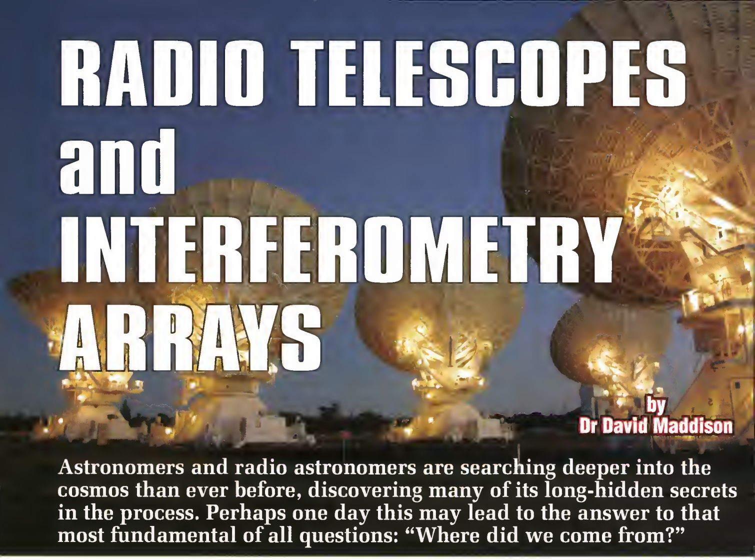


RADIO TELESCOPES and INTERFEROMETRY ARRAYS

by **Dr David Maddison**

Astronomers and radio astronomers are searching deeper into the cosmos than ever before, discovering many of its long-hidden secrets in the process. Perhaps one day this may lead to the answer to that most fundamental of all questions: "Where did we come from?"

Astronomers use two main types of telescopes to observe the universe.

First and most familiar is the optical telescope, which uses lenses or mirrors to focus light. The universe is normally observed at optical (visible) frequencies but in some cases in the infrared and ultraviolet spectrum.

Second is the radio telescope, which allows observations at radio frequencies. Typically, they use parabolic dishes or other types of tuned antennas to collect incoming radio signals.

Other types of radio telescopes allow observations in the gamma ray spectrum, the X-ray spectrum, and the microwave spectrum.

Table 1 shows typical wavelengths and frequencies for different types of telescopic observations.

Observations at lower radio frequencies, from 10-100MHz, typically use directional antennas somewhat similar to TV antennas, or large stationary reflectors made of wire mesh, with moveable focal points. Beyond 100MHz, they normally use parabolic dishes.

Some common observing frequencies in radio astronomy are 13.36-13.41MHz, 25.55-25.67MHz, 73.00-74.60MHz, 150.05-153.00MHz, 406.10-410.00MHz, 608.00-614.00MHz, 1.400-1.427GHz, 1.6106-1.6138GHz, 1.660-1.670GHz, 2.655-2.700 GHz, 4.800-5.000GHz, 10.600-10.700GHz and 18.280-18.360GHz.

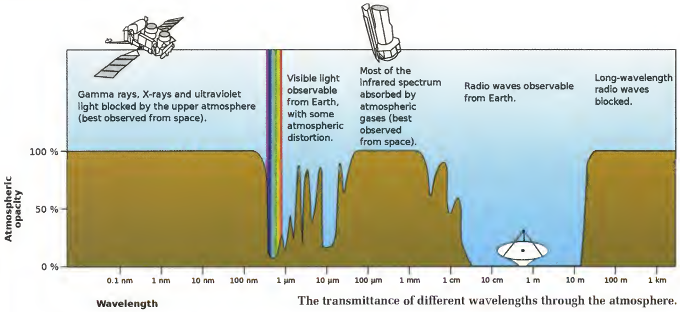
This is by no means a complete list but gives an idea of the ranges used. The two lowest frequency bands are used for solar and Jupiter observations; 73, 150 and 406MHz segments are used to observe pulsars and the 1.4GHz segment is used to observe hydrogen.

Not all radio wavelengths penetrate the Earth's atmosphere. Indeed, early radio astronomers thought no radio

TYPE OF OBSERVATION	WAVELENGTH	FREQUENCY
Gamma ray	<0.01nm	>10EHz
X-Ray	0.01 to 10nm	30EHz to 30PHz
Ultraviolet	10 to 400nm	30PHz to 790THz
Visible light	390 to 750nm	790 to 405THz
Infra-red	750nm to 1mm	405THz to 300GHz
Microwave	1mm to 1m	300GHz to 300MHz
Radio	1mm to 1km	300GHz to 3Hz

(Frequency prefixes are E for exa (10^{18}), P for peta (10^{15}), T for tera (10^{12}), G for giga (10^{9}); note the overlap between radio and microwave.)

