



International
Centre for
Radio
Astronomy
Research

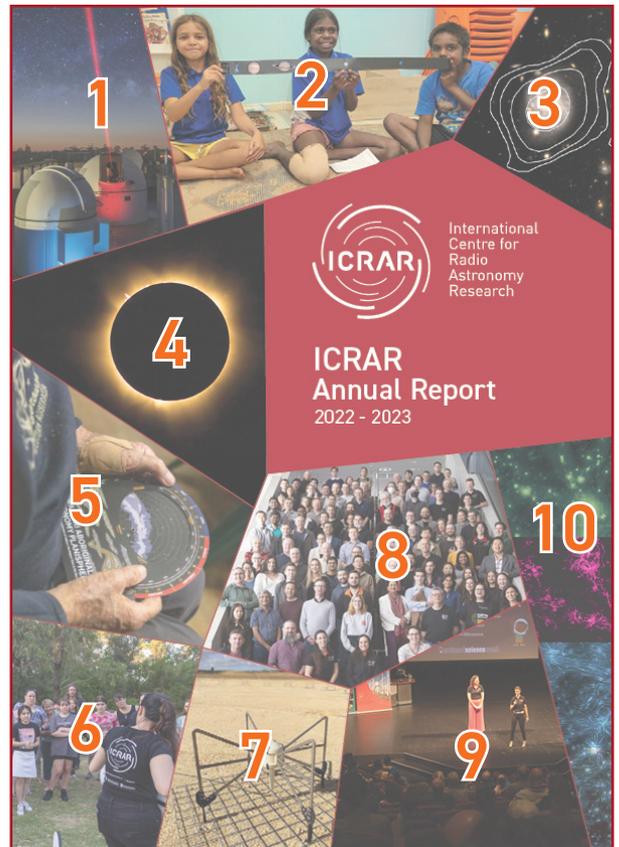
ICRAR Annual Report 2022 - 2023

national science week

ICRAR Annual Report

Cover Images

- 1 Artist's impression of a free-space optical communications terminal developed at ICRAR/UWA.
Credit: ICRAR.
- 2 Students at One Arm Point Remote Community School participating in an ICRAR school program during an outreach tour of the Kimberley & Pilbara.
Credit: ICRAR
- 3 A previously unobserved 'calm' Fast Radio Burst, detected by Dr Marcin Glowacki (ICRAR/Curtin) and team using the ASKAP radio telescope.
Credit: Glowacki et al.
- 4 The 2023 solar eclipse, as observed from Exmouth.
Credit: ICRAR.
- 5 A Wajarri planisphere, showing Yalibirri, the great Emu in the Sky, featuring art by Wajarri artist Judith Anaru, and produced by ICRAR with the help of Leonie Boddington, Bindiyarra Irra Wangga, Callan Bindo and the Wajarri Community Elders.
Credit: ICRAR/Judith Anaru.
- 6 Attendees at ICRAR's Stargirls STEM camp learn how to use a telescope from Outreach team member Leah Kalimeris.
- 7 An antenna from the Portable Space Domain Awareness System, developed from MWA radio telescope technology by ICRAR/Curtin, used to silently track satellites in Earth's orbit.
Credit: ICRAR.
- 8 The entire ICRAR family at the first ICRAR-con since 2019.
- 9 Dr Kat Ross (ICRAR/Curtin, left) and Dr Sabine Bellstedt (ICRAR/UWA, right) present 'From Eyes To Glass To Aluminium', ICRAR's flagship 2022 National Science Week event.
Credit: ICRAR
- 10 Stacked radio images of gas clouds (top), shock waves (second top), and magnetic fields (second bottom), reveal a new way of looking at the cosmic web (bottom) - the largest structure in the universe - assembled by Dr Tessa Vernstrom and team from ICRAR/UWA.
Credit: Vernstrom et al.



Acknowledgement of Country

Kaya! Wandjoo!

Hello! Welcome!

We acknowledge that Aboriginal and Torres Strait Islander people are Australia's first astronomers. We acknowledge their long-standing systems of knowledge on which we continue to build, and we acknowledge the Traditional Custodians of the unceded lands on which we are meeting today.

We are on Wajuk Noongar boodja, Wajuk Noongar country, and we pay our respects to their Elders past and present, and extend that respect to all First Peoples.

We acknowledge the Wajarri-Yamaji people who are traditional custodians of the land on which the MRO is sited.

INTERNATIONAL CENTRE FOR RADIO ASTRONOMY RESEARCH (ICRAR)

Annual Report Highlights

The following extract, from the ICRAR 2022 - 2023 Annual Report, contains a selection of highlights as they relate to ICRAR's Project Objectives and Outcomes.

ICRAR HIGHLIGHTS

Impact

- ICRAR's excellence in research, research training and building capacity in WA continued in the reporting year. With 96 enrolled postgraduate students and 158 staff. ICRAR supported job creation in the State through sustaining ICRAR's core employment and enhancing employment opportunities through translation and impact activities, additional competitive grants won, and by visits of national and international collaborators to WA.



Figure 1: ICRARCon 2023

ICRAR Staff and Students 2009-2023

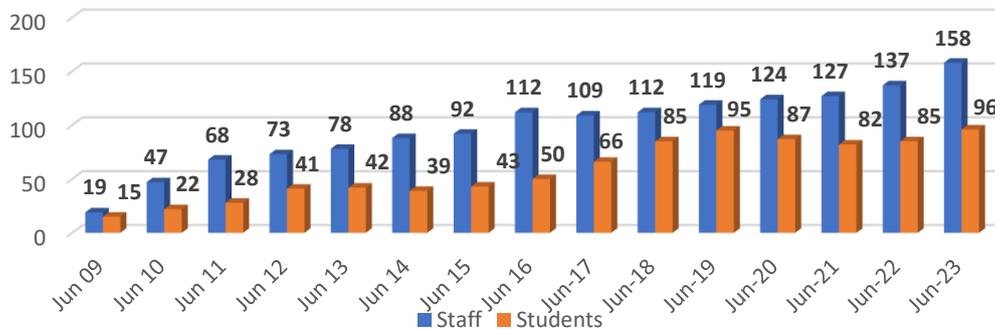


Figure 2

- The ICRAR postgraduate program continued to grow in strength after the challenges experienced during the COVID-pandemic. The program contributed to skills and expertise development in WA and added to the diversity of trained personnel in the State. 69 PhD and 27 Masters students are currently enrolled, with 31% of these being international students (19 nations), attesting to the excitement generated by radio astronomy and the high-impact science done by ICRAR. There was a significant increase in enrolments for the Master of Physics astronomy and astrophysics program, which doubled compared to pre-pandemic numbers, due to a significant increase in the number of international students. In this year, 18 students completed, including 12 PhD and six Masters students, creating a pipeline of critical capability for the WA economy and beyond. In addition to these, two Honours students also completed.

