Annual Report 2003-2004

ASTRON

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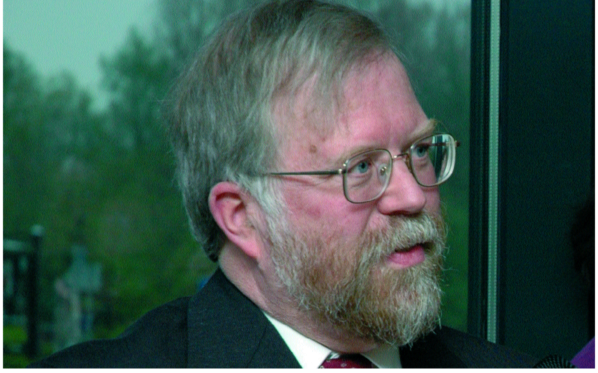


Preface

During the lifetimes of organizations there sometimes occur brief periods of profound change. The period covered by this report, the years 2003 and 2004, was such a period for ASTRON. In a short time we set upon a course hardly imaginable just a few years previously.
The vehicle of change was the LOFAR project, an initiative that began as an idea for a novel radio telescope but which quickly evolved into a multi-disciplinary research program involving more then twenty organisations to develop the technologies of large scale sensor networks.
The defining moment of change was the early afternoon of 28 November 2003, when our Minister of Education, Culture and Science convinced her Cabinet colleagues to ignore earlier advice and take a chance on LOFAR. This decision not only provided us the funds to develop and deploy the research infrastructure, but also committed us proactively to cooperate with other scientific communities in a multi-disciplinary program and with commercial partners to bring the technologies to market.
Organizational steps would be necessary to make the latter possible in practice and in anticipation, on 28 May 2003, we had already formally established AstroTech Holding bv, a fully owned holding company whose goal is to manage the commercial exploitation of our intellectual property. And on 14 November we joined with regional partners to establish the Integrated Development Lab, a foundation aiming to provide local companies with the expertise and facilities to develop new products based on our technologies. Our parent organization, NWO, has been most supportive of this effort and on 8 July 2004 effectuated the transfer of patent rights to ASTRON.
Internally, we restructured our R&D division during the report period, improving our ability both to manage large contracts and to ensure the early identification of patentable developments.
The interest from other research communities derived from a shared view that large scale, wide-area sensor networks feeding complex, real-time numerical models will become a generic technology having increasingly wide application in future. Application areas will include not only a new generation of radio telescopes but also the management of oil and gas extraction, fine scale weather prediction, control of inhomogeneous electricity networks and optimization of vehicular traffic flows, just to name a few of the many possible areas. This vision of 'adding sensor arrays to the GRID' met with initial skepticism in some quarters but as early as the end of the report period we were being invited present the idea to European wide policy forums.
If the required sensor, data transport and computational technologies have become ripe for this development, the organizational structures for their multi-disciplinary application are less so. We initially underestimated the organizational impediments and sociological resistance to multi-disciplinary activities. We can, however, point to a growing realization both in the Netherlands and across Europe that large scale research infrastructures will be an essential element of both the science system and the economic infrastructure of the future. Regarding the latter, we were most pleased to note toward the end of the report period that we had been identified by our Ministry of Economic Affairs as a center of technological excellence important to improving regional economic growth.
Properly managed, we expect to be able to take on both functions – motor for local economic development as well as fulfilling our basic mission in astronomy, continuing to operate observing facilities and carry out exciting instrumental projects. Our goal in future will be to develop a strong synergy between our technological efforts and the spin-off program. Examples of the kinds of exciting instrumental projects that will form the basis for this synergy are highlighted in this report.
These two years were by any measure a period of dynamic evolution in our organization. Unavoidably, some of our normal activities were left unaddressed. The annual reports for these years were such an activity. But we realize it is important ultimately to report on our efforts and we do this here – better late than never, as they say. Our many instrumental projects and astronomical research results are described in some detail.
In the spirit of the times we have decided to try something new with our annual reporting as well. Instead of recording our activities from the traditional, internal perspective, we have asked two well-known professional writers to prepare the report from a journalist's point of view. Rob van den Berg normally reports on new developments in technology and Govert Schilling specializes in astronomy and in space research. They interviewed individual ASTRON staff members and have assembled their reports based on those interviews. Their texts are presented here without editing by management. The picture they give emphasizes the developments they found most interesting. We hope our readers will agree with their choices.

Prof.dr. Harvey Butcher, Director

Rob van den Berg

1. *Technical Laboratory / Research and Development*

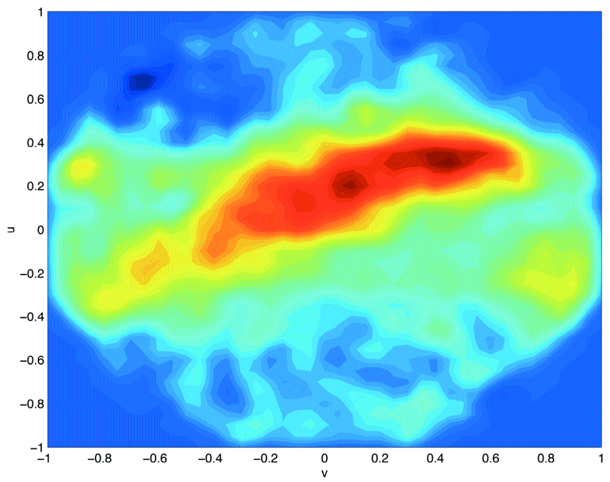
New eyes and ears for Dutch astronomers

Astronomical research in the Netherlands is regarded very highly in the world. To a large extent this may be credited to the access that Dutch astronomers have always enjoyed to the best telescopes in the world, but a lot is certainly also due to the availability of novel and highly advanced observing instruments. Many of those instruments originated in ASTRON's Technical Laboratory (TL) in Dwingeloo, where researchers and technicians are carrying out innovative research into new technologies for the telescopes of the future. TL, which recently changed its name to the Research and Development Laboratory is organised around several competence areas like Antenna systems, Optics, Microwave and Integrated Circuits, Digital Signal Processing, Mechanical Design and System Design. In general, many of those divisions co-operate during the lifetime of a project.
Anyone visiting the TL website or leafing through a TL brochure is bound to be impressed by the sheer number and variety of all different projects that are under development, with often clever and at the same time curious acronyms like VISIR, FARADAY, PHAROS and SPIFFI. Behind each of those names a team of researchers and technicians has been or is still working hard for sometimes long periods of up to seven or eight years on the successful realisation of the project. And even though this report is an overview of two years (2003-2004), one can hardly do justice to all the work that has been done. Worse even, we have decided to focus on those projects that made it to the finish line in those two years, the instruments that got installed on a telescope somewhere on a remote mountain top, and that allowed (Dutch) astronomers to peek further into hitherto unknown regions of the universe.
During the years 2003-2004 it was especially ESO's Very Large Telescope (VLT) in Paranal, Chile, that received quite a lot of attention from ASTRON visitors, since no less than three instruments were commissioned: VISIR, the Mid-Infrared Imager and Spectrometer saw its first light and so did a new camera for the SPIFFI spectrometer. And even though MIDI was already installed in 2002, it really proved its worth in mid 2003 by enabling astronomers to detect for the first time an extra-galactic object by infrared interferometry. Moreover, the WYFFOS spectrometer on the Isaac Newton Telescope on La Palma got a new camera. Also in the radio frequency field some interesting developments could be noted. The SKA-Design Study (SKADS) was approved in 2004, and will prove to be a further step in the development of the phased array concept for SKA, the mega-telescope of the future, and finally, within an extremely tight schedule of less than two years a set of Low-Frequency Front-End (LFFE) receivers for the Westerbork Synthesis Radio Telescopes (WSRT) were designed, built and installed. Below we will focus in much more detail on each of those developments.

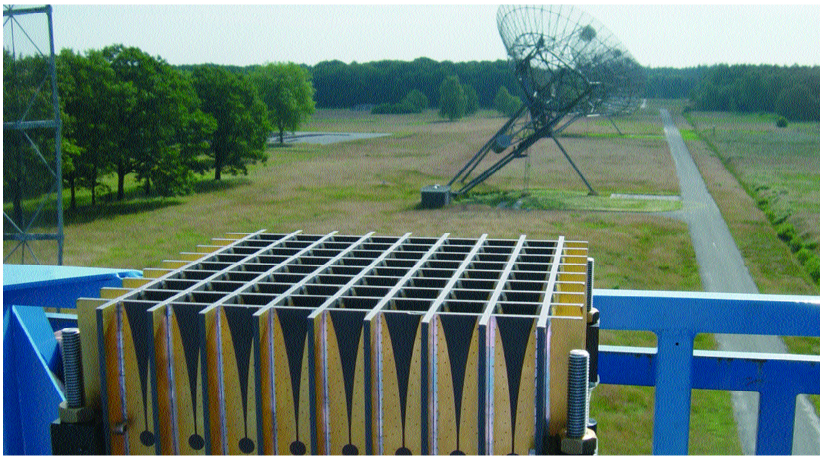
The square kilometre telescope

"Opening up a new era in radio astronomy." If it did not sound so contrite it would be the motto of SKA, the Square Kilometer Array telescope. A truly unique radio telescope with a collecting area of one square kilometre, giving it a hundred times the sensitivity of today's best radio interferometer. It is also the first telescope that was conceived as a global project, supported by no less than seventeen countries; in short, a one billion dollar, mega-science facility. It is no wonder such a huge project has a long development path. Whereas the design and prototyping started in 1997, it will take until 2009 before a final decision is taken on the design concept. Slowly but surely, however, the outlines are becoming clear, which is to a large extent the work of Arnold van Ardenne, ASTRON's project leader

Metingen met Thea.



Faraday PHAROS at WSRT.



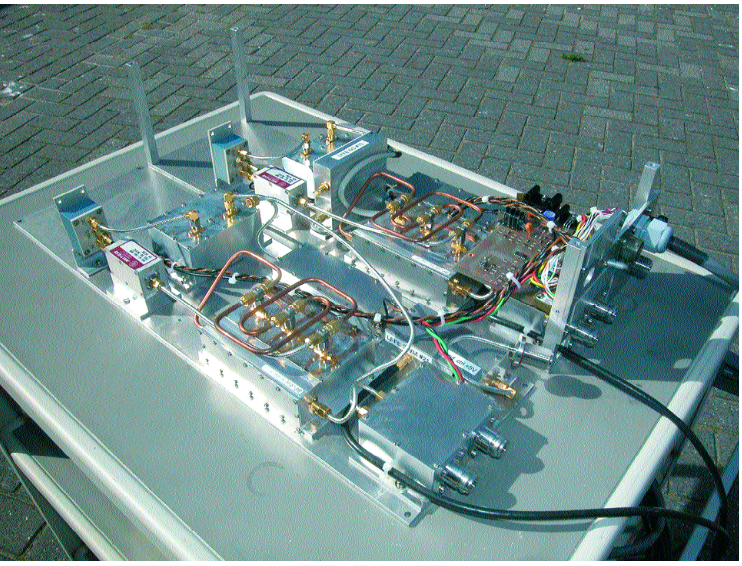
for SKA. For the last few years he has worked hard to convince his partners in the project of the benefits of phased-array technology for SKA, and he is optimistic that his vision will succeed.
SKA is to cover a broad frequency range, almost spanning three decades from 100 MHz up to 20 GHz, which is far too much for a single antenna technology. Van Ardenne: “The low-frequency part up to 2 GHz can very well be covered by so-called aperture arrays. These are flat antenna arrays, like LOFAR, in which the signals from the individual antennas are electronically delayed with respect to each other such that the telescope can look in various directions.” ASTRON’s research into the possibilities of aperture array technology started early into the SKA project with three design studies: the Adaptive Antenna Demonstrator (AAD), the One Square Meter Array (OSMA) and THEA, the Thousand Element Array. Van Ardenne: “With these three projects we have not only proven that the array technology is viable, but we have also been able to assess its astronomical implications. We have also come to realise that by itself it cannot cover the whole SKA frequency range, since the number of elements – and therefore the costs – increase with the square of the frequency.”
To cover the high frequency range parabola antennas are much better suited. Van Ardenne: “American astronomers like parabolas a lot, may be because they are like the classical optical telescopes. Phased-array technology can, however, also be applied within a parabola antenna. If one builds a detector with a large number of receivers in its focal plane, you can use the area of a parabola much more efficiently. Even though the collecting area remains the same; the field-of-view and the flexibility increase enormously.” To undertake the necessary research and development, and lay the groundwork required to produce two-dimensional receiver arrays at the foci of radio telescopes, two projects were set up: FARADAY, which ended in October 2004, and its successor PHAROS. Van Ardenne: “FARADAY delivered and tested two different focal plane arrays and investigated the important parameters that affect their operation. In this way it was able to give PHAROS a flying start.”
Both projects have also contributed in convincing the other parties within SKA, that array technologies really do make a difference. Van Ardenne: “The US is now setting up a new deep space network for satellite tracking using more and smaller parabolas. I am sometimes jealous of their determination and decisiveness: when they are convinced something is good, they lose no time in implementing it.”
In the meantime work has continued on extending the aperture array concept to the next higher level. At the end of 2003 the outline of the SKA-Design Study (SKADS) became clear, and early 2004 scientists from 29 institutes in eight EC countries and four non-EC countries put forward a joint proposal to the European Commission’s Sixth Framework Programme, which has in the meantime been granted. However, work can only really start once the funds become available, probably in the first quarter of 2005. One of the main deliverables of SKADS is a fully electronically steerable aperture array for the SKA low-frequency band (from 0.4 to 1.6 GHz): EMBRACE. This Electronic Multi-Beam Radio Astronomy Concept will be built on a similar principle as THEA, but with a few hundred tiles, each comprised of 64 active antenna elements. The signals from these

elements will be sent through fibre-optic cable at breathtaking speeds of 100 Gbit per second and processed at close to 1 petaflop operations per second. Van Ardenne: "This four hundred square meter array will offer at least two independent field-of-views and should ultimately be able to equal the sensitivity of a 25 meter parabola. Thus, it could become the fifteenth dish of the WSRT."

Listening in to the low frequencies

No more than eighteen months. That was the time required for designing, building and installing a set of simple low-cost, low-frequency receivers (115-180 MHz) for the WSRT. Project leader Bert Woestenburg and his team knew from the start that they had to move fast. And they succeeded nevertheless in what is truly a record time for a TL project. Early 2002 the first discussions started between the Radio Observatory Westerbork and the Technical Laboratory on the feasibility of these Low Frequency Front-End (LFFE) receivers. They would open up a whole new observation band for the WSRT, and at the same time supply valuable information in preparation for LOFAR, which should have a much better angular resolution and sensitivity. Therefore, both WSRT and LOFAR agreed to match the funds that were ultimately granted to this project by NWO in June 2003.
Most important concern with respect to the receiver design was the suppression of strong interfering signals from the FM- and local TV-transmitters (Smilde, NED1) at the edges of the proposed frequency band, as well as some strong in-band interferers. But there were numerous other requirements as Woestenburg explains: "With a single dipole antenna, you do not illuminate the telescope very well at these relatively low frequencies, because there is too much spill-over: a large part of the incoming signal is simply lost. Therefore, we decided to go for a mini receiver-array, consisting of just two antennas. In this way we should be able to compress the radio waves and collect the signals as efficiently as possible."
Furthermore, the antennas had to be easy to install, and they were not allowed to interfere with the existing receivers. Therefore, special attention in the mechanical design was given to a lightweight construction, with which the antennas could be moved between observing and stowed position, having the least possible effect on observations in the MFFE-observing bands. Woestenburg: "This system was pneumatically driven, since an electronic system would cause too much interference." The result of this work heavily relied on contributions from the Antenna Group and the Mechanical Design Group, as well as co-operation with the WSRT for telescope tests and evaluation. Since the feasibility study had already started well before the funds were granted, the first prototype receiver system could already be tested on the telescope in early November 2003. This helped to define the antenna configuration and also resulted in the addition of a filter to the signal chain to remove a strong pager signal at 169.75 MHz. From then on things really started moving at a

Artist's impression of the LFFE antennas (shown in red) in their observing position in front of the WSRT focus box, showing two antennas of the mini-array for each polarization.



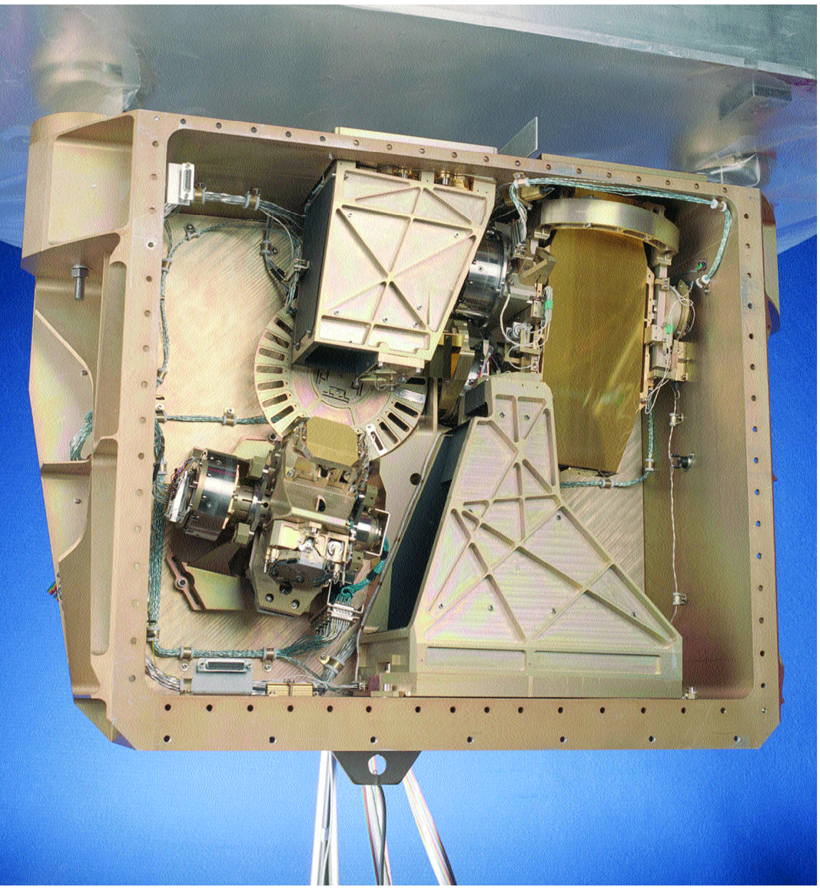
Picture of the interior of an LFFE-receiver unit, showing low noise amplifiers, filters and other electronics.

breathtaking pace. At the end of 2003 a final receiver system design was available consisting of the two-element arrays for two polarisations and the structures for moving the individual antennas in and out of the LFFE observing position. Production of receiver components for fourteen telescopes was started after the Design Review at the end of January 2004, whereas the antenna moving system was further detailed and parts for a prototype system were ordered in March 2004. After successful tests the production of a series of antennas and mounting structures started together with the installation of the first system on a telescope at the end of June 2004, barely one year after NWO support was obtained! In the meantime the production of components for the LFFE-receivers continued and assembly of complete receivers was started.
After a tight schedule for assembly and installation on the telescopes, in parallel with modifications to the existing MFFEs to enable control of the LFFE through the MFFE, the installation on the WSRT telescopes was completed in the beginning of October 2004 and the first commissioning observations were performed. Woestenburg: "The MFFE data that come in a number of frequency bands up to 9 GHz are mixed to the intermediate frequency range and then transferred. For the LFFE data we could make use of this same IF-frequency data transfer route." Based on the first successful results the system was made available for astronomical observations on November 29, 2004. This did not mean the end of the work, however. Lots of aspects of the system still had to be tested and characterised. It was found that the large data volume for a single twelve-hour run was testing the software, CPU, and stamina of the astronomers. Also many other 'users' turned out to share the observation window, generating a lot of radio-frequency interference, especially during the day when there is a lot of air traffic. However, by selecting a specific set of frequency bands, the optimal observation window could be found, and the LFFE receivers have become a valuable new tool for the users of the WSRT.

