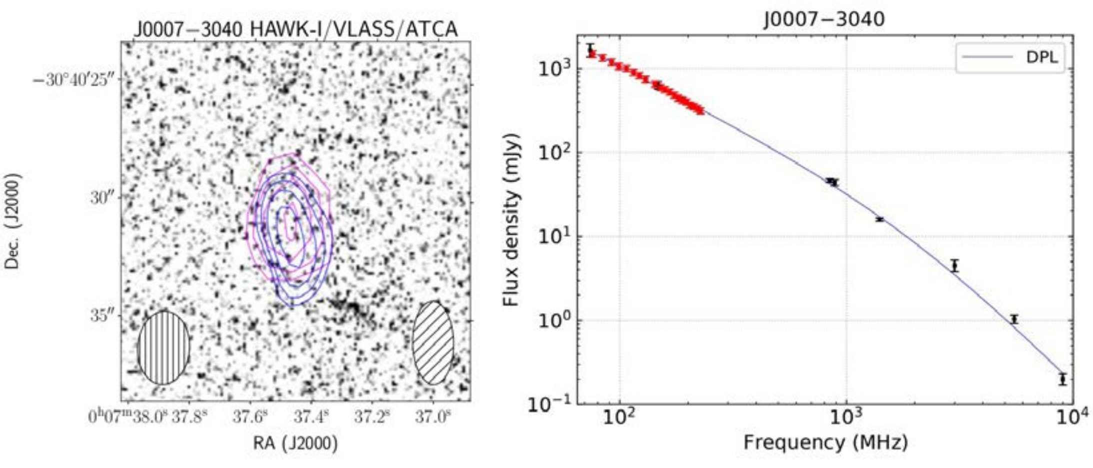


Fig. 3: The HzRG candidate GLEAM J0007−3040 from our new sample (Broderick et al. 2022). Left panel: Deep HAWK-I K-band image (greyscale) overlaid with VLASS (3 GHz; magenta) and ATCA (5.5 GHz; blue) radio contours. VLASS and ATCA synthesised beams are shown in the bottom left- and right-hand corners, respectively. The host galaxy is not seen near the centroids of the radio contours; it has a K-band magnitude > 23.5 [5σ; AB]. Right panel: The radio spectrum of GLEAM J0007−3040 from 74 MHz to 9 GHz. Data points from GLEAM are shown in red; the remaining data points in black are from the VLSSr (74 MHz), TGSS (147.5 MHz), SUMSS (843 MHz), ASKAP/RACS (887.5 MHz), NVSS (1.4 GHz) and VLASS (3 GHz) surveys, as well as our dedicated observations with ATCA at 5.5 and 9 GHz. The radio spectrum is best fitted with a smoothly varying double power law (DPL) with low- and high-frequency spectral indices of −1.39 and −2.75, respectively, either side of the break frequency at 1970 MHz. Given the combination of (i) a deep host galaxy K-band non-detection, (ii) a compact radio morphology (angular size 3 arcsec), and (iii) an extremely steep, curved radio spectrum, this is an HzRG candidate of particular interest. Image credit: left panel - Broderick et al. in prep.; right panel - Broderick et al. (2022).

CRAFT Bags Another Nine Fast Radio Bursts

CLANCY JAMES
Senior Lecturer

CRAFT, the Commensal Real-time ASKAP Fast Transients Survey with the Australian Square Kilometre Array Pathfinder, has continued its successful run of discoveries in 2021. A total of nine new fast radio bursts (FRBs; millisecond radio signals of unknown origin originating from outside the Milky Way) were discovered, of which seven have been localized to their host galaxies. Tantalizingly, this new FRB sample includes two bursts expected to originate from beyond a redshift of 1, meaning they have been travelling to us for more than half the age of the Universe. However, they are so distant that even the Very Large (optical) Telescope, VLT, cannot detect the host galaxies, and we must await time on the Hubble Space telescope to confirm expectations. Discovering the host galaxies of these events not only allows their origins to be analysed, but also provides critical information on the overall structure of the Universe – a detailed modelling task currently being undertaken by Wayne Arcus and Clancy James.

CRAFT was also the first to identify the host galaxy of the repeating FRB 20201124A, which was detected in an outburst period by the Canadian CHIME instrument. Using five bursts, ASKAP identified the host galaxy of the FRB, and the FRB's position within it (see Figure 1). This position was later confirmed with very long baseline interferometry. Key to this work was the efficient coding of a data analysis pipeline by Danica Scott, who not only localized some of the bursts from FRB 20201124A, but through computational wizardry, massively reduced the required human intervention in the process, so that it now runs mostly automatically. It is being implemented on the Pawsey supercomputer system for use in the next generation ASKAP FRB detection system now being commissioned, 'CRACO'. Automation of our data analysis methods will be critical once this system comes online during 2022, since the FRB discovery rate will then increase by an order of magnitude.

One such analysis will be the search for gravitationally lensed FRBs, where the curvature of space-time due to (for instance) lunar-mass black holes may result in multiple copies of the same FRB signal being detected, perhaps only microseconds apart. This analysis is being led by Mawson Sammons, and it probes the nature of dark matter, which is responsible for most of the mass of the Universe, but about which very little is known.

A new the addition to the group during 2021 was Marcin Glowacki, who was hired under an ARC Discovery Project grant to study the high-time-resolution properties of FRBs. Marcin comes to us from the University of the West Cape, South Africa. Marcin's main task will be to take add to Danica's analysis pipeline, and use the results to discover the FRB emission mechanism, and properties of the material through which FRBs travel.

The highlight of the year, of course, was the awarding of the American Astronomical Society's Newcomb Cleveland Prize, which is described in more detail on page 48.

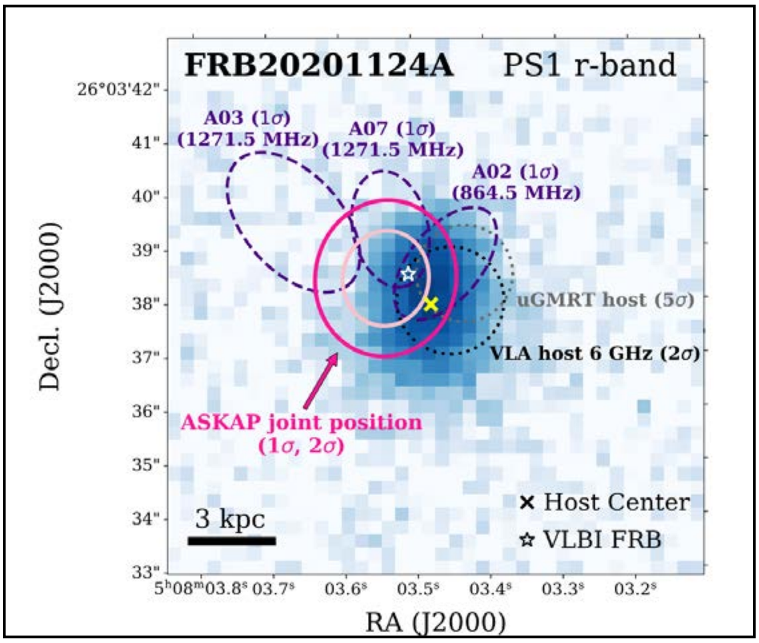


FIGURE 1

Figure 1 LEFT: the host galaxy of FRB 20201124A, showing the optical emission from the host galaxy (blue shading) about the centre (yellow cross), the best-fit positions of three bursts detected by ASKAP/CRAFT (purple ellipses), the combined best-fit position (pink), positions from other FRB instruments (grey, black), and the VLBI confirmed location of the FRB (star). Figure taken from Fong et al., ApJ Letters, v919 L23 (2021).

The Rapid Radio Brightening of a Gamma-Ray Burst

GEMMA ANDERSON
Senior Research Fellow

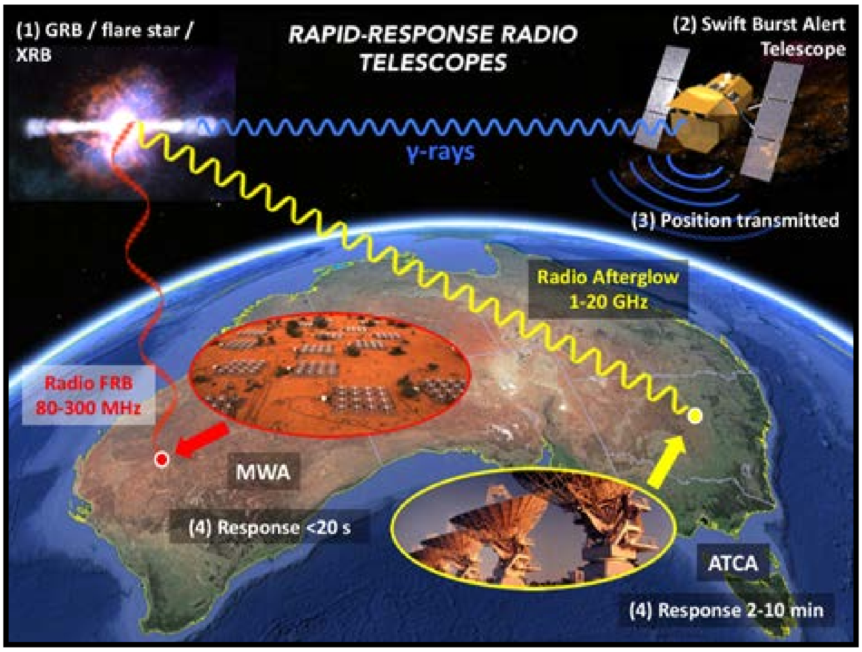
Gamma-ray bursts (GRBs) are explosive stellar events that form black holes. They are so bright and powerful we can see them from the very furthest galaxies in our Universe. Such violent explosions can also produce bright radio emission but little is known about how this light behaves at very early times.

In order to probe the very early-time radio light emitted by GRBs, I have driven the installation of a rapid-response observing modes on both the Australia Telescope Compact Array (ATCA) and the Murchison Widefiled Array (MWA). If a dedicated telescope such as the Neil Gehrels Swift Observatory detects a GRB, it transmits is position down to Earth. When our software receives an alert, it triggers both ATCA and MWA, causing them to automatically repoint and being observing the GRB within seconds to minutes of its discovery (see Figure 1). By bypassing the need for human intervention, we can ensure we are on target quick enough to probe unusual radio light emitted by explosive and outbursting (transient) astronomical events.

Swift detected a GRB on 7 Feburary 2021, which resulted in ATCA triggering on the event just 4 hours post-burst, when it had risen above the horizon. We monitored the GRB position for 12 hours at 5.5, 9, 16.7 and 21.2 GHz. These observations showed an unexpected radio flare that started 9 hours post-burst, lasting for 5 hours, with the strongest radio signature detected at 9 GHz (see Figure 2). Such a feature is not a known characteristic of GRB radio afterglows, which usually evolve on much longer (day to weeks) timescales.

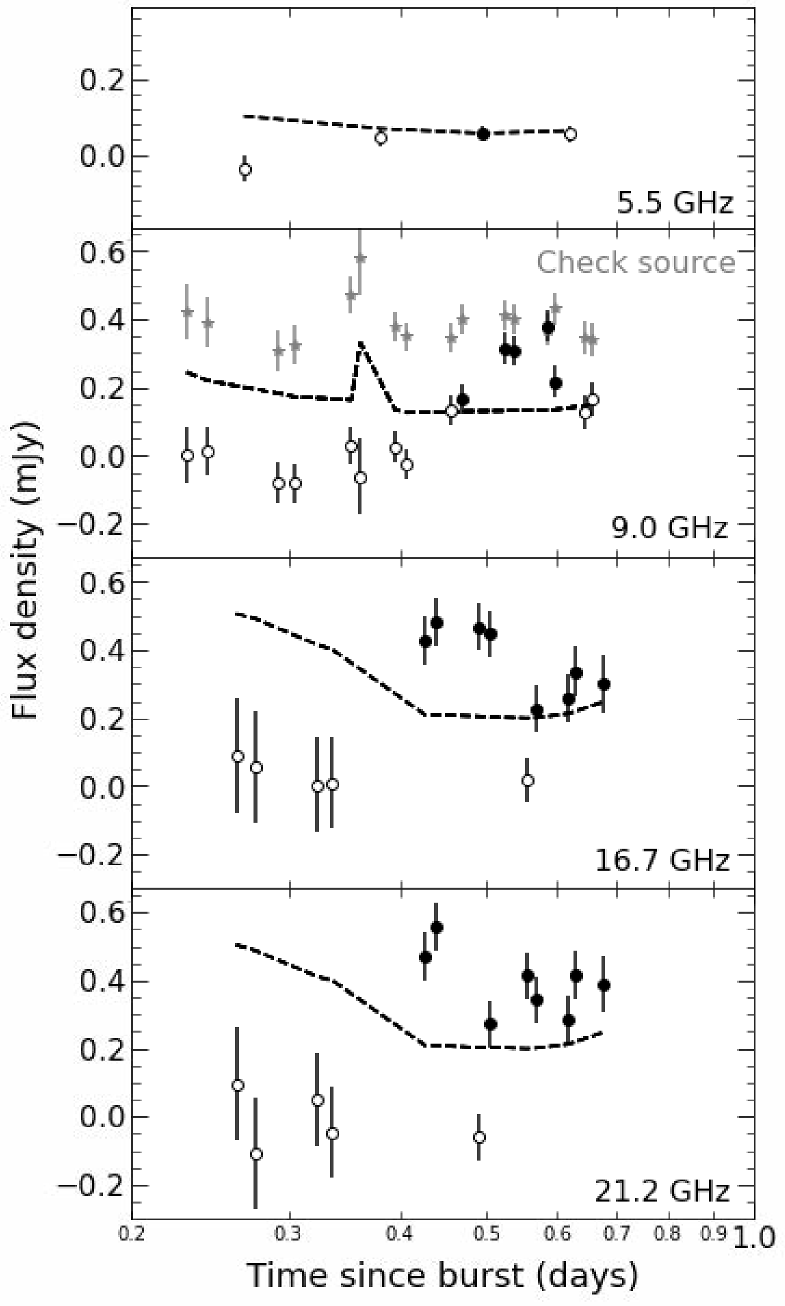
The flare is likely due to scintillation, which is caused by a clump of material in our own Galaxy passing in front of the GRB making the radio light twinkle, and thus boosting it above the ATCA detection sensitivity on minute timescales. It is only with rapid-response observing systems such as those on both ATCA and MWA that we can explore such unusual phenomena from GRBs at early (<1 day) times. This result provides insight into how far the material ejected from the GRB at near the speed of light has travelled in such a short time, and likely represents the earliest detection of radio scintillation from a GRB. It begs the question of what other phenomena may be revealed via rapid-response radio observations of transient events, further supporting the need for rapid-response transient triggering systems on the upcoming Square Kilometre Array.

FIGURE 1



ABOVE FIGURE 1: Flow diagram depicting the rapid-response observing system required for detecting early-time radio emission from GRBs. Following a GRB (1), Swift will detect the event (2) and then transmit its position down to Earth (3). This positional information will then be received by MWA and ATCA resulting in radio observations of the event with response times within minutes of the burst's detection (4).

FIGURE 2



ABOVE FIGURE 2: Radio light curves showing the early-time radio flare from GRB 210702A at four different observing frequencies obtained from ATCA rapid-response observations. The black data points are detections and the hollow data points show forced measurements at the position of the GRB when it was not detection. At 9 GHz, we have also included the light curve of a nearby 'steady" source, demonstrating that the observed variability from GRB 210702A is real.

A SMARTer Way to Discover Pulsars

SAMUEL JAMES MCSWEENEY
Associate Lecturer

The Southern-Sky MWA Rapid Two-Metre (SMART) pulsar survey is an ongoing campaign to discover new pulsars at low frequencies with the Murchison Widefield Array (MWA). With ~70% of the data collected so far, < 5% of which has been processed, we are pleased to report the discovery of three pulsars, J0036-1033 (Swainston et al., 2020), J0026-1956 (McSweeney et al., submitted), and J1002-2044 (Bhat et al., in prep), entirely in line with expectations. With each new discovery, we learn more about some of the MWA's unique features, which we can leverage to accelerate the rate of new pulsar discoveries.

One such feature is the complex sensitivity pattern of the MWA. All telescopes, including traditional dish telescopes, can be characterised by their so-called "beams": no matter which way the telescope is pointing, there is always some degree of sensitivity towards directions other than the boresight direction. One consequence of this is that signals from point sources (like pulsars) can be detected in beams that are not pointed directly towards them. In many applications (such as imaging), this kind of leakage is considered a problem, serving to mix signals coming from a range of directions, effectively limiting the resolving power of the telescope.

A dish telescope's beam shape is determined primarily by its physical construction: the shape of the dish and the location and design of the receiver (the hardware that actually detects the signal). For the MWA, however, the situation is entirely different. As an aperture array, the telescope is "pointed" by electronically introducing different amounts of delays to the signals detected by each element before summing their signals together. When the signals from all 128 MWA tiles are delayed-and-summed in this way, the result is called a tied-array beam, and the shape of this beam is determined both by the sensitivity pattern of each cross-dipole, as well as the way they are positioned relative to each other.

By design, the SMART survey uses the compact configuration of the MWA, because closely spaced tiles translates to a relatively large tied-array beam, making it computationally feasible to cover the whole sky with relatively few "pointings". However, the compact configuration includes a subset of tiles arranged in regular hexagonal patterns (the so-called "hexes"), and this has a remarkable (albeit predictable) effect on the beam shape, with the main regions of sensitivity forming a six-petalled flower shape, as illustrated in Figure 1.

For complete sky coverage, the tied-array beams should be formed with a separation not exceeding the full-width-half-maximum sensitivity of the central lobe. Consequently, multiple pointings will sample the overall "flower" shape. Thus, even though the "petals" are not as sensitive as the central lobe, a sufficiently bright pulsar will likely be detected in multiple pointings. In other words, down to a certain sensitivity limit, our chosen set of pointings is actually over-sampling the sky.

All of this adds up to a method for quickly sifting through the (millions of) pulsar candidates to find the true (sufficiently bright) ones. By comparing candidates across nearby pointings, we can quickly identify those with similar periods and dispersion measures (two quantities that uniquely characterise pulsars). We have recently integrated this methodology into the SMART web-app, developed and hosted by ADACS and DataCentral, to ensure that the most similar candidates get inspected first.

Although the above method was implemented only after the second pulsar (J0026-1956) was discovered, we know in hindsight that this method would have detected it immediately. The right-hand panel of Figure 1 shows all the pointings where J0026-1956 was detected, including both main lobe (central lobe) and grating lobe (petal) detections. Indeed, it was owing to the fact that this pulsar was detected in multiple pointings that first motivated us to look more closely at the MWA's complicated beam pattern, to see if we could leverage it for rapid confirmation of true signals. Now that this method is part of our processing pipeline, we look forward to an accelerated rate of pulsar discoveries as the SMART survey continues.

FIGURE 1a

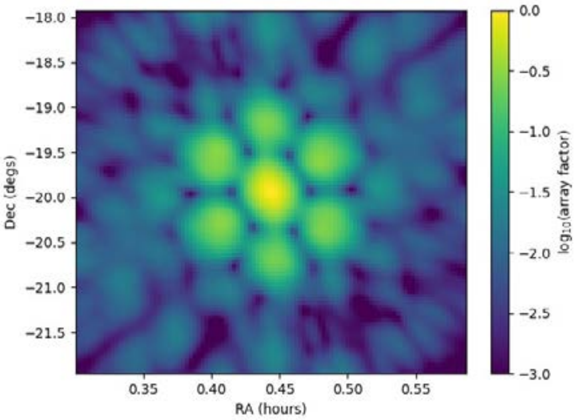
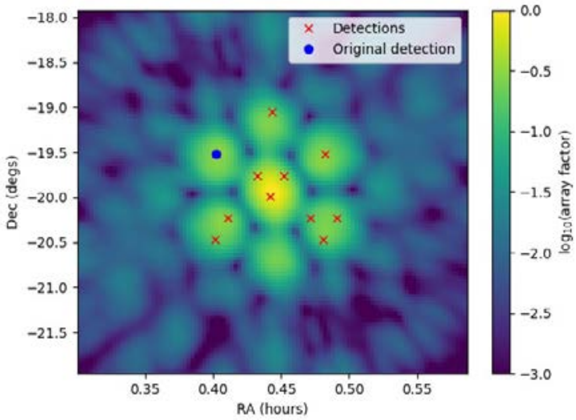


FIGURE 1b



The six-petalled beam shape of the compact configuration of the MWA. On the right hand panel, the detections of PSR J0026-1956 are overlaid, showing how the complex beam pattern can be leveraged to cross-correlate candidate detections across multiple tied-array beam pointings.
IMAGE CREDIT: Sam McSweeney

IMAGE CREDIT: AdobeStock

Pinpointing Pulsar Positions with the MWA Despite the Ionosphere

RAMESH BHAT
Senior Research Fellow

NICHOLAS SWAINSTON
PhD Student

With their physical size of ~20-30 km in diameter, pulsars – i.e. spinning neutron stars that emit beams of radiation from their poles – are perfect "point" sources. Indeed their magnetospheric environments, which dictate the physical processes that govern the emission of radiation, can be ~100,000 km in extent. Even then, their small sizes mean even the nearest pulsar (located ~1000 light years away from us) will only be a few microarcseconds in angular scale, and so cannot be resolved even with the angular resolution of "Earth-sized" Event Horizon Telescope that can image supermassive black holes. Pulsar science is therefore typically performed with large single-dish type telescopes.

With interferometric arrays like the Murchison Widefield Array (MWA), comprised of more than 100 elements, the main technical task is therefore to coherently combine the signals from all detectors to make a single-dish equivalent phased-array (tied-array) beam – a pencil beam with the imaging resolution of the telescope. This allows recording data at very high time and frequency resolutions needed for studying pulsars, whose emission often shows a rich, diverse and complex temporal structure.

To gear up the MWA for pulsar research, the Curtin pulsar team first developed a beamformer capability (in software) to generate a high-time-resolution beamformed output at 100-μs/10-kHz resolution from large volumes of raw data, recorded at a rate of 28 TB per hour from 128 tiles of the array (Ord et al. 2019). This was soon further enhanced by an implementation to reverse engineer the second-stage polyphase filterbank operation performed prior to voltage recording, attaining even higher time resolution of ~1 microsecond needed for millisecond pulsars, with rotation periods of a few milliseconds (McSweeney et al. 2020). Despite these encouraging developments to enable pulsar research with the MWA, and an impressive research output (over 20 publications and four PhD completions) over the past few years, ambitious projects like scanning the large swathes of the southern sky to search for new pulsars remained beyond the reach of the MWA. This required forming almost one million tied-array beams to tessellate the full southern sky, even with the compact configuration (128 tiles within ~300 metre) of the array that brings down the computational cost of beamforming by 2-3 orders of magnitude. To realise an all-sky pulsar search programme with the MWA – the Southern-sky MWA Rapid Two-metre (SMART) survey – further development was inevitable.

Curtin PhD candidate Nicholas Swainston embraced the challenge. Building on the foundation laid by the work of Ord and McSweeney, a functionality was developed for the beamformer that will allow synthesising a large number of beams at once (by simultaneous processing of over 100 data streams!), i.e. a multipixel beamformer functionality for the MWA. This improved the processing efficiency by an order of magnitude, which made a project such as SMART tractable for the MWA, and led to the first discoveries of new pulsars with this Australian SKA Precursor. Since the discovery of the first new pulsar last year (Swainston et al. 2021), two more pulsars have been discovered from SMART. As data processing ramps up in the coming year, more are expected to emerge.

Pinpointing the sky positions of the newly-discovered pulsars forms an integral part of followup strategy. Much narrower beam size provided by the extended configuration of the array and the ability to attain ~10" precision via forming a dense grid around the initial position was appealing for this important exercise. While the team demonstrated that the precision of this order can be achieved (Figure 1), a position wander of ~30" seen between different observations remained a puzzle. Investigations revealed this is often to do with applying sub-optimal corrections to the effects of the ionosphere that can cause apparent position offsets of pulsars in observations are made with the MWA, especially when calibration observations are made at large time and angular separations from the pulsar observations.

Using high-quality observational data collected through a separate pulsar project (led by Curtin co-supervised PhD student

Parul Janagal, based at the Indian Institute of Technology, Indore), Swainston and team performed a detailed investigation. This observation turned out to be a jackpot for pulsar detections, with 18 pulsars resulting from a single observation! The multipixel beamforming functionality was repurposed for studying the position offset and the resultant sensitivity loss, for all 18 pulsars encompassed in the observation. The analysis revealed offsets of the order of ~10″ to ~30″ and a sensitivity loss as much as ~30-50%, as shown in Figure 2.

As the MWA upgrade (Phase III) moves forward, and a real-time beamforming functionality becomes feasible for the MWA, it will be important to include this as part of routine system checks and calibration procedures. It can bring a significant saving telescope time – a precious commodity – by as much as a factor of four! This is an important consideration for even other low-frequency telescopes such as the Indian Giant Metrewave Radio Telescope with baselines out to ~25 km, and the SKA-Low which will have even longer baselines (up to ~65 km). It is also an important factor to consider for sub-arraying SKA-Low for some pulsar science applications. A paper detailing the related development and analysis is published in Publications of the Astronomical Society of Australia (Swainston et al. 2022, 39, e020).

