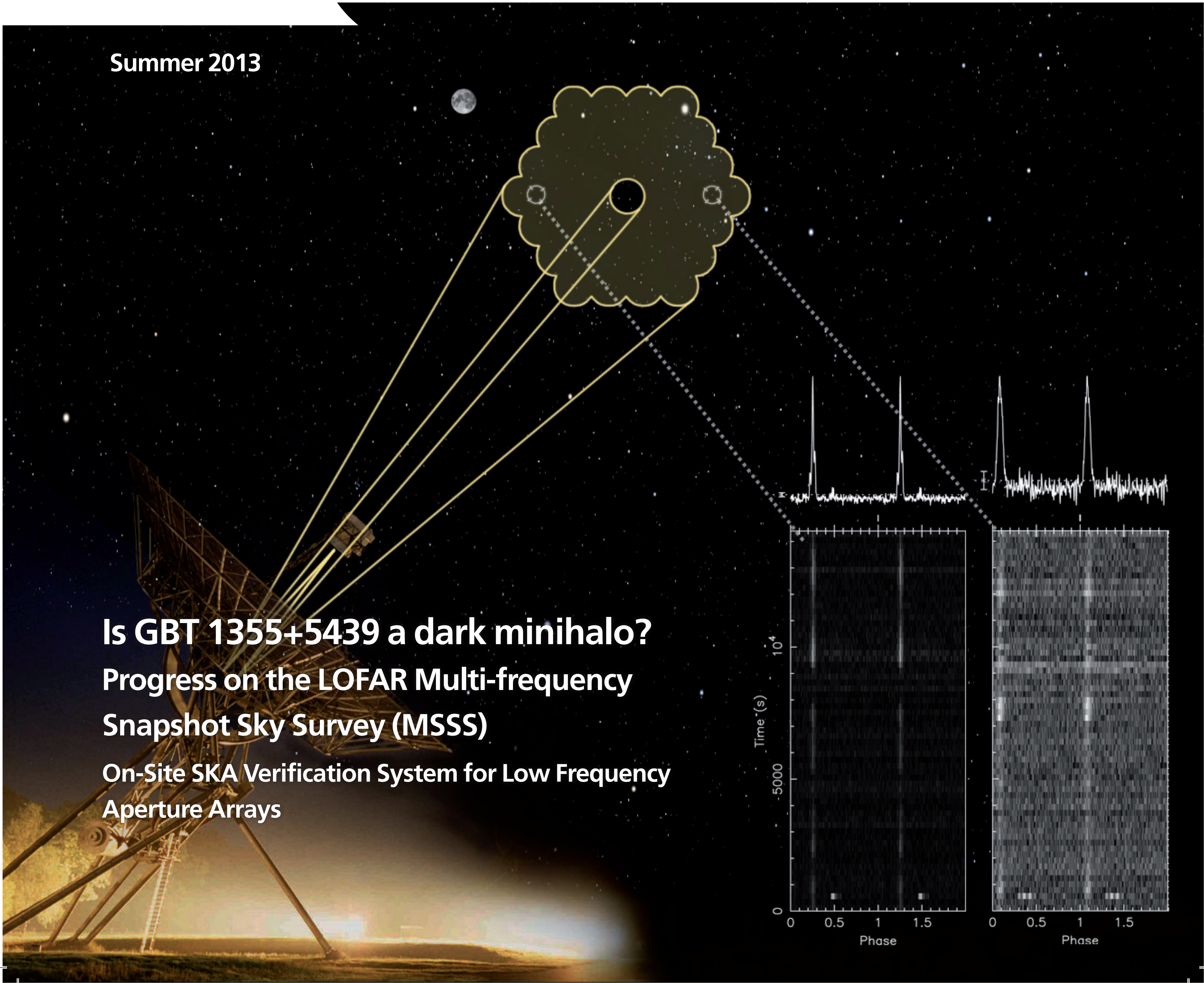
ASTRON news

Summer 2013



Is GBT 1355+5439 a dark minihalo?

Progress on the LOFAR Multi-frequency Snapshot Sky Survey (MSSS)

On-Site SKA Verification System for Low Frequency Aperture Arrays

Image cover:

The new field of view (the large hexagon) of the Apertif receivers on the Westerbork telescope is thirty times larger than the old one (central circle) and the full moon. With new high-speed cameras on Apertif, astronomers will be able to detect weak and rare cosmic flashes. Recently, with a test system, two fast blinking pulsars have already been observed simultaneously. These millisecond flashes are visible at the bottom right.

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Colofon

ASTRON
Netherlands Institute for Radio Astronomy.

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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Note from the editors

Welcome to the brand new Summer 2013 edition of the ASTRON News. It has been a challenge to fit in all the exciting things that have happened at ASTRON over the past months, so we hope you enjoy reading the newsletter in the summer sun!

In this edition you will find many in-depth science articles, ranging from updates on the Apertif receivers for the Westerbork telescope and the LOFAR Multi-frequency Snapshot Sky Survey, to new discoveries of dark galaxies and monster outflows from black holes. ASTRON engineers report on the DOME project, the Big Data project with IBM, and on techniques that use liquid cooling to improve signal processing in astronomical applications, as well as green computing.

Two ASTRON astronomers recently received grants to turn Westerbork's Apertif receivers and the LOFAR telescope into high speed radio cameras. Joeri van Leeuwen reports on the grant awarded by the Netherlands Organisation for Scientific research (NWO) for the Apertif upgrade and Jason Hessels tells us about his Vidi award, also from NWO, that will enable LOFAR to detect celestial objects that only appear for a blink of an eye. Read about this and more in the following pages!

Femke Boekhorst, John McKean, Stefan Wijnholds, Raffaella Morganti, Mike Garrett

Director's Corner

A few months ago, the LOFAR Science meeting took place in Dalfsen, the Netherlands. It was a chance for everyone to get together and enjoy the first results from LOFAR's commissioning phase and even some early results from LOFAR's first 'shared risk' observing semester ('Cycle 0'). It was clear, that the decisions we made in 2012 to focus significant resources on enhancing LOFAR station hardware, not to mention various firmware upgrades, were at last bearing fruit. The very deep Epoch of Reionisation images (now reaching noise levels of 30 microJy at 6 arcsecond resolution) were a particular highlight. We were also treated to the first images of Jupiter and the Sun, the first unique detection of several new Pulsars, and some unexpected science associated with LOFAR's first sky survey (MSSS). The progress being made in other areas such as transients and cosmic rays was also impressive. What struck many people at the meeting, was the fact that so many young people have recently stepped up to the plate, determined to exploit and further develop LOFAR's capabilities despite the extreme data challenge that it presents. The crucial role played by ASTRON's Support Scientist Group (under the leadership of Roberto Pizzo) was recognised as a major contributor and facilitator of the progress now being made.

Despite all these advancements, it is also clear that we need to make it much easier to exploit this fantastic new telescope, and with this in mind we have set up a LOFAR Calibration and Imaging Tiger Team to focus on the software developments required to get 'bread and butter' LOFAR continuum data into a state where science can be more easily extracted. ASTRON astronomer George Heald has agreed to lead this Tiger Team, populated by three full-time scientific software developers, and a software integrator with additional support also coming from the Radio Observatory. We hope to have the team fully in place by September this year.

The SKA has also been making a lot of progress since the last Newsletter appeared. A major milestone was the publication of the SKA1 Baseline Design. An important aspect of that document's evolution is a series of workshops that are now taking place in order to understand how the design addresses the various key science projects. The appointment of Robert Braun as SKA Science Director is another important step forward for the SKA - Robert was one of the first astronomers at ASTRON to take up the SKA cause, and he and Russ Taylor edited the first scientific case for the telescope in the mid-1990s. We wish Robert all the best in his new position - communications between the project and the scientific community need to be tightened, as we begin to iterate on a final design by the end of this year. ASTRON staff have also been busy preparing to respond to the SKA RfP (Request for Proposals). ➔

The RfP invites consortia to bid for various work-packages that will lead to the generation of a detailed design for the SKA telescope. ASTRON is leading two consortia - LFAA (Low Frequency Aperture Array) and MFAA (Mid-Frequency Aperture Array) and will play an important role in SDP (Scientific Data Processing).

About 50% of our proposed contribution to the SKA Design Phase is fully resourced - for example the SDP is almost entirely funded via our DOME collaboration with IBM. However, to fully realise our contribution to the LFAA and MFAA consortia, we will need to acquire additional funding resources. Fortunately, there is a programme under the auspices of the Dutch National Roadmap that presents an opportunity to secure more funding for the SKA design phase. We are preparing a proposal for the National Roadmap deadline of 1 October - the competition is fierce, but we believe we have an excellent case, including the strong engagement and support of Dutch industry & businesses, the Universities, other Dutch research organisations and the regional authority of the province of Drenthe.

One of the major challenges ASTRON is currently dealing with is a significant reduction of base budget - a structural cut that rises to 4% in 2014 onwards. Since ASTRON also relies on essentially doubling its base budget via external funding, the reduced matching capability translates into a 4% cut in terms also of our total budget. Longer-term uncertainties in our base budget require us to take a close look at our various priorities, project portfolio and commitments. We've recently received a lot of input from our Scientific Advisory Committee on these topics, and we are about to also consider these challenges together with our Board. We're confident that we can reach a solution that preserves our ambition without jeopardising our future.

I want to report on the fantastic progress being made with the new and renovated buildings at ASTRON. The new building opened its doors at the beginning of the year and the new colloquium room was inaugurated with a colloquium and workshop dedicated to the career of Prof. Arnold van Ardenne. Arnold retired earlier this year, but is retained by ASTRON as a consultant, working two days in the week. He shaped much of the R&D technology development at ASTRON from 1995 to 2005 but his impact went well beyond our shores, especially in the context of the SKA. Arnold re-introduced phased array antenna technology to radio astronomy after returning from his period in industry, at Eriksson. These initiatives led to LOFAR, SKADS-EMBRACE and eventually to the decision of the SKA Board that envisages Dense Aperture Arrays as a major component of SKA Phase 2 in South Africa. Many thanks to the building team at ASTRON, and to all our contractors for realising the new building and for making Arnold's retirement event so special and memorable.

At the end of April, the Netherlands formally installed a new King and Queen, Willem-Alexander and Máxima. I was lucky enough to meet Máxima during a tour of the royal couple in Drenthe. She clearly recollected her previous visits to ASTRON, and we hope that it won't be too long before the royal couple return again to Dwingeloo. ASTRON has enjoyed a long history of royal patronage, going back to the opening of the Dwingeloo and Westerbork telescopes in 1956 and 1970 by Queen Juliana, and in 2010 the opening of the LOFAR telescope by Queen Beatrix. At ASTRON, we enjoyed our own crowning ceremony with the recent appointment of Dr. Gert Kruithof, as the new Head of the R&D department. Gert is currently leading TNO's Business Information Services research department and will begin in Dwingeloo on August 15. We wish him every success in his new position, and look forward to interacting with him over the coming years.

The location and impact of jet-driven outflows of cold gas: the case of 3C293

Elizabeth Mahony (mahony@astron.nl), Raffaella Morganti, Tom Oosterloo (ASTRON), Bjorn Emonts (CSIRO, Australia) and Clive Tadhunter (Sheffield)

Over the past decade it has become clear that the growth and evolution of galaxies is strongly tied to that of the central supermassive black hole. This is generally attributed to feedback from the AGN, where outflows from the central regions are thought to heat up or blow out the gas, halting both further accretion onto the black hole and star-formation throughout the galaxy. However, the physical mechanisms responsible for driving this feedback remain unclear. Understanding these feedback processes is one of the primary missing links in our understanding of how galaxies form and evolve.

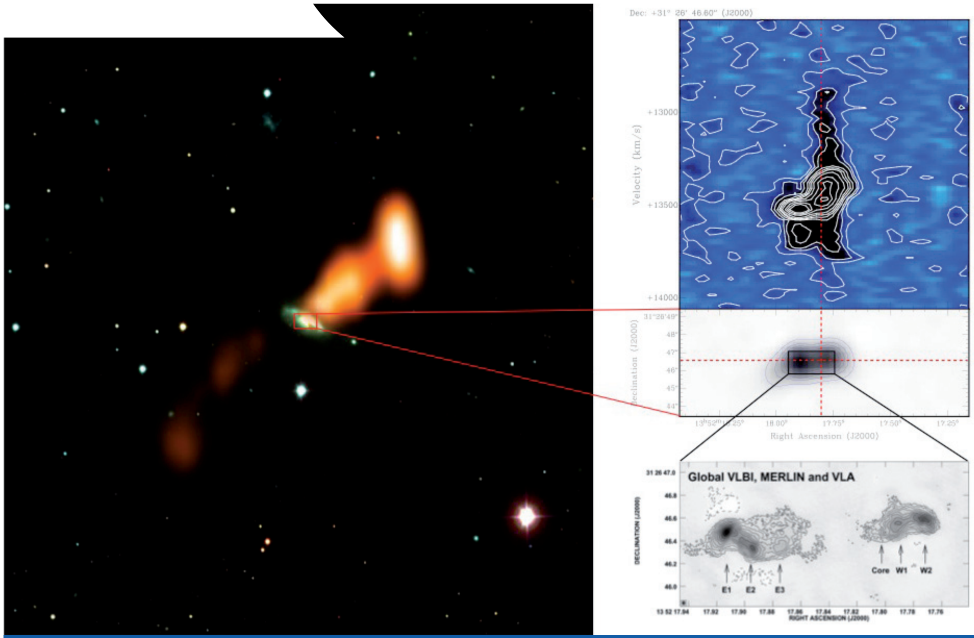


Figure 1: A neutral gas study of the radio galaxy 3C293. (left) The radio image (from the Westerbork data) shows the large scale radio lobes and is overlaid on an optical image depicting the host galaxy. (right) The new spectral line imaging with the VLA. These data show the inner radio lobes on arcsec-scales, and the corresponding position-velocity diagram, where the darker areas correspond to HI absorption. The higher resolution VLBI image is shown below for comparison. The vertical red line marks the position of the core and the horizontal red line denotes the axis along which the position-velocity diagram was extracted. The very broad absorption feature (~1200 km s^{-1}) is only detected in front of the western radio lobe.
© Elizabeth Mahony and Beswick et al. (2004).

While there are a number of plausible ways that outflows could be produced, recent results have shown that, in some cases, radio jets could be responsible for driving fast outflows of gas. One such example is seen in the nearby radio galaxy 3C293. Fast outflows of up to 1400 km s^{-1} were first detected in neutral hydrogen using Westerbork (Morganti et al. 2003). However, the spatial resolution was not high enough to determine if the outflows were coming from the central AGN or from the radio jets on scales of ~0.5 kpc from the central core. To investigate this further we have re-observed this galaxy with the upgraded Very Large Array (VLA), which provided the higher spatial resolution data needed to localise the HI outflows on arcsecond-scales.

Figure 1 shows these higher resolution data, where we resolve the two inner radio jets of 3C293. The position-velocity diagram (extracted along the radio-jet axis) shows that the very broad absorption feature detected in the previous Westerbork observations is associated with the western radio lobe, approximately 0.5 kpc from the core. This provides further evidence that the radio jet is responsible for driving this outflow. By pinpointing the location of this outflow we can now more accurately quantify the impact that radio jets have on their host galaxies, providing important constraints for numerical simulations.