VISIR feels the heat

In the early morning hours of April 30, 2004, when people in the Netherlands were about to enjoy their day off to celebrate Koninginnedag, a delicate astronomical instrument developed by ASTRON saw its 'first light' at the European Southern Observatory in Chile. With the successful commissioning of VISIR – the VLT Imager and Spectrometer in the InfraRed – a journey that had started at the end of 1996 finally came to an end.
VISIR is a complex multi-mode instrument designed to provide sensitive images, as well as spectra at a wide range of resolution. It was designed to operate in the mid-infrared at wavelengths between 8 and 28 micron, some forty times longer than visible light. In this relatively narrow window, where the earth's atmosphere allows infrared radiation to pass through, VISIR can sample images down to the diffraction limit of the telescope: a resolution which in the optical regime would allow one to see details of 500 meter on the moon. This represents an enormous leap forward in resolution.
The instrument consists of a camera and a spectrometer, and the latter was built, tested and installed by a team of ASTRON under the daily

guidance of mechanical engineer Johan Pragt. In his office in Dwingeloo he explains how the instrument took shape: "The good thing about VISIR is that at a very early stage in its development, the production department was involved. We decided to build the instrument out of one piece, a so-called monolithic design, which is extremely stiff. It is completely made out of aluminium, a very good reflector for the mid IR wavelength range. Finally, it has no adjustment screws whatsoever: it was produced to fit. Only on the focus of the detector we installed a motor drive, but we could just as well have fixed that also. That is really unique. When we took the decision to do this, we tried to foresee what kind of accuracies we should be able to reach with the newest generation of machine tools, and those turned out to be right." All parts are mounted on dowel pins, which make it easy to disassemble and reassemble, and allow the image to return to within an accuracy of a single pixel. Pragt: "You can imagine we had strict production requirements. Only a few companies in the Netherlands could deliver according to our specifications. Critical items, for example, were the mirror surfaces, which had to be extremely accurate on surface to within less than a micron. This is a difficult requirement in view of their large size. But when the complete instrument is mounted on the telescope it must remain rigid to within a few thousandths of a millimetre as the telescope moves during long observation times to acquire and then track objects anywhere in the sky. The machining of the mirror surfaces was done on special tools in the Philips Nat Lab in Eindhoven, but even they had to revise those to meet our specifications."



VISIR spectrometer, located at ASTRON. At the upper right you see the big gold coated echelle. All optics gold coated aluminium and the mechanical construction chromate coated aluminium. Typical overall dimensions 1000 x 1000 x 500 mm

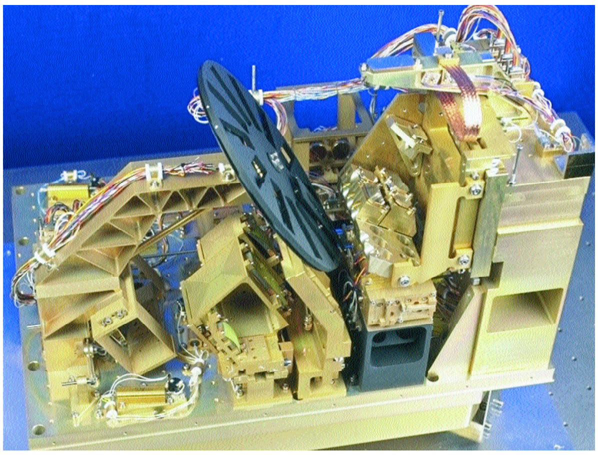
At room temperature the construction and optics of VISIR itself would emit strongly at exactly the same wavelengths that the instrument is sensitive to, and this 'terrestrial' background would swamp any faint mid-infrared astronomical signals. Therefore, the whole instrument is cooled to a temperature close to 20 Kelvin and its two panoramic 256x256 pixel array detectors to even lower temperatures, only a few degrees above absolute zero. It is kept in a vacuum tank to avoid the unavoidable condensation of water and icing which would otherwise occur. VISIR also includes a number of important technological innovations, most notably its unique cryogenic motor drive systems comprising integrated stepper motors and clutches. Needless to say, this makes for an extremely complex instrument and explains the many years needed to develop and bring it to the telescope. After ASTRON had finished working on it, the spectrometer went to Saclay, France. Pragt: "There it was for a long time to be integrated and aligned with the imager, and installed in the cryostat. After formal acceptance in February 2004, it was transported to Paranal, first by plane and then – slowly – by truck for 1500 kilometers along the Panamerican Highway. All this time the instrument was kept under vacuum so that as soon as it arrived it just needed to be cooled down." After seeing 'first light' at the cassegrain focus of the 8.2-m Melipal Telescope, it took until September before the full commissioning process was over. But then VISIR started to prove its worth.

Observing in the infrared is not easy. The sky and telescope emit radiation to such an extent that observing in the mid-infrared at night is comparable to trying to do optical astronomy in daytime. Ground-based infrared astronomers have thus become extremely adept at developing special techniques called "chopping' and "nodding" for detecting the extremely faint astronomical signals against this unwanted bright background. But the infrared offers a completely different view on the Universe. Whereas optical astronomy – in the visible part of the spectrum – is mostly directed towards light emitted by gas, whether in stars, nebulae or galaxies, mid-infrared astronomy makes it possible to detect dust. Dust is abundant in the universe in many different environments, ranging from cometary tails to the centres of galaxies.

A top-priority object on the VISIR target list is 'our own' Galactic Centre. One of the many reasons to observe this very interesting region is the presence of the active nucleus with a central black hole. In visible light this nucleus is totally obscured by foreground dust, but infrared light can propagate much better through dust clouds. Many other important astrophysical processes occur in regions obscured by dust, most notably the birth and death of stars. Stars are born in so-called molecular clouds, where they feed from and by which they are shielded. VISIR will try to peek into those otherwise hidden regions to study stellar "embryos". Also it should be able to image the death throes of stars, when they have burnt nearly all their fuel and shed much of their outer layers and dust grains form in their "stellar wind". But even without detecting anything at all, it had already contributed to the progress of infrared astronomy. Pragt: "The knowledge and experience we got from VISIR are helping us a lot in building the spectrometer box for MIRI, the Mid-Infrared Instrument, and one of the three main scientific instruments on the James Webb Space Telescope, the successor to the Hubble Space Telescope."

MIDI, first astronomical interferometer in the infrared

That it pays to combine the view of multiple telescopes is proven every day by the Westerbork Synthesis Radio Telescope WSRT. Interferometry in the radio frequency range has allowed astronomers to peek deep into the universe at unprecedented resolution. At higher infrared and optical frequencies it is much more difficult to do this same trick. This has everything to do with the fraction-of-a-wavelength accuracy with which the signals from different telescopes have to be combined in an interferometer: radio waves are longer than heat or light waves, so it is easier to make them interfere in the right way. But high on a mountain in Paranal, Chile it has been shown for the first time that infrared interferometry is not impractical with large optical telescopes. MIDI, the Mid Infrared Interferometric Instrument, is sensitive to light of a wavelength around 10 micron, the so-called "thermal infrared", because it is the radiation we call 'heat' in daily life. It can combine the light from two powerful 8.2-m VLT Unit Telescopes at a distance of a hundred meters, and thus create a virtual telescope with an angular



Midi: directly to the right of the filter (black) wheel you see the beambombiner plates on a linear slide. Some camera lenses are shown at the left, they are only transparant in the mid infra red wavelength.

resolution of about 0.01 arcsecond, which is ten to twenty times better than the diffraction limit of a single VLT telescope.

Extreme precision is key to proper operation of an interferometer. The light from the two telescopes is led to MIDI through tunnels. In order to obtain a meaningful interference pattern, the two path lengths have to be the same to within a fraction of a wavelength, so a fraction of 0.01 millimeter. This means that the signals need to be delayed with respect to each other. In a radio telescope like the WSRT this is done electronically, but the mid-infrared light is delayed optically, by bouncing it over long distances using mirrors. An additional requirement is that all parts that make up this optical system also have to be fixed with an accuracy of 0.01 millimeter. Finally, the whole instrument has to be cooled down to 35 degrees above absolute zero, in order to shield it from the infrared radiation from the environment.

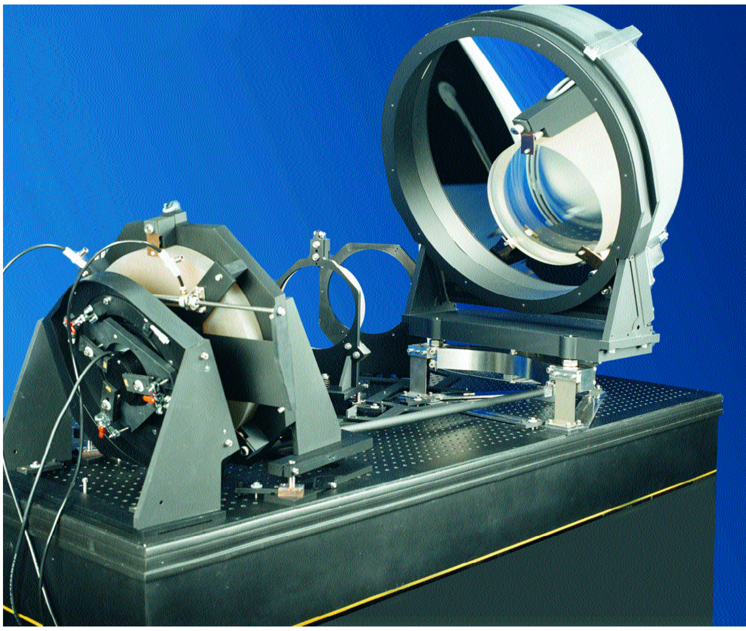
The detector is sensitive enough to study objects far away from our Milky Way galaxy. In the nights of June 14 and 16, 2003 MIDI was used to study the active core of the galaxy NGC 1068, a super massive black hole. With its high sensitivity to thermal radiation, MIDI is ideally suited to study cosmic material near a central object and heated by its radiation. The ultraviolet and optical radiation from the hot material surrounding the black hole heats the dust torus to several hundred degrees. The absorbed energy is then re-radiated in the thermal infrared between 5 and 100 microns. For the first time such a torus was observed at high resolution.

New eyes for WYFFOS and SPIFFI

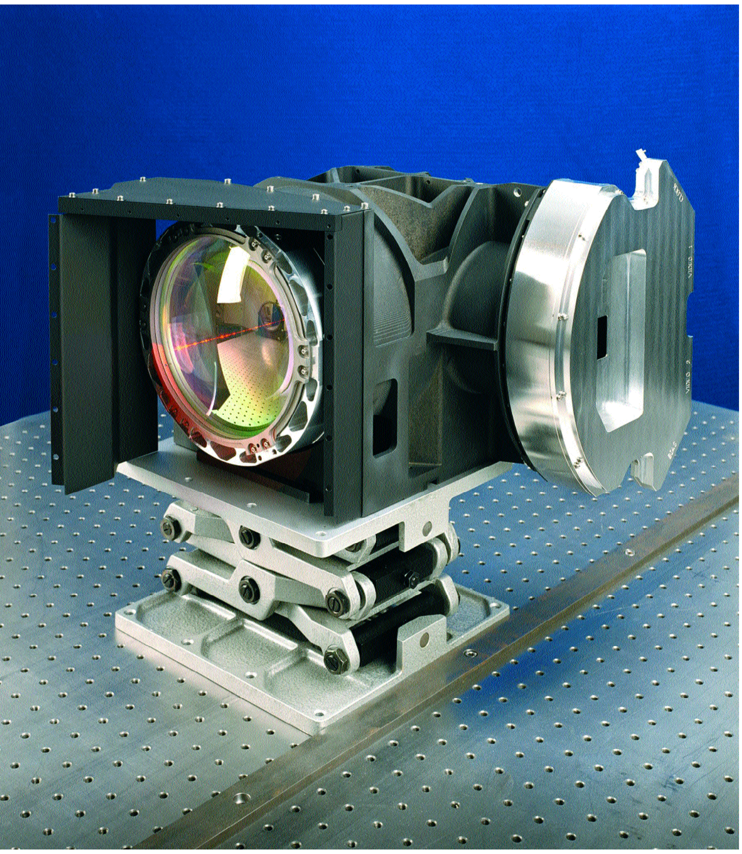
It is sometimes said that 'The devil is in the details', that even the grandest project depends on the success of the smallest components. This old wisdom was proven to be true during the development of the WYFFOS long camera for the spectrometer on the Isaac Newton Group's (ING) William Herschel Telescope (WHT) on La Palma. An inconspicuously small shutter turned out to have a will of its own and asked for a lot of extra attention from the design group.

The visible light collected in the WHT is fed via twenty-meter long optical fibres to the WYFFOS spectrograph, which unravels the light into its different colours and thus gives information on the various elements present in the astronomical object observed. To increase the number of objects visible with the spectrograph, ING decided to install a new fibre module, with twice the amount of fibres, thereby increasing its spectral resolving power, and improving sensitivity. This also made it necessary to replace both the camera and the detector. The new camera will also have a longer focal length and a far better performance than the existing one.

In 2001 the optical design and construction of this camera was contracted to ASTRON. And with a commissioning scheduled for June 2003, the WYFFOS team had its work cut out. For short periods even three designers worked in parallel to speed up the process. Only one year into the project the optical drawings were released and production of the huge spherical mirror – with a diameter of 670 mm – and the rest of the optics could start. This conspicuous mirror is made out of Zerodur glass, and is mounted on an Invar bar. Both



WYFFOS long camera temporarily installed on an optical bench at Astron. The big Spherical lens is prominent visible (670 mm diameter) and in it the meniscus lens is reflected.



SPIFFI camera installed at ASTRON, ready for transport. The first lens of the triplet at the left and the detector housing at the right. The huge black housing is a one piece product with total 5 lenses, a mirror and detector mounted to it.

materials have extremely small thermal expansion coefficients, so that any temperature variations do not require re-focusing.
Inevitably some setbacks occurred. During the Final Design Review (FDR) it was found that commercially available shutters did not fit and one had to be specially designed and built. In the beginning of 2003 the camera was fully integrated and installed on a temporary optical bench and successfully passed its optical tests. The instrument was disassembled, packed and shipped in September. This completed the final design phase, although there were some concerns regarding possible vibrations in the ASTRON shutter. It turned out that the pneumatic driving mechanism was not stable enough, and was causing shocks. So another type of cylinder was ordered, dampers were installed and after some re-design the shutter successfully passed all tests. At that point the camera had been delivered already and the shutter was therefore 'hand-carried' by ASTRON people to La Palma. For scheduling reasons on the William Herschel Telescope of ING the installation was delayed. In July 2004 a combined team of ASTRON and ING successfully installed and aligned the new camera into the WYFFOS instrument, after which ING staff re-commissioned it.
WYFFOS was not the only instrument that got a new set of eyes from Dwingeloo. SPIFFI is a spectrometer developed by the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, for the VLT at Paranal in Chile. At the end of 2002 ASTRON was asked to develop a new 2K-camera (2000x2000 pixels) to go with this spectrometer. With the optical system of such a camera one can project the light coming from the spectrometer grating on to the detector. That may sound easy enough, but one of the challenges was that the design of the spectrometer had been finished already, so the new camera had to fit within the space left over. But there were other challenges, explains project leader Johan Pragt: "A few large lenses (of up to 176 millimetres) in the camera had to be cooled down to 77 Kelvin. Add to this a "rather excessive" stiffness requirement for the camera – the image on the detector was allowed to move by no more than 1.5 micron for a 45 degree rotation of the whole telescope – and it is clear that also the SPIFFI 2K camera would be testing the strength of several design groups." The lens mounts were made from aluminium, but aluminium and glass are incompatible materials: whereas aluminium shrinks a lot, glass hardly does. So one has to mount the lens very carefully, without exerting a large force, yet at the same time the construction has to be extremely stiff. We solved the problem by adding a plastic between the lens and the aluminium, which compensates for the difference in thermal expansion coefficient. Extensive tests both in Dwingeloo and Garching showed that the design worked according to specification and the new camera turned out to be a great improvement to SPIFFI's operation.