FIGURE 1

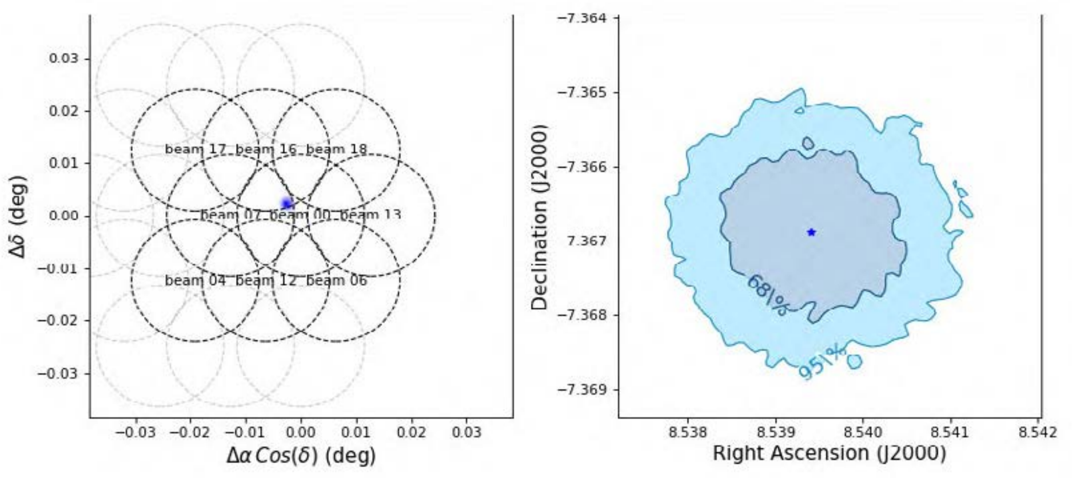


Figure 1 ABOVE: Localisation of the MWA-discovered pulsar PSR J0036-1033. The observation was centred at 155 MHz and the tied-array beam has a full-width half-maximum (FWHM) of ~1.26 arcminutes. The localisation method estimates the pulsar position to within 14 arcseconds. Left: the dashed lines represent the FWHM of the tied-array beams. The faint grey dashed lines are beams that are more than one beam width away and therefore not included in the localisation calculation. Right: the first (dark blue) and second (light blue) confidence intervals of the localisation (68% and 95% , respectively).
IMAGE CREDIT: Nick Swainstain/ Ramesh Bhat

FIGURE 2

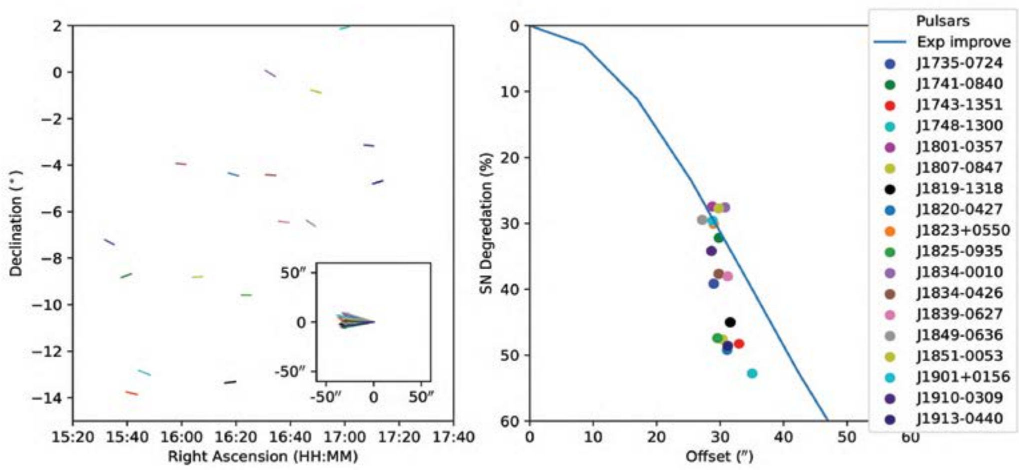


Figure 2 ABOVE: Position estimates using a grid of pointings around the 18 pulsars in observation 1276619416. The inset panel (left) shows the difference between the estimated position and that from the ATNF pulsar catalogue. In the left panel, the offset of each pulsar is increased by a factor of 100 for clarity. The right panel shows the degradation in the signal-to-noise ratio due to inaccurate pointing. The blue line represents the expected degradation based on the point spread function (beam response) of the telescope.
IMAGE CREDIT: Nick Swainstain/ Ramesh Bhat

Discovery of a Pulsar With Unusual Nulling and Sub-Pulse Drifting Properties

SAMUEL JAMES MCSWEENEY
Associate Lecturer

The Southern-Sky MWA Rapid Two-Metre (SMART) pulsar survey is an ongoing campaign to discover new pulsars at low frequencies with the Murchison Widefield Array (MWA). It is being conducted in two data processing stages, or "passes": (1) a shallow pass using 10 minutes of data per pointing and (2) a deep pass using 80 minutes per pointing. We are currently still conducting the shallow pass, and, despite the reduced sensitivity of this pass, have discovered three pulsars since the survey began.

This article is about the second discovered pulsar, PSR J0026-1956. Its identification as a strong candidate in the 10-minute data set was, as usual, followed up by examining the whole 80 minutes. Surprisingly, we found that although the pulsar did appear in the larger data set, its appearance was sporadic: it would be "on" for several minutes, and then the signal would switch "off" for several more minutes. Overall, we estimated the pulsar to be "off" to be some ~75% of the time; our detection of it in the first 10 minutes was indeed fortunate!

This switching "on" and "off" is not altogether unusual, as far as pulsars go, although no one understands the mechanism behind this switching of states. The "off" periods are called nulls, and the pulsars that exhibit this behaviour, nulling pulsars. The nulling fraction (~75% for J0026-1956) can vary dramatically from pulsar to pulsar, ranging from < 1% to almost 100%!

As we continued the search for new pulsars, we had another pleasant surprise. Our original detection was found in a beam that was not pointing directly at J0026-1956, but in which the pulsar was about 1° away in a grating lobe. Consequently, we found that the same pulsar signal appeared much brighter in the beams pointing nearest J0026-1956's true position—so bright, in fact, that we can see its individual pulses. When we stacked the pulses on top of each other (see Figure 1), we found that J0026-1956 was also a sub-pulse drifter!

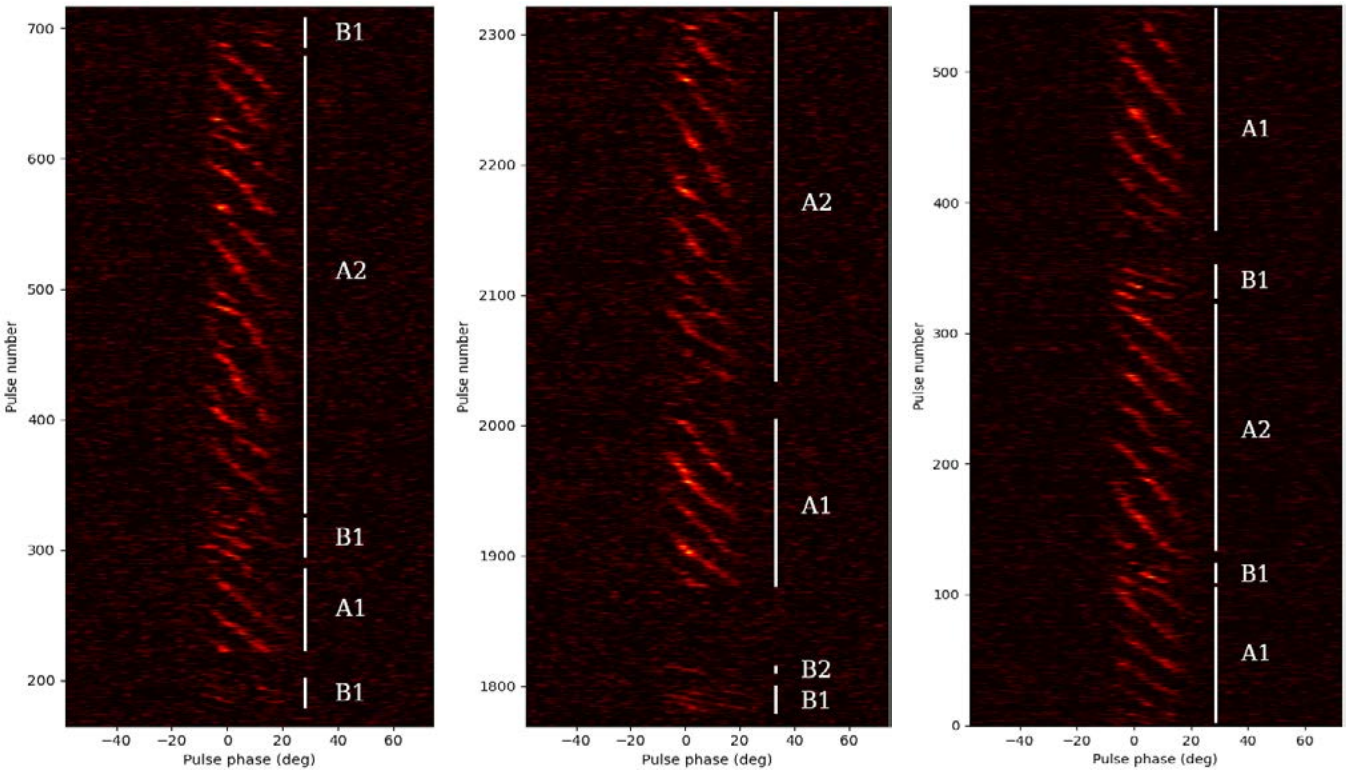
Subpulse drifting is the phenomenon where the individual pulses don't appear at exactly the same period as the rotation of the pulsar, but seem to "drift" in time throughout the pulse window. Subpulse drifting, like nulling, is a familiar phenomenon whose ultimate cause is still only poorly understood. Over the decades, both nulling and subpulse drifting have been intensely studied, as both phenomena have clear implications for understanding the underlying pulsar emission mechanism, another longstanding and important astrophysical mystery!

In some pulsars, a curious connection between nulling and sub-pulse drifting has been noticed, with the rate of drift changing just after a null sequence, and only settling back into a stable drift rate after some time. It's as if whatever is driving the sub-pulse drifting is temporarily halted during a null, and takes time to ramp back up to full speed. Many believe it to be due to a rotating carousel of electrical discharges just above the pulsar's surface. In a previous study of PSR B0031-07 (McSweeney et al. 2017), which has a nulling fraction of ~45%, the drift rate apparently never has time to settle down to a stable value before another null interrupts it. It now appears that J0026-1956 is a rare twin of B0031-07, as we see a similar pattern: whenever the pulsar is "on", the drift rate is continuously and gradually changing, as illustrated by the drift rate model fits in Figure 2.

Although neither nulling nor subpulse drifting is unusual on their own, the combination of them in J0026-1956, and the peculiar way that these two phenomena interact, make J0026-1956 a rarity, with B0031-07 being one of the only other known pulsars to show similar behaviour. The initial discovery and analysis is reported in McSweeney et al. (2022), and a deeper study of these phenomena, using a larger set of archival MWA data, as well as higher frequency data from the GMRT and Murriyang (Parkes), will be undertaken later in 2022.

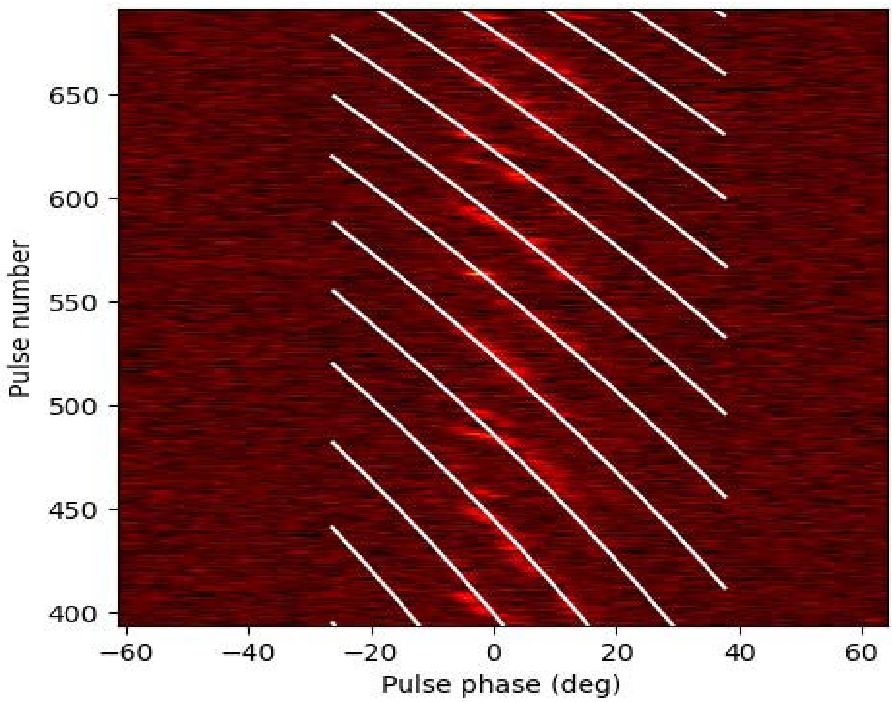
The discovery of J0026-1956, and the rich scientific rewards offered by such interesting and unique pulsars like this one, is a wonderful early vindication of the SMART survey. It is anticipated that as we transition into the deep pass processing stage, we will harvest a rich yield of pulsars that can, in their own unique ways, shed light on some of the deepest mysteries of the high energy astrophysics at play around these fascinating objects.

FIGURE 1



[The higher resolution version of these panels are attached to the email. However, feel free to use as many of these panels as you have room for (even one will do)]
IMAGE CREDIT: Sam McSweeney

FIGURE 2



One example of a sequence of drift bands from PSR J0026-1956, and a fitted model (white overlay), showing how the drift rate (the slopes of the drift bands) changes gradually over time.
IMAGE CREDIT: Sam McSweeney

The Most Massive Stellar-Mass Black Hole in the Milky Way

PROFESSOR JAMES MILLER-JONES
CIRA Science Director

Co-Author
ARASH BAHRAMIAN
Research Fellow

While black holes were first postulated in the 18th century, and predicted mathematically by Albert Einstein in 1916, it was not until the advent of X-ray astronomy that irrefutable proof was found for the existence of such exotic objects. In 1974, the evidence was beginning to pile up, and the well-known theoretical physicist Stephen Hawking made a famous wager with his colleague Kip Thorne, that the brightest X-ray source in the constellation Cygnus, known as Cygnus X-1, did not contain a black hole feeding on hot gas. Two decades later, he finally conceded the bet.

We now know Cygnus X-1 to contain a black hole in a 5.6-day orbit with a more massive companion star, in a system known as a high-mass X-ray binary. The black hole's gravity focuses the strong stellar wind from its companion, and captures a fraction of that material, which spirals around the black hole in an accretion disk that glows brightly in the X-ray band. The accretion of gas also powers a pair of oppositely-directed jets, which emit at radio wavelengths, and can be directly imaged by high-resolution radio telescopes.

By tracking the position of the jets with exquisite precision over time, our team was able to determine how fast the black hole was moving across the sky, how far away it was, and even how it was moving in its orbit around its binary companion. As we view an astronomical system from different vantage points in the Earth's orbit, it will appear to shift relative to more distant background objects – in the same way as a finger held at arm's length will appear to shift relative to the background when seen with one eye or the other. By measuring the size of this shift, known as the parallax of the system, we can determine its distance.

We had observed Cygnus X-1 daily with the US-based Very Long Baseline Array over its full 5.6-day orbital period. We noticed that around the orbit, the varying absorption of radio waves by the stellar wind of the companion star was affecting the measured position of the radio emission. When the jets from the black hole were seen through most stellar wind, the emission appeared to be coming from further downstream. This orbital modulation of the observed jet position had biased previous measurements of the parallax distance to the source. Correcting for this bias, we found that the source was slightly further away than previously believed, at a distance of 7,200 light years from Earth.

The larger distance implied that the black hole's companion star was more luminous than previously believed, which required us to revise previous estimates of its mass, and also that of the black hole. We found that the black hole's mass was around 21 times the mass of the Sun, and its companion star was around 40 times the mass of the Sun. This represents a 45% increase in the black hole mass, making it the most massive stellar-mass black hole known in our Milky Way galaxy.

Finding such a massive black hole in our own Galaxy was surprising. Our current understanding of how stars evolve suggested that very massive stars that evolve into black holes should first lose large amounts of mass in strong stellar winds. In a relatively metal-rich environment such as our Milky Way, the maximum predicted black hole mass was therefore limited to about 15 solar masses. Our measurement required a re-calibration of the strengths of stellar winds from the most massive stars at various key phases of their evolution. The far-reaching implications of this result led to its publication in the prestigious journal Science (Miller-Jones et al. 2021).

Although the revised mass of this first-confirmed black hole makes it the most massive such system detected via electromagnetic radiation, its mass is still dwarfed by many of the black holes being detected through gravitational wave radiation, by the Laser Interferometric Gravitational wave Observatory (LIGO).

These were believed to have formed earlier in the Universe, when the lower fraction of heavy elements in stars reduced the strengths of their stellar winds. Despite the fact that Cygnus X-1 contains a second massive star that may well collapse into a black hole, we found in a companion paper (Neijssel et al. 2021) that the two bodies are likely too far apart for the black holes to merge on a timescale comparable to the age of the Universe.

References:

Miller-Jones, Bahramian et al., 2021, Science, 371, 1046
Neijssel et al., 2021, ApJ, 908, 118

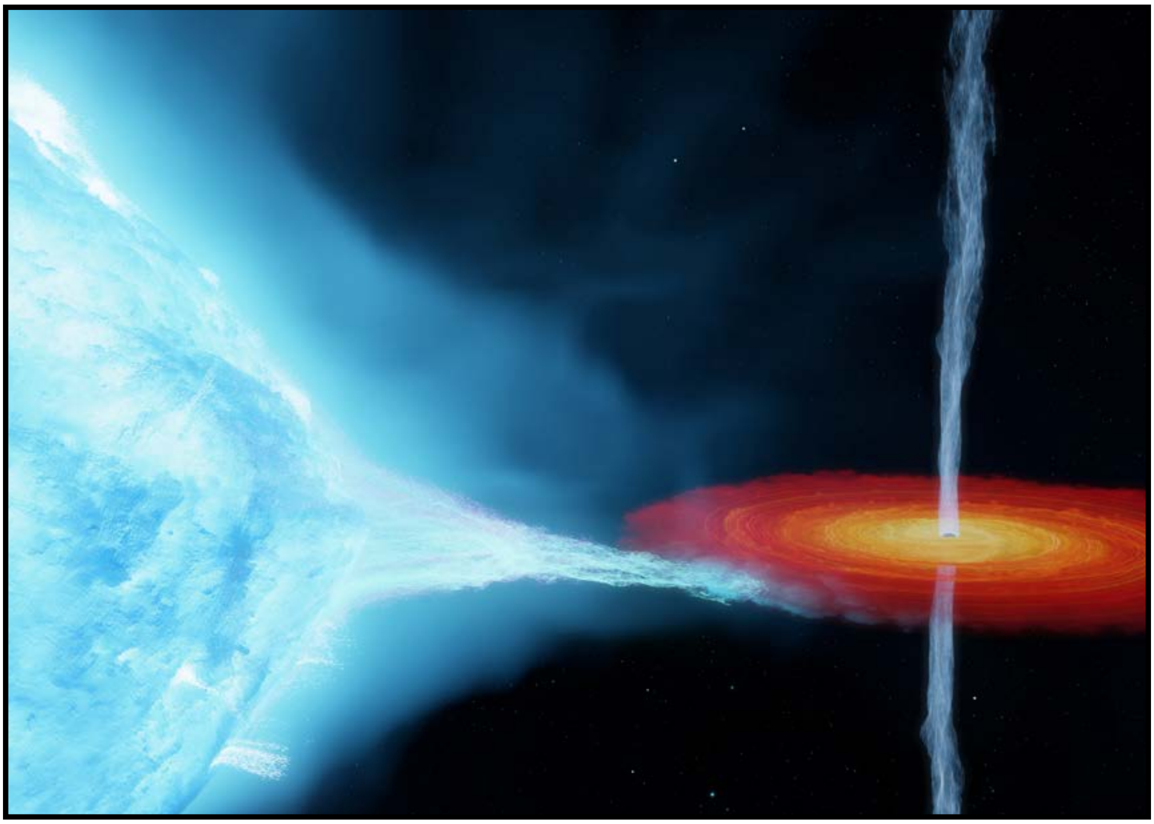


IMAGE ABOVE: Artist's impression of the black hole X-ray binary system Cygnus X-1. The gravity of the black hole attracts material from the wind of its companion star, which spiral inwards in an accretion disk. Relativistic jets are launched from close to the black hole, and we used these jets to track the motion of the black hole over time, showing it to be almost 50% more massive than previously believed.
IMAGE CREDIT: ICRAR

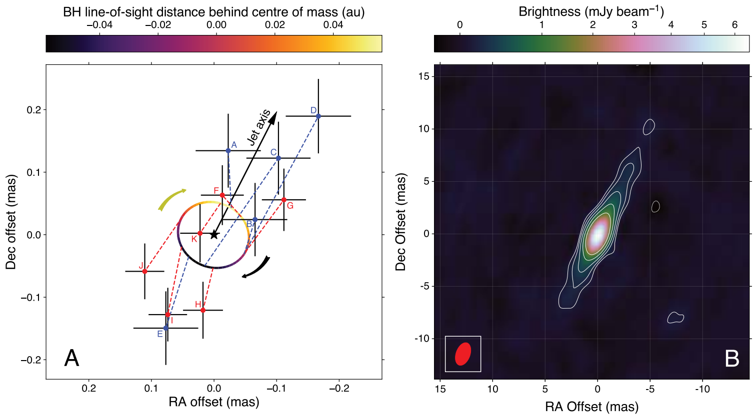


IMAGE ABOVE:"Our astrometric measurements of Cygnus X-1. Left panel shows the measured positions over 11 different epochs, with the best fitting model orbit and its direction of motion indicated. The colour bar shows the distance of the black hole in front of or behind the centre of mass of the system. Right panel shows the stacked high-resolution image of the jets in this system. Figure taken from Miller-Jones et al. (2021, Science, 371, 1046)."

The Galactic and Extra-Galactic All-Sky MWA Extended Survey

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KATHRYN ROSS
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BEN QUICI
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on behalf of the GLEAM-X team

JOHN MORGAN
Research Fellow

STEFAN DUCHESNE
PhD Student

In 2020, Dr Natasha Hurley-Walker commenced an ARC Future Fellowship to carry out a new survey with the Murchison Widefield Array (MWA): the GaLactic and Extragalactic All-sky MWA survey: eXtended (GLEAM-X). Together with a team of excellent researchers across MWA partner institutions, they endeavour to create an all-sky image of the sky that is twice the resolution and ten times as sensitive as the original MWA flagship survey, GLEAM.

Over a period of three years a collection of ~40,000 observations have been made by the MWA under the GLEAM-X banner. This represents approximately 2.4 Petabytes of raw telescope data -- an enormous computational challenge requiring supercomputer facilities to manage. If multi-processing computing platforms were not available, some 4 million hours would be required to transform the entirety of the raw GLEAM-X data files into science-ready data products. To enable this the GLEAM-X team have developed an end-to-end processing pipeline with key software components now being stored within a container based framework.

Throughout 2021 the GLEAM-X team has hit a number of notable milestones. Extensive developer effort, including refined quality-assurance metrics, has extended the ability of the GLEAM-X pipeline to reduce nights worth of MWA data in an entirely automated and unattended fashion. This includes not only the production of deep continuum images appropriate for source finding, supporting the primary goal of GLEAM-X, but also auxiliary data products appropriate for ionospheric analysis, transient/variability studies and compressed datasets for long term archiving. We have published 1,447 square degrees of GLEAM-X data processed by this pipeline in Hurley-Walker et al. (2022) as a demonstration of the complete survey. In summary, we combined data from four full nights of observing, and detected ~75,000 radio-components across 26 frequency bands from 70 to 230MHz – this exquisite frequency coverage has revealed a collection of unique and interesting sources (Figure 1).

We are currently partway through the processing of data release two using data collected from 28 nights of observing. Preliminary images of this dataset (an example shown in Figure 2) has leveraged the exceptional compute capabilities of the Magnus and Garrawarla clusters managed at the Pawsey Supercomputing Center, and detected over 400,000 galaxies. It is hoped that processing for the second GLEAM-X data-release will be completed within the year.

FIGURE 1

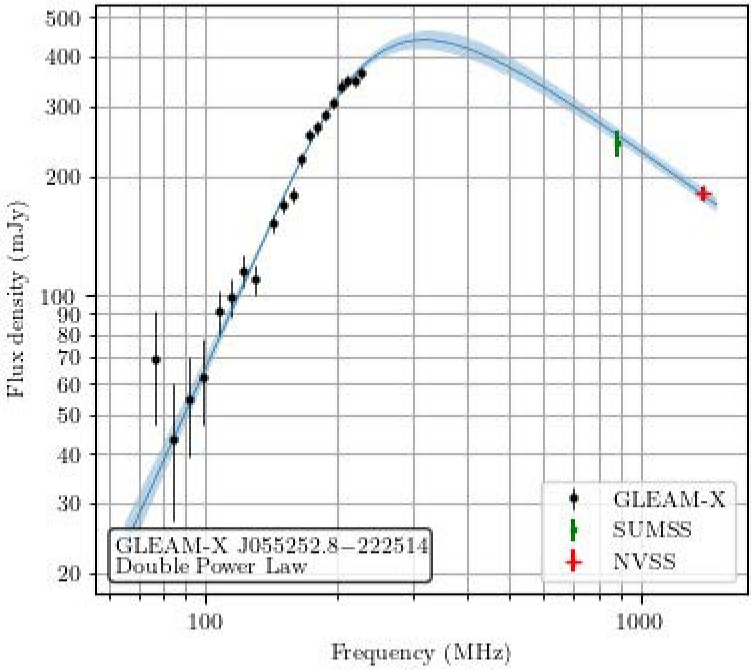


IMAGE ABOVE: Figure 1: Example SED of GLEAM-X J055252.8-222514, supplemented with data from the Sydney University Molonglo Sky Survey (SUMSS) and the National Radio Astronomy Observatory Very Large Array Sky Survey (NVSS). Overlaid in blue is a simple double power-law model optimised against all data, with the highlighted region representing the one-sigma confidence region.
IMAGE CREDIT: Tim Galvin GLEAM-X Team

FIGURE 2

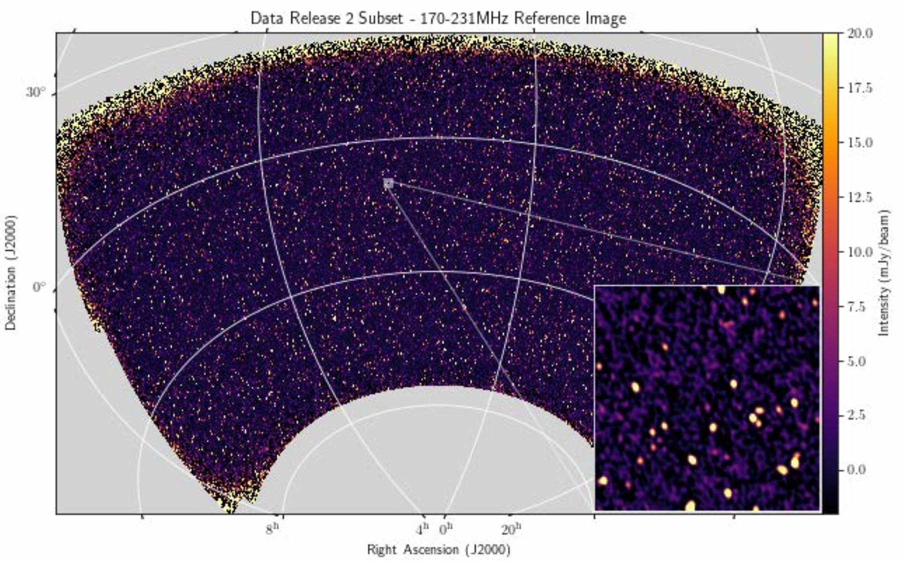


IMAGE ABOVE:Figure 2: Example image covering 170-231MHz made up of 16 nights of GLEAM-X data. The inset image in the lower right corner highlights the typical image fidelity across the larger image.
IMAGE CREDIT: Tim Galvin GLEAM-X Team

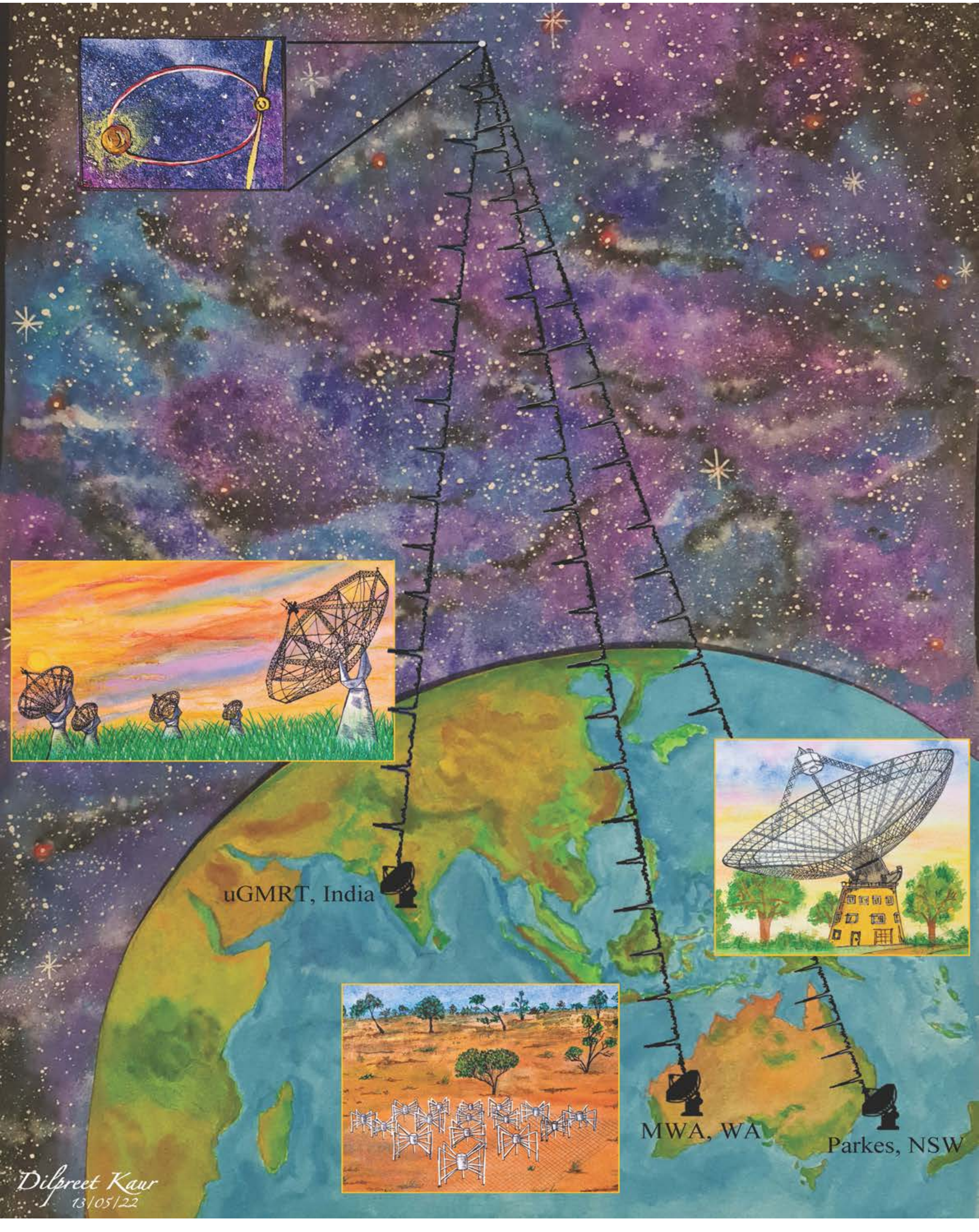


IMAGE ABOVE CREDIT: Dilpreet Kaur

Precision Counting of the Number of Electrons Toward a Millisecond Pulsar

RAMESH BHAT
Senior Research Fellow

DILPREET KAUR
PhD Student

Ever since their discovery more than 50 years ago, pulsars – fast-spinning, highly-magnetised, tiny, yet very dense stars – have continued to amaze astronomers. They are arguably amongst the most widely-exploited astrophysical objects. They are the sites of extreme environments, with physical conditions such as ultra-strong gravitational and magnetic fields; their exceptional clock-like rotational stability can be exploited for a wide variety of applications in physics and astrophysics. It is no surprise that science centred around pulsars is also a key science for the Square Kilometre Array (SKA) project.

