Exploring the Universe with the world’s largest radio telescope
SKA; the next generation radio telescope

The Square Kilometre Array (SKA) is one of the most ambitious science projects on earth, aiming to build a radio telescope that will enable breakthrough science and discoveries not possible with current facilities. Located over two sites in Australia and Africa, it will eventually provide over a million square metres of collecting area through many thousands of connected antennas.

But the SKA will not only be the world’s largest radio telescope. It will be the culmination of a long history of radio astronomy over many decades in all of the SKA partner countries, a history shaped by generations of world-leading astronomers.

With the SKA 2016 calendar, we decided to pay tribute to this heritage by featuring iconic radio telescopes that represent part of this history.

The numerous spin-offs generated by the development of these facilities as well as the contribution of these telescopes to radio astronomy, to science and to society in general have been and continue to be critical. They constitute an important driver for their countries and eventually others to be part of the extraordinary adventure of building a next generation radio telescope like the Square Kilometre Array.

We wish you an excellent year 2016!

SKA Organisation

Front cover image: Photo montage of all radio astronomy facilities featured in this calendar. You’ll find details for each of these telescopes by browsing the calendar.

Image above: Artist’s impression showing what the SKA will look like, with the impressive 15-m diameter dishes to be located in Africa featured on the left hand side of the image and the low-frequency antennas to be located in Australia on the right hand side. Credit: SKA Organisation
The CSIRO’s Parkes radio telescope, also known as “The Dish” in reference to a popular movie featuring the telescope, was completed in 1961. Measuring 64 metres in diameter, it is still the second largest radio telescope in the Southern Hemisphere.

Some of the milestones of The Dish include helping the Apollo 11 mission land on the moon, detecting the world’s first double-pulsar system and more recently, being involved in an international project to search for extraterrestrial intelligence.

After more than 50 years of operations, its scientific contributions over the decades led the national public broadcaster ABC to describe it as “the most successful scientific instrument ever built in Australia”.

Main image: Credit: CSIRO

Thumbnail: A short, sharp flash of radio waves (Fast Radio Burst, or FRBs) from a mysterious source up to 5.5 billion light years from Earth was detected by CSIRO’s Parkes radio telescope in Australia. Photo courtesy: CSIRO
### January 2016

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**Australia National Day**
- Date of the founding of Sydney, the first European settlement in Australia, 1788.

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**Notes**

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This map is intended for reference only and is not meant to represent legal borders.
The 26-metre John A. Galt Telescope was the first parabolic antenna established by Canada’s National Research Council (NRC) at the Dominion Radio Astrophysical Observatory (DRAO) in Penticton, BC. Achieving first light in 1960, it is capable of observing wavelengths from 3.5 to 74 cm.

The telescope played a significant role in the development of Very Long Baseline Interferometry (VLBI), a technique used to link widely separated antennas to form a “telescope” as large as an entire continent. In 2010 the telescope was awarded an IEEE Milestone Award for the “First Radio Astronomical Observations Using VLBI.” This milestone occurred on the morning of April 17, 1967 with observations from the Galt telescope and a second one at the Algonquin Radio Observatory located 3074 km away. This work was also awarded the 1971 Rumford Prize by the American Academy of Arts and Sciences.

The VLBI technique developed in part thanks to the Galt telescope is an essential part of the SKA, where hundreds and eventually thousands of antennas spread over hundreds of kilometres are connected and operating together as a single telescope.

Main image: Credit: Jennifer West
Thumbnail: Credit: NRC
## Notes

- African partner countries (non-member SKA Phase 2 host countries)
- SKA Headquarters host country
- SKA Phase 1 and Phase 2 host countries

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**February 2016**

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The Five hundred meter Aperture Spherical Telescope (FAST) is a National Astronomical Observatory of China (NAOC) mega-science project under construction in the Southwest of the country. FAST construction officially commenced in March 2011, and the first light is expected to be in September 2016.

Once completed, FAST will be the world’s largest single-dish non-steerable radio telescope, being three times more sensitive than the Arecibo Observatory. The telescope’s reflector will measure 500 metres in diameter and be equipped with 4,450 panels. Each panel is shaped like a triangle, with each side measuring 11 metres long.