Table 1: typical wavelengths and frequencies for different types of telescopic observations.



The transmittance of different wavelengths through the atmosphere.

waves at all would reach Earth from space as they would be reflected by the ionosphere.

(For more information see SILICON CHIP article May 2016 *"Atmospheric Electricity: Nature's Spectacular Fireworks"* siliconchip.com.au/l/aad5).

Fortunately, however, radio wavelengths do get through.

Competition for spectrum between astronomers and other users is an ongoing problem.

Frequencies between 327MHz and 809GHz, used to observe the spectra of various molecules, are partially protected from other use (see siliconchip.com.au/l/aad6).

Other parts of the spectrum are fully protected by international convention. See siliconchip.com.au/l/aad7 for a comprehensive list.

Big dish good; huge dish better

The reception of radio signals is naturally limited by the size of the dish antenna and where it is pointing.

And unlike optical telescopes which are constrained by weather conditions such as cloud and only able to be used at night, radio telescopes can be used continuously.

As can be seen from Table 1, they also operate at many times the wavelength used by optical telescopes and do not need to be made to the precision tolerances of optical equipment.

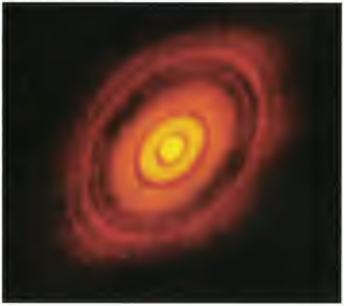
However, to obtain a resolution (the ability to separate close objects or distinguish small details) similar to that of optical telescopes, they have to be a great deal larger, due to the longer wavelengths of radio waves.

Lower frequencies require a larger dish size than higher frequencies. A common size of radio dish is 25m in diameter.

The largest fully steerable radio telescope is the 100m diameter **Green Bank Telescope** in West Virginia, USA with a collecting area of nearly 1 hectare. In comparison, the radio telescope at Parkes, NSW, also one of the largest in the world, is 64 metres in diameter but there is also a larger steerable dish in Australia, the 70m diameter DSS-43 antenna at the Canberra Deep Space Communication Complex.

The one time record holder for the largest radio telescope in the world is the **Arecibo telescope** in Puerto Rico, run by the US National Science Foundation.

Galaxy Centaurus A composite image with individual views in the X-ray, radio and optical wavelengths. The radio emissions from the hot spots are due to synchrotron radiation (radiation that results when a charged particle is accelerated in a curved path) and were imaged with the Jansky VLA telescope. It is one of the most powerful radio sources in the universe and was discovered in 1939. It is notable for the two enormous jets (purple in the radio image) being emitted from the core of the galaxy. ***Image credit: X-ray – NASA, CXC, R.Kraft (CfA), et al.; Radio - NSF, VLA, M.Hardcastle (U Hertfordshire) et al.; Optical - ESO, M.Rejkuba (ESO-Garching) et al.; CC-BY-SA-4.0***



(Above): the Atacama Large Millimeter Array (ALMA) built at an altitude of 5000m on the high dry desert plain near Cerro Chajnator in Chile which has an observing capability up to 1THz. *Image courtesy of NRAO/AUI.*

At right is a remarkable radio image obtained by ALMA showing what is thought to be a protoplanetary disk around star HL Tauri which is 450 light years away. The resolution of this radio image is higher than that normally obtained by the Hubble Space Telescope. *Image credit: ALMA (ESO/NAOJ/NRAO).*

Suspended over a natural crater, it is not steerable and has a diameter of 305m. However, some tracking is possible by moving the suspended focus platform via a series of cables.

The Arecibo telescope has now been surpassed by the similar Chinese Five-hundred-metre Aperture Spherical radio Telescope (FAST).

While it has a diameter of 500m, only a 300m diameter part of the surface is used at any given time (see SILICON CHIP, October 2016 www.siliconchip.com.au/Article/10327).

Simulating a larger diameter radio telescope

Due to the impracticality of building a fully steerable radio telescope beyond about 100m in diameter or even a partially steerable suspended type of telescope such as Arecibo or the Chinese FAST, it is necessary to find a way of simulating larger diameter instruments.

This can be done with a technique called "interferometry". In effect, interferometry superimposes the signals from two dishes and then uses the phenomenon of constructive and destructive interference in order to extract information.

However, while this greatly increases the resolution of the simulated telescope, the signal collecting ability is not the same as a single large telescope of equivalent size.

Interferometry is applicable to both radio and optical telescopes. In both cases, sophisticated mathematical transforms are used to combine the individual telescope outputs into a single image.

The particular mathematical signal processing technique to produce the final image is known as "aperture synthesis".

In aperture synthesis for radio telescope arrays it is necessary to electronically record both the amplitude and phase of the signals from each telescope for later reconstruction into a single image.