Among the headline science themes within "pulsars and gravity" is the applications of pulsars for performing exquisite tests of Einstein's theory of gravity or general relativity. This involves the use of specialised systems comprising neutron-star pairs, or pairs of a neutron star with another star, in close binary orbit. Another high-profile application of pulsars is using very fast-spinning ones known as "millisecond pulsars" (i.e. with spin periods of the order of a few milliseconds) to detect gravitational waves at very low frequencies – in the nanohertz range. These are among the high-priority science objectives for the SKA.

The importance of the latter is particularly reinforced by the detection of gravitational-waves by ground-based detectors such as the Laser Interferometer Gravitational-wave Observatory that are most sensitive to the kHz – Hz frequency range. These are produced by mergers of black holes that are ~50-100 times more massive than our Sun. To detect gravitational waves produced by even more massive black holes – those that are millions to billions of times more massive than the Sun, we need to synthesise a galactic-scale detector, which can be done only using a celestial distribution of millisecond pulsars, known as pulsar timing arrays (PTAs). The success on this front will be the next major milestone in gravitational-wave astronomy, and it will extend the new window for astronomy to the nanohertz-frequency range.

Alas, it turns out that's easier said than done! Bringing this scientifically compelling yet ambitious goal to fruition requires developing sophisticated telescope systems and instrumentation, and a deeper understanding of various intricacies (or idiosyncrasies!) of different pulsars, their environments, and alterations to their signals as they propagate through the intervening interstellar medium (ISM) that pervades between us and the pulsars. These challenges prompted pulsar astronomers to pursue this ambitious goal through an organised effort, leading to an international PTA collaboration. While it may be possible to develop some control on telescope or pulsar related aspects; e.g. being selective about which pulsars to be used for PTAs, or perfecting instrumentation or developing ways to calibrate them better, the ISM is rather tricky to deal with – it is weird, complex, and behaves subtly differently from pulsar to pulsar. Naturally, propagation effects on pulsar signals has become a subject of great interest within the PTA community.

The most basic (and prominent) of ISM effects is frequency-dependent arrival times of pulsar signals, resulting from their interaction with the free electrons that they encounter in the path. This "dispersion" effect manifests as a parabolic sweep in arrival times at the telescope. While the density of electrons is imperceptibly small – typically one electron per every ~10 cm-3, over the path lengths of 1000s of light years that pulsar signals traverse, they can amount to as much as 1020 over a column of square centimetre. Moreover, because pulsars are whizzing in space with velocities of the order of ~100 km/s, observations with telescopes sample different parts of the ISM at different times, and as a result the column density of electrons (called dispersion measure or DM) will vary with time. In principle, this can be precisely measured with advances in telescope instrumentation and processing techniques employed for PTA observations.

But it turns out there are further subtleties. Based on their detailed theoretical treatment of this important problem, Cordes et al. (2016) predicted that the DM as measured by an observer can also vary with the observing frequency, i.e. DM will be frequency-dependent (chromatic). At first, this may seem counterintuitive – why a physical quantity like the number of electrons should depend on the frequency band of observations? The answer lies in the complexity of signal propagation. The path lengths or volume of the ISM sampled by pulsar radiation is frequency dependent (as a result of multipath propagation effects), which can then lead to differences in measured DMs of the order of a few parts in thousands to a million. That may seem small, but they can still contribute significantly to the timing noise budget in PTA data, where attaining ~100 ns level precision for many pulsars is an important prerequisite. Developing a deeper understanding of such subtle effects, or even searching for the signatures of it in observations, is therefore crucially important for the success of PTAs.

Motivated by the early science results from millisecond pulsar observations with the Murchison Widefield Array (MWA), a team led by Curtin PhD candidate Dilpreet Kaur undertook concerted multi-telescope observing campaigns of one of the high-priority pulsars for PTAs. This pulsar, which goes by the name PSR J2241–5236, spins at a rate of more than 450 times per second, and on each rotation, its signal is visible to us for about 5% of the rotation period (i.e. for ~150 microseconds; see Figure 1). The data were collected through multiple observing sessions spanning about a month using the MWA (in Western Australia), the Giant Metre-wave Radio Telescope located in India, and the Parkes (Murriyang) radio telescope located in New South Wales, by ensuring all point to the pulsar around the same time (i.e. within a span of 24 hours). All data were carefully calibrated, analysed and scrutinised, so reliable and high-precision measurements of DMs can be made, with precisions of the order of a few parts in a million to a few parts in 10,000. The results (Figure 2) pointed to clear and compelling evidence in support of a frequency dependence – a conclusion that was arrived at after carefully considering (and ruling out) a multitude of effects, including those due to pulsar environments (e.g. stellar winds from the companion star) and pulsar emission (e.g. frequency dependence of radiation). These findings were published in the Astrophysical Journal Letters.

These results present the first definitive proof of the Cordes et al. predictions for a chromaticity in DMs. While the observed frequency dependence in DM is in qualitative agreement with the predictions, the magnitude of DM changes, and their observed scaling in frequency are clearly discrepant with the theoretical predictions, the cause of which remains unclear at this point. Regardless, these findings are expected to motivate further detailed investigations, presumably using more PTA pulsars, in an effort to understand their prevalence, and to investigate possible ways of mitigating it, as we march toward the ultimate goal of PTAs – the eventual detection of nanohertz-frequency gravitational waves.

FIGURE 1

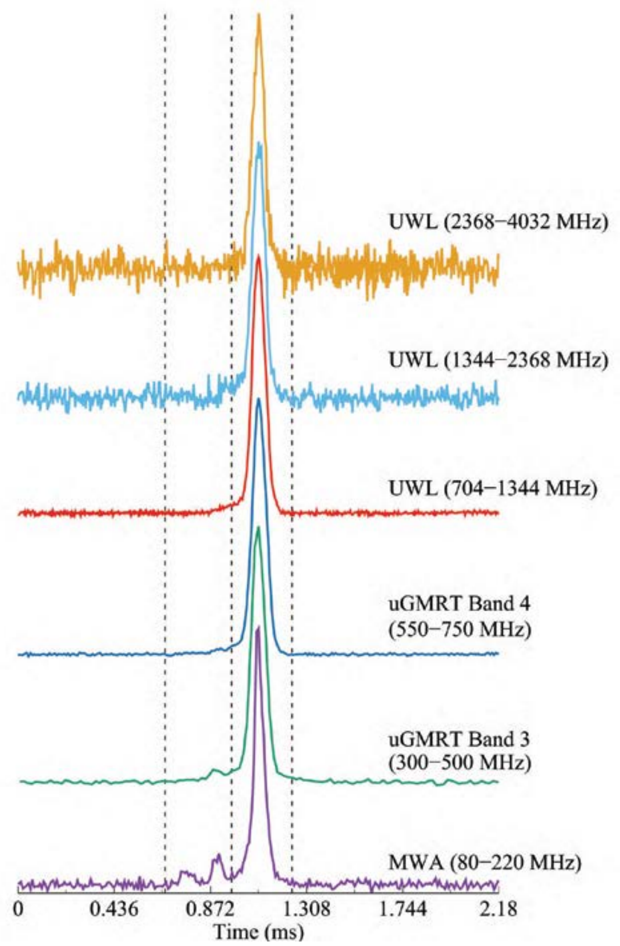


IMAGE ABOVE:Figure 1: Integrated pulse profiles of the millisecond pulsar PSR J2241–5236 showing average emission signatures at frequencies from 150 MHz to 4032 MHz. Observations with the ultra-wideband low-frequency (UWL) receiver at the Parkes (Murriyang) telescope span the frequency band from 704 to 4032 MHz, whereas those with the upgraded Giant Metrewave Radio Telescope (uGMRT) from 300 to 750 MHz and those with the Murchison Widefield Array (MWA) from 80 to 220 MHz.
IMAGE CREDIT: Ramesh Bhat/ Dilpreet Kaur

FIGURE 2a

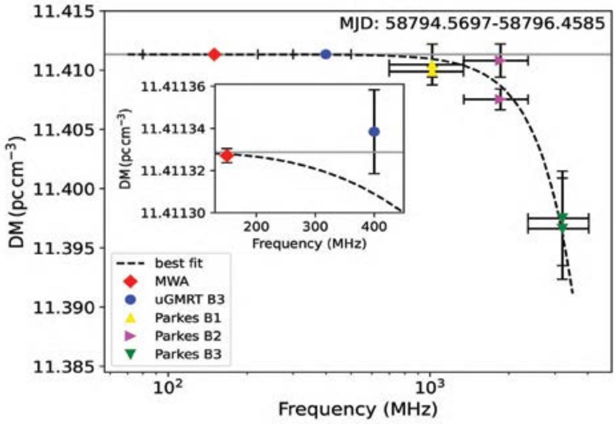


FIGURE 2b

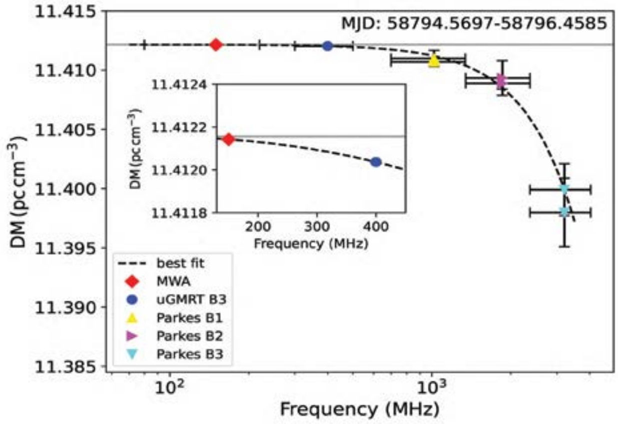


IMAGE ABOVE:Figure 2a & 2b:Measurements of dispersion measure (DM) of PSR J2241–5236 at multiple frequency bands in the frequency range from 80 MHz to 4 GHz. Observations were made within a 24-hour window, when all three telescopes (MWA, GMRT and Parkes) were pointed to the pulsar. The dashed line represents an empirical model fit (as a power law), and the solid grey line represents the reference DM value from the model fit. The inset plot represents the frequency range 100 to 500 MHz, to highlight the high precision obtained in the measurements (of the order of a few parts in a million for MWA data). The left and right panels show the results from two different analysis techniques (i.e. traditional timing versus wide-band timing).
IMAGE CREDIT: Ramesh Bhat/ Dilpreet Kaur

IMAGE CREDIT BELOW: AdobeStock

ENGINEERING

2021 was a challenging year, with no end in sight of the global COVID-19 pandemic. Both state and national borders remained tightly shut, with almost all meetings and classes migrating online. This was the second year into the ICRAR-III programme, and technical work largely continued the trajectory started in 2018, with a strong focus on the SKA-LOW prototype systems. Work on several industrial projects also continued. The team continued to work productively throughout the year. I would like to express my continued appreciation of the positive approach maintained by the engineering team throughout the year and the challenges of lockdowns, enforced separation from family in other Australian states and other countries, and of course concerns about becoming ill – widespread vaccination only became available in the second half of the year.

Professor David Davidson
CIRA Engineering Director

The deployment of a 256-element SKA-Low prototype station had been completed on the Murchison Radio-astronomy Observatory site shortly before COVID shut down the MRO – and the world – in March 2020 by CIRA and our Italian partners INAF. The prototype is known as the Aperture Array Verification System 2 (AAVS2), and complemented CIRA's Engineering Development Array 2.

Analysis, simulation, and commissioning work on these prototype stations continued throughout 2021. This resulted in numerous publications in journals and refereed conference proceedings, most notably in a special issue on SKA published by the SPIE Journal of Astronomical Telescopes, Instruments and Systems at year-end. The results also permitted the development of the first realistic sensitivity calculator for SKA-Low. Theoretical work on the sensitivity of polarimetric interferometric arrays also continued. Overall, the engineering group contributed to 31 papers during 2020.

Furthermore, this work inspired a series of outreach videos, leveraging computer gaming development tools and these simulation results to present highly realistic animations.

Much of this body of work is described in more detail in several articles in this annual report.

The continued pandemic resulted in all the major conferences in antenna, radio frequency and microwave engineering migrating to online or hybrid formats. This included the EuCAP'21 and IEEE AP-S symposia. CIRA staff contributed to these major meetings, organizing sessions, and presenting papers, as well as to several scientific meetings such as Science at Low Frequencies.

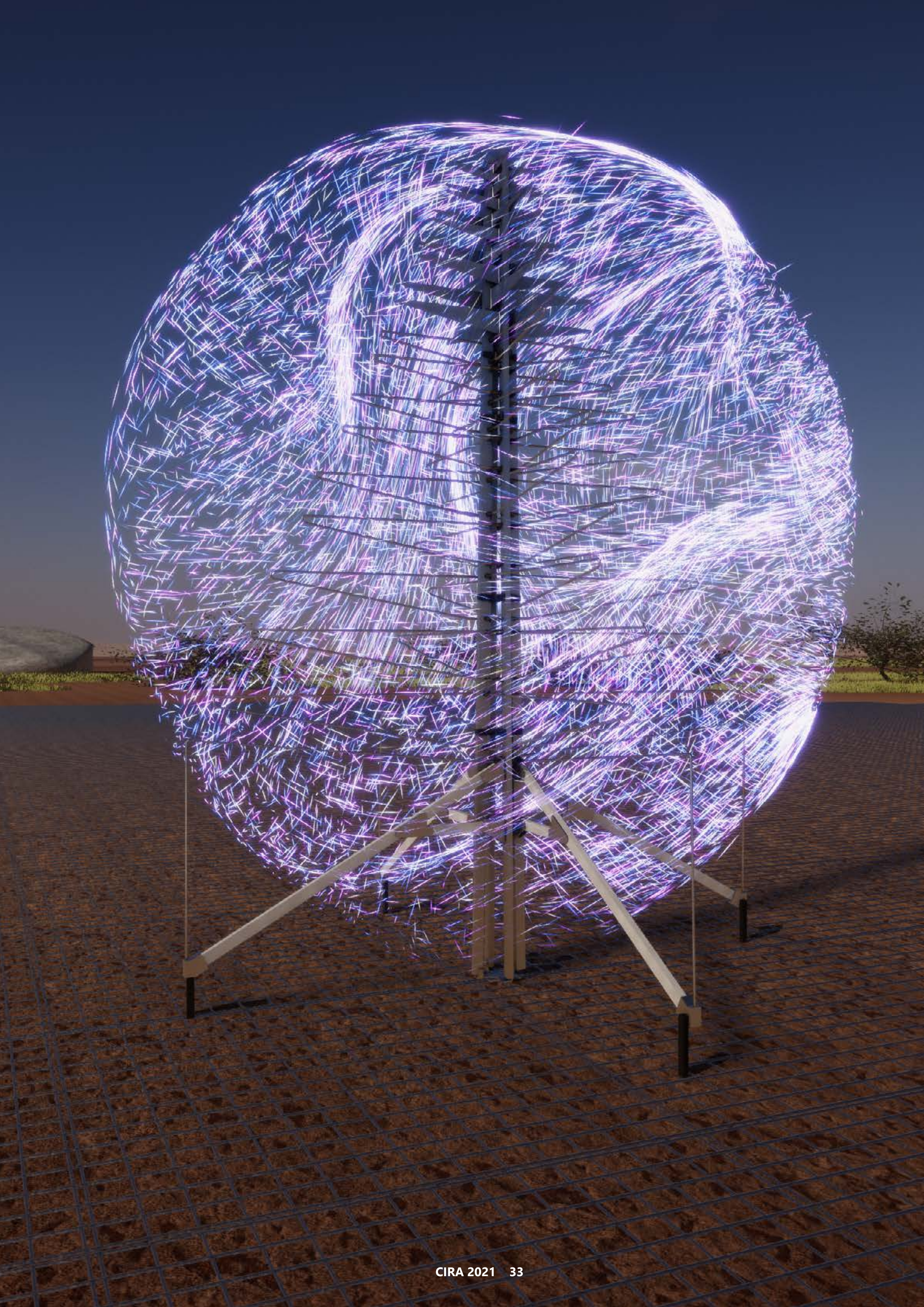
On the personnel front, two interns, Scott Haydon and Aaron Silvestri, joined the CIRA engineering group during the year. Dr Maria Kovaleva finished the year on high note; in December, she was promoted to Lecturer and was also awarded a Fulbright Scholarship. (She will take up the Fulbright in 2022, travel to the USA permitting).

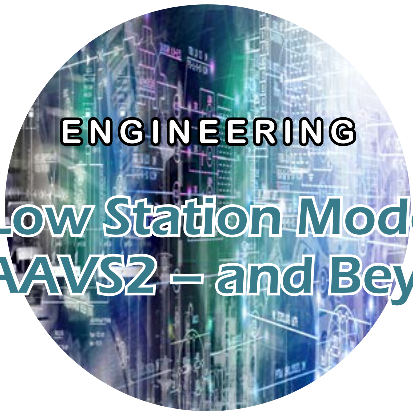
The engineering group also made major contributions to translation and impact, via demand-driven industrial research. Work continued into investigating high power microwave effects on electronic circuits for Defence Science and Technology. A white paper on phased arrays for submarine communications for developed for Lockheed Martin Australia. A project is in progress for the Defence Science Centre on a rapidly deployable space surveillance system. Some of this work is described in articles in this report.

Additionally, we continued our traditional teaching within electrical and electronic engineering, being responsible for three undergraduate courses and supervising around a dozen final year Electrical Engineering and capstone Computer Science projects. Delivering teaching almost entirely online proved very challenging and time-consuming.

With the first meeting of the Council of the SKA Observatory in February 2021, the year saw the official launch of the SKAO as an intergovernmental organisation. 2022 is likely to be dominated by the first stages of SKA construction and the CIRA engineering team is ready for the challenges that this will bring.

IMAGE CREDIT RIGHT: Scott Bell, ICRAR – CIRA





ENGINEERING

SKA-Low Station Modelling for AAVS2 – and Beyond

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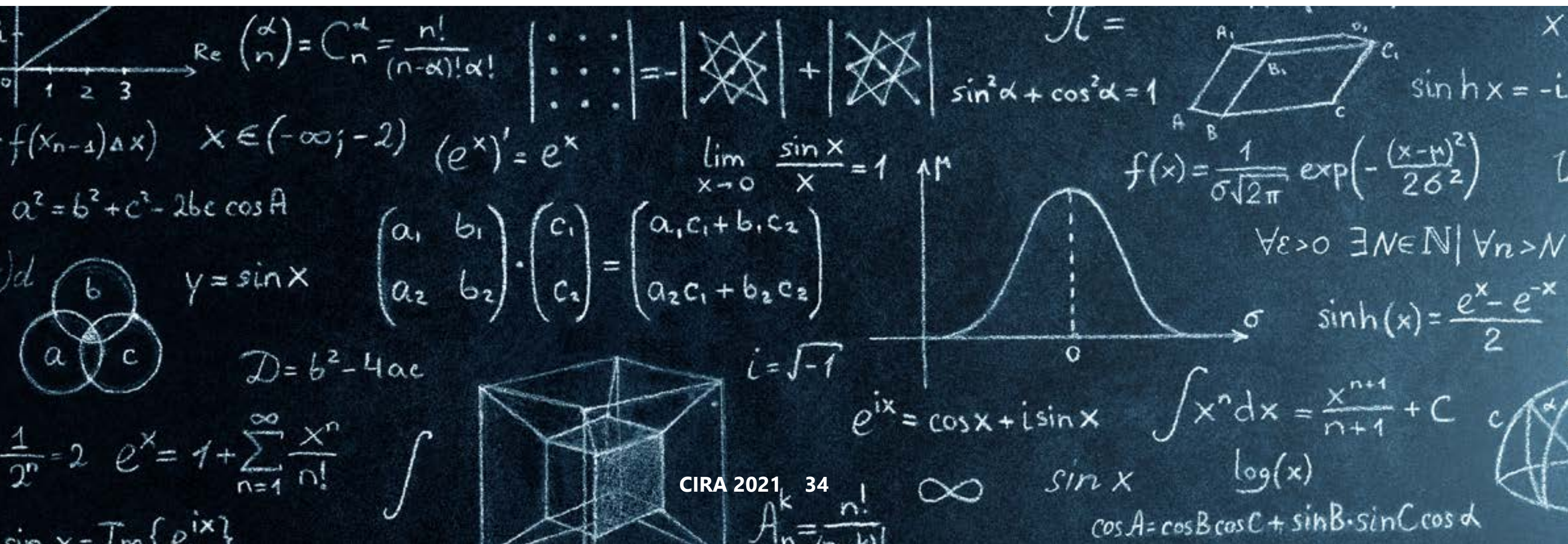
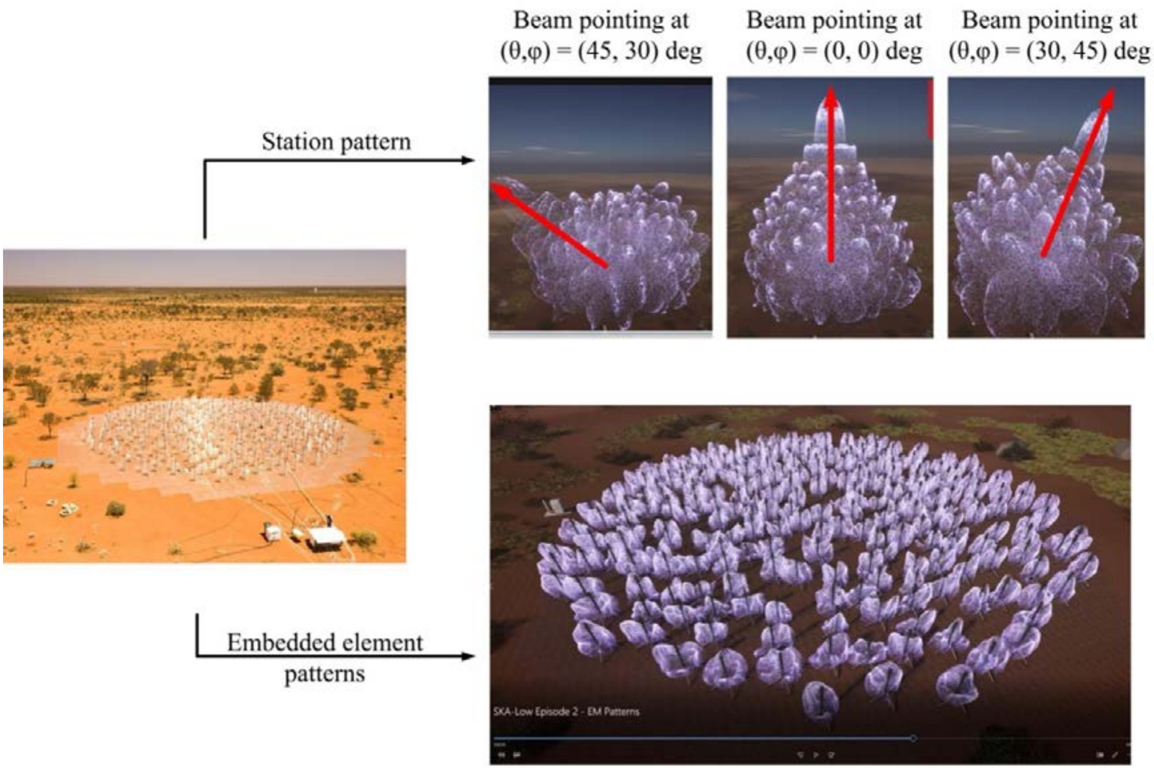
SKA-Low is the low-frequency (50-350 MHz) half of the Square Kilometre Array Observatory, to be built in Western Australia. It consists of a large number of ``stations'' - 512 are planned - each comprising an array of 256 dual-polarised log-periodic dipole antennas, known as SKALA4.1. These are installed on a ground mat with a maximum antenna to antenna spacing of 38 m; the ground mat is approximately circular, with a diametre of 42 m. Over a number of years, CIRA has successfully developed numerical models for various SKA-Low prototypes, the Aperture Array Verification System (AAVS) series, starting from AAVS0.5 with 16 antennas through AAVS1 (recently decommissioned) and now AAVS2, with AAVS3 under consideration.