APERTIF calibration using NVSS

Neeraj Gupta (gupta@astron.nl)

The Westerbork Synthesis Radio Telescope (WSRT) will soon be fitted with APERTIF, which will increase its instantaneous field of view to 8 deg² and will make the WSRT an efficient survey telescope. Spectral line and continuum imaging using radio interferometers such as the WSRT require correcting for various physical effects. Traditionally, this is done by determining the antenna based broadband complex gains via observations of bright radio sources such as 3C48, 3C147 and 3C286. Typically, for every 12 hours of full synthesis with the WSRT about 30 minutes are spent in observing these calibrators. Clearly, it will take prohibitively large amounts of time if each of the 37 compound beams of APERTIF are to be calibrated this way.

To move forward, we are developing a method based on self-calibration to use a local sky model (LSM) based on the NRAO VLA Sky Survey (NVSS) for the initial gain and bandpass calibration. The main sources

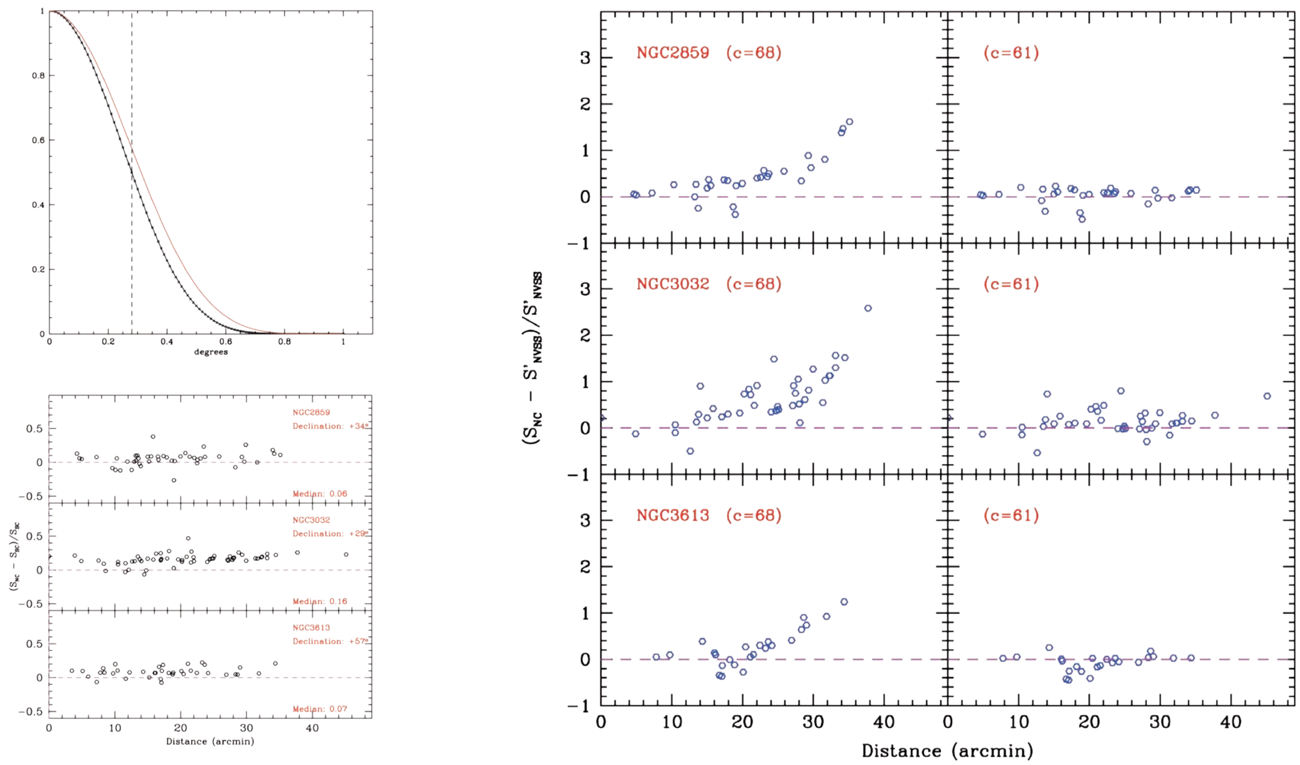


Figure 1: Testing the calibration of APERTIF using the NVSS. (Top-left) The WSRT primary beam attenuation as a function of distance from the pointing centre. The black line is for the typically assumed model (c = 68) and the red line is for c = 61, the best-fit model. (Bottom-left) A comparison of the derived flux densities obtained for sources in the three WSRT fields as a function of distance from the pointing centre. S_{SC} and S_{NC} are the flux densities in images obtained using standard calibration (SC) and NVSS LSM calibration (NC), respectively. The declination and the median of the relative flux densities are given in each panel. (Right) A comparison of the derived flux densities obtained for sources in the three WSRT fields as a function of distance from the pointing centre, for c = 68 and c = 61.

of error affecting this method are i) the uncertainties in the WSRT/Apertif primary beam model used to predict the LSM, ii) the additional large scale diffuse emission detected in NVSS, and (iii) variability in the flux density of the NVSS sources. Currently, we are using archival WSRT data to quantify these errors.

We have analysed several WSRT data sets using calibration software developed for LOFAR, following both the standard calibration approach using 3C147 or 3C48, and the calibration based on the LSM from NVSS, predicted using a WSRT primary beam model with constant c = 68, where the primary beam attenuation at radius, r, as a function of frequency, ν, is defined as $\cos^6(cr\nu)$ (see Fig. 1).

Here, the WSRT flux scale is set using a calibration based on the system temperature and the LSM is used only to solve for the antenna phases, and about 30% of the total 20 MHz bandwidth is averaged without bandpass calibration. By comparing the images from the two methods with the NVSS catalogue, we find that the WSRT primary beam at 1.4 GHz is better described by c = 61 ± 1 rather than c = 68, as is generally used (see right panel of Fig. 1). Further, we find the flux densities of the sources that are unresolved in the WSRT images to be systematically higher by about 10% (bottom left panel of Fig. 1). The next step will be to use the same LSM to solve for both the antenna amplitudes and phases, and to understand the cause of this flux density offset. With a better understanding of the systematic errors introduced by the additional flux detected in NVSS, this method is expected to provide the broadband complex gains of each compound beam of APERTIF.

'Big Data' project DOME at world's leading high tech event

The ASTRON-IBM DOME project was presented at the world's leading high tech event, the CeBIT 2013, in Hannover as part of the Big-Data focus area of the IBM booth. DOME is a collaboration between ASTRON and IBM, and focuses on the theme 'Big Bang Meets Big Data'.

The CeBIT was opened by Dr. Angela Merkel, Chancellor of the Federal Republic of Germany. The picture shows the Chancellor at the IBM booth talking to the IBM Germany General Manager Martina Koederitz. The inset (lower-left) shows some of the high tech instruments presented at the DOME booth: a dense aperture array antenna, a 3D stacked chip, a phase-change memory chip, a low power analogue-to-digital converter (ADC) chip so small a magnifier is needed to see it, and a very thin photonic link replacing a wire stack the size of a small tree trunk. Also a printed circuit board for a micro-server was on display, produced by a manufacturer in Drenthe. The inset on the right shows the scientific leaders of the project, Ton Engbersen of the IBM Zurich Research Labs (right) and Albert Jan Boonstra of ASTRON (left).

The project was interviewed by newspaper journalists (among others, journalists from the Frankfurter Allgemeine), news-sites journalists (CNET) and filmed by camera teams (e.g. Euronews, BBC Arabic). The challenges involved in the signal processing for the next generation radio telescope, the Square Kilometre Array (SKA), are impressive and the technology at the booth showed visitors and participants of the CeBIT that we are on route towards affordable low-power computing and signal processing as is required for the SKA.

The opening of the world's leading high tech event, CeBIT, by Germany's Chancellor, dr. Angela Merkel. The ASTRON-IBM 'Big Data' project called DOME participated in the IBM booth at the exhibition (right and bottom left).

New high-speed cameras for Westerbork telescope

Joeri van Leeuwen (leeuwen@astron.nl)

In March 2013, we were awarded an NWO-M investment grant from the Netherlands Organisation for Scientific Research to turn the new 'Apertif' receivers on the Westerbork telescope into high-speed cameras. These receivers will expand the Westerbork field-of-view by over a factor 30, enabling fast and sensitive surveys of the radio sky. The system was, however, restricted to making images at the rate of one every second. The new upgrade increases this to 10,000 frames per second – allowing astronomers to extend Apertif surveys to the dynamic, millisecond-variable radio sky. Our international team of astronomers will use these new high-speed cameras to detect bright radio flashes from our Milky Way, and beyond.

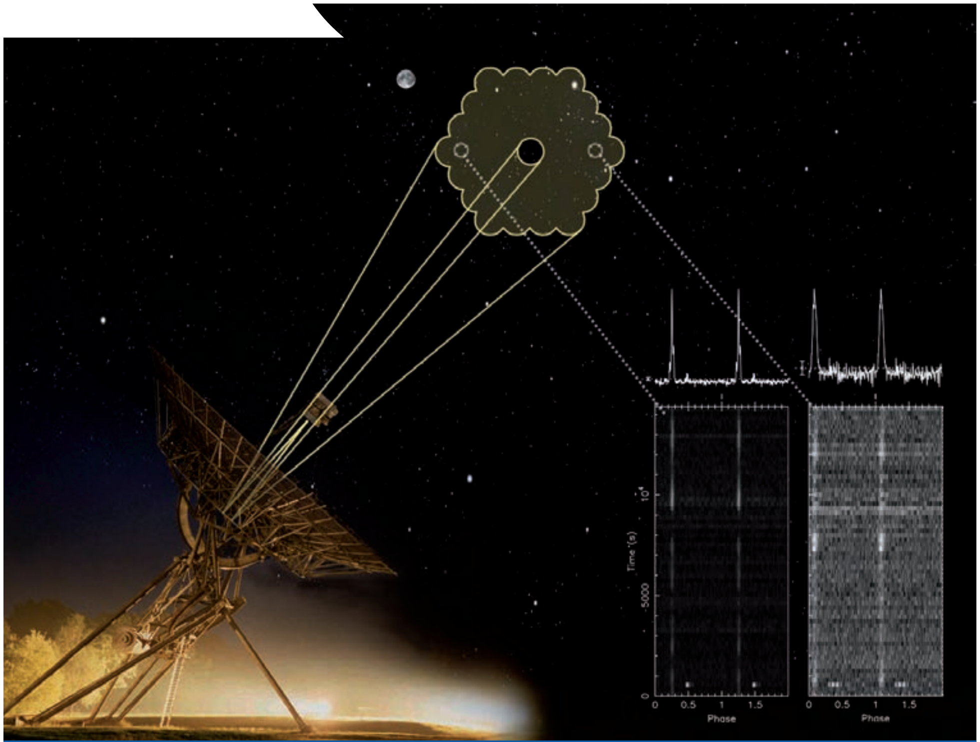


Figure 1: The new field of view (the large hexagon) of the Apertif receivers on the Westerbork telescope is thirty times bigger than the old one (central circle) and the full moon. With the new high-speed cameras, astronomers will be able to detect weak and rare cosmic flashes. Recently, with the test system, two fast blinking pulsars have already been observed simultaneously. These millisecond flashes are visible at the bottom right.

The Apertif receivers allow astronomers to sensitively scan the sky for radio galaxies that are mostly unchanging. All over the sky, however, many short bright radio bursts that last less than one thousandth of a second also go off. Radio pulsars, spinning Galactic lighthouses, emit some of these bursts, but others originate from far outside our Galaxy. The nature of these far-off bursts is unclear, but given their distance they must represent enormous explosions comparable to the 'supernovae' that are observed when massive stars explode.

Using the grant, the algorithms on Apertif's 'FPGA' imaging chips will be extended to form 10,000 frames per second. Furthermore, the image processing capacity will be extended with a 'GPU' supercomputer to immediately process the data that the telescope receives. The 'phased array feed' receivers and burst-detection processing of Apertif are pathfinder technologies for the Square Kilometre Array (SKA).

In a few years, the high-speed cameras will scan the sky for bright bursts. Thanks to the new processing capabilities these bursts can be recognised immediately, and their properties can be studied before they fade. That way, we aim to determine the nature of the explosive bursts.

Prof. Ir. Arnold van Ardenne retires

Earlier this year, Prof.Ir. Arnold van Ardenne retired after decades of leadership in the field of radio astronomy technology.

From 1994 onwards, he shaped much of the technology development at ASTRON and had a major impact in the international SKA project. In particular, Arnold pioneered the reintroduction of aperture array technologies to radio astronomy, eventually realized in the form of LOFAR and APERTIF.

In honour of his retirement, Prof. Ir. Arnold van Ardenne received a miniature Westerbork telescope developed and made by the mechanical group from ASTRON's R&D department.

The workshop 'Reinventing Radio Astronomy' in honour of Arnold van Ardenne's retirement was held in ASTRON's brand new auditorium.

In honour of Arnold's contribution to the field, a workshop was held with the appropriate title 'Reinventing Radio Astronomy'. Many of Arnold's friends, colleagues and family were present and the full programme, including all presentations is now available online: *http://www.astron.nl/ava2013/programme.php*

Arnold will continue to remain involved with ASTRON as a consultant to the NL SKA Office in Dwingeloo.

Declan Kirrane representing African -European Radio Astronomy Platform (AERAP) awarded Arnold van Ardenne a certificate in recognition of his outstanding engagement and lasting contribution to AERAP.

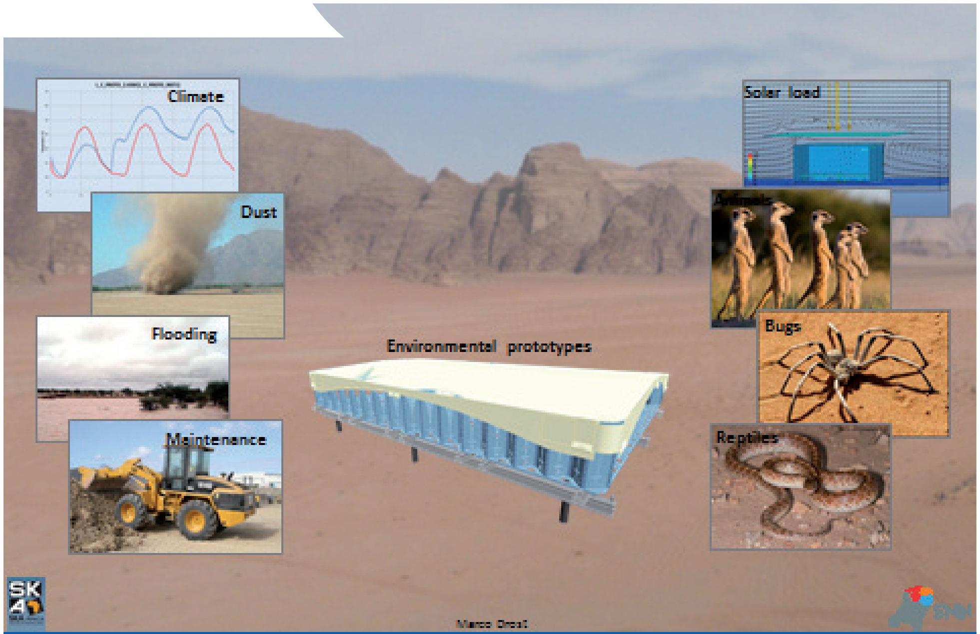
Engineering by 'natural selection'

Marco Drost (drost@astron.nl)

During the building and usage of the High Band Antenna and Low Band Antenna front-ends of the International LOFAR Telescope (ILT), the approach of engineering by 'natural selection' arose. Despite the fact that great care was taken during the design and development there were some unforeseen issues. Many design drivers like mechanical strength, thermal behaviour, production, assembly and cost, and other risks where identified and solved through simulations and testing. However, some other aspects where inadequate while others were 'over'-engineered. The impact of some of the more elaborate design drivers like dust, vegetation, water, bugs, rodents etc. are difficult or even impossible to predict, but very real in the case of the Square Kilometre Array (SKA). Since the realisation of the mid frequency aperture arrays (MFAA's) for the SKA is planned for SKA phase 2 (intended to take place between 2022 and 2025), there is enough time to gain practical experience that will make future engineering decisions more specific and based on real data. Rather than relying on gut feeling.