ICRAR HIGHLIGHTS

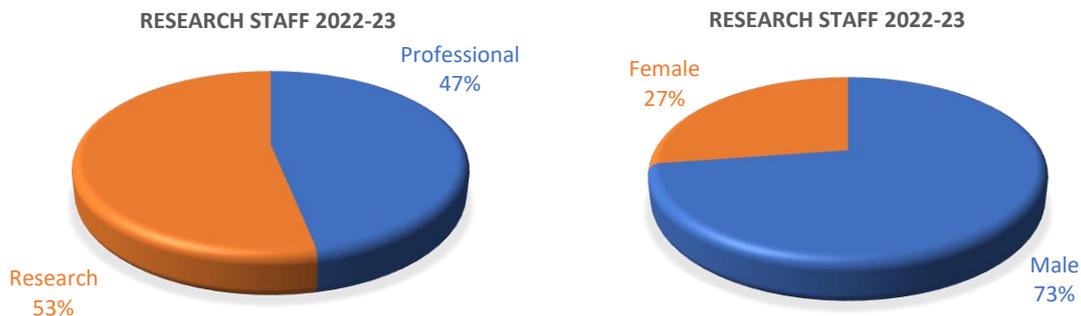


Figure 3

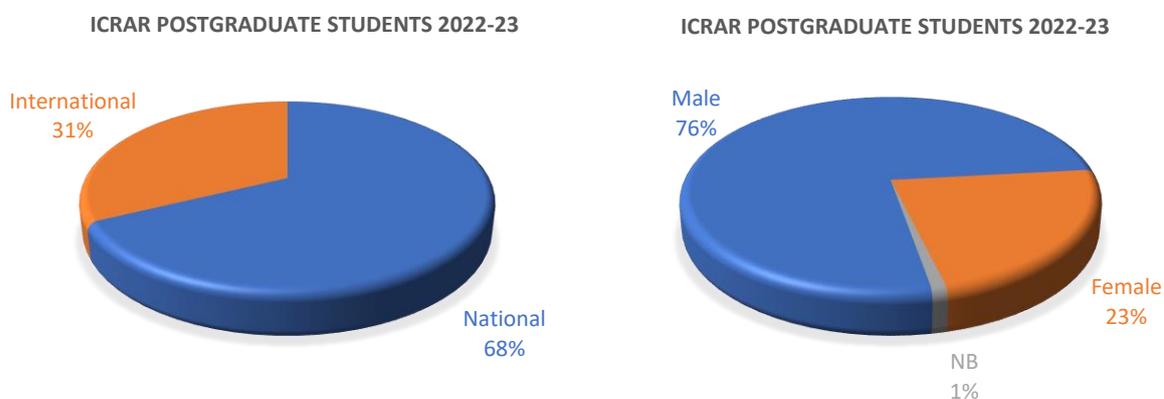


Figure 4

- ICRAR's excellence in science and technology was evidenced through 294 refereed publications including one in *Nature*, four in *Nature Astronomy* and one in *Nature Scientific Reports*. ICRAR published in high Impact Factor (IF) journals; 96% of the publications were in journals with an IF >3.0. 77 of the papers had ICRAR lead authors and 27 were led by PhD students. ICRAR publications have now attracted 113,000 cumulative citations. ICRAR collaborated globally as evident from the 85% of papers published with international co-authors. The top five collaborating countries were the USA, the UK, Germany, the Netherlands, and Italy.

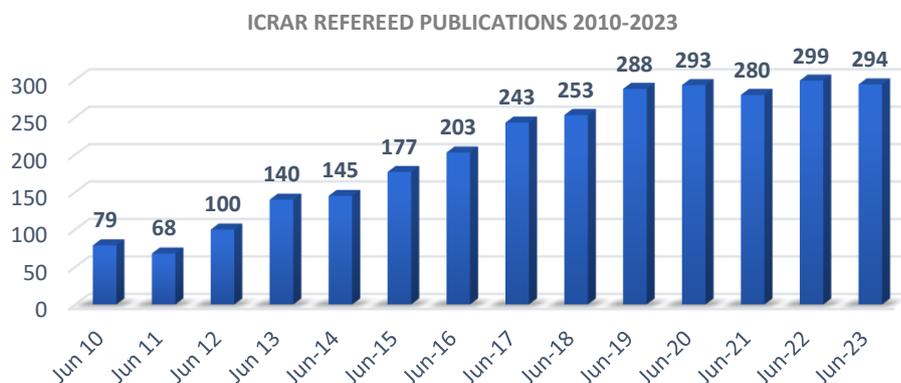


Figure 5

ICRAR HIGHLIGHTS

- ICRAR supported the Science, Technology, Engineering and Maths (STEM) agenda of WA and continued to develop the next generation of scientists and engineers. ICRAR staff contributed to 33 units of undergraduate and coursework teaching, delivered to 1,096 students in 2022-23, and ranging from Physics and Astronomy to Data Science, Computing, Mathematics and Statistics. Since 2009, ICRAR staff have taught 9,840 undergraduate and coursework students. ICRAR-Curtin staff contributed to a large third-year engineering unit ELEN3002, offered to students at overseas campuses in Malaysia and Sri Lanka. This year saw ICRAR-Curtin staff teaching into the Statistics discipline for the first time, providing ICRAR an opportunity with a link to a different group of students with a valuable skill set, some of whom could potentially go on to do project work at ICRAR. In addition, the staff also supervised two honours project students, 16 third-year undergraduate project students in Physics/Astronomy, and 17 final-year project students in Electrical Engineering. ICRAR students entered a range of professions, including academia, industry, and government. ICRAR staff also supervised undergraduate students across a range of summer programs, third year and Honours projects, providing students with a meaningful introduction to radio astronomy research and engineering, and providing training in data science, which can be applied to a range of fields, both in academia and in industry. Summer studentships at ICRAR provided an excellent opportunity for undergraduate students to experience cutting edge research in Australia. The latest ICRAR interns, eight students of diverse genders from around Australia and New Zealand, worked at ICRAR over 10 weeks in the Summer of 2022-2023. They studied diverse areas including using machine learning to find pulsars or to predict waves off the WA Coast, to looking for monster black holes or binary pulsars. 50% of the ICRAR summer internships were co-funded by Pawsey. Work experience opportunities were provided to Year 10 and Year 11 students to join ICRAR researchers and outreach & education staff for a high impact week of learning about astronomy, engineering, and data science as a career in WA.

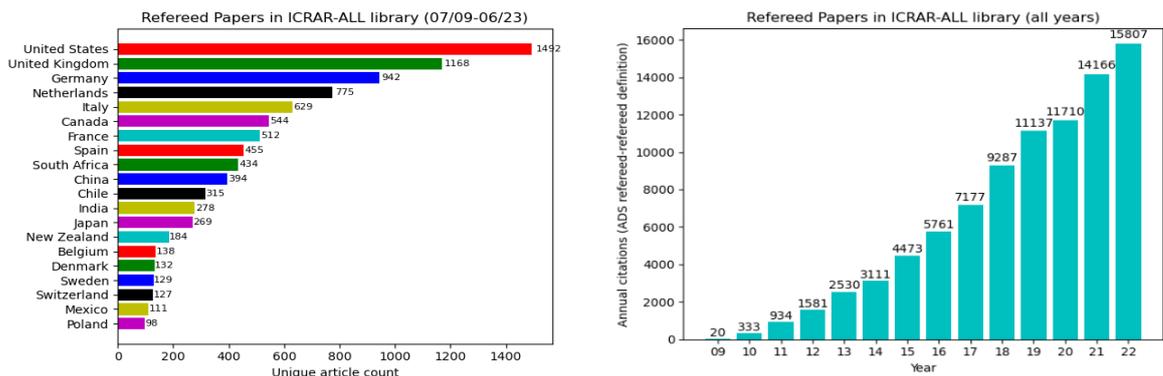


Figure 6

- ICRAR leveraged the State and Joint Venture (JV) funds by winning additional external grants and contracts worth \$25.7M in 2022-23 and \$49.7M from July 2019 to June 2023, with ICRAR III achieving 123% of ICRAR KPI of \$40M over the five-year period. Nearly 85% of these grants were won from outside of WA, benefitting and diversifying the WA economy. The value of additional grants and contracts from 2009 to 30 June 2022 is \$137.2M.

