

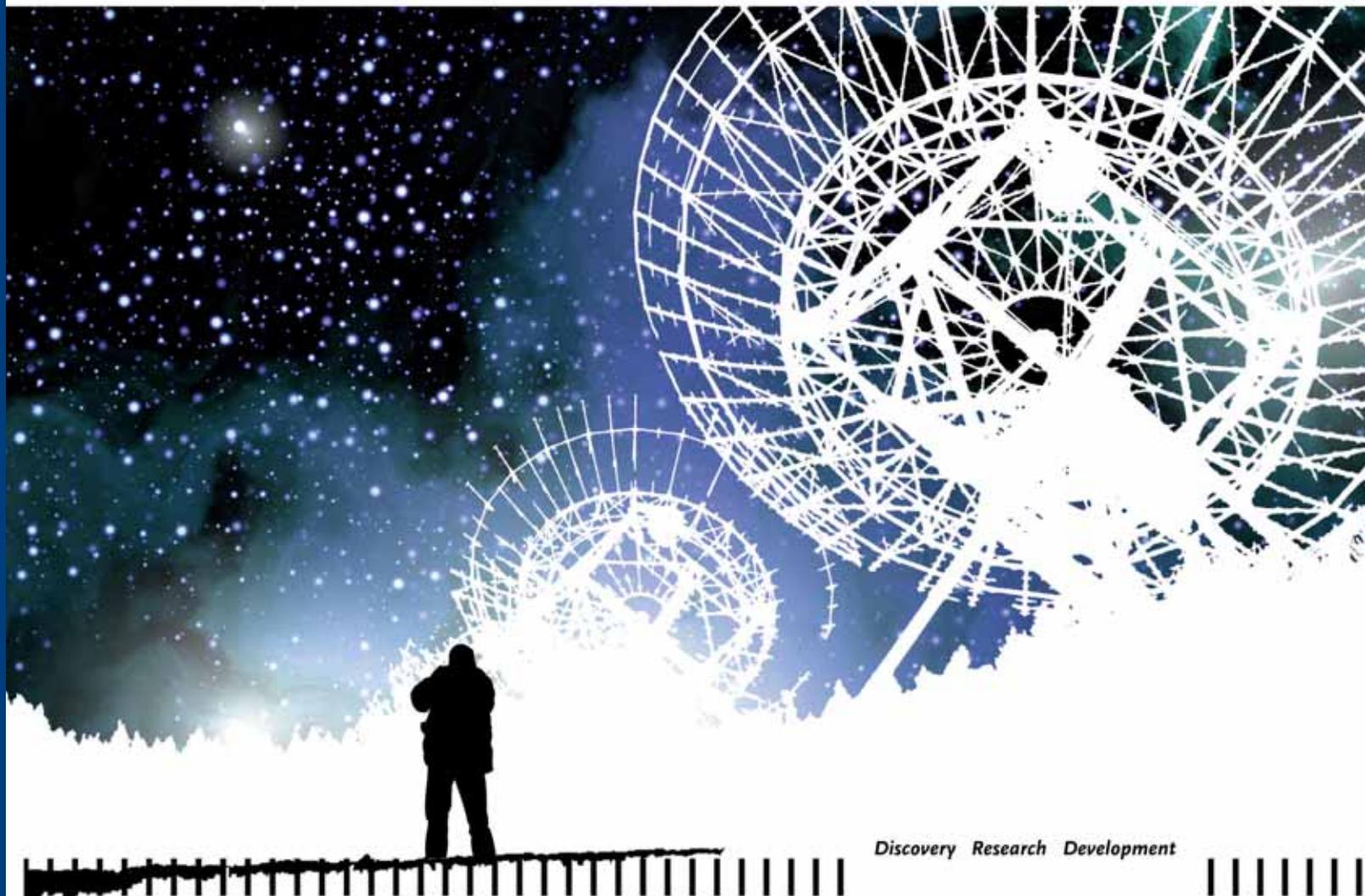


*Discovery Research Development*

# Annual Report 2002







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# 1. Report of the Director

The year 2002 at ASTRON was one of steady growth. The administrative changes we planned in 2001 were implemented successfully and provided the tools and the flexibility required to manage an expanding portfolio of activities.

At the Radio Observatory, the upgraded and modernized Westerbork array came into full and regular operation as one of the most sensitive instruments of its kind in the world. A formal ceremony seemed appropriate, so on 18 October we invited friends, dignitaries and the press to help us mark the achievement. A large tent was erected next to the control building in Westerbork, tours and presentations for the guests were provided, and congratulatory words were spoken by the Queen's Commissioner in Drenthe, Mr. R. Ter Beek.

The celebration concluded with a grand party lasting well into the night. Two days later we threw our doors open to the wider community, as part of National Science Day when all research facilities and science museums in the country are open to the public. Nearly five thousand visitors enjoyed our displays, presentations and hands-on demonstrations of our technologies, making this day also a roaring success.

On the instrumentation front, highlight of the year was formalizing our involvement in MIRI, a camera and spectrometer for the thermal infrared on the planned successor to the Hubble Space Telescope, the NASA/ESA James Webb Space Telescope. ASTRON's responsibility will be to provide the MIRI spectrometer optics and mechanics. We carried out a phase-A feasibility study, presented the results to ESA in September, and were pleased to learn right away that the project would be accepted by ESA for further development. At year's end we were awaiting the availability of funding to proceed with phase-B detailed design. During the year a consortium of twenty-six European organizations, led by the Astronomy Technology Centre in Edinburgh, was formalized to see the project through to completion.

Our long-term program to provide the technologies for a new generation of radio telescopes, to culminate in the Square Kilometre Array (SKA) having nearly two orders of magnitude greater sensitivity than current instruments, proceeded on two fronts.

On the organizational front, from 13-17 August, we hosted the global radio astronomy community in Groningen and Dwingeloo to discuss progress on the technologies needed, on the scientific requirements and on the organizational strategies for a global project. We were proud to be able to show off the Thousand Element Array (THEA) demonstrator to the delegates, including simultaneous all-sky imaging at two different frequencies.

In 2002, also our 'SKA pathfinder' project, LOFAR, moved into the system definition and feasibility study phases. LOFAR has been called variously the world's first 'software telescope,' 'a shared aperture multi-telescope' and on public occasions even the 'world's largest FM-radio.' An aperture array operating in the 20-240 MHz frequency range, LOFAR aims to demonstrate in an operational instrument the scientific advantages of multiple simultaneous fields of view and of all-sky monitoring for transient signals from cosmic phenomena. In March a major international workshop together with interested international groups was held in Austin, Texas. In October, together with our partners at M.I.T. and U.S.



The Queen's Commissioner in Drenthe, mr. R. ter Beek.

# 1. Report of the Director

Naval Research Lab, we asked an international panel of experts to help us with a formal system requirements review, which took place in Washington D.C. Additional workshops during the year in Sweden and Germany explored participation by European groups. As we informed the broader scientific community of our plans, research groups from geophysics and agriculture proposed adding sensors of various kinds to the LOFAR network, in addition to the RF antennas we astronomers had been planning. Contacts with commercial groups indicated substantial interest in the project from purely the technology development perspective.