Key to this work has been the development of models using the commercial electromagnetic simulation package FEKO, and careful verification against results computed by our INAF partners in Italy. There are large and complex numerical models, with well over a million degrees of freedom, and special acceleration algorithms are used to obtain the results in a reasonable time. This work was comprehensively documented in a paper jointly led by INAF and CIRA which has recently appeared in a special issue of a SPIE journal dedicated to the SKA [1].

Our initial work on AAVS2 produced simulations at approximately 20-30 MHz intervals over the 50-350 MHz bandwidth of SKA-Low. Current work aims to produce much finer frequency resolution, of the order an SKA channel (approximately 1 MHz). We are also investigating alternate station configurations; the current layout is quasi-random. SKAO has requested us to simulate another proposal known as the "Vogel" layout and work is currently in progress on this.

The outcome of this work has been a deep level of understanding of the complex electromagnetic behaviour of the closely-sited antennas which make up an SKA-Low station. It has been used to provide tools for the evaluation of station sensitivity [2,3], polarimetric performance [4], and developing intra-station calibration methods for the SKA Observatory. Additionally, this simulation work has been leveraged to produce three animated videos, which use tools from computer gaming (most notably Unity). Two are already publicly available, the first dealing with the overall design on an AAVS2 station [5] and the second with mutual coupling and individual "embedded element patterns" [6]. A still from one of the videos, showing the station beam, is shown in Figure 1.





Abovce figure 1: The array forms a station radiation pattern by combining all antennas in the array. This beam can be steered to the direction of interest. On the left is an aerial photograph of the AAVS2 prototype located in the Murchison Radio-Astronomy Observatory; on the right are accurate radiation patterns obtained from the commercial electromagnetic solver FEKO and imported into Unity for visualization purposes. θ is zenith angle, φ is azimuth angle from east toward north. (Credits: Scott Bell, ICRAR – CIRA).

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[2]. M. Sokolowski, et al, "Preliminary sensitivity verification of the SKA-Low AAVS2 prototype," 15th EuCAP, 2021. doi: 10.23919/EuCAP51087.2021.9410962.

[3]. M. Sokolowski et al. ``What is the SKA-Low sensitivity for your favourite radio source?", PASA, 39, E015, 2022. doi:10.1017/pasa.2021.63.

[4]. A. T. Sutinjo et al., "Sensitivity of a Low-Frequency Polarimetric Radio Interferometer", Astronomy and Astrophysics, 646, A143 2021. doi: https://doi.org/10.1051/0004-6361/202039445

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[6]. ICRAR, "SKA-Low Station Visualisation — Episode 2", https://vimeo.com/657724198.

IMAGE CREDIT AdobeStock

What is the SKA-Low Sensitivity for Your Favourite Radio Source?

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The low frequency (50 - 350 MHz) Square Kilometre Array (SKA-Low) will consist of 512 stations each composed of 256 dual-polarised antennas, and the sensitivity of an individual station will be crucial to realisation of the telescope's science goals. In 2019, two prototype stations, the Engineering Development Array 2 (EDA2) [1] using 256 MWA bow-tie dipoles and the Aperture Array Verification System 2 (AAVS2) using 256 SKALA4.1AL antennas, were commissioned at the Murchison Radio-astronomy Observatory (MRO).

These stations have been used for various engineering tests, verifications and enabled early science results [2]. The sensitivity of both stations was measured from very short (0.14 second) all-sky images from long (at least 24 hours) drift scan observations, and compared with predictions calculated with software utilising antenna beam patterns obtained from FEKO electromagnetic simulations of the SKA-Low stations.

The software package and simulations were developed over several years by the CIRA engineering team. The excellent agreement between measured and predicted sensitivity [1] confirmed that the stations perform as expected and the simulations are accurate, which triggered further work on the software package leading to development of the first sensitivity calculator for the future SKA-Low telescope [3].

In order to make it fast and efficient, sensitivity values were pre-computed in multiple pointing directions in 5o resolution, 10 MHz frequency and 1/2 hour time steps and saved as a small file-based SQLite database. A python package is available at https://github.com/marcinsokolowski . The web-based sensitivity calculator is also publicly available at http://sensitivity.skalow.link/ , and provides functionality allowing future researches using the SKA-Low telescope to calculate expected sensitivity of the telescope at a specified time, frequency, pointing direction, observing bandwidth, and station type (either EDA2 or AAVS2). Depending on the specified options the sensitivity at a specific pointing direction can be presented as a function of time or frequency. It is also possible to generate an all-sky image of the station beam sensitivity at all pointing directions over the entire visible hemisphere at a given observing frequency and time. The output format can be selected as either images or a zip file containing the same images and text files with the underlying sensitivity data.

Most importantly for future astronomers, the web-service also enables calculation of the expected standard deviation of the noise in the resulting sky images. As shown in Figure 1, a user can enter a name of a particular radio source and its coordinates will automatically populate the form using an external source catalogue. Similarly, the time when the source is above the horizon at the MRO will be automatically calculated and inserted into the form.

The user can overwrite default observing parameters, such as frequency (150 MHz), bandwidth (30 MHz), number of stations (512) and select the station type between AAVS2 (default) or EDA2. After clicking "Calculate" button the software will calculate standard deviation of the noise in X, Y and Stokes I polarisation images, and present these values on the output page together with the sensitivity (the effective area divided by the system temperature, hence A/T in Figure 2) as a function of time over the specified observing interval. This particular functionality provides future researchers planning to use the SKA-Low telescope with the first tool to plan the optimal start time and duration of their observations, calculate the expected sensitivity, and appropriately adjust observing parameters to achieve their science goals.

FIGURE 1

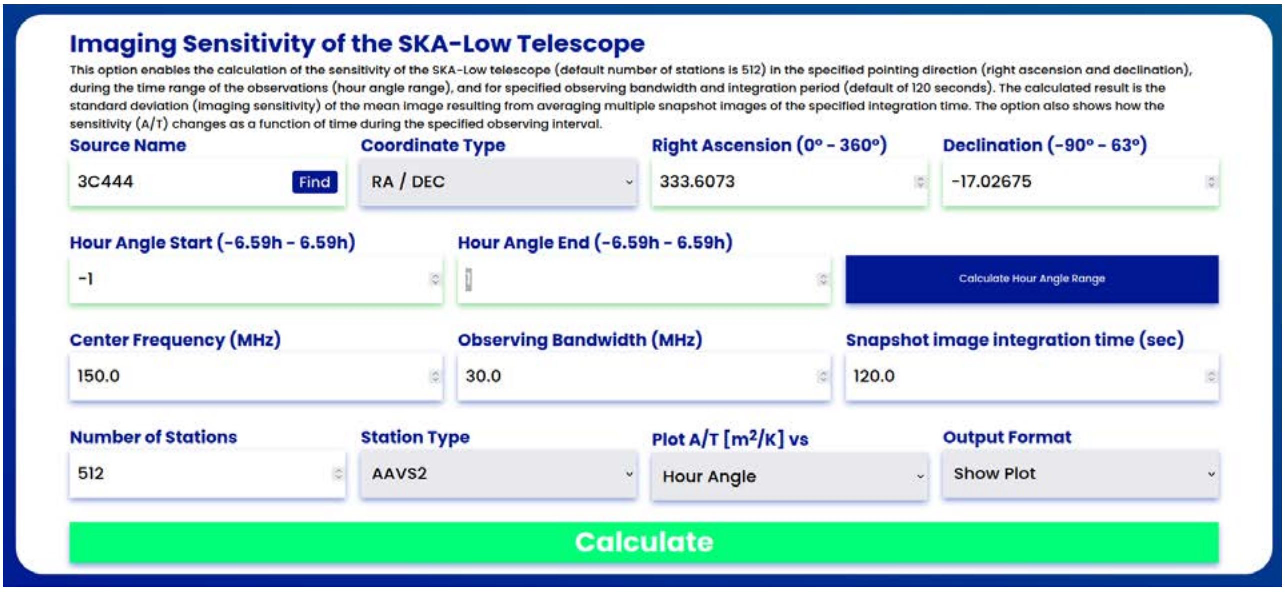

Figure 1 : Web page enabling researches using the future SKA-Low telescope to calculate expected standard deviation of the noise (sensitivity) in images of a specified source (or pointing direction), and observing parameters (e.g. frequency, bandwidth, station type etc.)

FIGURE 2

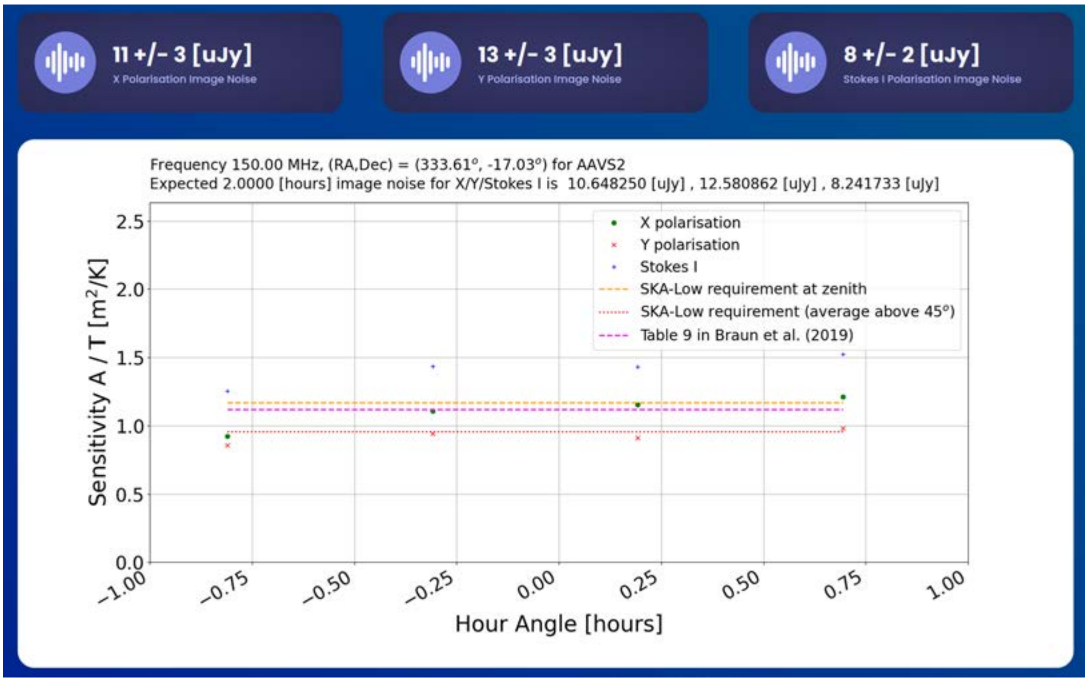

Figure 2 : Expected sensitivity in an image of 3C444 radio source resulting from 2 hour observation (+/- 1 hour around the transit time) at 150 MHz, with 30 MHz observing bandwidth, and the full SKA-Low telescope with 512 AAVS2-like stations

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[1] R. Wayth et al.,"The Engineering Development Array 2: Design, performance and lessons from an SKA-Low prototype station", SKAO special section of Journal of Astronomical Telescopes, Instruments, and Systems, 2021

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A Demonstrator for a Portable Space Domain Awareness System

RANDALL WAYTH
Associate Professor

ON BEHALF OF THE
SDA TEAM

With the orbital environment around Earth becoming more crowded and contested, there is an increasing needfor governments and organisations to monitor and track objects in orbit. Led by CIRA's Astronomical Instrumentation team with support from CIRA's Engineering team, a demonstrator system for space domain awareness using passive radar has been designed and developed. The system is required to be portable and self-contained,to be deployed in potentially remote locations.

Funded as a Defence Science Centre (DSC) project, purpose of the system is to demonstrate the capability of portable phased-array radio telescope systems to detect and track aircraft and objects in orbit by detecting reflected radio signals from commercial broadcast transmitters like radio and TV. The system takes advantageof CIRA's extensive radio astronomy and signal processing expertise as well as many years of research projects using the MWA and EDA2 radio telescopes to detect aircraft and satellites using reflected radio signals.

Systems based on radio telescopes like the MWA or EDA2 have the advantage of having a very wide field-of-view, which allows them to detect objects with poorly known orbits or to detect and determine the orbits of objects from scratch. Conventional tracking systems for objects in orbit use dedicated radar transmitters at higher radio frequencies and antennas with a narrow field-of-view. These systems are useful to refine/update the orbital parameters for known objects but are not well suited to making blind detections.

The system takes advantage of CIRA's radio astronomy expertise by using MWA dipole antennas, and commercial off-the-shelf (COTS) general purpose radio receivers (the Airspy R2) with custom modifications.

The overall system design uses COTS components as much as possible, such that the demonstrator system was designed and deployed in less than 18 months. The core requirement for operating the system as a phased-array, where the signals from all antennas are combined such that it acts like a sensitive signal antenna, is achieved by reticulating a clock and frequency reference signals to all receivers.

This system, which follows exactly the same principles used in radio astronomy, consists of CIRA-designed clock distribution units, an off-the-shelf GPS-based 10 MHz frequency standard, and COTS computers for signal processing. Together, the system constitutes a 32 antenna portable radio array system that can be used for many purposes, including passive radar and radio astronomy.

The system contains several novel aspects, including a logical separation between the antenna systems and the receiving systems. The receivers are agnostic of the antenna and are highly flexible, having an operational range covering roughly 50 MHz to 1800 MHz, with 2.5 MHz processed bandwidth. This gives the system the flexibility to change antennas, for instance if a different frequency band was being used for passive radar, with no impact on the receiver or downstream systems at all. For the initial demonstration, the system is targeting reflected FM radio and Digital TV signals in the 100-200 MHz range, which is perfectly suited to MWA dipole antennas.

The system has been deployed at Curtin University in the grounds around CIRA and the Curtin sports ovals.The final phase of demonstration will be a deployment at a remote site with distant radio transmitters and clear horizons.

This research was supported by the Defence Science Centre, an initiative of the Australian Government and State Government of Western Australia.

IMAGE LEFT : Engineer Jake Jones starting the SDA receivers during a deployment test on Curtin University's sports ovals.
IMAGE CREDIT: Randall Wayth

IMAGE RIGHT : The assembled receiver, clock and computing units, housed in a ruggedised container, during testing on Curtin University's sports ovals.
IMAGE CREDIT: Randall Wayth

IMAGE LEFT: The system deployed on Curtin University sports ovals, with 32 MWA dipole antennas in a 35 metre diameter ring.IMAGE CREDIT: Randall Wayth

System Equivalent Flux Density of a Polarimetric Tripole Radio Interferometer

ADRIAN SUTINJO
Senior Lecturer

MARIA KOVALEVA
Lecturer

System equivalent flux density (SEFD) is a figure of merit that characterizes the sensitivity of a radio interferometer. This paper extends the treatment for the SEFD of a radio interferometer in [1] from dual-polarized antennas to multiple-polarized antennas. Our particular focus, for illustration, is the tripole antenna. This is motivated by the lunar orbiting interferometer such as Discovering Sky at the Longest wavelength (DSL) array [2].

It consists of a mother satellite and six to nine daughter satellites located on the same orbit around the Moon. Besides one daughter satellite dedicated to the high precision measurement of the sky-averaged spectrum, the other daughter satellites form a reconfigurable linear interferometer array with variable spacing. The target frequency range of the interferometer is 30MHz and below. In this application, the field-of-view is the entire visible sphere surrounding the interferometer.

Therefore, we need an SEFD expression which is valid for the entire sphere and for any polarization of the sources therein. To the best of the authors' knowledge, there is no published formulation of SEFD for a tripole (or multipole) polarimetric interferometer other than ones based on approximate reasoning [3].

We derived and verified a system equivalent flux density, SEFD, expression valid for polarimetric radio interferometry with multipole antennas. The expression was demonstrated using an example tripole system based on the DSL lunar orbiting satellite currently under development. The paper derives a general expression that can be applied to any arbitrary multipole system and was shown to converge to the short-dipole approximation at ultra-long wavelengths as expected.

At the highest frequency of 30 MHz considered for the DSL mission, the short dipole approximation showed small but measurable SEFD deviation. Therefore, if the highest accuracy is desired, the full expression should be used. Also, although small in terms or wavelength, the presence of the satellite body perturbs the locations of the maxima and minima of the SEFD. These effects can be studied in detail using the general SEFD expression we derived in this paper.

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[3] Zarka, P., Bougeret, J.-L., Briand, C., et al. 2012, Planetary and Space Science, 74, 156, scientific Preparations for Lunar Exploration

FIGURE (A)

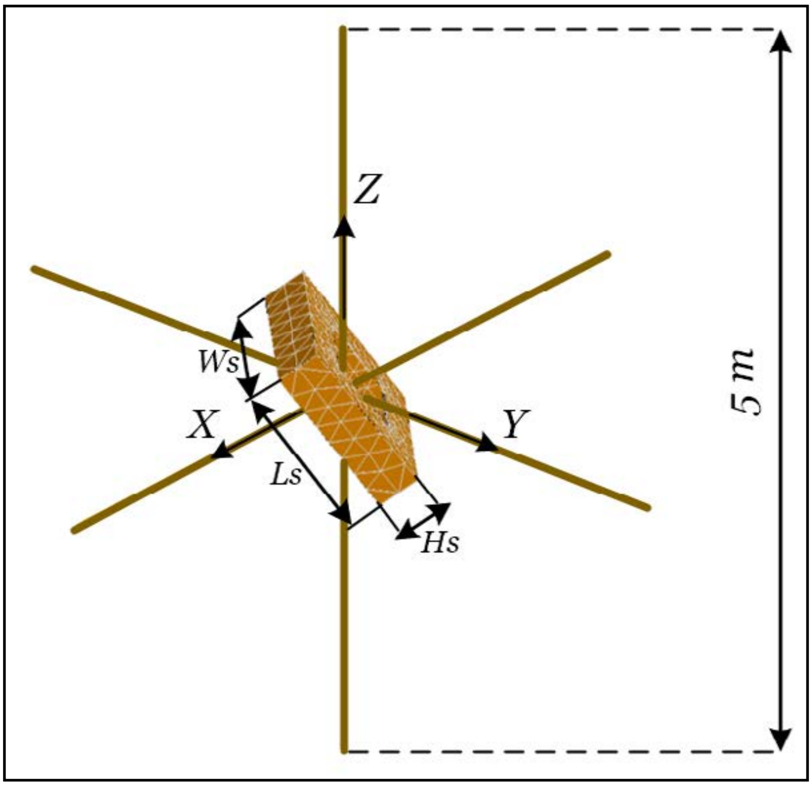

IMAGE ABOVE: Fig. (A) FEKO model of a tripole antenna with the daughter satellite,
IMAGE CREDIT: Maria Kovaleva

FIGURE (B)

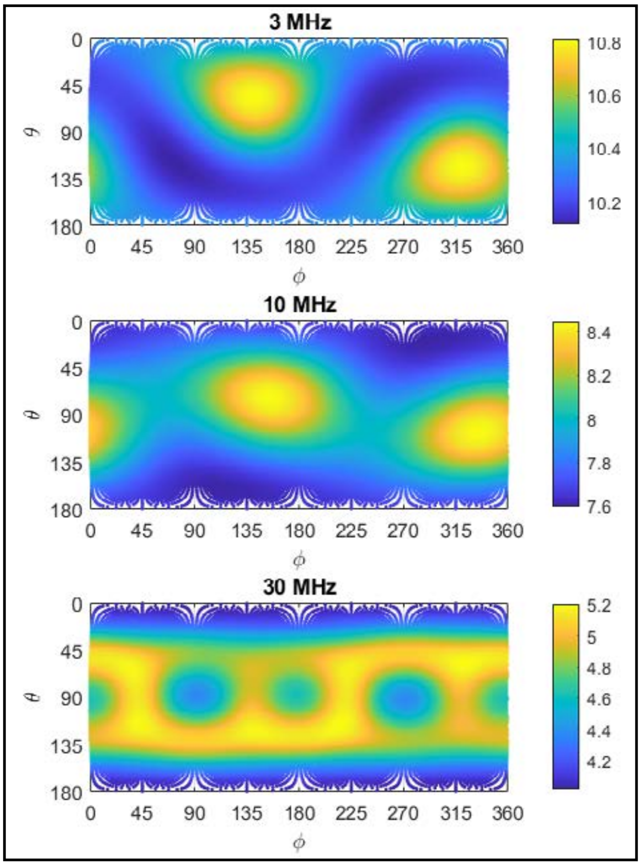

IMAGE ABOVE: Fig. (B) SEFD(θ,) in MJy at 3, 10 and 30 MHz for the orthogonal tripole simulated with the presence of the satellite body.
IMAGE CREDIT: Maria Kovaleva

Tom Booler
CIRA Operations Director

In 2021, pandemic related anxieties and frustrations persisted, but the rate of change slowed. 'COVID normal' set in. This brought its own set of challenges. On top of their personal health and welfare (and that of their families and loved ones... always most important!) the Operations Team had to contend with inconsistent work patterns; compromised supply chains; labour shortages; movement and access restrictions; and strained lines of communications, as international travel bans prevented the face-to-face interaction that is so important to maintaining relationships with our international collaborators around the globe. What doesn't kill us...

The specific endeavours and achievements of the Ops Team are evidenced in articles throughout this report. The scope and span of the activities they're engaged in bears out the breadth of expertise they bring to CIRA. The Team—which includes administrators, software developers, technicians, engineers and project managers—work across the program, supporting researcher led projects and initiating and delivering projects of their own.

The Leadership of the Ops Team are focussed on creating capacity. Capacity to learn from our experience, including our mistakes, and to do things better. Capacity to respond to opportunity, rather than just keep up with existing obligations. In order to keep up with 'demand', and to create the time and space necessary to do things better, 2021 saw continued investment in growing the Team. Dev Null, Ashwathi Nambiar, Venus Chico, Ali Smith, Angela Hautmann and Scott Bell all joined the Team. By the end of 2021, each of them had already made significant, positive contributions to the group—sharing the load, and bringing new and different skills, perspectives and experiences to the Team.

A few contributions in 2021 warrant special noting, and thanks.

The 'project' to replace the MWA correlator has been on the agenda since the day after the original correlator was commissioned. It began, in 2013, under the auspices of CIRA's early involvement in SKA pre-construction, then advanced in fits and starts when interest and resources allowed. When funding became available to replace the hardware, things got serious. Disparate threads of effort and planning had to be wrestled into a plan. Mia Walker took on the job. She doggedly 'herded cats' (intentional wordplay). She planned, tracked and reported diligently. And, in 2021, the MWAX correlator was installed and commissioned at the MRO. MWAX was a Team effort, with starring and supporting roles played by many. But as anyone in show business knows, success most often hinges on the Producer, and in this particular production that credit goes to Mia.

CIRA has made a variety of contributions to SKA design and planning, across several different categories. However, the Power and Signal Distribution (PaSD) system for SKA-Low Stations is the only element of the system that CIRA has designed. Like MWAX, the PaSD has been with us since the earliest days of SKA pre-construction. The Team at CIRA, in collaboration with industry partners, have designed no less than four different implementations of the system, in response to evolution in SKA requirements and changes in the Station that it has to support. In May 2021 CIRA was let a contract to design and verify the performance of a PaSD architecture that had changed significantly in the lead up to the SKA Low critical design review in late 2019. By the time the Team went on their well-earned break at the end of 2021 the first prototypes of the new system had been deployed and commissioned at the MRO. Again, the full list of contributions to this outcome are too numerous to mention. But enormous efforts from Phil Giersch, Luke Verduyn, Dave Emrich, Brian Crosse, Andrew Williams and Raunaq Bhushan were central to this important outcome.

2021 also saw further maturing of CIRA's Translation and Impact (T&I) initiative. T&I aims to lower barriers to collaboration, acting as a catalyst for impactful research, mutually beneficial long-term relationships, and societal benefits.

A number of articles in this report attest to the diversity of the non-core activities that CIRA researchers are engaged in. In 2021, CIRA developed a portable passive radar system, further explored the application of passive radar to space domain awareness, continued an investigation into the effects of directed energy on electronics, and continued working towards an Australia-China Joint Research Initiative for Radio Astronomy and the Square Kilometre Array.

The team bid farewell to Andrew Burton in December 2021. Over two years, Andrew established himself, and CIRA, as an exemplar of effective industry engagement. Forging relationships with SMEs across Perth and WA, he created unique opportunities for industry to work, in particular, on SKA precursor projects, including investigating performance of fibre links using Distributed Acoustic Sensing (DAS). One of Andrew's main achievements was supporting the Engineering team in their work with Defence, securing funding for two PhD students in this field.

As ever, the small but excellent CIRA Admin Team kept us on the rails throughout 2021. No attempt to reflect the extent of their contribution would do it justice, so no attempt will be made. Suffice it to say, they have my sincere thanks.

Real-Time 3D Animation for Research Visualization

SCOTT BELL
3D Digital Artist

My name is Scott Bell and I recently became a member of CIRA staff, my role is that of a 3D artist and research visualizer. I take the research and other information from researchers and help them adapt it into custom 3D animated videos, 3D models, Images, Interactive media, and many more potential mediums.

To create these projects I use a Real-Time Rendering workflow to quickly and efficiently develop and iterate many different ideas into appealing visual aids that researchers can use for anything they so choose, from informational videos to explain things that are difficult to explain with only words to images useful for papers, or presentations.

The main benefits of the workflow I use is the ease of making changes: if a change is wanted then it is easy to do so quickly without have to worry about how it affects the overall time of completion for the project as a whole.

Another benefit is the flexibility of the workflow as once an asset is created, an antenna for example, it can be used as many times for as many different projects as needed and projects can be altered to suit any number of different purpose if needed, nothing is set in stone and almost everything can be changed to fit whatever end result is desired.

So far in my time at CIRA I have worked on and completed several animations and other projects, most notably the SKA-Low Informational Animated Series, a series of three animations that go over the important to know information about the SKA-Low.

The impact and response to the animation workflow and its results have been surprisingly positive, through the SKA-Low animations many doors regarding other possible projects have been opened and I look forward to seeing what other amazing visual experiences will be developed in the future.

ABOVE IMAGE: A 3D Scene Depicting an artisitc interpretation of a black hole with accretion disk inside the unity 3D Engine
IMAGE CREDIT: Scott Bell

ABOVE IMAGE: A 3D scene depicting an MWA tile and the sky as seen through radio waves mapped by the MWA GLEAM-X Survey inside the unity 3D Engine
IMAGE CREDIT: Scott Bell

ABOVE IMAGE: 3D scene depicting the view from within the ring of a planet as it rotates inside the uniity 3D Engine
IMAGE CREDIT: Scott Bell

A Week at the MRO

ASHWATHI NAMBIAR
Technician

We have all read and wondered how infinitely (possibly) large the universe is and how small we are in the scheme of things etc. I knew the moment I signed up, that being a part of CIRA was different from any other job I had before.

SKA and MWA were the things I knew only through various medias and publications. So, when I was offered this role as an MWA technician it was equally thrilling and scary. A few weeks in working at CIRA I slowly eased into the project and things around me started making sense. Still, working for something that operates hundreds of kilometres away seemed a bit of a mystery. After 3 months of joining finally the chance arrived, to visit Murchison Radio Observatory, the home of all our telescopes for the first time; to see them all in person; to experience the true Australian desert. Apart from the fact that I would have to leave my family behind for a week, it was very exciting. And preparations for the site trip started.

On 20th of September early morning Venus and I met Dave Minchin at Perth airport and we boarded the plane to Geraldton. Having travelled to the site many times, Dave was very helpful and quite happy to show us around. After a short flight we arrived at Geraldton airport and went to the first stop at CSIRO for safety and cultural induction in a rental truck which was waiting at the parking lot.