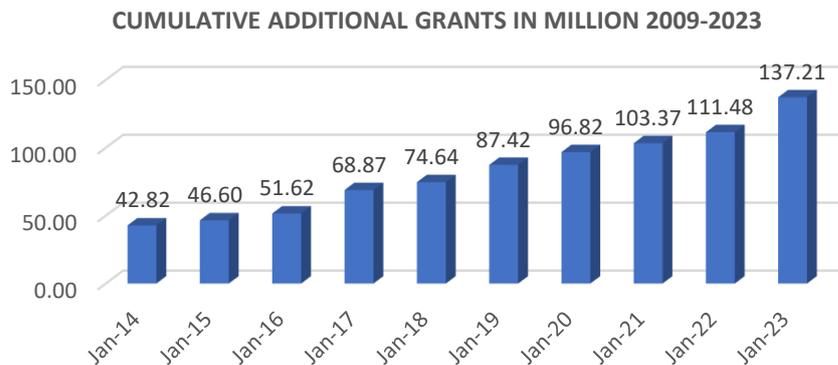


Figure 7

ICRAR HIGHLIGHTS

ICRAR III CHANGING PROFILE OF LEVERAGED INCOME (\$M) FROM RESEARCH, T&I AND SKA

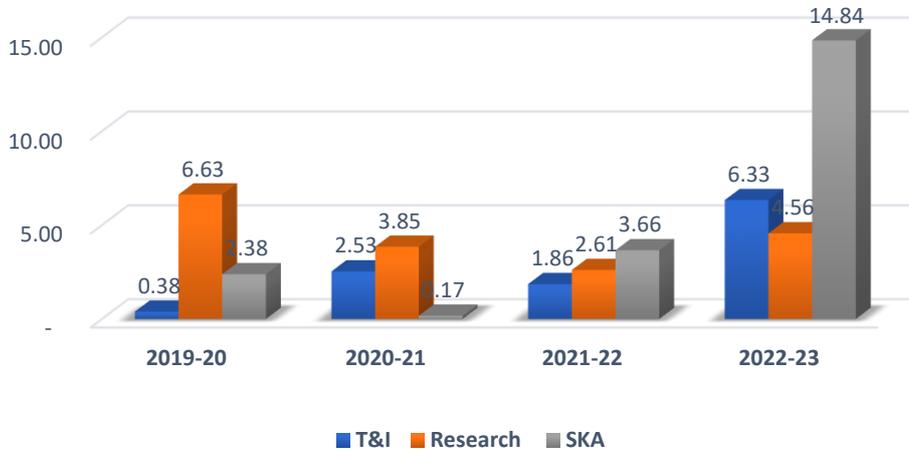


Figure 8: The Leveraged Income represents the total amount of the grants won/awarded in the respective year. The entire amount of the grant could either be received in a single year and/or received over a few years. The chart outlines ICRAR’s success in leveraging the State grant through securing non – State Government funding and increasing the proportion of revenue generated through translation and impact activities.

ICRAR contributed to the SKA construction as the sole source provider appointed by the SKA Organisation (SKAO) for the Software Development contract, and for the SKA-Mid Phase Synchronisation System to design, manufacture, install and commission an operational reference frequency distribution system for the SKA-Mid Telescope. These contracts were valued at around \$7.2M and \$12.5M respectively. A third contract with the SKAO was for the design and construction of a prototype SKA-Low Power and Signal Distribution system delivered this year, retiring a significant technical risk to the SKA-Low. The contract was worth \$3.2M and was also used to fund ongoing support of the Aperture Array Verification System (AAVS).

ICRAR had a professional services sub-contract to manage planning for Low Station Delivery. ICRAR staff also actively contributed to SKA committees/working groups with responsibility for SKA planning, SKA Regional Centres (SRC), and SKA Science Working Groups (SWG). A detailed list can be seen in **Appendix A**.



Figure 9: (Left) SKA-Mid Signal Engineering Team (Right) PasD Prototype.

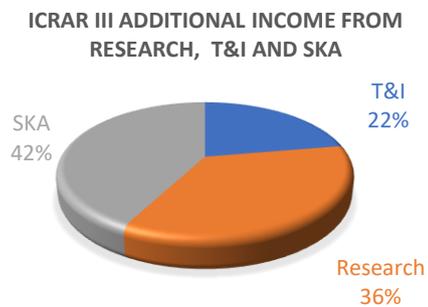
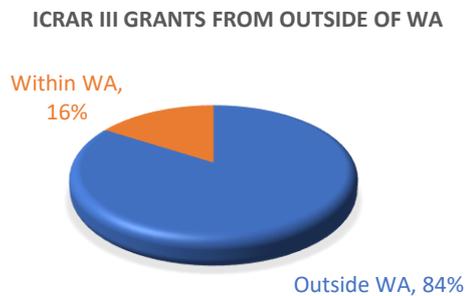


Figure 9

ICRAR HIGHLIGHTS

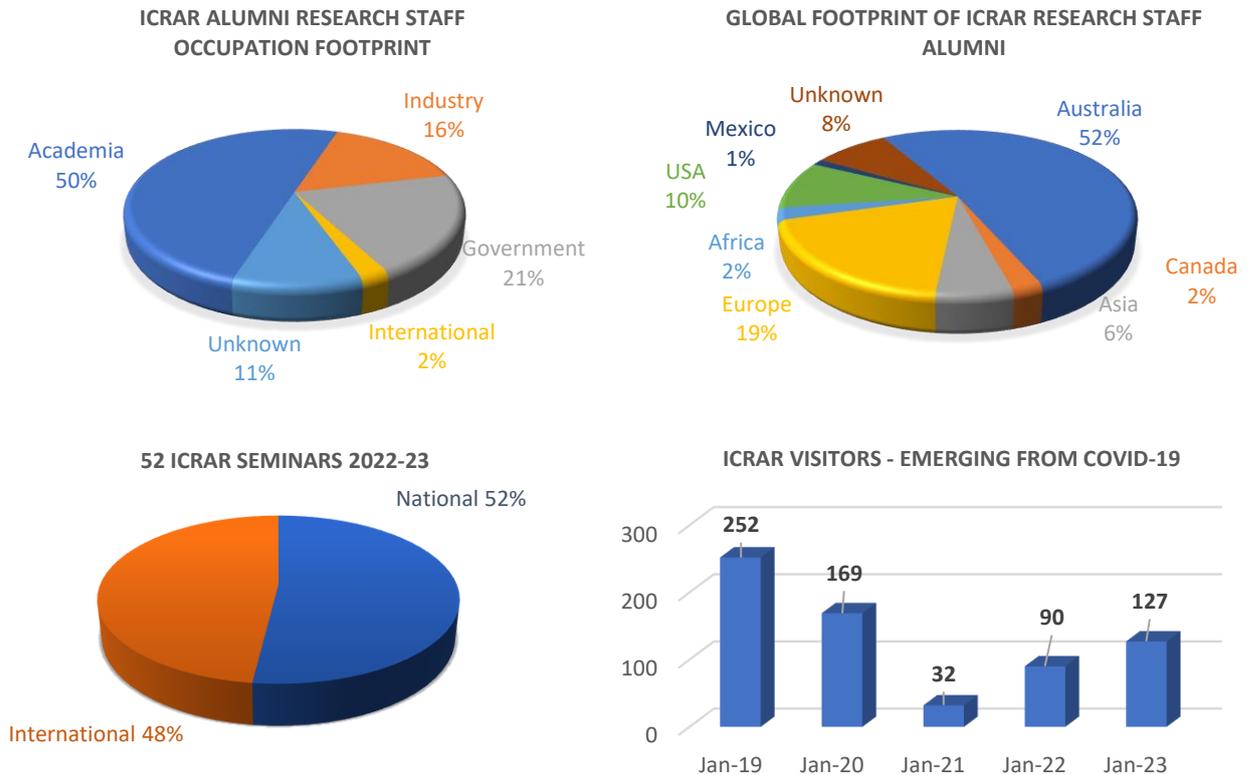


Figure 11

- ICRAR worked collaboratively with CSIRO, Pawsey and other organisations, through joint appointments, training activities, involvement in SKA construction activities, the Australian SKA Coordination Committee (ASCC), and ASKAP full survey projects, which commenced in late-2022.
- ICRAR continued to proactively support the establishment of the \$63M Australian SKA Regional Centre (AusSRC) effort with CSIRO, Pawsey, Curtin and UWA being the JV partners.
- ICRAR continued its focus on providing an enabling environment for research and innovation. Over 120 collaborators from 14 countries visited ICRAR, and 52 seminars were delivered by collaborators from eight countries and 30 organisations. 48% of seminars were presented by international speakers, with female researchers presenting 31% of these seminars.

