World-class astronomy in the outback

Murchison Radio-astronomy Observatory

Australian Government
Department of Industry, Science, Energy and Resources

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

About Boolardy Station

Boolardy is one of the oldest and largest pastoral stations in Western Australia. It was primarily used for sheep grazing and wool production until the 1980s, when it transitioned to cattle. The station has gradually been de-stocked, with no current pastoral activity.

The land is largely covered in mulga and acacias, with ground types ranging from sandy and stony plains, to ironstone and quartz ridges. The climate is arid with highly variable rainfall averaging 210 millimetres each year, with frequent drought periods. Water is available at accessible depths ranging from 15 to 60 metres.

The region was first explored in the 1850s. Local history recounts that Sir John Forrest, in his then-role of Surveyor General, nearly died on one of his early exploratory trips through the area and the local Wajarri people are credited with saving his life.

He went on to become the first Premier of Western Australia and in 1890 excised land from pastoral lease properties to give to the Wajarri people, establishing the Pia Wadjarri community.

Frank Wittenoom was one of the early leaseholders of the Boolardy Station and one of the key historic cottages in the homestead area is named after him.

In October 2017, the Wajarri Yamatji received legal recognition of their native title claim in the Mid West region of Western Australia, including Boolardy Station.

Murchison Radio-astronomy Observatory

Our Murchison Radio-astronomy Observatory (MRO) is located in the heart of Wajarri country in the Murchison Shire. The current MRO is entirely contained within the 3,500 square kilometres occupied by Boolardy Station.

The Murchison is the size of a small European country but with a population of only just over 100 people. It is this remote location that works so well for radio astronomy – in the same way that optical telescopes need a dark environment to detect light emissions from objects in space, radio telescopes need a 'radio quiet' environment.

Radio telescopes are designed to detect faint natural radio signals from objects in space, but this makes them sensitive to interference caused by Earth-based radio transmitters such as mobile phones, broadcasting towers, and even electrical equipment. The Australian Radio Quiet Zone WA is a legislated radio quiet zone established by the Australian and Western Australian Governments that is centred on the MRO, ensuring radio frequency emissions are managed and the radio telescopes can observe the sky with limited interference.

The MRO was established in 2009 and already hosts three world-class radio telescopes: the ASKAP radio telescope, the Murchison Widefield Array (MWA), and the Experiment to Detect the Global EoR Signature (EDGES). The site will also soon be home to the SKA-Low Telescope, one of two telescopes of the international SKA project.

A hybrid clean energy system, including a massive solar array, provides power to the MRO. Infrastructure on site also includes 8,000 fibre optic cables which transport more than 100 gigabits of data per second from the telescopes to the cutting-edge control building on the MRO.

The MRO is new, but the land it resides on is not. North west of the observatory at nearby Mt Narryer geologists have found some of the oldest rocks on the surface of the planet, estimated to be more than 3.6 billion years old.

As Australia's first astronomers, Aboriginal Australians have been observing the sky for tens of thousands of years. We are very grateful to the Wajarri Yamatji, traditional owners of the MRO site, for the support they have shown as we work to further astronomical knowledge from their ancient lands.

csiro.au/mro

Aboriginal people have lived in Australia for tens of thousands of years and the Wajarri Yamatji have lived in the Mid West region of Western Australia for much of this time. Stories about the stars form a crucial part of Wajarri lore. Standing on these wide-open lands we can see so much of the sky, it's no wonder the Wajarri have so many stories about the stars, galaxies and shapes they observe in the Murchison night skies.

We acknowledge the Wajarri Yamatji as the traditional owners of the Murchison Radio-astronomy Observatory site.

ASKAP radio telescope

Our latest radio telescope, the ASKAP radio telescope, is designed for fast, comprehensive and detailed surveys of the sky.

ASKAP has 36 antennas, each with a 12-metre wide dish, and an advanced phased array feed receiver. Each receiver allows for a wider view of the Universe, giving ASKAP the ability to be one of the fastest survey telescopes in the world.

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

The main science goal 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.

ASKAP detects radio waves between 700 and 1800 MHz, which are similar frequencies to digital TV broadcasts and 4G mobile networks. This means that the telescope itself must be located a long way from human settlements, so that terrestrial signals don't interfere with the weaker signals coming from natural sources in space.

A new era for astronomy

Rapid survey telescopes bring astronomy into a new era of discovery. In 2020, ASKAP's first all-sky survey discovered one million new galaxies and we will find millions more.