The process of doing this in an optical telescope array is much more difficult due to the high level of optical and mechanical precision required and explains why aperture synthesis has been done with radio telescopes since the 1950s but only since the 1990s with optical telescopes.

For a description of optical interferometry at the Very Large Telescope run by the European Southern Observatory in Chile, see the video *"Interferometers*

Composite image of radio galaxy CWAT-01 (centre) and its environment. Bremsstrahlung (breaking) radiation at X-ray wavelengths is shown as the grey to red colour gradients in several surrounding galaxies as well as CWAT-01. A 1.4GHz image is shown in white and was obtained from the VLA telescope. *Image courtesy of NRAO/AUI and Vernesa Smolcic, MPIA.*

and Extreme Interferometry: the VLT Interferometer" siliconchip.com.au/l/aad8 Aperture synthesis and other sophisticated interferometric techniques requires the use of fast computers to do the appropriate mathematical transformations.

The fundamental mathematical technique involved in aperture synthesis is the Fourier transform, which decomposes a complex signal into a series of sine waves that represent that signal.

It is based upon the idea that any time-varying signal, even a square wave, can be represented by a sufficient number of individual sine waves of different frequency, phase and amplitude added together.

In order to obtain high quality images in a reasonable time there needs to be many different possible distances between a number of pairs of telescopes.

The separation distance between any given pair of telescopes in an array is known as the baseline.

The number of baselines that can be generated for a given number of fixed position telescopes "n" is $(n^2-n)\div 2$ and the number of samples that can be obtained at once is n^2-n .

For example, the Australia Telescope Compact Array with six telescopes would have 15 possible baselines and 30 simultaneous signal samples.

More than 15 baselines are possible, however, the telescopes are moveable and so a large number of baselines can be generated and in addition, the rotation of the Earth can be used to add more baselines by taking measurements at different points in the Earth's rotation.

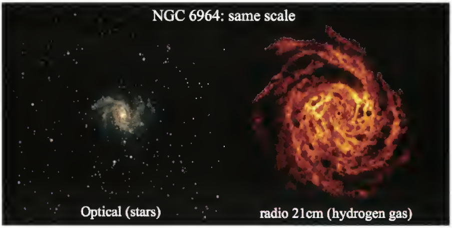
In addition to multiple baselines, multiple frequencies can be observed to obtain greater detail about an object of interest. In modern equipment, an extremely large number of frequencies can be simultaneously observed which also makes for a huge data processing exercise requiring the fastest computers.

In fact, some telescope facilities have even been built before there were sufficiently fast computers to process the data that they generated.

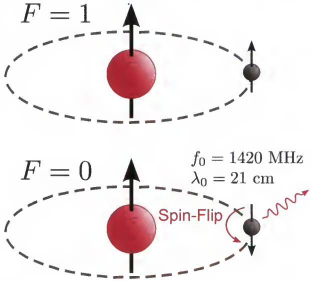
For aperture synthesis, in configurations when antennas are close together, a large region of sky is visible at low resolution. When far apart, a small region of sky is visible at high resolution.

The effect of moving antennas closer or further apart is somewhat like the zoom lens on a camera.

You can experiment with an online simulator at siliconchip.com.au/l/aad9



Comparison of optical image and radio image to same scale showing the large amount of hydrogen gas surrounding galaxy NGC 6964 imaged in the 21cm hydrogen line. The origin of this gas is not yet fully understood, the possibilities being that it was blown out of the young galaxy, it is left over material from a young universe or it represents starless satellite galaxies. *Image courtesy of Prof. Tom Oosterloo.* siliconchip.com.au/l/aada



The origin of the 21cm 1420MHz signal from a neutral hydrogen atom is the electron spin flipping, resulting in the emission of a radio signal. This frequency can easily pass through interstellar dust clouds that would otherwise block light and it also passes through the Earth's atmosphere with ease.

Aperture synthesis telescope arrays

The **Allen Telescope Array (ATA)** is a radio telescope array conceived for the purpose of simultaneous astronomical observations as well as SETI (Search for Extraterrestrial Intelligence).

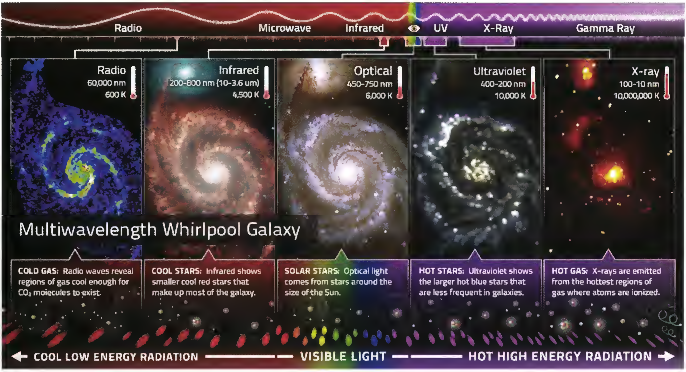
Located 470km from San Francisco, it has 42 6.1m dish antennas but 350 are planned for the future. Its operational frequency range is 500MHz to 11.2GHz.