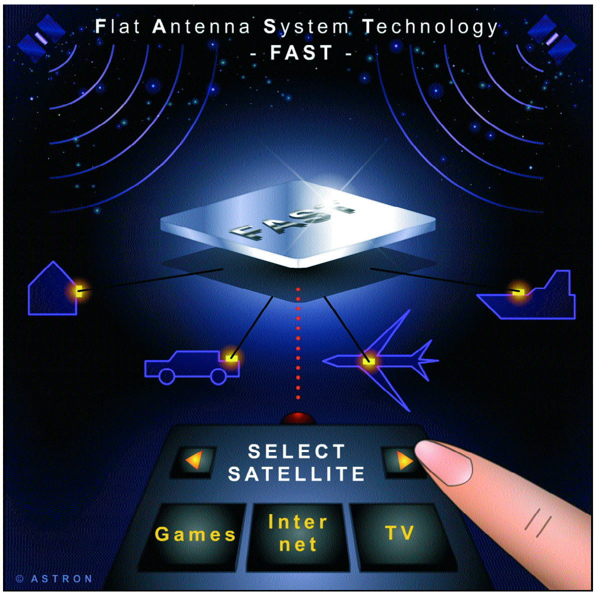
Rob van den Berg

2. ASTRON opens itself to the market

"The Netherlands has become a country of mediocrity, where average marks are enough. If the Netherlands wants to maintain a leading role in the world's economic and political affairs, we should aim to be first class. [...] Therefore, we should aim to strengthen the innovation potential of the Netherlands in order to secure a leading role for this country in the European knowledge economy of 2010." These words – a true mission and vision statement – can be found on the website of the Innovation Platform, a project started by the Dutch government in September 2003 to strengthen the country's knowledge economy. One of the reasons for starting it is the so-called knowledge paradox: a lot of potentially useful scientific and technological knowledge is available, but it never makes it into the market. There is obviously a lack of co-operation between knowledge institutions and companies, insufficient innovation in education, and therefore it is difficult to create a more favourable climate for entrepreneurs and knowledge workers. This can only be remedied by establishing partnerships: no organisation can thrive in isolation. No wonder the members of the Platform are key players in the Dutch knowledge economy and leaders in government, industry, academia and education.
ASTRON never needed such a wake-up call. Albeit on a smaller scale, the organisation has been very active in establishing partnerships with the outside world, both with the business community, with universities and with governmental organisations. In more than fifty years of building and exploiting instruments for astronomical research – such as the Westerbork telescope – it has contributed to the leading position that Dutch astronomy now has in the world. It is clear that with this accumulated know-how and experience, innovative applications can also be realised outside the field of astronomy. For instance, the latest generation of radio telescopes are based on extensive sensor networks, spanning large areas. This state-of-the-art technology can also be applied in other areas, such as telecommunications, transport and logistics, surveillance systems etc. And it is generally acknowledged that this may work in two ways: a good relationship with the business community is paramount for ASTRON's long-term R&D programmes.
The exchange of technology occurs in several ways. First of all, there is the spin-off of ASTRON's know-how and expertise to the business community in the form of consultancy and R&D, almost always on a project basis. In addition, large production series are contracted out to industrial partners such that expertise is gained in the field of production methods at low cost and high volume. The relationship with the business community is furthermore given shape by establishing and extending the networks around themes, which can be traced back to the fields of expertise of ASTRON.
To support such commercial partnerships, which are also invaluable for its own core business, ASTRON established the Bureau of Technology Transfer (BTT) in 2002. However, the years 2003-2004 have witnessed a strengthening of the ties between ASTRON and the outside world, not in the least by the foundation – on 28 May 2003 – of the AstroTec Holding (ATH), which was established for all commercial partnerships not directly related to ASTRON's main objectives. One of the people, who has actively participated in all these developments and not only contributed a great deal, but also currently leads ATH, is Arnold van Ardenne, former head of ASTRON's Technical Laboratory (and nowadays called the R&D division).
When he sketches the history of ASTRON's involvement in commercial partnerships in the last couple of years, it is difficult not get swept along with his enthusiasm. Van Ardenne: "Initially, the Bureau of Technology Transfer consisted of two people, Ronald Halfwerk, who was looking towards the outside, and Hendrik Jan Boer, who was more focused on what happened inside ASTRON, and therefore also responsible for establishing its

position on intellectual property. This combination of tasks and responsibilities is an absolute pre-requisite if you decide to open yourself up to the outside world." In those early days of commercialisation the relationship with the business community was given shape by establishing networks around themes, which could be retraced to the fields of expertise of ASTRON. To this end an optical cluster and a radio frequency cluster were established consisting of small, medium and large business in the northern provinces of the Netherlands. Van Ardenne: "Within the framework of the SKAIHigh project that we established, we thought we needed these links in order to be able to apply for government funds. But it did not work very well. It is difficult to consolidate and strengthen clusters that basically consist of competitors. Therefore, we chose another structure for its successor, the NorthStars project." This was built on a collaboration with SRON (Stichting Ruimte Onderzoek Nederland) in Groningen, "A natural partner of ASTRON within NWO", as Van Ardenne explains "They are space, we are ground, but you should realise that modern technology often does not care where it is applied – you could just as well launch a radio satellite." NorthStars again tried to seek partnerships, taking into account the lessons learnt from its predecessor. Van Ardenne: "ASTRON had in the meantime succeeded in establishing itself as a knowledge base, an institute where high-quality research is done. That is the reason we decided to try to build market clusters, in which the parties needed each other, were mutually dependent. We wanted to do R&D at the request of a company, but subsidised by the government, such as the Samenwerkingsverband Noord Nederland (SNN), which is basically responsible for redistributing part of the money from the natural gas that is found here. SNN would act as a facilitator, as a financial motor behind this kind of studies. In this way knowledge from within ASTRON could be transferred to the outside world." One of the areas that turned out to be very successful is the development of a new kind of wireless LAN antenna – a spin-off of phased array technology called a Flat Antenna System (FAST) – originally at the request of BySky, a satellite Internet provider from Ruinen, Drente (for details, see the section on FAST).

"BySky was interested in developing alternatives for satellite dish antennas and with ASTRON's work on phased array techniques for the SKA program, and we thought we were able to offer just that. The research for the SKA-telescope, or Square Kilometer Array, is relatively generic in nature; it has a broad orientation. So if you identify markets for flat antenna technology, be it for the consumer market, or for civil, defence or health care applications, you have to shift the focus away from SKA to this potential market. There may also be a big benefit for ASTRON, however, since you get experience in making components, in developing the printed circuit boards, and most importantly, in integrating the whole system. And on top of that you get a very good idea whether these components can be mass-produced." Even though the development work on FAST was officially stopped in January of this year, ATH started looking into other potential application areas, such as the delivery of in-flight entertainment



Artist impression of a Flat Antenna System (FAST) intended for communication with satellite transponder for the reception of various TV-signals and/or multimedia applications.

in aeroplanes using similar antennas, and also for application of this technology on cruise ships or inland shipping. Van Ardenne: "Also on the water people want to have access to the Internet, and we discovered that there is hardly anything available at the moment. This implies however, that we have to extend the original design of the FAST antenna. Apart from solving the production problems, which we will continue to do in close co-operation with our partners such as THALES, we will also have to add new functionalities. The antenna should be able to send – it should have an uplink capability. And that requirement is far from trivial; you cannot just build it in without doing any research. Having learnt from NorthStars I have become somewhat more careful, but I am convinced there are parties that are willing to invest in this project. In finding such new opportunities, chance plays a role, but sometimes you can help chance a hand, sometimes we have the ideas ourselves, and sometimes we bring parties together for a specific goal. NorthStars has given us a large network of relationships."
The follow-up work from FAST is one the three main directions that emerged during 2004. The second is the application of Radio-Frequency Identification (RFID) techniques, for instance in logistics. Van Ardenne: "An increasing number of products are protected and tracked by means of RFID. A well-known example is protection against shoplifting. Here, the challenge is to bridge the largest possible distance between a label and the antenna. In this case an optimal antenna design is very important. ASTRON advises the business community in calculating the properties of different kinds of antennas." The most promising outlook is, however, one that is also the most down-to-earth: an automated fire extinguisher for use in computers or computer rooms. It consists of a solid compound that ignites at a certain temperature, and then starts to expand, forming a non-toxic foam, which drives out the air and oxygen and thus extinguishes the flames. This material is far from new, but with the addition of a smart sensor and a radio-frequent link to a central control unit, one can set up a kind of monitoring system. Van Ardenne: "It may seem very obvious, but no one has ever done it. The added value of ASTRON/ATH is our ability to consider the whole system, and not come up with a sub optimal solution by focusing on the individual components."
ATH currently has five employees, but from time to time expertise that is available within ASTRON is hired at commercial rates. Van Ardenne: "One should, however, not underestimate the cultural differences that exist. ASTRON people are generally oriented towards generating questions, whereas our product developers are focused on solving problems: we go for 80% optimal solutions, as long as the customer is happy. That is a wholly different way of looking at things." Even so, the link with ASTRON is extremely valuable, Van Ardenne acknowledges. There is no doubt that ATH is in a very comfortable position: being able to make use of the many years of experience acquired within ASTRON – partly with government support and funding – and of its IP portfolio. However, it is clearly a win-win situation as ASTRON also stands to benefit, when the money that will ultimately flows into ATH is routed back to be used on own projects; and all that at a very limited risk, and with a good chance of success. Van Ardenne: "In the current situation that ATH is in, we have to fulfil political expectations. We have to show that we are actively working on stimulating the local economy. The local companies that see the opportunities are more than willing to co-operate with us. And we try to engage those that do have problems with our way of working, by distributing part of the work to them, since we also act as a kind of broker. That is our strong point, we can deliver a systems approach. So it is not our intention to for instance let our workshop compete with small businesses on the outside. But if we have something special, such as the light-weighting method, we will try to license it. We have made considerable progress so far, but we can only be really satisfied when we make concrete steps in setting up daughter companies that are really making money. At the moment we are only spending. It always takes longer than you think, and that can be very annoying."
ATH is truly unique within the Dutch R&D system: none of the other areas within NWO have

something similar. According to Van Ardenne this is strongly related to the way NWO finances projects: “This is not geared towards the way we work. NWO stimulates astronomical research, but not the underlying technology that makes it possible. Projects like LOFAR and SKA require a technological leap, which goes far beyond the NWO budget. We need to generate our own money in order to enable astronomical observations. Fact is that there are lots and lots of possibilities here in the North, because of SNN with its subsidies, and the Noordelijke Ontwikkelings Maatschappij (NOM), which is friendly in terms of its investment possibilities. With this in mind Van Ardenne decided to start another project at the end of 2003. Within this Integrated Development Laboratory (IDL) four knowledge parties in the north of the country – ASTRON, SRON, RUG and TNO – will join and focus on the market. One of the reasons for doing this is that with support and back-up from ASTRON, some projects really exceed ATH’s capabilities. We started looking into business cases like digitally monitoring the quality of the road system in the Netherlands, or the dikes. This is a relatively old idea, based on the fact that the surveillance and monitoring of the dike system in the Netherlands is extremely old-fashioned. It has not changed for hundreds of years. There is a growing awareness within the institutions that are responsible for this that there are potentially much better solutions. Such a problem can, however, only be tackled in a much wider perspective, and therefore we need the environment of IDL. We might need to start a standard laboratory in which dike failure can be studied and surveillance technologies can be developed. You see there are a lot of interesting developments lying ahead of us. It has been an interesting three-stage rocket: BTT, ATH, IDL: we are off to a successful flight.”

The back side of a mirror. Light weighting has been applied from this backside by milling through the holes.

ASTRON Extreme light-weighting

The optical astronomical instruments that ASTRON develops for both space and ground-based applications require extremely light and stiff structures. Also new materials with corresponding new production technologies are used more and more with all their special requirements and restrictions. The traditional techniques of machining metal parts are limited, and generally not suitable for the next generation of astronomical instruments. The best way to make those is to start from a single piece of material, preferably without any type of glue or bolts. To manufacture such a monolithic structure ASTRON employees developed a new manufacturing technology, extreme ASTRON light-weighting, which is specifically tailored to the most modern 5-axis milling machines. Via small openings on the outside of a block of material, the inside can be hollowed out for more than 95%, leaving walls as thin as three tenths of a millimetre, with heights of up to hundred millimetres! In this way a 50% weight reduction is obtained without giving in anything on bending stiffness in materials like aluminium, steel and ceramics. It seems obvious that this kind of structures would be ideal for space-based instruments. However, for the new MIRI spectrometer on the James Webb Space Telescope – the successor of the Hubble Telescope – the technology proved to be too revolutionary. Therefore, the extremely lightweight constructions and mirrors will for the first time be applied in X-Shooter, a ground-based spectrometer for the near infrared, which is currently under development

FAST

A normal dish or parabola antenna has to be mechanically aimed at the satellite in order to receive the signal. Such an antenna is efficient, but rather big (and therefore considered ugly). There is, however, an alternative way to steer the beam, that is based on phased-array technology. On a phased array antenna, which is a flat – and therefore much less conspicuous – there are a large number of receivers. By giving a specific time delay to each individual signal from those receivers, one can look in various directions. The goal of the FAST project was to design a phased array antenna, which could switch between those various orbital positions. To develop and manufacture such an antenna ASTRON sought co-operation with small and medium size local companies. Standing in front of a printed circuit board of the actual FAST antenna, project manager Koos Kegel explains about the challenges he and his team faced during this process: “The triangular shape which forms the basis of the antenna can be simulated in the computer. Three of those elements, rotated over a sixty degree angle, are sufficient for detecting one circular polarisation, whereas an additional three elements take care of the other circular polarisation. The six antenna sub-array forms a hexagonal flower-like pattern.”

This pattern is repeated many times over the whole surface of the antenna, because the more elements, the more power can be collected from the satellite. This immediately gave rise to a problem: the sheer number of elements, which needed to be positioned with a sub-millimeter accuracy were exceeding the capabilities of the available CAD/CAM software. The designers had to find tricks to allow them to make any changes, without having to wait for a long time. Kegel: “The large number of elements also led to problems in manufacturing of the circuit boards. Our first printed circuit board manufacturing company proved not to be able to produce boards with this complexity and pointed us towards Thales. Even THALES had never produced printed circuit boards with this amount of complexity before – requiring more than a hundred process steps. Although they have all tooling and experience available, the iterative approach of optimising the manufacturing of this board had an impact on the total project time schedule. And unfortunately also on the quality, because not all second iteration boards functioned well enough for the demonstration. We all learnt a lot and we are sure that if we were to do it again, it would be good. We know where the problems are and how they should be solved.”

The electronics were assembled in Leeuwarden at Neways using the ball grid array technology, a type of microchip connection methodology. Ball grid array chips typically use a group of solder dots, or balls, arranged in concentric rectangles to connect to the circuit board. See the silver-coloured spots in the figure. Kegel: “Neways had never before produced hardware operating in the 10GHz band and never experienced board-to-board ball grid array assembly either. The difficulties in getting functioning antenna boards forced them to assemble ‘first-time-right’, having in mind that the antenna boards would bend significantly when heated up during soldering. Neways solved this by fixing the board using a dedicated metal frame. The commitment of both THALES and Neways was really amazing, in spite of the difficulties they experienced.” Kegel’s team also had to overcome some challenges themselves. A crucial element in a phased array antenna is the phase shifter, which electronically delay the various signals. Those were ordered from an American company but never delivered. Kegel: “The American government considered these chips of strategic (military) importance, and blocked an export license. The good thing was that we, on a side track, started the design of our own low-cost replacement for the American phase shifter. In the end these were manufactured in Taiwan and packaged in Hong Kong within a three-week period.” In the Figure, the black squares are the ASTRON-made phase shifters. A further illustration to the whole team’s ingenuity is the fact that to date, no less than six patent requests have resulted from the project so far.

It turned out to be impossible to test the full array

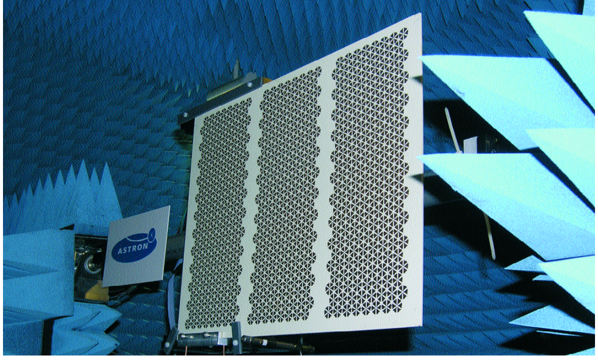


Figure shows the antenna mounted in the special anechoic room.

with 144 sub-arrays within the specified time frame. Therefore, the focus was shifted towards the realisation of a mini-array containing sixteen sub-arrays to prove the operating principle. On December 2, 2004, the capabilities of FAST were demonstrated by placing it in the anechoic room and exciting it with a satellite-like signal in the 10 GHz band. Electronic correction of the physical rotation of the antenna showed that the phased array performance worked. Although not all 144 antenna sub-arrays were controlled, the beam forming performance was perfectly well able to compensate for the antenna's mechanical displacement. Additionally, successful demonstrations were given to the SKA Forum and by presenting live an ESA press conference received from the ASTRA satellite. The FAST technical project was officially terminated in January 2005. There has been considerable spin-off of the FAST development within the ASTRON organisation, for instance in the use of certain simulation software packages. Also LOFAR adopted novel design approaches which were initiated for FAST on system simulation, hardware design, software design and prototype testing.

Other projects in 2003-2004

After establishing AstroTec Holding in May 2003 a management team was set up with some external consultants. They were to link the palette of technological expertise of ASTRON with the right business opportunities. This resulted in the three main directions that the work at ATH is currently taking (see main text). Apart from that a number of smaller studies were performed, mostly of advisory natures.

- For a manufacturer of intra-ocular contact lenses ATH looked into testing methods for quality control. In these kinds of lenses irregularities are difficult to trace because of their strength. Based on ASTRON's findings, the manufacturer has indicated its intention of making the next step towards semi-automatic lens testing.
- On behalf of a manufacturer of optical components a study of noise patterns was performed. It is important to be able to measure interferences ('noise') as objectively and quantitatively as possible. The 2D Fourier analysis turned out to provide a good indication of the method in which these characteristic numbers can be reduced.
- ASTRON researchers also developed a prototype anti-theft system for a number of provincial libraries. A microchip in every book and a radiofrequent detection system at the exit and entrance gates are used to identify the status of the book. If the book has not been properly assigned to library member, an alarm goes off.
- A producer of fluorescence microscopes was troubled by speckle patterns in their images and had tried to solve this problem by continuously jittering the optical fibre with an electromotor. This did remove the unwanted speckles but also smeared out the images and limited the microscope's sensitivity. People in the IR/optics group at ASTRON were intimately aware of how such interference effects arise, so they were able solve the problem, and thus enable this company to improve its product.

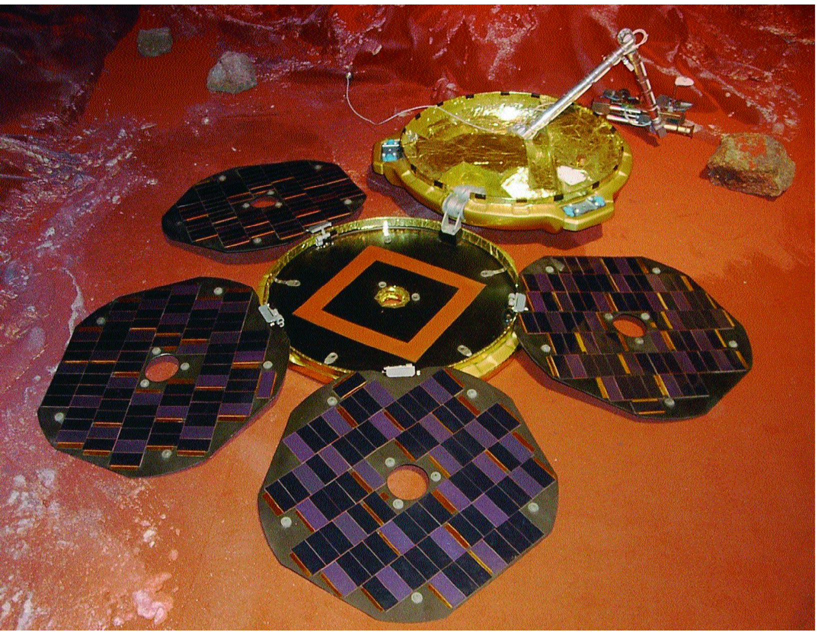
A much more down-to-earth, but no less interesting application came out of a contact with Mustad Friesland, a company from Drachten that produces more than six hundred types of horseshoes. Mustad Friesland wanted to introduce automation technology in their production process. At their request ASTRON did a study and recommended the company to buy a 5-axis milling machine and to introduce computer-aided design and manufacturing (CAD-CAM) software. Ultimately, it also trained Mustad Friesland personnel and guided the process of implementation of this novel technology.
Finally, ever since the early BTT days ASTRON has been the organiser of a course in radio technology, which is now held twice a year, and is never short of attendants: people working with wireless components, field engineers that lack a solid theoretical background, but also employees from mobile phone companies. ATH tries to address the specific needs of every attendant by engaging experts not only from within ASTRON, but also from outside.