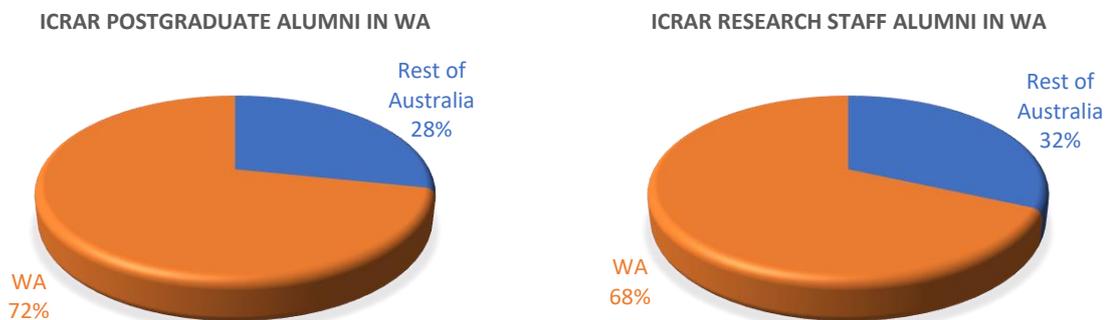
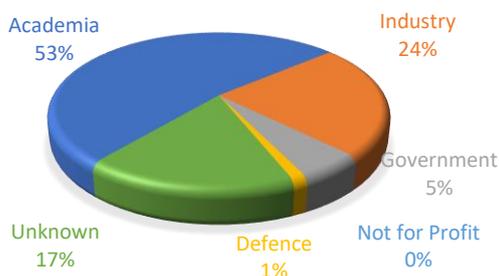


Figure 12

ICRAR HIGHLIGHTS

- ICRAR-trained researchers, including research staff and postgraduate students, are global ambassadors of WA. They are an important resource for expanding and enhancing the skills base, capability, capacity, and job diversity in WA and beyond. Based on information available, ICRAR's 169 alumni postgraduate students are working in 19 countries, with 53% in academia, 24% in industry, and 5% in Government and 17% unknown. 58% of postgraduate alumni are in Australia with 72% of these in WA, adding to the skills base and advancement of the WA economy.
- ICRAR's 86 research staff alumni are working in 16 countries, with 50% in academia, 16% in industry, 21% in government jobs and 11% yet to be tracked. 50% of these are in Australia, and of that, 68% are in WA. ICRAR has made substantial contribution and added significantly to the highly trained skills base of WA and enriched its job diversity.

ICRAR POST GRADUATE ALUMNI OCCUPATION FOOTPRINT



GLOBAL FOOTPRINT OF ICRAR POSTGRADUATE ALUMNI

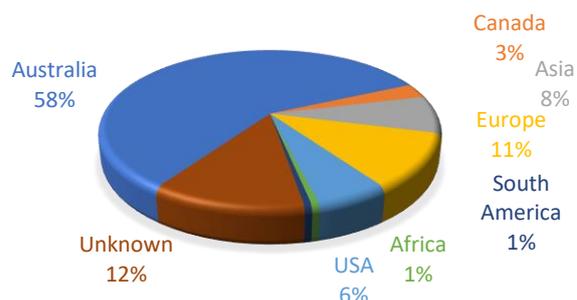
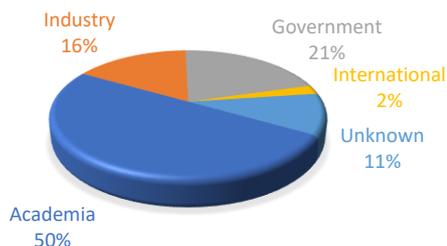


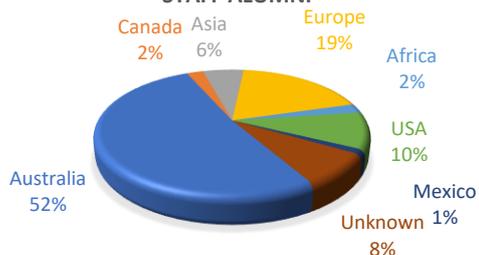
Figure 13

- ICRAR Translation and Impact (T&I) enabled and supported 62 collaborative projects and opportunities across both nodes. These projects enabled the translation of radio astronomy-related expertise and capability for impact in WA's Space, Defence, Data, Marine, and Manufacturing industries. Highlights of some of these project activities can be seen in the Translation Section of this report and the details can be seen in the attached Appendix A.

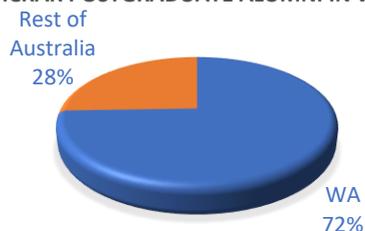
ICRAR ALUMNI RESEARCH STAFF OCCUPATION FOOTPRINT



GLOBAL FOOTPRINT OF ICRAR RESEARCH STAFF ALUMNI



ICRAR POSTGRADUATE ALUMNI IN WA



ICRAR RESEARCH STAFF ALUMNI IN WA

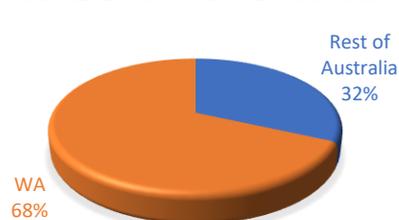


Figure 14

ICRAR HIGHLIGHTS

- ICRAR's Communication, Education and Outreach (CE&O) team travelled to various parts of WA, including regional communities, to deliver astronomy-themed events and programs for 155 schools with activities that engaged over 3,000 learners. The team reached over 8,500 community members and travelled hundreds, or in some cases, thousands of kilometres to outback Australia, to engage with remote and Indigenous communities to support the STEM agenda of WA and ICRAR. The team worked collaboratively with SciTech, Perth Observatory, WA Museum Boola Bardip, Astrotourism, Astronomy WA, Deadly Science, and other agencies.
- ICRAR actively contributed to supporting the women in STEM agenda of WA. ICRAR hosts a visiting fellowship for senior women astronomers and ICRAR staff led University and Faculty level initiatives in this area. ICRAR-UWA won the Astronomical Society of Australia's Gold Pleiades award for excellence in its diversity, equity, and inclusivity initiatives. Since 2009, four ICRAR female staff have won highly prestigious Science and Technology Australia's Superstars of STEM fellowships.

Research Excellence

- ICRAR's researchers collaborated globally to publish 294 refereed scientific papers, spanning a wide range of topics within radio astronomy, engineering, and Data Intensive Astronomy (DIA), and conducted impactful and innovative science with both the SKA precursor facilities, and a range of other leading radio telescopes from around the world. These are paving the way for the science that will be done with the SKA.
- Key impactful publications included details of a new measurement of the Hubble constant (determining the expansion rate of the Universe) using the short-lived, energetic events known as Fast Radio Bursts (FRBs); the description and initial data release for the low-frequency southern hemisphere sky survey conducted by the Murchison Widefield Array (MWA) (known as GLEAM-X), which will provide the community with valuable and widely-applicable scientific data, and will help underpin initial sky models for the SKA; analysis of the second data release from the international pulsar timing array, which showed tentative evidence for a signal from the long-sought gravitational wave background; and a possible association between a gravitational wave signal from merging neutron stars and a FRB, which if confirmed, would unify two exciting fields in astronomy.
- The ICRAR science team reached significant milestones in the scientific exploitation of the Australian precursor telescopes of the Square Kilometre Array (SKA), ASKAP and MWA. The WALLABY team made available to the scientific community its first data release, providing atomic hydrogen maps obtained with the ASKAP telescope for hundreds of galaxies, covering 180 square degrees of the observable sky — the equivalent area of over 700 full moons. Observations with the MWA, as well as other radio telescopes, have allowed ICRAR researchers to detect for the first time, the radio emission coming from shock waves traveling through the cosmic web. These works provide a knowledge base for the full exploitation of ASKAP surveys, started in late-2022, and prepare the way for SKA-Mid and SKA-Low scientific exploitation.

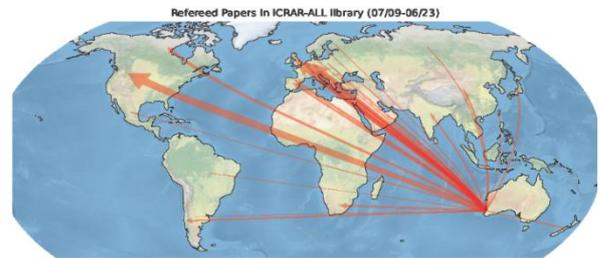


Figure 15



Figure 16: As gravitational waves warp spacetime around Earth, they distort the arrival times of radio waves from distant pulsars. OzGrav / Swinburne / Carl Knox