We were most encouraged when the provinces of Drenthe, Friesland and Groningen joined together to include LOFAR as part of their future regional investment plans. Unfortunately, the national government fell in April. Following elections in May, the new governing coalition decided to eliminate all funding for new regional investment. Fortunately, a national program to stimulate the knowledge-based sector of the economy was retained and we were encouraged to submit LOFAR for financing within that framework. Year's end found us busy preparing the economic case for investing in a new large radio telescope.

Our Radio Observatory participates in the joint activities of the network of radio observatories in Europe. As a service to the network we also host the Joint Institute for VLBI in Europe (JIVE), which supports and coordinates joint operations in Very Long Baseline Interferometry (VLBI).

An important milestone during the year was a gathering in the Hague on 5-6 June of representatives of funding agencies from Italy, Spain, Netherlands and UK, and from the national radio astronomy facilities of Germany and Sweden, to decide on the future funding of JIVE. Based on the favourable recent evaluation of JIVE by the European Science Foundation, the meeting agreed to guarantee funding for an additional five years, until 2007.

In an important related development, glass fibres and DWDM (Dense Wavelength Division Multiplexing/interfacing) electronics could then be installed to enable all radio telescopes in the European network to be connected to the processing facilities at JIVE in Dwingeloo.

We anticipate these connections within several years will lead to regular real-time VLBI observing sessions, and will serve to provide on-line access to LOFAR by radio

astronomers across the continent. After the summer the initial fiber cables were laid and brought into operation between Dwingeloo and Amsterdam, the major international internet gateway to Europe and a major hub within Europe. A demonstration by JIVE personnel of VLBI data transport between Dwingeloo and Manchester UK

using these fibres was made for the international iGRID Conference in Amsterdam on 24-26 September. With these activities fresh in mind we initiated plans to reorganize and extend our headquarters building in Dwingeloo to accommodate the new activities.



Fiber cables were laid between Dwingeloo and Amsterdam.

Finally, several personnel matters during the year are especially worthy of note.

On 16 April, our own Albert-Jan Boonstra won the prestigious Telecommunications Prize of the Royal Institute of Engineers (KIvI) at The Hague. He received the award in recognition of his innovative work on filtering algorithms to retrieve a desired signal from a background of unwanted signals. This work is of increasing importance in the wireless telecom world, but is of course also directly relevant to observing faint celestial radio sources at frequencies outside the bands designated for radio astronomical use.

To support the interest at the University of Nijmegen in using LOFAR for particle astrophysics, we decided to sponsor a part-time professorship at that university. Dr. Heino Falcke of the Max-Planck-Institut für



# 1. Report of the Director



Radioastronomie in Bonn was selected to assume the chair. From 9 September he became the very first LOFAR professor!

The global SKA project has grown to the point that a formal project office and full-time director has become necessary. Following a global search by an international panel, Richard Schilizzi was selected to take on this challenging job. At year's end he was transferring his JIVE responsibilities to interim JIVE director, Michael Garrett, in the expectation of assuming his new duties from 1 January 2003.

Finally, the ASTRON Board found itself in the unusual situation that all Board members were scheduled to complete their terms of service during the year, leaving us potentially with a continuity problem. Ever pragmatic, the Board decided (i) to extend the terms of professors Ed van den Heuvel (as chairman), George Miley (as secretary–treasurer) and Walter Hoogland; (ii) to extend prof. Wim van Bokhoven's term for a shorter period, until a replacement from the Technical University in Eindhoven can be found; (iii) to appoint prof. Henny Lamers to replace Bram Achterberg from Utrecht, and (iv) to appoint prof. Thijs van der Hulst to replace Tjeerd van Albada from Groningen. Also during the year the Board invited prof. Jan Kuijpers to represent the increasingly active astrophysics group in Nijmegen on the Board, and also began a search for an additional member with a background in applied physics that might be appointed in a coming year.

Looking back on 2002, we at ASTRON can say: "it was a very good year". A year in which the basis has been set for the future. Again the Westerbork Synthesis Radio Telescope is one of the most sensitive instruments of the world, ready for very interesting science. The research activities of the Technical Laboratory will determine the success of new astronomical equipment. At ASTRON, we are ready for 2003!

## 2. Technical R&D

The ASTRON technical laboratory is responsible for the technical Research & Development programme. The programme focuses on innovative instruments for existing telescopes as well as on developing technologies for future observing facilities. In the technical lab highly trained professionals work on the achievement of technical goals. It often starts with an idea, which is elaborated into a concept. This concept may subsequently lead to a particular prototype or instrument through a controlled R & D process. Often external parties such as national and international partners (c.g universities, competence centres and companies) are invited to collaborate in this process.



## 2. Technical R&D

### 2.1 Highlights TL 2002

After a long lead time, the WSRT (Westerbork Synthesis Radio Telescope) upgrade was technically finished. To take full advantage of the new capabilities, this year's emphasis was on expanding the correlator capabilities, for example with special observing modes. As a result, the WSRT has become the only synthesis telescope with full sub arraying- and mapping capability using different frequency bands.

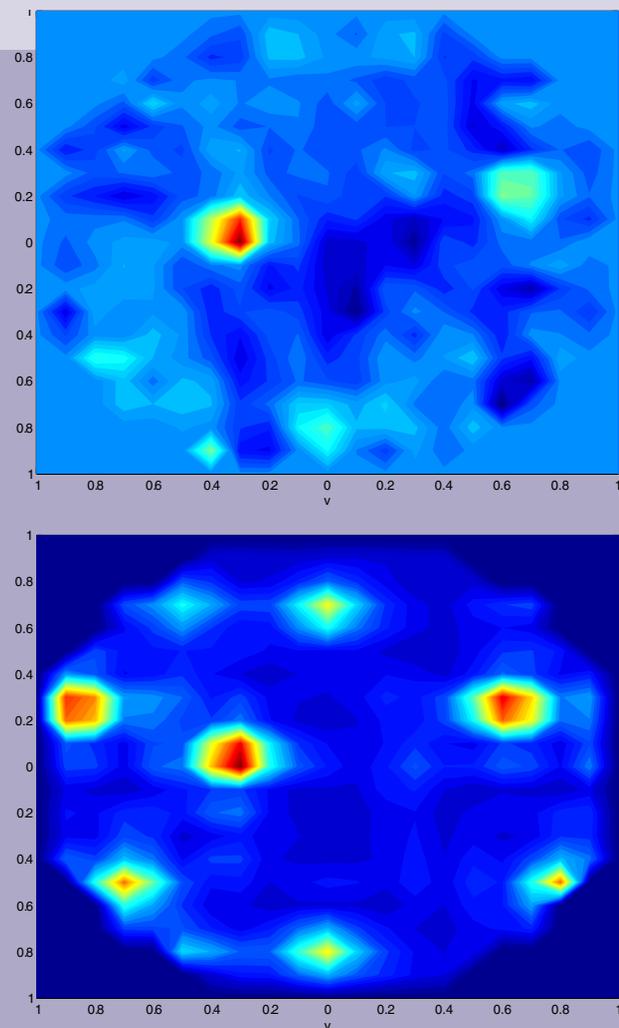
Apart from its unique astronomical capabilities, the system is also a perfect reference framework for new developments. As a result, a feasibility study to a new low frequency front-end was successfully finished in anticipation of early science exploration for LOFAR. Other developments include the design for a new interface to the pulsar backend and to VLBI, (Very Long Baseline Interferometry), now made necessary and to investigating the potential of a very high efficiency feeds. These will be built in phased array technology and a study is done in the context of the EU-FP5 project "Faraday".

