CSIRO

SKAO

World-class astronomy in the Australian outback

Inyarrimanha Ilgari Bundara,
the CSIRO Murchison Radio-astronomy Observatory

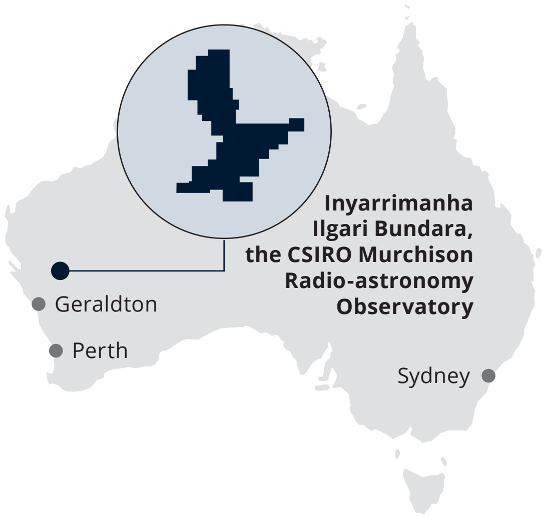
Australian Government
Department of Industry, Science and Resources

GOVERNMENT OF WESTERN AUSTRALIA
Department of Jobs, Tourism, Science and Innovation

Wajarri Group

Welcome to Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory in the heart of Wajarri Country in Western Australia – one of the best locations in the world for radio astronomy.

The observatory currently hosts three world-class radio instruments: the ASKAP radio telescope, the Murchison Widefield Array (MWA), and the Experiment to Detect the Global EoR Signature (EDGES). It is also the site where the international SKA Observatory (SKAO) is building the SKA-Low telescope – Australia's first mega-science facility. These instruments are providing a new window into the mysteries of the Universe, which will be further realised when the SKA-Low telescope comes online later this decade.



Radio telescopes are powerful instruments designed to detect the faintest radio signals from objects across the Universe. This ability makes them particularly sensitive to radio interference caused by transmitters, such as mobile phones, broadcast towers and even electrical equipment.

The Murchison is one of the best places on Earth for radio astronomy – a large area with a small population, remote so that it has comparably little radio interference, and its location in the Southern Hemisphere meaning a clear view into the centre of the galaxy. And, while the telescopes are at the frontier of technology, they come with a low impact on the land.

Aboriginal Australians are Australia's first astronomers and share a long-standing knowledge of the sky. An Indigenous Land Use Agreement (ILUA) has been negotiated with the Wajarri Yamaji, the Traditional Owners and native title holders of the land on which the observatory sits.

We are grateful to the Wajarri Yamaji for partnering with us in establishing the observatory on Country and for the support they have shown as we work together towards furthering astronomical knowledge from their ancient lands.

Wajarri representatives Russell Simpson and Valerie Jones sign the ILUA at a community meeting. Credit: Wajarri Yamaji Aboriginal Corporation (WYAC)

Visiting the observatory

The Australian and Western Australian governments established a radio quiet zone centred on the observatory. It protects this unique radio astronomy site by ensuring radio frequency emissions are managed and the radio telescopes can observe the sky with limited interference.

When visiting the observatory remember we are a working scientific site, with a rich heritage and remote location, as well as host to the construction of a mega-science project.

That means that

- all electronic devices (including smart watches and fitness trackers) must be switched off, or in flight mode with bluetooth and wifi switched off
- cameras can only be used with permission – including from phones
- everything must be left as you found it – do not collect any rocks, plant life or soil
- the environment contains hazards – consider your personal safety and ensure you keep hydrated and sun safe, keep with the group and don't wander outside designated areas
- you may encounter animals on site – do not interact with the local wildlife for your, and their, protection.

Inyarrimanha ilgari bundara – sharing the sky and stars

Aboriginal people have lived in Australia for tens of thousands of years. The Wajarri Yamaji have lived in the Murchison region of Western Australia for much of this time.

In 2022, CSIRO, along with Australian and Western Australian Governments, signed a new Indigenous Land Use Agreement (ILUA) with the Wajarri Yamaji, the Traditional Owners and native title holders of the land on which the observatory sits.

Negotiated over many years, the new ILUA allows construction of the SKA-Low telescope on an expanded observatory, provides benefits for the Wajarri community and protects Wajarri cultural heritage alongside the construction and operation of the telescopes.

Heritage is not simply about sites and objects, but all that is passed down from one generation to the next through oral tradition, including language, stories, places of significance, history, belief and memories. It's what connects the past with the present, and continues to have relevance into the future.

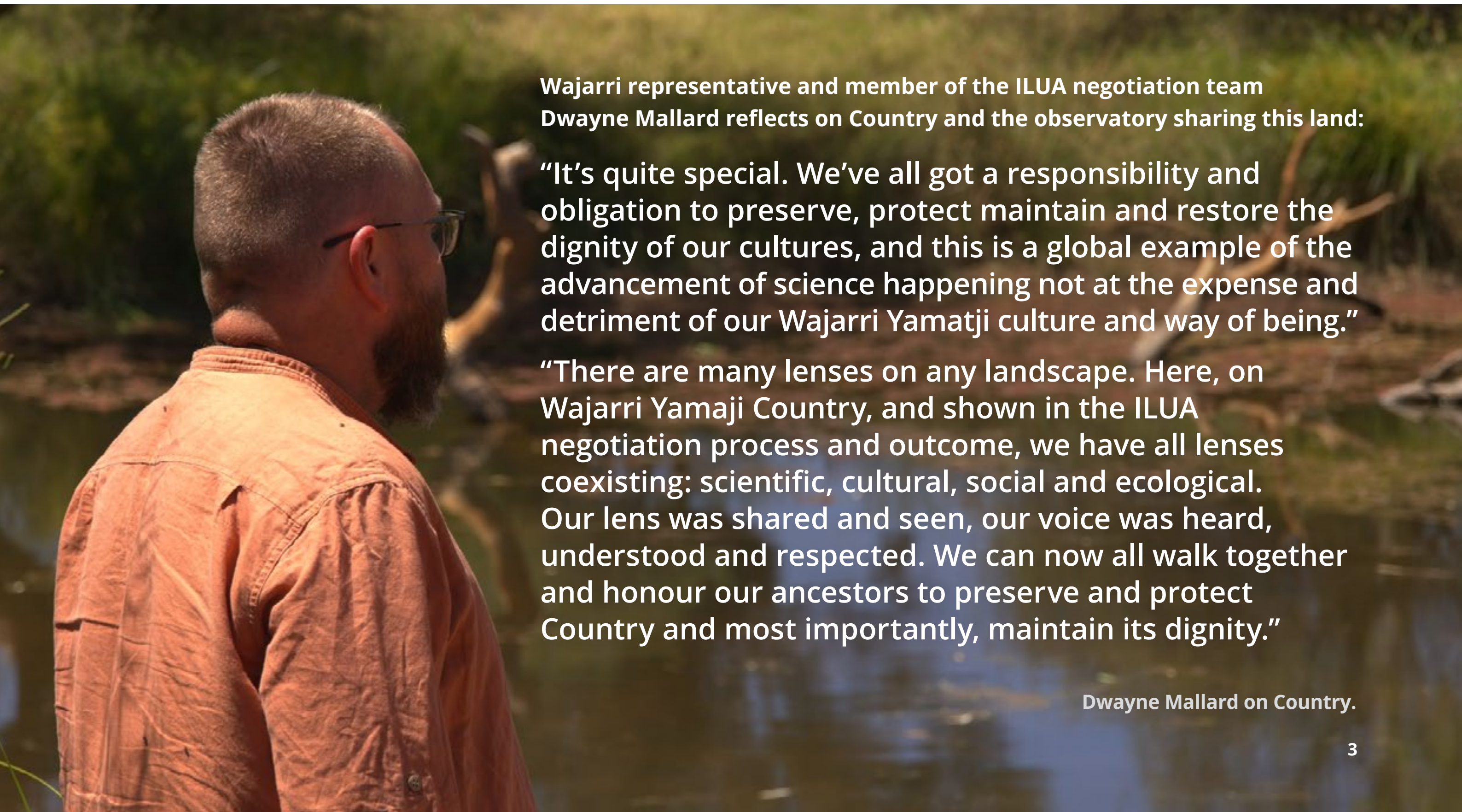
The Wajarri Yamaji have a strong connection to Country, both the land, water and sky, and value the Sun, Moon and stars for information and seasonal survival, as well as for the keeping of culture and stories.