It has had various funding difficulties and the SETI Institute that runs it is always in search of donations toward the project, the biggest donor being the Paul Allen Family Foundation. (Paul Allen was a co-founder of Microsoft).

The ATA is recognised as an important technological milestone towards the building of the Square Kilometre Array (SKA). The ATA has been used to produce numerous scientific papers in the area of conventional radio astronomy which is a great outcome, since the discovery of any extraterrestrial civilisations is unlikely.

The operational status of the telescope can be seen live at siliconchip.com.au/l/aadb

ALMA (Atacama Large Millimetre Array) is a 66-telescope array built in the Atacama Desert of Chile at an



Comparison of images taken at different wavelengths showing different features. In particular, note the difference between images taken at radio wavelengths and visible light.

altitude of over 5,000m.

It is designed to operate at submillimetre and millimetre wavelengths from 0.3mm to 9.6mm (or 999GHz to 31GHz).

The dishes are either 7m or 12m in diameter and their surfaces are made to an astonishing accuracy of 25 microns or around one quarter of the thickness of a sheet of paper.

The individual 115 tonne telescopes can be moved around the site and set at baselines of between 150m and 16km by a special 130-tonne transporter; there are no railway tracks to move the dishes as at some other sites.

ALMA is the most expensive radio telescope project on Earth, costing US$1.4 billion and it has been fully operational since early 2013. It is run by an international partnership between Europe, the United States, Canada, Japan, South Korea, Taiwan, and Chile.

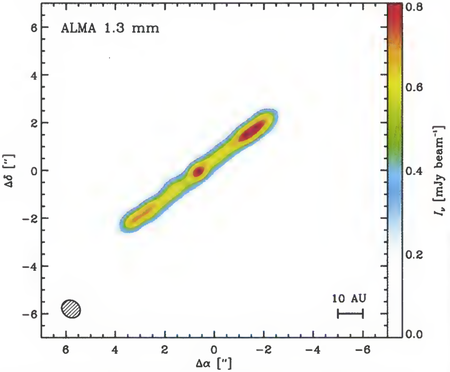
When in operation, the telescope produces an incredible 120Gbits of data per second per antenna or 8 Terabits per second for the whole facility.

This data is fed into a special dedicated supercomputer called a correlator which has 134 million CPUs and can perform 17 quadrillion calculations per second while consuming 140kW of electricity.

Despite its enormous power, it is designed to perform processing of telescope data only; it can do nothing else.

The high altitude of the site makes work difficult so the control centre is

Australian, Anthony (Tony) Beasley who is Director of the National Radio Astronomy Observatory (NRAO) in the US at "*Earth's largest radio telescope -- ALMA | Tony Beasley | TEDxChar-*



Radio image at 1.3mm wavelength (231GHz) from ALMA facility showing edge-on view of the dust disc around the star AU Mic (32 light years from Earth) suggesting the early stages of planetary formation. The scale bar represents 10 astronomical units (au). One au is the average earth-sun distance. ***Image courtesy of NRAO/AUI.***

Getting into radio astronomy on the cheap!

You don't necessarily need multi million dollar equipment to get into radio astronomy. Amateur radio astronomy is well within the reach of individuals these days.

Take a look at siliconchip.com.au/l/aadv Examples of things that an amateur can monitor are the upper atmosphere, emissions from Jupiter, the Sun and our galaxy siliconchip.com.au/l/aadw

Some samples of signals you can expect are at siliconchip.com.au/l/aadx

Other things you can do is detect meteors as they enter the atmosphere and monitor the 21cm hydrogen spectrum line (siliconchip.com.au/l/aady) using a domestic satellite dish antenna.

See the Radio Jupiter article at siliconchip.com.au/l/aadz

Also see siliconchip.com.au/l/aae0 and siliconchip.com.au/l/aae1

There is a commercially available amateur radio telescope, the Spider230, which is described at siliconchip.com.au/l/aae2

Also have a look at "*Amateur Radio Astronomy - Filippo Bradaschia*" siliconchip.com.au/l/aae3 Interferometric techniques are discussed in the video.

Making radio observations of the Sun can be done with a software-defined radio (see the first of a series of project articles on this topic at siliconchip.com.au/l/aae4) and a domestic satellite dish is described at "*Amateur Radio Telescope using SDR*" siliconchip.com.au/l/aae5

An amateur shows equipment at his observatory at "*BAA Radio Astronomy Group*" siliconchip.com.au/l/aae6

Radio telescope interferometry is also possible for amateurs.