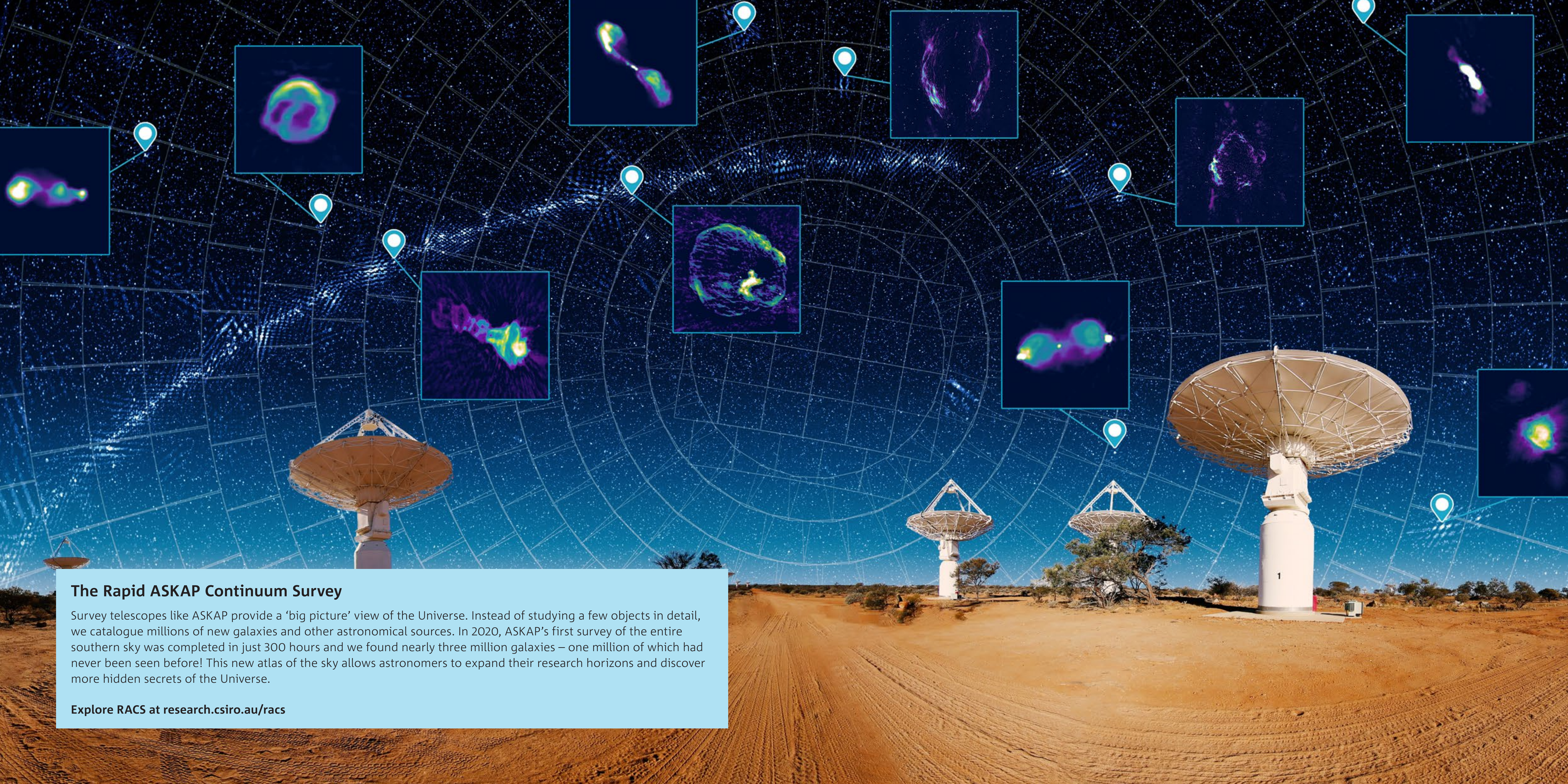
Hundreds of astronomers from Australia and around the world have gathered into survey science teams with unique research goals that rely on ASKAP data. These include:

- mapping the velocity of cosmic gas clouds
- measuring the strength of magnetic fields in space
- understanding star formation throughout cosmic history, and
- studying the origins of transient sources such as fast radio bursts.

As well as making new discoveries, pathfinder telescopes like ASKAP push the boundaries of technology. Experience gained with ASKAP and other pathfinders has guided the design and construction of the world's largest radio observatory, the SKA Observatory. 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.

csiro.au/askap

Strangely circular shapes, dubbed 'odd radio circles', were discovered in large survey data by researchers using ASKAP. Though distant, faint and rare, odd radio circles are huge: about a million light years across and encircling multiple galaxies. After ASKAP had detected the first few, other telescopes are now searching for them. Much about odd radio circles remains a mystery – but as our instruments get better, so will our understanding of the Universe.