ICRAR HIGHLIGHTS

- ICRAR added to the esteem and prestige of WA as the scientific achievements of ICRAR staff were recognised via a number of high-profile national and international awards, demonstrating the impact that their work is having both within and beyond the scientific community. Simon Driver was awarded a highly coveted Australian Research Council (ARC) Laureate Fellowship. Connor Bottrell was awarded a Forrest Foundation Fellowship. William MacDonald was awarded the Astronomical Society of Australia Bok Prize for the best Master's thesis; Andrew Sullivan was awarded the Australian Institute of Physics prize for best Honours thesis and Andrei Ristea won the UWA Postgraduate Student Association prize for the best scientific talk. PhD student Kathryn Ross was named joint winner of the ExxonMobil Student Scientist of the Year category at the WA Premier's Science Awards. Nichole Barry won the Astronomical Society of Australia's Louise Webster Prize for outstanding research by an early career scientist. Natasha Hurley-Walker won both the STEM Academic and Research Category at the Women in Tech WA Awards, and the Curtin Faculty of Science and Engineering's Mid-Career Researcher of the Year Award. Adelle Goodwin was named one of Science and Technology Australia's Superstars of STEM, and Nichole Barry was accepted into the Australian-American Young Leadership Dialogue Program. Natasha Hurley-Walker, Gemma Anderson, Tyrone O 'Doherty, James Miller-Jones, Danny Price and Arash Bahramian were recognised at Curtin's annual Research and Engagement Awards. Danny Price was recognised as one of WA's Young Tall Poppies for his outstanding contributions to science research, communication, and outreach. Maria Kovaleva and Ruby Wright were selected for the prestigious Fulbright Visiting Scholar Program. Jishnu Thekkeppattu and Torrance Hodgson from ICRAR-Curtin and Mitchell Cavanagh and Jessica Thorne from ICRAR-UWA won the ICRAR Ken and Julie Michael Prize. These awards and recognition are a testament to the high-quality work being conducted at ICRAR, demonstrating that it is among the best research being performed both within the State and within the entire Australian and international astronomical community.

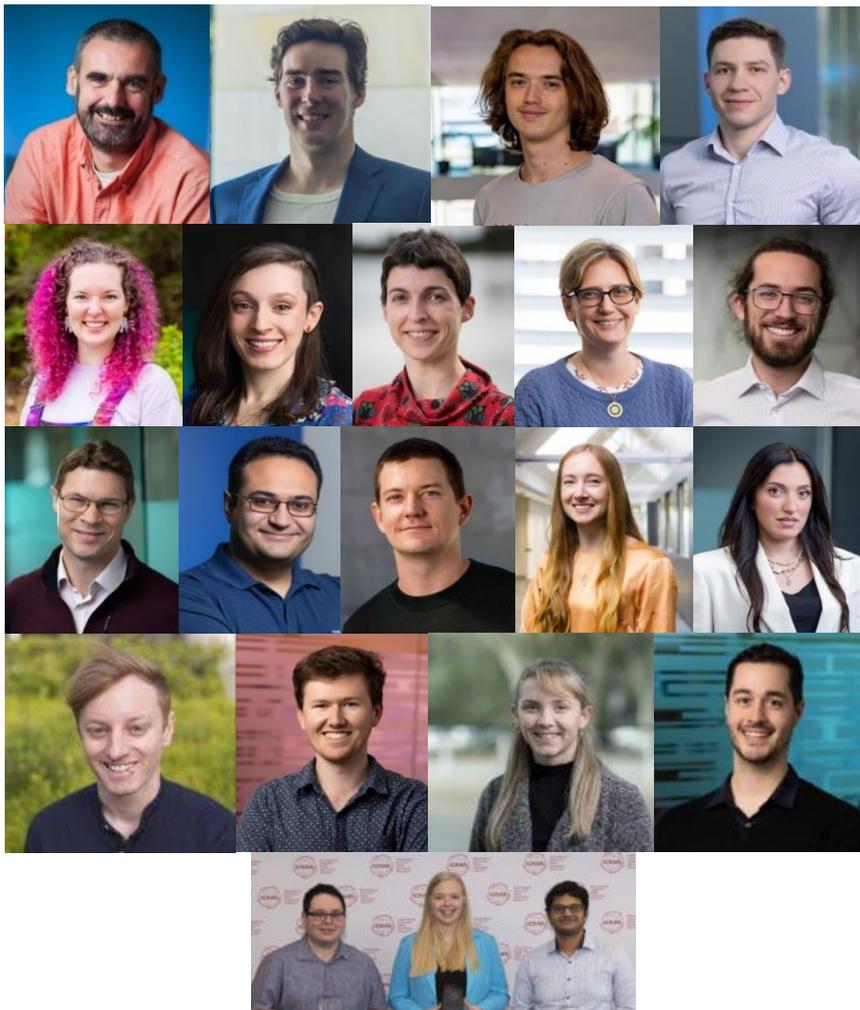


Figure 17

ICRAR HIGHLIGHTS

- To complement SKA precursor surveys, the science staff worked on multi-wavelength surveys and computational theory and developed a new specialised software to dramatically improve the quality of the images obtained by the James Webb Space Telescope (JWST). The technology can be applied to process a wide range of observations including next generation facilities. ICRAR staff combined numerical simulations with Artificial intelligence (AI) to classify more than 20,000 galaxies per minute, opening new ways to use AI for astronomical research and a unique training ground for students.

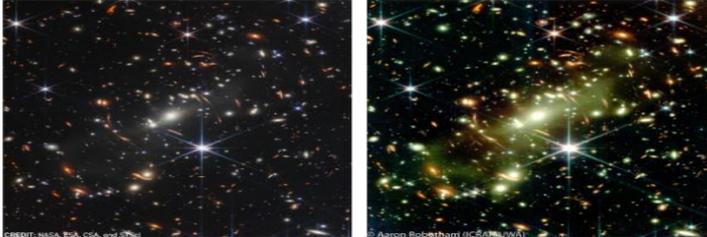


Figure 18: Comparison between the standard JWST data reduction (left) and the improved version (right) developed by ICRAR staff.

- ICRAR-Curtin successfully designed the SKA-Low Station Power and Signal Distribution (PaSD) system. The PaSD was subject to the most demanding and unprecedented electro-magnetic interference (EMI) specification in SKA-Low. The prototype PaSD hardware designed by ICRAR-Curtin and manufactured in WA, successfully underwent radiated emissions testing at a highly specialised facility in South Africa and retired a significant technical risk to the success of SKA-Low. The ICRAR-Curtin team successfully met the extraordinary challenge of designing a sophisticated, reliable, and cost-effective power conditioning, control and monitoring system that has an almost undetectable electromagnetic footprint. To put the target-set and met - into context, a mobile phone on the surface of the moon would cause more radio-frequency interference for the SKA antennas than the PaSD positioned among them.

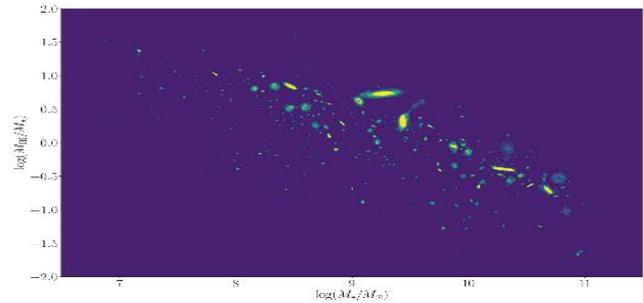


Figure 19: Total HI intensity maps of the galaxies included in the first public data release of the ASKAP/WALLABY survey, gridded by their gas fraction as a function of their stellar mass.

- The DIA team worked with local and global partners including Pawsey Supercomputing Centre and Oak Ridge National Laboratory on survey projects DINGO and CHILES to investigate the potential use of advanced compression technologies and technologies to clean the data more effectively for the interference contributions from human activities. The team contributed to design activities for future instruments including the Next Generation Very Large Array (NG-VLA, United States) and the Next Generation Event Horizon Telescope (NG-EHT, global), as well as the South Korean array and the German Effelsberg Multi-beam demonstrator.
- ICRAR research focused on designing signal processing systems for radio telescopes and the search for life beyond Earth, leading Australia's involvement in the US\$100 million Breakthrough Listen initiative: the most rigorous and comprehensive search for extra-terrestrial intelligence (SETI) ever undertaken. Also, success with the Fulbright Visiting Scholar Program enabled collaboration with US experts in phased-array antennas and strengthened collaboration between ICRAR and a world-leading research group in the US.
- ICRAR researchers applied for and won telescope and supercomputer time as Principal Investigators (PI). Total telescope time awarded to ICRAR researchers as PI in the reporting year was 1,860 hours on 12 national and international facilities located in over seven countries, and 11.9 million CPU hours of supercomputer time. Since 2009, ICRAR has won 48,285 hours of telescope time. The Pawsey Supercomputing facility was the main facility used by the Principal Investigators (PIs) and processed almost 100% of ICRAR's data. Since 2009, ICRAR has won 105.8M hours of supercomputing time. During 2022-23, ICRAR researchers faced significant difficulties in processing data on the Pawsey supercomputer and in accessing the facility due to various upgrade failures.