See videos at "*140MHz wide band interferometer*" siliconchip.com.au/l/aae7 and "*140MHz wide band interferometer 2*" siliconchip.com.au/l/aae8 and also some other videos on that author's YouTube channel.

lottesville" siliconchip.com.au/l/aadc

Also see "*ALMA | Atacama Large Millimeter/Submillimeter Array [HD Timelapse]*" siliconchip.com.au/l/aadd for a time lapse video of the telescope in action.

Another excellent video is "*ALMA - Deep Sky Videos*" at siliconchip.com.au/l/aade

Also see "*The history of ALMA (the Atacama Large Millimeter/submillimeter Array)*" siliconchip.com.au/l/aadf

The **Australia Telescope Compact Array (ATCA)** is located outside of Narrabri, NSW, 500km NW of Sydney. It comprises one fixed and five moveable telescope dishes of 22m diameter, each weighing 270 tonnes. The telescopes are moved along a straight 3km section of railway track.

Operated by the CSIRO, it is part of the Australia Telescope National Facility. It can also be operated in conjunction with other telescopes such as the single 64m dish at Parkes, NSW and a 22m dish near Coonabarabran, NSW to form a very long baseline array.

The ATCA welcomes visitors, see siliconchip.com.au/l/aadg and you can see its operational status at siliconchip.com.au/l/aadh

It was featured in the TV series *Sky Trackers*. There is a video showing the telescopes being repositioned called "*Driving Radio Telescopes at the Compact Array*" siliconchip.com.au/l/aadi Also, see a time-lapse video of the telescope in action at "*Australia telescope compact array time-lapse*"

The US Arecibo Observatory in Puerto Rico. In addition to radio astronomy, this telescope is also used for radar astronomy (creating radar images of solar system objects) and in atmospheric observations. It sits in a natural depression. For its radar work it has four transmitters, one of which has an effective radiated power of 20TW at 2.38GHz. Limited beam steering is achieved by moving the receiver, suspended from three towers.

Impression of what the night sky looks like in radio wavelengths, superimposed over an optical image of the land area. The radio image is at 4.85GHz and is what would be seen with a 100m telescope from Green Bank, West Virginia. *Image courtesy of NRAO/AUI.*

Artist's conception of the Allen Telescope Array in its eventual completed form. The longest baseline will be 900m in its final form; it is 300m with the present 42 antennas. *Image credit: Jcolbyk, CC-BY-SA-3.0*

Decommissioned antennas at the Mullard Radio Astronomy Observatory near Cambridge, UK, include the single-track-mounted "One Mile Antenna" (1964) in the foreground and the two "Half Mile Telescope" (1968) dishes in the background. The remains of the 4C Array (1958) are on the right. *Image credit: Cmglee, CC-BY-SA-3.0.*

siliconchip.com.au/l/aadj

The **Karl G. Jansky Very Large Array (VLA)**, located in New Mexico, USA, consists of 27 25-metre, 209-tonne telescopes, in a Y-shaped array.

Each arm of the Y is 21km long and telescopes can be parked at a number of stations, giving a total of 351 independent baselines. The frequency coverage is 74MHz to 50GHz or 400cm to 7mm.

It was built from 1973 to 1980 but received a major upgrade in 2011 and was renamed in 2012.

It has been featured in a number of movies. See video *"Beyond the Visible: The Story of the Very Large Array"* siliconchip.com.au/l/aadk

The **One Mile Telescope** near Cambridge (UK) was the first to use Earth rotation aperture synthesis. Now decommissioned, it was built in 1964 and comprised two fixed parabolic dishes and one moveable dish on one half mile (800m) of railway track.

The total baseline was one mile or 1600 metres.

The moveable dish could be parked at 60 different stations along the track to generate different baselines.

The track was straight to within 9mm and the track was gradually raised from one end to the other by a total of 5cm, to allow for the curvature of the earth. The dishes each weighed 120 tonnes and were 18 metres in diameter.

The operating frequencies were 408MHz and 1407MHz. The telescope was the first to produce radio maps with a resolution greater than the human eye.

As aperture synthesis requires extensive computing power, it used the Atlas computer at Cambridge University with up to 128kB of 48-bit word ferrite core main memory to compute the necessary inverse Fourier Transforms.

