Radio astronomy
There is a world to discover
Cover illustration: Galaxy M87, observed with the LOFAR telescope. © Francesco de Gasperin, on behalf of the LOFAR collaboration.
Welcome to the universe!

ASTRON is the Netherlands Institute for Radio Astronomy where astronomers are researching the signals that stars, galaxies, and planets emit in the form of radio waves.

Mission
The mission of ASTRON is to facilitate radio astronomy discoveries. This means that ASTRON not only does fundamental astronomy research, it also designs and manages some of the world’s best radio telescopes as well as pushing back the boundaries of technology to create ever better and more sensitive instruments.

ASTRON’s engineers and astronomers are renowned all over the world. The astronomers conduct pioneering research on our own Milky Way, and on far-off star systems. The engineers develop innovative antennas, high-tech electronics and intuitive software. Thanks to good cooperation between the technicians and the scientists, even after sixty years the Westerbork Synthesis Radio Telescope (WSRT) is still one of the best telescopes in the world. LOFAR (the Low Frequency Array), designed and developed by ASTRON in recent years, is a unique instrument that is going to measure the earliest phases of the universe, as well as underground tremors in the province of Drenthe.

Partners
ASTRON also hosts the Optical/Infrared instrumentation group of the Netherlands Research School for Astronomy (NOVA) and JIVE, the Joint Institute for VLBI (Very Long Baseline Interferometry) in Europe. JIVE combines the signals from radio telescopes across Europe, Asia and South Africa. ASTRON is part of the Netherlands Organisation for Scientific Research (NWO).
Astronomy research

The ASTRON astronomers use different radio telescopes to help us learn more about the universe.

Compact objects
Some ASTRON scientists research neutron stars and black holes. Several thousand of these are visible in the sky using a radio telescope. They are what remains when ordinary large stars explode at the end of their lives. This kind of research, which is impossible in laboratories due to the gigantic pressure and gravity, helps us learn more about how atoms function and how time and space can be distorted.

Magnetic fields between stars
Magnetic fields appear to determine how stars are formed, and how high-energy particles fly through the universe. ASTRON astronomers study these magnetic fields in and around distant galaxies.

Hydrogen gas in galaxies
Galaxies are mainly comprised of hydrogen gas. By examining the radio waves emitted by that gas, we can gain a detailed picture of how these galaxies were formed, how they change over time, and how the stars in these systems begin to shine.

Very distant galaxies
ASTRON astronomers make very sensitive images of the sky. They use them to study very distant galaxies as they were long ago. This provides information on how black holes grow, and on how star systems are drawn together and fuse.

The era of reionization
When the universe was about a billion years old, it was ‘reionized’ by the rays of the first galaxies and became transparent. By looking very far away, and thus far back in time, we are using the LOFAR telescope to try to see how the first, young galaxies formed.
In this photo, made with the Westerbork telescope, a cluster of galaxies (called Abell 2218) is working like a gravitational lens on much more distant young star systems behind them. Copyright: ASTRON.
ASTRON’s radio telescopes

ASTRON’s activities concentrate on developing innovative instruments, the implementation of these instruments, such as the Westerbork telescope and the LOFAR telescope, and scientific astronomical research with these telescopes.

The telescope consists of fourteen parabolic (dish) antennas, each of which has a 25-metre diameter and can be directed towards a different part of the sky.

In the Dwingeloo control room, which receives the Westerbork antenna signals, complex electronic systems convert the signals into digital information that can be read and processed by a computer. The specially developed software ensures that the data from the fourteen individual antennas is combined to form one huge parabolic antenna. Once the computer has finished its calculations, the result is a map or images of the likely development of the Epoch of Reionisation (EoR).

One of LOFAR’s tasks is to search for radio signals emitted by hydrogen during the reionization period, the period from what is known as the cosmic dark ages until the first stars and galaxies formed. These signals are so weak that this search can be compared to looking for a needle in a haystack, as the radiation is overshadowed by the much stronger radiation from our own galaxy and sources of radio waves outside it.
astronomical object that has been observed, including information about movement, pulsations (vibrations), magnetic fields and other characteristics.

Since new technology has been introduced into the Westerbork telescope, much more information about a much larger part of the sky is retrieved in a shorter period of time.