The Technical Lab being heavily involved in explorative research to the next generations of radiotelescopes, made impressive technical and organizational progress. To illustrate this, at the end of the year, about 40% of the activities of the Technical Lab were spent on LOFAR as a unique and exciting LOW Frequency ARray for radioastronomy. This resulted in a successful System Requirement Review by an international panel in preparation of the Preliminary Design Review (PDR), early 2003. Progress indicated good management control, a well thought through System Design with understanding of key areas like the high speed optical network together with industry, Radio Frequency Interference, Calibration and Central Processing, and last but not least, a highly motivated team.

As part of the growing scientific potential, a number of LOFAR telescopes were built and located as a test array ("LOPES") for high particle physics experiments in Germany.

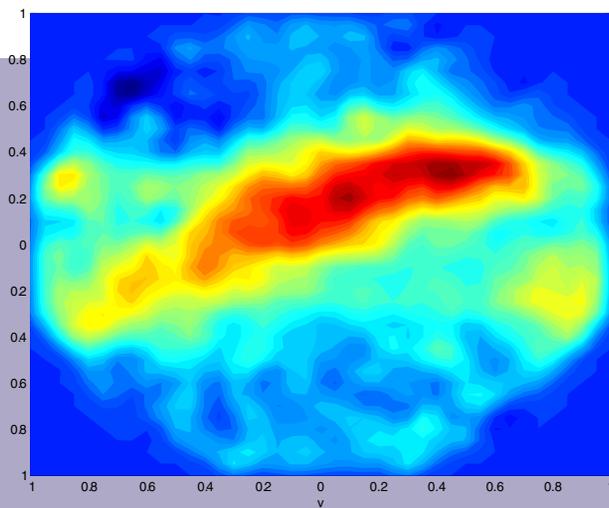
On another track were our efforts to explore the technical feasibility of the Square Kilometre Array on initial SKA R&D, partly supported by a five years NWO grant. This led to impressive results with the small telescope "THEA"; as the first radio telescope in the world it used innovative phased array technology for astronomical and other observations. For example, a full sky measurement

was done on the galactic centre and of GPS satellites demonstrating the enormous advantages of the electronic rather than conventional, mechanical telescope approach. The presentation of this on the seventh International SKA workshop in Groningen, has led to enhanced international supports for "our" concept and gave ASTRON a head start in the shaping of the SKA project. Further exposure of our achievements took place at the



Intensity contour plots showing the distribution of GPS satellites over the sky at a certain hour measured at frequencies of 1227.6 MHz (left) and 1575.5 MHz (right) respectively measured with two fully independent THEA beams and RF systems.

## 2. Technical R&D



Total HI map of galactic neutral hydrogen based on measurements with an array of four tiles constituting a 4 sq.m. radiotelescope. It established a small but important step to the Square Kilometre Array.

27th General Assembly of URSI (International Union for Radio Scientists) in Maastricht in August in presentations and at the exhibition. This meeting was attended by some 1500 international radio-scientists and organized under the aegis of URSI by the Dutch URSI Committee of which ASTRON holds the chair.

With a workshop held in Dwingeloo in December, preparations were started for the next step: a European SKA study in the context of FP6, the sixth Framework Program of the EU. Here also, the increasing interest for Focal Plane Arrays in reflectors (as studied in FARADAY under ASTRON leadership) became clear. It hence became evident that a follow up program was needed of which an outline was presented.

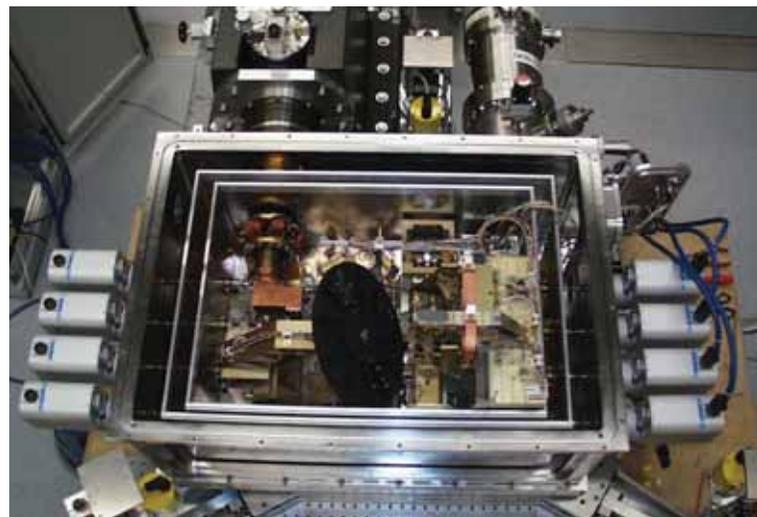
It also became clear that a novel approach to low costing for the SKA is essential, a two-day workshop was held with TNO-Industrie to help define the next steps. This resulted in a view on integrated developments, and first steps toward potential commercial applications of phased array technology supported partly by regional funding.

Several proposals on Applied Technologies were rewarded e.g. one on extending the STW-NOEMI work on "RFI mitigation". This study is done in collaboration with Delft Technical University and resulted in the building of a fifth THEA tile located at the WSRT.

In appreciation of the quality of this work was the awarding of the national "Telecommunicatie Prijs" on behalf of the "Koninklijk Instituut van Ingenieurs", to Albert-Jan Boonstra. He is responsible for our RFI - program, and received the award in view of the chosen signal processing approach.

The Technical Lab was and became further involved into the development of a range of Optical and Infrared instruments.

For example both the VISIR spectrometer and the MIDI 10 micron beam combiner for interferometry, were further tested cryogenically at the collaborating laboratories in Saclay and Heidelberg, Germany. After shipment to Chili, this ultimately let for MIDI to the spectacular and first-time-ever detection of fringes using two VLT's of ESO's observatory in Paranal in December.



