The Radio Observatory at ASTRON: News from the WSRT and LOFAR

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Abstract

The Netherlands Foundation for Radio Astronomy, ASTRON, has guided the Westerbork Synthesis Radio Telescope, WSRT, through a significant upgrade in the nineties and is now reaping the rewards of the new instrument's high sensitivity, dynamic range, calibratability, and flexible observing modes for delivering results in forefront fields of astronomical research. In recent years it has been involved in low frequency precursor programmes for the Low Frequency Array, LOFAR, and is acting as a test bed for novel antenna techniques such as phased array feeds (PAF's) on the way towards high speed surveying capability and as a technology demonstrator for the Square Kilometre Array, the SKA. Furthermore, a new 5 cm wavelength receiver was added and a new powerful pulsar backend completed. A recent major addition to the Observatory is the Low Frequency Array (LOFAR) which is being constructed, commissioned and has started delivering calibrated astronomical data. The Observatory is assuming responsibility for the operation of this new large facility as it is growing towards completion in 2009. In this *Observatory Report* an overview of recent accomplishments and a forward look are given.

1. Introduction

This *Observatory Report* provides an overview of the recent significant activities that have taken place at ASTRONs Observatory department: the organizational division that operates the observing facilities of ASTRON. The plural form here is an important change: once again, since the suspension of astronomical research on the Dwingeloo radio telescope, the observatory features two astronomical observation facilities. Firstly, the Westerbork Synthesis Radio Telescope (WSRT), the trustworthy workhorse instrument that has been facilitating first rate science since the last century's seventies and that has undergone a major upgrade in the nineties. Secondly, the new Low Frequency Array, LOFAR, which has recently gone into a mode of deployment, where new parts are incrementally incorporated into the science instrument as they become available, and commissioned into the system; an installation scheme that will come to completion in 2009.

Highlights of the science carried out at the WSRT in recent years will be noted, as well as recent, current and future technical developments. The promising early results achieved in commissioning observations with the first small sections of LOFAR will be described, as they offer a foretaste of the spectacular results to come. The instrument will be described, along with the status of the hardware, early 2008.

2. The WSRT

The WSRT is a linear array of 14 telescopes of 25 metres diameter, on an East-West line and with a total baseline length of 2.7 km. Four telescopes are placed on rail tracks to allow covering a dense range of baseline spacings.

2.1 Technical developments at the WSRT

The Low Frequency Frontend, LFFE, that was developed by ASTRONs R&D division earlier in the decade, was installed, commissioned and put to work. The antenna design that can be moved in and out of the (prime) focus of each of the 14 telescopes is a marvel of ingenuity and has been performing very well. The frequency band of 115 to 175 MHz, can now be accessed for the first time in full polarization on a large scale synthesis facility and with a modern multi-channel backend. The instrument has been used intensively for several astronomical projects and to learn about the environment in which the 'high band' part of the LOFAR telescope will operate.

A single frontend operating in the 'methanol' band (6-7 GHz) was developed and put into operation. It is mainly used for VLBI in one of the WSRT telescopes, providing direct left- and right-hand circular polarization channels. The frontend is performing well and contributes to the European VLBI Network coverage of this band.

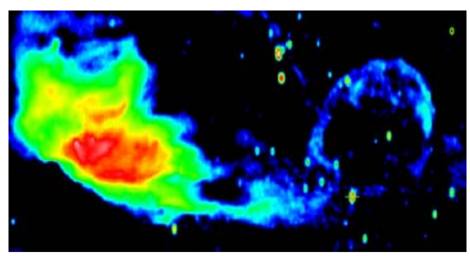
ASTRON is dedicated to the development of Phased Array Antennas as the prime technology for the SKA at lower frequencies, and also to the development of Phased Array Feeds (PAFs) for use in the focus of radio telescopes, also as a technology to be used for the SKA at mid frequencies. The latter applies to the WSRT in its role as test bed for these PAFs. A major project that aims to build and install PAFs on the WSRT telescopes is APERTIF. A pilot technology research project, now underway, involves a 80x80 cm aperture, populated with 8x7 crossed polarization Vivaldi elements. A total of 60 receivers amplify the 1-1.7 GHz signals that are sent via coaxial cable to frequency converters that deliver the signals to a prototype LOFAR digital backend. An extensive programme of tests is being carried out to characterize the antenna elements, their interaction, the lna's, and the beam forming properties of the array in dishes of this F/D ratio.