An impressive engineering marvel, FAST will enable astronomers to jump-start many science goals, such as surveying the neutral hydrogen in the Milky Way and other galaxies, detecting faint pulsars, looking for the first shining stars, hearing the possible signals from other civilizations, and many others.

FAST was proposed as a potential design for the SKA in the early stages of the project, which would have seen a number of such dishes built to operate together.

Main image: Photo taken in late November 2015 showing the impressive progress in the construction of the telescope, which started in March 2011. Credit: FAST Project/NAOC

Thumbnail: Artist’s impression showing what FAST will look like when completed. Credit: FAST Project/NAOC
The Five hundred meter Aperture Spherical Telescope (FAST) is a National Astronomical Observatory of China (NAOC) mega-science project under construction in the Southwest of the country. FAST construction officially commenced in March 2011, and the first light is expected to be in September 2016. Once completed, FAST will be the world's largest single-dish non-steerable radio telescope, being three times more sensitive than the Arecibo Observatory. The telescope's reflector will measure 500 metres in diameter and be equipped with 4,450 panels. Each panel is shaped like a triangle, with each side measuring 11 metres long. An impressive engineering marvel, FAST will enable astronomers to jump-start many science goals, such as surveying the neutral hydrogen in the Milky Way and other galaxies, detecting faint pulsars, looking for the first shining stars, hearing the possible signals from other civilizations, and many others. FAST was proposed as a potential design for the SKA in the early stages of the project, which would have seen a number of such dishes built to operate together.

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Giant Metrewave Radio Telescope (GMRT). INDIA

GMRT currently is the world’s largest radio telescope facility operating at low radio frequencies, consisting of an array of 30 fully steerable, 45 metre diameter antennas, spread out over a 30 km region around Khodad, near Narayangaon town of Pune district in western India. The GMRT was built and is operated by National Centre for Radio Astrophysics (NCRA) of the Tata Institute of Fundamental Research, Pune and has been in operation since 2002.

Astronomers from all over the world regularly use this telescope to observe many different astronomical objects such as HII regions, galaxies, pulsars, supernovae and sun and solar winds. Each year on National Science Day the observatory invites the public and pupils from schools and colleges in the surrounding area to visit the site.

In 2015, SKA Organisation accorded the status of a “SKA Pathfinder” to the GMRT, in recognition of important technical and scientific developments being carried out for upgrading the GMRT. In particular, the team at GMRT and NCRA are developing the Telescope Monitoring software that will be used for the SKA.

Main image and thumbnail: Credit: NCRA
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Notes

African partner countries
(non-member SKA Phase 2 host countries)

This map is intended for reference only and is not meant to represent legal borders

Full members
SKA Headquarters host country
SKA Phase 1 and Phase 2 host countries

The Netherlands

Located in Cagliari, Sardinia, Italy, SRT is a major radio astronomical facility, the biggest in the country. It combines one of the largest steerable collecting area all over the world (64m dish). The optical system is based on a quasi-Gregorian dish antenna with mirrors shaped to minimize the standing wave bouncing between the two reflectors. Three additional mirrors increase the number of focal positions. A collaboration between INAF and the Italian Space Agency (ASI), SRT is an important node in the International and Space VLBI network.

First light: 8 August 2012
First success: observation of a “magnetar” in 2013 (thumbnail above), a subclass of neutron stars having magnetic fields more than 100 times higher than those typically observed in normal pulsars (in themselves exceptionally high).

Recently, SRT detected the signal from ESA’s probe Rosetta orbiting around Comet 67P / Churyumov-Gerasimenko. Italy is one of the founding members of the SKA and is currently leading the current international negotiations towards establishing SKA Observatory as an Inter-Governmental Organisation.

Main image: Credit: INAF/OA Cagliari
Thumbnail: Credit: NASA’s Chandra X-Ray Observatory
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**Notes**

- African partner countries (non-member SKA Phase 2 host countries)
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LOFAR is located in the Netherlands and surrounding countries with 47 operational stations, in total 50,000 antennas, and operates from 10 till 250 MHz.