ASTRON plans to roll out four prototypes at the South Africa Karoo site, covering a broad selection of design solutions, such as different protection levels, fully closed housing up to a simple top cover, bare electronics or protected by coatings. A wide variety of mass production materials and production methods are incorporated in these four prototypes. The dimensions (about 3.5 x 3.5 metre) of the prototypes are optimised to ensure a sufficient size to produce trustworthy results without making them too expensive. Several design aspects depend on the prototype size, for instance, wind, rain, maintenance and thermal conditions. Edge elements also interact differently with the environment than the mid elements, so size does matter!

The environmental prototype project is at a stage where the first outsourced parts and materials have been delivered to the construction hall at the Westerbork telescope. The next step is to build and test the prototypes at the Westerbork telescope before they are shipped to the Karoo site in South Africa in the third quarter of this year.



Design drivers for mid frequency aperture arrays (MFAA's), of which some are difficult to quantify!

Is GBT 1355+5439 a dark minihalo?

Tom Oosterloo (oosterloo@astron.nl), George Heald, Erwin de Blok

One of the quests of extragalactic astronomy is to find a dark galaxy. When looking at smaller and smaller galaxies, star formation becomes less and less efficient and the number of stars a galaxy forms becomes fewer and fewer. One big question is whether this means that, in the extreme, below a certain mass limit, stars are formed no longer and we are left with a 'dark' object.

Recently, deep observations of a region around the nearby galaxy M101 performed by Chris Mihos and collaborators revealed a candidate dark galaxy in that region of the sky, that is, an HI cloud that has no optical counterpart, even in very deep images. We observed this object, called GBT 1355+5439, with the Westerbork Synthesis Radio Telescope (WSRT) to investigate its nature and found some interesting clues.

Figure 1 shows the distribution of the HI in GBT 1355+5439. One immediate result is that the column densities of the HI are very low and are well below the critical value below which no star formation is expected to occur, consistent with the lack of any optical counterpart.

One complication in assessing the nature of GBT 1355+5439 is that its distance is not known. Our results show that if it is assumed to be physically close to M101, its properties are very similar to those of the dark objects of the Local Group model for the Compact High Velocity Clouds proposed by Robert Braun about 15 years ago. However, Braun's model has met serious objections, both theoretical and observational. The same objections would apply here, making it less likely that GBT 1355+5439 is a dark galaxy near M101.

If GBT 1355+5439 is to be a dark galaxy, it has to be much closer and the fact that it is observed near M101 on the sky would be a coincidence. Interestingly, if we assume it to be a member of the Local Group, its properties are very similar to the population of dark objects that have recently been proposed to exist by Riccardo Giovanelli and co-workers. It might well be that GBT 1355+5439 is the first case of such a dark Local Group object imaged in HI.

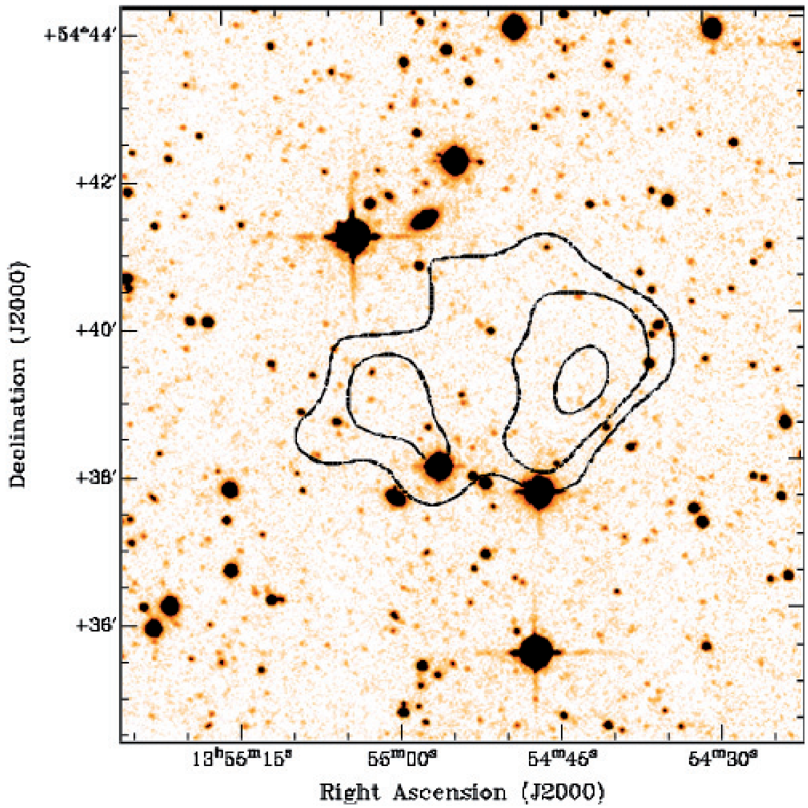


Figure 1: The HI content of GBT 1355+5439. The total HI contours are at 1.5, 3 and 6 x 10^{19} cm^{-2}, and are overlaid on a very deep optical image, kindly provided by Chris Mihos. The limiting V magnitude of the optical image is 29 mag $arcsec^{-2}$.

Line Spectroscopy with LOFAR

J. B. Raymond Oonk (oonk@astron.nl)

The gaseous medium between the stars, known as the interstellar medium (ISM), plays a key role in galaxy evolution. From this gas reservoir stars are born and supermassive black holes are fed. The interaction however is not just one way, as stars at the end of their lives release most of their material back into the ISM as supernovae, and black holes stir and heat-up this medium through their powerful outflows. Astronomers have extensively studied the ISM through all available observing windows. This has led to the so called three-phase, that is, cold (T = 80 K), warm (T = 8000 K) and hot (T = 500000 K), model of the ISM in which a complex process of gas recycling takes place.

The cold ISM phase consists of molecular and atomic gas. This gas has been extensively studied at cm- and mm-wavelengths using primarily the carbon monoxide (CO) lines for the molecular gas and the 21 cm hydrogen (HI) line for the atomic gas. Whereas the role of the molecular gas in the ISM is now relatively well understood the same cannot be said about the atomic gas. The HI line, with the exception of those rare instances in which both emission and absorption of the associated gas can be measured, does not provide us with the necessary temperature and density information for the atomic gas. However, nature provides an alternative in the form of low-frequency radio recombination lines (RRLs).

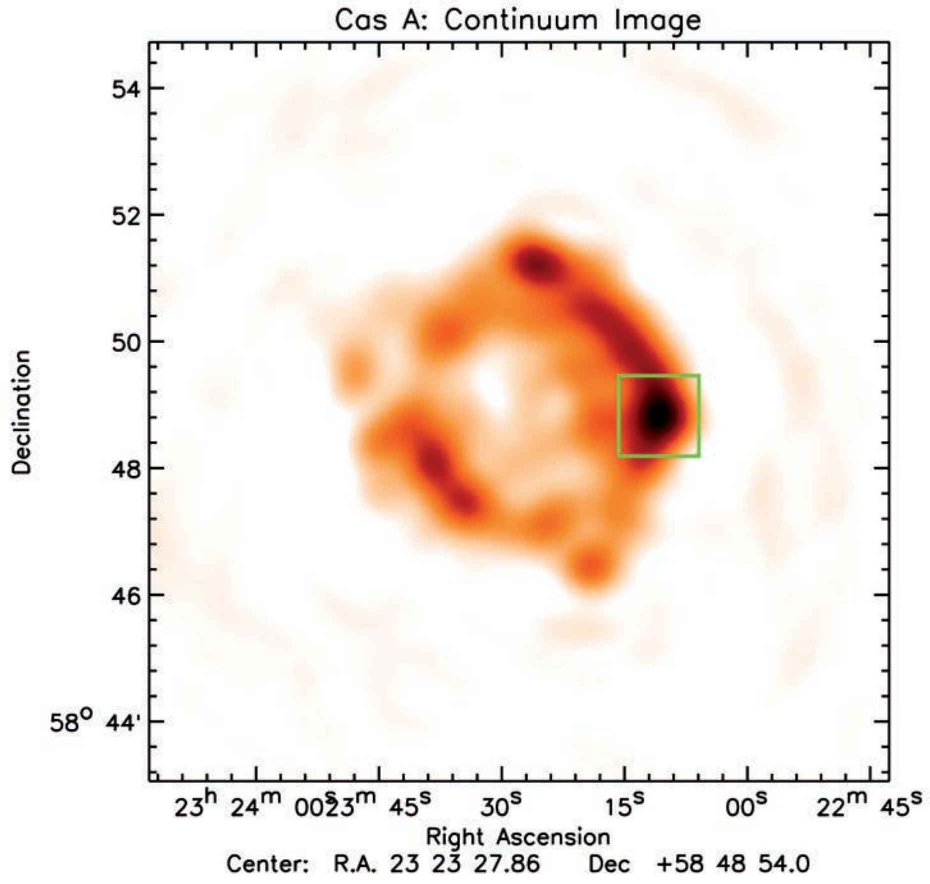


Figure 1: LOFAR radio continuum image of Cassiopeia A at 52 MHz radio (Asgekar et al., 2013, A&A, 551, L11). Cassiopeia A is a famous supernova remnant in the northern sky. After a massive star ends its life, it releases most of its birth material back into the ISM through an enormous explosion. At low radio frequencies we see the remnant of this explosion in the form of a shockwave traveling outwards. This image was made from a single sub-band (0.2 MHz bandwidth) and has a beam size of 40 arcsec.

The observed strength and width of these RRLs depend sensitively on the properties of the gas in which they originate. In particular, carbon RRLs, due to their low ionisation potential and strong amplification at low frequencies, provide a useful probe of the cold atomic gas. The unprecedented sensitivity, resolution and frequency coverage of LOFAR now makes it possible for us to observe these RRLs with a high signal-to-noise ratio, see Figs. 1 and 2. ➔

In the coming months we will expand upon these results and embark upon a survey of these lines in our own Galaxy and beyond.

Using LOFAR we will therefore finally be able to determine the role of the cold atomic gas in the evolution of our Galaxy.

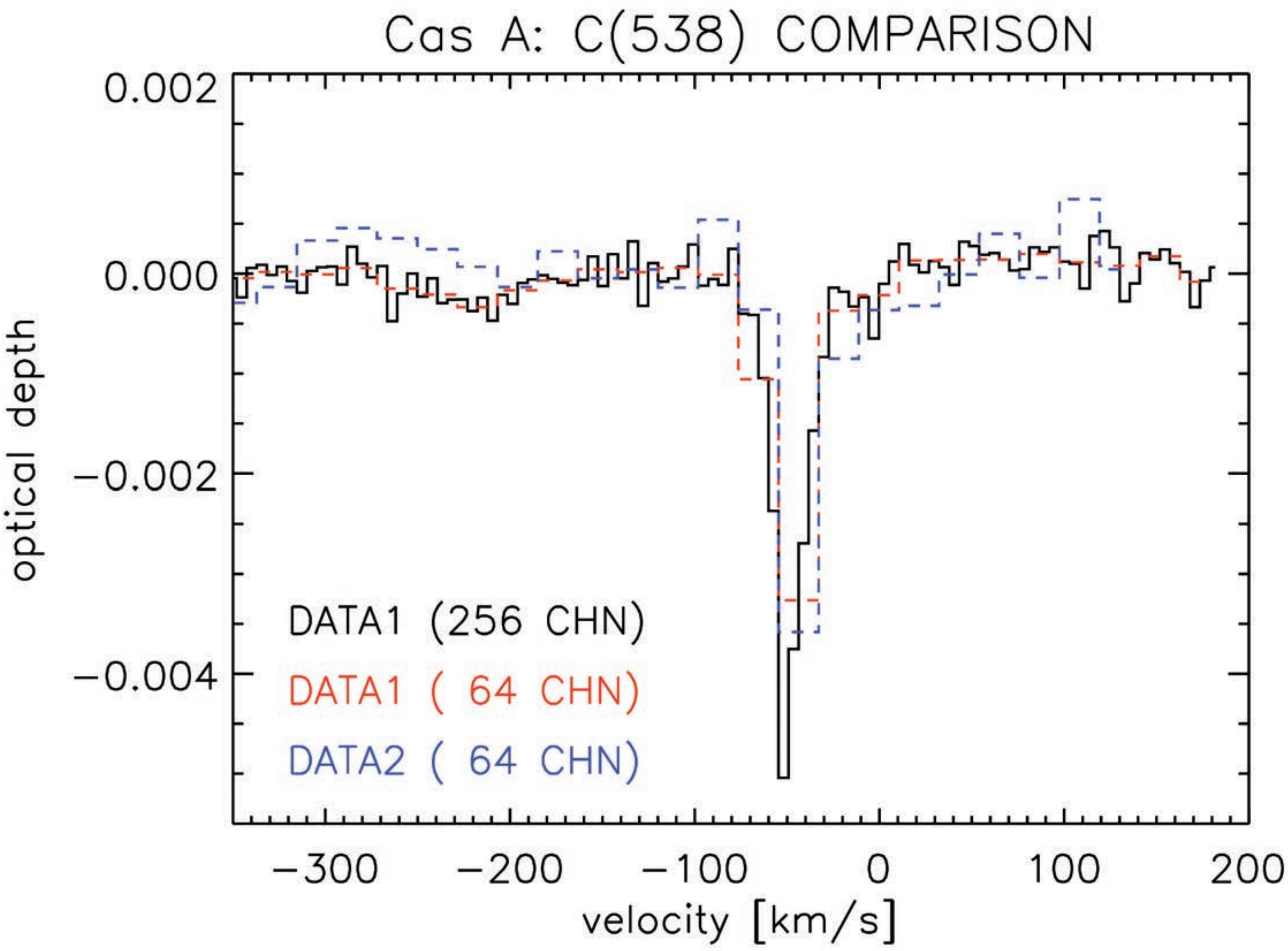


Figure 2: LOFAR carbon RRL detection at 42 MHz (Asgekar et al. 2013). The cold atomic ISM gas between the supernova remnant Cassiopeia A and us shows bright carbon RRLs in absorption. Here we show the optical depth line profile as a function of velocity for the carbon RRL transition between quantum levels 539 and 538. By measuring the optical depth and the width of the carbon RRLs as a function of quantum number we can determine the temperature and density of the associated gas.