Govert Schilling

3. *Westerbork views the universe*

ASTRON's Westerbork Synthesis Radio Telescope, completed in 1970, was recently upgraded and is still one of the most powerful and sensitive radio observatories in the world. Research areas in 2003 and 2004 covered a wide range of astronomical topics. Science writer Govert Schilling describes some of the highlights.

Late December 2003, between Christmas and New Year's Eve, the Westerbork Synthesis Radio Telescope (WSRT), famous for its ability to unravel the secrets of the distant universe, temporarily transformed itself into a Search & Rescue-device for a lost spacecraft. While mission managers in London and Darmstadt tried to find out what could possibly have gone wrong with their costly device, the fourteen radio dishes of the Westerbork observatory tried to pick up a faint signal from Britain's Beagle 2 Mars lander, that should have touched down on the red planet on Boxing Day.



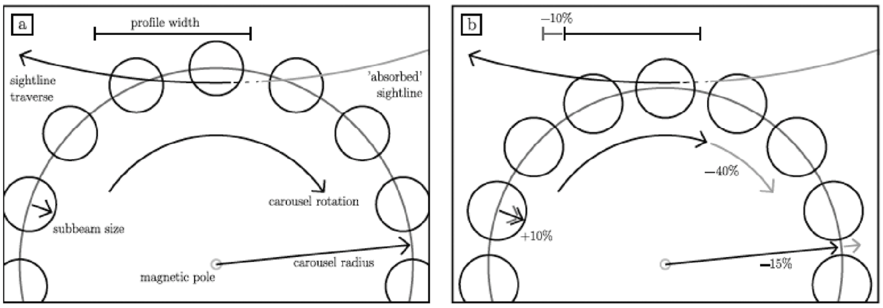
The Beagle 2 Marslander.

Beagle 2 was the first European attempt to soft-land a spacecraft on another world. Developed and build by a British team led by Colin Pillinger of the Open University in Milton Keynes, the small lander hitched a ride to Mars as a piggyback payload of the European Space Agency's Mars Express spacecraft. Launched in early June 2003, Mars Express released the probe on Christmas Day, just before it settled down in an elongated orbit around the planet. But although Beagle 2 went off in the right direction, it was never heard of again, for reasons sill not completely clear.

'Mission managers asked the Jodrell Bank Observatory in England to search for the faint carrier signal of the lander,' says Westerbork Observatory director Willem Baan, 'but they were hampered by strong winds, and asked us to assist in the search.' Because of the flexibility of the Westerbork observing programme, it was easy to oblige. Moreover, it wasn't the first time that Westerbork was on the lookout for a lost spacecraft. In early 2000, the radio observatory took part in the search for NASA's Mars Polar Lander, which got lost in November 1999.

Mars Polar Lander was never found – most likely, it crashed down close to the planet's south pole – and unfortunately, the search for Beagle 2 also turned up empty. 'It turned out that the frequency of the Beagle 2 transmitter was just outside our receiving band,' says Baan. 'With hindsight, we might have been able to do something about this, but there was very little time.' It would have been in vain anyway, since Beagle 2 kept its silence – like Mars Polar Lander, it probably crashed as a result of some technical failure.

According to Baan, it's quite unusual for the Westerbork telescope to be aimed at a solar system body. Most of the time, the observatory is being used for studies of radio-emitting pulsars in our



Subbeam carousel geometry in the normal and the post-null configuration. a) The normal configuration, with a sight line that is partially obscures by 'absorption'. b) After nulls the carousel is smaller and revolves less quickly. The subpulses are wider and have moved closer together. On the non-absorbed, trailing edge, the pulse window moves inward. The leading edge of the profile is located where the absorption ends and does not move.

Milky Way or for observations of distant galaxies, sometimes at the very edge of the observable universe. 'There's just not that much interest for solar system observations,' he says. But it's a big, big universe out there, harboring lots of unsolved mysteries, and the recently upgraded Westerbork observatory is very much in demand. Says Baan: 'It may be 35 years old, but it's a state-of-the-art telescope.'

Martian dust

Not much planetary research has been carried out with the Westerbork telescope, but one notable exception is the work of Maarten Roos-Serote of the University of Lisbon, Portugal. In 2003, together with colleagues from the University of Amsterdam, he measured the radio emission of the planet Mars, which had an unusual close approach to Earth that summer. 'Our goal,' says Roos, 'was to "listen" for the radio signature of global dust storms on Mars, caused by discharges between electrically charged dust particles in the planet's atmosphere.' Unfortunately, no global dust storm developed in 2003, but Roos's data will constitute a ground truth for future radio observations of the red planet. 'Eventually, we hope to learn more about the properties of the Martian dust particles,' says Roos.

Pulsar puzzles

For instance, Westerbork's ability to observe at two or three frequencies at once is a big advantage, says pulsar expert Joeri van Leeuwen of the University of British Columbia in Vancouver, Canada. Pulsars are extremely small, extremely dense and extremely rapidly spinning stars that emit very regular pulses of radio waves and other types of radiation. Ever since Westerbork was equipped, in 1998, with a dedicated data analysis computer called PuMa (short for pulsar machine), it has been one of the leading pulsar observatories in the world.

Long-term studies of the precise arrival times of the radio pulses are very important to better understand the evolution of a pulsar, whose strong magnetic field continually slows it down ever so slightly. The high-precision timing program of pulsars, carried out by Ben Stappers of ASTRON and the University of Amsterdam and his colleagues, is done in close collaboration with other large radio observatories that are part of the European Pulsar Timing Array, says Baan. 'The pulsar group at Westerbork is one of the most active.'

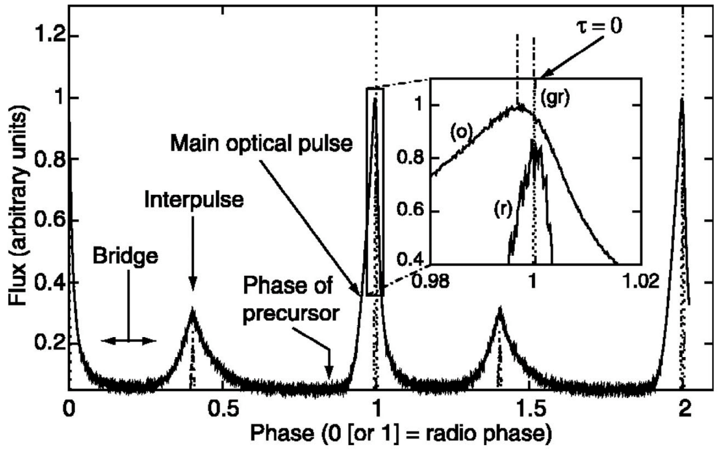
Van Leeuwen's PhD-research at Utrecht University, completed in 2004, focused on the detailed behavior of the pulsar hot spots that generate most of the radio-emitting charged particles. About half of the 1500 known pulsars show multiple spots, arranged in a ring around the star's magnetic pole. 'Many theories have been put forward to explain this mechanism,' van Leeuwen says, 'but even the most successful ones leave many questions unanswered. It's a bit depressing.' However, his Westerbork observations of a pulsar known as PSR B0809+74 have shed new light on this enigma.

The ring of twenty or so hot spots is only visible once every rotation of the pulsar (which typically lasts a fraction of a second), and even during these brief snapshots, only the two or three spots that emit exactly in our direction can be seen. Moreover, explains Van Leeuwen, the whole ring rotates around the magnetic pole, as a result of magnetic forces. 'So in every snapshot, they are at slightly different locations,' he says, 'and observing them is a bit like watching cart wheels in a western movie, which may seem to be slowly rotating backwards because the spokes are at slightly different locations in every successive movie frame.'

Van Leeuwen's Westerbork observations provided pulsar astronomers with a surprising result: it turned out that the hot spot carousel is rotating much more slowly than astronomers had expected. 'This was the very first time we were actually able to measure the drift rate of the carousel,' he says. Unfortunately, the new result has not yet delivered the key to the pulsar puzzle, although any viable theory should of course be able to explain the slow rotation rate. Says van Leeuwen: 'There's much more work for theoreticians to do.'

Crab matters

By far the most famous pulsar is the blinking star in the heart of the Crab Nebula – the remains of a stellar explosion that occurred in 1054 in the constellation Taurus the Bull. ASTRON's Ben Stappers and Richard Strom, together with an Irish team led by Andy Shearer, used the Westerbork radio telescope in conjunction with the 4.2-meter optical William Herschel Telescope on La Palma (Canary Islands) to study the possible link to the very regular optical pulses (which could be observed thanks to a rapid-readout device build by the Irish astronomers) and the much more erratic radio pulses. 'The optical pulses appear to be just a bit brighter during the very largest radio pulses,' says Strom, 'but the correlation isn't particularly strong.' Incidentally, this suggests that the occurrence of giant radio pulses cannot be produced by changes in the magnetic field of the pulsar. 'Our guess is that giant radio pulses may be related to changes in the density of the radio-emitting plasma,' says Strom.



The Crab pulse profile showing the optical light curve (o), the average radio light curve at 1380 MHz (r), and a single giant pulse at 1357.5 MHz (gr). τ, 6789 time. Two periods are shown for clarity. Various pulse parameters have been identified. Also shown is the location of the precursor observed at lower frequencies and the bridge emission seen particularly at higher frequencies. On this scale, the GRP width corresponds to 0.00035 units of phase (12 μs), the radio pulse to 0.009(300 μs), and the optical pulse to 0.045 (1500 μs). The avalanche photodiode (APD) band pass for these observations was from 6000 to 7500 Å. Phase 0 corresponds to the arrival at the solar system barycenter of the peak radio pulse. The optical light curve for this plot was divided into 5000 phase bins.

Shearer, A., et al., 2003, "Enhanced Optical Emission During Crab Giant Radio Pulses", Science, 301, 493.

Cosmic fireworks

Pulsars may be bizarre and mysterious, but at least you know where to find each of them in the sky, and astronomers can go back to them anytime they want. Not so with gamma-ray bursts, the most energetic events in the universe. They pop up unexpectedly at random places, only to fade away in a few weeks or so. Still, the Westerbork observatory has played an important role in the unraveling of these powerful flashes of gamma rays, which were first observed by military satellites in the 1960's.

Gamma-ray bursts are the birth cries of black holes – the mortal remains of exploding supergiant stars in distant galaxies. New bursts are detected by orbiting gamma-ray observatories, which automatically relay their findings to robotic telescopes on the ground – the initial optical counterpart of the gamma-ray burst may become invisible within seconds or minutes after the burst. 'At radio wavelengths, there's a bit more time,' says Evert Rol of the University of Leicester, United Kingdom, who used the Westerbork array in 2003 and 2004 to study the radio afterglows of gamma-ray bursts. 'But still, you need to act pretty quick.'

Back then, Rol was part of the gamma-ray burst group at the University of Amsterdam. 'After each new alert, we had to decide whether the burst was interesting enough to follow it up with Westerbork observations,' he says. If so, a few phone calls with René Vermeulen or Tony Foley, who were in charge of planning the Westerbork observations, would suffice to change the schedule. As part of their so-called override proposal, Rol and his colleagues were allowed a certain amount of telescope time that could be claimed almost anytime they wanted. 'In some cases, we were observing within half an hour,' he says.

A big advantage of using the upgraded Westerbork array was the ease of changing receivers. 'Observing a burst afterglow at various wavelenghts allowed us to study the spectral energy distribution,' says Rol. 'Unfortunately, Westerbork isn't designed to observe the shortest radio wavelengths, so in that respect the American Very Large Array (VLA) radio telescope in New Mexico is better.' However, he adds, Westerbork can observe bursts at a time they are below the VLA's horizon, while the VLA cannot observe at 13 centimeter wavelengths. 'We're really quite complimentary.'

By far the most interesting gamma-ray burst during 2003 and 2004 was GRB 030329 (named after its detection date), in the constellation Leo the Lion. 'It was extremely bright, relatively close, and it provided the first clear evidence of a link between gamma-ray bursts and supernova explosions,' says Rol. More than two years after the event, the radio afterglow is still visible, and astronomers continue to study this remarkable event using the Westerbork array. Says Rol: 'Not many radio telescopes have the necessary sensitivity to do this kind of work.'

Sharp vision

Gamma-ray bursts are intrinsically variable sources: their brightness rises and falls in the course of days or even minutes. However, the Westerbork telescope has also been used extensively in the study of 'twinkling' radio sources, whose brightness variations are due to interstellar gas in our own Milky Way galaxy. As the Earth orbits around the sun, we look through different patches of this rarefied interstellar material. Studying the resulting radio scintillation of a point source like a quasar (the active core of a distant galaxy) can then provide astronomers with detailed information about the quasar's structure. In 2003 and 2004, the 'Earth orbit synthesis' technique has regularly been applied to the quasar J1819+3845 by ASTRON's Ger de Bruyn and by Jean-Pierre Macquart of the University of Groningen, who pioneered the idea in 2002.

Mapping galaxies

Pulsars and gamma-ray bursts may be extremely interesting phenomena, but the main goal of the Westerbork Synthesis Radio Telescope has always been the study of neutral hydrogen gas in our Milky Way and in other galaxies. 'About 80 percent of all Westerbork observations is devoted to extragalactic work,' says observatory director Willem Baan. Over the past years, the radio telescope has produced impressive maps of the hydrogen distribution in a number of relatively nearby galaxies. 'Westerbork is ideally suited for this kind of work,' says Baan. 'Moreover, the pictures are just very pretty – they have terrific PR value.'

ASTRON's Tom Oosterloo adds that the Westerbork telescope may be a bit less sensitive at some frequencies than the American Very Large Array, 'but observing one single galaxy for a total of twenty 12-hour periods would never be possible at the VLA,' he says. And that's exactly what Oosterloo and his

colleagues have done to map the extremely faint gaseous halos around galaxies like NGC 6946 and NGC 891. The observations clearly show that these galaxies are embedded in huge clouds of rarefied neutral gas, that extend way up above and below the thin spiral disk that is visible in optical photographs.

Older radio observations already hinted at the existence of these extended structures, says Oosterloo, and deep optical photos had shown clouds of hot, ionized gas surrounding some galaxies, albeit at smaller distances. But only after the recent upgrade of the Westerbork telescopes, which more or less tripled the sensitivity, it became possible to confirm and study the neutral hydrogen halos in detail. 'The very regular spacing of the individual radio dishes of the Westerbork telescope has also been an important factor,' says Oosterloo. 'As a result, the radio maps are extremely trustworthy.'

The origin of the halo gas is not completely clear. It could be primordial gas left over from the formation of the galaxies, or the gas could fall back after having been blown into space by supernova explosions and star forming activity in the galaxy's disk. According to Oosterloo, both mechanisms could be active simultaneously. 'Close to star-forming regions, you can actually see the gas being blown away,' he says, 'but some of the more massive concentrations are probably the result of primordial clouds or small satellite galaxies being ripped apart by tidal forces.'

The answer may come from a detailed study of the chemical composition of the clouds. Westerbork only sees the relatively abundant hydrogen, but gas that originates in the galaxy's disk should also contain traces of heavier elements. 'We are thinking about ways to detect these,' says Oosterloo. One way would be to study the light of a distant quasar that shines through the halo and look for absorption signatures of oxygen and nitrogen.

Fast clouds

According to ASTRON's Robert Braun, the extended halos of galaxies like NGC 6946 and NGC 891 are probably related to the decade-old riddle of high-velocity clouds in the outskirts of our own Milky Way galaxy. Recent observations indicate that these clouds of neutral hydrogen are also partly due to the ejection of gas from the galactic disk, while other clouds appear to be falling into the Milky Way for the first time. Using the sensitivity of the upgraded Westerbork telescope, Braun has produced detailed maps of the high-velocity clouds surrounding our Milky Way's nearest large neighbor – the Andromeda galaxy – and found that some of them appear to be related to tidal streams of stars, resulting from the break-up of a small satellite galaxy of Andromeda. 'This could not have been done without the new data correlator at Westerbork, which enables us to study the gas at a large number of different frequencies simultaneously,' he says.

Building clusters

Westerbork has not only revealed the gaseous halos of other galaxies, it even shed light on the formation of galaxy clusters – the largest coherent structures in the universe. But the discovery by Michiel Brentjens and Ger de Bruyn of intergalactic gas flowing into the Perseus cluster of galaxies was serendipitous. 'We were looking for the very faint signal of Thompson-scattered radio waves,' says Brentjens, who is at the University of Groningen – 'something we didn't find.' Instead, Brentjens and ASTRON's de Bruyn found backing evidence for the theory of hierarchical structure formation in the universe.

The Perseus cluster is a rich group of a few hundred galaxies at some 235 million lightyears away. It's actually part of the much larger, elongated Perseus-Pisces supercluster, which contains thousands of individual galaxies. 'We had designed a novel observational approach to detect the faint signal we were looking for,' says Brentjens. 'The idea was to observe at a large number of low-frequency channels at once – something that can only be done efficiently with the Westerbork telescope.'

Surprisingly, the two astronomers detected two linear structures at the northwestern edge of the cluster, where Perseus connects to the Perseus-Pisces supercluster. Both were some 9 million lightyears long and more than 300,000 lightyears wide. Apparently, Brentjens and de Bruyn had stumbled upon the radio signature of faint shock waves in the rarefied intracluster gas, produced by material that falls in from the supercluster with velocities of a few thousand kilometers per second. Similar structures were found a year later in another cluster by an Italian team using the Very Large Array radio telescope .

According to Brentjens, the find lends support to the hierarchical model for structure formation in the universe. In this model, primordial material from the big bang first collects into thin, filamentary structures – the precursors of giant superclusters like Perseus-Pisces – and subsequently streams along these filaments into the 'nodes' where several superclusters intersect. These nodes are the birth places of galaxy clusters like Perseus.
In the Westerbork observations of one of the two radio-emitting shock waves, a large, hollow structure was detected. Brentjes believes this is a giant bubble of hot, low-density gas injected into the cluster by the active nucleus of the central galaxy, known as NGC 1275 or Perseus A. Apparently, Westerbork is on the trail of the complex interplay between active galaxies, galaxy clusters, and the large-scale structure of the universe. 'Astronomers always thought that the Perseus cluster was relatively quiet,' says Brentjens, 'but recent x-ray observations also support the view that this is a pretty active region.'

Changing constants?