The PuMaII pulsar backend, the second generation Dutch pulsar-machine, has been put into operation and has been performing nearly flawlessly. The backend features high processing speed (385 Gflops), a total of 160 MHz bandwidth, automatic search modes and full dedispersion. Together with a new tied array correlation strategy that creates 8 subbeams in the primary field of view, especially implemented at the WSRT for this purpose, the combined instrument yields the fastest pulsar discovery machine in the world.

The WSRT has been a major participating radio telescope in the European VLBI Network, EVN. It has been delivering tied array data on disk, in Mk5 format, and was also one of the very first eVLBI stations, streaming data via a 1 Gb/s dedicated fibre to the EVN correlator centre. The WSRT, together with ASTRONs R&D department, has been working on a new Tied Array Distribution Unit, TADU, that produces combined signals for two subarrays for a total of 160 MHz bandwidth. The unit allows flexible configurations both for VLBI (Mk5b) and for pulsar backend applications.

2.2 WSRT Astronomy

From the enormous number of observing projects that were and are undertaken during the reporting period at the WSRT only a small number of highlights can be mentioned here.



The WSRT has done observations of the black hole Cygnus X-1, with enough sensitivity and resolution to show a bubble, void of matter, created by the jet emanating from the black hole. The significance of this observation is that it has shown that black holes in general do not just gobble up energy and matter from their surroundings, but can also inject a great amount of energy back into the interstellar medium. (Gallo, et al, 2005)

The SINGS initiative, the Spitzer Nearby Galaxy Survey, aims to gather data in many frequency windows, and the WSRT has embarqued on a mission to contribute continuum data on a significant subset of the targeted galaxies. Such a comprehensive multi frequency survey ranging from UV to radio, including many tracers of the interstellar medium, will allow to make sense of the many competing processes occurring in a galactic disk. The full survey samples 75 galaxies nearer than 30 Mpc. The WSRT SINGS programme provides data for a subset of 30 SINGS galaxies, supplemented with five starburst galaxies. (Braun, et al, 2007)

As an example of the science being done with the WSRT in the field of pulsars, the exciting results from a survey of single pulses is noted. Using a new sensitive method the WSRT has surveyed 12% of the radio pulsar population for 'drifting subpulses' and in the process discovered a number of cases of surprising behaviour. When individual pulses are plotted in stacks, sometimes the drifting subpulses stand out by showing drift-bands that can be characterized by parameters in pulse phase and drift repetition rate. By using the ‘two-dimensional fluctuation spectrum’ (2DFS), where Fourier transforms are calculated along lines of various slopes, signs of drifters can be spotted with high sensitivity, along with parameters that signify drift stability and indications of odd behaviour. It was concluded that about half of the pulsars have drifting sub-pulses. The research provides input to the physical models that explain pulsar emission zones and magnetic fields. (Weltevrede, 2007)

Very deep WSRT observations of the neutral hydrogen in the edge-on galaxy NGC891 have revealed an extensive halo of HI in this galaxy. This gaseous halo extends out to 20 kpc above the disk and is one of the first detections of cold gas accretion from the intergalactic medium by a galaxy. Gas halos have been known to exist in spiral galaxies and our own galaxy is no exception. Getting the most from a sensitive and stable radio telescope, such as the WSRT, and observing an edge-on galaxy allows getting a clear view of the halo. That allows analyzing the kinematics of the halo in detail. For NGC891 it was discovered that the kinematics are regular and symmetric, especially in the lower halo. The gas is co-rotating with the disk, although it is lagging w.r.t. the disk. It was discovered that the lag is larger for gas higher up in the halo. About 10% of the gas in the halo is in the form of gas clouds or filaments whose kinematics don’t follow the rotation pattern of most of the halo gas. The origin of the halo gas is thought to be twofold: ‘galactic fountaining’ in which star formation and stellar winds drive gas outward from the disk, and accretion of gas from the intergalactic medium. The observations show that both mechanisms are active in NGC891. (Oosterloo, et al, 2007)

Faraday rotation measure synthesis proved to be a valuable tool for low frequency polarimetry. Applied to 310–370 MHz data, the technique revealed extremely complex structure in the polarized Galactic synchrotron foreground, particularly in two fields (Schnitzeler, Katgert, and de Bruyn 2007; De Bruyn and Brentjens 2005; Brentjens 2008, in preparation). In both fields multiple emission components at different Faraday depths along the same line of sight are the norm, rather than the exception. Extremely deep polarization maps of Abell 2255 were constructed by Pizzo (2008, in preparation), featuring noise levels of 40 μJy beam^{-1} at 350 MHz. Furthermore, polarization was detected in deep observations of the Galactic Fan region with the Low Frequency Frontends (LFFE) of the WSRT at 150 MHz by Bernardi.