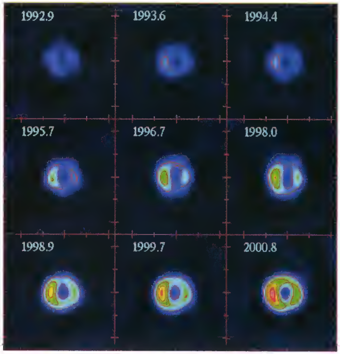
The original 1966 paper describing this telescope can be seen at siliconchip.com.au/l/aadl

A 1965 video describing the telescope can be seen at *"Superscope Probes Space (1965)"* siliconchip.com.au/l/aadm (first minute only).

Also see *"Watching the Skies HD 720p"* siliconchip.com.au/l/aadn for a drone fly-over of the site.

The **Square Kilometre Array (SKA)** will have a collecting area of one square kilometre and be 50 times more sensitive than any other radio telescope. It is being built in South Africa and Australia. See previous SILICON CHIP articles in December 2011 (siliconchip.com.au/Article/1232) and

The Karl G. Jansky Very Large Array with telescopes in close configuration.
Image credit: Photo by Dave Finley, Courtesy NRAO/AUI



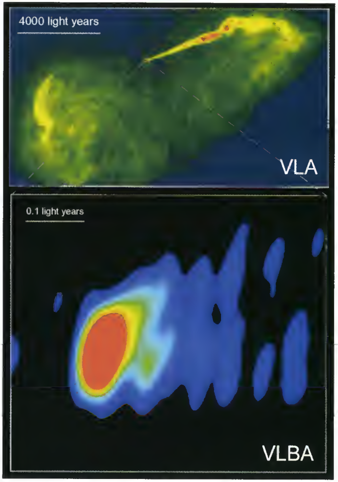
Sample image from ATCA showing the evolution with time (decimal years) of supernova 1987A which many SILICON CHIP readers may remember happening. The remnant is changing and getting brighter as the hot gases continue to expand and generate a shockwave. The gas from the explosion is colliding with gases previously ejected from the dying star.

July 2012 (siliconchip.com.au/Article/599).

The Very Long Baseline Array (VLBA) is a radio interferometer array consisting of ten 25m, 218 tonne antennas spread across the far reaches of the United States from Hawaii to the Virgin Islands giving an 8611km baseline.

It makes observations from 90cm to 3mm or 0.3GHz to 96GHz in eight different bands and two sub bands. It can be used, if necessary, with other telescopes such as at Arecibo and the Very Large Array (VLA).

The Westerbork Synthesis Radio Telescope (WSRT) as seen from the air. Like the ATCA, it has a linear configuration.



Comparison of images taken from the VLA and the VLBA telescopes of galaxy M87 located 50 million light years away. The much higher resolution VLBA image shows a detail near the black hole at the centre of the galaxy with a gas jet formed into a beam by powerful magnetic fields. *Image credit: NASA, National Radio Astronomy Observatory/National Science Foundation, John Biretta (STScI/JHU), and Associated Universities, Inc.*

The **Westerbork Synthesis Radio Telescope (WSRT)** is located in the Netherlands and consists of fourteen 25m dish antennas in a linear arrangement 2.7km long. Ten dishes are fixed and four are moveable on tracks.

The telescope was completed in 1970 but was upgraded from 1995-2000 and further upgraded recently. Frequency of operation is 120MHz to 8.3GHz.

The telescope is often used with others for very long baseline interferometry. APERTIF or APERture Tile In Focus is the latest upgrade in which the detectors have been replaced with focal plane array types.

This means the instrument will have a 40 times greater field of view than the old detectors which had a field of view about the size of the moon and it will be used for surveys of the Hydrogen line and searches for pulsars and more.

The greater field of view enables sky surveys at a much faster rate than previously possible.

See video "*Westerbork Synthesis Radio Telescope (WSRT) and APERTIF*" siliconchip.com.au/l/aadq

A brief history of radio astronomy – and some of the people who

Radio emissions from space were first observed by Karl Jansky at Bell Telephone Laboratories in 1932 who was investigating sources of static that might interfere with a 10 to 20 metre transatlantic radio service.

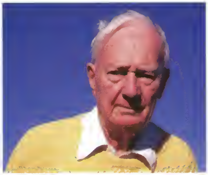
Karl Jansky – the first person to detect radio emissions from space in 1932.

He identified three sources of static – close thunderstorms, distant thunderstorms and a source of unknown origin which was determined to be from space – the centre of the galaxy in particular, which we now know to contain a supermassive black hole.

Grote Reber was a radio amateur and amateur astronomer who combined his interests to become a pioneer radio astronomer. (He was in fact the world's *only* radio astronomer for from 1937 to 1946).

He extended the work of Jansky and in 1937, as an amateur, built his own 9-metre dish radio telescope.

His first attempts to find signals at 3.3GHz and 900MHz failed but



American Grote Reber, at one time the world's only radio astronomer – and Tasmania's adopted son.