Are the fundamental constants of nature truly constant? Maybe not, according to recent claims by a few cosmologists who have studied distant quasars in the early youth of the universe. In particular, the so-called fine-structure constant may have changed slightly since the Big Bang, and some physicists have suggested that this might implicate a slow change in the speed of light. In 2003, the Westerbork radio telescope has been used to check these far-reaching claims by looking for spectral lines of the hydroxyl OH in the quasar PKS 1413+135. According to Nissim Kanekar of the National Radio Astronomy Observatory in the United States, who was then at the University of Groningen, the Westerbork observations are consistent with no changes in the fundamental constants, at least not in the past three billion years.

Unsurpassed

A full description of all the scientific research carried out with the Westerbork Synthesis Radio Telescope in 2003 and 2004 would fill almost this entire annual report. Apart from the highlights described in these pages, Westerbork was successfully used for a wide range of other astronomical studies, from mapping the magnetic fields in our own Milky Way galaxy to studying the radio properties of the most distant galaxies ever observed, in the Hubble Deep Field. 'Each semester, some twenty observing proposals are approved,' says observatory director Willem Baan, 'and details can be found on the ASTRON website.' Meanwhile, thanks to the major upgrade that was completed in 2002, foreign interest in using the Westerbork telescope has increased substantially. 'We used to have about twice as much observing proposals than we could accommodate,' says Baan, 'but the oversubscription rate has now increasde to a factor of five for some parts of the sky. In its ability to perform very high-sensitive observations at moderate resolution and relatively low frequencies, the Westerbork Synthesis Radio Telescope is unsurpassed.'

The Westerbork upgrade

After the major upgrade of the observatory, which was completed in 2002, the Westerbork Synthesis Radio Telescope is in fact ‘a brand-new telescope,’ says observatory director Willem Baan. Work on the upgrade already started in the first half of the 1990’s, when the telescope was nearing its 25th anniversary. ‘It has become much more sensitive and flexible,’ says Baan. ‘Westerbork is a state-of-the-art facility again.’
Marco de Vos, lists four main improvements that have been realized during the upgrade, one of which is the Telescope Management System. The new software system is more flexible, he says, for instance in the way it lets the user split up the 14-dish array in two or three sets of telescopes that observe different parts of the sky.
Another very important change has been the new digital correlator – a dedicated supercomputer that combines the data from the various antennas into one coherent observation. ‘The new correlator uses a specially designed computer chip that has been developed here at ASTRON,’ says de Vos. ‘The same chip is now being used in about ten other radio observatories around the world.’
The mechanical structures of the individual antennas have been refurbished, while the actual ‘mirror surface’ of the 14 telescopes were cleaned and mounted anew. As a result, says de Vos, the surface accuracy of the telescope has increased substantially.
Most importantly, sixteen new multi-frequency front-ends have been built – one for each antenna, and two spares. Using five cryogenically cooled receivers mounted on a rotating mechanism, it is no longer difficult and time-consuming to chance the observing frequency of the observatory. ‘Changing the frequency during an observation takes less than one minute,’ says Baan.

Other facilities

The Westerbork Synthesis Radio Telescope is ASTRON’s main radioastronomical facility, but it’s not the only one. A few tens of meters behind ASTRON’s headquarters, just outside the village of Lhee, is the venerable 25-meter Dwingeloo telescope, which, at its dedication on 17 April 1956 by Queen Juliana of the Netherlands, was the largest radio telescope in the world for a few months. The Dwingeloo telescope was used to make the first maps of the spiral pattern of our Milky Way galaxy, but even in 1994, it made headlines with the discovery of a very faint, nearby galaxy obscured clouds of gas and dust in the Milky Way.
‘Dwingeloo has not been used anymore since 1998,’ says Willem Baan, the director of the Westerbork observatory. The Dwingeloo Obscured Galaxy Survey (DOGS) was the last major project carried out with the historic instrument. ‘In fact, DOGS has been completed with one of the 14 Westerbork telescopes.’
Hopefully, the Dwingeloo telescope will be turned into a national scientific monument, maybe on the occasion of its upcoming 50th anniversary in April 2006.
Then, of course, there’s LOFAR – ASTRON’s new LOw-Frequency ARray (see the story starting on page 25). Construction of LOFAR started in late 2003, and by the end of 2004, the first scientific results with the Initial Test Station were obtained. ‘The big news of course is that it works,’ says Baan. ‘Using just a few small antennas, we already produced our first low-frequency snapshot maps of the sky.’
Finally, ASTRON is also home to JIVE – the Joint Institute for VLBI (Very-Long Baseline Interferometry) in Europe. JIVE is a collaboration of a large number of radio observatories, most of which are in Europe. By combining the various telescopes, a virtual observatory almost as large as the Earth can be simulated, with an unprecedented resolving power.

Using Westerbork

The Westerbork Synthesis Radio Telescope is mainly used for extragalactic research. About 70 percent of the observing proposals are from Dutch astronomers; the remainder is from foreign scientists. ‘Dutch radio astronomers have a lot of experience with the facility,’ explains Westerbork director Willem Baan, ‘so they come up with very good proposals.’ Incidentally, the WSRT Program Committee (WSRT PC), which decides on the granting of observing time, consists of representatives from all of the astronomy faculties at Dutch universities, and also has a number of foreign members.
The observing schedule for Westerbork is divided into six-months periods, with some 20 proposals being accepted per semester. ‘The PC selects the proposals on the basis of scientific merit,’ says Baan, ‘but they also try to make sure that a wide variety of astronomical topics is accomodated.’ So although the observatory is ideally suited for studies of gas dynamics in other galaxies, niche areas are certainly not neglected, as long as the science is sound.
Despite the fact that cosmic radio waves can be observed in bright daylight, most of the Westerbork observations are actually carried out at night, says Baan. ‘During the night, the level of radio interference from artificial sources is much lower, and the observations are much cleaner. Reaching a maximum signal-to-noise ratio is always the ultimate goal.’
Most of the observations are carried out automatically, and Westerbork has an observing efficiency of at least 80 percent. Of the 168 hours in every week, Baan estimates that maybe 30 to 40 hours are not used for actual observations. ‘These three or four day slots are used for maintenance, and for the development and testing of software and hardware,’ he says.

PhD theses

In 2003 and 2004, a total of four PhD theses were published on the basis of observations with the Westerbork Synthesis Radio Telescope. Michiel Kregel of the University of Groningen made a study of fifteen edge-on spiral galaxies – galaxies whose thin disk of stars and gas is viewed from aside as seen from the Earth. The goal of the study was to determine the three-dimensional structure and the thickness of these disks. From a combination of Westerbork observations and optical studies, Kregel concludes that more massive galaxies also have thicker disks, that the thinnest disks are embedded in massive dark halos, and that this dark matter extends well into the galaxy’s core, in good agreement with theoretical predictions.
Marco Beijersbergen, also of Groningen University, studied galaxies in the Coma cluster – a large concentration of hundreds of galaxies at a distance of some 450 million lightyears. The Westerbork observations of the cluster members revealed the influence of the thin gas that fills the cluster. For instance, the high-velocity spiral galaxy NGC 4921 contains much less gas than had been expected, probably because the gas has been pushed out of the galaxy by the hot intracluster material. Also, Beijersbergen detected a few subgroups of galaxies that appear to have been added to the cluster population fairly recently.
The PhD research by Joeri van Leeuwen of Utrecht University, on the properties of radio pulsars and the rotation rates of the so-called pulse carousels, is described in the main text. Finally, the fourth thesis, by Hans-Rainer Klöckner of Groningen University, describes the study of extragalactic mega-masers of hydroxyl. A maser (Microwave Amplification by Stimulated Emission of Radiation) is the microwave equivalent of a laser. The powerful maser emission of hydroxyl (OH) in the cores of galaxies has been used to map out the molecular and dust structures surrounding the nuclei of galaxies and the starformation regions in the cores. This thesis provides a survey of the field of hydroxyl mega-masers and is based on WSRT data combined with high resolution data taken with the European VLBI Network (EVN).

Govert Schilling

4. ASTRON brings LOFAR to the Netherlands

At the start of 2003, LOFAR was not much more than a promising idea. Less than a year later, ASTRON received a government grant of 52 million euros for the construction of one of the largest radio telescopes in history, and by late 2004, the first test observations were performed in Exloo. Science writer Govert Schilling on nightmares, hanging by a thread and a minister who sticks her neck out.

In February 2003, Eugène de Geus started from a nightmare, bathing in sweat. A car accident in the morning pip, just outside The Hague; whirling paper on the highway A12; a clock which continues to tick steadily to 11 a.m. The adamant deadline for submitting the LOFAR grant application would never be met. A bad dream, for sure, but also a warning: one unforeseen event and the chances for the project are gone.

The following morning, de Geus's resolution was fixed: all paper and file work will be copied twice; two cars will drive to The Hague, and moreover they will arrive there a day before the deadline expires. As if it concerned a military operation where absolutely no risk can be taken. It was typical for the events around the financial backing of LOFAR, which was eventually secured in November 2003. de Geus: 'We sat in a huge roller coaster for a year, which fortunately finished at the top.'

Leading position

LOFAR (LOw-Frequency ARray) will become the largest radio telescope in the world: at least fifteen thousand small antennas, scattered over a 350 kilometre-wide area, and mutually coupled through a super-fast network of optical fibres. The heart of the telescope lies in Exloo in the northeastern Dutch province of Drenthe, but LOFAR is so large that part of the antenna fields will end up in northwestern Germany. Thanks to LOFAR, the Netherlands will preserve its leading position in international radio astronomy. Still, it was a near thing or the 52 million euros of government support had been never granted.

LOFAR director de Geus – also deputy director of ASTRON – is convinced that his radio astronomical cuddly toy never would have existed without the visionary initiative of George Miley, who at the time was the scientific director of Leiden Observatory – the same institute where the legendary radio astronomy pioneer Jan Oort worked practically his whole life. At the end of the nineties, Miley came up with the idea of the low-frequency telescope, which would be loosely based on the futuristic design for SKA, the Square Kilometre Array.

The work on SKA really got going in 1997, says de Geus. SKA will be a telescope with a total area of a square kilometre, not built from traditional radio dishes, but from tens of thousands of flat 'phased array'-antennas such as those applied in radar technique. 'Apart from Arnold van Ardenne, at the time the head of the research and development department of ASTRON, nobody was seriously considering that technique,' says de Geus. 'Radio astronomers can be a little bit conservative.'

However, the development of SKA would take up so much time that scientists would not be able to use it for a long time to come. And that prospect was not in keeping with the mission of ASTRON: enabling discovery in astronomy through innovative instrumentation and facilities management. de Geus: 'A disengagement loomed between ASTRON-activities and its users.' According to Miley, a low-frequency telescope would be a clever shortcut that could be realised in the short term. Moreover, a technical plan for such a telescope turned out to be ready in the drawer of ASTRON-engineer Jaap Bregman.

Unexplored territory

LOFAR is sensitive to radio waves with frequencies between roughly 20 and 200 megahertz. Ham radio operators would call this high-frequency waves, but in astronomy it's hardly impressive – radio astronomers generally work at gigahertz frequencies. Nevertheless, a lot of interesting phenomena can be studied in those 'low octaves'. 'LOFAR will study unexplored territory,' says ASTRON director Harvey Butcher. Hardly surprising then that other groups were also thinking about low-frequency radio telescopes, for instance at the Naval Research Laboratory (NRL) in Washington and at the Massachusetts Institute of Technology (MIT) in Cambridge, USA.

ASTRON astronomers were of course well aware of this American interest. 'The world of radio astronomy is too small not to know each other very well,' says de Geus, who himself has been a postdoc at the university of Maryland and at the California Institute of Technology for seven years. Australian colleagues also had an interest in a LOFAR-like instrument, and it was only natural to cooperate intensively with each other.

Not that cooperation was always easy and straightforward. In the United States, engineers envisioned a large antenna field, consisting of countless high poles connected by long wires – comparable to the very first radio telescope of Karl Jansky, built in the mid-20th century. The Dutch design was more strongly based on the phased array technique developed for SKA. But according to de Geus, there was also a dispute between the Naval Research Laboratory and MIT concerning the best strategy. 'It was not just us against them, but also them against them.'

Another point of concern was the tight timetable for LOFAR. Low-frequency radio waves from the universe are disturbed by the ionosphere – a high layer in the Earth's atmosphere that contains large numbers of electrically charged particles. As a result, cosmic radio sources will 'twinkle', just like stars twinkle because of atmospheric turbulence. The turbulence in the ionosphere is strongest when there are many eruptions on the sun, therefore LOFAR can best be calibrated if the sun shows little activity. This means that the telescope must be ready in 2007, when the next solar minimum is imminent.

'For the international project management, we contracted Jan Reitsma, who had worked on the production of solar panels at Fokker Space,' says de Geus. 'But his project approach, with a very strict planning, interim reviews and coherent task packages, demanded a serious culture change from the scientists involved. In the academic world, particularly in the United States, no one was used to this way of working. However, I am convinced that a project of this scope would never have gotten off the ground without such a business-like approach.'

After signing a Letter of Intent in 2001, all partners eventually went along with the proposed approach, but international cooperation was a frequent source of friction. Agreed deadlines were often not met; interim evaluations were not always taken seriously, and miscommunication abounded. All too bad, according to de Geus. 'There was nothing wrong with the content of the international project, which was excellent, but the process was a problem.'

Economic spin-off

And of course financing was a problem. The total costs for the construction of LOFAR were estimated at 134 million dollars, and none of the partners had the guarantee that a grant application in their own country would produce sufficient resources. However, in the Netherlands the necessary financial preliminaries had already been performed. In 2001 ASTRON already received a subsidy of 6.9 million euros from the 'Samenwerkingsverband Noord-Nederland' of the provinces Groningen, Friesland and Drenthe, for the very first development phase of LOFAR. The economic importance of LOFAR played an important role in that grant.

First phase of the LOFAR sensor network. Each red dot represents a (sensor) station.

‘Astronomical research has become very expensive’, says Butcher, ‘and such a direct spin-off happens to advance acceptance by the society at large.’

The same economic spin-off, as well as the potential non-astronomical applications of the LOFAR sensor network, would be just as important for the request of a much larger subsidy from the Knowledge InfraStructure workgroup (KIS) of the Interdepartmental Committee for Economic Structure strengthening (ICES), which has several hundred million euros to distribute in each cabinet period. A strictly astronomical instrument would never qualify for an ICES/KIS subsidy, but if the potential importance of LOFAR also for agriculture, geophysics, economy and ICT would be emphasized, then a well-founded project proposal would perhaps stand a chance.

Such a project proposal was drafted in early 2003, by a consortium of eighteen Dutch partners that had been hastily put together. ‘The final deadline for the subsidy application was Monday 17 February 2003, at eleven o’clock in the morning,’ says de Geus, who still vividly remembers his nightmare of a couple days before that date. ‘We have worked on it up to the last moment; this was an extraordinarily important moment. During those days, LOFAR entirely dominated my life.’

It would remain exciting for months. During the spring of 2003, an eight-person Committee of Wise Men evaluated all subsidy applications within ICES/KIS – which in the mean time had been renamed to BSIK: Besluit Subsidies Investeringen in de Kennisinfrastructuur (Decree Subsidies Investments in Knowledge Infrastructure) – with the aim of providing the government with recommendations in the summer. This committee in turn was advised by two sub-committees: one of the Royal Dutch Academy of Sciences (KNAW), which assessed the scientific contents of the project proposal, and one of the Netherlands Bureau for Economic Policy Analysis (Centraal Planbureau, CPB), which focused at the economic relevance.

‘We had to put in an appearances in The Hague at the strangest moments,’ says de Geus, for whom 2003 was an extraordinarily emotional year. ‘For example, I promised to join the June school camp of my eldest son on the island of Ameland. But that same week, we also had to give a presentation for the CPB. So I took a suit with me in the camp luggage, and in Harlingen-Harbour I was picked up by a driver in the morning who returned me to the boat again that evening.’ The recommendations of the two sub-committees were not public, but word had it that LOFAR had gained a top score at the KNAW-committee, while the CPB-committee was also surprisingly positive.

But the race was not yet over. Within the Committee of Wise Men, some dissenting voices could also be heard. All that emphasis on the geophysical and agricultural and technological aspects of LOFAR – wasn’t that just a cheap trick of the radio astronomers to pocket government money by a detour? In the end, the telescope might very well turn out to be just a pure scientific instrument, with hardly any economic pay-off. On the basis of that lingering doubt, the Committee subtracted one full point from the average score that LOFAR had gotten from the two sub-committees – enough to result in a negative recommendation to the Dutch ministers counsel, who would make the final decision.

A hard hit

The bad news arrived as a hard hit in early October. George Miley, who in a sense fathered the LOFAR project, feared that a negative government decision on the grant application could mean the death-blow for Dutch radioastronomy. ‘Our leading position is built on the commitment and the pioneering work of Oort,’ he said at the time. ‘If the Netherlands does not take part in LOFAR, you throw away that inheritance.’ de Geus couldn’t agree more: ‘If the LOFAR subsidy is not granted, the United States and Australia will take over the leading role.’

Evidently, it was high time for a firm lobby campaign, which was carried out in close cooperation with the Amsterdam PR office Stratix. Politicians were plied with letters and visits; journalists were urged – successfully – to give LOFAR more public exposure, and numerous administrative heavyweights – from the major of Stadskanaal and the Queen's Commissioner in Drenthe up to the ambassador of the United States – threw themselves in the fight. de Geus and Butcher ran right and left, hung on the telephone for hours per day, and raced from one networking drink to the next dinner party.

'All that time, the future of LOFAR was hanging by a thread,' says de Geus. 'Up to and including the ministerial council meeting of 28 November, the day on which a definitive decision had to be taken, there was a big chance it would go wrong. The fact that LOFAR eventually received 52 million euros – a large percentage of the requested 73 million – is mainly the merit of the Dutch minister of Education, Maria van der Hoeven, who strongly supported the project in the ministerial council. Says de Geus: 'She stuck out her political neck very far. Never before had the government turned down a recommendation from the Committee of Wise Men.'

Van der Hoeven had been enthusiastic about LOFAR from the very beginning, she says. 'I believed LOFAR would be able to reinforce our country's international scientific prestige. Not that there was something wrong with that, but it is always good to put your own country firmly on the scientific map.' In particular, van der Hoeven liked the very fundamental character of the project. 'I am convinced that there must be sufficient opportunities for fundamental research; applications will then follow automatically,' she says. 'LOFAR is the living proof of this mechanism: the project has the potential to generate a wide variety of applications from the start. I am especially proud of the influence LOFAR has on the ICT-domain.'

However, the BSIK subsidy was granted on the condition that the partners in the LOFAR consortium would cough up at least the same amount of money themselves (the so-called matching), and that LOFAR would indeed be built in the Northeastern part of the Netherlands. And that went down the wrong way with the international partners, because an extensive test campaign had shown that Western Australia would be the ideal location for the low-frequency telescope: just like an optical telescope must be far from artificial sources of light, you preferrably build a sensitive radio telescope in an area where there is as little radio noise and interference from the surroundings as possible.