It takes roughly 3.5 hrs by road to reach MRO from Geraldton through mostly deserted dirt road. So, the safety induction was mainly about the road trip, emergency procedures and radio channels to use. MRO is 300Kms away from the closest city Geraldton. So, getting immediate help in an emergency at the site is not easy. Taking precautions and staying safe is the best way to go. So, we were taught about the safe working practises and precautions to take at the radio quiet zone.

The traditional owners of the MRO site are Wajarri-Yamatji people. During the cultural induction we learned about them and were asked to pay utmost respect to the landscapes and people there. After the induction and after collecting the shipments from Perth to the site, we got our lunch and setoff. Andy met us on the way in his minibus and I decided to join him to avoid travelling in the back seat.

Spring is beautiful in WA. And it's magnificent in the outback! The myriad of colours welcomed us as soon we left the city, and I didn't know where to look at. The fact that the landscape around me is entirely different from where I grew up added to the excitement. The nonstop commentaries and exclamations from me were very well tolerated by Andy and he was kind enough to stop at various stops for us to take pictures. I sincerely hope the drive to MRO was as enjoyable to him as to me. The site closes at 4:30 pm and no one is allowed after that. So, we decided to go straight to our accommodation (Boolardy station).

When you think of an accommodation facility in the middle of nowhere, I didn't know what to expect, but it was not this. Boolardy station was quite lovely, and comfortable and managed by very nice people. It had individual rooms with attached bathrooms, common laundry, kitchen, entertainment room, pool, gym, and a lot to help you to unwind after a long day of work. I must say the chef-ran kitchen is impressive too!

We set off the next morning with all our gears and packed food and water. The realization of how profoundly different it is only dawned on me in its full weight, when I landed at the MRO site.

The grandeur of the project and its ambitions, how pathetically small we humans are, even on the scale of earth, heck, even in comparison to the vastness of the desert we stand, and yet how aspiring our ambitions are, how brilliant the minds who rose to the challenge, how mysterious the secrets we endeavour to discover – which would question the very foundations of reality as we know it...

Andy McPhail gave us a quick tour around the site. Seeing the things that we worked on in the comfort of airconditioned labs operating here in its original scale was enlightening. Andy Insisted on keeping our radios close to communicate as it is very easy to get lost, hydrating ourselves and overall staying safe. Even though it was spring, and desert was carpeted with beautiful wildflowers, working under the hot sun was challenging for us as first timers. We were trying to imagine how it would have been in the summer and real sandfly season. But the realisation that we are a part of this huge project was somehow filling us with pride and humbling at the same time

The following days passed quickly, and we worked on EDA2, AAVS1 tiles and learned a lot from Andy and Dave. Slowly we got into this routine of leaving to site fully packed early in the morning, work, hydrate, and return to the accommodation and only then connect to the outside world through your trusty LAN cable. These days also helped us to see the things and luxuries that we took as granted in a different light.

There was a ministerial visit at the site on our last day. We were lucky to have a small chat with Minister for Science, Roger Cook and the Curtin Vice-Chancellor, Prof Harlene Hayne during our work. After the visitors left it was time for us to pack up too.

We helped Andy and Dave pack up the shipments to send to Perth and shutting the site down for the weekend. Then we collected our bags from Boolardy and left for Geraldton. My return drive was with Mia. I enjoyed our long chats about families and growing up, stories about MRO visits and even waiting for another vehicle to pass just to give the two-finger salute!

After boarding the flight and waiting it to take off those past days flashed through my mind. The things we learned, how much we had "toughened" from how we arrived and much more. As much as I looked forward to reuniting with my family, I realised how lucky I had been to get such an amazing opportunity.

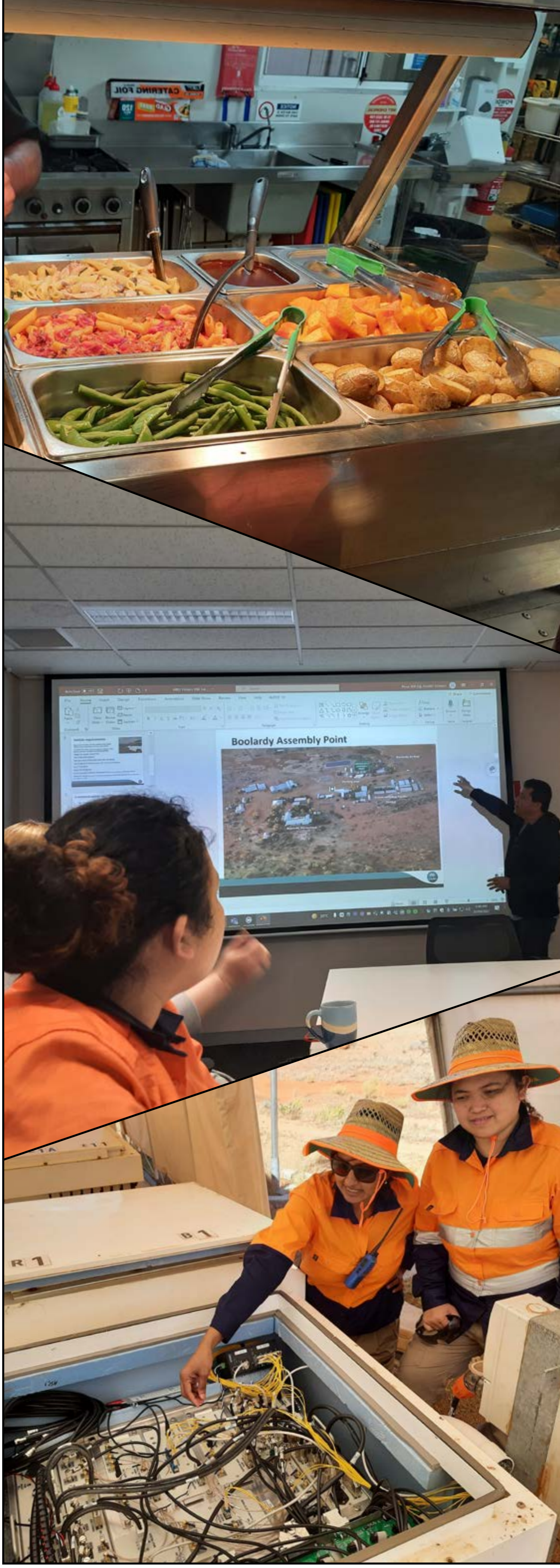

IMAGE CREDITS: Ashwathi Nambiar

Rapid Prototype Development for the SKA PaSD Project

PHILLIP GIERSCH
Technical Officer

With the signing of contracts in July 2021 CIRA began development of a Power and Signal Distribution System (PaSD), to control and monitor all aspects of an SKA Field Station. This would involve the production of multiple prototype devices and their associated circuit boards, cabling, fixings and enclosures, in a time when the world's supply chains were in upheaval and component lead times had blown out.

The PaSD system needed to be fielded at the MRO in December 2021 to allow for real world testing over the hottest months of the year, allowing only a short time frame for prototyping, development, assembly, testing and qualification work. To achieve these rapid development cycles a lot of new processes, new suppliers and new ways of operating had to be adopted.

With issues relating to previous external designs and a desire to have greater knowledge and control of the process, all printed circuit board design work was brought in house at various stages of the project. This required hiring additional staff and gaining additional expertise to accomplish this goal. This allowed us to solve problems and iterate designs without adding an additional layer of communication and management that is a requirement with external electronic design companies.

Previously the design and development method adopted by CIRA relied on calculated and theoretical designs with limited prototyping, with the hope of fewer modifications during development. Historically circuit board production was expensive and lead times were long. Production systems however have changed greatly in the last decade, the rise of low-cost international fabrication houses enabled allowed for a two-week turn around on prototype circuit boards. Costing a few dollars per board plus shipping this has allowed CIRA to adopt a design philosophy of rapid iteration to quickly advance and improve our designs based on both mechanical changes such as enclosure size and shape, EMC requirements and lessons learned through practical testing.

Even though CIRA and the PaSD team worked diligently, CIRA was not immune from the COVID related supply chain issues particularly present in the semiconductor field. This resulted in significant delays in electronic parts procurement, with lead times on many components increasing from approximately two weeks, to 12 months or longer. Bills of material would become outdated before designs were even completed. Stocks of components would regularly go from "thousands" to "no stock available" within hours.

This situation required us to significantly expand our supplier base, scouring multiple suppliers from all over the globe, many with only a few pieces each of the desired components. But even this did not allow us to get the required supplies of some components in time. Wherever possible multiple options for each component were specified and boards were designed to have maximum compatibility between component size, supplier and footprint. Printed circuit boards were partially assembled externally for speed, with the critical and/or limited supply components added in house by our team to try and stretch our supply and limit any component wastage.

In the end through a great deal of hard work and rapid diagnosis of problems, the PaSD development team was able to field a functional prototype system in the first week of December 2021, just in time for some of the hottest weeks of the year. This system is still providing the PaSD team and SKA with a trove of information to improve and iterate the system.

A huge amount of credit has to go to the CIRA PaSD team of Brian Crosse, Raunaq Bhushan, Luke Verduyn, David Emrich, Andrew Williams, Andy McPhail, Venus Chico, Ashwathi Nambiar, and Dave Minchin

FIGURE 1

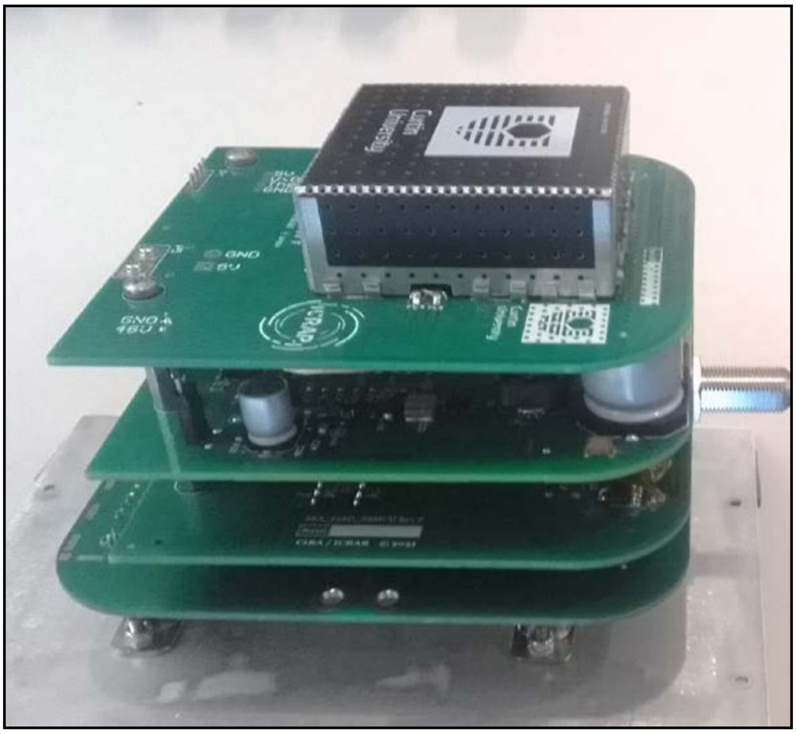

IMAGE ABOVE: Figure 1 SMART BOX Electronics Package Circuit Board Stack-up developed as Part of the PaSD Project This Required over two dozen Prototype iterations across all the boards in the stack and hundreds of individual components
IMAGE CREDIT:Phillip Giersch

FIGURE 2

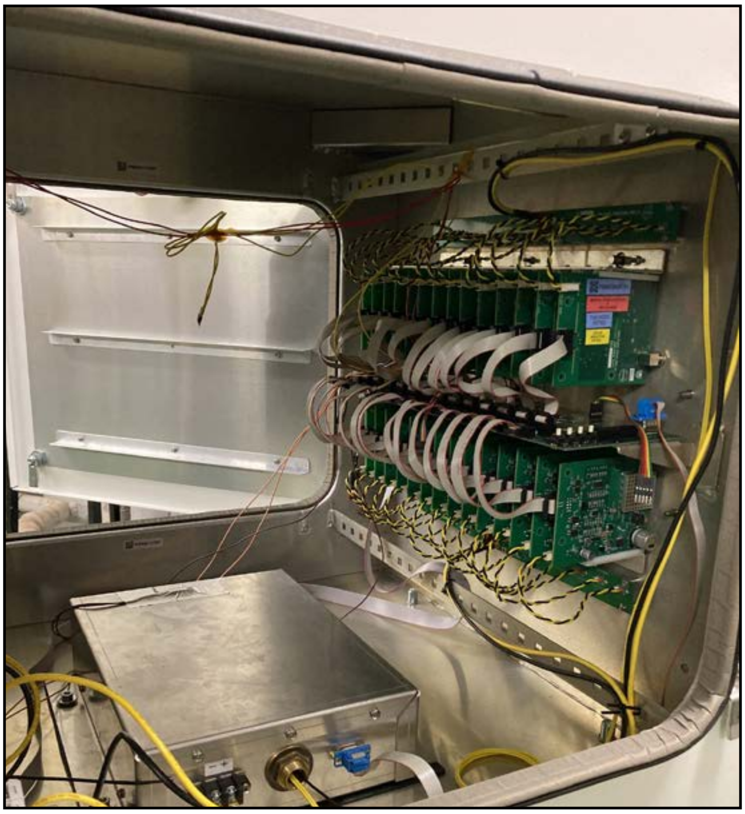

IMAGE ABOVE: Figure 2 The electronics Inside one of our prototype Field Node Distribution Hubs, built as part of the PaSD Project. Visible are 28 Power and Data over Coax Cards (PDOC's), 2 48v Power Distribution boards and the Field Node Control Board. The enclosure at the bottom of the image houses the FNDH communication equipment. Securing the parts for even this one prototype was a significant effort.
IMAGE CREDIT: David Emrich

TOP LEFT PG 61 IMAGE: Ashwathi Nambiar ,Minsiter Roger Cook, Venus Chico, Mia Walker on site at the MRO
FAR RIGHT IMAGE: Native Flora
IMAGE MIDDLERIGHT: ASKAP telescope
IMAGE FAR RIGHT: Accommodation
IMAGE BELOW: Ashwathi Nambiar & Venus Chico
IMAGE CREDITS: Venus Chico

Outback Australia and the MRO

VENUS CHICO
Technician

It is both an honour and a privilege to be able to explore the Murchison Radioastronomy Observatory. As I have just recently joined the team March of last year, I am still learning my way around. Being sent to a trip to the MRO was indeed a great opportunity for me to learn things. I am very lucky to have been given such chance to see the site up-close and experience the life in the outback.

I can still vividly recall that day we arrived at Geraldton. Half of the day we spent attending inductions; other half, exploring the beauty of the outback and the wreath flowers along the way. We were very lucky to visit MRO that time of year when wildflowers are in full bloom. Do you know that these wreath flowers are rare? Yet they grow in abundance along Mullewa and Pindar Road..

Finally, we arrived at the Boolardy Station, which will be our home for the next five days. Seeing we are in the middle of nowhere, I was quite impressed with it. Although very basic, it has all we need to rest comfortably. And the people running the place are very lovely and accommodating.

I kid you not, working at the MRO site is very humbling. I think, the fact that you are just a small dot in that very large field, far away from any luxuries you are accustomed to, changes the way you see things. Imagine, that very same field enables us to connect to the universe and its mystery---it is really something. Everything about it is just spectacular; the ASKAP dish antenna towering above me, the stretch of MWA dipoles scattered around, the wildlife surrounding us.

MRO environment can be very amazing, but also hostile at the same time. It can be quite a challenge to work under the scorching sun, not forgetting about the sandflies that will keep bugging you every now and then. But at the end of each day, you will feel a sense of pride by being part of a great team doing even greater things.

The next three days swiftly passed. On our last day, we have been given the opportunity to meet the Minister for Science, Roger Cook and the Curtin Vice-Chancellor, Prof Harlene Hayne during our field work. As we packed our bags that day, I am already looking forward to my next trip there. I will surely miss a lot of things about that place; our daily trip to the site, the wildlife around me, the people, and the place itself. I am glad that I took this trip, for it gave me an invaluable learning experience that I can be truly proud of.

IMAGE ABOVE: Panoramic view
IMAGE ABOVE MIDDLE: Venus Chico in front of sign
IMAGE LEFT: Dead kangaroo
IMAGE FAR LEFT: Steve the Lizard & Dipole 1
IMAGE CREDITS: Venus Chico







3D Printing

Halfway through 2021 CIRA purchased a Raise3D E2 IDEX 3D printer

LUKE VERDUYN
Technician Specialist

The name IDEX means independent dual extruder. The printer has two extruders that move independent of each other enabling the user to print in one of three modes: multi-material/colour, copy, and mirror. In copy and mirror mode we can print two of the same components (mirrored or normal) in the same amount of time as printing one.

Using CAD software, we design the components that we need, and we can design them however we want because the printer does all the heavy lifting. So, we start by prototyping. The ERA telescope needed supports for the RTL SDR's, so we designed a prototype that uses different spring features so that we can move the RTL SDR clamp out the way so that they can be removed.

The final version of the cradle and clamp is shown in image 4, this will hold 10 RDT SDR's and it will be mounted to a base plate.

The ERA logo was imported into the CAD software and used as a stencil where the label model was created and then using the multi-colour feature, we printed the label for the enclosure in white and red. The clamps for the USB ports were printed too, there is one for each end of the hub and gets mounted to the walls of the enclosure.

Figure 9 shows all items that were printed being used in the enclosure. The last item that was needed was N-type blanking grommets, but there are no COTS items available so we 3D printed a mould to make our own out of silicone. There are two halves of the tool that gets mounted together with one inlet and at each end of the tool is an outlet. The inlet is where the silicone is injected into the mould, when the silicone squirts through the two outlets, the mould is filled and we then wait at least 24hrs for it to set.

This is a small number of items that can be done with the 3D printer and many more applications have been done so far which include and not limited to: Drill jigs, assembly jigs, cutting jigs, FFF (Form, Fit and function), Visual aids (e.g., Beam patterns), and tools.

IMAGE ABOVE: Figure 1: 3D printer. Credit:
IMAGE CREDITS: Raise3D, https://www.raise3d.com/products/e2/, 2022.

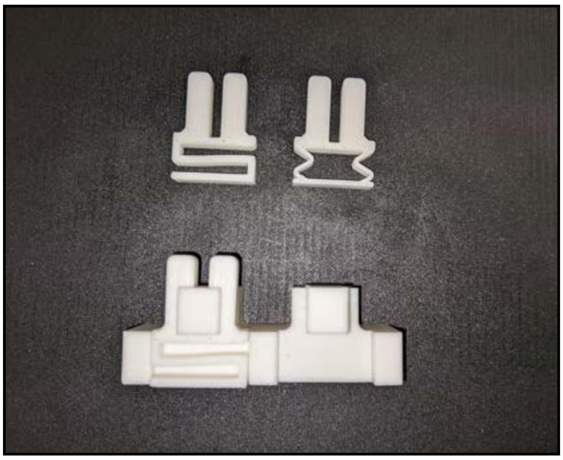

IMAGE ABOVE: Figure 2: First RTL SDR cradle and clamp prototype.
IMAGE CREDITS: Luke Verduyn

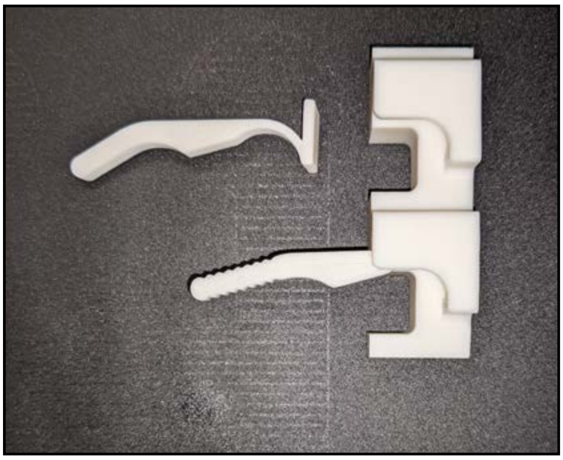

IMAGE ABOVE: Figure 3: Second RTL SDR cradle and clamp prototype.
IMAGE CREDITS: Luke Verduyn

IMAGE ABOVE: Figure 4: Cradle and clamp final version. IMAGE CREDITS: Luke Verduyn

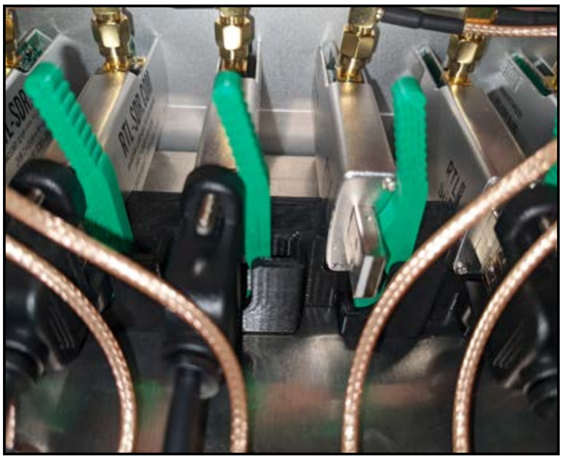

IMAGE ABOVE: Figure 5: Clamp in closed position to retain RTL SDR. IMAGE CREDITS: Luke Verduyn

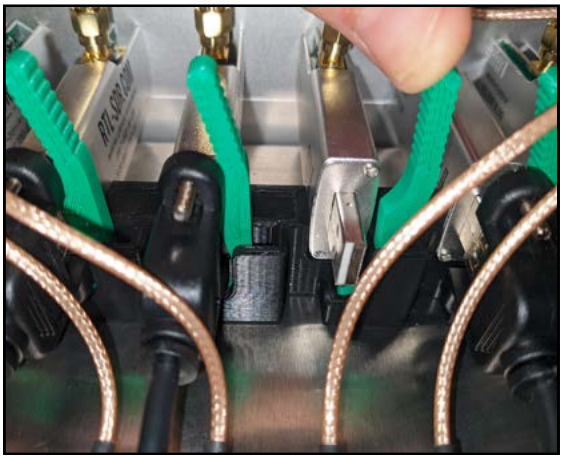

IMAGE ABOVE: Figure 6: Opening clamp to release RTL SDR. IMAGE CREDITS: Luke Verduyn

IMAGE ABOVE: Figure 7: ERA label in dual colour. IMAGE CREDITS: Luke Verduyn

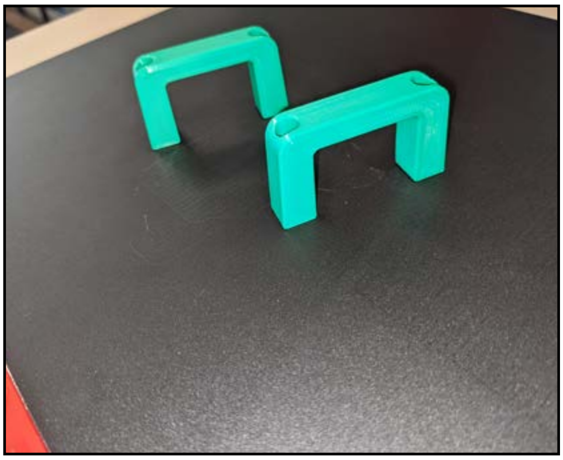

IMAGE ABOVE: Figure 8: USB port clamps IMAGE CREDITS: Luke Verduyn

IMAGE ABOVE: Figure 9: Enclosure with all components fitted. IMAGE CREDITS: Luke Verduyn

3D printing cont ...

IMAGE ABOVE: Figure 10: 3D printed grommet mould
IMAGE CREDITS: Luke Verduyn

IMAGE ABOVE: Figure 11: Filled mould.
IMAGE CREDITS: Luke Verduyn

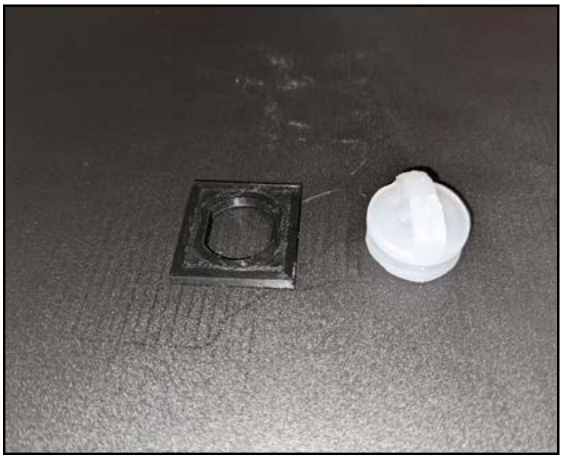

IMAGE ABOVE: Figure 12: Silicone Grommet with a test N-type connector cut-out.
IMAGE CREDITS: Luke Verduyn

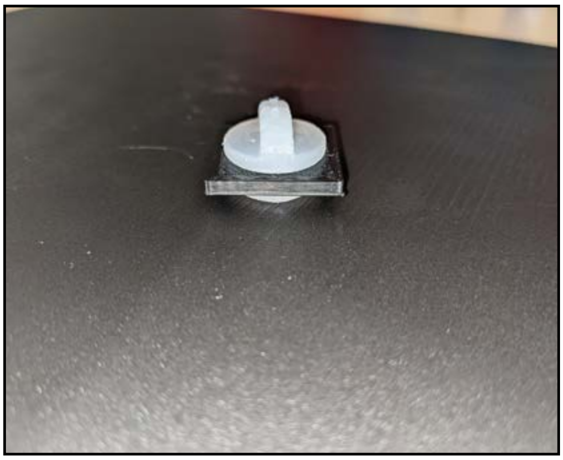

IMAGE ABOVE: Figure 13: Grommet fitted to test piece.
IMAGE CREDITS: Luke Verduyn

SKA PaSD: Testing Custom-Built Electronic Hardware

DAVID EMRICH
Instrument Engineer

The SKA Power and Signal Distribution (PaSD) system has been a major focus of the Operations team within CIRA since the middle of 2021. This has seen the design and development of several custom circuit boards and the integration of these, along with Commercial Off-the-Shelf (COTS) equipment, into complete sub-modules and modules, such as power supplies, SMART Box electronics packages and the like.

Starting at the level of custom circuit boards, relatively complete testing is required to ensure that the designs meet both functional and non-functional requirements, and functional requirements need at least partial re-testing when the boards are integrated into their respective modules.

This creates the need for supporting hardware known as 'test jigs' which provide the required inputs to, and monitor the outputs from, each Device Under Test (DUT). Many of these inputs must be representative of other hardware elements which do not yet exist, for example, push-buttons that simulate physical state changes within the system, such as open doors etc.

Test jig hardware must frequently be able to simulate both nominal and fault conditions for the inputs and outputs of the DUT to check that it takes the appropriate actions when external faults occur. Support for continuous monitoring of power consumption, temperature on critical items, and other non-production aspects must often be included as well.

Furthermore, with circuit boards containing microprocessors, rudimentary test software must be quickly written, tailored to human-in-the-loop testing. This code must operate independently of any other production software systems especially those that are still under development. This helps to confirm the correct mapping between internal microprocessor functional elements, and the physical inputs and outputs those elements are supposed to control and monitor.

And finally, those circuit boards containing microprocessors need to be built into suitable temporary hardware setups, for the software developer who is writing the production software, in parallel with the hardware development effort!