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. In 2020, ASKAP’s first survey of the entire southern sky was completed in just 300 hours and we 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

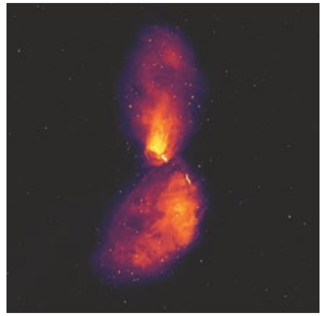
Murchison Widefield Array

The Murchison Widefield Array (MWA) is a radio telescope made of thousands of spider-like metal antennas, arranged in regular grids known as tiles spread over several kilometres within the MRO. Like ASKAP, the MWA is an official precursor instrument to the SKA.

The MWA watches the sky constantly and is tuned to receive radio frequencies between 70 and 300MHz. It is special because of 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.

Research using the MWA is examining the Universe in more detail than previously possible at low frequencies. The four 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 forming approximately 13 billion years ago.
- The dynamic Universe – high-sensitivity surveys of the dynamic radio sky.
- 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.



Centaurus A, the nearest active supermassive black hole to Earth, imaged with the MWA telescope. Credit: Ben McKinley, ICRAR/Curtin and Connor Matherne, LSU. 2021

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.

Some of the scientific achievements made by astronomers using the MWA 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 GLEAM all-sky survey, and
- the discovery of new pulsars and an ultra-long period magnetar.

The MWA has been developed by an international collaboration, including partners from Australia, New Zealand, Japan, China, India, Canada and the United States. 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 is provided by partner institutions and the Australian Government under the National Collaborative Research Infrastructure Strategy.

mwatelescope.org

MWA
MURCHISON
WIDEFIELD
ARRAY

Upgrading a telescope

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 were placed in specific patterns; two hexagonal grids 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.

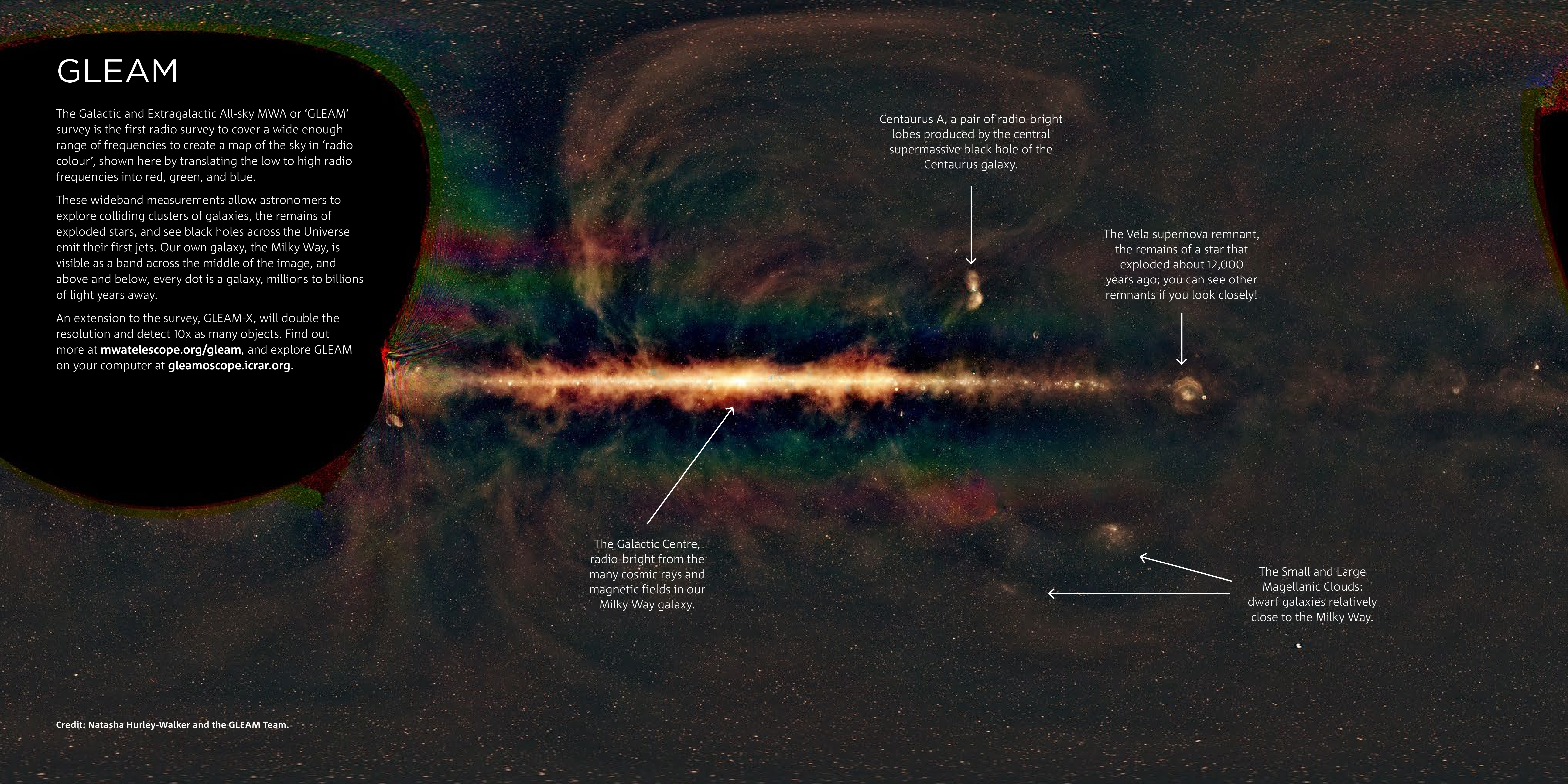
The MWA signpost off the main road into the Observatory. Credit: Greg Rowbotham, ICRAR/UWA (2016).