The hot, dry Murchison landscape features rivers, creek beds and water holes – home to unique plants and animals. Many Wajarri people frequent Country and spend time hunting and collecting traditional foods and medicines, as well as visiting sites of significance in the area. Several communities have developed on Wajarri Country, including the closest community to the observatory, Pia Wadjarri.

The Wajarri language is still spoken across Wajarri communities with many words in use at the observatory, including names for the MWA radio telescope and each antenna of the ASKAP radio telescope.

As part of the new ILUA the expanded observatory received a Wajarri traditional name, Inyarrimanha Ilgari Bundara. Inyarrimanha ilgari bundara means 'sharing the sky and stars' in the Wajarri language and is the latest name to be gifted to the site by the Wajarri Yamaji. The dual name used for the observatory, like the other Wajarri names on site, reflects and celebrates our partnership with the Wajarri community. We look forward to continuing work with the Wajarri to reflect Wajarri culture and language, including names for SKA-Low telescope buildings and components and more broadly across the observatory.

We acknowledge the Wajarri Yamaji as Traditional Owners and native title holders of the observatory site.



Wajarri representative and member of the ILUA negotiation team Dwayne Mallard reflects on Country and the observatory sharing this land:

"It's quite special. We've all got a responsibility and obligation to preserve, protect maintain and restore the dignity of our cultures, and this is a global example of the advancement of science happening not at the expense and detriment of our Wajarri Yamatji culture and way of being."

"There are many lenses on any landscape. Here, on Wajarri Yamaji Country, and shown in the ILUA negotiation process and outcome, we have all lenses coexisting: scientific, cultural, social and ecological. Our lens was shared and seen, our voice was heard, understood and respected. We can now all walk together and honour our ancestors to preserve and protect Country and most importantly, maintain its dignity."

Dwayne Mallard on Country.

Ancient land under brilliant skies

While the radio astronomy observatory on Wajarri Country is relatively new, the land it resides on is not.

Nearby Mt Narryer has some of the oldest rocks on Earth, estimated to be 3.6 billion years old. The Murchison landscape contains minerals hundreds of millions of years older than the rocks they're within. These minerals will have formed before the Earth's crust and remain unchanged ever since.

The observatory as we know it today occupies the 3,500 square kilometres that make up the historic Boolardy Station. One of the oldest and largest pastoral stations in Western Australia, Boolardy was primarily used for wool production until it transitioned to cattle in the 1980s. Since it became host to radio astronomy the station has gradually been de-stocked, with no current pastoral activity.

The observatory was first established in 2009, both for Australian radio astronomy and as part of the Australian bid to host the SKA telescope.

The original observatory site hosts ASKAP and MWA, which are world-class telescopes in their own right as well as SKA telescope precursors – providing technological, design and operations guidance for the SKA telescopes.

The Wajarri Yamaji, as Traditional Owners and native title holders of the land, partnered with CSIRO and the Australian and Western Australian governments to bid for hosting the SKA telescopes, joining international delegations to showcase Australia as a potential host for the SKA project.

In 2012 it was announced that Australia's bid was successful, alongside South Africa, and that Australia would host one of the two SKA telescopes, SKA-Low.

The successful bid needed an expanded observatory site, and in 2022 a new ILUA was signed enabling expansion of the site and construction of the SKA-Low telescope at Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory.

Radio astronomy in the Murchison

1990

Early 1990s
Development of the SKA telescope concept begins globally.

1996
Investigations start for potential SKA telescope sites in Australia.

2000

2001
First testing for radio quietness in the Murchison.

The WA Government creates the first radio quiet protections for the Murchison region.

2007
Boolardy Station is chosen as the location for the observatory.

CSIRO's ASKAP radio telescope on Wajarri Country under the Milky Way.

2010

2009
The first ILUA is signed with the Wajarri Yamaji, officially establishing the observatory.

2012
The SKA telescope sites are decided – SKA-Low in Australia and SKA-Mid in South Africa.

The ASKAP radio telescope opening ceremony.

2013
The MWA telescope is operational.

2016
Pastoral activities end at Boolardy Station, accelerating the observatory land's regeneration.

2017
The first test array for the SKA-Low telescope starts observing.

2020

2020
ASKAP's first all-sky survey, RACS, is completed.

2021
The SKAO is established.

Australia signs the Host Country Agreement for the SKA-Low telescope with the SKAO.

2022
A new ILUA with the Wajarri Yamaji is signed, expanding the observatory.

SKA-Low telescope construction begins.

2023
Infrastructure preparation – including optical fibre, power cables and mesh – begins for the SKA-Low telescope on site.

2024
SKA-Low antennas begin installation.

Artist's impression of the SKA-Low telescope. Credit: DISR.

SKA-Low telescope

The SKA-Low telescope is part of the SKAO – a global scientific facility that will deliver half a century of transformational science, revolutionising our understanding of the Universe and delivering benefits to society through global collaboration and innovation.

The SKA-Low telescope will be made up of 131,072 two-metre-tall antennas, spanning out from a central core along three spiral arms that stretch 74 km end-to-end. SKA-Low will detect radio signals from the Universe in the frequency range of 50–350 MHz, similar to FM radio stations or TV signals.

In Australia, the SKAO is collaborating with CSIRO to build and operate the SKA-Low telescope. Institutions in Australia, China, India, Italy, Malta, the Netherlands and the UK contributed to the design of SKA-Low, and its components will be manufactured all over the world.

SKAO

skao.int

SKA-Low: revealing the Universe's faintest details

Resolution: making the cosmos clearer

Both SKA telescopes can achieve higher resolution than a single large telescope, thanks to the large separation between the farthest antennas. High resolution translates into sharper images which reveal much finer detail.

Sensitivity: shining a light on the distant Universe

In radio astronomy, the sensitivity of a telescope depends on the collecting area available to capture signals from space. SKA-Low provides 400,000m^2 of collecting area, so it can detect very faint radio signals and combine and enhance them in a way never before possible.

Survey speed

SKA-Low uses a technique called beamforming to digitally point the telescope anywhere in the sky by combining signals from some or all of the antennas in the array. The SKA-Low telescope has a huge field of view, allowing the telescope to survey more of the sky at much faster speeds than other telescopes.