In the tight timeline in which the PaSD prototype was developed and fielded, all these activities had to occur in parallel, and the same engineering team responsible for delivering working hardware to site before the end of 2021, also undertook the task of creating the test jig hardware and low-level microprocessor firmware.

One benefit of this parallel work-flow is that the very lowest level hardware input-output routines in the test software were immediately available for the software developer to incorporate into the production firmware, which also allowed the production software to be ready in time.

In the future, these test jigs and associated low-level testing code will very likely form the basis of the design of semi- or fully-Automated Test Equipment (ATE) that the SKA will use to test and accept production hardware.

The same ATE can also be used to re-qualify boards and sub-systems that have suffered field failures and been repaired, before they are returned to site as spares and eventually re-integrated into the telescope.

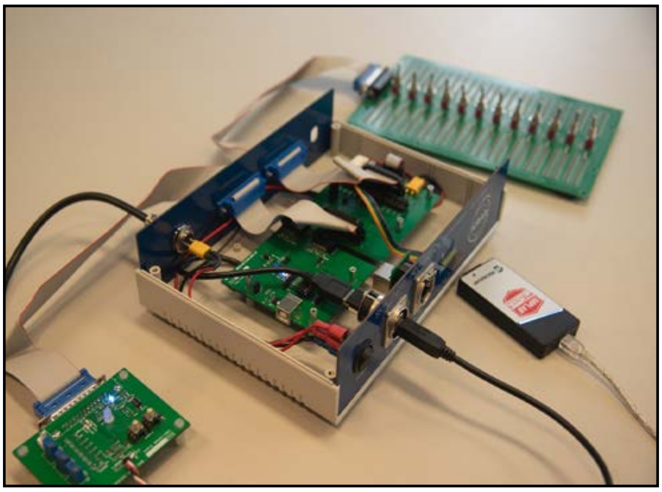

IMAGE ABOVE:Figure 1: Software Development setup for SMART Box microprocessor board. External circuit board simulate the user interface (lower left) and on/off/fault conditions for the 12 Front-End-Modules (upper right).
IMAGE CREDITS: Mia Walker

Efficiently Preprocessing MWA Visibilities

DEV NULL
Developer

When you work on an interferometric radio telescope like the Murchison Widefield Array (MWA) every day, it is easy to overlook how magical these instruments truly are. They use a mix of electrical engineering, signal processing, astronomy, and high-performance computing to trick an array of radio antennas into imaging electromagnetic waves that have been travelling through the universe for billions of years.

The voltages induced in the antennas pass through a series of signal processing stages where they are cross correlated into a torrent of raw visibility measurements. Each data point is like a tiny piece in a multidimensional Fourier-space puzzle from which science products like image cubes and power spectra can be synthesized. For the best results, pre-processing is needed to remove the imprint of each stage in the signal processing chain, excise the radio environment noise and transform the data into a format supported by the astronomy software package being used.

For the vast majority of MWA users, the minutia of pre-processing is helpfully abstracted away by the MWA All-Sky Virtual Observatory (MWA ASVO) frontend, but there is quite a bit going on under the hood when it comes to manipulating the gains and phases of a multidimensional array of complex Fourier-space matrices.

There is usually a trade-off between code readability and performance. Cotter is written in C++ and makes heavy use of multidimensional pointer arithmetic. Although it is very performant, it was not written with readability in mind. By contrast, PyUVData is written in Python, uses the NumPy library for array operations, and has excellent documentation. However, it struggles with significant performance issues by comparison.

Enter Birli, a preprocessing suite written in Rust, with similar performance to Cotter, and similar developer ergonomics to PyUVData. Birli uses the ndarray library to create transposed views into the visibility array, avoiding expensive array copies. Although it has had only a year to mature, Birli has now reached feature and performance parity with Cotter.

To quantify the performance difference between these approaches, a benchmark was performed using a small 50GB observation on a Nimbus instance. Although Birli and Cotter used similar CPU and memory resources, Birli finishes more than twice as fast because it made better use of threading. The PyUVData results suggest that the visibilities are being duplicated in memory, and despite spawning multiple threads, there is a bottleneck which limits the performance to that of a single core.

Application	Elasped time [min]	Max Resident Mem [GiB]	Avg. CPI
Birli	1:58.42	49.476	1070%
Cotter	4:56.75	47.260	301%
PyUVData	16:41.87	122.348	101%

In conclusion, if you need to perform expensive computations efficiently with large arrays of interferometer visibility data, Rust has significant benefits in performance, testability and developer ergonomics when compared to Python and C++. There are several emerging Rust projects on the MWA Telescope GitHub organization which would serve as a great starting point, including Birli, Hyperdrive, Marlu, mwalib, mwax stats and Giant Squid.

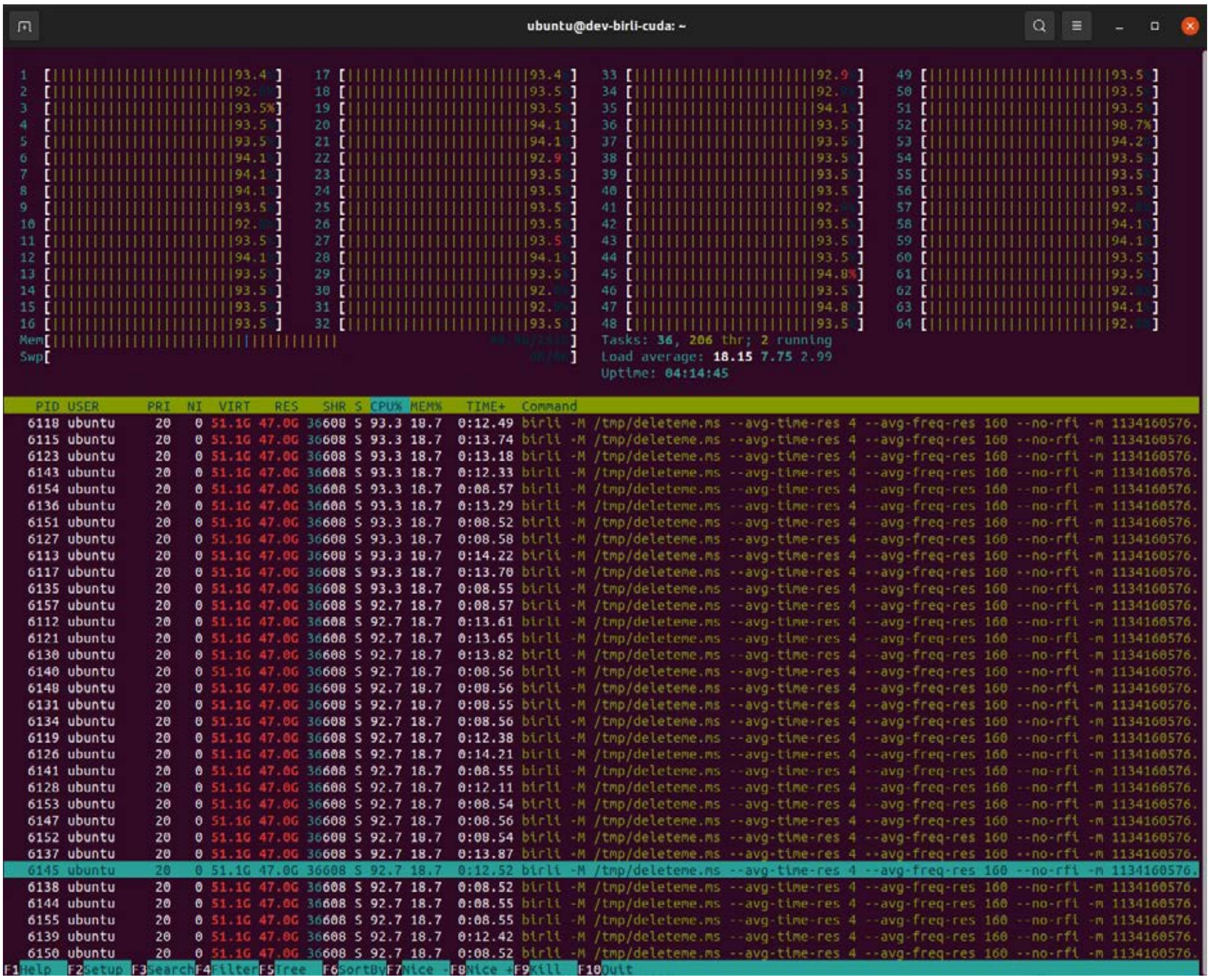

IMAGE ABOVE: "htop captures Birli saturating all 64 cores of a Nimbus instance while pre-processing an observation"
IMAGE CREDITS: Dev Null

IMAGE CREDIT AdobeStock

Designing the SKA-MWA Signal Bridge

JAKE JONES
Senior Technical Officer

The SKA-MWA Signal Bridge is a project that will allow beamformed data from SKA prototype arrays such as AAVS2 and EDA2 to be injected-into and correlated with the MWA Telescope. Having this capability is not only beneficial for commissioning these SKA prototypes but also provides a substantial increase in collecting area for the MWA and provides a number of opportunities to do novel research. In 2021 we embarked on designing this system which resulted in a number of engineering challenges.

The raw data that is output from both the MWA and SKA receivers is divided into frequency channels by their respective channelizers. However, the MWA and SKA channelizers are vastly different with each system having different channel widths and channel spacings, in addition the SKA channelizer is oversampled resulting in channels that overlap. This presents a challenging problem because the SKA data must be converted into MWA style channels before it can be sent to the MWA correlator (MWAX).

The SKA-MWA Signal Bridge will exist between the SKA Tile Processing Modules (TPM) and the MWAX Correlator. It will perform the core function of converting the SKA channelised data into MWA style data, before transmitting it on the MWAX network. From the perspective of the MWAX correlator, the signal bridge will appear just like any other MWA tile albeit with much different properties.

A number of possible designs were considered during the design process but it was determined that the conversion from SKA data to MWA data could be achieved with the following architecture outlined in Figure 1. In essence, the conversion is achieved by first dividing the spectrum into very fine frequency channels using the Fast Fourier Transform (FFT). Next, the data is rearranged into the correct channel bands, before each band is aggregated into a single data stream using the Inverse FFT.

This system architecture was fully simulated as part of the verification process and the results made it clear that although this design is simple in principle, a number of systematic effects must be addressed in practice. Namely, the frequency response of the chanellisers will introduce error unless it is corrected for, and increased error can be expected around FFT block boundaries which will need to be mitigated if shown to be too large.

Finally, we conducted several experiments where we captured raw data from both the MWA and EDA2 of calibrator sources such as CenA. Using this data we partially implemented the signal bridge design, fine-channelising and re-arranging the data before we correlated the EDA2 beam with an MWA tile. It became obvious that there were problems with the channel indexing and unexplained time delays within the system, however once corrected for, we obtained the result shown in Figure 2. This figure shows the correlation between the EDA2 and an MWA tile, it clearly shows an obvious fringe suggesting that the two signals are strongly correlated. The frequency axis spans a single MWA channel and includes portions of data from 3 individual SKA channels. This successfully demonstrated both the signal processing and software engineering aspects of the design.

Overall, we have designed and verified the signal architecture for the SKA-MWA signal bridge and have begun to demonstrate it in practice. Simulating the system and testing the design with real data was an invaluable part of the process, revealing a number of potential issues early on in the design phase. As of now, we have only tested the system in an offline capacity, moving forward we intend to fully implement the system and demonstrate it working in real-time.

FIGURE 1

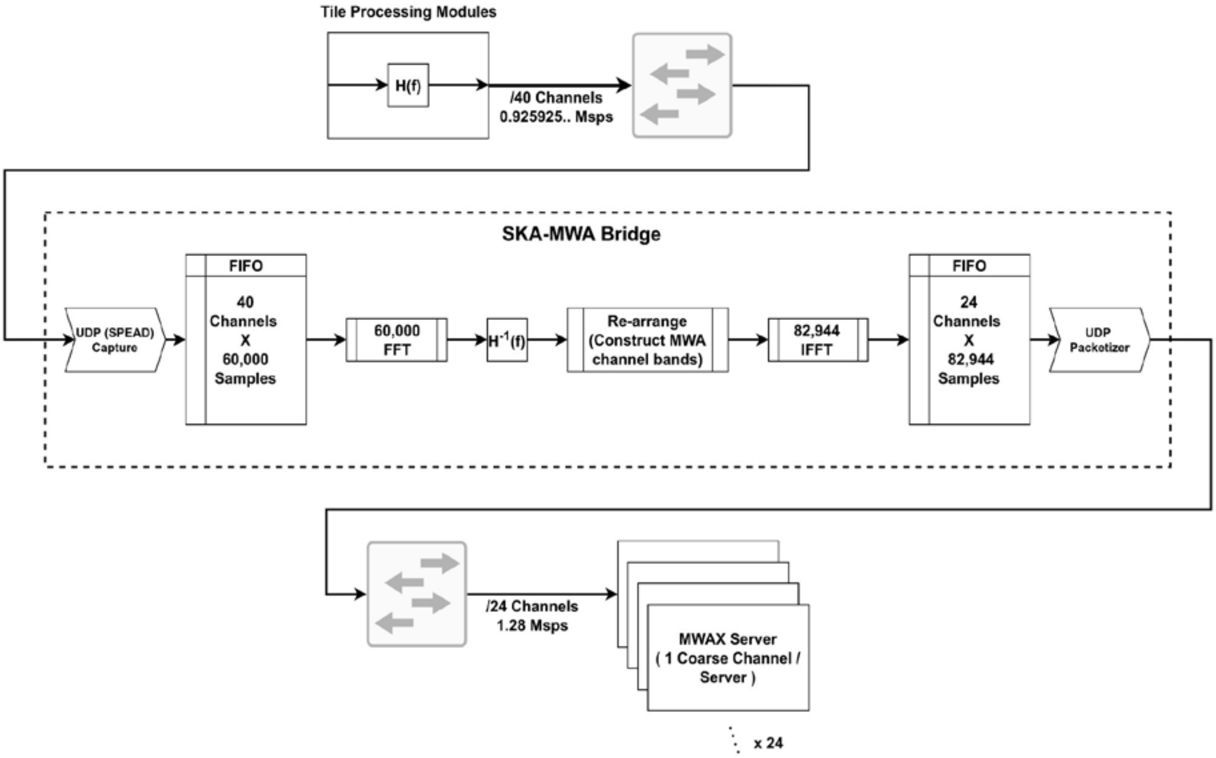

IMAGE ABOVE: Figure 1: The signal processing architecture of the SKA-MWA Signal Bridge
IMAGE CREDIT: Jake Jones

FIGURE 2

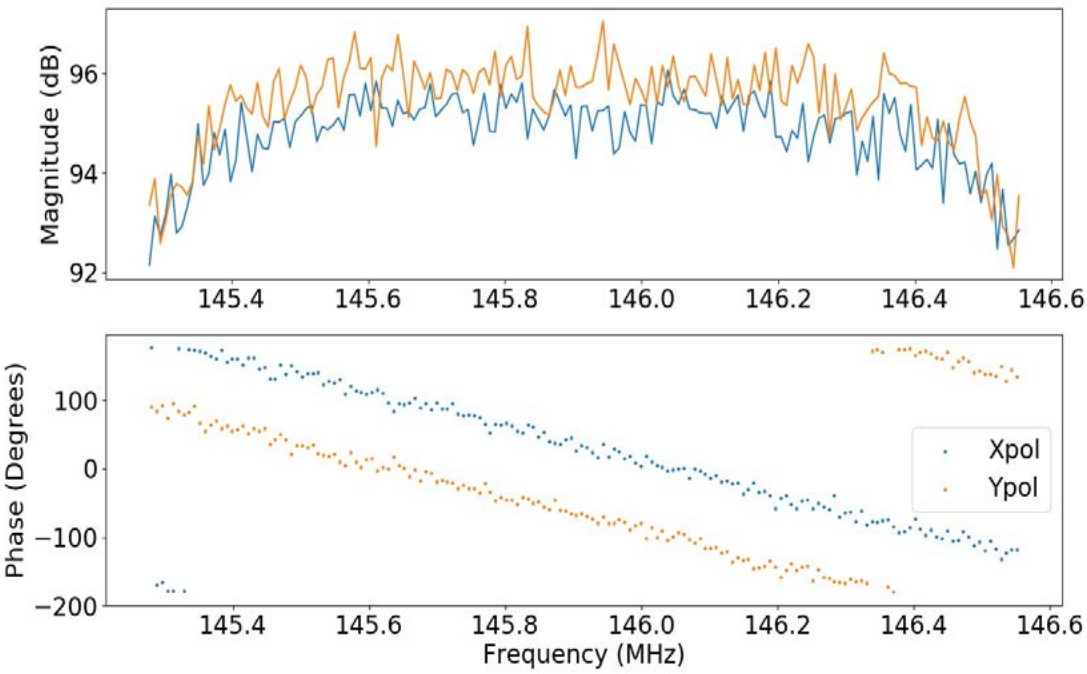

IMAGE ABOVE: Figure 2: The correlation between the EDA2 and an MWA tile, after converting 3 individual SKA channels into a full MWA channel band.
IMAGE CREDIT: Jake Jones

SKA PaSD: A Rapid Design Achievement

RAUNAQ BHUSHAN
Project Manager

Early in 2021, the SKAO became an intergovernmental organisation as part of its path to building the worlds largest radio telescope. With this new identity, the SKAO gained the power to issue and sign contracts and CIRA had the honour of entering into the very first contract the SKAO issued in June of 2021.

This contract was structured around the design and test of the Power and Signal Distribution (PaSD) work package, a central component for the SKA-Low telescope. The key function of this system is to condition and distribute power to every one of the SKA-Low antennas, while also aggregating their raw signals for processing. While this may seem simple on the surface, the system is also required to provide detailed telemetry and control of individual signal chains and antennas, all while meeting the world's most stringent EMC/RFI requirements. Add in the scale of SKA Low, and you end up with a culmination of many simple components that ultimately make a complex engineering system, that needs to be effectively mass produced.

One of the key risks this project aimed to address was the management of heat sensitive components embedded within the system, which if allowed to get too hot, would have severely compromised the quality of data produced by the telescope. As such, the CIRA design team embarked on the extremely ambitious goal to design, assemble and field a set of prototypes in just 5 months so the system could be deployed and tested at the peak of the Australian summer.

And so at the beginning of June 2021, with a concept designed around a set of requirements, the CIRA ops team began to break down the system into a sensible product tree and got to work. Over the next two months, the team rapidly and efficiently progressed the design of 14 different PCBs 3 complex mechanical enclosures and software packages to stitch the system together. The team successfully completed a detailed design review by the middle of August with the SKAO and continued prototype development rapidly and efficiently.

During the 5-month period, the extremely talented CIRA ops team pulled together their unending resourcefulness, guided by invaluable experience, grit and agility to find ways to design, build and iterate in a way that ultimately led to the deployment of prototypes by the first week of December 2021.

The result was validation of the prototypes ability to manage the thermal characteristics of the system by reducing the differential of the key components with ambient air temperature from ~17C to ~4C, thus mitigating risks to telescope performance. Before CIRA shut down for the year in 2021, not only were the prototypes functioning in their intended environment, but they were broadcasting live telemetry data to users around the globe, validating the efficiency of the design efforts and effectiveness of the system designed and built by engineers here at CIRA.

IMAGE ABOVE: Figure 1: Prototype SMART Box on site
IMAGE CREDITS: David Minchin

IMAGE ABOVE: Figure 2: Prototype FNDH on site
IMAGE CREDITS: David Minchin

The CIRA Development Committee (DevCom) provides advice to the CIRA Directors, and aims to foster an environment where all staff can flourish irrespective of role, age, gender, sexual orientation, disability, race, religion, etc. It recognises that a way to promote diversity and representation, at all levels, is through development and support of existing, and future, staff and students. It draws on University and other resources to provide initiatives to develop CIRA's talent and to improve the overall working environment. The committee is also a portal to provide advice for academic and nonacademic staff on career development, progression and recognition.

DevCom Mission Statement

Diversity, Inclusion & Equity
The CIRA Development Committee

SAMUEL MCSWEENEY
Associate Lecturer
CHAIR Development Committee

The Development Committee (DevCom) continued its work throughout 2021 to support and increase diversity, inclusion, and equity among CIRA's growing staff and student bodies. A major emphasis has been visibility, which is a key component in demonstrating CIRA's continued commitment towards the support and inclusion of various diverse minority groups, as well as highlighting areas where CIRA can improve. To this end, CIRA supported and led many initiatives and activities throughout the year.

CIRA's community is truly an international one, with staff and students coming from many far-flung places around the world. To celebrate and showcase CIRA's racial and cultural diversity, DevCom ran two cultural activities, based on and coinciding with (1) the Indian festival Diwali, including Rangoli, and (2) the Islamic celebration of Milad un Nabi. Volunteers from DevCom gave short explanations about the cultural significance of these cultural dates, accompanied by traditional foods from the respective cultures. Both of these were well attended and enjoyed by CIRA members.

Closer to home, DevCom showed its recognition of and support for Indigenous Australian culture by running a series of initiatives coinciding with NAIDOC week. The Journal Club that week included the presentation of some recent work done in the field of Indigenous astronomy, recognising First Nations peoples as the first astronomers in this region. At the same Journal Club, DevCom also unveiled an astronomy-specific Acknowledgement of Country that ICRAR-UWA's diversity committee had developed alongside Yamatji elders (whose traditional lands are where the MRO is located). An online quiz to test our knowledge of local Indigenous language and culture was also developed and published, and greatly enjoyed by all. Despite these initiatives, we recognise that Indigenous peoples are underrepresented at CIRA, and DevCom continues to explore ways to grow and foster inclusion and diversity in this area.

Another strong theme of 2021 has been the visibility of the diversity of gender and sexual orientation. While the paucity of women in astronomy (and more broadly, STEM) is a strong, ongoing focus of DevCom's activities, we also conducted some activities aimed at improving visibility of minority groups across the LGBTQIA+ spectrum. We celebrated Trans Visibility Day by holding an arts-and-craft activity to construct trans flags that can be displayed around CIRA. Wear It Purple Day was widely taken up by many CIRA staff and students, commemorated with a group photo. DevCom also encourages all CIRA staff and students to put their pronouns on public display, either with pronoun stickers kindly provided by ICRAR-UWA, or including pronouns on various online platforms commonly used at CIRA (e.g. Slack, Teams, Webex). DevCom was also instrumental in implementing the inclusion of pronouns on official name badges for both ICRAR and Curtin's EECMS school.

DevCom also supports a number of social initiatives aimed at fostering the physical and mental well-being of CIRA's members. Many of these activities are organised and run by volunteers (e.g. yoga sessions, hiking events, sporting clubs, social movie viewings), and occasionally run by DevCom itself, such as the "CIRA Olympics" day that saw CIRA staff and students competing in fields as varied as paper plane flying, sudoku, and power walking! These events do a great deal to foster sociability and comradeship among CIRA's ever-growing staff and student bodies.

The 2021 CIRA Development Committee consisted of Dave Minchin/Sammy McSweeney (Chair), Kat Ross (Scribe), Nipanjana Patra, Budi Juswardy, Mia Walker, Anshu Gupta, Adelle Goodwin, Mawson Sammons, Ben Quici, Kariuki Chege.

IMAGE CREDIT PAGE 70: AdobeStock

HIGHLIGHTS FROM 2021

TERESA SLAVEN-BLAIR
Outreach Coordinator

The ASTRO 3D MWA EoR research group at CIRA sought to make the most of state COVID-19 protections in 2021 and ran or attended several in-person outreach events.

In June, Outreach Coordinator Teresa Slaven-Blair collaborated with the Millen Primary School's Fathering Project to run an astronomy themed fundraiser for about 60 children and their parents. There were two observing stations, one with a Dobsonian telescope borrowed from Curtin STEM Outreach and one with a radio telescope built by Teresa and CIRA PhD student Jishnu Thekkeppattu.

There were also three activity stations, including building the Milky Way out of Play Doh and using Slinky's to understand redshift, as well as food and merriment provided by the Fathering Project.
CIRA participants were Ben McKinley, Christene Lynch, Dev Null, Jack Line, Jishnu Thekkeppattu, Kariuki Chege, Mike Kriele and Teresa Slaven-Blair.

IMAGE ABOVE: Fathering Project Playdough Activity
IMAGE BELOW: AstroRoscks Festival Mt Magnet
IMAGE CREDIT: Teresa Slaven-Blair

In September Teresa was invited to join the ASPIRE WA's Astro Tour into the heart of Western Australia, in their mission to encourage remote and Indigenous students to consider university education. Together with Greg Rowbotham from UWA, Teresa ran Solar System activities with primary and middle-school aged students at Mullewa, Meekatharra, and Mount Magnet District High Schools.

The tour ended with the Mount Magnet AstroRock Fest, where CIRA's Mia Walker and Harrison Barlow joined to run their own activities. Teresa ran a stall indoors with her "Epoch of Bubbles" invention; a bubble art activity to communicate the basics of the Epoch of Reionisation, as well as giving an interview on Radio Mama about her journey into the field of astrophysics.

Like many others at CIRA, the ASTRO 3D MWA EoR team joined the Perth Astrofest in November with two stalls. The ever popular "Epoch of Bubbles" activity was running inside, while the teams self-built radio telescope was attracting a lot of attention outside from keen hobbyists interested in being able to detect the neutral hydrogen signal from the Milky Way galaxy with not much more than some corflute and alfoil. CIRA participants at the ASTRO 3D stalls were Anshu Gupta, Cath Trott, Chris Jordan, Christene Lynch, Jack Line, Jishnu Thekkeppattu, Kariuki Chege, Mike Kriele, Nicole Barry and Teresa Slaven-Blair.

IMAGE ABOVE: ASTROFEST 2021
IMAGE CREDIT: Teresa Slaven-Blair

IMAGE BELOW: ASTROROCKS FESTIVAL MT MAGNET 2021
IMAGE CREDIT: ICRAR

THE 12TH IAES WINTER SCHOOL INSPIRING THE NEXT-GENERATION OF RADIO ASTRONOMERS AND ENGINEERS

IMAGE CREDIT ABOVE: AdobeStock

DANNY PRICE
Senior Research Fellow

The Indigenous Australian Engineering School (IAES) is a week-long camp to introduce indigenous students to careers and studies in engineering. The program is hosted at Curtin on behalf of Engineering Aid Australia, and targets high-school students in years 9-12 with an aptitude and interest in science, technology, engineering and mathematics (STEM). For several years, CIRA has participated in the IAES and provided financial support.

In July 2021, CIRA once again welcomed IAES winter school students for a half day, to give them an idea of what astronomers do and what skills they can develop if they continue in their STEM studies. Drs. Kate Harborne and David Gozzard joined us from the ICRAR-UWA node, and brought along a "Tiny Radio Telescope" for a hands-on demonstration of radio astronomy. The students helped to assemble the telescope, then learned how an antenna converts electromagnetic waves into a voltage on a cable that can be analysed on a computer. While rain got in the way of astronomical observations, the students learned how to read the spectrum produced by the Tiny Radio Telescope and used the telescope to investigate the local radio environment.

After their brief introduction to radio astronomy, I asked the students to ponder an intriguing question: Are we alone in the Universe? To help them decide, I chatted to the students about just how vast the Universe is, and how many stars and exoplanets we think there are in the Milky way. I then introduced them to the Drake Equation: a back-of-the-envelope method for estimating how likely we are to detect signatures of technology from beyond Earth.

To test out our new back-of-the-envelope skills, we did an experiment with a jar full of M&Ms to come up with a Drake equation estimate. We concluded that life is rare and special – and that we would need billions more M&Ms to do the experiment properly. And of course, the jar of M&Ms was awarded to the student who most closely estimated the total number of M&Ms.