ICRAR HIGHLIGHTS

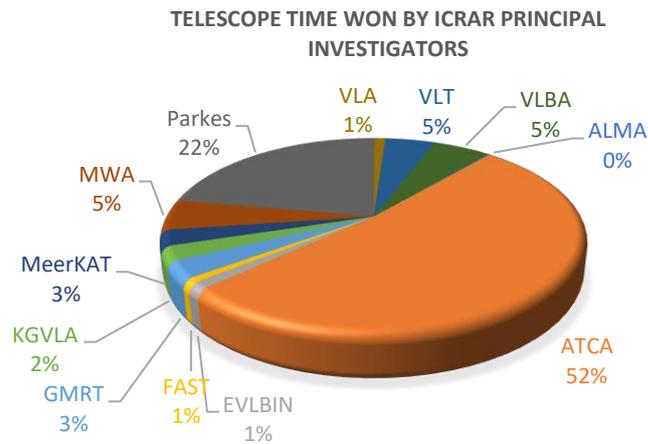


Figure 20

Translation

- Translation was a key area of focus in this reporting year. ICRAR translated its research expertise and skills developed for the SKA into diverse areas, including Space, Data, Defence, Marine, Agriculture, Citizen Science, and other areas. This year, ICRAR undertook over 62 Translation and Impact (T&I) activities, including 42 projects and 20 opportunities pursued across a range of areas at both ICRAR nodes. Of these, 17 were completed successfully, 34 are in progress and the remainder are currently on hold. Demonstrating the transferability of radio astronomers’ skills and capabilities to diversify the WA economy was a key focus area for ICRAR. The T&I team facilitated activities and events that highlight transferable skills and career pathways to and from radio astronomy.
- The T&I team organised events to raise the profile of radio astronomy as a study pathway, communicate the potential for non-academic career pathways beyond radio astronomy, and highlight female role models in the field. Students of data science, engineering, physics, mathematics, and statistics from the JV universities were invited to participate in an event hosted in collaboration with Engineers Australia, featuring a diverse panel of industry professionals with backgrounds in radio-astronomy related studies and roles. In another event, engineers and industry professionals from Engineers Australia were hosted to highlight the diversity of the tangential and complementary engineering capabilities supporting radio astronomy – from electrical and electronic, to mechanical, and mechatronic engineering. The visitors networked with ICRAR staff, toured the ICRAR specialised test facility for observing directed energy effects on electronic devices and systems, and met experts in research visualisation and electromagnetic modelling and simulation.

2022-23 LEVERAGED GRANTS FROM T&I AND SKA

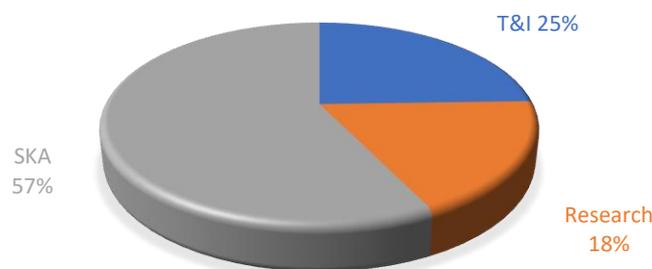


Figure 21

- The ICRAR Science, Engineering and DIA programs continued to train high-quality graduates, and mentor them through to successful outcomes (as demonstrated by several awards won by students including WA Premier’s Science Awards). Several of these students went on to take up industry or translation-related roles at the conclusion of their studies (including at the Bureau of Meteorology,

ICRAR HIGHLIGHTS

Horizon Power, and CSIRO's Future Science Platform), while others continued their academic careers via postdoctoral positions. This demonstrates the broad range and applicability of the skills that ICRAR's PhD students gain during their studies at ICRAR and add to the diversity and excellence of skills and jobs in WA and beyond.

- ICRAR's Astrophotonics team continued to make substantial contributions to the Space and Communications fields to ensure reliable, high-speed, and secure space communication infrastructure. The team was awarded \$6.5M to build a next-generation communications network that can send data to and from objects in space, such as satellites and spacecraft, at a significantly faster rate than current technology. Led by Sascha Schediwy, the project, named TeraNet, received \$4.4M from the Australian Space Agency (ASA) with additional financial contributions from UWA, JTSI and Goonhilly and in-kind support from Geoscience Australia and Thales, and in collaboration with ESA, CNES, AARNet, DLR and Fugro. The grant will allow the team to create a world-unique ground station network capable of supporting low-Earth orbit communications, lunar communications and next-generation optical precise positioning and timing services. The location of one of the new nodes will be within the newly established Goonhilly facility at the Mingenew Space Precinct (MSP), 330 km north of Perth, and the mobile node will be first deployed at the ESA New Norcia Deep Space Tracking Station.
- The Astrophotonics team strengthened its collaboration with industry partners and agencies including Defence-funded extension of SmartSat P1-01/18 project to enable free-space optical communications showcase at Exercise Talisman Saber. The team was invited to contribute to CSIRO's free-space quantum-assured time transfer programme. The team applied for joint ARC Industry Fellowship application with QuantX Labs on free-space optical precise positioning and time synchronisation. The team also secured \$115k as part of the Next Generation Technologies Fund by DSTG, with a focus on Quantum Enhanced Communications
- The ICRAR-Curtin operated MWA telescope secured funding for five years (from mid-2023) of operations from the National Collaborative Research Infrastructure Scheme (NCRIS) via an allocation by Astronomy Australia Limited (AAL). The MWA was the only project in the AAL-administered astronomy program that didn't receive a funding cut, highlighting recognition of the outstanding job ICRAR-Curtin does in operating and maintaining the MWA in service of the Australian and international radio-astronomy communities. The renewed NCRIS funding, combined with contributions from ICRAR and MWA partner institutions, will ensure that the MWA is able to continue its engagement with WA industry, in Geraldton and the mid-West in particular; to train the next generation of data scientists, engineers and astrophysicists; and to support SKA's ongoing risk mitigation and organisational development.



Figure 22: (Left) Artist's impression of a free-space optical communications terminal developed at ICRAR-UWA (Right) Portable Space Domain Awareness System, developed from MWA radio telescope technology by ICRAR-Curtin

ICRAR HIGHLIGHTS

- ICRAR's Engineering team successfully concluded a project to demonstrate the feasibility of utilising radio-astronomy technology and techniques to constitute a mobile system with utility for Space Domain Awareness (SDA). The project was funded by the WA Government's Defence Science Centre, under a Collaborative Research Grant. Working with several WA companies and suppliers, a multi-disciplinary team, led by Randall Wayth, adapted radio-astronomy system architecture - dependent on significant fixed infrastructure and optimised for a pristine radio-quiet environment - to be portable and operate robustly in an environment saturated with the radio-frequency pollution that characterises modern human infrastructure. The project culminated in a deployment to the Australian Automation and Robotics Precinct (AARP), where the team demonstrated the feasibility of the approach by tracking aircraft transiting Perth's airspace. The development achieved through this WA Government funded project has been directly leveraged by a number of follow-on initiatives involving further industry collaboration.
- ICRAR researchers teamed with Australian-owned company Nova Systems to prototype a new facility for Space Domain Awareness to deliver a prototype passive array radar system, which can locate and track satellites and space junk orbiting Earth. The system is being developed by translating technologies and techniques developed by ICRAR-Curtin engineers supporting the operations of the MWA telescope. Once the facility is complete, more than 2,400 antennas will be installed, with advanced electronics and software systems, the majority of which are manufactured in WA. In 2022/23, three Spacefest Lite research reports were delivered to the Australian Department of Defence demonstrating the utility of data derived from this facility.