SKAO: a global collaboration revealing our Universe

The SKAO is an Intergovernmental Organisation whose mission is to build and operate cutting-edge radio telescopes on behalf of its member states and partners.

The SKAO has a global footprint – bringing together members from across five continents. The SKA telescopes – the SKA-Low telescope being built on Wajarri Country in Western Australia and the SKA-Mid telescope being built in the Karoo in South Africa – together with SKAO global headquarters in the UK, will be the largest and most capable radio astronomy observatory in the world.

Constructing and operating SKA-Low and SKA-Mid will position the SKAO as the leading research infrastructure for radio astronomy globally, providing science capabilities to the international astronomical community for decades to come.

The SKA telescopes are underpinned by the great scientific discoveries of the SKA precursor telescopes, including ASKAP and the MWA at the observatory here in Australia, and MeerKAT and HERA in South Africa, and SKA pathfinder instruments from across the globe.

Artist's impression showing what the SKA-Low telescope will look like when built. Credit: DISR.

Building SKA-Low

In late 2022 the SKAO marked the start of on-site construction activities for both the SKA-Low and SKA-Mid telescopes.

Construction of the SKA-Low telescope is an immense undertaking and is expected to take around eight years from start to finish.

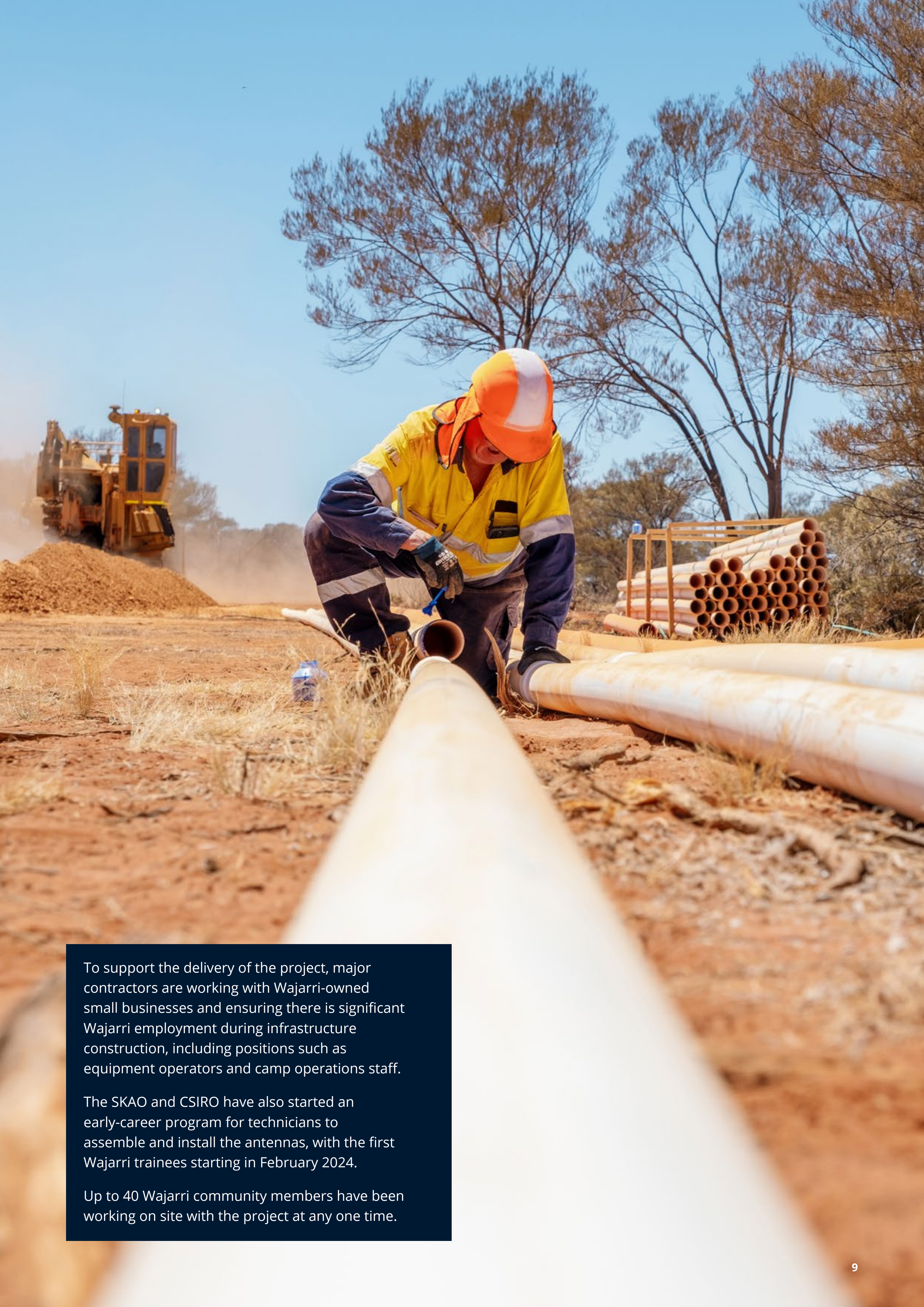
The first year of construction was dedicated to preparing the site for deployment of the telescope. To access the antenna sites and infrastructure, we have created hundreds of kilometres of roads, power and optical fibre connections and prepared the site for critical infrastructure at the core and spiral arms. In addition to the antenna stations, there will be remote and central processing facilities on site that combine and process the signals received by the antennas and link directly to supercomputers located more than 600 km away at the Pawsey Supercomputing Research Centre in Perth. The on-site computing facilities are shielded to avoid radio interference generated by the computing technology and electronics inside affecting the telescope observations.

Early construction works have also included a laydown yard for essential materials, such as bundles of the 100,000 sheets of mesh, antenna components and hundreds of kilometres of power and optical fibre. A 200-bed construction camp was built to provide accommodation to people working on site. A 1,200m airstrip has also been established for emergency access and evacuation at the SKA site.

Wajarri heritage during construction

Building SKA-Low has a low impact on the environment and Wajarri heritage monitors have been present during all initial ground-disturbing activities. Heritage monitors help to ensure the preservation of cultural heritage and the identification and preservation of any cultural artefacts discovered. The SKA-Low telescope configuration was adapted with Wajarri input to ensure the telescope and significant cultural sites can exist side by side at the observatory.

Members of the SKA-Low team build a prototype SKA-Low antenna.



To support the delivery of the project, major contractors are working with Wajarri-owned small businesses and ensuring there is significant Wajarri employment during infrastructure construction, including positions such as equipment operators and camp operations staff.

The SKAO and CSIRO have also started an early-career program for technicians to assemble and install the antennas, with the first Wajarri trainees starting in February 2024.

Up to 40 Wajarri community members have been working on site with the project at any one time.

SKA-Low benefits

Next-generation facilities such as the SKA telescopes create impact beyond science.

Benefits will be delivered at a global, national and local level, from economic outcomes to social impacts, education, innovation and technology.

Sustainability

Sustainability is a foundational value of observatory activities both for the SKAO and CSIRO.

The SKAO and its partners are helping to address global challenges by contributing to some of the United Nations Sustainable Development Goals to achieve a better and more sustainable future for all.

The SKAO has already halved the estimated power consumption of the SKA telescopes thanks to the adoption of innovative design and more efficient technologies during the pre-construction phase of the SKA project, expanding on the sustainability impact of the existing hybrid power station and technology developed by CSIRO.