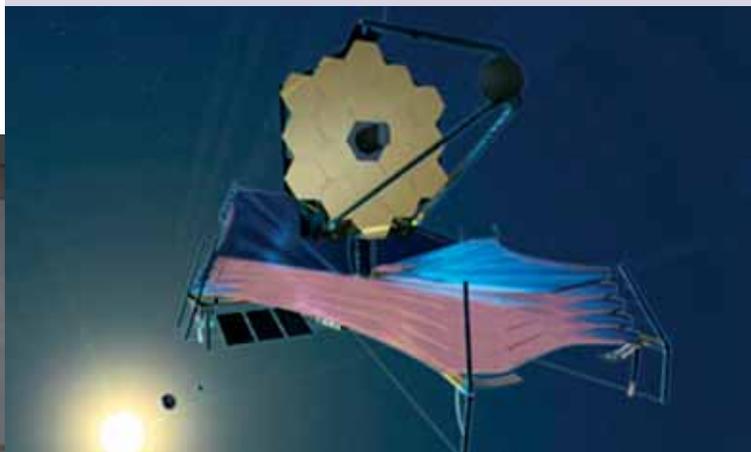
The MIDI instrument in the cryostat in the lab at the MPI in Heidelberg before shipment to Paranal

Further developments for ESO entail a mechanical and optical study for Synfoni ("SPIFFI") through NOVA (Dutch research school for radio astronomy), electronic support for OMEGACAM and an orientation on X-SHOOTER as a potential second generation instrument for the VLT.

The Final Design Review of the long camera "WYFFOS" for the WHT (William Herschel Telescope) on La Palma was successfully passed and assistance was given to the DOT (Dutch Open Telescope).

## 2. Technical R&D

ASTRON's Technical Lab could capitalize on our work on ground-based IR-instrumentation like VISIR and MIDI in taking part in the instrumental development for the James Webb Space Telescopes. Being the nominal successor of the Hubble Space telescope, this telescope is planned for launch after 2010. Through Leiden University, proposals on behalf of the Dutch consortium of which ASTRON is part, were forwarded to NOVA and to NWO in order to increase the national funding. This aims to develop the Mid-InfraRed Instrument (spectrometer) and is now called MIRI. Both proposals were granted and the Phase B study could start after the successful passing of the Phase A study.



Artist's concept of the James Webb Space Telescope.

The ESO-endorsed architectural study for the ALMA Advanced Correlator, was formally drawn to a closure at a European ALMA Workshop. A follow-up study was started addressing some major technology issues for a possible "Future Correlator" in cooperation with institutes in France (IRAM, Bordeaux) again under the aegis of ESO. We envision that, if not leading to indeed a Future Correlator, then at least it would result in a major functional improvement of the planned ("Baseline") correlator. Also, it is fully relevant for our LOFAR and SKA developments and is connected to E-VLA, e-Merlin and the European VLBI network.

In response to wishes from industry, we again organized the by now third RF-course through our Bureau of Technology Transfer. These "outward" orientations lead to a coherent approach to the generation and control of a patents portfolio resulting in four applications in 2002. As a sideline we supported the development Receiver developments for SHAO (Shanghai observatory) as element of the KNAW (Koninklijke Nederlandse Akademie voor Wetenschappen (Royal Netherlands Academy of Arts and Sciences)) and Chinese Academy for Science exchange support.

The increased projectportfolio necessitated to put more emphasis on an improved management system. This resulted in the extension of the Processupportgroup with a Projectcontroller primarily to support LOFAR, and a new projectplanning tool called Primavera. This tool complements the new financial support tool Navision, constituting an integrated resource- and financial planning system.

### 2.2 Radio projects

#### a. ALMA

The Atacama Large Millimeter Array (ALMA) is a next generation radio telescope operating in the mm/sub-mm wavelength window. Compared with present day telescopes, ALMA will provide higher sensitivity and higher spatial resolution over a wider bandwidth. Since there are many astronomical applications for ALMA, the instrument must be versatile and flexible in order to satisfy a broad range of observing modes.

ALMA is developed by an international cooperation between the USA, Europe and Japan. ASTRON is part of the European ALMA Back-End team. ALMA will be constructed at the Chajnantor site, a high-altitude plain (elevation 5000 m) at the Chilean Andes mountains.

The first generation correlator ("Baseline Correlator") designed and currently under construction by the National Radio Astronomy Observatory (NRAO) is a traditional XF correlator incorporating many channels and digital filtering. In parallel, the European team has started the design of a second-generation correlator (2GC) for ALMA to enhance the observational possibilities and sensitivity using the latest technology and new design ideas. The 2GC is based on a hybrid architecture design

## 2. Technical R&D

(intermediate between the XF and FX designs), whose main characteristics have progressively emerged from the European Phase 1 study. Compared to the baseline correlator the 2GC will provide higher sensitivity and spectral resolution, and a very flexible use of the ALMA resources.

In Phase 1, the focus was to address the main risks of the second-generation correlator by working out the architectural design and studying specific sub elements in more detail. In March 2002 the feasibility study of the 2GC for ALMA was finished. From this phase was concluded that there are no architectural showstoppers.

The project is continued with a second Phase. During this phase the risks identified in Phase 1 will be mitigated. Eventually, this will lead to a Preliminary Design Review in 2005. In October 2002 the European team agreed over a number of system requirements, architectural design decisions and the plans for Phase 2. For ASTRON, three Work Units are defined: 2GC system design, interconnect technology study and the correlator chip development. After a short description of the system and the results of Phase 1, subsequent sections will provide more details of each Work Unit.

### ALMA System Overview

In Figure 1 a sketchy overview of the ALMA system is given, showing only the data path. The system boundaries of the 2GC are indicated. In the baseline design of ALMA, 64 dual polarized antennas are assumed. Each antenna delivers four bands for two polarizations of 2 GHz widths. The 8 base bands are first processed in the analog domain and converted into the digital domain by a 3 bit A/D converter with a sample rate of 4 GHz. From there, the signals from the antennas are transmitted to the main building via optical links. In the first generation correlator XF architecture is adopted, i.e. the correlation functions are calculated for the full 2 GHz band. Since, the digital processing chips are not able to run at 4 GHz, the signals are time-multiplexed at a 125 MHz rate. The first generation correlator developed by NRAO is a 2 bit correlator which provides 64 spectral channels over the

base band in full polarization mode.

For the 2GC, the European team proposes to use a hybrid architecture. Within this architecture the signals are filtered, prior to correlation. In this way the correlator can run at a lower clock rate, without using time multiplexing. The correlations are calculated with a 3 bit correlator, leading to almost 10 % sensitivity improvement over a 2 bit correlator. For each base band 1024 spectral channels are calculated in full polarization mode.

### Results Phase 1 Study

In 2001 and the beginning of 2002 the study of the effects of re-quantization took full momentum, based on the initial architecture. Simulations and theoretical studies were made resulting in recommendations for the filter section in the HXF. Component and technology studies were carried out on fast backplane technology topologies and resulted in a demonstrator backplane (see Figure 2) with test reports. A comparative architectural study was performed on the processing requirements for XF, HXF and FX architectures, in collaboration with the Leiden Institute for Advanced Computer Studies.



Figure 2 Demonstrator backplane.

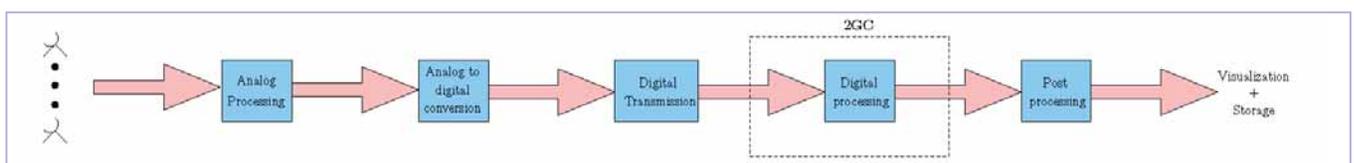


Figure 1 Overview of the ALMA system.