Investigating nearby galaxies with a fine-tooth comb

Megan Argo (argo@astron.nl)

Very Long Baseline Interferometry produces exceptionally detailed images of the radio sky, but, due to limitations inherent in hardware correlators, the area that can be mapped is often limited to a matter of arcseconds, even though the telescopes are sensitive over a much larger field of view. This limitation has meant that large-area VLBI surveys require too much telescope time to be practical. The recent development of software correlators means that it is now possible to correlate many separate fields (known as 'phase centres') from a single observation, allowing us to map much larger areas of the sky. One application of this technique is in the study of nearby galaxies; M31 and NGC253, two of our nearest galactic neighbours, have both recently been mapped in this way.

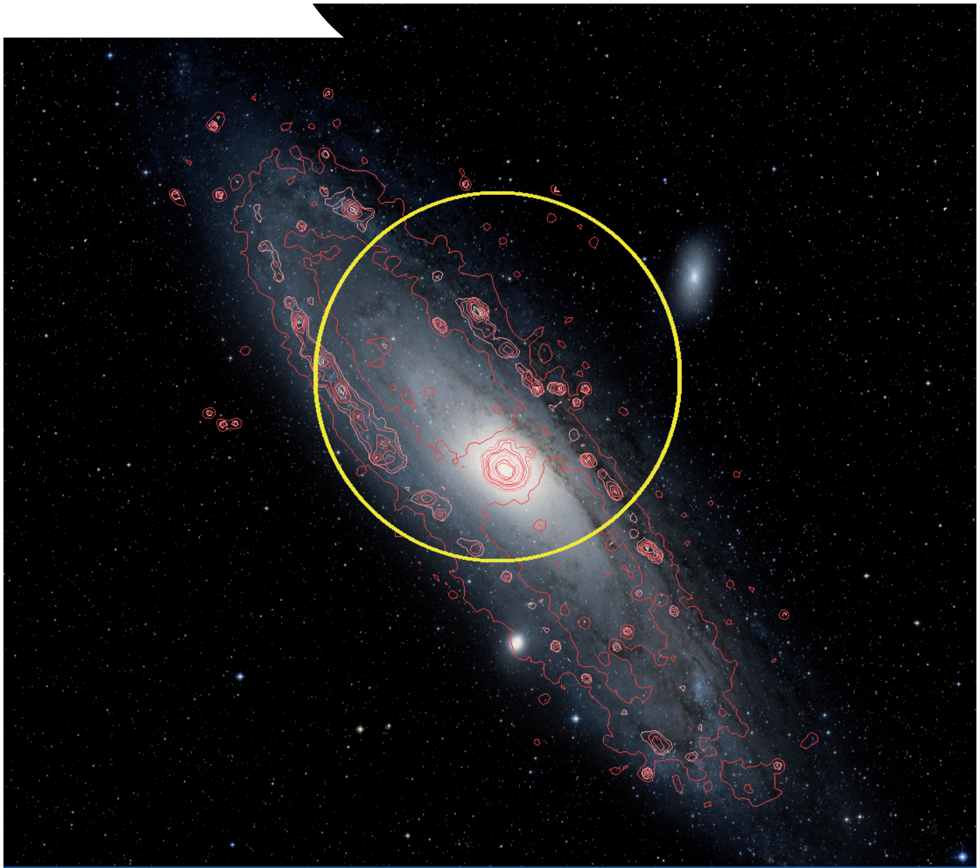


Figure 1: M31 as seen in optical light (from Aladin). The contours show the low-resolution radio emission from archive VLA observations, while the yellow circle roughly represents the primary beam of the VLBA at 1.4 GHz, an area half a degree across, about the size of the full moon. The use of this new technique allows us to image fields at milli-arcsecond resolution anywhere within this region.

M31, also known as the Andromeda galaxy, is the nearest spiral galaxy to our own Milky Way and is easily visible to the naked eye. Spanning some four degrees, it is too large even for one wide-field observation. Together with collaborators at ICRAR in Australia, we have observed part of the galaxy with the VLBA and, using the DiFX software correlator, placed phase centres on each of the radio sources known from previous arcsecond-scale surveys. Of the ~200 catalogued objects, we detected only 16, all of them background AGN. The objects in M31 itself are all too extended or diffuse to be detectable with the long baselines of VLBI, but the background AGN are giving us a valuable and unique insight into the ionised interstellar medium in another galaxy, and a series of follow-up observations are underway (Morgan et al. ApJ, 2013, in press).

NGC253 is one of the closest starburst galaxies containing a large population of X-ray sources. Working with a different team, the galaxy was observed simultaneously, over three epochs, with the VLBA, Chandra, and NuSTAR, a small high-energy X-ray satellite launched in 2012. Using the X-ray maps, we placed phase centres over each of the bright objects to look for radio emission and variability, carrying out the widest VLBI survey of the galaxy to date (Lehmer et al. ApJ, submitted; Wik et al. in prep; Argo et al. in prep).

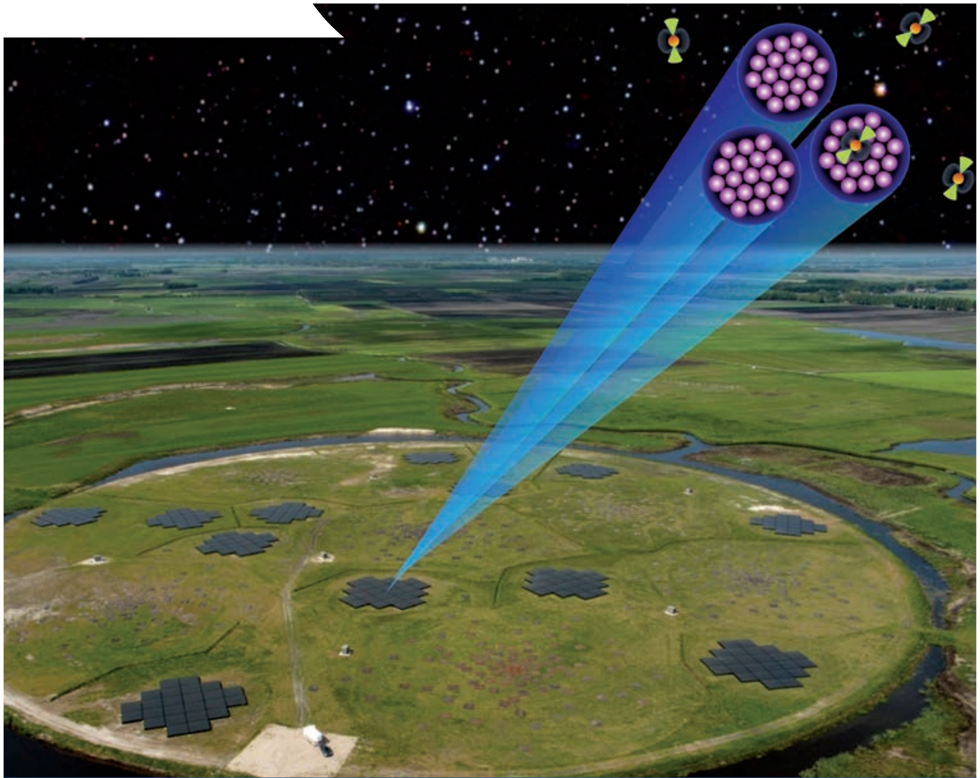
Jason Hessels wins Vidi award

Astronomer Jason Hessels (ASTRON and University of Amsterdam) has been awarded a 'Vidi' grant of 800,000 Euros from the Netherlands Organisation for Scientific Research (NWO). With this grant, Hessels will build a research team that will turn the LOFAR radio telescope into the world's premier high-speed radio camera.

Looking up on a starry night, it's easy to imagine that the Universe is unchanging. In reality, however, the Universe is teeming with activity: there are massive explosions from accreting black holes, bright radio flashes from ultra-magnetic pulsars, and likely other spectacles that have so far escaped our prying eyes. These fleeting events can happen faster than the blink of an eye and, importantly, they trace the most extreme astrophysical phenomena. Catching these rare performances poses a major challenge for observational astronomers, but the scientific payoff is well worth the effort.

Hessels and his new team will mould the Low-Frequency Array (LOFAR) telescope into 'DRAGNET', the world's premier high-speed, wide-angle camera for radio astronomy. Radio waves are a unique and powerful way of investigating the most extreme astrophysical processes. Also, LOFAR is a unique radio telescope, which provides the exciting opportunity to monitor the heavens for rare, powerful explosions as never before possible. With his Vidi grant Hessels will search the sky for new pulsars (rapidly spinning, super-magnetic neutron stars) and will try to detect radio signals from the Universe's most extreme explosions: supernovae and gamma-ray bursts. Compared with previous radio telescopes, LOFAR can view a much larger fraction of the sky at once, which is critical for catching these rare events in the act.

Also, Alessandro Patruno, researcher at the University of Amsterdam and affiliated to ASTRON, was granted a Vidi on the related subject of neutron stars. He will use the Vidi at Leiden University to set up a research team.



The central core of the LOFAR radio telescope array along with an artist's conception of how the telescope views the sky through a large field of view.

Breaking news: ERC Starting Grant awarded to Jason Hessels

In the week of 10 June, Jason received the news that he was also awarded an ERC Starting Grant for close to 2 million Euros. He will use the grant to process high time resolution LOFAR data in *real time*, which is not possible to do with the complementary Vidi award and which will enable the highest possible observing efficiency and rapid localization of rare transient events.

Starting Grants from the European Research Council aim to support up and coming research leaders in forming their first major research team. The grants are highly competitive, with a typical success rate around 10%.

Holland High-Tech: Top Talent for Top Performance

Dutch companies and knowledge organisations in the national Top Sector HTSM (High Tech Systems and Materials) set themselves apart by their technological excellence, and are world leaders in their market segments. The HTSM ambition is to double exports from 32 billion Euros in 2009 to 77 billion Euros in 2020. This is why Holland High-Tech House (HHTH) presented itself at the Hannover Messe (8-12 April). The Messe is the largest industrial trade fair in the world. The HHTH was present in both Hall 2 with Research & Technology, and Hall 4 with the Dutch supply industry. This is an obvious platform for presenting the entire Dutch high-tech sector, to representatives of major companies and knowledge organisations.

Bertholt Leeftink, Director-General of Industries and Innovation of the Ministry of Economic Affairs, is giving a speech at the VIP-meeting of the Hannover Messe 2013. On the right is Mrs Ineke Dezentje-Hamming (General Director of FME) and left of the far table is Director General of the Netherlands Organisation for Scientific Research (NWO), Hans de Groene.

NWO institute ASTRON was part of the Holland High Tech House at the Hannover Messe. The knowledge and expertise gained by research and development in radio astronomy has given ASTRON the capability to design and build extremely sensitive antenna systems, sensor technology, embedded computing, smart software, nano-photonics, low noise amplifiers, low-power micro electronics and precision technology. Among other things, ASTRON showed the technology of the International LOFAR Telescope, which is also relevant for the SKA. For instance the water cooled Uniboard, which is currently the ultimate high-performance embedded processing platform ASTRON has to offer. Another example is a photonic smart-antenna demonstrator.

The picture shows the VIP-meeting at the Holland High Tech House held on Wednesday 10 April. Mr. Bertholt Leeftink, Director-General of Industries and Innovation of the Ministry of Economic Affairs, is making a statement to Mrs Ineke Dezentje-Hamming (General Director of FME, the entrenpreneur organisation for the technological industry) and in front of Hans de Groene (left of the far table), Director General of the Netherlands Organisation for Scientific Research (NWO). He is outlining the open communication in Dutch industries internally, and their readiness to collaborate with other companies. This gives Dutch industries a tremendous advantage in finding high-tech solutions for the global challenges we are facing.

High school girls are scientists for a day on Girlsday 2013

Monique Ankone (ankone@astron.nl)

After the great successes of the previous years, ASTRON organised the Girlsday for a fourth time. On Thursday the 25th of April, ASTRON, JIVE and the NOVA Optical/Infrared group opened their doors to young girls aged 14 to 15 years in order to awaken their interest in science and technology. VHTO, the Dutch National Expert Organisation on Girls/Women and Science/Technology, organises the annual Girlsday on the fourth Thursday of April. It is a European initiative to make young girls enthusiastic about technology and ICT, and can also help them in their choice of profiles in high school or in their choice for further studies towards a career in science and technology.

This year, 32 high school girls from four high schools in the North of the Netherlands visited ASTRON, JIVE and the NOVA Optical/Infrared group (see picture on the next pages). On this day, astronomers and engineers introduced the girls to their daily routine and exciting workshops. The girls learned how antennas and other instruments for radio telescopes work and they could even build their own radio receiver. They also had the opportunity to take a journey through the Universe with the inflatable planetarium and had the chance to chat to female astronomers and engineers from other countries such as Germany, France and South Africa.

New coordinator education and diversity

My name is Monique Ankoné and I started to work for ASTRON as the coordinator of education and diversity since November 2012. I am educated in Astronomy, Physics Education and Science communication. From the youngest age I can remember, I wanted to be a scientist and my initial interests pointed me towards Astronomy.

In 2009, I finished my bachelor thesis, where I determined the absolute fluxes of stars for use as calibrators in the photometric reduction of data from the Global Astrometric Interferometer for Astrophysics (GAIA) satellite. However, finishing my bachelor I realised that I wanted to work more in the PR-field of astronomy. Therefore I chose an astronomical master thesis in combination with science communication and worked at the Netherlands Research School for Astronomy (NOVA). Due to my interest in the PR-field of astronomy, I started in 2010 a project with the inflatable Universe. The inflatable Universe is a portable, inflatable planetarium/dome with space inside for about 25 students. Visiting schools with the inflatable planetarium, gave students the opportunity to take a journey through the Universe. The movement of celestial objects can be simulated and special objects in the Universe, like planets in the Solar System and exotic sources like supernovae and quasars, far away in the Universe can be seen zoomed in. As the projection is on the entire dome, visitors will feel immersed in a real Universe.

Next to being an enthusiast in astronomy, I am also a physics teacher at H.N. Werkman College in Groningen. Being a physics teacher is great, because every single day is different whether you like it or not…. But what's even better is that as a physics teacher you can make a true difference in a student's life. Especially in high school when they are deciding what they want to be. You can show them what true science is, the art of observation, questioning, and how interesting astronomy is!

32 high school girls from the north of the Netherlands visited ASTRON, JIVE and the NOVA Optical/Infrared group during Girlsday 2013.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The LOFAR Multi-frequency Snapshot Sky Survey (MSSS): Progress Update

George Heald (heald@astron.nl) on behalf of the MSSS Team

MSSS – LOFAR's first all-sky survey – has two primary goals. First, MSSS is currently producing the first broadband low-frequency catalogue of the northern sky. Second, the MSSS effort has led the charge in the development of automated data processing techniques for LOFAR's imaging modes.