Colin Lonsdale, of the Massachusetts Institute or Technology's Haystack Observatory, accused his Dutch colleagues of taking a 'detrimental, unilateral decision', to which the Americans had no other choice but to quit from the collaboration. According to Lonsdale, by redefining LOFAR as a regional infrastructural development project, ASTRON violated the understanding to jointly build a cost-effective instrument whose design and location are based entirely on scientific arguments.

Van der Hoeven is of another opinion. 'ASTRON and LOFAR have let the financial argument prevail,' she says. 'This is the way things go: the first one to obtain the financial means can start to build. The money, which has not been obtained easily in the first place, would of course never have been there if the telescope would have been built in Australia. I have been honestly proud that ASTRON and LOFAR have had the guts to persevere.'

Lead

Butcher admits that he also rather would have built LOFAR in Western Australia 'if we did not have to comply with the conditions of the BSIK grant.' But de Geus emphasises that the scientific case for LOFAR isn't compromised by the choice for the Dutch location 'I cannot believe our choice came as a real surprise to the MIT team,' he says. 'Right from the beginning we've made it clear that the BSIK grant would come with an obligation to invest

in the Netherlands. I still keep the presentation slides in which that is stated adamantly.'
As a matter of fact, says Butcher, there never has been a high-running dispute, and ASTRON scientists still regularly collaborate with their colleagues at MIT's physics faculty, although the U.S. scientists are developing plans for a smaller LOFAR-like instrument, to be built in the United States or in Australia. 'But our lead is at least one complete solar cycle of eleven years,' says de Geus – a newly developed instrument can never be built on time to be calibrated in 2007, during the next solar minimum. Moreover, within a few years everyone will be able to submit observing proposals for LOFAR, although external parties will have to share some of the exploitation costst of the instrument. de Geus is very confident: 'Of course the Americans will soon be using LOFAR.'

After the hectic year of 2003, 2004 was relatively quiet, but certainly not less important for de Geus and his colleagues. 'In that year, we really set to work,' he says, 'and the organisational structure has been further set up. New applications for the use of the LOFAR's sensor network have been considered and selected, and the collaboration with IBM got of the ground. These were of course very tense discussions.'

And the telescope itself? By the end of 2003, it consisted of a test field with 64 antennas, whose construction had started already in November 2003. Inconspicuous 'open pyramids' of pvc tubes housing copper wires, in the fields between Exloo and Buinen, mutually connected by optical fibres, and all coupled to a central processing unit in a steel container. The test station passed an important landmark on 11 December 2003 with the recording of the first interferometric fringes – a proof that the telescope's principle is sound. 'The technique works excellent with a few tens of antennas,' says ASTRON electronical engineer Yde Koopman, 'and there is no reason why it wouldn't work with fifteen thousand.'

But that's something for the future. It is still an open question whether the LOFAR consortium will manage to raise the required matching of 52 million euros, and whether the complete telescope can be built for the resulting total amount. But de Geus remains optimistic. 'Even if we end up with many antenna fields in the core area of LOFAR and a bit less along the spiral arms, the telescope will be very acceptable for astronomical applications. And in the future the number of antennas will only increase.'

11 December 2003. Harvey Butcher (l) and 'technical father' of LOFAR Jaap Bregman (r).

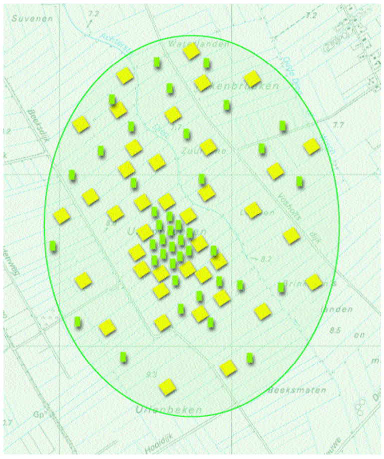
Prototype of the LOFAR LBA antenna.

LOFAR consortium

ASTRON leads the LOFAR consortium – a collaboration of research institutes, universities and private ventures. The consortium consists of the following partners:

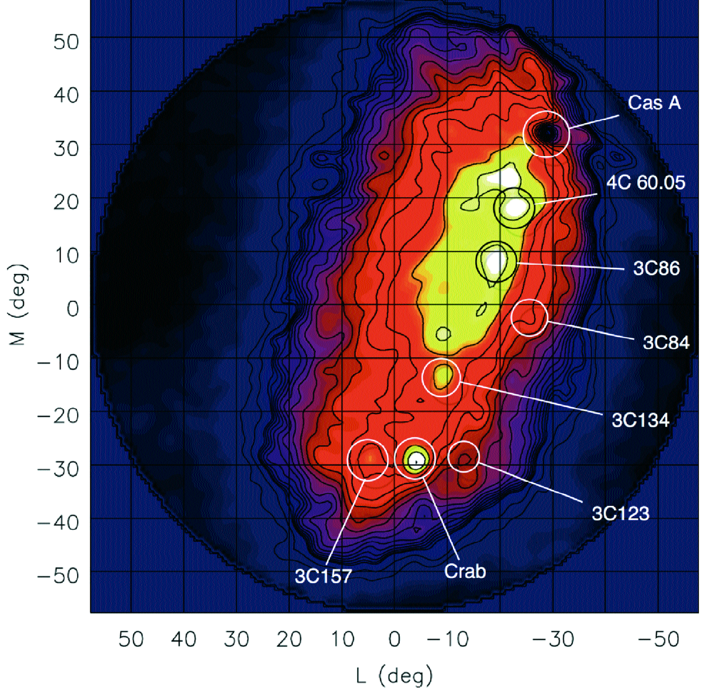
- ASTRON, Netherlands foundation for research in astronomy
- Astronomical institute 'Kapteyn', University of Groningen
- Rekencentrum, University of Groningen
- OmegaCEN Data Centre, University of Groningen
- Leiden Observatory
- Astronomical institute 'Anton Pannekoek', University of Amsterdam
- Radboud University Nijmegen
- Max-Planck-Institut für Radioastronomie, Bonn
- Center for Technical Geosciences, Technical University Delft
- KNMI (Royal Dutch Meteorological Institute), De Bilt
- Dutch Institute for Technical Geosciences (TNO-NITG)
- Agrotechnologies and Food Innovations (A&F)
- Ordina Technical Automation BV
- Science[&]Technology BV
- Dutch Space BV
- Twente Institute for Wireless and Mobile Communications BV
- Intelligent Systems Consortium, Technical University Delft
- Leiden Institute for Advanced Computer Sciences (LIACS)
- National Research Institute for Mathematics and Computer Science (CWI)
- Technical University Eindhoven
- Department of information sciences, University of Uppsala

Infrastructure



Prelimenary central core confideration.

For the construction of the central part of LOFAR, and therefore also for the Initial Test Station (ITS), ASTRON had to acquire 320 hectares of agricultural ground in the municipality Borger-Odoorn. That was rather more difficult than expected, because in total about forty landowners were involved, including a few big ones. 'Sill, most people were willing to cooperate,' says ASTRON director Harvey Butcher. 'The agricultural quality of the ground between Exloo and Buinen is rather poor.'
In April 2003, ASTRON organised a large hearing for the local population, which was attended by approximately 250 people. Of course there were numerous questions, for example about LOFAR's presumed impact on the environment and about the radiation risk – radio astronomers have to explain time after time that their instruments do not produce radiation, but exclusively pick up and study it. 'We have handled this vey carefully, and we have always walked a very open route,' says Butcher.
In the course of 2003, approximately ten meetings were held with organisations like the Northern Agriculture and Horticulture Organisation, the Environmental Federation Drenthe, a local butterfly society, et cetera. In consultation with the province and the municipality, LOFAR was incorporated in the

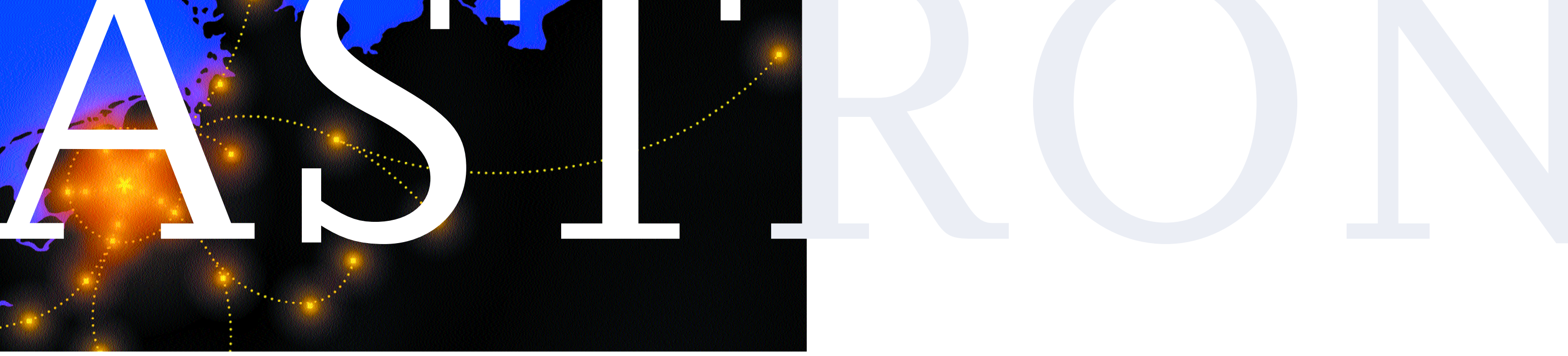


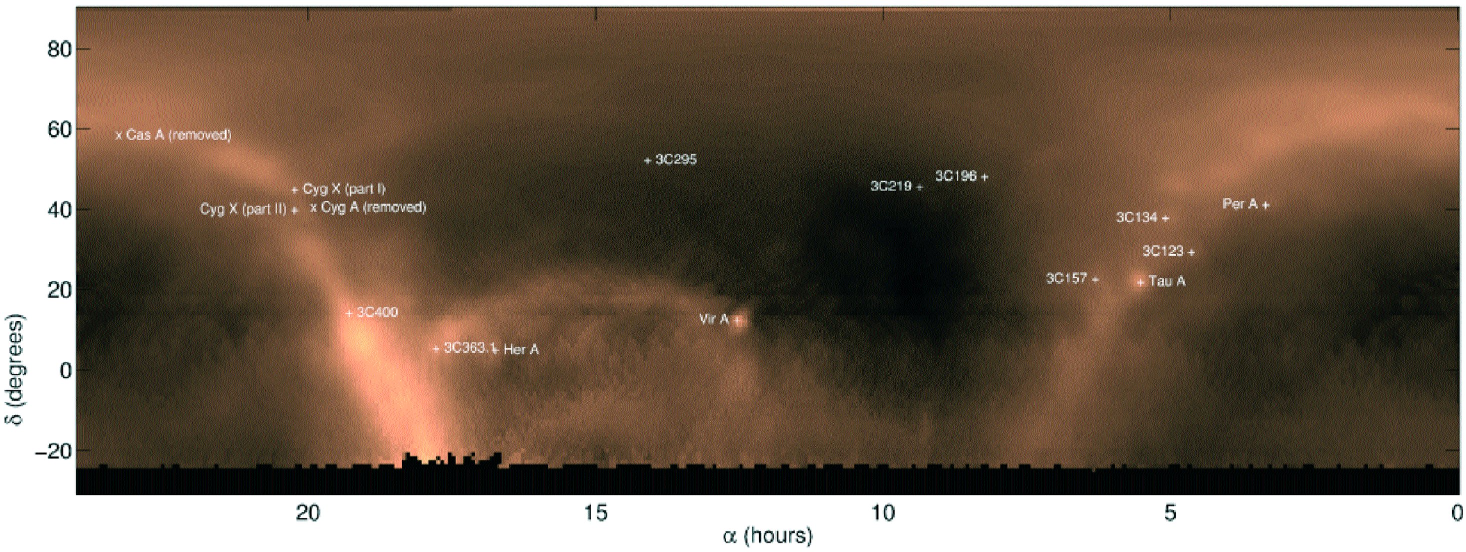
Caption: 30 MHz map of the sky taken with the Initial Test Station (60 antenna's operating at 10-40 MHz, resolution of ~3 degrees at 30 MHz). Integration time is 6.7 seconds, total bandwidth 1.05 MHz selected from the clean channels in the 24-31 MHz frequency range. The brightest discrete source Cas A (3C461) has been subtracted. Other well known discrete sources are also indicated. The diffuse emission is due to the Milky Way. The resolution of the final array will improve by a factor of ~250,000 (with 100 km baselines) compared with this ITS image and the sensitivity will go up by at least 7 orders of magnitude (more collecting area and longer integration time plus broader bandwidth). Image produced by M. Brentjens (ASTRON/RUG).

Second Provincial Environmental Plan, and the LOFAR core area, which has always had an agrarian destination, was designated as a future nature area. Incidentally, a specific environmental impact report for LOFAR turned out not to be necessary.
It looks as if almost all of the 320 hectares of the core area will be bought by ASTRON in the long run. In some cases ground is bought elsewhere, which can then be exchanged with the local owner. 'We didn't encountered any big problems,' says Butcher. 'Most people are quite interested in having a large astronomical facility being built in their area.'
As of 2005, a walking tour Exloo-LOFAR has already been realised, in association with the tourist office Borger-Odoorn, and someday, a bicycle path may be made through the area, says Butcher. 'But not too close to the antennas,' he warns, 'because people affect the observations: the water in your body reflects low-frequency radio waves.'

Astronomy with LOFAR

LOFAR is a unique scientific instrument, that will provide astronomers with an entirely new look on the universe. The cosmos has never before been observed in much detail at these wavelengths, which range from just over one to approximately thirty meters. Almost every area of astronomy will profit from the low-frequency observations of LOFAR.
Very close to the Earth, LOFAR is able to map the structure of the ionosphere in full detail. The ionosphere is a layer in the Earth's atmosphere that contains many electrically charged particles. Its structure is strongly influenced by outbursts of the sun, but also by explosions in the distant universe, like gamma-ray bursts.
Solar outbursts are also observed directly by LOFAR. Coronal mass ejections blow huge quantities of ionised gas into space with high speeds, and these outbursts cause geomagnetic storms and disturbances in radio communication on Earth, while satellites in space and power stations on the ground can get deranged.
LOFAR's observations will make it possible to respond better to this so-called 'space weather'.
Low-frequency radio waves are also produced by pulsars – rapidly spinning and extremely compact stars – and by Jupiter-like giant planets orbiting other stars. Moreover, LOFAR will hunt for ultra-high energetic cosmic rays: electrically charged particles that rush through the universe with almost the speed of light, and whose origin is shrouded in mystery.
At larger distances, LOFAR is able to observe massive galaxies. This way, astronomers hope to get a better view of the origin and the early evolution of the first galaxies in the universe: by looking at very large distances, you automatically look far back in time, because it took billions of years for the light of those distant galaxies to reach us.
However, the 'holy grail' of LOFAR is the epoch of re-ionisation, an important period in the early youth of the universe. Approximately half a million years after the big bang, the universe contained just neutral atoms of hydrogen and helium, but after the first stars and galaxies had formed, that neutral gas became ionised by the





A map of the northern sky at 30 MHz as observed with LOFAR's Inital Test Station. To make weak sources on the map visible, the two strongest sources, Cassiopeia A and Cygnus A have been subtracted. Detected sources from the 3C catalogue have been indicated (Courtesy of Stefan Wijnolds; ASTRON).

energetic radiation of those new objects: the neutral atoms got rid of their electrons, and the gas changed into a plasma: a mixture of positively charged atomic nuclei and negatively charged electrons.
The neutral hydrogen gas in the very early universe emitted radio waves at a wavelength of 21 centimeters, but due to the expansion of the universe, that radiation has been enormously stretched during its long travel to the Earth. The expectation is that LOFAR might observe this strong 'redshifted' radiation at a wavelength of a few meters. If so, astronomers will have their first chance to study the early dark ages of the universe.

Software telescope

The concept of LOFAR is absolutely unique. Eventually, the observatory will consist of approximately fifteen thousand small antennas, grouped in a few hundred fields. Most of those fields lie within the 'core area' of the telescope, in Drenthe; a smaller number will be at much larger distances, along five giant 'spiral arms' that reach well into Germany. Thus, LOFAR will end up with a diameter of 350 kilometres.
The technique of having a number of individual telescopes work together, is called interferometry. Interferometry is also the basis of ASTRON's Westerbork Synthesis Radio Telescope, which consists of fourteen 25-meter dishes. By carefully combining the received signals from the different antennas ('in phase'), the array obtains the same image sharpness as a fictitious giant telescope as large as the distance between the outermost two dishes.
LOFAR will use interferometry to simulate a radio telescope with a diameter of 350 kilometre, with an extremely high resolving power. Moreover, by using many antennas (and extremely sensitive receivers), LOFAR reaches a high sensitivity, so that faint radio sources at the edge of the observable universe can be observed. But LOFAR is also unique in a another respect. The dish antennas of Westerbork must all be turned in the same direction to observe a particular celestial body. In contrast, LOFAR looks in all directions at once, and contains no moving parts. As a result, the instrument is relatively cheap. The simple antennas (not much

more than copper wires in protective pvc wrappings) are sensitive to radiation from all possible directions, and they observe every low-frequency radio source that is above the local horizon.
Fifteen thousand omnidirectional antennas that watch the whole sky at once – that obviously results in an enormous mush of radio signals. Still, a powerful supercomputer is able to extract the desired information from that radio mush. For this extensive data analysis, all radio signals are brought together by means of optical fibre, and in a sense it is the software that determines in which direction LOFAR actually observes. The underlying principle is that the radiation from a certain point on the sky does not arrive on all antennas at exactly the same moment. For example, if a radio source is low above the Eastern horizon, the LOFAR antennas in Germany will pick up a certain radiowave just a little bit earlier than the antennas in the Netherlands. By taking into account those tiny differences in arrival time, it is possible to precisely filter out the radiation from a particular source from the background noise.
The same technique even makes it possible to filter out unwanted radio noise: LOFAR can also be 'blindfolded' in certain directions by the software, and if required, the resulting blind spot can contiuously be moved around. Thus, unwanted radio signals, for example from GSM antenna masts or passing planes, can be kept at bay.