The first successful test observations were performed on July 8/9 2009 and the first science observations were taken in December 2012. LOFAR is a very versatile facility contributing in many areas of low frequency radio astronomy, such as probing the Era of Reionisation, producing high-resolution images and pulsar observations. A rare feature is the ability to record data for each of its thousands of antennas. This can be used to detect radio waves from cosmic particles.

The main image shows the inner LOFAR stations. The colour map (thumbnail above) indicates the predicted radio waves of a cosmic particle, where red is high intensity and blue is low intensity. The circles show the measured intensity from the antennas, which matches the predictions.

LOFAR is an SKA pathfinder, testing technologies very similar to those that will be applied to SKA-low, the low frequency instrument of SKA to be located in Australia.

Main image: Credit: Top-Foto, Assen
LOFAR antenna close-up: Credit: Hans Hordijk
Thumbnail: Credit: Stijn Buitink and the LOFAR Key Science Project Cosmic Rays
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**Notes**  

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The Warkworth 30m Radio Telescope is at the Warkworth Radio Astronomical Observatory, just south of Warkworth about 50 km north of Auckland. It is operated by the Institute for Radio Astronomy and Space Research, Auckland University of Technology.

New Zealand has been very active in radio astronomy over the years, including at Warkworth, and has strongly developed international collaborations in the recent past, using facilities around the world. For instance, about 90% of all refereed publications in radio astronomy in the country use data coming from telescopes such as LOFAR, the Australia Telescope Compact Array (ATCA) or the Murchison Widefield Array (MWA).

While no SKA infrastructure will be located in New Zealand, the country is deeply involved in developing technologies for the project, in particular through the Science Data Processor (SDP) and Central Signal Processor (CSP) consortia.

Image credit: Hufton and Crow for SKA Organisation.
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Hartebeesthoek Radio Astronomy Observatory (HartRAO). SOUTH AFRICA

HartRAO (Hartebeesthoek Radio Astronomy Observatory) 26m radio telescope is located 65 kilometres north-west of Johannesburg, South Africa.

The radio telescope is an equatorially mounted 85 foot Cassegrain design built by Blaw Knox in 1961. For several years, it assisted in tracking many unmanned United States space missions, including the Ranger, Surveyor and Lunar Orbiter spacecraft (which landed on the Moon or mapped it from orbit), the Mariner missions (which explored the planets Venus and Mars) and the Pioneer missions (which measured the Sun’s winds).

Nowadays, the HartRAO telescope is used for astronomical, astrometric and geodetic Very Long Baseline Interferometry (VLBI) connected with telescopes around the globe. The XDM, a prototype dish for the MeerKAT radio telescope, was also constructed at HartRAO. The XDM dish design was first used in KAT-7, a seven-dish engineering testbed and science instrument located at the MeerKAT and SKA site in the South African Karoo.

Image credit: Thomas Abbott
### August 2016

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**Notes**

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African partner countries (non-member SKA Phase 2 host countries)

This map is intended for reference only and is not meant to represent legal borders.

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India National Day

Independence from the British Empire in 1947.

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Full members

SKA Headquarters host country

SKA Phase 1 and Phase 2 host countries
Onsala Space Observatory. SWEDEN

Onsala Space Observatory is home to many radio telescopes. On the main image are shown two of these, the 20-metre telescope in its white protecting dome (left) and the majestic 25-metre telescope, here taking part in international long-baseline observations.

It is also one of the world's few fundamental geodetic stations, which means its position in three-dimensional space is better-known than almost anywhere else on Earth.

Onsala has been the home of Swedish radio astronomy since 1949, and is now also the base from which new technology and new ideas are being developed in many international collaborations.

For instance, SKA-related technologies tested at Onsala include the Wideband Single Pixel Feeds (WBSPF), an element of the SKA Advanced Instrumentation Programme aiming at developing a broad spectrum single pixel feed for the SKA.

Main image and thumbnail: Credit: Onsala Space Observatory/Anna-Lena Lundqvist
The Lovell Telescope.

UNITED KINGDOM

For over 50 years the giant Lovell Telescope at Jodrell Bank has been a familiar feature of the Cheshire landscape and an internationally renowned landmark in the world of astronomy. Originally known as the “250 ft telescope”, it then became the Mark I telescope around 1961 and was renamed to the Lovell Telescope in 1987 after its creator Sir Bernard Lovell, first Director of Jodrell Bank Observatory.