Since our progress update in the last edition of the ASTRON Newsletter, the HBA part of the survey (covering the 120 to 160 MHz frequency range) has kicked off and is proceeding in earnest along with the Cycle-0 observations that dominate LOFAR's observing schedule. At the time of writing, approximately 25% of the 3616 MSSS-HBA survey fields have been observed, and the projected completion is in mid-2013. The MSSS Team is currently producing first images, mosaics, and source catalogues from the data with excellent results. An example MSSS image mosaic is shown in Figure 1. This mosaic brings together 32 separate MSSS-HBA fields, and all eight-frequency bands (for a combined image bandwidth of 16 MHz, centred near 140 MHz). The full mosaic area covers over 200 square degrees! A sub-region of this mosaic has been designated as the 'MSSS Verification Field' and will be presented in a forthcoming journal publication.

Many well-known sources (nearby star-forming galaxies, distant radio galaxies, supernova remnants, etc) have been detected in the thousands of MSSS-HBA images that are currently being produced. A milestone was reached when the first newly identified source was discovered in an MSSS image! Shown in Figure 2, the new source has been classified as a giant radio galaxy (GRG), associated with one member of the galaxy triplet UGC 9555. The GRG measures 36 arcminutes across (it appears larger on the sky than the full moon), equivalent to a projected size of several million light-years. Compared with other GRGs, this one is relatively large for its radio power, suggesting that it may be older than other known GRGs. Since LOFAR is well suited to finding old GRGs, there may be many more of these sources awaiting detection! ➔

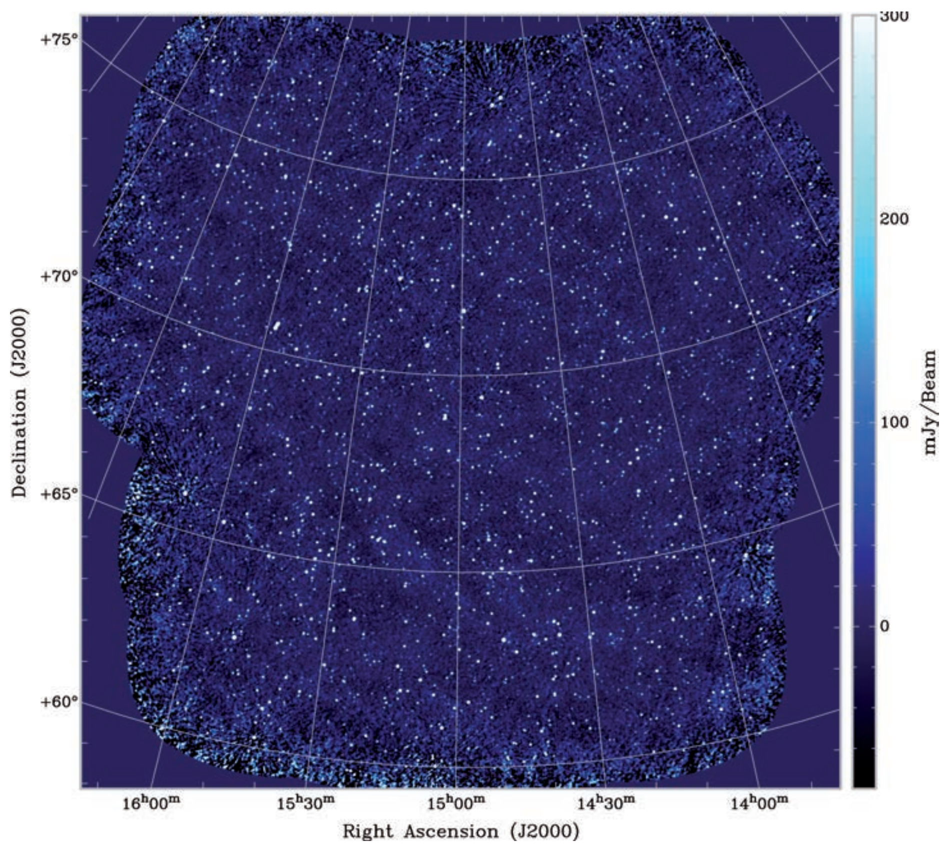

Figure 1: MSSS-HBA mosaic centred on the MSSS Verification Field. The mosaic was formed from 32 individual MSSS-HBA fields, and the full 16 MHz bandwidth between 120 and 160 MHz. The angular resolution is about 2 arcminutes, and the image noise is approximately 10 to 15 mJy/beam.

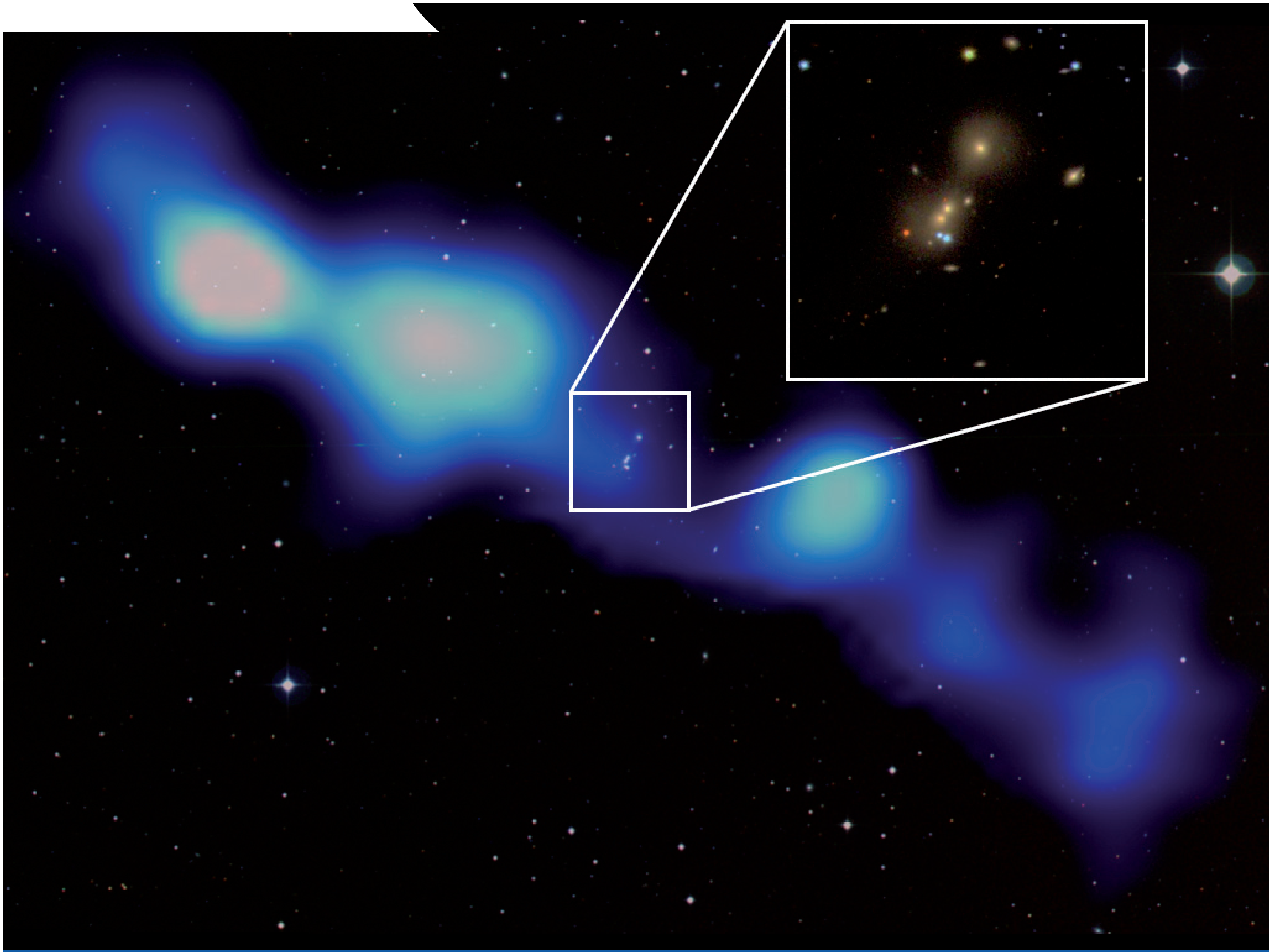

Figure 2: The newly discovered giant radio galaxy. The MSSS-LOFAR data, shown as the blue-white colours, are overlaid on an optical image of the field from the Digitized Sky Survey (DSS). A close-up view of the galaxy triplet UGC 9555 from the Sloan Digital Sky Survey (SDSS) is also shown in the inset.

The MSSS observing status, along with a comprehensive summary of the properties of the MSSS data, are being collected and presented via a customised web interface. The interface is available on the ASTRON website, and will eventually also provide access to the MSSS data products when they are publicly released. You can keep track of the MSSS survey progress by visiting the website: *http://msss.astron.nl*

A Multi-frequency study of the Lockman Hole Region: preparing for LOFAR deep surveys

Gabriele Guglielmino (Università di Bologna; INAF; ASTRON), Isabella Prandoni (INAF), Raffaella Morganti (ASTRON)

One of the most debated issues about the sub-milli-Jansky (sub-mJy) radio sources, responsible for the steepening of the 1.4 GHz sources counts, is the origin of their radio emission. Understanding whether the dominant triggering process is star formation or low luminosity nuclear activity has important implications on the study of the star formation/black hole accretion history with radio-selected samples. In order to shed light on the physical properties of sub-mJy sources an important role is played by multi-frequency radio observations: radio spectral indices may help to constrain the origin of the radio emission, allowing us to distinguish between self-absorbed AGN cores and optically thin synchrotron emission that is typical of star-forming galaxies and/or AGN radio lobes. LOFAR observations will play an important role allowing, for the very first time, observations of the sub-mJy radio source population at very low frequencies (30 to 200 MHz), a frequency domain never explored before, where self-absorption phenomena are expected to become increasingly important.

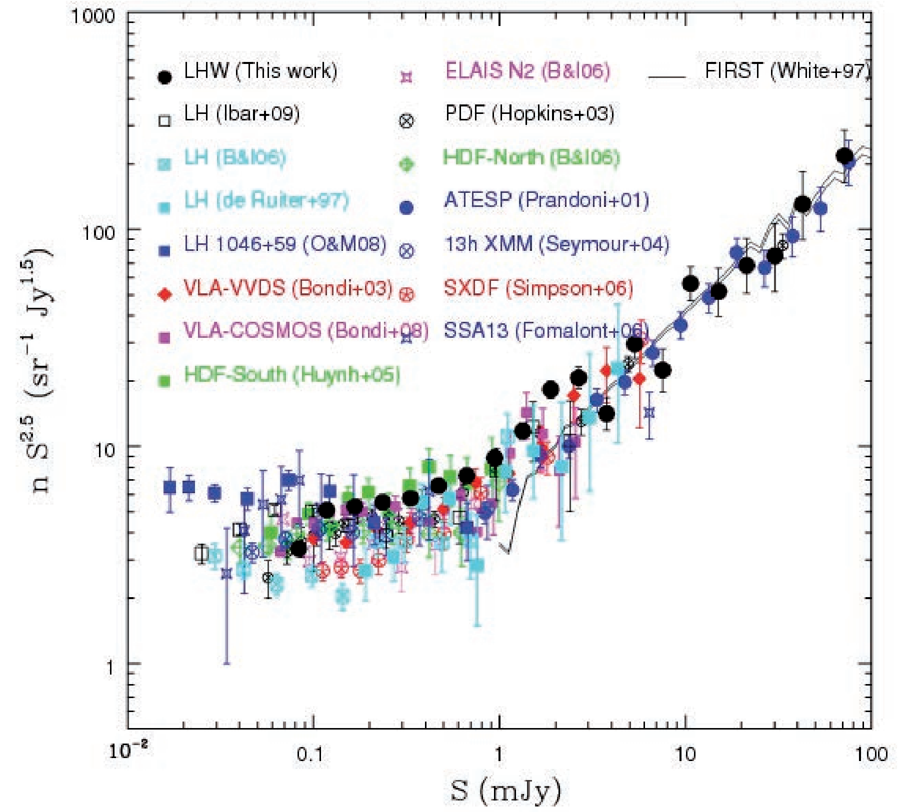

Figure 1: Normalised 1.4 GHz differential source counts for different samples. The LH counts derived from the WSRT mosaic are indicated as filled black circles.

In order to make progress on this topic, the joint ASTRON/INAF-IRA PhD student Gabriele Guglielmino has targeted the Lockman Hole (LH) Region at several radio frequencies with the Westerbork Synthesis Radio Telescope WSRT (1.4 GHz and 345 MHz) and with the LOFAR HBA (150 MHz). The Lockman Hole is one of the best studied regions of the sky in different wavebands (in particular optical and infrared); therefore providing important complementary information (for example photometric redshifts) to the radio data.

The LH region was observed with the Westerbork Synthesis Radio Telescope (WSRT) at 345 MHz and 1.4 GHz (Guglielmino et al. 2013a, 2013b). ➔

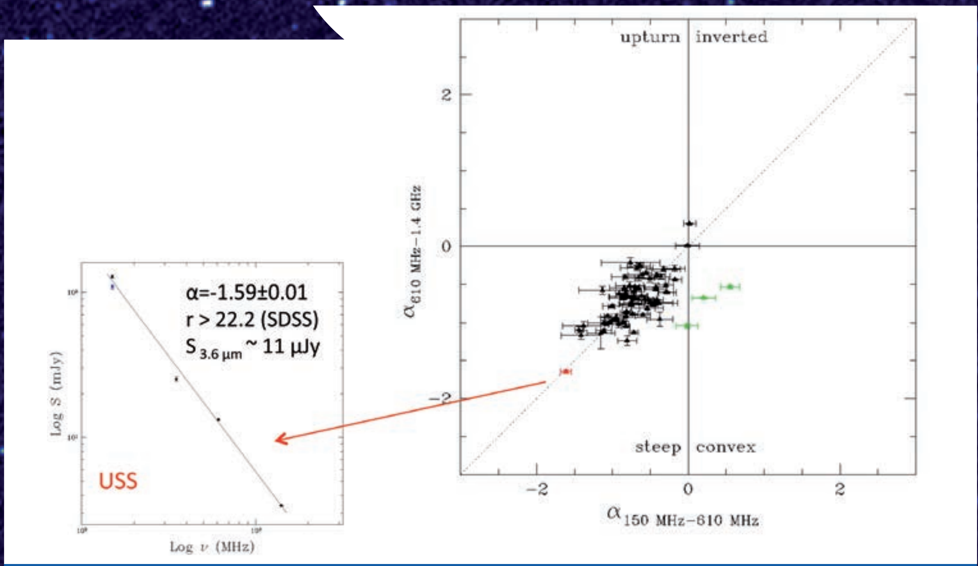

Figure 2: 610-1400 MHz and 150-610 MHz spectral index distribution for the bright (S > 15 mJy) 150 MHz-selected sample. The diagonal line indicates the one-to-one correlation, that is, spectra described by a single power-law. The left panel shows the spectrum of the USS source discovered in the sample.