Big, bigger, biggest
ASTRON has developed new technology that can perform extremely sensitive measurements of the entire sky with a revolutionarily large field of view. The so-called Apertif receivers, an innovation of ASTRON engineers, create a two-dimensional radio ‘camera’ in the focal point of each Westerbork antenna, thus increasing the field of view of all the antennas by a factor of thirty. This means that astronomers need much less time to acquire far more information about a larger part of the sky. This will have immense consequences for science and for research on the as yet unknown radio sky.

The importance of the Apertif technology reaches further than Westerbork alone. It has been further developed to become part of the largest radio telescope in the world, the Square Kilometre Array (SKA). ASTRON is one of the leaders of the international consortium that will realise the SKA in the next years.

Tom Oosterloo is senior astronomer at ASTRON and principal investigator on the Apertif programme.
Oosterloo: ‘We want to use Apertif to chart the entire sky in no more than four years. Without this technology that would take us about a century. You can compare it to digital cameras with sensitivities of one or of forty million pixels!’

The difference in collecting area of the Westerbork telescope with the Apertif technology and without this technology. The illustration on the left shows the collecting area of the Westerbork telescope without the Apertif technology. The right-hand illustration shows the collecting area of the telescope with Apertif. The Apertif technology has increased it by a factor of thirty, enabling astronomers to gain much more information about a larger part of the sky in a much shorter period. Copyright: ASTRON.
The International LOFAR Telescope
On 12 June 2010, Her Majesty Queen Beatrix of the Netherlands officially opened the International LOFAR Telescope (ILT). This new generation of radio telescopes can chart the creation of the earliest galaxies, black holes and gas clouds during the ‘birth’ of the Universe, on a wavelength that was not previously useable.

Radio signals
The light of the sun takes eight minutes to reach the earth. Light and other signals from the closest stars need several years to reach the earth. It can take millions and sometimes billions of years before astronomers can observe signals from objects and galaxies much further away. This means that astronomers can look back in time, and thus determine how objects were formed. The radio signals from the first galaxies in the universe took over thirteen billion years to reach the earth. Studies of phenomena so far away need very big telescopes indeed. This is why ASTRON built the LOFAR telescope.

LOFAR combines data from 25,000 mini antennas into a virtual radio telescope with a diameter of a hundred kilometres!
Geert Kuper works as a radio telescope operator in ASTRON’s Radio Observatory department. In recent years he has mainly been involved with the launch of LOFAR. Geert is looking forward to the LOFAR results: ‘It’s really exciting. We may even be able to observe the expanding borders of the universe. I’m particularly interested in the cooperation between man and technology. We get requests from astronomers from all over the world. One of my jobs is to make sure that this kind of cooperation runs as smoothly as possible.’

LOFAR: observations at lower frequencies

The LOFAR telescope can instantly perform high resolution, sensitive observations at low frequencies. LOFAR is made up of 25,000 small antennas of two distinct types: the Low Band Antenna (LBA), used for observations at frequencies between 10 and 90 MHz, and the High Band Antenna (HBA), for observations at frequencies between 110 and 250 MHz. The various Dutch LOFAR stations are located in a large central area between Exloo and Buinen in the province of Drenthe, and in roughly thirty smaller antenna fields spread over the provinces of Friesland, Groningen and Overijssel.
Superfast computing power
The LOFAR stations are linked with each other via a very fast fibre-optic network. This network is in turn linked to a supercomputer at the Donald Smits Center for Information Technology at the University of Groningen. This supercomputer combines the data from the thousands of small antennas into a virtual radio telescope with a diameter of about a hundred kilometres. Other European countries are also constructing LOFAR stations that will be connected to the network, which means that even sharper images can be made of the furthest away stars and galaxies.

European dimension
Astronomers in various European countries have secured funding to construct their own LOFAR station. LOFAR's potential is increased dramatically by extending the array in this way. The greatest distance between these international stations is about 1500 kilometres – which means that the enlarged LOFAR will be able to see details that are fifteen times smaller than the existing 40-station array in the Netherlands can observe. This increase in resolution will be of great value, allowing astronomers to study stars, galaxies and black holes in much finer detail. The funding for eight international LOFAR stations has been secured so far, creating a true European Sensor Network.

LOFAR and partners
Several partners are also involved in LOFAR. The LOFAR project is financed by the BSIK decree (Investments in Knowledge Infrastructure (Subsidies) decree), by NWO, ASTRON, the SNN (Northern Netherlands Assembly), the European Union and the project partners. The total investment is about EUR 100 million. For more information please go to: www.astron.nl and www.lofar.org.