Looking ahead, the SKAO aims to carefully monitor and limit as much as possible the environmental impacts of the construction and operation of its telescopes over their entire lifetime. For instance, based on current planning, the SKAO is due to source a substantial fraction of its electricity needs from solar and other renewable sources, with the long-term goal of minimising its carbon footprint and ultimately obtaining a majority of power from renewable sources.

These plans include solar photovoltaic facilities to be used at both SKA telescope sites in Australia and South Africa, as well as exploring other ways to maximise the use of sustainable power for its computing facilities.

An environmental expert from the SKA-Low team surveying the site for endangered Western spiny-tailed skink habitat.

Ventia is providing the power and fibre for the SKA-Low telescope, and some of the computer processing facilities. Credit: Ventia.

Technology

Landmark science facilities like the SKAO have a strong track-record of facilitating the transfer of new technology into commercial outcomes.

Delivering the SKA telescopes will require novel computing and technology solutions, and these will have broad benefits. New technology around faster fiber optic cables and more powerful computers will eventually filter into our everyday lives.

ASKAP receiver technology has already been licensed to Australian space start-up, Quasar Satellite Technologies, that is having an impact outside radio astronomy.

As host of the SKA-Low telescope, Australia has the opportunity to work at the forefront of the data science and analytics sector, which is increasingly central to the jobs of the future and economic growth, linking local science institutions, industries and businesses to a long-term global project.

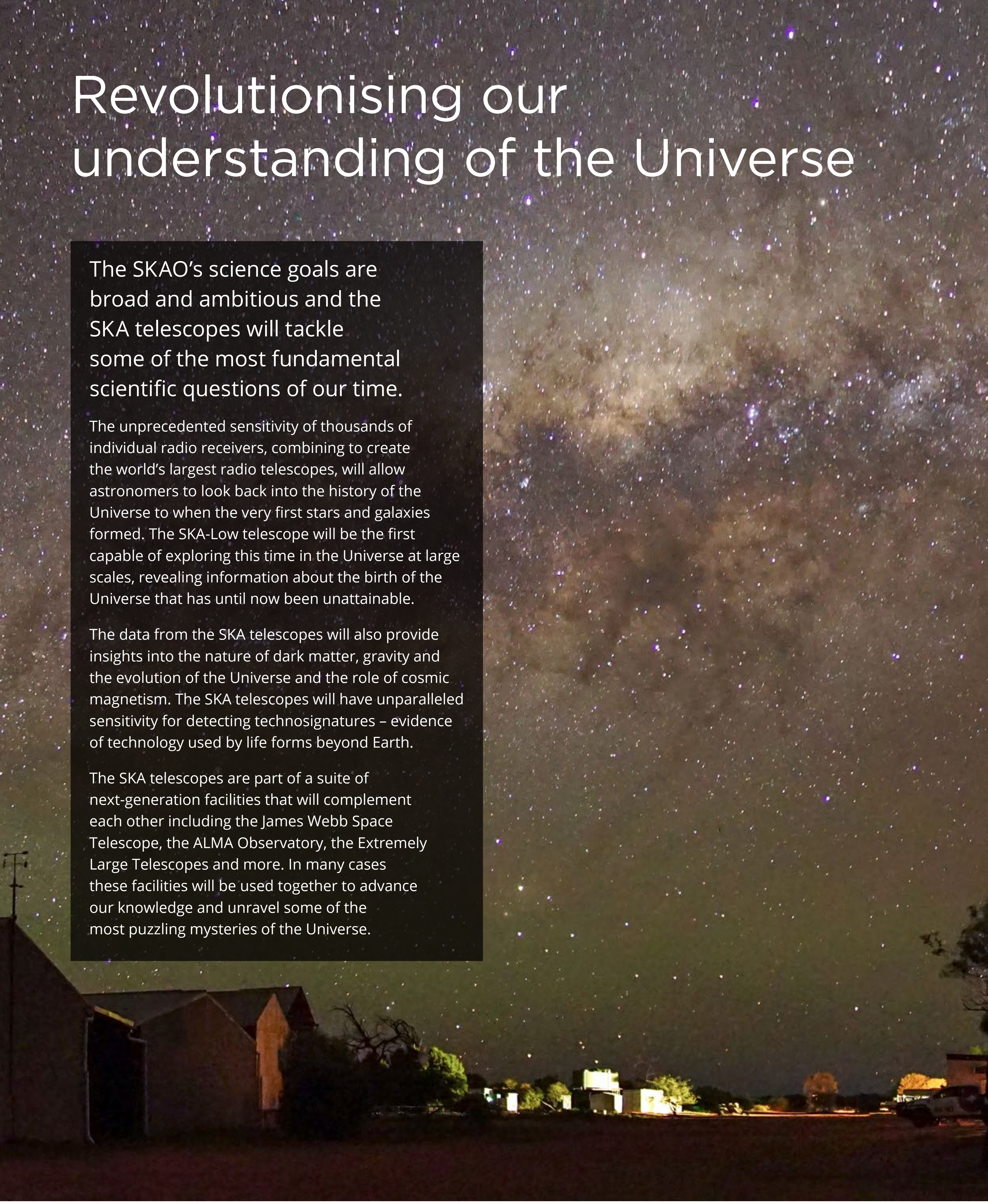
The SKA project will also inspire future generations of STEM students, all through Australia playing host to part of the SKAO – the largest and most capable radio observatory ever built.

Local benefits of a global project

Australian businesses are already benefiting from the economic opportunities of being a SKA telescope host nation. Australian company Ventia was awarded the infrastructure contract for SKA-Low in 2022 and has been active on site ever since, and local Perth-based AVI are contracted to manufacture the 7,300 smart boxes that will power the SKA-Low antennas.

Further collaboration between industry and the research sector will support the development of advanced digital technologies and expertise.

Hosting the SKA-Low telescope is also providing great outcomes for the Mid West Region of Western Australia. Construction is providing opportunities for local companies, as well as infrastructure benefits to the region, such as fibre connectivity for communities local to the observatory – the Murchison Settlement and the Pia Wadjarri community.



Revolutionising our understanding of the Universe

The SKAO's science goals are broad and ambitious and the SKA telescopes will tackle some of the most fundamental scientific questions of our time.

The unprecedented sensitivity of thousands of individual radio receivers, combining to create the world's largest radio telescopes, will allow astronomers to look back into the history of the Universe to when the very first stars and galaxies formed. The SKA-Low telescope will be the first capable of exploring this time in the Universe at large scales, revealing information about the birth of the Universe that has until now been unattainable.

The data from the SKA telescopes will also provide insights into the nature of dark matter, gravity and the evolution of the Universe and the role of cosmic magnetism. The SKA telescopes will have unparalleled sensitivity for detecting technosignatures – evidence of technology used by life forms beyond Earth.

The SKA telescopes are part of a suite of next-generation facilities that will complement each other including the James Webb Space Telescope, the ALMA Observatory, the Extremely Large Telescopes and more. In many cases these facilities will be used together to advance our knowledge and unravel some of the most puzzling mysteries of the Universe.

The galaxy centre as seen from the observatory.

ASKAP radio telescope

CSIRO's latest radio telescope, ASKAP, is designed for fast, comprehensive and detailed surveys of the sky. ASKAP is an official precursor instrument to the SKA telescopes.