The astronomy theme continued into the evening when the students visited Perth Observatory, on the land of the Whadjuck people, Noongar boodjar. During the visit, Elder Shaun Nannup spoke about Dreaming stories of the sky, and how Indigenous Australians have used the night sky for navigation, calendars, cultural lore and songlines for thousands of years.

Students who participate in the IAES program are eligible for scholarships toward STEM studies from Engineering Aid Australia. I hope to see some of the IAES scholars return to CIRA in the coming years as part of the future generation of radio astronomers.

IMAGE CREDIT ABOVE: AdobeStock

IMAGE ABOVE: Danny Price teaching IAES students about the Drake Equation with M&Ms.
IMAGE CREDIT: IAES

IMAGE ABOVE: David Gozzard and Kate Harborne leading a hands-on radio astronomy lesson with the Tiny Radio Telescope
IMAGE CREDIT: IAES

The ASTRO 3D West Coast Writing Retreat

TERESA SLAVEN-BLAIR
Outreach Coordinator

The ASTRO 3D West Coast Writing Retreat was held at Rottnest Island in November of 2021, organised by Anshu Gupta for ASTRO 3D's Western Australian members. The aim of the retreat was to assist attendees with their writing goals, by providing a distraction free and supportive environment to focus on writing for five days. Writing goals ranged from completing sections for scientific papers, thesis chapters, funding applications and outreach articles.

While the primary activity of the retreat was silent writing, it was interspersed with reading and providing constructive comment on others writings, discussing good writing techniques, cycling, snorkelling, board games and plenty of socialising with each other and the wildlife.

The biggest distraction were the quokkas, one of whom visited the writing room every afternoon in an attempt to steal food provided by the hotel hosting the event.

IMAGE LEFT While we focus on writing, a quokka attempts to steal food off the table behind us.
IMAGE CREDIT: Teresa Slaven-Blair

IMAGE RIGHT: A happy quokka eating a Moreton Bay Fig leaf outside the writing room.
IMAGE CREDIT: Teresa Slaven-Blair

IMAGE LEFT: Group photo underneath the Bathurst lighthouse.
IMAGE CREDIT: Teresa Slaven-Blair

IMAGE MIDDLE Going snorkelling at Little Salmon Bay.
IMAGE CREDIT: Teresa Slaven-Blair

IMAGE MIDDLE: Group photo next to Pinky Beach.
IMAGE CREDIT: Teresa Slaven-Blair

Science & Engineering Teaching 2021

Professor James Miller-Jones
CIRA Science Director

Professor David Davidson
CIRA Engineering Director

CIRA staff and students continued to make a significant contribution to undergraduate teaching and project supervision right across the School, delivering coursework units into both the Physics and Astronomy, and the Electrical Engineering (EE) majors. Staff members also provided project supervision into all four disciplines within the School; within Physics and Astronomy and EE, acting as clients for several Capstone projects within the Computing major, and supervising Honours and Masters projects within the Mathematics and Statistics discipline. The growth of our engagement across the School has been a highlight in 2021, enabling us to interact with talented students from all disciplines, and fostering the growth of interdisciplinary collaboration. Indeed, one of the RTP scholarships awarded to CIRA students in 2021 was for a project jointly supervised between CIRA and the Mathematics and Statistics discipline.

In total CIRA teaches into eleven undergraduate coursework units within the Physics major, and a further four modules within the EE major. This represents well over 500 students, with particularly large enrolments in the third-year EE modules on Engineering Electromagnetics and Transmission Lines, and Electronic Design. The former is also delivered at the Curtin campuses in MIRI and SLIIT, with CIRA staff providing the teaching and assessment materials and moderating the assessment results. Within the Physics major, our staff teach both core Physics units, as well as the specialised Astronomy electives, and many of the students taking our Honours-level units go on to enrol in PhDs.

The project supervision provided by CIRA staff is also important, whether at third-year or Honours level, or during summer internships. By providing our students an early opportunity to engage with our research, they are able to develop their research skills, and explore different areas of our work. Such student projects can even lead to peer-reviewed publications, with one such student-led paper having been published in 2021. With 7 third-year Physics project students, 6 Physics Honours students, 11 summer students (5 funded by ICRAR or Pawsey, and 6 through EECMS), 12 final-year engineering project students, as well as 2 students from Mathematics and Statistics, and 3 groups of Computing Capstone students, our supervisory activities represent a significant effort by CIRA research staff, and are greatly valued.

Looking ahead to 2022, we keenly anticipate the return of face-to-face teaching and examinations, and we look forward to engaging more closely with all four disciplines within the School.

2021 UNDERGRAD STUDENTS TEACHING PROJECTS

In 2021 Dr Maria Kovaleva mentored two undergraduate students, Janus Silvestre and Kit Hon Liew, in Engineering with a hands-on focus at CIRA

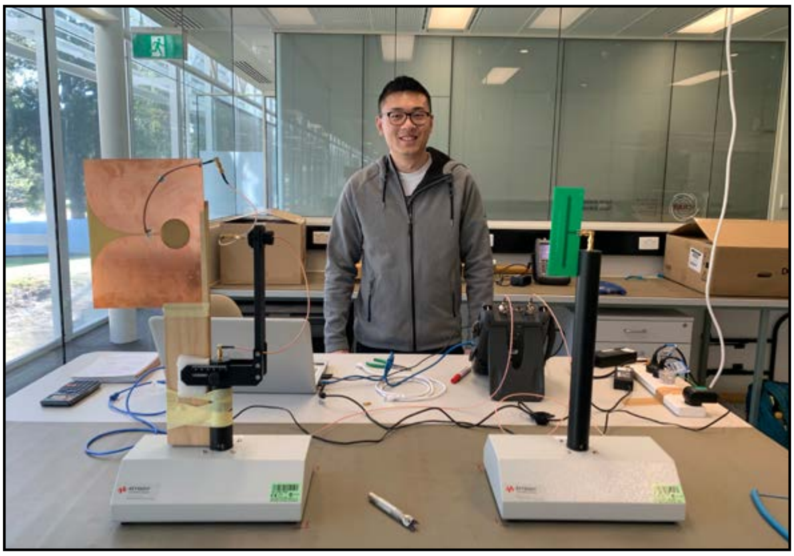

IMAGE LEFT: Kit Hon Liew performing automated radiation pattern measurement of his Vivaldi Antenna prototype using Dreamcatcher ME1300
IMAGE CREDIT: Maria Kovaleva

IMAGE RIGHT : David Kenney instructing Janus Silvestre on health and safety practices in antenna prototyping
IMAGE CREDIT: Maria Kovaleva

THE ICRAR WORK EXPERIENCE STUDENT PROGRAM

ADELLE GOODWIN
Associate Lecturer

The ICRAR work experience program continued through 2021, with CIRA hosting 10 work experience students in September and December. The work experience program enables high school students to experience the working life of ICRAR's astronomers, engineers, and educators and to get a taste of what a day in the life of an astronomer/engineer is like. Usually students split their time across the ICRAR nodes, with two days at CIRA, two days at UWA, and one day at Pawsey. The year 10 and 11 students each spent two days at CIRA and enjoyed a range of activities and discussions with astronomers and engineers.

From searching for satellites in MWA observations with Prof Randall Wyath, to an introduction to Python coding involving Pokemon with PhD student Kathyrn Ross, the students were exposed to the every-day tasks that the astronomers and engineers at CIRA carry out. They listened to individual astronomers and engineers talk about their research and roles at the institute, took a tour of the radio frequency lab, and played with a real MWA antenna.

The students each wrote a blog about their experience, which is published on the ICRAR website with some snippets provided below. Overall the students experienced an informative and fun couple of days at CIRA, and thoroughly enjoyed the program.

"All in all, I had a great time here at ICRAR and am honestly sad that the week ended so soon. I highly encourage anyone that has even the slightest interest in astronomy to come to do work experience here as you can hear from so many different people and realise astronomy isn't just looking through a telescope. The friendships you form with other work experience students are also rewarding. Thank you to everyone that made my time at ICRAR such a wonderful experience."

Bernice Luk, year 10 work experience student
September 2021

"Overall, the work experience was insightful and interesting for me, I have learned a huge load of information across many subjects from antenna engineering to astrophysics and computer science. I would absolutely recommend this experience for anyone even remotely interested in Astronomy as you are able to see what a wide range of people do for a job and the types of options that are out there."

Arina Levkovskaya, year 10 work experience student
September 2021

KAT ROSS ANNOUNCED AS SYDNEY OBSERVATORY ASTRONOMY AMBASSADOR

ARTICLE CREDIT: https://www.maas.museum/media-story/kat-ross-announced-as-sydney-observatory-astronomy-ambassador/

ABOVE IMAGE CREDIT: ICRAR

The Powerhouse has today announced the appointment of Kat Ross, astrophysicist and founder of the #IncludeHer campaign, as the new Sydney Observatory Astronomy Ambassador.

Kat Ross is a Ph.D. candidate at Curtin University, Perth, studying 'baby' black holes, galaxy evolution and the history of the Universe. A dedicated campaigner for women in STEM, Ross launched the #IncludeHer campaign after discovering NSW students in Year 11 and 12 Science were being taught by only two female scientists and almost 80 male scientists. Now a national movement, #IncludeHer aims to address this imbalance in the Australian curriculum to include a more diverse representation of scientists.

Advocacy for women in STEM will be a focus of Ross' ambassadorship with Sydney Observatory. Working with Powerhouse curators, she will develop a portfolio of science programs, livestreams and learning programs that will engage students and audiences with astronomy and the history of women in astrophysics. On 24 September, Ross will present her first livestream from Sydney Observatory showcasing astronomical objects that women have created that have significantly contributed to our understanding of the Universe.

Ross follows Gomeroi astrophysicist Karlie Noon who was appointed as the first Sydney Observatory Astronomy Ambassador in August 2020. Noon presented her final Southern Sky Livestream as seen from the Observatory's telescopes on 21 August 2021 which is available to watch on demand.

The Sydney Observatory Residency Program has been announced for a second year, with expressions of interest open until 11 October 2021.

Launched in 2020, the Sydney Observatory Residency Program provides a supported environment for researchers, artists and creatives to undertake a project relating to the Observatory's disciplines, collection and programs. Residencies are open to established and emerging academic researchers, artists, scientists and creative organisations, with interdisciplinary collaborations encouraged. The program offers studio and research space in-kind at the Sydney Observatory alongside the opportunity for residents to collaborate with Powerhouse curators on projects and public programs. Each 2022 resident will receive a $5,000 honorarium.

Lisa Havilah, Chief Executive, Powerhouse Museum said: "Encouraging young women to consider a career in STEM is a focus of Sydney Observatory and the Powerhouse. We are thrilled to welcome Kat Ross as the next Sydney Observatory Astronomy Ambassador. We look forward to working with her to celebrate the many achievements of women in astronomy."

Kat Ross, 2021 Sydney Observatory Astronomy Ambassador said: "I have been a strong advocate for women in STEM for several years. Currently, only around 30 percent of all female students select STEM-related subjects in higher education, and I believe a large factor contributing to this is the lack of diverse representation in our science curriculum.

Celebrating the achievements of women in astronomy will inspire young women to explore a career in this field. This will be a large focus of my ambassadorship and I am thrilled to continue this important work with Sydney Observatory."

Built in 1858, Sydney Observatory is positioned on the highest point of Warrane (Sydney) and is considered a site of significance for the Eora nation. The Observatory plays a central role in the history of timekeeping, meteorology and astronomy in Australia. For over 160 years, it has led many significant projects, including the creation of New South Wales' first meteorological records and the charting of over 430,000 stars in the southern sky.

SYDNEY OBSERVATORY RESIDENCY PROGRAM
Closing date: 11 October 2021
Applicants can register their interest at maas.museum/sydney-observatory-residency-program
The Sydney Observatory Astronomy Ambassador program is proudly supported by Crown Sydney.

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NSW GOVERNMENT | Museum of Applied Arts & Sciences

NICHOLE BARRY WINNER OF THE "PROMOTING EQUITY AND DIVERSITY" AWARD AT THE ASTRO 3D ANNUAL AWARDS

IMAGE CREDIT: ICRAR

CALLAN WOOD AWARDED THE INAUGRAL JEAN-PIERRE MACQUART MEMORIAL SCHOLARSHIP

ABOVE IMAGE CREDIT: CURTIN MEDIA
Callan Wood being awarded the JP Macquart Scholarship by Sherine Watson

"The inaugural Jean-Pierre Macquart Memorial Scholarship, established in honour of the late Associate Professor Macquart, was awarded to Mr Callan Wood, to undertake PhD research on 'Real-time imaging of jets from accreting black holes'. Mr Wood will be supervised by Professor James Miller-Jones, and will be generously supported by scholarship while undertaking his PhD research."

Science & Technology AUSTRALIA

ABOVE IMAGE CREDIT: Kathryn Ross

STEM PRIDE SCHOLARSHIP

Eleven outstanding STEM professionals from around Australia participated in 2021 Science Meets Parliament. There are 4 categories: Indigenous, STEM Pride, Regional and Technology Scholarships.

CIRA PhD Student Kathryn Ross was awarded the STEM Pride Scholarship and will attend the Science Meets parliament later in 2021.

Alessandro Paduano awarded the best talk at the ICRAR Student Day

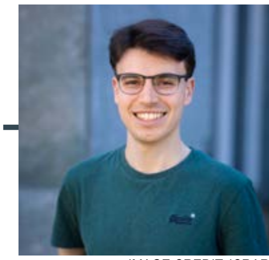


IMAGE CREDIT: ICRAR

BELOW IMAGE CREDIT: Curtin Media

2021 Curtin Research Awards
James Miller-Jones, Clancy James, Danica Scott, Ramesh Bhat, Callan Wood and Jean-Pierre Macquart honoured

TEAM SIRIUS WINS PERTH BIODESIGN

Team Sirius won the judges' prize at the 2021 Perth Biodesign for their monitoring technology that aims to protect our smallest and most vulnerable patients from avoidable injuries associated with peripheral intravenous catheters.

Premature babies rely on intravenous (IV) therapy to receive essential lifesaving treatment, but while IV infusion is necessary it is not without risk of injury caused by unintended leakage of fluid into the surrounding tissue. Current practice largely relies on regular observation by nursing staff to detect leakage, and in these tiny patients the injury can occur very quickly.

From speaking with doctors working in neonatal medicine and having seen first-hand the care needs for premature babies the team saw the opportunity to reduce harm to babies, distress to families and associated health care costs by developing a monitoring device small enough for these tiny patients.

Their aim is for novel use of technology to enable early detection of peripheral IV catheter leakage to help improve patient outcome while freeing up the time of nursing staff.

"The problem we are aiming to solve is very close to home for one of the members of our team and after hearing their stories we felt it was of high clinical need and very worthy of the effort." Oscar Beilin

The multidisciplinary team first met when the Biodesign course commenced in October 2020 and is made up of:

- Cade Trigg, a physiotherapist working in the medical device industry;
- Deepika Gupta, an Orthotist with the WA Department of Health;
- Dr Karen Pedersen, Manager with the WA Department of Health;
- Dr Nipanjana Patra, a Research Fellow at Curtin Institute of Radio Astronomy;
- Oscar Beilin, a Mechanical Engineering master's student at UWA.

Sirius was one of four teams who presented at Tuesday night's Perth Biodesign event hosted by the City of Perth at Council House. Other solutions presented were a digital platform to improve therapy compliance in post-stroke patients with facial palsy, a device to assess the throat in non-compliant paediatric patients, and a novel urinary catheter designed to prevent bacterial infiltration which leads to blockages.

The Perth Biodesign course is a fast-paced, hands-on course for aspiring biomedical innovators and entrepreneurs with a drive to improve healthcare.

ABOVE IMAGE CREDIT: 'STARTUP NEWS'
Team Sirius holding the 2021 Perth Biodesign trophy. L-R Deepika Gupta, Oscar Beilin, Cade Trigg, Dr Nipanjana Patra, Dr Karen Pedersen. Photo by City of Perth
https://startupnews.com.au/2021/05/14/team-sirius-wins-perth-biodesign/

Over 7 months, multidisciplinary teams identify unmet clinical needs during a clinical immersion and invent a medical technology solution, whilst learning about the medical device development and commercialisation process.

Previous winners include VeinTech in 2019 and eMotionGait in 2018. The program forerunner was SPARK Co-Lab, established in 2015 and based off a program with a similar name from Stanford University. It morphed into Perth Biodesign in 2018 which is run by Accelerating Australia, a national consortium of medical and clinical organisations.

The 2021 Perth Biodesign course, administered by The University of Western Australia (UWA), received X-TEND WA grant funding from the New Industries Fund, managed by the Department of Jobs, Tourism, Science and Innovation, and from a consortium of partners including UWA, Edith Cowan University, Curtin University, Murdoch University, Harry Perkins Institute of Medical Research, Telethon Kids Institute, the AMA (WA), and the Perron Institute.

Course co-director, Intan Oldakowska, said that Team Sirius was a deserving winner:

"After 7 months of demanding work, all the teams identified strong unmet clinical needs and presented innovative solutions to address them, so it was incredibly difficult for our judges to choose an overall winner.

The Sirius team identified a great need in an underserved population and has developed a commercially and technically viable technology concept to address this need, with fantastic support from their Alumni Mentor Jacob Petersen and Business Mentor Dr Simon Graindorge."
Intan Oldakowska

The teams presented their ideas to a panel of expert judges including: Ian Brown, Chair of Perth Angels; Dr Kath Giles, CEO of OncoRes Medical; and Dr James Williams, Investment Director at Yuuwa Capital.

FORREST PHD SCHOLARSHIP RECIPIENT PHD STUDENT TYRONE O'DOHERTY

Mr O'Doherty said "he was thrilled to be named a Forrest PhD Scholar by the Forrest Foundation."

"I am looking forward to continuing my studies at Curtin in 2021 and working alongside distinguished researchers for my PhD project. This opportunity will help me to make a real-world impact with my research," Mr O'Doherty said.

CAPTION CREDIT: Curtin Media
IMAGE CREDIT: ICRAR

ABOVE IMAGE CREDIT: Curtin Media
Mia Walker receiving award from PROVOST, Professor John Cordery

Mia Walker

recipient of the 2021 Safety and Health Representative Achievement Award

IMAGE CREDIT: Australian Academy of Science

Associate Professor Cathryn Trott Winner of the Australian Academy of Science Nancy Millis Medal for Women in Science

Teresa Slaven-Blair

Received the Education & Outreach Award at the ASTRO 3D Annual Awards shared with Greg Rowbotham

IMAGE CREDIT: ICRAR

Outreach Coordinator Teresa Slaven-Blair jointly won the ASTRO 3D Supporting Education/Outreach Activities award at the 2021 end of year ASTRO 3D Annual Retreat.

The main retreat was held in the Blue Mountains, but Perth-based members ran a local retreat at the University Club at UWA, as state restrictions meant they could not leave and re-enter WA at the time. The award was voted on by members of ASTRO 3D, and Teresa drew with Greg Rowbotham from ICRAR-UWA for the top spot.

ASA ASM
BEST STUDENT POSTER AWARDED TO
MIKE KRIELE

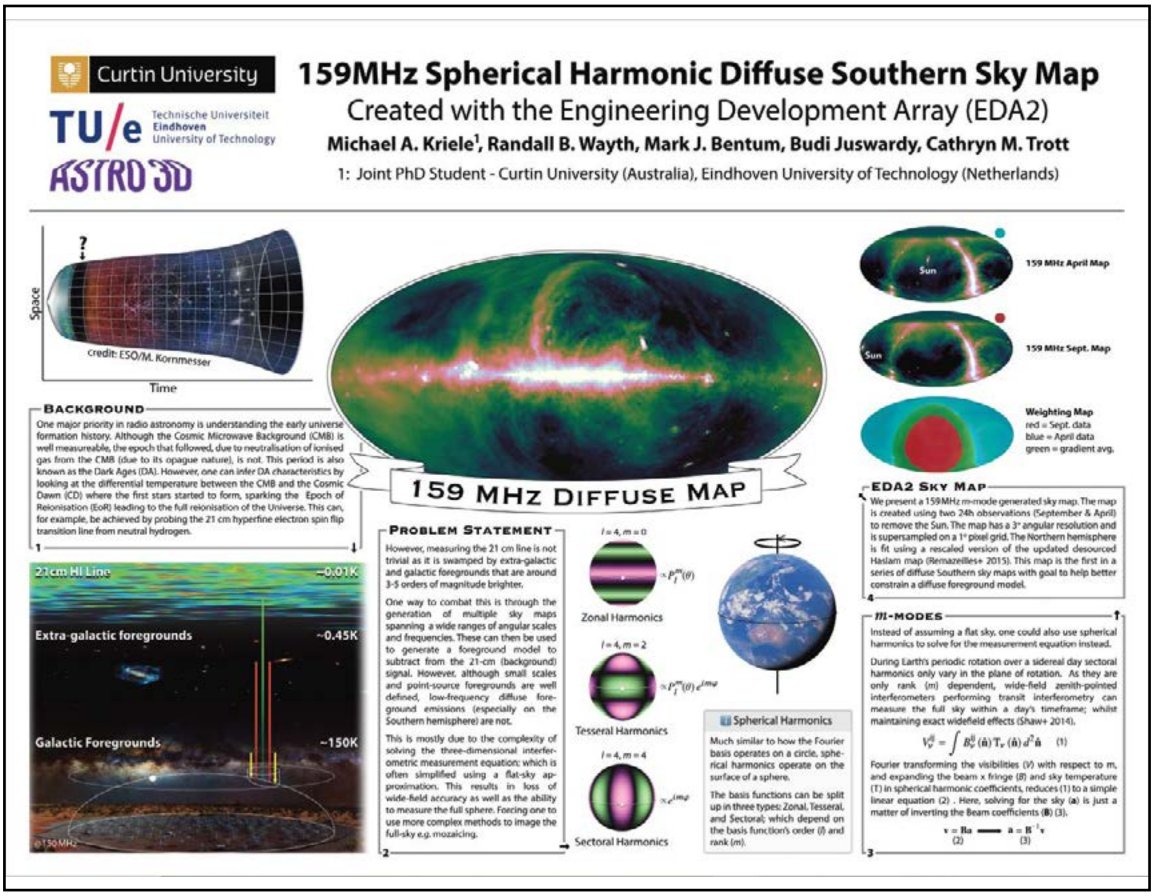


IMAGE CREDIT: Mike Kriele

Defence Science Centre Scholarships
Awarded to
AARON SILVESTRI & SCOTT HAYDON

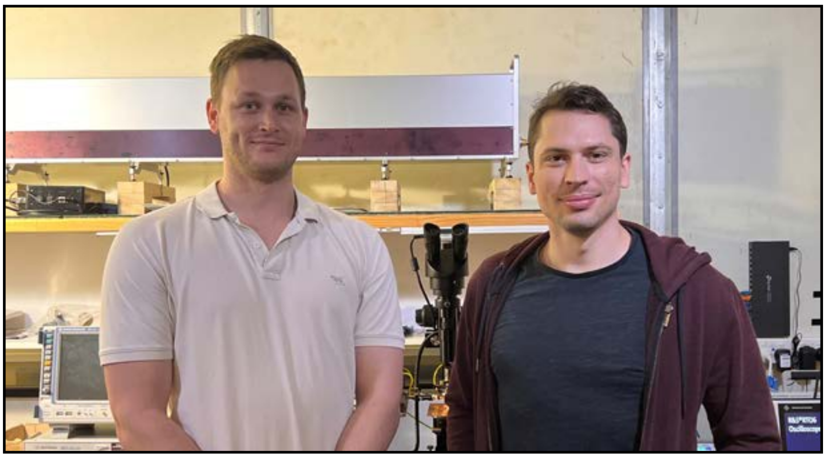


IMAGE CREDIT: Chamila Thrum

Freya North-Hickey, Wayne Arcus,
Clancy James,
Ron Ekers and the late Jean-Pierre Macquart
winners with other non-Curtin
authors of the:

The American Association for the Advancement of Science Newcomb Cleveland Prize

(Most Impactful paper in Journal Science)

IMAGE CREDIT: https://www.science.org/content/page/aaas-newcomb-cleveland-prize

For over a decade, fast radio bursts (FRBs)—flashes of radio emission from distant astronomical sources—have intrigued astronomical observers and the public alike. Most FRBs are extremely fleeting one-off pulses, lasting just milliseconds; making it nearly impossible to precisely localize their origins. Theories abound about the sources of FRBs but without basic information like the distance to their host galaxies, researchers cannot begin to translate their observations into information such as the total energy released in a burst or the environment within which the burst emerged.

Precise astronomical localization requires an interferometer, which in this case involved an array of radio telescopes working in concert to act as a much larger antenna with superior resolution. Further complicating efforts to identify the sources of FRBs, even the best telescopes can only see a very limited fraction of the sky at a time—typically less than 1 deg2, making it highly unlikely that an array will be directed at the correct patch of space to capture an FRB in real time. Bannister et al. present the first-ever precise localization of a non-repeating FRB, made possible by utilizing the Australian Square Kilometre Array Pathfinder (ASKAP) telescope and its phased array feed, consisting of 36 12-m dishes each capable of observing a 30 deg2 field-of-view. This wide field-of-view scans continually in lower resolution with real-time processing to trigger the temporary recording of raw telescope data when a signal of interest is detected. The raw data are of sufficient angular resolution to accurately isolate a host galaxy for a signal source. In essence, Bannister et al. demonstrate how we can achieve high time resolution and high angular resolution in radio astronomy.

Bannister et al.'s identification of only the second host galaxy of an FRB, has revealed stark differences in the astronomical origins of these bursts. These distinct host galaxy types suggest that FRBs have different physical origins, and that we might require multiple explanations for the FRB phenomenon. Bannister et al. also confirm that these phenomena are extragalactic, and therefore extremely energetic.

ARTICLE CREDIT: https://www.science.org/content/page/aaas-newcomb-cleveland-prize

Dr Maria Kovaleva in December 2021 received the Fulbright Future Scholarship (Funded by the Kinghorn Foundation)

IMAGE ABOVE: Dr M. Kovaleva receiving a letter of offer from Consul General David J. Gainer, US Embassy in Australia
IMAGE CREDIT: Maria Kovaleva

Maria will use her Fulbright Scholarship to visit the Radio Astronomy Systems Research Group at BYU in Utah to collaborate with their experts in phased-array antennas and strengthen a research collaboration between Australia and the U.S. The project aim is to develop novel techniques for large-scale phased array electromagnetic analysis that will improve the quality of radio astronomy imaging.

IMAGE CREDIT: ICRAR

Professor Steven Tingay
Awarded a Curtin – CSIRO – Industry PhD Scholarship to work with DUG on processing radio astronomy data.

MANAGING MENTAL HEALTH IN ACADEMIA

Numerous surveys have found that students in academia often suffer high levels of mental health problems. Kat Ross shares her personal experiences and several ways that we can all work together to improve this growing and often debilitating problem amongst our communities.

KATHRYN ROSS
PhD Student

ABOVE IMAGE CREDIT: Sciencemag.org

In 2019 I moved to Perth to start my PhD. Even at the time, I knew this was a big step, and so I took proactive steps to set up a support system for my mental health.

Wow, am I glad I did.

Mere months later I was diagnosed with anxiety. Would this have been discovered if I hadn't taken the initiative to protect my mental health? I will forever be grateful to my past self for taking the early steps to look out for my well being.