## 2. Technical R&D

The feasibility of the hybrid architecture was studied by proposing possible architectures at chip, board and correlator level. By the end of 2001 the ALMA Scientific Advisory Committee (ASAC) provided the ALMA Back-End Team with explicit guideline specifications for the 2GC. Although some issues in these guidelines still need further study, our overall conclusion was that the hybrid architecture is a feasible and a cost-efficient way to realize these specifications. There are no architectural showstoppers and the required technologies exist.

### Second Generation Correlator System Design

The feasibility study of Phase 1 was based on a number of assumptions. For the next phase, freezing the requirements is essential.

In a European Back-End Team meeting held in October 2002, agreement upon the requirements was reached. Furthermore decisions on a number of issues for the filter architecture were taken. Based on the decisions taken, the architecture was more refined.

The proposed system architecture is depicted in Figure 3. For the 2GC 80 antennas are assumed to accommodate also the ALMA Compact Array (ACA) and antennas used for calibration. To cope with extensions in the future, the internal interconnect infrastructure of the correlator sub-system at the board level is designed for 96 antennas. A general architecture has to fulfil the currently known requirements, but also has to add extra features, which may turn out to be useful later on. The goal is to cope, within reasonable boundaries, with evolving observing modes and strategies suggested by the scientific users. Therefore the 2GC has to offer high flexibility to exchange the number of basebands, subbands within a baseband, and antennas against spectral resolution. The 2GC flexibility is embedded mainly in the correlator and filter subsystems architecture.

In the 2GC, each 2 GHz band is split in 34 subbands accommodating an overlap between the filters of 6 %. For the filter bank a two-stage digital filter section is proposed with digital mixers and bandwidth selection. In this way the filters can be tuned over the 2 GHz band and in a specific band can be zoomed in for high spectral resolution observations. After the filter section, the signals are correlated at a rate of 125 MHz.

### Interconnect technology study

In Phase 1 the internal interconnections required were

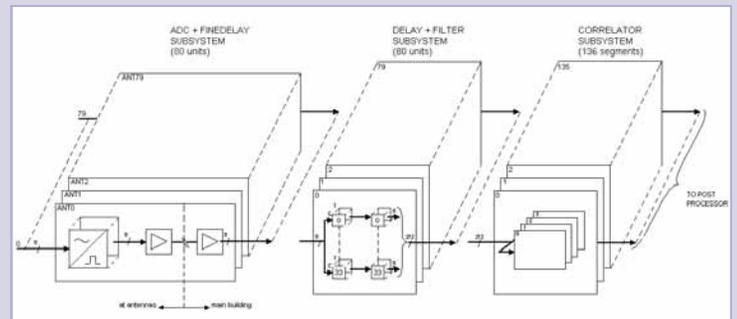


Figure 3 System architecture of the A/D converters and the 2GC (delay, filter and correlator subsystem).

already identified as a risk. From the interconnect study in Phase 1 was concluded that serial interconnects and serial back planes are recommended to use in the 2GC. Furthermore the feasibility of multi-drop topologies was demonstrated. This resulted in the conclusion that multi-drop topologies are feasible for one to two connections with 3.125 Gbps. However, the design of such topologies is critical and trace lengths must be kept as short as possible to reduce reflections. Therefore the robustness of point-to-point connections compared with multi-drop connections must be balanced with costs.

Phase 2 is started with a market survey. From this survey interconnect solutions suitable for the architecture of the second-generation correlator will be chosen. Given the most cost effective solution a cabinet to cabinet demonstrator will be built, to show that the chosen high speed technology is under control and can be used for the 2GC.

### Correlator chip development

In this Work Unit the correlator chip will be designed in a generic hardware description language: VHDL. In this way the chip is designed independent of the technology to be used.

The complexity of the correlator depends mainly on the complexity of the multiplication scheme used for a single multiplier. Hence, it is important to reduce the hardware resources of the multiplier. This can be accomplished by changing the weights in the multiplier, at a cost of a larger degradation. To verify the degradation given a set of weights, a simulation model was set up. From this the most optimal weights from a degradation point of view are determined. These must be traded off with the hardware cost of the optimal weight implementation. This must lead to a cost-effective optimisation in terms of multiplier hardware and the degradation.

## 2. Technical R&D

### b. FARADAY (Focal Arrays for Radio Astronomy, Design Access and Yield)

The Faraday program had a contractual start at the first of November 2001 and an actual start with a kick-off meeting at 30 November 2001.

Faraday is a European fifth framework programme with a total of five partners. Within Faraday ASTRON work is concentrated on Focal Plane Arrays. Focal Plane Arrays is a new development where a phased array antenna is mounted in the focus of a telescope. This contrary to traditional systems that use a single antenna in the focus, or in some exceptional cases a couple of (horn) antennas. The traditional solution has a number of drawbacks; the illumination is fixed and cannot be modified or optimized; creating an image is time consuming due to the limited number of beams (mapping process). Just putting more horns in the focus will be huge, and multiple beams created with horns are (too) far apart in the sky. A phased array in the focus can overcome these drawbacks.

The prime objective of Faraday is therefore the design of a focal plane array for reflector antennas with:

- Maximal coverage of Field Of View, realized by means of multi-beaming. This implies an overlap of the beams at a level of  $\sim 3\text{dB}$ : closely grouped beams.
- Optimal aperture illumination. The target is to improve the illumination of the standard antenna feed with 20-30% and therefore the efficiency of the telescope.

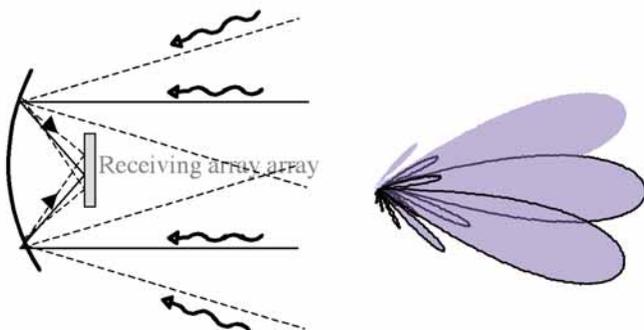


Figure 1 Schematic diagram illustrating the FARADAY concept; left) a receiving array at the focus of a parabolic telescope showing the radiation coming from three different directions being captured by the array; right) the effective reception "beams" of an array/telescope combination. In principle a very large number of beams can be formed.

The principle idea of Focal Plane Arrays is based on sampling the fields in the focus with a large number of antenna elements, where the signals are added in such a way that an optimal beam is constructed.

For the sampling of the field with a large number of compact elements and over a large frequency band, only one antenna element is found to be suitable: the Vivaldi antenna. With other institutes ASTRON conducts (already for several years) research on the Vivaldi antenna with as main application phased arrays for the Square Kilometre Array. Figure 2 shows a photograph of the prototype array. It is a dual polarization array with Vivaldi antenna elements and a total of 144 elements. The array has been developed in cooperation with the University of Massachusetts and, besides used for Focal Plane Arrays, an important prototype for Square Kilometre Array research.