ASKAP is part of the Australia Telescope National Facility, owned and operated by CSIRO. All of ASKAP's 36 antennas have been gifted a Wajarri name, selected by the Wajarri Yamaji to represent items of importance to Country, community and the telescope's construction.

Each ASKAP antenna is a 12m wide dish with an advanced phased array feed receiver. The receivers allow for a wider view of the Universe, making ASKAP one of the fastest survey telescopes in the world.

Fast surveys generate an enormous amount of data which means supercomputing is an essential part of the telescope. ASKAP sends 100 trillion bits of raw data every second from its outback location. At the Pawsey Supercomputing Research Centre in Perth the raw data is converted into maps of the sky that are used for astronomical research using custom CSIRO software.

One of the main science goals of ASKAP is to study the origins and evolution of galaxies, which are the building blocks of the Universe. Over the next five years, ASKAP will detect tens of millions of galaxies and reveal the cosmic environments in which they live. This will help us to understand the Universe as a dynamic place that has evolved over 13.7 billion years – all the way from the Big Bang to the state in which we find it today.

A new era for astronomy

Rapid survey telescopes bring astronomy into a new era of discovery. ASKAP's first all-sky survey discovered one million new galaxies and that was only the beginning.

Hundreds of astronomers from Australia and around the world have gathered into survey science teams with unique research goals that rely on ASKAP data. These include:

- mapping the velocity of cosmic gas clouds
- measuring the strength of magnetic fields in space
- understanding star formation throughout cosmic history
- discovering new phenomena throughout space (such as 'odd radio circles'), and
- studying the origins of transient and variable sources – intermittent signals from deep within our own or other galaxies.

CSIRO

csiro.au/askap

ASKAP antenna | Wajarri names

Our ASKAP radio telescope has 36 antennas and each one has its own Wajarri name.

1 **Biyarli** | galah
2 **Birliya** | tree with edible gum
3 **Bundara** | star
4 **Bimba** | edible gum
5 **Gagurla** | bush pear
6 **Wilara** | moon
7 **Irra barndi** | good talk
8 **Jirdilungu** | milky way
9 **Balayi** | look out
10 **Bardi** | witchetty grub
11 **Manggawarla** | hat
12 **Yalibirri** | emu
13 **Jabi** | lizard
14 **Gagu** | crow
15 **Birri-birri** | butterfly
16 **Jindi-jindi** | willy wag tail
17 **Marlu** | kangaroo
18 **Ilgarijirri** | things belonging to the sky
19 **Biji-biji** | caterpillar
20 **Wana** | women's hitting stick
21 **Minda** | shade
22 **Nyingari** | zebra finch bird
23 **Nyambi** | traditional dance
24 **Janimaarnu** | Chinese
25 **Magumarra** | Wajarri Elder
26 **Yamaji nyarlu** | woman
27 **Yamaljinggu** | Wajarri Elder
28 **Yagu** | mother
29 **Diggiedumble** | table top
30 **Nyarluwarri** | seven sisters
31 **Mungal** | morning
32 **Woodrudda** | hill in Yallalong
33 **Budara** | hill on Wooleen Station
34 **Jinawirri** | Wajarri Elder
35 **Ngubanu** | dingo
36 **Birli** | lightning

A new era of technology

As well as making new discoveries, telescopes like ASKAP push the boundaries of technology. Experience gained with ASKAP has guided the design and construction of the SKA telescopes. The receiver technology has been licensed to an Australian space start-up, Quasar Satellite Technologies, and has been further purposed into a new receiver for Murriyang, CSIRO's Parkes radio telescope.

But it's not just what is on the dishes that is pushing boundaries. ASKAP's torrent of survey data provides the motivation to develop a new generation of data processing methods which will be used when the SKA telescopes come online in the future.

Fast radio bursts

The first fast radio burst was detected with Murriyang, CSIRO's Parkes radio telescope in 2007. When ASKAP began operating, it was the best instrument in the world for finding them. Innovative use of the antennas' wide-field of view meant that more bursts could be discovered in one year than had been in the previous decade. While the origin of the bursts remain a mystery, they have been used to solve other long-standing questions like how matter is distributed across the Universe.

Wajarri artist Judith Anaru's *CRAFT*, 2019, is a depiction of a fast radio burst.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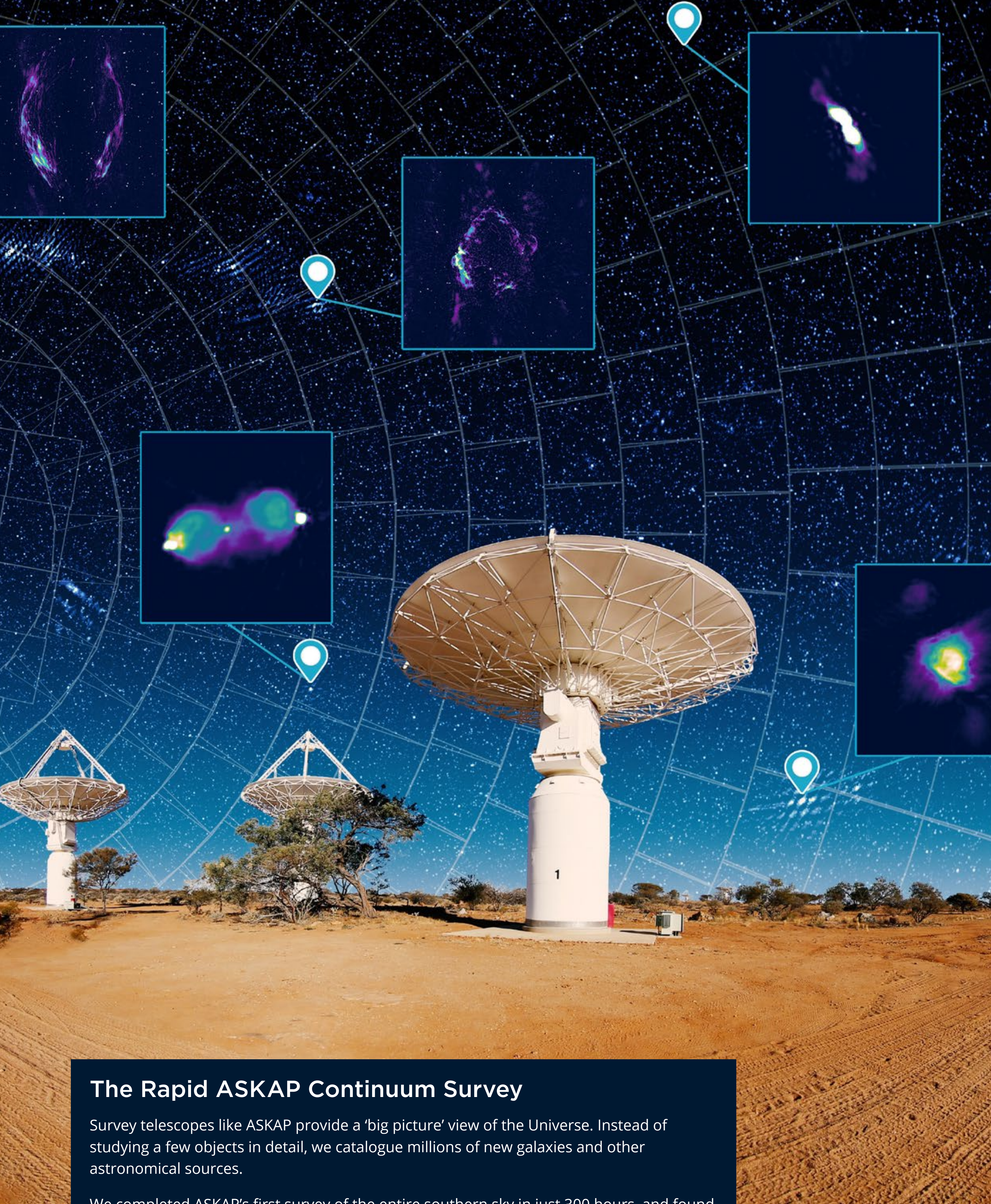


The Rapid ASKAP Continuum Survey

Survey telescopes like ASKAP provide a 'big picture' view of the Universe. Instead of studying a few objects in detail, we catalogue millions of new galaxies and other astronomical sources.