Because in 2020 I was also diagnosed with depression.

I was only able to get this diagnosis and help when I needed it most because I already had that support system in place and because I had taken time to choose supervisors I was comfortable discussing these issues with.

The thing is, when talking with academics and people who had or were doing a postgraduate degree, most seemed to personally relate and understand that this was almost 'inevitable' when doing postgraduate research.

Indeed, Nature has completed several surveys of postgraduate students to assess their satisfaction and mental health. The most recent of which, performed in 2019, found 36% of respondents had sought help for anxiety or depression directly related to their studies.

But here's the thing about inevitability: if something is going to happen, that means we know about it. And if we know about it ...We can prevent it.

And if something is preventable then that means someone needs to be in charge of preventing it.

Mental health disorders should not and can not be some kind of permanent requirement of postgraduate students. If mood disorders are so prevalent, then what is currently being done to protect students who are already so vulnerable to issues relating to mental health?

For the most part (at least in my experience), discussions of mental health in academia are surface level. Students are told to "take care of your mental health", but there is never any follow-through on this request. There is no formal system where the mental health of students is assessed and no formal checks to ensure there is sufficient support for them should they need it.

Students are left to flounder and find these resources on their own or rely on having a supervisor who is perceptive enough to notice symptoms of poor mental health. Far too often, poor mental health is left under the radar until it culminates into a much larger problem when it could've been caught and helped earlier.

IMAGE CREDIT: Susmita Sett

Now that it's a new year and many new students are beginning their postgraduate studies. There are several things I would love to see implemented in institutions to aid current and incoming students:

MENTAL HEALTH CHECKS

Most postgraduate degrees have regular "milestones" or checkpoints to mark the student's progress and ensure they are on track to finish on time. It would be so simple to include checkpoints that assess the student's mental health and their access to help and resources needed for them.

COMPULSORY MENTAL HEALTH TRAINING

Mental health issues can be compounded for people in minority groups, for example, it is far more likely for women and people of colour to struggle with Imposter Syndrome. Having supervisors and people in the lab who are not only trained to notice symptoms of poor mental health but also understand how people's mental state can be influenced as a result of their personal history, background, sexual orientation, gender identity etc. can be a game-changer.

OPEN DISCUSSIONS ABOUT MENTAL HEALTH IN INSTITUTIONS

I've had enough of the seminars that tell students to "prioritise sleep", "set healthy work hours" and "practice meditation" while ignoring the toxic institutions that overlook the negative environment for everyone. This may be a long term goal, but I dream of one-day seeing research groups and institutions creating safe spaces for everyone to ask for help and find the resources they need. As part of these changes, we need to also seek advice from, include and incorporate the services of mental health professionals.

2020 was particularly rough for many of us, but poor mental health has been on the rise for students for a long time. Let's start taking immediate and proactive steps to provide targeted mental health support. I hope that we can learn from the last year and head into 2021 wiser and working towards helping students with their mental health.

RESOURCES

If you wish to access resources and support, the following services are available across Australia:

- Lifeline - 13 11 14
- BeyondBlue - 1300 224 636
- Mindspot - 1800 614 434
- QLife - 1800 184 527

Further information, including website links and operating hours about these services (and more), can be found on the Australian Government Health Direct website.

Minister Cook Site visit to the MRO
23RD SEPTEMBER 2021

On The 23rd September 2021 the Minister for State Development, Jobs and Trade; Tourism; Commerce; Science; the Hon. Roger Cook MLA visited the MRO.

"I had the opportunity to see the emerging Square Kilometer Array (SKA) project first hand. The SKA is a global, mulitgenrational 2 billion Euro scientific project, builidng the world's largest radio telsescope in WA and South Africa.

The SKA is one of the world's premiere deep tech initiatives which will help to answer some of our biggest scientific questions by looking back as far as the beginning of the universe.

It's through these mass scale, complex endeavours that we make new discoveries, extend our capabilities and develop new technologies and innovative solutions.

Thanks to Curtin University and CSIRO for hosting and showcasing some of the work that led to WA becoming home to one half of the SKA - including the Murchison Wide Arrand and the Australian SKA pathfinder initiatives."

QUOTE CREDIT: Minsiter Cook's Facebook Page

IMAGE CREDITS: Office of the Hon. Roger Cook MLA

Associate Professor Cathryn Trott Elected as a Deputy Member of the Academic Board

MELANIE JOHNSTON-HOLLITT APPOINTED DIRECTOR OF THE AUSTRALIAN SPACE DATA FACILITY

Associate Professor Cathryn Trott Joins the Australian Academy of Science National Committee for Astronomy

(DEVELOPS THE DECADEL PLAN AND MID-TERM REVIEW)

Executive Director of CIRA
Professor Steven Tingay
&
Director of Operations
Tom Booler
Awarded $250000 of Curtin Strategic funding for MWA Support

CIRA SKA Team sign $2m first contract with the SKA Observatory led by IGO and will attract construction credit for Australia

All involved with AusSRC work and management $680M funding announced by PM. $64.4M over the next 10 years for AusSRC (primarily between CSIRO, UWA, Curtin)

Visualising SKA-Low in 3D Informational Animated Series

MARIA KOVALEVA
Lecturer

DANIEL UNG
Support Engineer

ANDREW BURTON
Business Devlopment Manager

SCOTT BELL
3D Digital Artist

MIA WALKER
Project Officer

CIRA Engineering group has an incredible capability to generate digital twins of SKA-Low antennas and accurately calculate their electromagnetic response in the presence of other antennas taking the mutual coupling into account. Visualisation of an SKA-Low station with its sophisticated arrangement of 256 antennas, RF cables, 24 SMART Boxes sending signals to a Field Node Distribution Hub and otherwise invisible beam patterns is a powerful way of showcasing our engineering capability to various stakeholders – from students and public to the government partners and industry collaborators.

For about six months, Daniel Ung and Dr Maria Kovaleva collaborated with a 3D Digital Artist Scott Bell to create high-quality 3D animated videos about an SKA-Low station and its functionality. Antenna models and their beams were exported from FEKO Altair and remodelled to Blender, and the final video was generated in Unity game engine. To generate an interesting flow of visuals and preserve the technical accuracy, the process required creative thinking, collaboration, self-reflection and a lot of patience from everyone involved. Every single detail had to be discussed, and every sentence in a text box had to be revised dozens of times to find that exact short version that just like a piece of a puzzle contributes to the whole canvas of presentation.

Three episodes of Informational Animated Series are now complete and available to watch on ICRAR Vimeo (https://vimeo.com/icrar). The first episode called “Introduction”, as the name suggests, gives an introduction to the components of an SKA-Low station. Antennas, their locations, Smart boxes and the Field Node Distribution Hub are not artist interpretations, but accurate recreations of the engineering CAD models. The environment of the Murchison Radio Astronomy Observatory was created by Scott from scratch using available photos and videos as references. Episode 1 features "Heart of Thunder" by Vindsvept.

The second episode called “EM Patterns” shows the beams (radiation patterns) of individual antennas and the combined beam. An interested viewer will notice that when an isolated antenna becomes surrounded by many others, its beam no longer resembles the isolated beam. With the mutual coupling, all 256 beams are different, and their shape depends on the antenna location. The main feature of this episode is a station beam, which is formed by the summation of all 256 antennas. This is a highly sensitive radiation pattern with the main lobe pointing to the sky in its neutral position. Episode 2 features "Peaceful Mind" by Astron.

The third episode called “Beam Steering” is dedicated to the concept of electronic beam steering. Due to its inherent technical nature, this episode was the hardest to create, but with the contribution from Mia, it turned out better than we could have imagined. The audience will get an intuitive understanding of how modern aperture arrays work. In the end of the episode, the beam points in arbitrary directions in the sky with a prominent main lobe and low side lobes, as desired. Episode 3 features "The Watchers" by Nigel Stanford.

This initiative resulted not only in a series of animated videos for SKA-Low, but also in Scott becoming a continuing 3D Visual Artist at CIRA. We are looking forward for more exciting 3D visualisations!

IMAGE LEFT: FIG 1 A snapshot from Episode 1 "Introduction"
IMAGE CREDIT: Scott Bell ICRAR – CIRA

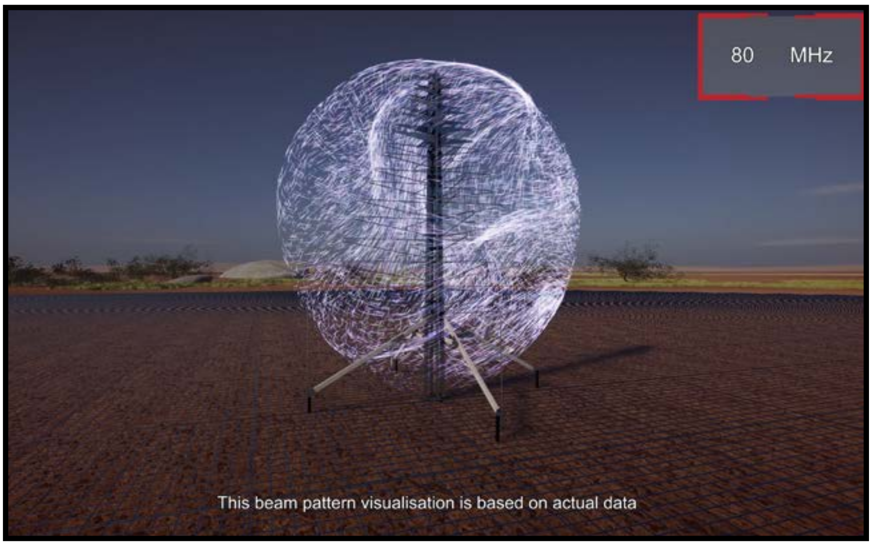


IMAGE RIGHT: FIG 2 A snapshot from Episode 2 "EM Patterns"
IMAGE CREDIT: Scott Bell ICRAR – CIRA

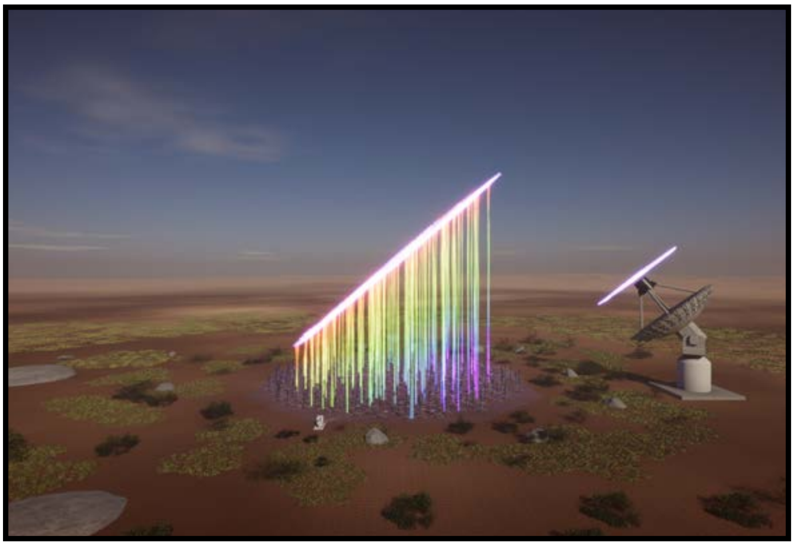


IMAGE LEFT: FIG 3 A snapshot from Episode 3 "Beam Steering"
IMAGE CREDIT: Scott Bell ICRAR – CIRA

IMAGE CREDIT: PROSPERO Productions

"A magical odyssey of discovery of stars, space and time; via the world's largest radio telescope, and our oldest living culture."

"The full dome feature is produced by Prospero Productions in partnership with Yamaji Art and in consultation with internationally renowned astrophysicist, Professor Steven Tingay, joint winner of the Premier's WA Scientist of the Year 2020."

Deep in the Australian Outback, two children, Max Winton and Lucia Richardson, go on a magical odyssey through time and space, exploring the mysteries of the Universe via one of the world's largest radio telescopes and its oldest living culture. In the arid heartland of the Murchison region of Western Australia, Max and Lucia, visit the remote site of the future Square Kilometre Array or SKA radio telescope. There, they learn about the beginnings of time and space and the life cycle of stars. Then through a special door, Max and Lucia enter the ancient land of the Yamaji people where they meet with artist, Charmaine Green. She becomes their guide as they travel through the land of her ancestors and introduces them to other artists and their paintings. The artists share with the children star stories that have been passed on from generation to generation. Max and Lucia discover how much the scientific world and the ancient world have in common, for we all live under one sky, a shared sky.

STAR DREAMING is a 180-degree immersive Full-Dome feature documentary wherein scientists and Indigenous artists reveal the mysteries of the Universe, the stars, time and space. It's a relatively unknown story that one of the biggest mega-science projects in the world is happening right here in WA!

Deep in the Murchison, on the land of the Yamaji people, is the Australian site for one of the world's largest radio telescopes - the Square Kilometre Array (SKA). The state-of-the-art SKA radio telescope has been decades-in-the-planning and once complete, will be able to pick up radio waves that have taken billions of years to get to Earth. It will allow scientists to look back further into the Universe than ever before.

Indigenous Australians have gained meaning from the stars for over 60,000 years, making them some of the oldest astronomers on earth. STAR DREAMING is an art-meets-science-collaboration for all ages.

The movie is a breathtaking journey through science and Aboriginal culture; fusing live action with cutting-edge CGI technology and astrophysics, featuring animated Indigenous artworks and graphic recreations of the constellations. The film is narrated by one of Australia's best known and most loved performers, and Yamaji man, Ernie Dingo.

"STAR DREAMING is a bold concept and a very unique viewing experience, telling a story that hasn't been told this way before," said writer and producer Julia Redwood.

"This movie will be screening across Australia and around the world – at planetariums and museums. STAR DREAMING will put the WA outback, our Indigenous culture and their amazing art, and this Western Australian science success story – in front of eyes on a global scale," she said.

Director, Perun Bonser said: "It's been an honour to collaborate with Prospero and Yamaji Art, and I'm excited for the premiere of my debut feature in the dome at CinefestOZ, and beyond. STAR DREAMING is a must-tell story, and I look forward to see how audiences resonate with the movie."

Yamaji artists including Margaret Whitehurst, Wendy Jackamarra and Charmaine Green, as well as Barbara Merritt and Kevin Merritt are featured in the documentary, alongside their artwork of famous star patterns such as the Seven Sisters, the Jewellery Box and one of the most important star stories to the Yamaji people – the Emu in the Sky.

"Many of our stories get handed down from generation to generation and are important to us as they tell us about our lore, culture, social structures and important hunting seasons. Stories and information that we will still use today," said Yamaji Elder, Kevin Merritt.

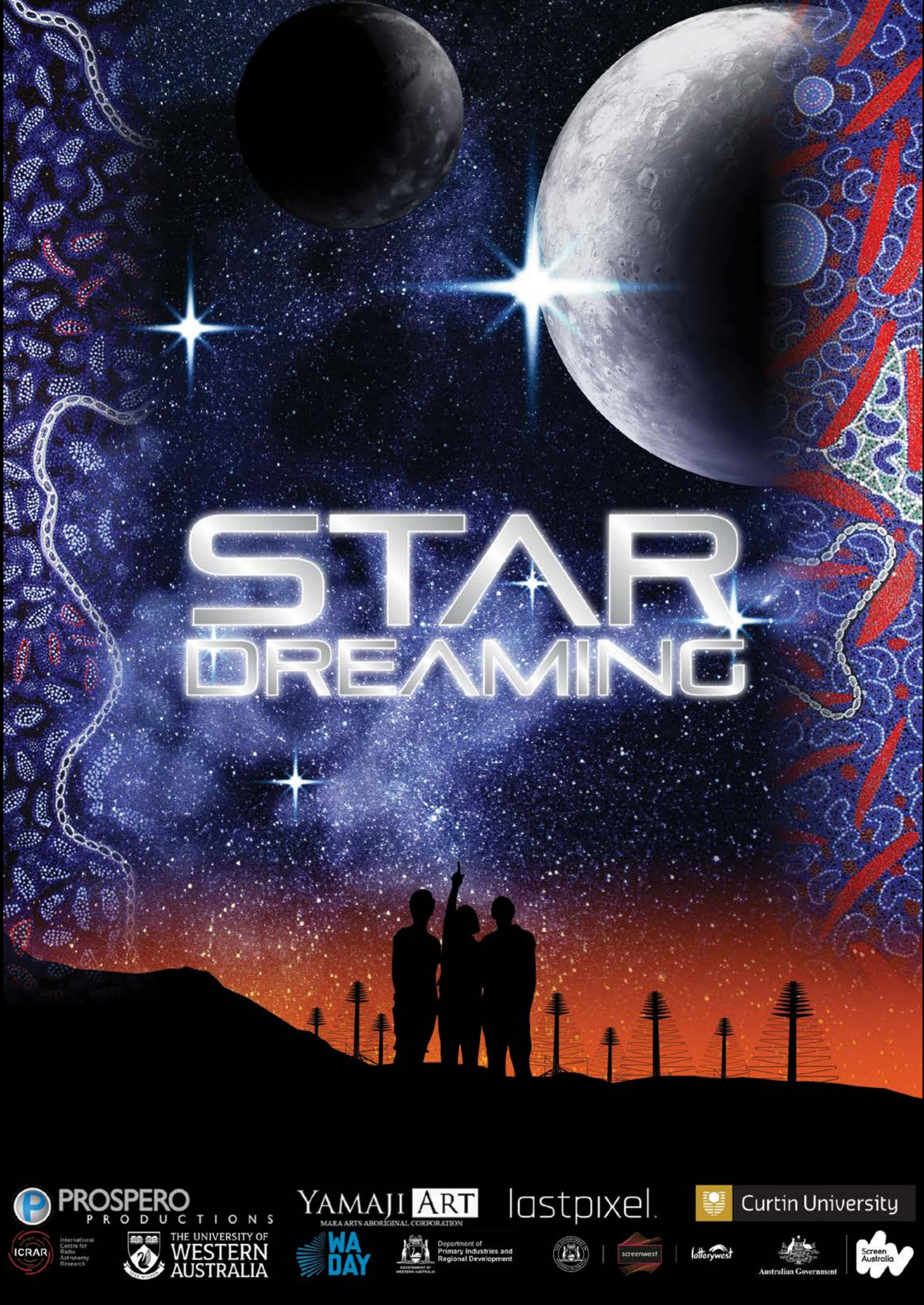
Internationally renowned astrophysicist, Professor Steven Tingay has worked alongside Yamaji Art for the last decade, exploring Indigenous and non-Indigenous views of the Universe and the human stories that connect us all to the night sky.

"STAR DREAMING extends my collaboration with Yamaji Art, taking our unique relationship to a new format and to new audiences, which is extremely exciting. We can't wait to bring our stories to the world, with the world's most advanced telescope, the SKA, as the background," said Professor Steven Tingay.

In addition to director, Perun Bonser, the filmmaking team consists of producers Julia Redwood and Jules Fortune in collaboration with Yamaji Art in Geraldton and in consultation with Professor Tingay, in his role as Deputy Executive Director of the International Centre for Radio Astronomy Research (ICRAR) at Curtin University. Director of Photography is Michael McDermott ACS and Executive Producers are Julia Redwood, Jules Fortune, Ed Punchard and Ian Booth.

ARTICLE CREDIT: PROSPERO Productions Media Kit

IMAGE CREDIT LEFT: PROSPERO Productions
DESIGNER: Darryl Bellotti
EMU IN THE SKY ARTWORK: Margaret Whitehurst


STAR
DREAMING
PROSPERO PRODUCTIONS
YAMAJI ART
MARA ARTS ABORIGINAL CORPORATION
lastpixel.
Curtin University
ICRAR
International Centre for Radio Astronomy Research
THE UNIVERSITY OF WESTERN AUSTRALIA
WA DAY
Department of Primary Industries and Regional Development
screenwest
lotterywest
Australian Government
Screen Australia

BEYOND THE MILKY WAY

IMAGE CREDIT : Natasha Hurley-Walker
BELOW TOP IMAGE:Natasha Hurley-Walker & Associate Professor Cathryn Trott at the launch of Beyond the Milky Way Boola Bardip Museum
BELOW MIDDLE IMAGE: Natasha Huley Walker holding a lamp at the MRO
BELOW BOTTOM IMAGE: Assoc Prof Cathryn Trott filiming at the MRO at dusk

ASSOCIATE PROF CATHRYN TROTT
Associate Professor

DR NATASHA HURLEY-WALKER
Senior Lecurer & ARC Future Fellow
PhD Student

In 2021 Assoc Prof Cathryn Trott and Dr Natasha Hurley-Walker joined White Sparks Pictures to film a Virtual Reality (VR) documentary about the Murchison Radio Astronomy Observatory. We had five days of very early starts and late evenings, filming when the low sun sets the antennas ablaze with colourful light. Most enchanting was the opportunity to film at night.

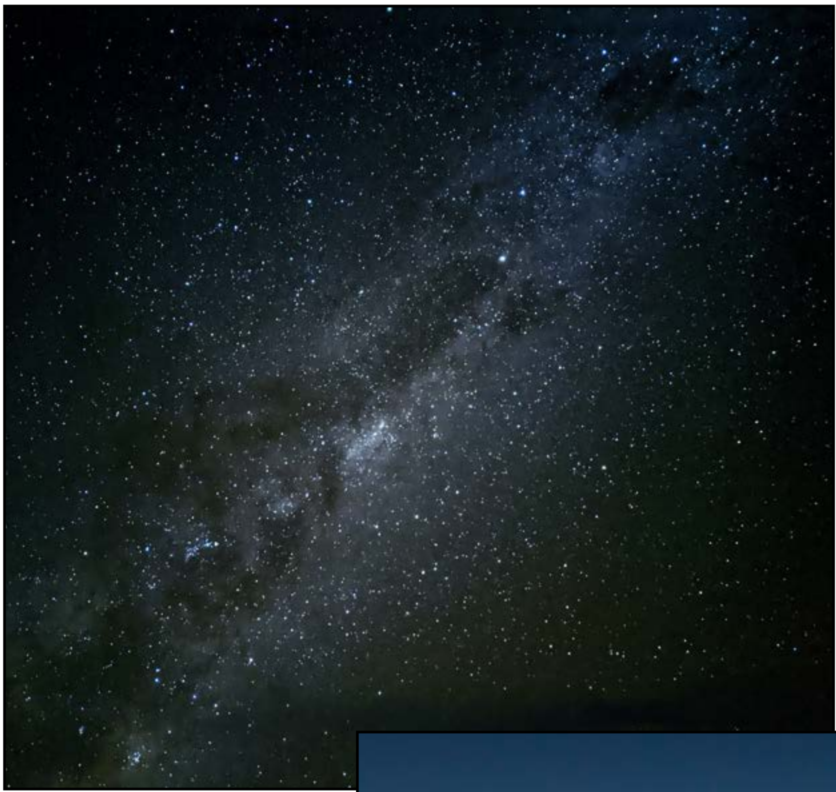
At one point we switched all artificial lights off to calibrate the cameras, and the moonless sky was absolutely breathtaking, with the Indigenous constellation of the Emu reaching from the horizon to over our heads. Filming in the glow before dawn was accompanied by only the sound of the wind.

The documentary premiered at the WA State Museum Boola Bardip, and featured the MWA's impressive wideband and widefield capabilities. It also showcased the SKA prototype antennas, which glowed in the dawn light.

Cathryn described the Square Kilometre Array antenna design, and how it was tuned to detect evidence of the first stars from the Cosmic Dawn.

Natasha also spoke about the GaLactic and Extragalactic All-sky MWA (GLEAM) survey. The VR experience gives viewers the sensation of floating in the radio sky, allowing them to look around as if they really were seeing with radio eyes.

The documentary was very popular, and due to demand was extended from a run of two months to three, before going on tour internationally.



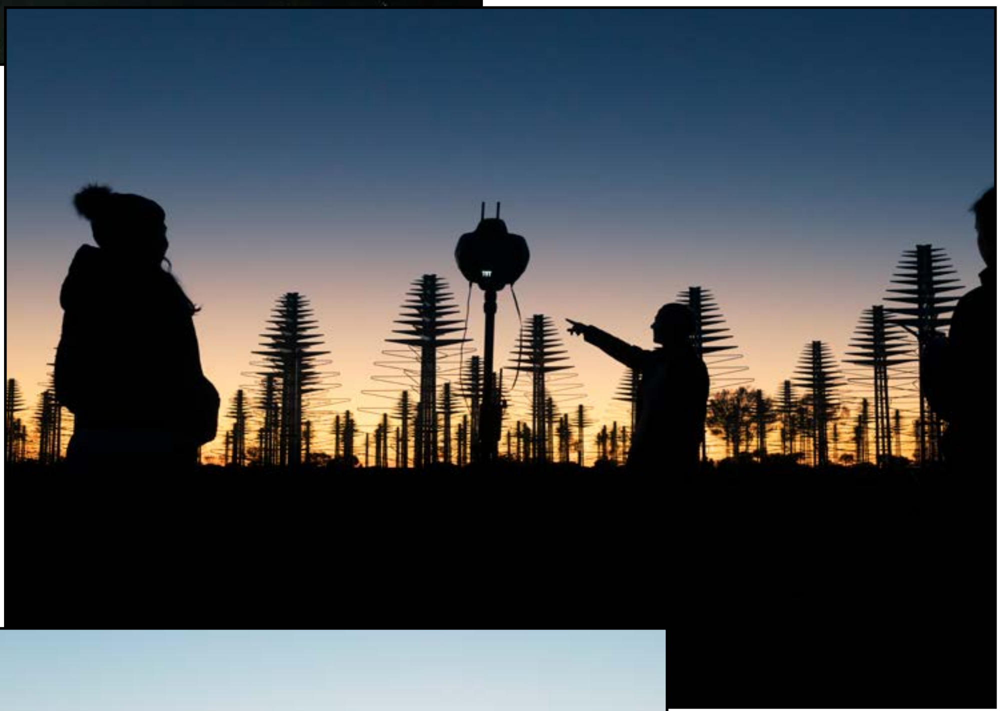


IMAGE CREDIT: Natasha Hurley-Walker
TOP IMAGE: The Emu in the Sky as seen from the MRO
MIDDLE IMAGE: White Sparks Production Team setting up for dusk filming
BOTTOM IMAGE: Natasha Hurley-Walker filming with the White Sparks crew.

The Hidden Universe Discover the SKA

FILMED BY: BRIGHT SPARKS MEDIA

HOSTED BY
KATHRYN ROSS
PhD Student

Throughout 2021, several researchers were filmed for the documentary episode "The Hidden Universe: Discover the SKA" with the production team at Bright Sparks Media.

The Hidden Universe was a fabulous showcase of the ground-breaking research being conducted at CIRA and the role it will play with the SKA. I was lucky enough to be a host for this documentary and talk about several exciting research areas including the Epoch of Reionisation and the design of the MWA, all from the beautiful outback location at the MRO.

Several CIRA staff were featured including Associate Professor Trott and Professors Johnston-Hollitt and Tingay, each highlighting exciting research areas. The final documentary was a huge success, aired on Channel 7 in early January 2022, and a perfect representation of the diversity of topics expertise based here at CIRA.

IMAGE ABOVE: Kathryn Ross at a home viewing of "The Hidden Universe"
IMAGE CREDIT: Kathryn Ross

IMAGE ABOVE: Kathryn Ross hosting and being filmed for "The Hidden Universe" documentary by Bright Sparks Media
IMAGE CREDIT: Kathryn Ross

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