These observations have resulted in one of the deepest 1.4 GHz mosaics obtained so far (down to about 10 microJy rms noise) on such a large area of the sky (about 6 sq. degr.). The extracted source catalogue, (about 6000 radio sources down to $S_{1.4\,GHz}$ ~ 50 microJy) provided one of the most statistically robust determinations of the 1.4 GHz source counts in the flux interval 0.1 < S < 1 mJy (see Fig. 1, black points).

During the commissioning phase of the LOFAR telescope, the LH field was observed at 150 MHz. The derived image represents the first LOFAR flux calibrated full-resolution (about 5 arcsec) image of a deep field. This was achieved by implementing observing and calibration strategies that proved to be very successful, and that are becoming a standard for other similar fields. From this image, a bright source sample was extracted. This can be considered complete down to *S* > 15 mJy. It is worth noticing that the 150 MHz source flux densities were corrected for the primary beam attenuation following an original statistical approach, described in detail in Gabriele's PhD Thesis.

A spectral index study of the mJy sources in the LH region was performed using the available catalogues (1.4 GHz, 345 MHz and 150 MHz) and a deep 610 MHz source catalogue available from the literature (Garn et al. 2008, 2010). A general trend towards flatter spectral indices going to deeper flux densities was found. This flattening is in line with previous results in the literature, mainly obtained at higher frequency. This supports the hypothesis that self-absorbed core dominated AGN may play a significant role in the faint radio population.
In order to better investigate whether self-absorption effects do play a role at 150 MHz, the low- and high-frequency spectral indices were compared in so-called radio 'colour-colour' plots (one example is shown in Fig. 2). The sources were found to nicely distribute around the one-to-one spectral index correlation (see diagonal line), indicating that a single power law can describe their spectra over the entire spectral range considered (150 to 1400 MHz). In other words, a significant extra-flattening of the spectra was not found down to 150 MHz; only three sources (green points in Fig. 2) showing a significant curvature. In other words, self-absorption effects, if present, do not affect a significant fraction of the mJy radio population, at least down to a few tens of mJy and down to a frequency of 150 MHz.

As a final remark, it is worth noticing that an ultra-steep spectrum (USS) source was serendipitously discovered in the field (see red point in Fig. 2). Its overall spectrum can be fitted by a power law with a slope alpha = 1.6 (see left panel of Figure 2). Such a source does not have an optical counterpart down to the SDSS limit of r ~ 22.2 magnitude, but is associated with a very faint infrared counterpart, supporting the hypothesis that this source is at high redshift. This is a first example of the many USS sources that are expected to be discovered by the upcoming wide-field deep LOFAR surveys.

Building on these first encouraging results, new LBA and HBA observations (obtained as part of Cycle-0), will be exploited to extend the multi-frequency analysis of the LH to deeper flux densities and lower radio frequencies.

Measuring the antenna response of LOFAR

Maria Krause, Anna Nelles and Jörg Hörandel (Radboud University of Nijmegen) on behalf of the Cosmic Rays Key Science Project (m.krause@astro.ru.nl)

Instead of observing astronomical sources, in Autum of last year LOFAR had a look at a flying octocopter.

Since June 2011, the LOFAR telescope has been used to measure cosmic rays from space. These atomic nuclei have such a high energy that when they collide with particles in the atmosphere, they generate a cascade of millions of secondary particles that travel as a so called air shower towards the Earth's surface. Charged secondary particles travel along a bent trajectory in the Earth's magnetic field. They thereby emit radiation, mostly in the MHz frequency regime.

LOFAR has been delivering beautiful data of cosmic rays with an unprecedented number of antennas. However, in order to understand the physics behind the phenomenon, every single signal has to be corrected for the direction-dependent sensitivity of the LOFAR antenna. The understanding of the antennas is therefore crucial.

So far, we have been building on the expertise at ASTRON, where a considerable amount of work has been put into describing the response of the low-band antenna. However, as the radiation from air showers is created in the Earth's atmosphere, ➔

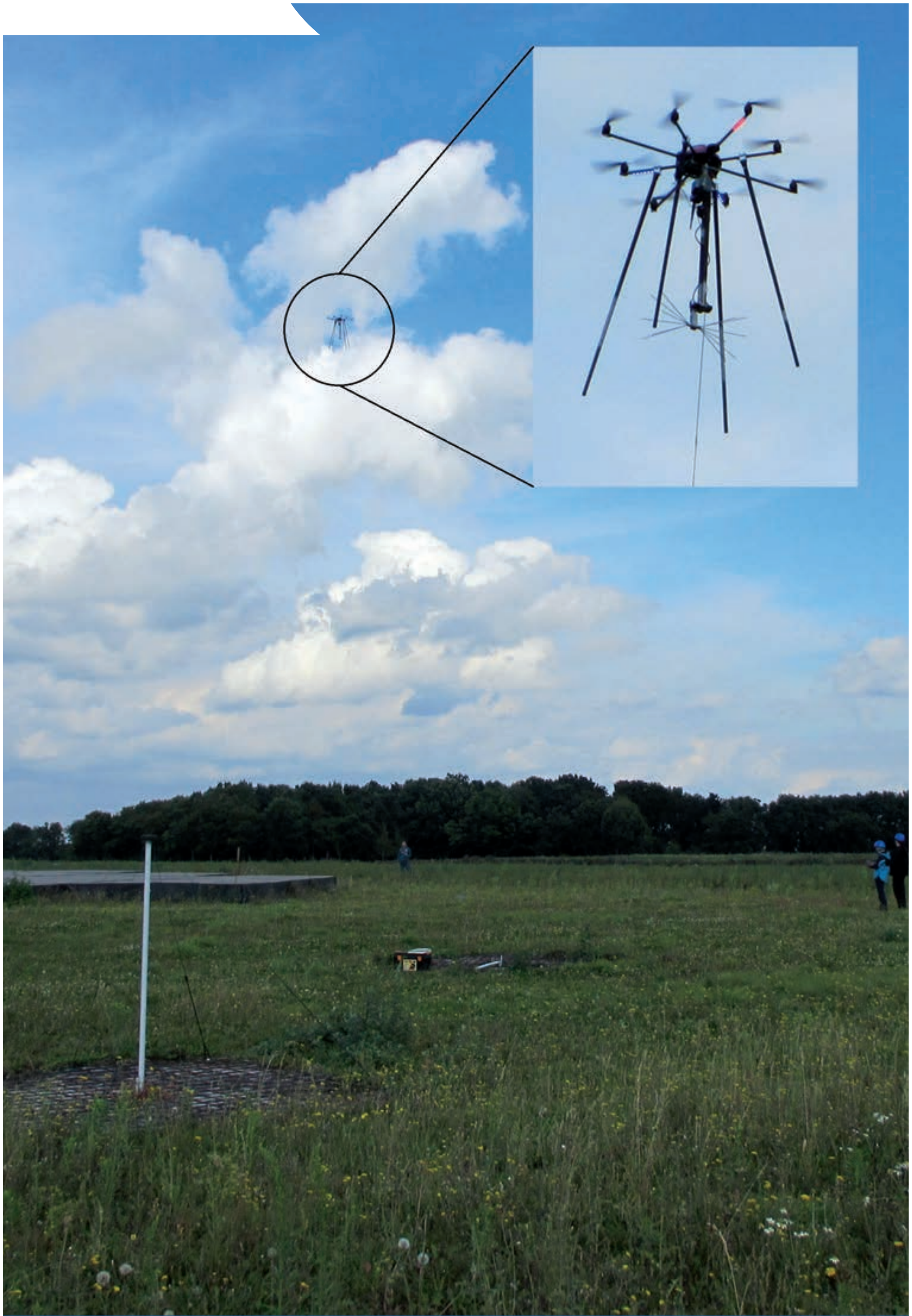

Figure 1: The octocopter with the artificial source above LOFAR.

none of the usual calibration tools of LOFAR can be used to verify our results. There is no natural steady source within the atmosphere to calibrate on. Thus, an artificial source is needed, which can be measured with a single antenna.

A calibrated antenna was flown on an octocopter (Fig. 1) over several LOFAR antennas to measure their response pattern in situ. So far, the pattern has only been simulated. The response was measured with respect to the direction and for all frequencies. A nice dipole response was observed (Fig. 2), which can now be compared in detail to simulations and will help to improve them.

Additionally, a pulse generator was flown. The corresponding measurements can be used as an independent crosscheck of the timing calibration of the system.

The results from this campaign will be fed back into the standard LOFAR reconstruction pipelines.

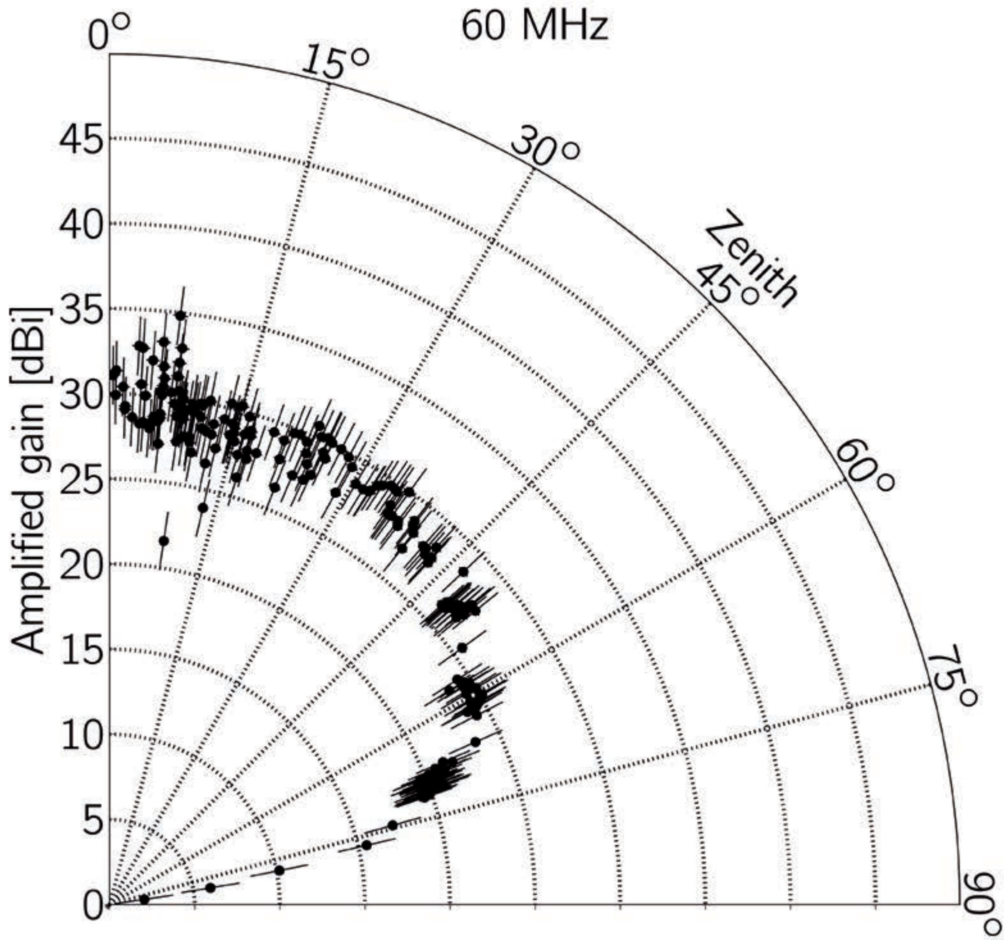

Figure 2: The antenna gain response as a function of direction at 60 MHz as measured with the octocopter above LOFAR.

The team (ICRAR, Cambridge University and ASTRON) during the antenna system test of the first on-site AA-Low Verification System at MRO in Western Australia.

On-Site SKA Verification System for Low Frequency Aperture Arrays

Benedetta Fiorelli (fiorelli@astron.nl)

As the Square Kilometre Array (SKA) project approaches the construction phase, verification systems have been developed for AA-Low, the aperture array system for the low frequency band of the SKA, with the aim of verifying array performance and functionality. An on-site AA-Low verification system has recently been deployed in Western Australia, making a step forward in the evaluation of the system design. The low-end frequency band of the SKA will be covered by a wideband aperture array specified to work around the 50 to 350 MHz frequency band in an irregular configuration defined to be sparse at frequencies higher than 110 MHz. The design recently selected to be the future AA-Low antenna is the log-periodic antenna designed at the University of Cambridge, called SKALA.

To demonstrate and evaluate potential telescope design solutions, a series of Aperture Array Verification Systems (AAVSs) have been developed. Updating the AAVS0 located in Cambridge, AAVS0.5 has been realised at the Murchison Radio-astronomy Observatory (MRO) in Western Australia and it represents the first Verification System at the SKA-low site. The array consists of 16 dual-polarised SKALA elements designed by the University of Cambridge, placed in a random configuration covering a circular area of approximately 10 m in diameter.

Locating the array in the Australian desert allows us to evaluate the requirements related to the site's peculiarities along with the antenna system functionality. In the last week of April 2013, a set of measurements and field tests have been taken with AAVS0.5 by a team from ICRAR, Cambridge and ASTRON. The activity produced a higher level of knowledge of the challenges related to the remote location and the site peculiarity. Measurement results will come soon, so watch this space!

New LOFAR guides complete training course

Femke Boekhorst (boekhorst@astron.nl)

On Saturday 20 April near the LOFAR telescope in Exloo, after two months of training, seventeen volunteers became official tour guides to the LOFAR core area.

The Mayor of Borger-Odoorn, Marco Out, handed the LOFAR guides their certificates after they gave their first official tour through the LOFAR core and the associated nature preserve.

The training was set up by a group called the LofarTafel (a group of entrepreneurs in Exloo promoting LOFAR in the region), and by the foundation Het Drentse Landschap (the organisation for nature and landscape preservation in Drenthe), and is supported by ASTRON.

These organisations, but also local entrepreneurs, have regularly received questions from tourists and visitors in the area whether tours at the LOFAR telescope were possible. This gave rise to the idea for a course in which volunteers can be trained to do presentations and tours about the LOFAR telescope and the surrounding nature area.

The LofarTafel started the course in the beginning of this year. ASTRON supports the initiative by informing the guides about the LOFAR telescope and all its facets, and helping them with questions and materials such as photos and presentations.

The volunteers are trained to serve a broad audience consisting mainly of tourists and passersby in the area. The LofarTafel (*http://www.lofarzone.nl*) is the coordinator of the project and organises the visits to the telescope, together with ASTRON and Het Drentse Landschap.

The first official tour of the new LOFAR guides and the handing over of the certificate by the Mayor of Borger-Odoorn. The image on the top left shows one of the new guides (left) who just received his certificate for the course from the Mayor of Borger-Odoorn, Marco Out (middle). In the same image, on the right, is the coordinator of the training course. The pictures on the right and below show the new LOFAR guides in action. On their first tour, they guided forty enthusiastic people through the LOFAR area.

Radio morphological changes of the gamma-ray binary LS 5039

Javier Moldon (moldon@astron.nl), Marc Ribo, Josep M. Paredes (University of Barcelona).