Figure 23

- The Space domain, expertise of ICRAR-UWA researchers was celebrated in a unique week of events that were co-hosted with the ISC, for the JWST First Images released from NASA. ICRAR's science team members have been involved with The James Webb Space Telescope Webb since 1996 and obtained over a hundred of the very first coveted hours booked on Webb, and ICRAR hosted the only Australian live event from NASA, with only four other live feeds internationally. A public lecture by Professor Garth Illingworth was held to explain the First Images and provide the history and scientific impact of the JWST. This was a fully booked event with a lot of positive community feedback.
- ICRAR continued its collaboration with Perth based DUG Technology in the field of high-performance computing and facilitated introductions for DUG to its industry collaborators, Nova Systems and Electro Optic Systems (EOS), leading to nascent research collaboration in the field of space domain awareness. An in-person introduction to Breakthrough Listen Project Director, Andrew Siemion, led directly to a commercial agreement for the provision of DUG hardware to the University of California, Berkeley, to support the Search for Extra-terrestrial Intelligence.
- ICRAR's machine learning DIA team experts continued their collaboration with the Bureau of Meteorology (BoM) and the Oceans Institute (OI), a member of the Australian Research Council (ARC) Research Hub for Offshore Floating Facilities, to translate their expertise in machine learning and big data management to improve marine forecasting off the WA coast. The team finalised the operational roll-out of a system improving the swell forecast of BoM for selected positions in the north of Western Australia. This system is running on the Amazon cloud and produces forecasts on an hourly basis year-round, except during hurricane season. During the year, the team augmented the machine learning models and significantly improved the prediction results. This activity is being funded by BoM and OI.
- Additional staff were hired to support the various AI/ML projects. A new collaborative project was started with Algoma University in Canada to develop assistive digital technologies to support disabled and impaired people. Since two of DIA's team members have disabilities, this is a project that is directly using first-hand experience. The team also advanced a project to spot and identify whales using minimal invasion technology and is continuing its fruitful collaboration with local company, YTrace, which is a spin-off from the former CRC for Honey Bee Products.
- Building on the National Quantum Strategy and revised list of Critical Technologies, researchers from ICRAR along with UWA, met with representatives from State Government, Defence, Chief Scientist of

ICRAR HIGHLIGHTS

WA and Pawsey for presentations on quantum communications from ICRAR. The Astrophotonics group is approaching quantum technologies from the point of view of adapting high-precision metrology work to quantum applications, with T&I supporting broader engagement with industry applications and potential research collaborations.

- There were 14 industry-sponsored postgraduate research students at ICRAR, across the Engineering, DIA and Science teams. Fostered through close relationships and collaboration, the support that these students received from the Defence, Finance, Computing, and Space industries is testament to the value to the workforce of directly relevant and transferable skills developed through radio astronomy.

Communication, Education and Outreach (CE&O)

- ICRAR staff participated in many outreach events and contacted nearly 12,000 people to help increase scientific engagement across the State, with over 200,000 being contacted since 2009. In the reporting year, staff and students continued to engage with the broader community via school visits, public talks, radio interviews, articles for online fora such as *ABC* and other news channels, *The Conversation*, and even filming for a documentary. Particularly noteworthy media engagement arose from the SKA Commencement Construction Ceremony in December 2022, and the total solar eclipse in April 2023. See **Appendix A**.
- ICRAR, in conjunction with CSIRO, Carol Redford from Astrotourism WA and Elders from the Wajarri Yamatji group, developed an Indigenous planisphere with funds from DISR. The planisphere was officially launched at stargazing events in the Murchison in October 2022.
- ICRAR's Astrofest was held at the end of October with about 2,500 people attending the event despite heavily overcast skies. As part of the Astrophotography exhibition, an additional stall was added with two Indigenous artists (Madeline Anderson and Catrina Smith) showcasing their artwork and selling the Indigenous planispheres.

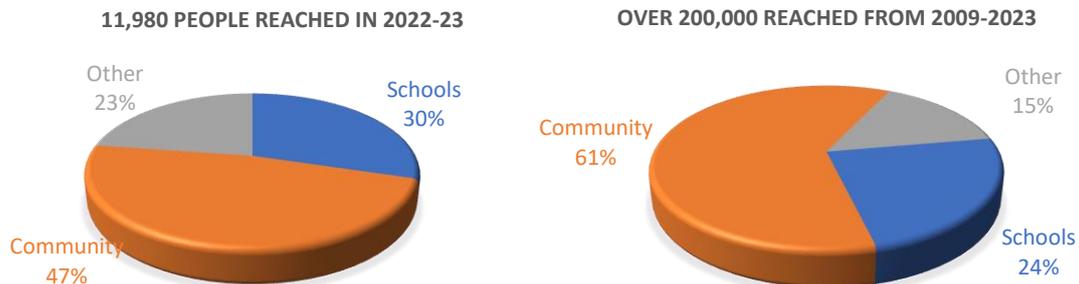


Figure 24

- School children from Pia Wajarri are frequent visitors to the MWA, or Gulgumarnu, meaning “*the ear that listens to the sky*” and they were hosted by ICRAR to put their own, unique, artistic stamp on one of the spider-like MWA antennas that they had seen on site. Having fostered a long history of collaboration centred around Wajarri artwork depicting the night skies, ICRAR's engagement with the Yamaji community extended to the performing arts this year. The acrylic painting, ‘*Star Dreaming*’, by Yamaji artist Margaret Whitehurst was donated to, and is on display at the Curtin Art Collection. Yamaji Calisto, a cross-cultural collaboration between ICRAR, Yamaji Art in Geraldton, and opera producers from Rome, Italy, brought together Yamaji language, song, visual and performing arts, and Italian early opera, to tell cross-cultural stories of astronomy and the night sky.

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- A Stargirls in STEM Camp was successfully run for female and non-binary participants by the CE&O team with ICRAR researchers for three days to encourage girls in STEM in WA. The students interacted with ICRAR's astronomers, engineers and data scientists, and used the SPIRIT observatory, experienced the Beyond the Milky Way VR production, and visited the Pawsey Supercomputing Centre. Under the SPIRIT program, students were instructed on the access and use of research grade, remotely accessible robotic telescopes. More than 700 students from 16 schools participated in the SPIRIT program.



Figure 25: (Left) Stargirls in STEM. (Far right) Solar Eclipse, April 2023.

- The CE&O team completed a regional tour of the mid-west, Kimberley and Pilbara regions and engaged with 14 schools and delivered programs to more than 1,000 students.
- ICRAR distributed eight press releases between 1 July 2022 and 30 June 2023, resulting in 1,182 articles mentioning ICRAR. The media coverage received an actual estimated audience of 2.68 million, with Australia, USA, Spain, China, and India being the biggest audiences. ICRAR's audience across our social channels increased by 11.2% compared to the previous year, with the biggest net growth coming from LinkedIn and Facebook. Since ICRAR launched in late 2009, we have distributed 145 media releases, leading to more than 24,200 articles world-wide and an estimated audience of over 52 million.

Diversity, Equity & Inclusivity

- ICRAR is strongly committed to supporting diversity, equity and inclusivity. ICRAR's Development Committee (DevCom) at ICRAR-Curtin and Development, Equity and Inclusivity Committee (DEI) at ICRAR-UWA, continued to raise awareness of the issues and provide support to ICRAR staff and students. The Committees led many initiatives and activities throughout the year to support, celebrate and showcase ICRAR's diversity, including multicultural festivals and their cultural significance, accompanied by traditional foods. ICRAR supported the visibility of the diversity of gender and sexual orientation and supported activities that were aimed at improving visibility of minority groups across the LGBTQIA+ spectrum, including celebration of Pride month, Rainbow Dinners and Wear it Purple Day. ICRAR nodes continue to implement the inclusion of pronouns on official name badges. ICRAR staff and students ran social initiatives aimed at fostering the physical and mental well-being of team members. The Committees encouraged staff and students to attend seminars on mental health issues and management of these, as well as the support services available within the JV universities. This included the training on unconscious bias, Ally training and mental health first aid training. ICRAR showed its recognition of and support for Indigenous Australian culture by running a series of initiatives coinciding with NAIDOC week, including presentation of some recent work done in the field of Indigenous astronomy, recognising First Nation people as the first astronomers in this region and reconciliation week breakfast for staff and students. Activities to support diversity, equity and inclusivity can be seen at <https://www.icrar.org/about/diversity/>.
- Dr Maria Labate from SKAO Headquarters visited ICRAR as the Senior Women Visiting Fellow, delivering talks to, and holding meetings and discussions with students and staff on career pathways and work life balance. The visiting fellowship program resumed this year after a gap of four years due to COVID restrictions.
- ICRAR has actively contributed to supporting the women in STEM agenda of WA. ICRAR became a Champion of the AAS of Science STEM Decadal Plan. Details can be seen here <https://www.science.org.au/support/analysis/decadal-plans-science/women-in-stem-decadal-plan>). ICRAR supported Innovators Tea Party to encourage girls in STEM.