Since the summer of 1957 it has been quietly probing the depths of space, a symbol of our wish to understand the universe in which we live. In particular, in its early days the telescope was used to track both Soviet and American probes aimed at the Moon in the late 1950s and early 1960s. Even now, it remains one of the biggest and most powerful radio telescopes in the world, spending most of its time investigating cosmic phenomena which were undreamed of when it was conceived.

Jodrell Bank is one of the birthplaces of radio-astronomy and as such, benefits from a long expertise in radio-astronomy.

It is home to e-Merlin, the UK’s national interferometer, where signals from 7 radio telescopes around the country are combined.

The team working on the signal and data transport technologies essential to the SKA is based at Jodrell Bank.

Main image: Credit: Manchester University

Thumbnail: View of the SKA Headquarters, with the Lovell telescope in the back.
Iconic radio telescopes at SKA partner countries

- **Effelsberg telescope. Germany.** Effelsberg is the second world’s largest steerable telescope. Credit: MPIfR/Norbert Tacken
- **Nobeyama telescope. Japan.** Credit: National Astronomical Observatory of Japan
- **IRAM 30-m telescope. Spain.** Credit: wikimedia.org
- **Green Bank Telescope. GBT is the world’s largest steerable telescope. USA. Credit: NRAO/AUI**
- **Jansky Very Large Array (J-VLA) telescope. USA. Credit: NRAO/AUI**
- **University of Porto Solar Radio Spectrograph. Portugal**
- **Nançay Observatory. France.** Nançay is home to a LOFAR station and to the Nenufar telescope, both pathfinder facilities to the SKA. Credit: Station de Radioastronomie Observatoire de Paris/CNRS/Université d’Orléans. I. Thomas
- **Instituto de Telecomunicações GEM 9-metre radiotelescope. Portugal**
Building up on their long tradition in radio astronomy, both Australia and South Africa, host countries for the 2 SKA telescopes, have been developing precursor instruments in preparation for the SKA. These precursors are and will be in future carrying out scientific study related to future SKA activities, as well as helping the development and testing of new crucial SKA technologies.

In Australia, the Murchison Widefield Array (MWA) is the low frequency precursor to the SKA, already in operation and delivering first-class science (middle photo). The MWA has been developed by an international collaboration, including partners from Australia, India, New Zealand, and the United States. The second precursor telescope in the country is the Australian SKA Pathfinder (ASKAP), currently under commissioning (bottom photo). First scientific results published in 2015 demonstrated the excellent capability of the Phased Array Feeds (PAF) receivers, and what the full ASKAP telescope will be able to do on much larger areas of the sky and to much larger distances.

In South Africa, the precursor telescope to the SKA is called MeerKAT, an array of sixty four 13.5-m diameter antennas (top photo). MeerKAT is currently being built some 90 km outside the small Northern Cape town of Carnarvon and the end of construction is foreseen in 2017. MeerKAT will be a world-class instrument in its own right before being integrated into the mid-frequency component of the SKA Phase 1.

Image credits, from top to bottom: MeerKAT: Sarel - Photowise; MWA: John Goldsmith, Celestialvisions.com.au; ASKAP: Alex Cherney/terrastro.com
December 2016

Notes

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SKA Headquarters host country
SKA Phase 1 and Phase 2 host countries

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Full members
The Square Kilometre Array (SKA) will be the world's largest radio telescope, revolutionising our understanding of the Universe. The SKA will be built in two phases - SKA1 and SKA2 - starting in 2018, with SKA1 representing a fraction of the full SKA. SKA1 will include two instruments - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies.

A telescope's capacity to receive faint signals - called sensitivity - depends on its collecting area, the bigger the better. But just like you can't compare radio telescopes and optical telescopes, comparison only works between telescopes working in similar frequencies, hence the different categories above.

The collecting area is just one aspect of a telescope's capability though. Arrays like the SKA have an advantage over single dish telescopes: by being spread over long distances, they simulate a virtual dish the size of that distance and so can see smaller details in the sky, this is called resolution.

How does SKA1 compare with the world's biggest radio telescopes?