Gamma-ray binaries are extreme systems comprising a massive young star and a compact object (black hole or neutron star) that produce non-thermal emission from radio wavelengths up to very high energy gamma rays, typically above tera-electronvolts (TeV). Two distinct scenarios can explain the gamma-ray emission; particle acceleration in the jet of a microquasar powered by accretion, or shocks between the wind of the massive star and the relativistic wind of a young non-accreting pulsar. The broadband emission is modulated by the binary orbital cycle, which suggests that the physical conditions are also periodic and reproducible. The diversity of these systems, together with the reproducibility of the conditions within each system, makes gamma-ray binaries excellent physical laboratories in which high-energy particle acceleration, diffusion, absorption, and radiation mechanisms can be explored.

Nevertheless, the number of known gamma-ray binaries is still very limited, and only about six binary systems are considered compact gamma-ray binaries. These systems produce outflows of relativistic particles emitting synchrotron radio emission up to several astronomical units, or a few milli-arcseconds (mas) at typical distances of 2-3 kpc. Very Long Baseline Interferometry (VLBI) provides mas resolution capable of directly imaging the radio outflow.

LS 5039 is a gamma-ray binary consisting of a bright O-type star and an unknown compact object with an orbital period of 3.9 days. It displays persistent and periodic X-ray and gamma-ray emission up to 4 TeV. The synchrotron radio emission appears to be extended when observed with VLBI on mas-scales. The source shows a main core and extended bipolar emission, which was initially interpreted as steady jets of a microquasar. However, high-resolution VLBA radio imaging showed that the morphology changes in only five days, which is difficult to interpret in a simple and shock less microquasar scenario, whereas it is expected within the young non-accreting pulsar scenario.

To fully understand this changing morphology, we conducted a multi-epoch VLBA campaign at 5 GHz, ➔

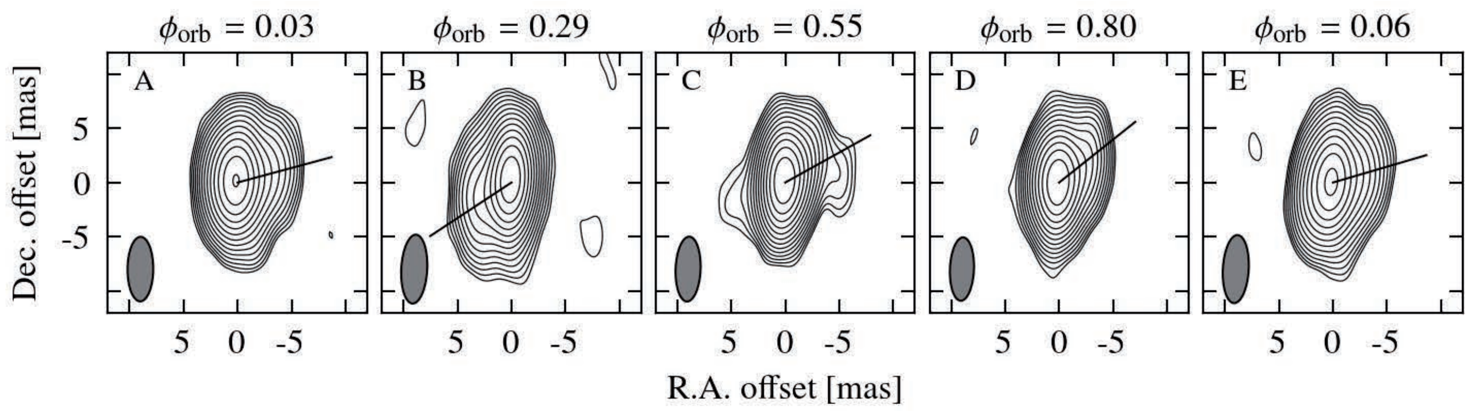

Figure 1: VLBA images of LS 5039 at 5 GHz obtained during five consecutive days. The lines show the direction of the main extended component. Fast changes can be seen after the peri-astron passage (runs A and B). The same morphology seen in runs A and E is a strong indication of periodic morphological changes.

observing the source during five consecutive days to cover an orbit of 3.9 days and an extra day to disentangle orbital and secular variability. We found that the direction and sense of the whole extended structure changes continuously, as shown in Figure 1. Fast changes are observed in images obtained only one day apart. Also, the source morphology during two consecutive peri-astron passages (runs A and E) is very similar, showing that the changes within the same orbital cycle are periodic.

To confirm the repeatability of the changing morphological structure of LS 5039, we analysed the available archival VLBI data for the source, which includes eleven observations conducted with the VLBA and the EVN, between 1.7 and 8.5 GHz, and spanning one decade, between 1999 and 2009. We sorted the images by orbital phase and found that images at similar orbital phases show similar morphology, even when separated by several years. We found that the changes, occurring periodically every 3.9 days, are remarkably stable on time scales of years.

We computed a model to reproduce the changing radio morphology of LS 5039 by assuming the young non-accreting pulsar scenario, where the structures are produced by a one-sided outflow that is bent due to the fast orbital motion of the pulsar around the massive star. Including radiative losses (synchrotron and inverse Compton in the Thomson regime) and adiabatic cooling, we produced synthetic images corresponding to the VLBI observations described above. This model describes correctly the main features in most of the observed images, except for the observations shortly after the peri-astron passage. The model sets the inclination of the binary system close to 70 degrees. This implies a mass of 1.8-2.0 Solar masses for the compact object, which is compatible with the presence of a neutron star.

These results strongly support the young non-accreting pulsar scenario as a natural way to interpret the radio images. On the other hand, the radio images strengthen the link with other gamma-ray binaries showing similar properties, and suggest that all gamma-ray binaries may contain young pulsars.

New manager business development

My name is Daniëla Mikkers and I joined ASTRON on February 1st, 2013. From that day on, I am exploring my new world and space: a new function on Business Development in this highly interesting knowledge based research institute. I will search for an opportunity to valorise the knowledge, technology, processes and capabilities as built up within ASTRON.

For the last twelve years, I have worked for Fokker Aerostructures. I started as an engineer (my background is Materials Science) but I quickly moved to the commercial activities within the programme. The last few years I've negotiated the bigger contracts like Ariane 5 and the JSF engine, on technical, commercial, legal and financial aspects. Besides these I was involved in New Business Development Programmes.

Together with my family (my partner Rob and two sons Nick & Noël) I live in Hoogeveen, I only need to hit the gas pedal three times and I am home ;-). I have a lot of interests, but not always enough time for my hobbies. Being a Mum to two little energetic boys is my biggest, I can say. Furthermore, I like to play tennis at least two times a week. I like reading, cooking (or better: eating) and wine. And I loved to walk my dog, but sadly he died a few months ago. Hopefully, within a few months we will welcome a new Rhodesian Ridgeback pup in our house, to be born sometime in June.

My door is always open for everyone. It is nice to experience that ASTRON colleagues already find their way towards me with good, challenging ideas, brain dumps, or just a little chat. So, you are all always welcome!

Scaling from LOFAR to SKA-Low

Jaap Bregman (bregman@astron.nl)

When a new instrument has to be built that is not a copy or only a slightly scaled version of a working one, the important question is which scaling laws actually apply. These scaling laws were the topic of my thesis on 'System Design and Wide-field Imaging Aspects of Synthesis Arrays with Phased Array Stations', which I successfully defended on December 14, 2012 at the University of Groningen.

SKA-Low, the low frequency system of the Square Kilometre Array, is a new instrument envisaged to be about ten times more sensitive than LOFAR. This can either be realised by building larger stations or by building more stations or a proper combination of both. Since source subtraction for the large number of baselines will dominate the processing for SKA-Low imaging of narrow continuum bands, there are important questions about whether the required processing power can be afforded, and how it could possibly be reduced.

Recent wide band continuum images with LOFAR demonstrated 25 μJy thermal noise showing the power of multi-direction self-calibration, but needed the subtraction of a few thousand sources. This subtraction dominates the processing for imaging and is strongly dependent on the side lobe level of the point spread function (psf) of the synthesis array.

My recent dissertation discusses, besides other topics, the approach to address this issue and shows a nonlinear behaviour for the number of sources that need subtraction to reach the thermal noise floor in an image as a function of psf side lobe level and of the field size. I investigated the impact of this nonlinear behaviour for the three options for the SKA.

For an array with the same configuration as LOFAR, we have the same rms side lobe level in the psf. Increasing the station size decreases the thermal noise and the beam solid angle at the same rate. As a result, approximately the same number need subtraction. However, having the same number of sources in a smaller beam, implies that we need to subtract to lower flux levels.

Alternatively, we could maintain the station size of LOFAR and increase the number of stations, which decreases the rms of the psf to first order at the same rate as the thermal noise. This approach keeps the number of source subtractions per visibility at the same level, but the larger number of baselines increases the processing. ➔

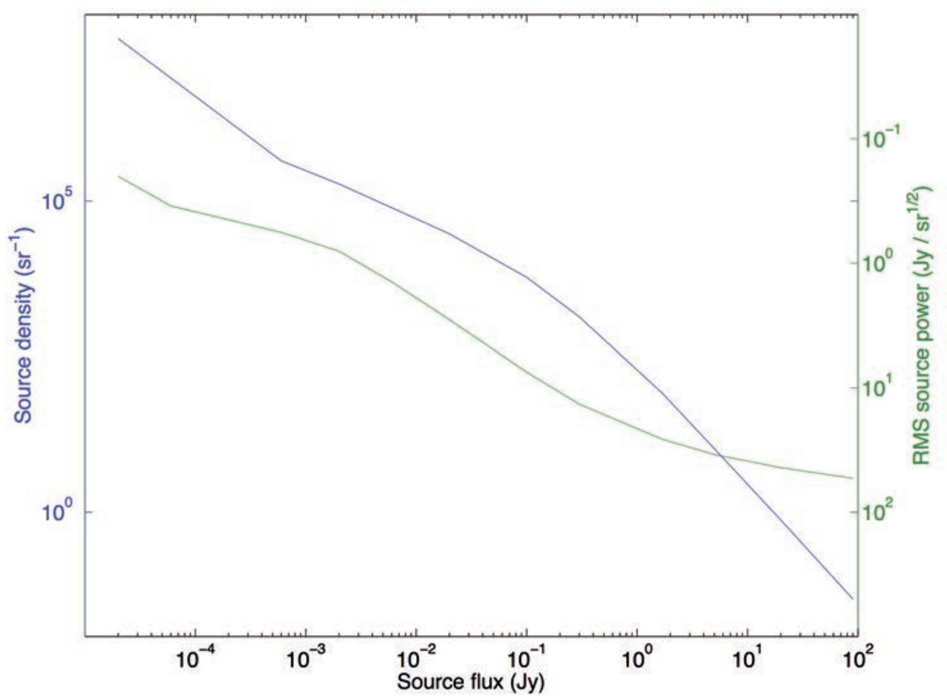

Figure 1: The expected density of radio sources and rms source power as a function of flux density. The green curve shows the rms source flux σ(< S) [Jy sr $^{-1/2}$] at 1.4 GHz for all objects up to the flux threshold S and the blue curve shows the source counts N(> S) [sr $^{-1}$] of all objects exceeding that threshold.

Fig. 1 shows the number of sources that exceeds a certain flux level as well as the rms of the fluxes of all sources below that threshold. Since both curves are not straight parallel lines, the actual number of required subtractions deviates from the previous approximations and needs the folding in of the beam solid angle, the thermal noise level and the psf rms level.

With a very low rms side lobe level there is a progressive reduction in the number of subtractions. A high side lobe level needs a progressive increase in subtractions of ever-weaker sources to the extent where we would need to subtract sources buried in their own noise floor. In the latter case, we can no longer identify the sources that need subtraction and we reached side lobe confusion.

An important effect of a denser station distribution is a denser uv-distribution that provides complete spatial sampling over the central part of the aperture plane and even over-sampling of the inner part. Appropriate weighing and tapering could then result in very low side lobes and low psf side lobe noise, but will also lead to an increased thermal noise. Further investigation is needed to show how we can optimise the SKA-Low configuration for the appropriate weighing to obtain minimum image noise at affordable processing cost.

Figure 2: Jaap Bregman shows his PhD Diploma, flanked by his two paranimphs, Jan Noordam (left) and Stefan Wijnholds (right), and the Pedel of the RUG (far-left).

A chameleon pulsar that shows fast magnetospheric changes

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New observations of the variable, mode-changing pulsar B0943+10 using a combination of the LOFAR, XMM-Newton and GMRT telescopes have produced perplexing results. The simultaneous X-ray and radio monitoring has revealed that this source, whose radio emission is known to switch from bright to quiet periodically in radio, behaves in reverse when observed at X-ray wavelengths. These are the first X-ray emission switches ever detected in a pulsar, and the properties of this emission are unexpectedly puzzling. No current model can explain this switching behaviour, but it is clear that the global pulsar magnetosphere must change between different states within only a few seconds.

The strong magnetic fields in pulsars, approximately one million times stronger than the fields scientists can make in laboratories on Earth, are known to produce both radio and X-ray radiation beams. As the star spins and these beams repeatedly sweep over Earth, the lighthouse-like neutron star is detected as a radio and/or X-ray pulsar. Although pulsars were discovered more than 40 years ago, the exact mechanism by which pulsars shine is still a matter of significant debate.

Quickly after their discovery it was noted that some radio pulsars switch in behaviour between two or even more states, changing the pattern and intensity of their radio pulses. These unpredictable, sudden changes often happen within a single rotation period. Pulsar PSR B0943+10 is a paragon of such mode-changing pulsars. It spins every second, but switches at intervals of several hours between a radio-bright, highly organised mode, and a quieter chaotic mode. This metamorphosis takes place within seconds, after which the pulsar remains stable in its new state for hours on end.

The switch between such radio-bright and radio-quiet states has recently been shown to be correlated to the pulsar spin-down. As pulsars rotate and sweep their magnetospheres around, the particles and currents on that magnetosphere apply a breaking torque on the neutron star. In several sources the amount of slowdown is clearly related to whether the radio pulsar is in a bright or quiet state. ➔

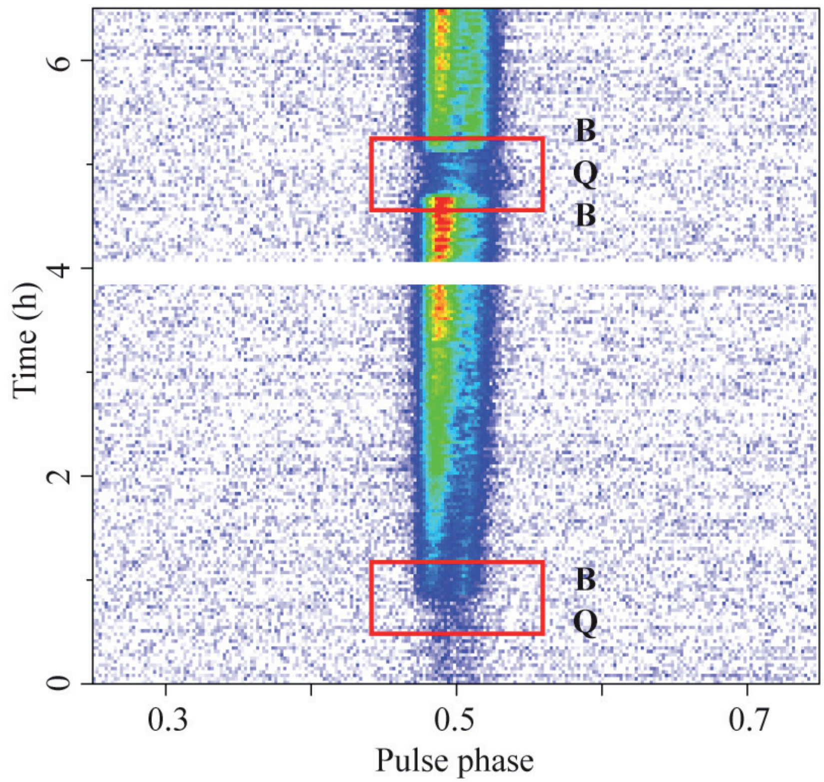

Figure 1: High sensitivity observations of the radio pulsar B0943+10. The LOFAR data clearly show the pulsar's intermittent behaviour on hour timescales. The pulsar starts off (bottom) in the quiet mode (Q), changes to the bright (B), the quiet and then the bright modes again.