ICRAR HIGHLIGHTS

- ICRAR staff actively contributed to the respective JV university's equity and diversity initiatives. James Miller-Jones was nominated as Chair of the Faculty of Science and Engineering's Equity, Diversity and Inclusion Committee. Renu Sharma was appointed Chair of the Culturally and Linguistically Diverse Working Group. Elisabete Da Cunha was appointed as the Equity and Diversity Contact Officer at UWA and Luca Cortese was appointed a member of the Gender Equity Diversity Working Group.
- ICRAR Climate and wellbeing surveys were organised to gain insight and assess any issues faced by staff and students, and to aid in the development of an action plan. ICRAR has been recognised by the ASA for its commitment to advancing diversity and inclusion in astronomical sciences and technology. In the reporting year, ICRAR-UWA was awarded the Gold Pleiades Award. It was the only organisation to receive this award across Australia and New Zealand in 2019, 2021 and 2023 till 2025.
- ICRAR's outreach team travelled to regional communities to deliver astronomy-themed events and programs for local schools with activities that engage a spectrum of learners. The team works with communities separated by hundreds, or in some cases, thousands of kilometres of outback, to support the STEM agenda of WA and ICRAR.



Figure 26: (Left) Maria Labate. (Right) ASA Pleiades Gold Award 2023-25.

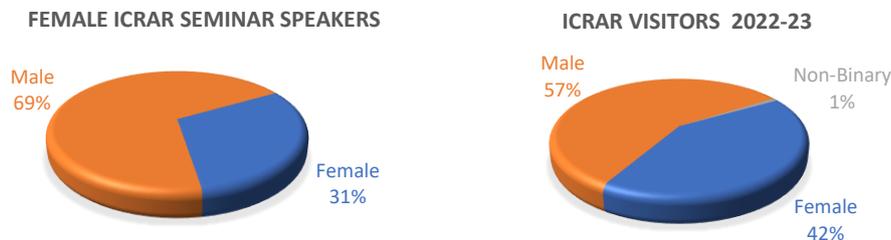


Figure 27

Difficulties Faced in 2022-23 and in ICRAR III

The impact of the COVID-19 pandemic on ICRAR's core activities (highlighted in ICRAR Board meetings, Finance and Audit Committee meetings and in previous ICRAR Annual Reports) has stretched into the reporting year. Staff travel was still restricted during the first six months of 2022/23, and the cumulative effect of COVID-related departures and hiring delays was still felt. Despite these difficulties, ICRAR managed to deliver on its KPIs without excessive staff burnout.

In addition to these difficulties, ICRAR faced the impact of a rapid expansion in hiring by SKAO and CSIRO in WA, and an industry-wide shortage of skilled personnel. Combined with ICRAR's limited ability to offer contracts beyond mid-2024, this made it exponentially more difficult to retain existing staff and hire new staff. The inability to recruit staff with the required level of expertise and skills may lead to further under-expenditure in the next financial year if not urgently addressed. Applications for 2024/25 funding and 2025/26 to 2029/30 were submitted to JTSI on 15 December 2022 and 31 June 2023, respectively.

SECTION H.2: ACRONYMS (ICRAR 2022-2023 ANNUAL REPORT)

ACRONYM	DESCRIPTION
AAL	Astronomy Australia Limited
AARNet	Australian Academic and Research Network
AARP	Australian Automation and Robotics Precinct
AAS	Australian Academy of Science
AAVS	Aperture Array Verification System
ACAMAR	Australia/China Consortium for Astrophysical Research
AI	Artificial Intelligence
ARC	Australian Research Council
ASA	Astronomical Society of Australia
ASA	Australian Space Agency
ASCC	Australian SKA Coordination Committee
ASTRON	Netherlands Institute for Radio Astronomy
ASKAP	Australian SKA Pathfinder
ASTRO 3D	ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions
AUD	Australian Dollar
AusSRC	Australian SKA Regional Centre
BOM	Bureau of Meteorology
CE&O	Communication, Education and Outreach
CHILES	Cosmos Hi Large Extragalactic Survey
CNES	French National Space Agency
COO	Chief Operating Officer
COVID-19	World wide pandemic originating in 2019
CPU	Central Processing Unit
CRC	Cooperative Research Centre
CRC HBP	Cooperative Research Centre for Honey Bee Products
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAS	Distributed Acoustic Sensing
DAE	Deloitte Access Economics
DEI	Development, Equity and Inclusivity Committee
DevCom	Development Committee
DI	Data Institute
DIA	Data Intensive Astronomy
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DINGO	Deep Investigation of Neutral Gas Origins ASKAP Survey
DISR	Department of Industry, Science and Resources
DPIRD	Department of Primary Industries and Regional Development
DSTG	Defence Science and Technology Group
ECR	Early Career Research
ED	Executive Director
ELEN3002	Engineering Electromagnetics and Transmission Lines (3rd year Engineering unit)
EMI	Electro Magnetic Interference
EOS	Electro Optic Systems
ERA	Educational Radio Array
ERA	Excellence in Research Australia
ESA	Electronically Steered Arrays
ESA	European Space Agency
ESD	Electrostatic discharge
FAA	Financial Assistance Agreement
F&A	Finance and Audit
FIDDG	Federal Foreign Interference Due Diligence
FRB	Fast Radio Bursts
FTE	Fulltime equivalent
GLEAM	GaLactic and Extragalactic All-sky MWA
HBP	Honey Bee Products
HDR	Higher Degree Research
HPC	High Performance Computing
ICRAR	International Centre for Radio Astronomy Research
IF	Impact Factor
IGO	Inter-Governmental Organisation
INAF	Italian National Institute for Astrophysics
IP	Intellectual Property

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ACRONYM	DESCRIPTION
ISC	International Space Centre
JTSI	Department of Jobs, Tourism, Science and Innovation
JV	Joint Venture
JWST	James Webb Space Telescope
KIAA	Kavli Institute for Astronomy and Astrophysics
KPI	Key Performance Indicator
KSP	Key Science Project
LGBTQIA+	Lesbian, gay, bisexual, transgender, queer (or questioning), intersex, and asexual (or allies)
LIEF	Linkage Infrastructure, Equipment and Facilities
Lol	Letters of Intent
MEM	Management Executive Meetings
ML	Machine Learning
MOU	Memorandum of Understanding
MRO	Murchison Radioastronomy Observatory
MSP	Mingenew Space Precinct
MWA	Murchison Widefield Array
NAIDOC	National Aborigines' and Islanders' Day Observance Committee
NAOC	National Astronomical Observatory of China
NARIT	National Research Institute of Thailand
NASA	National Aeronautics and Space Administration
NCRIS	National Collaborative Research Infrastructure Scheme
NDA	Non-disclosure agreement
NG-VLA	Next Generation Very Large Array
NG-EHT	Next Generation Event Horizon Telescope
NEC-4	New Engineering Contract – 4
NZ	New Zealand
OI	Oceans Institute
PaSD	Power and Signal Distribution
PCE	Proxy Central Equipment
PI	Principal Investigators
PSI	Poseidon Scientific Instruments
R&D	Research and Development
SA	South Africa
SaDT	Signal and Data Transport
SAT.FRQ-MID	SKA-MID Phase Synchronisation System
S-ITF	System Integration Test Facility
SDA	Space Domain Awareness
SDH&P	Science Data Handling and Processor
SDP	Science Data Processor
SETI	Search For ExtraTerrestrial Intelligence
SHAO	Shanghai Astronomical Observatory
SKA	Square Kilometre Array
SKAO	Square Kilometer Array Organisation
SME	Small and Medium Enterprises
SPIRIT	Spice-Physics-ICRAR Remote Internet Telescope
SPFR	Special Purpose Financial Report
SRC	SKA Regional Centres
SRR	Systems Requirements Review
STEM	Science Technology Engineering and Maths
SWG	Science Working Groups
T&I	Translation and Impact
UK	United Kingdom
USA	United States of America
UWA	University of Western Australia
VR	Virtual Reality
WA	Western Australia
WALLABY	Widefield ASKAP L-band Legacy All-sky Blind Survey
XAO	Xinjiang Astronomical Observatory