Nature development
The central LOFAR area, housing the sensors, has also been developed as a nature reserve. The courses of the stream and other small waterways that flow through the area have been altered to stimulate development of a wetland area with a wide variety of grasses and herbs which will attract many species of birds, butterflies and insects. More than 360,000 cubic metres of soil has been moved to create a marsh with gullies and brooks, in addition to elevated areas to house the LOFAR stations. Establishing a...
nature reserve means that future development in the area will be limited, which is an objective that both scientists and environmental organizations share.
Future technology: the Square Kilometre Array

Fundamental questions are the order of the day in astronomy. How are galaxies formed? Was Einstein right with his theory of relativity? When and how were the first light sources created? What is the nature of dark energy and dark matter? In order to be able to answer these questions, a much more sensitive telescope than LOFAR is needed. The international astronomy community has therefore decided to build a telescope that can answer these questions – the Square Kilometre Array, or SKA.

The SKA is a new, revolutionary radio telescope. The total collecting area for the SKA is about one square kilometre, thus making the telescope fifty times more sensitive and ten thousand times faster than current radio telescopes.

The development of the SKA is a cooperation among seventy institutes from twenty countries. The first phase of the SKA will cost about 650 million euro. The plan is to build this telescope in 2018 in Australia and South Africa.

The SKA will operate over a wide range of frequencies. ASTRON engineers have developed new technology for frequencies lower than 1 GHz – entailing large numbers of fixed antennas. ASTRON is the coordinator of a European consortium that has developed a large-scale version of this technology.

1EMBRACE is an acronym for: Electronic Multi Beam Radio Astronomy Concept.
The consortium has shown that this technology is suitable for astronomy applications and that such a system can be produced cheaply enough to cover a square kilometre with this kind of antenna in the future.

Chris Broekema is a high performance computing researcher in ASTRON’s computing group. His work comprises the design and construction of programmes and computer systems capable of processing the enormous streams of data produced by modern radio telescopes. Chris: ‘I’ve been involved with the design and construction of LOFAR my entire working life. The official opening of LOFAR by Queen Beatrix on 12 June 2010 was thus a real high point for me. I think my work is very challenging. What we are trying to do is at the very limits of what’s possible, and so we have to get the absolute maximum out of the limited resources we have. ASTRON is doing cutting-edge work in a number of fields that could also be of use outside radio astronomy. One of the important research themes within my group is “green computing”, the most efficient possible use of computers with the aim of using as little energy as possible for a particular task. The technologies we are developing within ASTRON certainly have the potential for use elsewhere.’
ASTRON and the business world

In order to answer the major astronomy questions, ASTRON must continually push back the frontiers of technology. That makes ASTRON’s work extremely relevant for industry and high-tech companies.

ASTRON designs its projects in such a way that the business world is involved as much as possible in the development of new instruments and innovative high-tech systems. Technology Transfer within ASTRON also concentrates on imparting ASTRON’s expertise via innovation projects and consultancy. The measuring facilities in ASTRON’s Dwingeloo laboratories can be hired by companies. The technology developed for radio astronomy is applied in medicine (e.g. in MRI scanners), radio communication (police, fire brigade) and security (RFID, radio-frequency identification). Even wireless internet (WiFi) originated in radio astronomy.
ASTRON and education

Astronomy and astronomical instruments such as ASTRON develops are excellent ways of engaging the interest of young people and imparting knowledge about science and technology.

ASTRON offers everyone from primary school pupils to university students various opportunities to visit the institute. In addition to an excursion, secondary school pupils can perform a practical assignment at ASTRON with the Dwingeloo telescope, or pick the scientists’ brains for their profile assignments.

ASTRON, in cooperation with JIVE and the NOVA Optical/Infrared group, also organizes a special Girls’ Day. On this day, girls aged between 12 and 14 are given the chance to follow an active programme in science and technology and to talk to female scientists and engineers. This offers them the opportunity to learn what working in science and technology is all about.
ASTRON is part of the Netherlands Organisation for Scientific Research (NWO).

Our mission is to make discoveries in radio astronomy happen, via the development of novel and innovative technologies, the operation of world-class radio astronomy facilities, and the pursuit of fundamental astronomical research.

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