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**.



Credit: Natasha Hurley-Walker and the GLEAM Team.

SKA-Low Telescope

The SKA project, previously known as the Square Kilometre Array, aims to deliver the largest and most sensitive radio astronomy facility in the world, built and operated by the SKA Observatory (SKAO).

The SKAO will use cutting-edge technology to enable transformational science, revolutionising our understanding of the Universe. The SKA project promises to have a major impact on society, in science and beyond.

Science

The SKAO's science goals are broad and ambitious. It will investigate the history of the Universe as far back as the cosmic dawn, when the very first stars and galaxies formed, to seek answers to some of the biggest questions in astronomy. The SKA telescopes will build on and enhance the great scientific discoveries of the SKA pathfinder telescopes, including ASKAP and the MWA.

Hosting SKA-Low

SKA-Low is the first mega-science project to be hosted in Australia. We are preparing the MRO for the construction and operation of SKA-Low.

Prototype systems for SKA-Low have been installed on the MRO site, led by Curtin University and the Italian National Institute of Astrophysics, with support from the Netherlands Institute for Radio Astronomy. Testing these SKA-Low antennas has helped confirm the final design.

Having the MWA telescope and the prototype SKA-Low system on the same site has enabled engineers to make direct comparisons between them, which has been important to the development process.

One global observatory

The SKAO is one observatory with two telescopes: SKA-Low in Western Australia and SKA-Mid in South Africa. Australia is a member of the SKAO, an intergovernmental organisation headquartered in the UK, and will co-host its facilities together with South Africa and the UK.

SKA-Low is the low-frequency array that will be located at the MRO. In Australia, CSIRO is collaborating with the SKAO to operate SKA-Low and support construction.

SKA-Low will consist of an array of 131,072 Christmas tree-shaped antennas, grouped in 512 stations, each with 256 antennas. The antenna stations will span out from a central 'core' along three spiral arms, stretching 65 kilometres end-to-end. The SKA low-frequency antennas will cover the frequency range 50-350 MHz, similar frequencies to FM radio stations and TV stations.

It will complement SKA-Mid, an array of 197 'dish' antennas, each 15 metres in diameter, dotted across the Karoo and operated with the support of the South African Radio Astronomy Observatory.

The two separate telescope arrays will, together with the data processing centres and the UK-based headquarters, form a single observatory.

This is radio astronomy on an immense scale. Spreading the antennas over huge distances will enable very fine resolution imaging, revealing the Universe in a level of detail never seen before.

skao.int

Driving innovation and technology

Designing the SKA telescopes was a global effort overseen by the precursor to the SKAO, involving 600 experts from 20 countries over six years. The project will help to develop new technologies that will likely yield substantial benefits in our everyday lives in years to come.

Processing SKA telescope data will require the development of high-speed data transmission and data analytics beyond anything that's been done before. Innovative design and adoption of more efficient technologies has also enabled the telescope to vastly decrease its estimated power consumption, to meet its sustainability goals.