The photograph of the array was taken during evaluation tests in the Near Field Scanner antenna measurement room at ASTRON. Similar tests have been performed by the CSIRO. CSIRO (Australia's Commonwealth Scientific and Industrial Research Organisation) is partner in the Faraday project and interested in using FPA's (Focal Plane Arrays) for the use in conjunction with Lunenburg lenses.

### Beamforming Concept

The fields at the focus plane of large reflectors have been analysed with Physical Optics simulation software. The output of these analyses gives information about the optimum antenna element, waiting in order to intercept the fields with a maximum efficiency. Questions as how many elements are required, what efficiency could be achieved, how many beams are possible etc. are now being answered. A picture of a focus field distribution is given in figure 3 for a total of nine beams. As can be seen in the figure, the fields of these beams can be intercepted with very similar circular feeds. What also can be seen is that the fields are slightly overlapping. Intercepting the signals efficiently can be done with a sampling array only, where signals of the elements can be used for more than one beam, which is clearly not possible with horn arrays. With focal plane arrays up to one hundred beams are possible - however the field distribution of more off-axis beams are not as nice circular as shown in figure 3. They get a-symmetric and more oval shaped. This is not a major problem; it can be handled with a proper beamformer design.

## 2. Technical R&D

Intercepting the focus fields with an antenna array needs a beamformer; signals have to add with the proper weighting in order to construct the beam. Figure 4 shows a scheme of a possible beamformer. The signals of a nine antenna elements are used, one central element and two rings of four elements each. Figure 5 sketches the physical layout of the antenna elements. As can be seen in the scheme, signals of the central element and the rings are manipulated in phase and amplitude before they are summed.

### Novel Antenna Structure Development

A development has been started to design a  $19 \times 19$  dual polarization array, which can form nine overlapping feeds in the focal plane of a Westerbork reflector with more than 70% expected illumination efficiency. The far field reflector patterns overlap at the half power points for the frequency range between 2.2 and 5.0 GHz. This array will be built in a new technology; metal plate Vivaldi antennas. Figure 6 gives a picture of a  $19 \times 19$  element array, assembled mechanically from laser-cut brass plates.

A set of  $3 \times 4$  arrays is being evaluated to verify the impedance matching of the micro strip line to the slot line for a fixed cavity and radial stub size.

### Integrated Circuit Design for Focal Plane Arrays

ASTRON decided to join the Indium Phosphide (InP) Integrated Circuits activity of the partners in the Faraday programme. The InP material has been evaluated for the use in Low Noise Amplifier (LNA) design for frequency range, 2-5 GHz. Simulations gave an indication that also these relatively low frequencies can benefit from the superior performance of InP. Therefore ASTRON used a share of the InP wafers for the design of LNA's. Four LNA's have been designed; they can all be used in active antenna concepts. The usable bandwidth is projected from 0.5 to 5 GHz, which makes them suitable for other developments as the Square Kilometre Array. Results will be compared to the commonly used GaAs technology. A microphotograph of one of the LNA's is shown in figure 7.

### c. LOFAR

At ASTRON in 2002 LOFAR was an important project. LOFAR (Low Frequency Array) will be the first telescope of a new generation. Lofar-antennas will be able to 'see' the

entire history of the Universe. LOFAR uses low-cost antennas and relies on broad-band datalinks and advanced digital signal processing. Read all about it in Chapter IV.

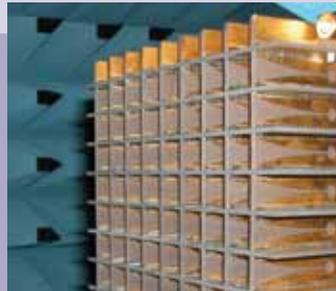


Figure 2 A photograph of the Vivaldi array used to synthesize the experimental beams

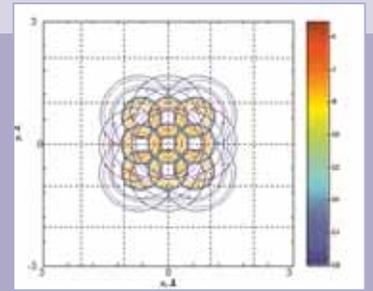


Figure 3 The simulated focal field distributions for a situation with nine beams around the focus

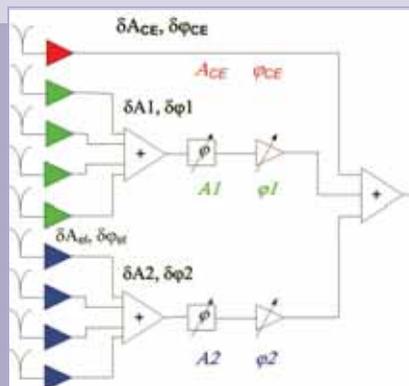


Figure 4 Schematic of a single beam beamformer using nine antenna elements

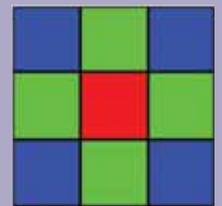


Figure 5 Physical relations of the nine antenna elements used to generate a beam

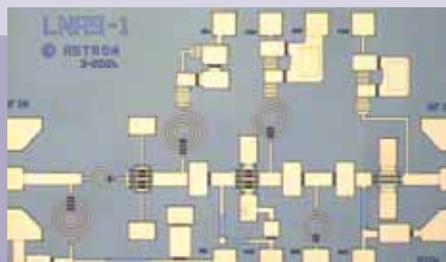


Figure 6 Photograph of the missing Vivaldi proto-type array

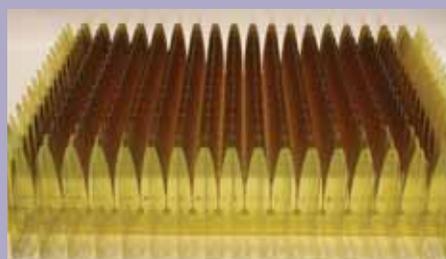


Figure 7 Microphotograph of an InP Low Noise Amplifier Integrated Circuit (actual size  $1 \times 1.5$  mm)

## 2. Technical R&D

### d. NOEMI

The purpose of the Nulling Obstructing Electromagnetic Interferers or NOEMI-project (a joint ASTRON - TU Delft project, supported by STW, the “Stichting voor de Technische Wetenschappen”), is to investigate the effectiveness of digital array signal processing techniques for RFI mitigation. The main goals of the project are to study the RFI mitigations algorithms theoretically, to measure and characterize the interfering signals and to demonstrate the effectiveness of the algorithms in a small scale demonstrator at the WSRT. Finally, the implications of the acquired knowledge for the RFI mitigation aspects of the LOFAR and SKA radio telescopes will be reported. The NOEMI project was extended with one year to February 2003, in order to capitalize on the utilization aspects, and to fully exploit the knowledge in the project. In 2002, one of the research topics for the project was RFI mitigation using a phased array reference antenna at the WSRT.