2. LOFAR CS1

LOFAR is the Low Frequency Array that is being designed, developed and deployed by ASTRON. The instrument will consist of colocated groups of antennas (called ‘stations’), operating in the bands from 30 to 80 MHz (low band) and from 115 to 250 MHz (high band). Roughly half of the total number of antennas, both low and high band, will be concentrated in a central core area, a few km across. The current (scalable) design plan is to build a minimum number of 36 ‘Core’ and ‘Remote Stations’, with a total number of 25000 individual antennas, reaching baselines of close to 100 km. In addition, a number of ‘International Remote Stations’ will be deployed in Europe in collaboration with international partners, and operated jointly from the LOFAR control centre of ASTRON in Dwingeloo. LOFAR will be the first large scale aperture array system, and as such it is also an important technology concept demonstrator for SKA. This unique instrument is well underway with antenna systems, low noise amplifiers, signal processors, a very large bandwidth fibre signal transmission system, a central supercomputer correlator, a major software signal processing effort and new calibration theory and software, all coming on line recently. ASTRONs Observatory is responsible for the operation of LOFAR and leads the commissioning of parts of the system, as they become available through to 2009.

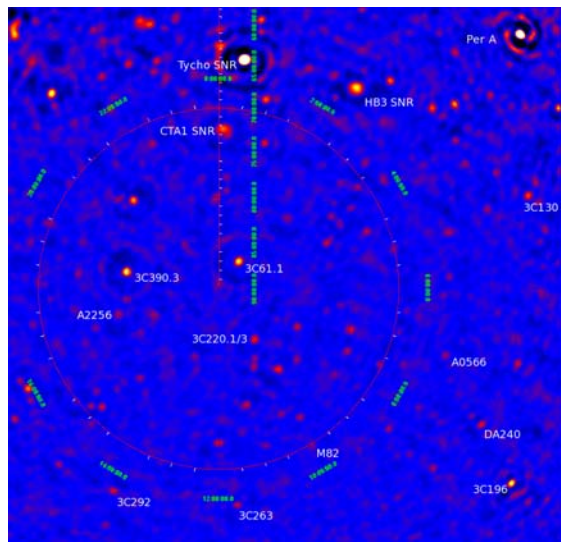
2.1 Technical

The LOFAR programme was kicked off with the installation of a first prototype station, The Initial Test Station ITS, used to test antenna, receiver and backend concepts. This minimalistic first system has delivered magnificently and produced the first instantaneous all sky radio maps. The ITS was dismantled in 2006, and installation work on the first ‘Core Station’ was started (CS1) on the site where the central core will be built in the North of The Netherlands. The second generation hardware has been tested extensively. Early 2008 all hardware design was mature enough to be frozen and bulk orders for mechanical and electronic parts were placed.

The nature of the distributed design of the telescope and the demand for easily mass produced components has set a new paradigm in radio astronomy instruments. This is most noticeable for the front end electronics: the antenna and receiver systems. A very effective and low cost design for the low frequency antennas was worked out, and the design for ‘tiles’ of high band antennas is very innovative. Reliability and serviceability are of prime importance.

The first international low band station at Effelsberg is fully operational and will soon be connected to the rest of LOFAR via high speed data links. Other international stations will follow suit shortly.

2.2 LOFAR Astronomy



Over the past few years, the LOFAR project has seen a steadily improving sequence of prototype radio telescopes in the field. Since the first low resolution observations with the Initial Test Station (ITS) by Wijnholds and Brentjens in 2004 and 2005, the term “wide field imaging” denotes “all-sky imaging”. The all-sky maps by Yattawatta with the current test setup at CS1 between 10 and 90 MHz contain hundreds of sources at a resolution of approximately 30’ and are confusion limited at a dynamic range of more than 5000:1. The longest continuous observation lasted for 85 hours straight. Pulsar B0301+19 was clearly detected in one of the first high band antenna observations by Stappers and Karuppusamy around 200 MHz during the summer of 2007, with only a few antennas installed.

The image shows a zoomed-in portion of a LOFAR low band all-sky map, with just 24 dipoles and with a total integration of 85 hours around 42 MHz. The NCP was tracked and Cas A and Cyg A subtracted from the data, to show numerous objects, some of which have identification labels in the image.

3. References

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