Processing the data 'deluge'

The SKA telescopes require significant data processing both on and off site to manage the extremely large volume of information they will collect.

SKA-Low data will be processed at the MRO in a state-of-the-art computing facility which will transmit the data to the Pawsey Supercomputing Research Centre in Perth for imaging. From here it will be distributed to SKA Regional Centres (SRCs) around the globe, including in Australia, which will act as windows to the Observatory and enable the world-leading science the SKA project promises.

The development of the SKA project in Australia and membership of the SKAO is coordinated by the Australian Government's SKA Office in partnership with the Western Australian Government, CSIRO and the International Centre for Radio Astronomy Research. The Australian SKA Office can be contacted at **SKA@industry.gov.au**

MRO control building

The MRO control building houses on-site computing facilities, called correlators, for ASKAP and the MWA. ASKAP antennas send analog radio signals via optical fibres to the building, where they are converted to digital signals, combined to form 36 beams from each antenna, and finally combined to turn all 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 to a large borefield, making use of the cooler temperatures underground.

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 pristine radio-quiet environment of the MRO.

The control building also includes workshops where maintenance is conducted on ASKAP's electronic systems, including the PAF receivers, correlator electronics, and the networking and computing equipment that keeps the MRO running.

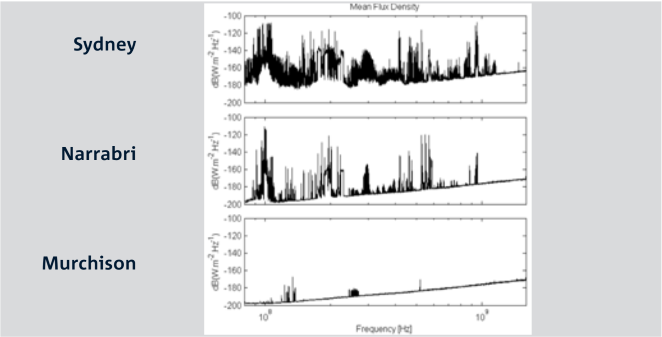
Powering the MRO

As part of our long-term commitment to Australian astronomical research and future energy technology, we have constructed a dedicated power station for the MRO.

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.

Our 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 shielding we designed. The shielding keeps electromagnetic interference to levels that don't harm the radio astronomy observations.



MRO 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.

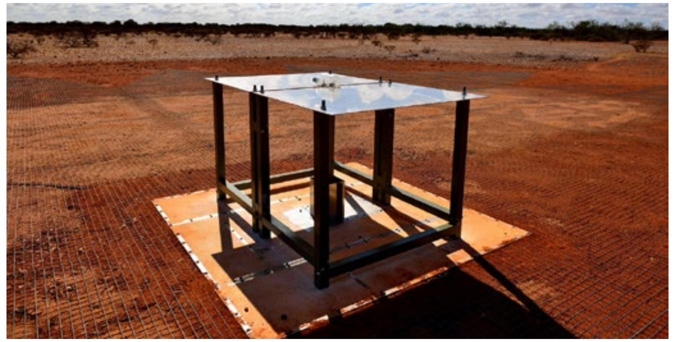
This radio frequency interference can be caused by radio transmitters such as mobile phones, two-way radios and broadcasting towers, or by electrical equipment such as vehicles, appliances or electrical machinery.

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 streetlights 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 Australian Radio Quiet Zone WA (ARQZWA) was established by the Australian and Western Australian Governments to protect radio astronomy receivers from harmful radio interference, while allowing opportunities for coexistence with other activities.

Above 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 is better, and the Murchison is much better again. (Note the strength shown is not linear but in decibels.)



EDGES

The EDGES experiment led by Arizona State University has been operating at the MRO 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.

The MRO has been built with the support of:

AARNet

Arizona State University

Astronomy Australia Limited

Australian Communications and Media Authority

Australian Government – Department of Industry, Science, Energy and Resources

Australian Government – Department of Education, Skills and Employment

Curtin University

International Centre for Radio Astronomy Research

Meenangu Wajarri Aboriginal Corporation

Mid West Development Commission

Murchison Shire Council and Shire residents

MWA Collaboration

The University of Western Australia

Wajarri Yamatji

Wajarri Yamaji Aboriginal Corporation

Western Australian Government

Yamatji Marlpa Aboriginal Corporation

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Front cover: The Milky Way stretches above the ASKAP radio telescope; while the setting Moon, hidden behind the pedestal, is reflected in the phased array feed of antenna number 6.

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