#### Spatial filtering and performance analysis

In 2002, an analysis was made on the performance of the spatial filtering algorithms, based on perturbation theory. This gave insight in the performance in case the interferer directions are known a priori, and in case these are estimated from observational data. It was found that under certain conditions, especially when the interferer power is comparable to the system noise power, the filtered covariance matrix estimates are biased. The bias and variance were studied under various (stationarity) conditions. The project extended the spatial filtering algorithms for RFI mitigation, by incorporating directional reference antennas which are pointed at the interferer. The advantages are that the interferer characteristics (signature vector) can be estimated more accurately, and that the (matrix) conditioning of the problem is improved by adding reference antennas. Both effects, in principle, lead to better spatial filter performance.

#### Scalar and polarization gain calibration

A paper on fast and asymptotically efficient scalar gain calibration was submitted to the IEEE Tr. SP.P (IEEE Transactions on Signal Processing), and will appear in January 2003. The scalar gain estimation method was extended to calibration of polarized antenna arrays. It was shown that closed form solutions exist for the polarization problem, and it was also shown that at least three emitting point sources, with arbitrary but different

and known polarization states, are needed for a full solution. A performance analysis was carried out using both the closed form solution and an iterative parallel factor analysis method. A polarization calibration method, and a fast weighted scalar gain method, were submitted to the patent office. This polarization work fits nicely in the polarization framework developed by Hamaker et al.

#### KIVI telecommunication prize

Albert-Jan Boonstra, project member of NOEMI working both at ASTRON and the T.U. Delft, represented the T.U. Delft in the annual KIVI telecommunication presentation contest, and won. This contest is among the Dutch universities for the best Ph. D research in telecommunication. His presentation was on sensor array RFI mitigation.

#### RFI mitigation strategy

In a joint effort with the LOFAR project, the potential use of the results of the NOEMI project was studied in the context of RFI mitigation for LOFAR. The results are written in the LOFAR report “LOFAR RFI Mitigation Strategy”.

#### Tile preparation and tests

The project has commissioned a separate NOEMI THEA tile, which was constructed by ASTRON. Control and tracking software were written and tests were performed. Multiple satellite detections were made and galactic HI was detected with a single NOEMI/THEA tile. At the ICT congress in The Hague, the ASTRON - NOEMI THEA tile was presented. Using an online connection to one of the ASTRON Dwingeloo THEA tiles, the concept of an internet telescope was demonstrated by a (near) real-time display of GPS satellites above Dwingeloo. In December, at the WSRT, initial measurements of the TL Lingen sound carrier waves were done, showing that the systems were functioning properly.

Figures 1 and 2 show the set-up used. The two tile beams and six of the 14 (single polarisation) telescope outputs were connected to the WSRT DLB IF system. In order to match the WSRT frequency mixing scheme, the tile (internal) IF system was slightly adapted. The DLB outputs were connected to the NOEMI data recorder, where the NOEMI DSP correlator formed covariance matrices of the input data. The autocorrelation output of the two tile beams were, via a control link between the NOEMI data controller and the NOEMI data recorder, used for updating the two tile beam directions.

## 2. Technical R&D

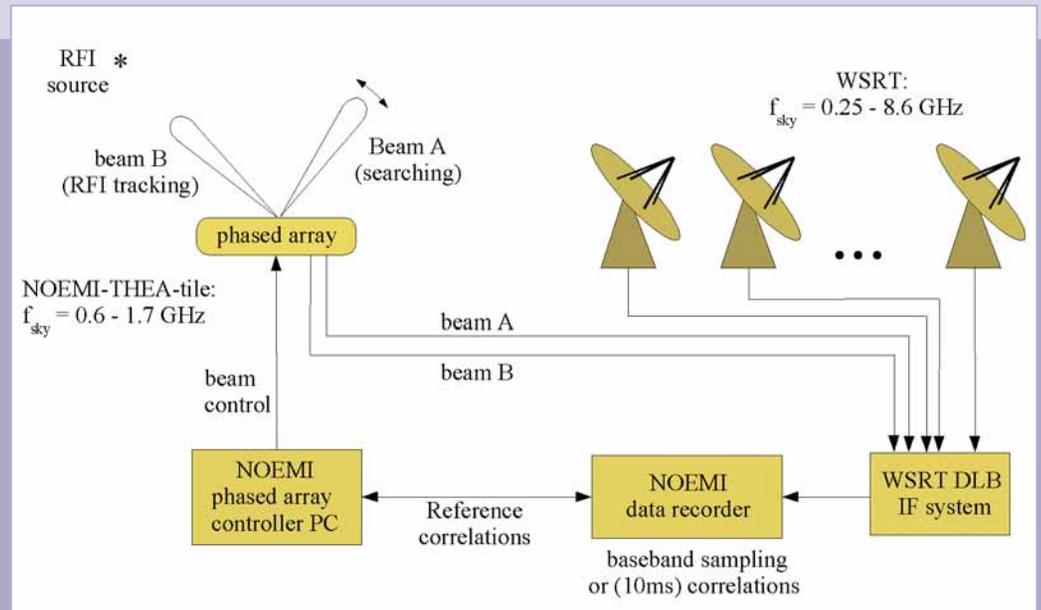


Figure 1. Experimental set-up for spatial filtering test at



Figure 2. NOEMI-THEA tile at the WSRT site during initial tests.

Figure 3 shows results for a recording of the geostationary satellite afristar (digital radio). The figure shows the effect of the spatial filter on the autocorrelations (left figure) and the cross correlations (right figure) in case the spatial filter is based on the WSRT signals only and in the case the NOEMI-THEA tile is used as a reference antenna.

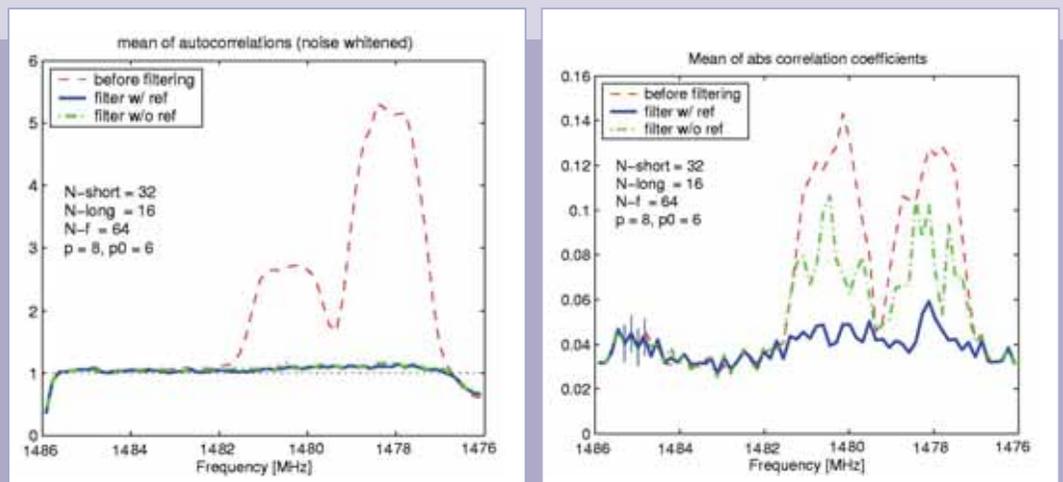


Figure 3. Afristar satellite transmission: effect of spatial filter on autocorrelations (left) and on cross correlations (right), using short integration times.