Grote Reber's home-built 9m dish antenna built in his back yard in Wheaton, Illinois.

in 1938 he was finally successful in finding signals at 160MHz, confirming Jansky's finding. He went on to make the first "radio map" of the sky in 1941. His telescope still exists today in Green Bank, West Virginia.

In the 1950s, Reber found he could not compete with large and expensive instruments being built then so he moved his focus to radio signals in the 500kHz to 3MHz range.

These signals from space are however reflected by the ionosphere. In 1954 he moved to Tasmania where he found it to be a quiet radio environment and ideal for observations of this nature.

He made observations late at night after the night side of the ionosphere deionised. He died in Tasmania in 2002.

Grote Reber speaks about his telescope in this video recorded in 1987, a fascinating talk and highly recommended: *"Grote Reber (NRC) :: The Wheaton 31.5 ft Paraboloid: Construction and First Measurements"* siliconchip.com.au/l/aadr

Grote Reber reminisces about his work in radio astronomy in an article entitled *"A Play Entitled the Beginning of Radio Astronomy"* at siliconchip.com.au/l/aads

There is a Grote Reber Museum at the University of Tasmania: siliconchip.com.au/l/aadt

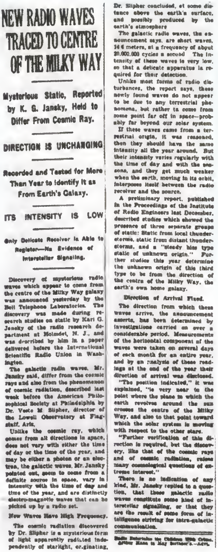
In 1942, radio waves from the sun were first discovered by Stanley Hey who was investigating interference to military radar.

During WWII there was a great development of radar and other radio equipment and this technology was vital for later developments in radio astronomy. The first radar reflections from the moon were made in 1946.

After WWII a radiophysics group was established at Cambridge University, developing radio interferometric techniques along with the technique of earth rotation aperture synthesis.

In 1974 Sir Martin Ryle won the Nobel Prize in Physics for this work.

In the 1940s Australian scientist J.G. Bolton was the first to associate a radio source with an optical image, in this



NEW RADIO WAVES TRACED TO CENTRE OF THE MILKY WAY

Mysterious Static, Reported by K. G. Jansky, Held to Differ From Cosmic Ray.

DIRECTION IS UNCHANGING

Recorded and Tested for More Than Year to Identify It as From Earth's Galaxy.

ITS INTENSITY IS LOW

Only Delicate Receiver Is Able to Register—No Evidence of Interstellar Signaling.

Discovery of mysterious radio waves which appear to come from the centre of the Milky Way galaxy was announced yesterday by the Bell Telephone Laboratories. The discovery was made during research studies on static by Karl G. Jansky of the radio research department at Holmdel, N. J., and was described by him in a paper delivered before the International Scientific Radio Union in Washington.

The galactic radio waves, Mr. Jansky said, differ from the cosmic rays and also from the phenomenon of cosmic radiation, described last week before the American Philosophical Society at Philadelphia by Dr. Vesto M. Slipher, director of the Lowell Observatory at Flagstaff, Ariz.

Unlike the cosmic ray, which comes from all directions in space, does not vary with either the time of day or the time of the year, and may be either a photon or an electron, the galactic waves, Mr. Jansky pointed out, seem to come from a definite source in space, vary in intensity with the time of day and time of the year, and are distinctly electro-magnetic waves that can be picked up by a radio set.

New Waves Have High Frequency.

The cosmic radiation discovered by Dr. Slipher is a mysterious form of light apparently radiated independently of starlight, originating, Dr. Slipher concluded, at some distance above the earth's surface, and possibly produced by the earth's atmosphere.

The galactic radio waves, the announcement says, are short waves, 14.6 meters, at a frequency of about 20,000,000 cycles a second. The intensity of these waves is very low, so that a delicate apparatus is required for their detection.

Unlike most forms of radio disturbances, the report says, these newly found waves do not appear to be due to any terrestrial phenomena, but rather to come from some point far off in space—probably far beyond our solar system.

If these waves came from a terrestrial origin, it was reasoned, then they should have the same intensity all the year around. But their intensity varies regularly with the time of day and with the seasons, and they get much weaker when the earth, moving in its orbit, interposes itself between the radio receiver and the source.

A preliminary report, published in the Proceedings of the Institute of Radio Engineers last December, described studies which showed the presence of three separate groups of static: Static from local thunderstorms, static from distant thunderstorms, and a "steady hiss type static of unknown origin." Further studies this year determine the unknown origin of this third type to be from the direction of the centre of the Milky Way, the earth's own home galaxy.

Direction of Arrival Fixed.