Applications

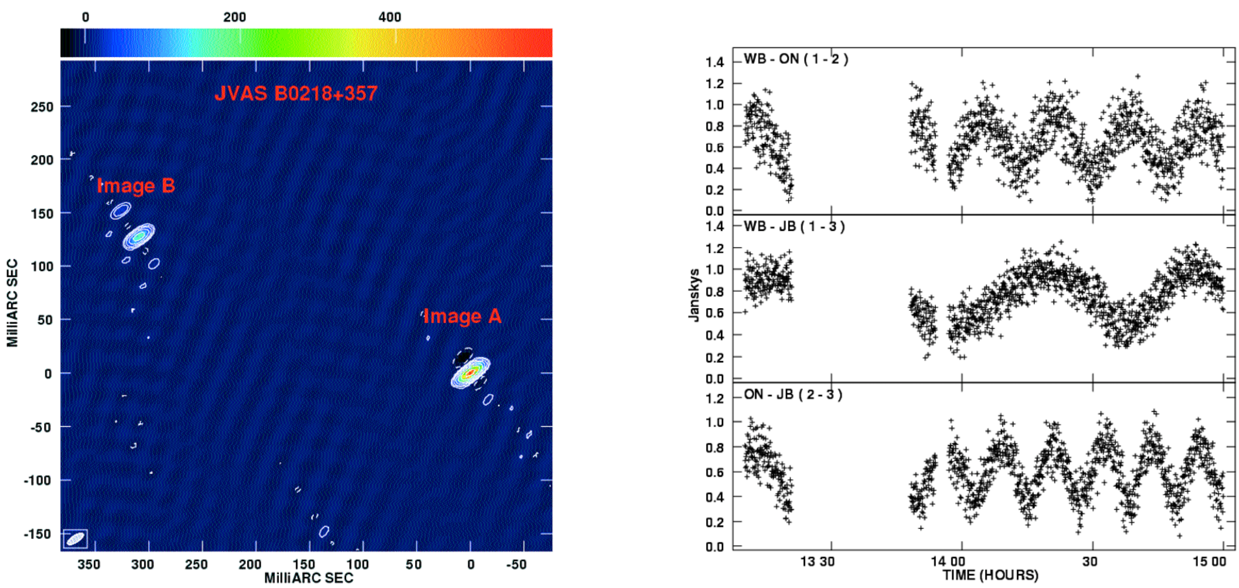
LOFAR is a telescope, and telescopes are intended for astronomical research. But the infrastructure of LOFAR offers much more possibilities. An array of fifteen thousand measuring devices, scattered over an area of hundreds of thousands of square kilometres, mutually linked by a glass fibre network and connected to a supercomputer, is of course very interesting to other scientists too: the capacity of the network is large enough to hook up many other types of sensors.
For example, the test station in Exloo have already been equipped with geophones: extremely sensitive microphones that register tiny seismic movements in the Dutch soil. Thanks to the large number of sensors and the long-term data taking they provide, geoscientists get a better picture of the subsurface structure, and of the speed and the cause of the slow downward motions in the northern part of the Netherlands.
Another future application of the LOFAR sensor network is so-called precision agriculture, which involves continuous monitoring of soil quality, temperature and humidity, and plant growth and diseases, at thousands of places at once. Crop production can then be increased by automatically taking very specific and local measures.
According to LOFAR director Eugène de Geus, directly using the infrastructure of an astronomical instrument for other technological applications is a first. 'Also, ASTRON astronomers and engineers are used to asking and answering very complex questions; they have a lot of experience with large, complex projects, as well as a unique possession of system knowledge.'
Meanwhile, many new potential applications of the sensor network are being examined, and ASTRON is setting up several business cases, for instance in meteorology, air pollution, water management, and wind monitoring. For example, Shell New Energy is very interested in high-precision wind measurements in the northeastern part of The Netherlands, because that would enable a much more efficient utilization of wind turbines in northern Germany.
Last but not least, LOFAR also plays an important part in the ICT world. The radio telescope will use extremely fast optical fibre networks, which have sufficient capacity to also transport business and private internet traffic. Thanks to LOFAR, numerous Dutch municipalities will soon be able to offer super broadband internet on their business areas.

5. JIVE

In 2003, the Joint Institute for VLBI in Europe (JIVE) celebrated its tenth anniversary. This year was a pivotal one for the institute, in particular Prof. Richard Schilizzi resigned as director of JIVE at the end of 2002, in order to take up his new position as SKA International Project Director. At the end of 2002, the JIVE Board thus began an international search to find a new director of JIVE. In May 2003, Dr. Michael Garrett was appointed Director JIVE, having served as interim director for the first half of the year. In the second half of the year, several changes were made to the organisational structure of JIVE and many of the staff's responsibilities and duties changed. This has had a beneficial effect on the efficiency of the institute, especially in terms of production VLBI correlation and network support.

During the period of this report the new Memorandum of Understanding (MoU) between the various JIVE Foundation funding partners was finally completed – this secures base funding for JIVE over the next 5 years (2003-2007). The JIVE funding partners now include: NWO (NL), ASTRON (NL), PPARC (UK), INAF (IT), IGN (ES), OSO (SE) and MPIfR (DE). Associated with the introduction of a new MoU, a revised set of Statues were considered by the board and were formally accepted by all parties by the end of 2004. ASTRON remains the host institute of JIVE.

The financial position of JIVE in 2003-2004 was boosted by changes to the annual funding and expenditure profile, and in particular the success of the FP6 RadioNet I3 project coordinated by Prof. Philip Diamond (Jodrell Bank Observatory). JIVE has also been in receipt of various awards from the European Space Agency, mostly aimed at supporting the ESA Huygens mission (see below). By the end of 2004, work had already started in preparation of the submission of a large proposal to the EC Research Infrastructure CND programme. The proposal called "EXPReS" (Express Production Real-time e-VLBI Service), seeks to make e-VLBI a



First e-VLBI real-time image (left) and data (right) of the gravitational lens system, 0218+375. The data were observed by a three telescope array (Westerbork, Onsala and Jodrell Bank) and correlated at JIVE in real-time production grade astronomical instrument. A key feature of the proposal is to ensure that e-MERLIN and e-VLBI can operate as a single instrument – the transparent combination of the two arrays would represent an unbeatable combination boasting an angular resolution ranging from arcsecond to milliarcsecond scales, with sub-microJy noise levels.

During the period of this report JIVE continued to expand its support to EVN users and the VLBI network of radio telescopes. JIVE Support Scientitsts continued to support visiting astronomers in the analysis of VLBI data. Over the period of this report, 76 visits were made to JIVE. Many astronomers also made use of the scheduling support provided by JIVE. In addition, the EVN correlator at JIVE was upgraded to the new Mark5 (PC disk-based) recording/playback system – representing an investment by JIVE, the EVN institutes and ESA of 0.75 Million Euro. By the end of 2004, the correlator was operating transparently with 16 Mark5 systems – the largest Mark5 capable VLBI correlator in the world.

Perhaps the main highlight of 2003-2004 was the development of real-time e-VLBI – connecting a sub-set of the EVN telescopes to the correlator at JIVE via high-speed optical fibre networks. This e-VLBI activity was strongly supported by the Dutch national research network SURFnet (via the

Artists impression of Huygens descending through the atmosphere of Titan by parachute. JIVE will lead a global VLBI array of radio telescopes to track the probe during its descent and eventual touch-down.

Gigaport project) and DANTE (operators of the pan-European Optical Fibre Research network – GÉANT). April 2004 saw the generation of the first international e-VLBI image (see Figure J1) and the first science demonstration was conducted in September 2004. The EXPReS project seeks to make e-VLBI a state-of-the-art scientific instrument.

By the end of 2004, excitement was growing as JIVE prepared to lead a large international radio astronomy effort to track the decent of the Huygens planetary probe through the atmosphere of Titan using VLBI techniques. The probe is expected to land on the surface of Titan in January 2005 and the aim of the VLBI observations led by JIVE is to pin-point the location of Huygens probe to a ~ km precision throughout the period of its descent (expected to last 1,5 – 4 hours –see Figure J2). These data will be processed at JIVE using the EVN correlator and special high-resolution software correlator, also developed by JIVE. The VLBI results, together with Doppler measurements of the probes carrier signal will hopefully permit the 3-D trajectory of the Huygens probe to be calculated, and will help understand the wind dynamics of Titan in both the lower and upper atmosephere. The successful reception of radio signals from Huygens will be the first indication that the probe has survived re-entry.

Individual science results produced by JIVE scientific staff included the first publication in the journal Nature of data processed by the EVN correlator at JIVE. During 2003-2004 JIVE staff were involved in the publication of 79 astronomical papers in refereed journals or conference proceedings. In 2003, the JIVE Board of directors decided that JIVE should co-sponsor PhD students studying in the Netherlands, and JIVE was successful in finding other external support for additional PhD students and Post-doctoral research positions. JIVE was involved in co-sponsoring with ASTRON, two workshops during the period of this report – a European workshop entitled "Astronomical Molecules" held in Zwolle and an international Workshop on "Interstellar Scintillation of Extragalactic Radio Sources", held in Dwingeloo.

6. *General information*

Public relations

The visit of our minister of education, culture and science, mrs. van der Hoeven, on February 23, 2004 was without a doubt the most important event for ASTRON in 2003 and 2004. This visit was on the occasion of the signing of the contract for the 52 M€ Bsik funding of LOFAR. In her speech at this occasion, mrs. van der Hoeven expressed her personal involvement and the importance of LOFAR for the Netherlands.
In addition, February 23 was the day that IBM and ASTRON signed a contract for joint research and development of streaming supercomputers (supercomputers with very high volumes of data throughput). The joint activity implies the application of the IBM BlueGene/L technology in LOFAR. The official ceremonies took place at ASTRON in Dwingeloo and were witnessed by ASTRON employees, LOFAR consortium members, and friends of LOFAR who helped secure the funding. All our guests were invited to a festive get-together in the Drenths museum in Assen, where they were treated to a very attractive astronomy lecture by the chairman of ASTRON's governing board, professor Ed van den Heuvel.

We have undertaken many more efforts to make our activities known to the world and beyond. Many visitors were attracted to the activities going on at ASTRON. In 2003 we estimate that 1,200 people visited ASTRON and 1,500 in 2004. This does not count the visitors to our open days (1 day each year in October). In both 2003 and 2004 we estimate that 2,500 people visited our open days.

FLTR: prof. dr. H. Butcher, director ASTRON, mr. R. ter Beek, commissioner of the province Drenthe, mrs. M. van der Hoeven, minister of education, culture and science, prof. dr. E. van den Heuvel, chairman ASTRON board.

2003

Visits

7/1	Students electronics techniques Hanzehogeschool
15/1	Minister van der Hoeven
15/2	NVWS division Schothorst Amersfoort
3/3	Accountants KPMG
4/3	Students ROC Zwolle HF techniques
5/3	Students Roelof van Echtenschool
6/3	NOZEMA
12/3	Ministerial advisors ministries of Economic Affairs, Finance, and Education, Culture and Science
24-26/3	Students Optics course
25/3	Club van 9
25/3	Rotary Club Groningen
7-9/4	RF-course – various companies
28/4	Adult higher education
15/5	VERON division Deventer
15/5	Students HTS
20/5	Students Leiden University following course ‘observing techniques’
12/6	finalists physics Olympiad
13/6	SNN directors Northern funding program
13/6	Students physics, mathematics and informatics University of Utrecht
17/6	Personnel TNO
19/6	SRON
19/9	Lobby club SNN
13/8	GSK Designers
27/8	Students plant ecology University of Groningen
30/8	NLTO Drenthe
1/9	CDA chairmen Regional and National
11/9	IMAG
12/9	Township secretaries Drenthe
19/9	Former employees agricultural information service
24/9	Inhabitants Zuiderstraat Buinerveen
26/9	ICT in veenkoloniën (town Stadskanaal)
11/10	Township Westerveld with partnertowns Ilmenau en Kolitska
13/10	Danish students
15/10	Central Works council NWO
21/10	Drenthe college ICT
22/10	Networking organization Diligentia Den Haag
24/10	Heads environmental divisions 12 provinces
28/10	Agricultural society Exloërmond
1/11	Planetarium Artis

Maria van der Hoeven, minister of education, culture and science.

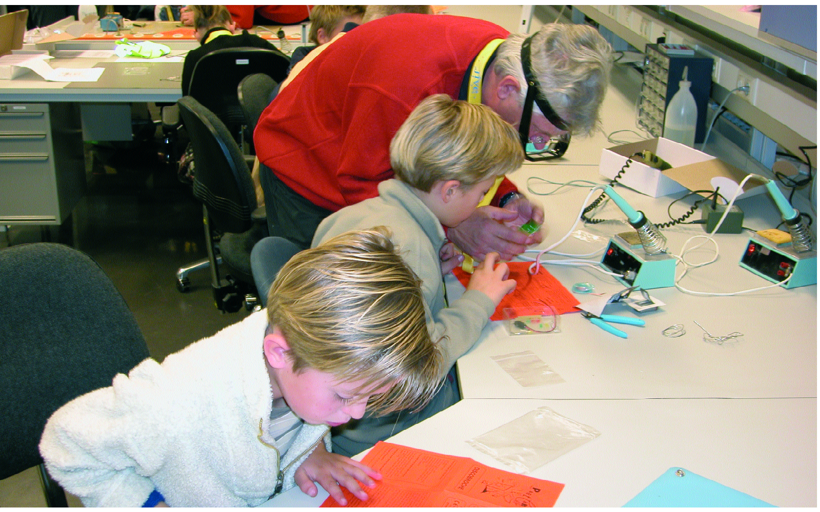
4/11	Course RF techniques
7/11	NVWS Assen
12/11	Watership Reest en Wieden
26/11	Land owners LOFAR central area
11/12	Society of public services directors
16/12	NERG thematic meeting on LOFAR
17/12	University of Nijmegen Honours program

Press and publicity

7/1	ASTRON: headquartersof the world's largest radio telescope
10/1	Minster van der Hoeven pays working visit to ASTRON in Dwingeloo
27/1	1,2 miljoen Euro for involvement companies in astronomical instrumentation
19/2	Revelations of an active nucleus in a galaxy
17/3	Falcke searches for fireworks in black holes
19/5	ASTRON builds new camera for telescope in La Palma
30/6	NLTO and ASTRON on one wavelength
5/11	Solar storm scan be predicted by LOFAR
12/11	ASTRON second prize with new 'extreme light weighting' method
28/11	52 Million Euros for ambitious LOFAR Project

Exposure in the media

14/10	Radio 1, De Ochtenden (Miley, De Geus)
21/11	Netwerk, TV1 (Miley en De Geus, Rijpstra and Mastwijk)
22/11	Interview Radio Drenthe (Bentum)
18/11	RTV Drenthe, Drents Diep (De Geus, Mastwijk and Swierstra)
22/11	Radio Drenthe, Cassata (interview Butcher)
28/11	RTV Drenthe (52 million Euro), NOS Journaal, Radio 1 journaal



'Kidslab' at the open day.

Specific pr

12-2	Symposium Provincial government Drenthe “Drenthe 2030 Plus”
Feb	LOFAR brochure
8-3	Open day province Drenthe
12-19-3	Stand on CeBIT in Hannover
4-4	KiVi spring meeting
Juni	kladbloc
Juli	brochure R&D Lab
Aug	brochure IDL
4-5-9	participation “ICT Kenniscongres” Den Haag
18-9	BZK day organised by province
19-10	Open Day Dwingeloo
13-12	National physics teachers’ day Noordwijkerhout

2004

Visits

11-1	Lions 40+
15-1	MBO students Hoogeveen
20-1	Watership Regge en Dinkel
21-1	Police Borger Odoorn
11-2	WDR (German radio)
18-2	CDA Borger-Odoorn
19-2	Facility Managers Nederland
25-2	Students mechanics and electrotechnique MBO Noorderpoortcollege
3-3	Film crew WSRT Casema Media
11-3	Elementary school Iederwijs Uffelte
15-3	VERON (society for experimental radio research)
19-3	2nd year students geosciences University Utrecht
21-3	open day Schaapskooi Ruinen
24-3	Town interest group Buinen (Erik Huizing)
26-3	Students en former-students Geography/planning RUG
14-3	Companies day Bureau Technology Transfer
15-4	students 5 VWO (physics & mathematics) organised by RUG
16-4	Physicists from 21 countries
21-4	NVWS division Delft
21-4	National geodetic society
27-4	Students technical physics TU Delft
11-5	IDEA foundation
11-5	Provincial government and society of townships Drenthe
13-5	directors Rabobank Beilen
13-5	personnel department province Drenthe

15-5	KNVWS België
18-5	division Zonal planning
19-5	Teachers Design/engineering Windesheim Zwolle
25-5	research school Fantom
26-5	Kivi
2-6	Students astronomy University Leiden
2-6	SME society division North and provincial government
4-6	watership Reest en Wieden
11-6	CDA division Drenthe
14-6	Higher education for the elderly
15-6	town government Coevorden
16-6	German journalists
21-6	college students Utrecht
22-6	A-Eskwadraat (student society university of Utrecht astronomy)
28-6	Rotaryclub
29-6	Syntens Digiclub
15-7	seniors summerschool Groningen
13-7	Participation Children's activity route Bicycle tour Drenthe
24-7	astronomy summerschool European high-school teachers
27-8	Council and town-government 9 townships North-east Groningen
3-9	Bureau Boot (geodesy)
20-9	Rotaryclub Dedemsvaart
21-9	businessclub Westerveld
21-9	Technicians Ordina
22-9	Computer department NWO
23-9	Computer department Province Drenthe
23-9	Technicians Ordina
27-9	Friesian Exportclub/Chamber of Commerce Friesland
28-9	club Heerenhof Zuidwolde
29-9	North Stars Business Making Event
29-9	Dision Traffic and Transportation, ministry of transportation
2-10	European commission (SNN)
12-10	ABN AMRO/Notaries Assen
13-10	Students astronomy University of Amsterdam
14-10	Board council of natural sciences NWO
15-10	Chamber of commerce Meppel and Gemrna partner
27-10	Committee on town planning
28-10	Jan Marijnissen (national politician)
28-10	NVWS division Zaanstreek
2-11	civil servants Sweden (organisastion Province Drenthe)
3-11	Rotary Beilen
5-11	Rotary Coevorden
9-11	Rotary Assen
11-11	Secretaries
13-11	Students TU Delft
18-11	Lionsclub Drenthe south-west

19-11	Hanse Passage and Province Drenthe
20-11	NVWS division east Westfriesland
26-11	Town council Groningen and board of governors University of Groningen
30-11	Managers ICT higher education
9-12	Honours programme University of Nijmegen
2-12	township Westerveld
15-12	Intervision group Waterschap

Press and publicity

17-2	persinvitation for February 23rd
22-2	Minister van der Hoeven (OCW) at ASTRON in Dwingeloo
23-2	IBM Blue Gene supercomputer used by LOFAR
1-4	Radioastronomers reveal the heart of the Milky Way and take its measure after 30 years
8-4	ASTRON employee ir. Jaap Bregman receives prestigious Vederprize
12-5	ASTRON's VISIR instrument gets 'first light' on European telescope in Chili
19-5	ASTRON, Westerbork memorial center and Staatsbosbeheer start unique project for elementary school teachers
30-9	Open Day: the world's largest radiotelescope in Drenthe
11-10	LOFAR maps subsurface in Northern Netherlands

LOFAR enginering manager Marco de Vos in front of the cameras.