We completed ASKAP's first survey of the entire southern sky in just 300 hours, and found nearly three million galaxies – one million of which had never been seen before! This new atlas of the sky allows astronomers to expand their research horizons and discover more hidden secrets of the Universe.

Explore RACS at research.csiro.au/racs

Murchison Widefield Array

The Murchison Widefield Array (MWA) is a radio telescope made of thousands of spider-like metal antennas.

These antennas are arranged in regular grids known as 'tiles', which are spread over several kilometres within the Observatory. The MWA is an official precursor instrument to the SKA-Low telescope.

The MWA is tuned to receive radio frequencies between 70 and 300MHz, and is special for its very wide field of view, high angular resolution, nanosecond time resolution, and digital pointing agility. This makes the MWA invaluable for quickly mapping the sky and studying rare and faint events as they happen.

Since its launch in 2013, the MWA has collected tens of petabytes of data which are sent over dedicated fibre and the National Broadband Network to the Pawsey Supercomputing Research Centre in Perth. From there, the data are accessed and analysed by hundreds of researchers from around the world using the All-Sky Virtual Observatory.

Research using the MWA is examining the Universe in more detail than previously possible at low frequencies. The MWA's five broad areas of investigation are:

- Early Universe cosmology – searching for and studying the Epoch of Reionisation, the time when the first stars and galaxies began to light up the Universe approximately 13 billion years ago.
- The dynamic Universe – high-sensitivity surveys of the dynamic radio sky, searching for short-timescale and highly variable phenomena.
- Galactic and extragalactic research – studies of the Milky Way and distant galaxies.
- Solar, heliospheric and ionospheric studies – investigating our Sun and its effect on near-Earth space weather, including applications such as improving early warnings of solar storms.
- Pulsars and fast transients – studying flashes of radio light in more detail than ever before.

MWA
MURCHISON
WIDEFIELD
ARRAY

mwatelescope.org

Gurlgamarnu is the Wajarri name given to the MWA telescope, meaning 'the ear that listens to the sky'.

This image represents sitting around a campfire, sharing stories on the stars and sky. The fire takes the form of a meteor as it streaks across the sky, the storytellers sit below and observe, and the dots represent their journey through the stars as they relive stories passed down to them through generations.

Some of the scientific achievements made by MWA astronomers include:

- detecting the largest known eruption in the Universe since the Big Bang
- solving the century-old coronal heating problem
- putting limits on the first-ever fast radio burst with a traceable origin
- the breakthrough discovery of plasma tube structures in the Earth's ionosphere
- involvement in the world's first detection of gravitational waves and radiation from a neutron star merger
- the creation of a catalogue of 300,000 galaxies and the first radio-colour panorama of the Universe in the Galactic and Extra-Galactic All-Sky MWA and Extended (GLEAM and GLEAM-X) surveys, and
- the discovery of new pulsars and an ultra-long period magnetar.

The MWA telescope and its science have been developed by engineers and astrophysicists from across the globe. Institutes in Australia, Canada, China, Japan, Switzerland and the United States currently form the MWA Collaboration, providing funding and critical hardware to the telescope.

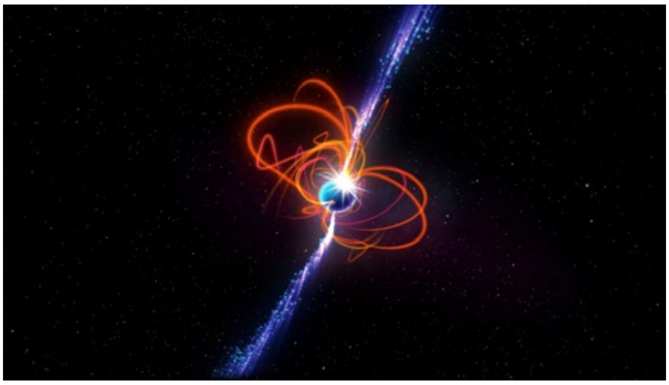
The MWA project is led by Curtin University, and the telescope is maintained and remotely operated by a small team based at the Curtin Institute of Radio Astronomy. Funding for MWA operations is provided by the Australian Government via the National Collaborative Research Infrastructure Strategy (NCRIS), administered by Astronomy Australia Limited (AAL).

Engineering a telescope

MWA technology has been developed to withstand the challenges of the Murchison outback, including extreme temperatures, lightning storms, highly acidic soil, and curious fauna.

The MWA has grown in both size and capability over the years. The original prototype had 32 tiles (512 antennas) in 2011, which was expanded to 128 tiles (2048 antennas) in 2013. The next upgrade in 2016 added another 128 tiles, giving a total of 256 tiles (4096 antennas). These tiles were placed in specific patterns; two hexagonal groups close to the centre of the array, and the rest scattered far away. This doubled the resolution of the telescope and increased its sensitivity by a factor of 10, permitting the detection of finer structures and even fainter objects. In late 2021 the MWA received a significant upgrade with the replacement of its aging 'correlator', the computational engine that acts as the telescope's 'brain'.

The current phase of telescope development involves the design and procurement of new and replacement hardware necessary to upgrade aging instrumentation. This will enhance the telescope's capability, ensuring the resilience of the telescope through the remainder of the decade.