The existence of correlated variations in both the rotation and emission suggest a connection between a pulsar's immediate vicinity and, on a grander scale, its co-rotating magnetosphere, which may extend up to about 50,000 km for objects like PSR B0943+10. In order for the radio emission to vary so radically on the short timescales observed, the pulsar's global environment must undergo a very rapid – and reversible – transformation.

Now, a handful of radio pulsars can also be weakly detected at X-ray frequencies, but their variability was unknown. Some emission-mechanism theories, however, predicted that there should be a correlation between the well-ordered radio-bright mode of radio emission in PSR B0943+10, and the bright X-rays.

This pulsar is a weak X-ray emitter, but is exceedingly strong at low radio frequencies. Over a total of 40 hours, ASTRON's LOFAR telescope was able to identify any switches down to a few seconds accuracy. The GMRT telescope in India provided coverage at slightly higher radio frequencies. Using the mode switches determined by LOFAR, all of the X-ray data taken simultaneously with the XMM-Newton satellite could be sorted into the two radio modes.

The results were surprising. The X-rays did indeed change their behaviour synchronously with the radio emission, as might have been expected – but in reverse. Whenever the radio signal was strong and the pulses were well ordered, the X-rays were weak. When the radio emission switched to weak and unordered, the X-rays more than doubled – and showed pulsations. Thus B0943+10 appears to switch between being a radio and an X-ray pulsar.

Overall, there appears to be a persistent X-ray component, consisting of non-thermal X-rays, that is always present. During the radio-quiet and X-ray bright phase, a pulsating component consisting of thermal X-rays appears. None of the leading models for pulsar emission predict such behaviour. Thermal X-rays are usually explained by hot spots on the neutron star surface that rotate in and out of our view as the pulsar spins. We know, however, that we are almost looking onto the pulsar pole of B0943+10, leaving little place for a hotspot to periodically hide. The most viable scenario appears to be that at every turn the hotspot is blocked by an opaque part of the pulsar magnetosphere.

The totality of the mode transition in PSR B0943+10 – the changes in radio profile and pulsation ordering and, now, the switching on and off in X-rays of a likely hotspot – implies that we are dealing with a rapid and global magnetospheric state change. Through radio and X-ray 'before' and 'after' snapshots, we have shown that a magnetosphere 10 times the size of the Earth completely changes personality within a few seconds; such a near-instantaneous transformation challenges our current understanding of pulsars and magnetospheres in general.

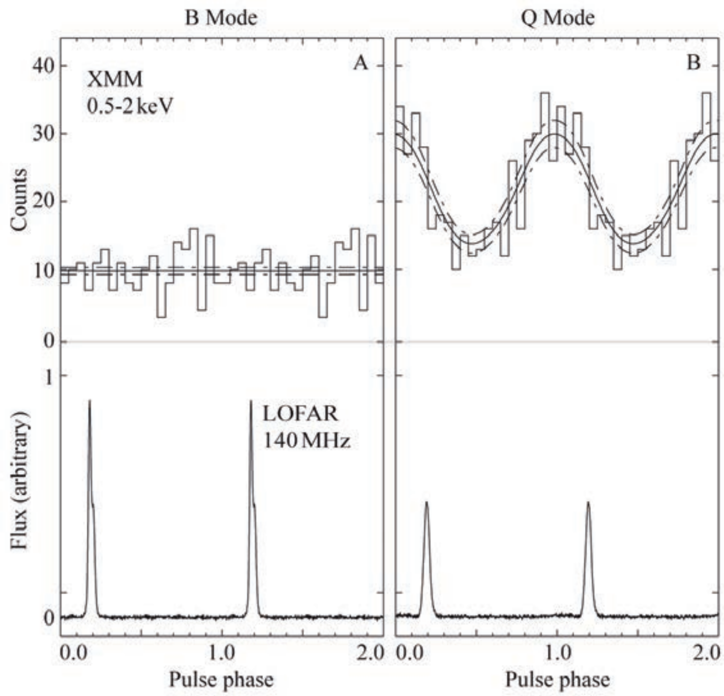

Figure 2: The X-ray and radio pulse phase profiles aligned in the bright and quiet modes. (Top-left) There is no evidence for a pulsed signal in the B-mode X-ray data, only a flat distribution showing the DC emission from the pulsar. (Top-right) The X-ray profile in the Q-mode represents a 7-sigma detection on top of a flat DC level. (Bottom) The radio pulse profiles from LOFAR during the radio bright (left) and radio quiet (right) modes.

Liquid cooling is key to green computing

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At DESP-group (Digital and Embedded Signal Processing), we are always looking for techniques to improve the signal processing for astronomical applications. With the increase in processing capabilities per chip, the power consumption increases as well. To cope with this increase and maintain high-density systems, new cooling techniques are needed. For the current systems, such as the Apertif beamformer, a forced airflow and passive heat sinks on the FPGAs (Field Programmable Gate Array) are used. We have now done tests to replace the heat sinks with water blocks and pump liquid through them to cool the hot spots on the processing boards.

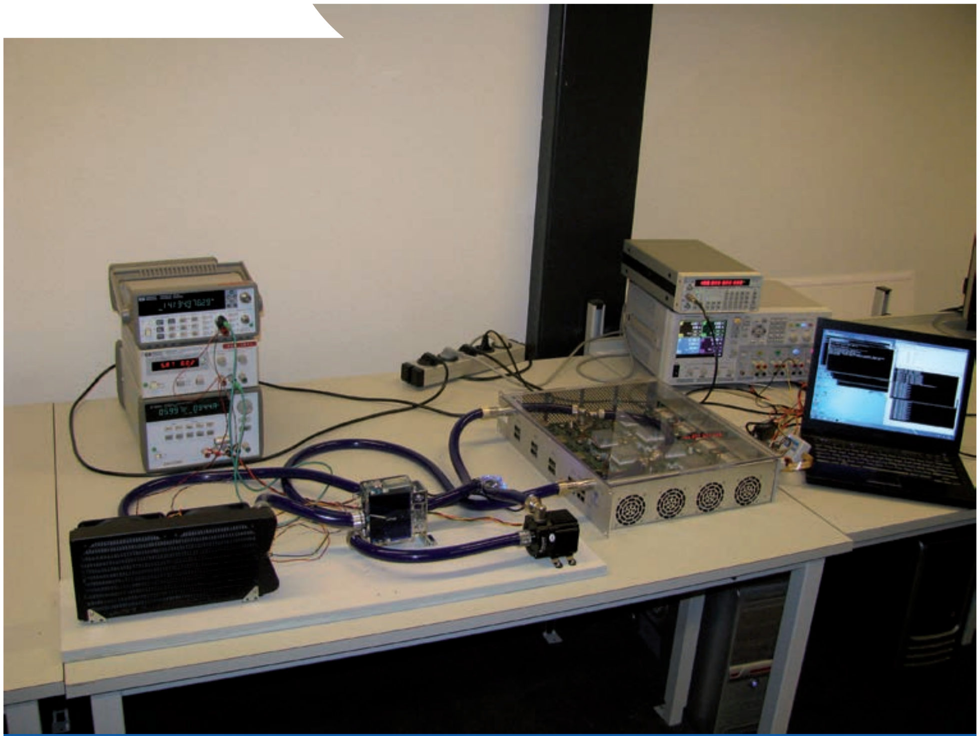

Figure 1: the liquid cooled system for UniBoard.

Liquid is pumped from the reservoir towards UniBoard. On UniBoard, water blocks replace the standard heat sinks. In the water blocks the heat from the FPGA is transferred to the liquid. The liquid from UniBoard is cooled down in the radiator and flows back to the reservoir. The liquid is non-conducting; a leak will not damage the board, and has additions to prevent corrosion and algae. With the quick release couplings, the board can be decoupled from the chain without spilling liquid.

With the test setup, the capacity of the liquid cooling is sufficient to run at half speed and still decrease the temperatures of the FPGA from 60° C with passive heat sinks to 30° C. The power consumption needed to cool UniBoard with liquid is decreased by 40%; this is the only cooling at the board level. When UniBoard is used, for example, as the Apertif Correlator, the heat from the subrack is transferred to the room (high frequency closed chamber) and from this environment to the outside of the building. With liquid cooling we can transfer the heat directly from the FPGA to the outside of the building without using additional power.

From these tests we have gained knowledge on how to cool more powerful FPGA based processing boards like UniBoard with less energy consumption for cooling. Although the price of a liquid cooling system is higher, the power consumption and the FPGA temperature are decreased, increasing the lifetime of the system. Another benefit of liquid cooling is the reduction of noise generated by the fans for passive cooling. Together with the efficiency of FPGA's for processing, liquid cooling is the way forward for green computing.

Building process at ASTRON still in motion

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Since the update in the last ASTRON news, the building process is still going strong. People have moved into their new offices in building '2012' at the end of last year, despite some minor hiccups (for example rain leakage).

The focus of the building team has moved to finishing the new colloquium room, the new meeting room, the new control room and renovating building 1980 with the new entrance, reception and library. The renovation was quite rigorous as you can see in the pictures. The building climate will also be improved by better insulation of the roof and façade, and fresh air circulation. All will be finished at the end of the summer. The astronomers will move to their new offices in building 1980 and their temporary housing facilities will be removed.

After finishing building 1980, the building team will start with the adjustments and improvements to building 1996. We expect everything to be ready around the summer of 2014.

Building 2012 from scratch. The picture on the left shows building '1996' and '1980'. On the right: building 2012; on the far left hand side you can see part of building 1996.

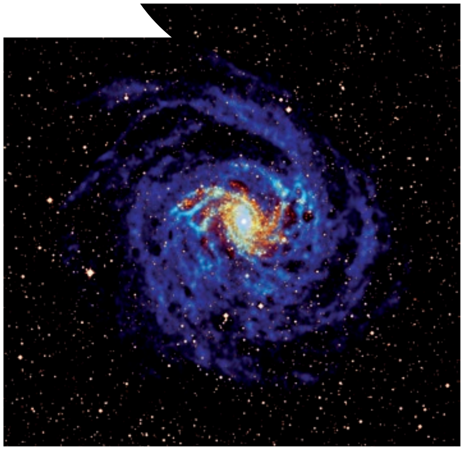
The pictures at the top and above show building 1980 before the renovation, and the activities so far. © Ingrid Arling, ASTRON.

Visiting ASTRON

In the past months, a number of students and government officials visited ASTRON. Some won a contest, some designed some really cool technology and others were professionally curious.

On 1 March, the elementary school Harm Smeengeschool from Beilen visited the Westerbork Synthesis Radio Telescope (WSRT). Thanks to pupil Douwe Westerdijk, the whole class won a trip to the Westerbork telescope. The 5th grader thought of a new name for the experiments along the Milky Way path, where visitors can experience the weight of the same object on different planets. The new name of the experiment, 'Overbrug de zwaartekracht ('bridge over gravity'), was made with a little help from his father...

How do we challenge and inspire high school students with an interest in technology? ➔



Pupils from an elementary school from Beilen, the Netherlands, visited the Milky Way path and the Westerbork telescope, after winning a contest.

The answer is Technasium, a form of education that stimulates students to further their career in higher technological education and choose a job in technological sectors.

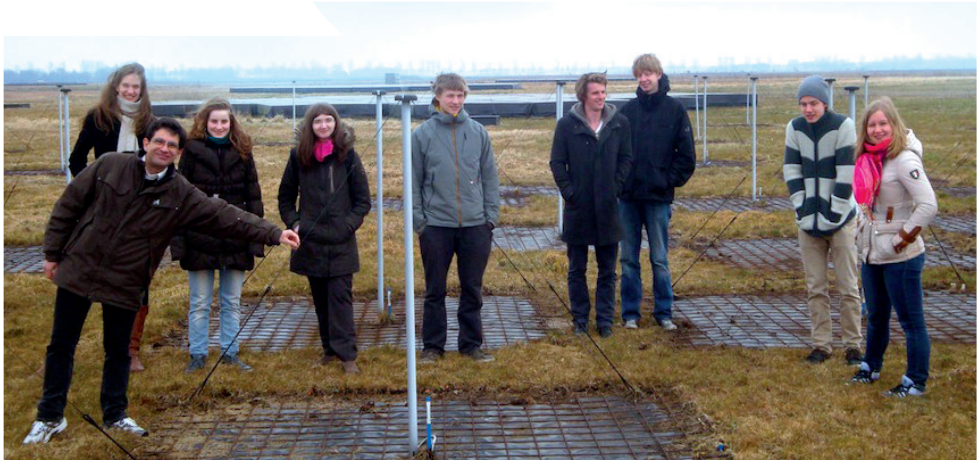
In the period between November 2012 and February 2013, the students from the Technasium class of the Roelof van Echtencollege in Hoogeveen participated in a research and design assignment, commissioned by ASTRON. For about two months, it was the job of the students to find out how they could place LOFAR antennas on the surface of the moon. The students made very impressive models, ranging from rockets, bringing the LOFAR antennas to the moon, to robots that can place the antennas in just the right position on the lunar surface. The image below left shows the students with a robot they made to walk the surface of the moon.

High school students from a school in Hoogeveen designed technology to help put LOFAR antennas on the moon.

State Officials, Council Members and Clerks of the Province of Drenthe visited ASTRON on 8 March in honour of International Women's Day. As you can see from the pictures to the right, the women were all wearing a yellow flower; International Women's Day is associated with the mimosa, a yellow spring flower, which has become a symbol for mutual solidarity. In the middle of the pictures, antennas from the EMBRACE project are visible.

Delegates from the province of Drenthe visited ASTRON on 8 March in honour of International Women's Day.

On 9 April, just before the rain came that day, students from the University College Utrecht visited the LOFAR telescope and the Westerbork Synthesis Radio telescope. The picture on the bottom right shows the students amongst the LOFAR Low Band Antennas, with the High Band Antennas behind, near Exloo, Drenthe. Dr. Filipe Freire, who is teaching a course on Astronomy and Cosmology at the college, guided them.



Students from the University college of Utrecht visited the LOFAR telescope.

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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