Exposure in the Media

7-1	Interview De Limburger (Bentum)
1-2	Interview NRC Handelsblad (De Vos)
3-2	ANP Photo
5-2	Interview 'Kijk op het Noorden' (De Geus)
9-2	Interview Radio 1 ITS LOFAR (Koopman/Bennema)
20-2	Interview Radio 1 Journaal (De Geus/Bentum)
23-2	Interview Radio Drenhthe (vd Heuvel)
23-2	TV Drenthe
23-2	RTLZ (vd Heuvel)
25-2	Interview EOS (Bentum)
Mrt	Interview Automatiseringsgids over IBM (De Vos)
Mrt	Interview Radio East on LOFAR (Bentum)
22-5	Interview Radio Drenthe on visitor's center (Lemmens)
23-5	Cable newspaper Drenthe (Lofar visitior's center and announcement May 24)
24-5	TV Drenthe on visitor's day (Csonka)

Specific pr

9-2	Q&A session zonal plan LOFAR central
Feb	LOFAR Newsletter nr 4
Feb	Folder zonal plan LOFAR
23-2	visit Minister OCW, reception Drenths museum Assen
Mrt	The World of ASTRON and LOFAR (dvd)
8-3	Enterpreneurs meeting Borger-Odoorn
16-3	Semi finalists "RUGkrakers" in Exloo and visit ITS
22-28-3	Participation CEBIT Hannover
Apr	Lofar brochure (Dutch and English)
12-10	press event Exloo: placement of geophones
22-10	CREST meeting, Advisory committee on research, science and technology to European Counsel of Ministers
15-17-11	participation European Union IST Event The Hague

Personnel & Organization

Division	2003	2004
General affairs	27 (♂)	26 (♂)
	17 (♀)	16 (♀)
Radio Observatory	36 (♂)	37 (♂)
	2 (♀)	3 (♀)
Research & Development	87 (♂)	92 (♂)
	10 (♀)	10 (♀)
Total	179	184

Age	2003	2004
<25	5	2
25-35	47	46
35-45	51	52
45-55	38	45
55-65	36	37
>65	2	2

	2003	2004
Full time	154	161
Part time	25	24

Nationalities	2003	2004
French	6	6
British	2	3
Ukrainian	1	1
German	3	5
Russian	2	2
Japanese	2	2
Romanian	1	1
Swedish	1	1
American	2	2
New Zealands	1	1
Canadian	1	1
Italian	2	1
Indian	1	1
Chinese	1	1
Bulgarian		1
Total	26	29

Absence because of sickness	2003	2004
	2,2%	2,0%

Financial Report 2003

ASTRON Institute
Financial Report of 2003, compared with 2002

		2003 Budget	2003 Actual	2003 Difference	2002 Actual
INCOME					
Government Grants-Ministery of Education, Culture & Science		6.992.500	6.870.736	121.764	8.870.165
Subsidies/Contributions by third parties		11.271.600	5.204.073	6.067.527	2.692.572
Cash Management		48.000	25.937	22.063	81.212
Other Income		72.500	512.474	-439.974	83.854
	Total Income	**18.384.600**	**12.613.220**	**5.771.380**	**11.727.803**
EXPENDITURES					
Grants/Expenditures	Projects	14.376.100	9.124.315	5.251.785	4.684.138
	Radio Observatory	2.578.900	2.276.968	301.932	1.946.457
	Operations	9.822.400	9.542.581	279.819	8.984.897
	Allocations to projects	-8.410.100	-8.521.256	111.156	-5.652.806
	Total Expenditures	**18.367.300**	**12.422.608**	**5.944.692**	**9.962.686**
	BALANCE	**17.300**	**190.612**	**-173.312**	**1.765.117**

Financial Report 2004

ASTRON Institute
Financial Report of 2004, compared with 2003

		2004 Budget	2004 Actual	2004 Difference	2003 Actual
INCOME					
Government Grants-Ministery of Education, Culture & Science		7.752.400	13.036.450	-5.284.050	6.870.736
Subsidies/Contributions by third parties		14.604.800	2.865.202	11.739.598	5.204.073
Cash Management		20.000	19.877	123	25.937
Other Income		222.500	905.156	-682.656	512.474
	Total Income	**22.599.700**	**16.826.685**	**5.773.015**	**12.613.220**
EXPENDITURES					
Grants/Expenditures	Projects	18.468.200	13.319.673	5.148.527	9.124.315
	Radio Observatory	3.204.500	2.857.268	347.232	2.276.968
	Operations	11.230.600	11.441.291	-210.691	9.542.581
	Allocations to projects	-10.303.600	-10.845.960	542.360	-8.521.256
	Total Expenditures	**22.599.700**	**16.772.272**	**5.827.428**	**12.422.608**
	BALANCE	**0**	**54.413**	**-54.413**	**190.612**

The accountant has postponed the audit certificates for the annual report 2003 and 2004. This in connection with:

1. Ongoing discussions with the Province Drenthe about the conversion of a loan of M€ 2,1 into a subsidy by the Province Drenthe on behalf of the project LOFAR;
2. In the annual report 2004 € 386.000 is taken into account as a provision in the results for the SKA design study. For this project we expect a subsidy, for which we have reached a verbal consent.

Board en managementteam

Board

Prof. Dr. E.P.J. van den Heuvel	University of Amsterdam (Chairman and member until April 2004)
Prof. Dr. G.K. Miley	Leiden University
Prof. Dr. W. Hoogland	University of Amsterdam (until March 2003)
Prof. Ir. P. Hoogeboom	TNO (from March 2003)
Prof. Dr. J.M. van der Hulst	Kapteyn Institute (Chairman from April 2004)
Prof. Dr. H.J.G.L.M. Lamers	Utrecht University
Prof. Dr. J.M.E. Kuijpers	Radboud University
Prof. Dr. Ir. W.M.G. van Bokhoven	Technical University of Eindhoven (until August 2004)
Prof. Dr. Ir. J.H. Blom	Technical University of Eindhoven (from August 2004)

Management Team:

Prof.Dr. H.R. Butcher	Executive Director, Chair
Dr. E.J. de Geus	Director External Affairs and before that Director General Affairs until June 2004
K.P.H. Determan	Director General Affairs a.i. (from June 2004)
Ir. A. van Ardenne	Director Research and Development
Dr. W.A. Baan	Director Radio Observatory
Ir. B.A.P. Schipper	Head of Facilities Management (until December 2003)

Guests:

Dr. M.A. Garrett	Director JIVE (from May 2003) and before that Director JIVE a.i.
Mrs. J.W. Roorda	Head of Human Resource Department (from September 2003)

7. *Publications and colloquia*

Publications Westerbork Synthesis Radio Telescope 2003

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Publications Westerbork Synthesis Radio Telescope 2004

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19. Murakawa, K., et al. “Near-infrared coronagraph imager on the Subaru 8m telescope”, PASJ, vol. 56, p. 509, Hawaii, USA, 2004
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27. Veen, A.J., Leshem, A., Boonstra, A.J., “Signal Processing for Radio Astronomical Arrays”, IEEE Conference Proceedings Sensor Array and MultiChannel Workshop (SAM’04), Sitges, Spain, July 2004.
28. Wild, W., Venema, L.B., Cernicharo, J., “ESPRIT Exploratory Submm space Radio Interferometric Telescope”, Proceedings International Symposium Exploring the Cosmic Frontier, Astrophysical Instruments for the 21st Century, Berlin, May, 2004.
29. Wild, R. de, “A Generic Digital Beam Former Platform for Phased Arrays in Radio Astronomy”, ProRISC Workshop, Veldhoven, November 25-26, 2004. 30. Witvers, R., Vaate, J.G. bij de, Sarmasanu, A., “MMIC Gaas and InP very low noise amplifier designs for the next generation radio telescopes”, Proceedings GAAS Conference, European Microwave Week, Amsterdam, October, 2004.

Joint ASTRON - JIVE colloquia 2003

Date	Speaker	Topic
January 17	Willem van Straten	ASTRON, WSRT, *Annual-orbital parallax and nearby binary millisecond pulsars.*
January 24	Harm Habing	Leiden University, *AGB stars: putting things together.*
February 14	Tiziana di Salvo	University of Amsterdam, *Millisecond X-ray pulsars and their connection to millisecond radio pulsars.*
February 21	Maria Messineo	Leiden University, *86 GHz SiO masing stars in the Inner Galaxy.*
February 28 (canceled)	Eline Tolstoy	Kapteyn Institute, Groningen, *Measuring chemical evolution in dwarf galaxies from the epoch of reionisation.*
March 7	Andreas Quirrenbach	Leiden University, *Taking the Measure of the Universe.*
March 14	Nissim Kanekar	Kapteyn Institute, Groningen, *HI 21cm studies of damped Lyman-alpha systems.*
March 28	Hayley Bignall	JIVE, Dwingeloo, *Radio Variability and Interstellar Scintillation of Blazars.*
April 4	Cesar Gonzalez	Kapteyn Institute, Groningen, *Elliptical Galaxies: Merger Simulations & the Fundamental Plane.*
April 9	Moshe Elitzur	Onsala Space Observatory/University of Kentucky, USA. *IR from AGN: Support for Unified Schemes.*
April 17	Evan Skillman	University of Minnesota, Minneapolis, USA, *Measuring Star Formation Rates in Dwarf Galaxies from HST Observations.*
April 18	Good Friday	No Colloquium.
April 25	Olivier Vallejo	Observatoire Astronomique de Bordeaux, *Extensive study of the flocculent spiral galaxy NGC 4414. Dynamics, interstellar medium and star formation.*
May 2	Steve van Straaten	Sterrenkundig Instituut 'Anton Pannekoek', *The power spectra of the accreting millisecond pulsar SAX J1808.4-3658.*
May 9	Nigel Douglas	Kapteyn Institute, Groningen, *First results from the PN Spectrograph at La Palma.*
May 13	Helen Buttery	Cambridge University, *Searching for high-redshift clusters of galaxies in SUMSS.*
May 20	Travis Rector	NRAO, USA, *The Search for and Study of AGN: An Integrated Approach.*
May 23	58th Dutch Astronomers Conference	Kleve, Germany. No Colloquium
June 6	Andrei Lobanov	MPIfR, *Physical conditions in luminous AGN.*
June 13	VLBA conference	Socorro, No Colloquium.
June 20	Jacqueline van Gorkom	Columbia University, New York, *The Evolution of Galaxies in Clusters: an HI perspective.*

Date	Speaker	Topic
June 24	Colin Cunningham	UK Royal Observatory, *Current and future programme of the UK ATC.*
June 25	Heino Falcke	ASTRON, *Radio Emission from Cosmic Rays - First Results from LOPES-10.*
June 27	Stefan Wijnholds	ASTRON, *Measurement results from THEA.*
July 1	Diego Lambas	Observatorio Astronomico Cordoba, Argentina, *Environment and interactions determining star formation activity in galaxies.*
July 4	Stephanie Cazaux	Kapteyn Institute, Groningen, *Molecular hydrogen formation in the interstellar medium.*
July 17	Kazuya Hachisuka	University of Valencia, Spain, *Towards an understanding of the dynamics of the Milky Way.*
September 5	Antonis Polatidis	MPIfR, Bonn, *The expansion and age determination of Compact Symmetric Objects.*
September 12	Denise Gabuzda	University College Cork, Ireland, *Revealing Helical Magnetic Fields in Active Galactic Nuclei.*
September 19 (canceled)	Melanie Johnston	Leiden Unviersity, *Detecting Cluster Magnetic Fields.*
September 26	Koji Murakawa	Subaru Observatory, Hawaii, USA, *Instrumentation and Science with the Subaru/CIAO.*
October 3	Willem Jellema	SRON, *Experimental Verification of Electromagnetic Simulations of a HIFI Mixer Sub-Assembly.*
October 10	Ole Moeller	Kapteyn Institute, Groningen, *Complications in Gravitational Lensing: Doubles, Groups and Disks.*
October 16	Brian Sutin	The Observatories of the Carnegie Institution of Washington, USA, *A New Wide Field Imaging Spectrograph for the Magellan Telescopes.*
October 22	Dave Sanders	Institute for Astronomy, University of Hawaii, USA, *The Infrared Universe: The Cosmic Evolution of Superstarbursts and Massive Black Holes.*
October 31	Johan H. Knapen	University of Hertfordshire, UK, *Fuelling starbursts and AGN.*
November 14	Alexander Ollongren	Leiden University, *Communication with extra-terrestrial intelligent beings (CETI).*
November 21	Ralph A.M.J. Wijers	University of Amsterdam, *Energetics and dynamics of collimated gamma-ray bursts.*
November 28	Robert Braun	ASTRON, *Tidal Streams, Low Mass Companions and the Cosmic Web of M31.*
December 3	Andy Fabian	Cambridge University, *Broad iron lines from accreting black holes: gravitational redshift and light bending?.*
December 5	Brian Boyle	ATNF, Australia, *The 2df QSO Survey.*
December 12	Michiel Kregel	Kapteyn Institute, *Groningen, Edge-on Galaxy Disks: Stellar dynamics and new implications for dark matter.*

Colloquia ASTRON – JIVE 2004

Date	Speaker	Topic
January 7	Corina Vogt	*Measuring Cluster Magnetic Fields from Faraday Rotation Maps.*
January 16	Neil Nagar	Kapteyn Institute, Groningen, *The Not-So-Silent Majority: Accretion in Nearby 'Normal' Galaxies.*
January 23	Steven Tingay	Centre for Astrophysics and Supercomputing Swinburne University of Technology, Australia, *The changing face of Australian VLBI.*
January 30	Magda Arnaboldi	I.N.A.F., Observatory of Turin, *INTRACLUSTER STELLAR POPULATION IN NEARBY CLUSTERS.*
February 6	Ruud Haring	IBM, *The BlueGene/L hardware architecture.*
February 13	Zhang Xizhen	Beijing National Astronomical Observatories, CAS, China, *Radio astronomy at the Miyun station.*
February 20		Dense Molecular Gas Workshop at Zwolle, held on 17-20 Feb, No Colloquium.
March 5	Sylvain Alliot	Leiden University, *Architecture Exploration for Large Scale Array Signal Processing Systems.*
March 12	Andrew Cole	Kapteyn Institute, *Chemical Evolution and Star Formation History of the Large Magellanic Cloud.*
March 19	Gerhard De Lange	Space Research Organization of the Netherlands (SRON), *Development of the heterodyne mixers for HIFI band 3 and 4.*
March 23	Rene Rutten	Isaac Newton Group of Telescopes, *Now and tomorrow at the 4.2-m William Herschel Telescope.*
April 1	Andrej Sobolev	Ural State University, Astronomical Observatory, Russia, *Modelling Environment of Massive YSOs on the Basis of Maser and "Quasithermal" Line Emission.*
April 2	Marc Ribo	CEA-Saclay, France, *Recent multiwavelength results on microquasars.*
April 9	Good Friday	No Colloquium.
April 23	Ilian Iliev	CITA, University of Toronto, Canada, *Small-scale structure at high-z: observability and effect on reionization.*
April 30	Queen's Birthday	No Colloquium.
May 7	Remko Stuik	Leiden University, *MUSE and CHEOPS: Future AO assisted instrumentation on the VLT.*
May 14	Peter Barthel	Kapteyn Institute, *To be or not to be active - The occurrence and driving force of nuclear activity in galaxies.*
May 28	Dutch Astronomer's Conference	Vlieland, No Colloquium.
June 4	Joeri van Leeuwen	Astronomical Institute, Utrecht University, *Drifting subpulses and the pulsar emission mechanism.*

Date	Speaker	Topic
June 11	ASTRON Conference	"Extra-planar Gas", held 7-11 June, No Colloquium,
June 18	Richard Schilizzi	SKA, Dwingeloo, Square Kilometer Array.
June 25	Ivan Agudo	MPIfR, Bonn, *VLBI Observations and Numerical Modelling of the Inner Jets in AGNs.*
Sepbember 8 cancelled	Igor Karachentsev	Special Astrophysical Observatory, Russian Academy of Sciences, *The local universe: population, structure, velocity field.*
Sepbember 17	Bart Smolders	Philips Semiconductors, *RF SiP: The next wave for wireless system integration.*
Sepbember 24	Mark Verheijen	Kapteyn Institute, Groningen, *An HI Perspective on Galaxy Evolution in Clusters.*
October 1	Wouter Vlemmings	Cornell University, *Pulsar astrometry and applications.*
October 15 new date	Albert-Jan Boonstra	ASTRON, *Spatial filtering of interfering signals at the initial LOFAR phased array test station.*
October 22	Walter Jaffe	Sterrewacht Leiden, *First results from MIDI.*
October 29	Ken Freeman	Australian National University, *Galactic Disks.*
November 5	Richard McDermid	Sterrewacht Leiden, *The SAURON Survey of Early-Type Galaxies.*
November 12 Note: In Dutch	Matthijs Streutker	Economic Sciences, RU Groningen, *De effectiviteit van onderzochte reductiemethoden en heuristieken bij bekabelingsvraagstukken van LOFAR.*
November 16 Note: special day	Phil Edwards	ISAS, Japan, *From VSOP to VSOP-2.*
November 19	Andreas Eckart	I. Physikalisches Institut, Universität zu Köln, *News from the Center of the Milky Way.*
November 26	Saleem Zaroubi	Kapteyn Institute, *Probing the intergalactic medium with the Lyman-alpha forest.*
December 10	Emanuele Ripamonti	Kapteyn Institute, *Numerical Modeling of Primordial Protostellar Collapse.*
December 17	Andrey Baryshev	SRON Groningen, *The ALMA Band 9 Receiver.*

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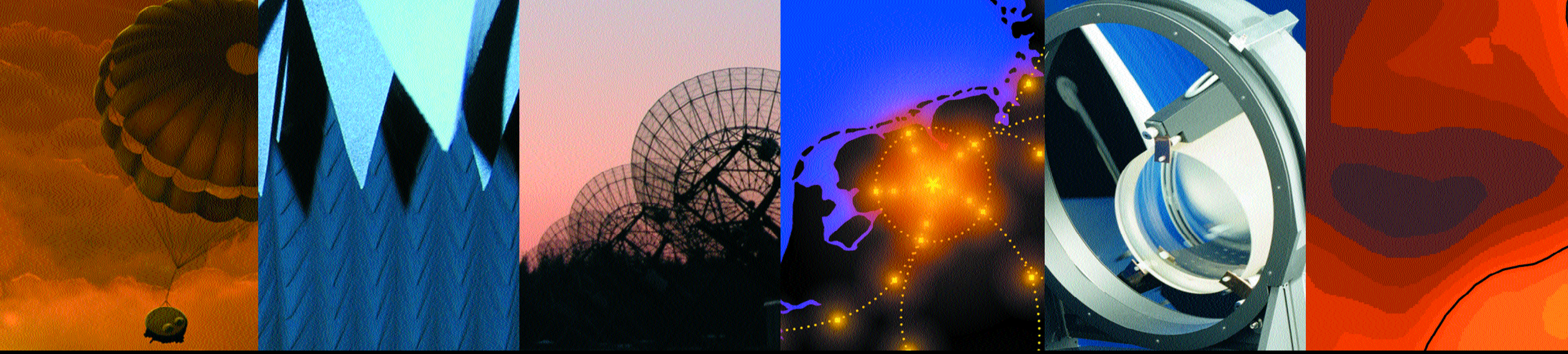

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