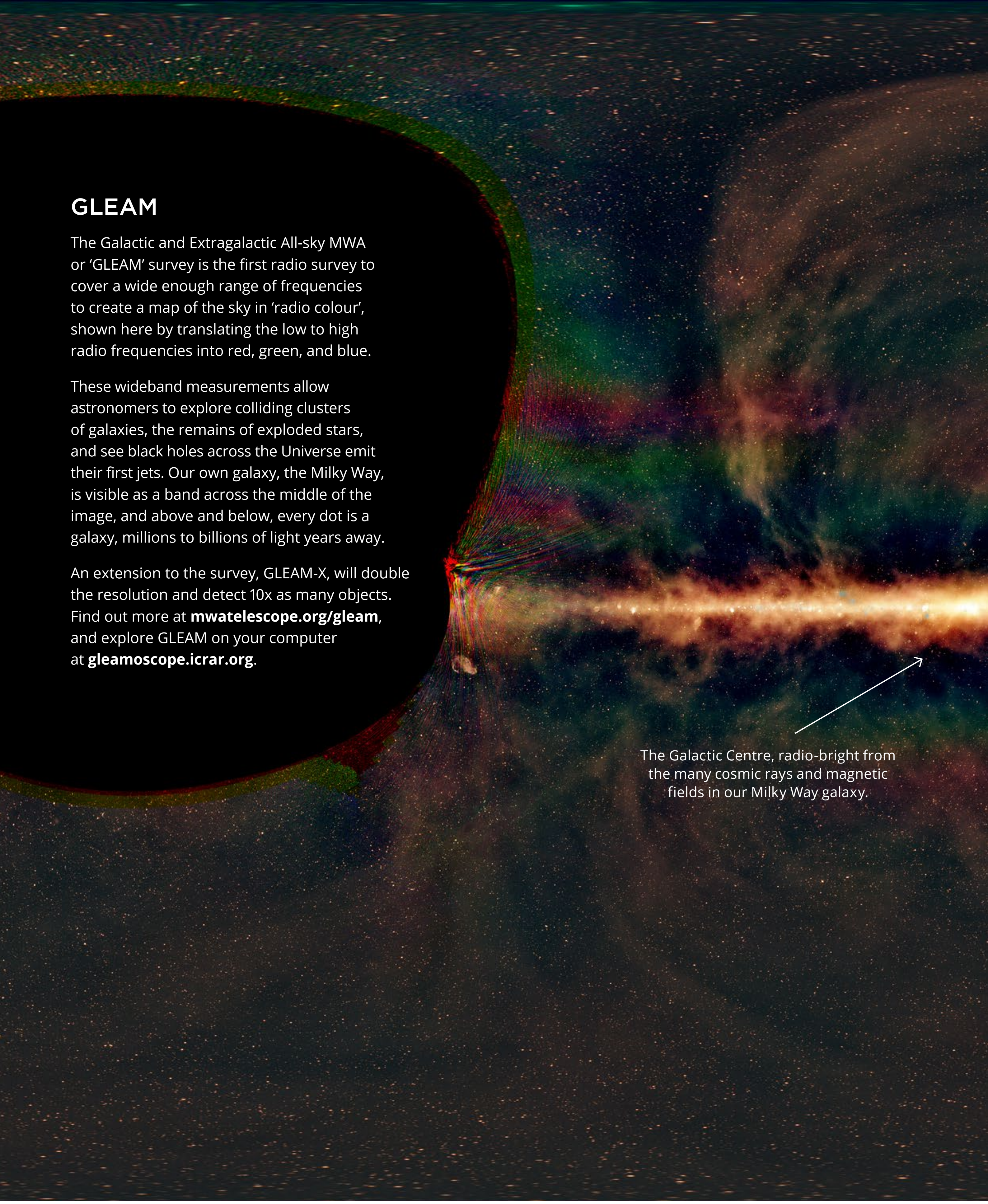
An artist's impression of the ultra-long period magnetar – a rare type of star with extremely strong magnetic fields that can produce powerful bursts of energy. Credit: ICRAR.

GLEAM

The Galactic and Extragalactic All-sky MWA or 'GLEAM' survey is the first radio survey to cover a wide enough range of frequencies to create a map of the sky in 'radio colour', shown here by translating the low to high radio frequencies into red, green, and blue.

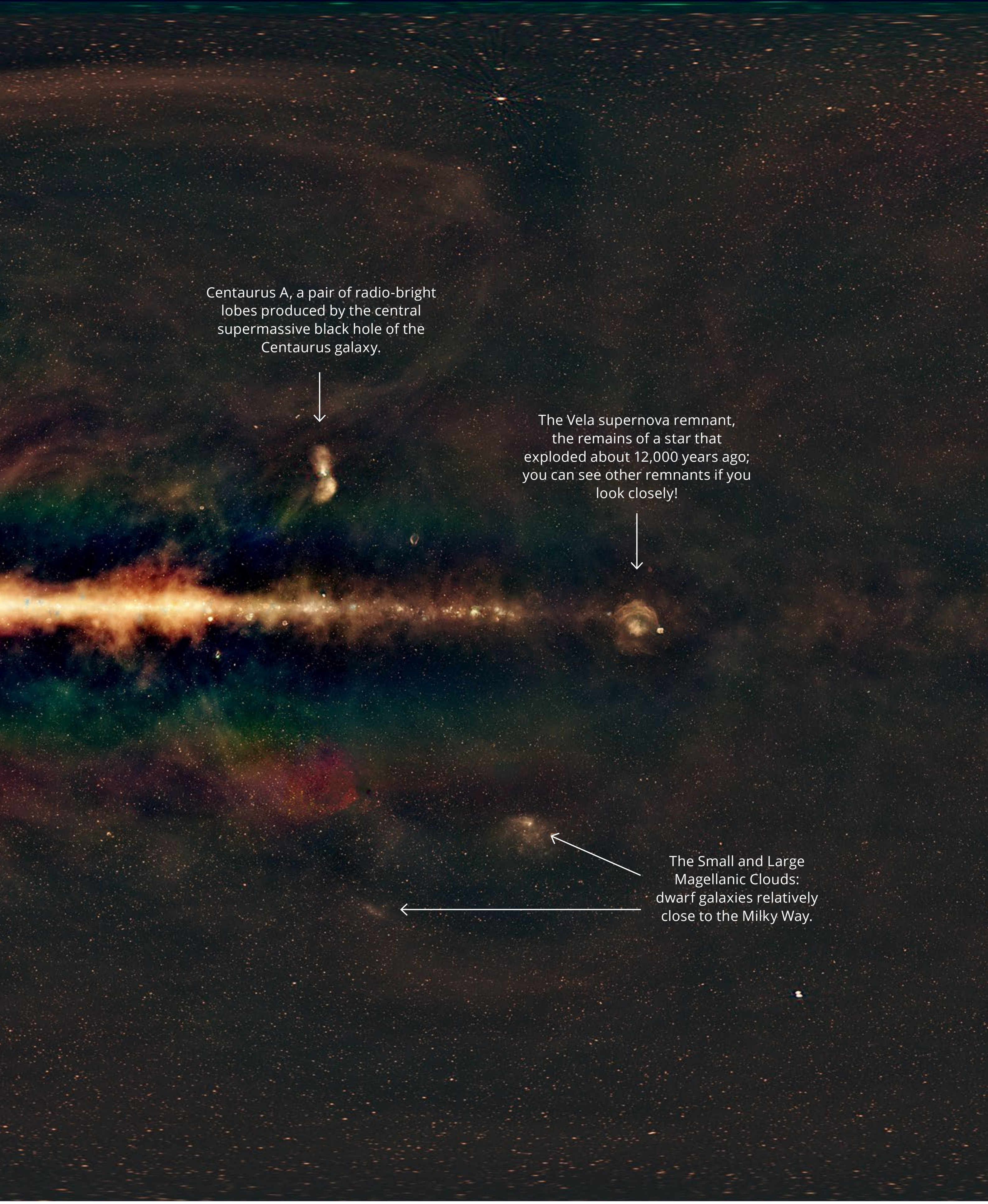
These wideband measurements allow astronomers to explore colliding clusters of galaxies, the remains of exploded stars, and see black holes across the Universe emit their first jets. Our own galaxy, the Milky Way, is visible as a band across the middle of the image, and above and below, every dot is a galaxy, millions to billions of light years away.

An extension to the survey, GLEAM-X, will double the resolution and detect 10x as many objects. Find out more at **mwatelescope.org/gleam**, and explore GLEAM on your computer at **gleamoscope.icrar.org**.