The direction from which these waves arrive, the announcement asserts, has been determined by investigations carried on over a considerable period. Measurements of the horizontal component of the waves were taken on several days of each month for an entire year, and by an analysis of these readings at the end of the year their direction of arrival was disclosed.

"The position indicated," it was explained, "is very near to the point where the plane in which the earth revolves around the sun crosses the centre of the Milky Way, and also to that point toward which the solar system is moving with respect to the other stars.

"Further verification of this direction is required, but the discovery, like that of the cosmic rays and of cosmic radiation, raises many cosmological questions of extreme interest."

There is no indication of any kind, Mr. Jansky replied to a question, that these galactic radio waves constitute some kind of interstellar signalling, or that they are the result of some form of intelligence striving for intra-galactic communication.

New York Times of 5th May 1933 announcing the discovery of radio waves from space. The article notes that "its intensity is low", an ongoing problem for radio astronomers.

pioneered it

case the Crab Nebula.

After an earlier 1944 prediction by Hendrik van de Hulst of an emission from hydrogen at 1420MHz, Harold Ewan and Edward Purcell at Harvard University detected hydrogen emission in 1951.

They published the work after it was corroborated by Dutch and Australian astronomers. This lead to hydrogen maps being made of our galaxy which revealed its spiral structure.

A team lead by Australian J. Paul Wild in the mid 1950s led to the discovery and explanation of solar radio bursts from the sun. In 1955, Bernard Burke and Kenneth Franklin discovered radio emissions from Jupiter. In 1961-63 unusual quasi-stellar objects were discovered at Cambridge University, with accurate position determination by the newly-commissioned radio telescope at Parkes, NSW.

The discovery of the first interstellar molecule 1963 was made by observations of spectral frequencies. Many other molecules have since been discovered and an Australian group at Monash University was very active in this area.

In 1964 the cosmic microwave background radiation was discovered by accident by Arno Penzias and Robert Wilson at Bell Labs. They found a persistent background noise in a horn

Robert Wilson and Arno Penzias, awarded the 1978 Nobel Prize for Physics after "accidentally" discovering evidence of the "big bang".

antenna which they could not remove, even after taking all possible precautions to minimise electronic noise in the antenna such as cooling the receiver to liquid helium temperatures.

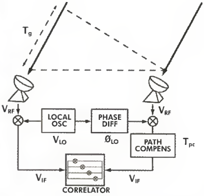
The noise was eventually determined to come from all areas of the sky and was considered to be evidence of the Big Bang.

For this finding they won the Nobel Prize in Physics in 1978.

In 1978 Jocelyn Bell Burnell and Antony Hewish, working at the University of Cambridge, discovered pulsars. Australia had a leading role in the discovery of many more pulsars.

Many people may not be aware of the existence or importance of radio astronomy that once occurred in suburban Sydney's Dover Heights in the eastern suburbs, Rodney Reserve in particular.

During WWII it was a military radar site but was taken over by the CSIRO Division of Radiophysics, who were there from 1946 to 1954. Many major

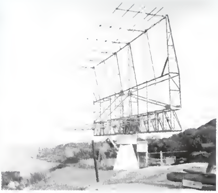


Scheme for combining signals from two radio telescopes in astronomical interferometry. The geometric delay in signal arrival time Tg is corrected in the path compensator delay Tpc. In an array of telescopes all signals are obtained for all baselines and all orientations, different orientations in respect of the radio source being obtained as the earth rotates.

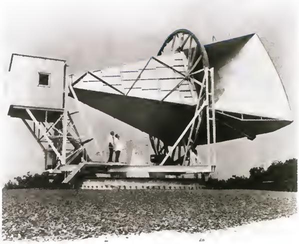
discoveries were made there establishing Australia as a leader in radio astronomy.

One technique developed there was sea interferometry, whereby a direct signal and a reflected signal were received at an antenna and combined to make an interference pattern from which the strength and size of a radio source could be determined.

In 1946 Ruby Payne Scott used the interferometer to discover that radio waves from the sun come from sunspots. You can read more about radio astronomy at Dover Heights at siliconchip.com.au/l/aadu **SC**



A 12-element Yagi array on the cliffs at Dover Heights (Sydney), used in sea interferometry, which was operated at 100MHz and used to identify 104 radio sources. Three of the most important discoveries made were radio waves from the Crab Nebula (due to a supernova explosion observed by the Chinese in the year 1054) and the galaxies Centaurus A and Virgo A. *(Courtesy CSIRO)*



The Holmdel Horn Antenna, a large microwave horn antenna that was used as a radio telescope during the 1960s at Bell Telephone Laboratories in Holmdel Township, New Jersey, USA. It was designated a National Historic Landmark in 1988 because of its association with the research work of two radio astronomers, Arno Penzias and Robert Wilson.