The Galactic Centre, radio-bright from the many cosmic rays and magnetic fields in our Milky Way galaxy.

Credit: Dr Natasha Hurley-Walker (ICRAR/Curtin University) and the GLEAM Team.



Centaurus A, a pair of radio-bright lobes produced by the central supermassive black hole of the Centaurus galaxy.
The Vela supernova remnant, the remains of a star that exploded about 12,000 years ago; you can see other remnants if you look closely!
The Small and Large Magellanic Clouds: dwarf galaxies relatively close to the Milky Way.

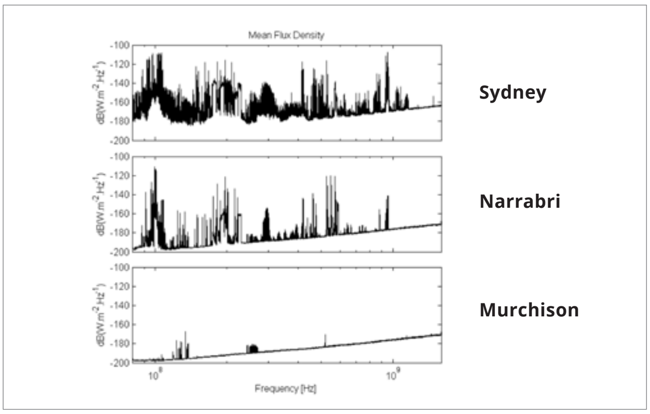


Image: These plots show the radio noise at three Australian locations. The horizontal axis is frequency (the same for all three) and the vertical axis is the strength of the radio noise detected. Sydney is the noisiest location, Narrabri, home of CSIRO's Australia Telescope Compact Array, is better, and the Murchison is much better again. (Note the strength shown is not linear but in decibels.)

The radio quiet zone

Radio telescopes are designed to detect faint natural radio signals from space, but this also makes them very sensitive to the interference caused by human-made radio transmissions. This radio frequency interference can be caused by radio transmitters such as mobile phones, two-way radios and broadcasting towers, or by electrical equipment such as vehicles, appliances or electrical machinery.

The main reason to build an observatory in such a remote location is to avoid Earth-based radio transmissions that interfere with sensitive radio astronomy receivers. In the same way that it is necessary for us to avoid city street lights when trying to observe the night sky with our eyes, radio astronomers must distance themselves from radio communications networks that allow mobile phones and other services to operate

The radio quiet zone was established by the Australian and Western Australian Governments to protect this unique radio astronomy site, ensuring radio astronomy receivers can operate with limited impact from harmful radio interference, while allowing opportunities for coexistence with other activities.

Centred on the observatory, the radio quiet zone is a circular area 520 km wide. Within the radio quiet zone signal levels from radio transmitters and electrical devices are controlled to limit interference to radio telescopes. Within the inner 70 km radius area of the radio quiet zone, radio astronomy is the primary radio-communications activity, with other activities considered secondary.

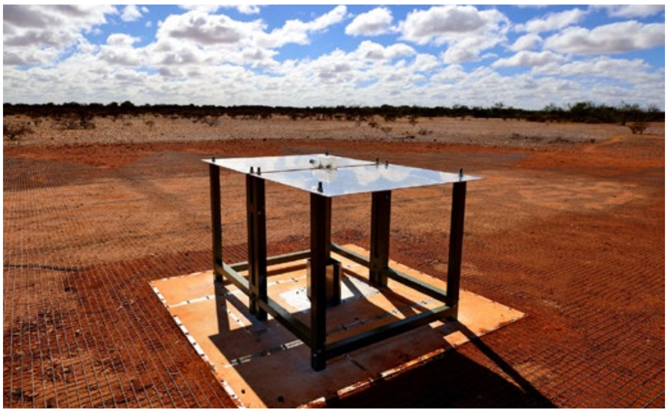
Powering the observatory

As part of CSIRO's long-term commitment to Australian astronomical research and future energy technology, a dedicated power station has been constructed for the existing telescopes at Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory.

The station consists of a 1.85 MW solar array, a lithium-ion battery that can store 2.5 MWh of electrical energy, and four diesel generators. It is the world's first hybrid-renewable facility to power a large remote astronomical observatory. It was built in partnership with Horizon Power and Energy Made Clean.

CSIRO modelling indicates that using this photovoltaic system and storage battery saves up to 800,000 litres of diesel a year and cuts carbon dioxide emissions by about 2,000 tonnes a year. What makes this power station unique is the CSIRO-designed shielding. The shielding keeps electromagnetic interference to levels that don't harm the radio astronomy observations.

The SKA-Low telescope will require an additional 3 MW power station at the observatory, intended to be sourced largely from renewable sources.



Precursors control building

The precursors control building houses on-site computing facilities, called correlators, for ASKAP and the MWA.

The 8,000 fibre optic cables across the observatory transport signals from the antennas to the control building.

ASKAP antennas send analog radio signals through the optical fibres to the building, where they are converted to digital signals and combined to make the 36 antennas into one giant telescope.

The MWA correlator uses off-the-shelf fast computing hardware to combine signals from 256 tiles of antennas.

The control building also houses chillers that extract waste heat from the correlators and transfer it underground maximising cooling efficiency and minimising energy usage.

The control building doorways are an airlock-style pair of doors. The massive steel doors seal tightly shut to ensure that the radio frequency emissions from the computers inside can't escape outside to pollute the radio-quiet environment of the site. The control building also includes workshops where maintenance is conducted on ASKAP's electronic systems, including the receivers, correlator electronics, plus the networking and computing equipment that keeps the observatory operating.

Similar buildings will be required across the observatory for the SKA-Low telescope – a large Central Processing Facility near the core and many smaller Remote Processing Facilities along the spiral arms.

EDGES

The EDGES experiment led by Arizona State University has been operating at the observatory since 2009. The goal of EDGES is to study the first stars and galaxies. These objects formed when the Universe was less than 500 million years old, more than 13 billion years ago. The assumption might be that EDGES looks for light from early stars, but it actually looks for the cosmic fingerprints of early star formation. When stars first formed, they altered primordial hydrogen gas that filled the early Universe, leaving a tiny imprint in the radio spectrum that we can still see today.

Susan Merry,
Our Home, 2023

"Our home: years ago our old people used to walk everywhere hunting for food and water.

Our home: we used to live on Boolardy and go and stay at the top shed. My uncle and brothers and other family members used to go mustering sheep for shearing.

Today all you can see are the antennas large and small, with the wildflowers and hands representing that we all come as one on Land."

– Susan Merry, 2023

Susan Merry, *Our Home*, 2023. The SKAO Council assisted in the creation of this artwork during their visit to the observatory site in 2023.

We acknowledge the Wajarri Yamaji as Traditional Owners and native title holders of Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory.

csiro.au/mro

The SKA project in Australia

SKAO

In partnership with:

Australian Government
Department of Industry, Science and Resources

Department of Jobs, Tourism, Science and Innovation
GOVERNMENT OF WESTERN AUSTRALIA

CSIRO

Wajarri Group

aus SRC
SKAO Regional Centre Australia

ICRAR
International Centre for Radio Astronomy Research

Pawsey

Front cover: Artists' impression of the SKA-Low telescope. Credit: DISR.

B&M | 24-00060