## 2. Technical R&D

### e. The Thousand Element Array Experimental Platform (THEP)

The Thousand Element Array (THEA) is the third in a series of demonstrators that will show the feasibility of the phased array concept. This concept is seen by ASTRON, but also by an increasing number of European Radio-astronomy Institutes, as the most powerful for the realization of the Square Kilometre Array (SKA).

At the end of 2001 the 5-year SKA R&D (Square Kilometre Array) programme could be concluded with the completion of four THEA tiles and back-end. With the complete system only initial tests had been executed. The THEA system has subsequently being adopted the THEA Experimental Platform, with which a large number of very successful radio astronomy and related tests could be performed. A particular highlight has been at the SKA-conference in Groningen (13 –16 August), where we could present the first HI surveys with a phased array system, proclaimed as the “World’s first dynamic 24 hour full sky HI survey”.

Although THEA started out as a thousand element array, the available resources limited the system completion to a 256 elements, four tile array. The intended experiments - both electrical as well as astronomical - have not been affected by this limitation. Only the effective area of a 4 square meter array, drives a requirement for longer integrations times for the same observation. After the completion of the four tiles, an additional tile has been built to function as a RFI reference station for the NOEMI project (Nulling Obstructing Electromagnetic Interferers), an NWO project aimed at the development of interference rejection hardware and software.

#### Introduction in the THEA system

The THEA tile is a closed unit of 64 single polarization antenna elements with a one square meter collecting area. After a Low Noise Amplifier the signal is split into two beams after which the RF beamforming network, down conversion and digitization, creates two independent tile beams. The two beams are subsequently transported with a fiber link to the THEA back-end.

For the signal processing and digital beamforming in the THEA back-end a flexible, but powerful solution has been adopted. The incoming 1.25Gbit/s serial data stream on the fibers is converted to parallel, and subsequently the data is clocked on the Digital Beam Former (DBF).

The DBF can be configured for summation of two or four signals, or can be set to just feeding the data directly to the Digital Signal Processing board (DSP). The DSP board performs the Fast Fourier Transform (FFT), auto-and-cross- correlation and subsequent integration. The final output spectra (1024 times 20 kHz) of the system are then stored on a hard-disk or on storage CD’s. A number of Graphical User Interfaces have been created in order to allow the user to work interactively with the system.

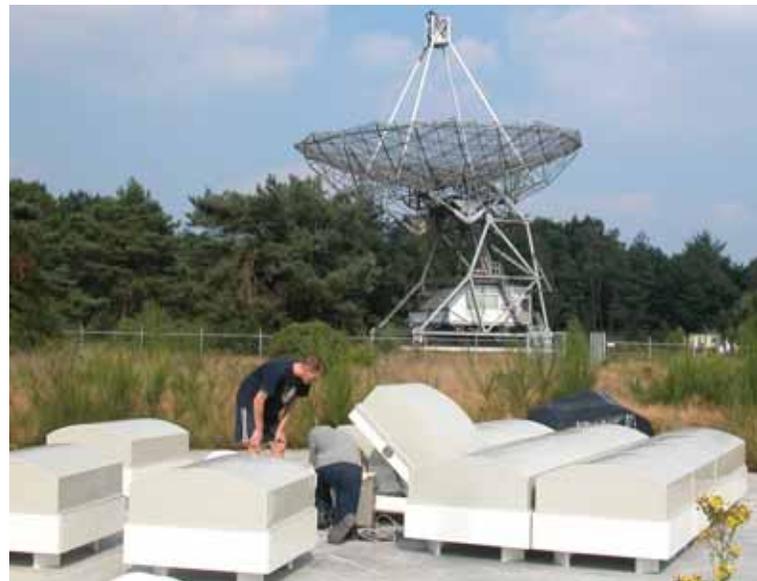


Figure 1. Integration and test of the THEA tiles at the test platform near the Dwingeloo telescope

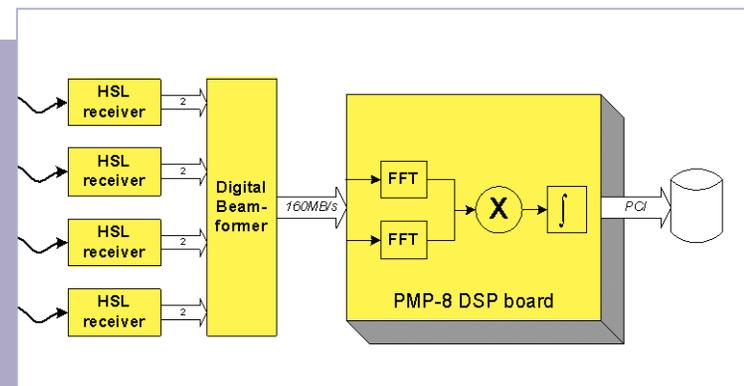


Figure 2. Block diagram of the Signal Processing Back-end

## 2. Technical R&D

### Calibration

For a proper functioning of a phased array system, a careful calibration of all the individual elements is required. An initial calibration is performed in the Near Field Scanner antenna measurement room. A re-calibration at the outside test-range has been made possible by means of a dedicated transmit horn in a nearby mast. By using two beams of which one scans, and the other is pointed at the source, the correlation between the beams has been used, as the stability of the source is taken out of the equation. The two beams can be from one tile, or from different tiles. This calibration method can be used with other signal sources as for example GPS satellite signals. In Figure 2 results are shown from a calibration on a geo-stationary satellite, Afristar, which transmits at 1480MHz. The corrections are calculated from the data of one beam as reference beam fixed at the calibration source while sweeping a second beam over the sky. It turned out that the optimal result could be obtained when this procedure was repeated once or twice, using the correction calculated in the previous iteration as starting point for the next.

### THEA Experiments

With THEA a number of demonstration and evaluation measurements have been performed. The demonstration measurements served to show that it is possible to perform measurements that are expected to work, such as multi-frequency multi-beaming and array beam forming. In the evaluation measurements specific aspects of the system have been examined more closely to explore the limitations of the system.

Due to the electronic scanning capabilities of the phased array antenna, full sky measurement maps can be made fast. A picture of an observation of the Global Positioning Satellites (GPS) is shown in Figure 4. The measurement frequency is 1227.6MHz and 1575.5MHz, where the lower frequency image on the left suffers a little from a lower signal level at this military frequency. Some basic array aspects are demonstrated with this measurement. Due to the spacing of the array,  $\lambda/2$  for 1200MHz, grating lobes will be present when the array is pointed off zenith. Being a multi-beam system, detection of these kind of RFI sources can be done by dedicating a percentage of the time of one beam to locate Radio Interferences. The obtained information can then be used for deterministic nulling in the RF beamforming or in the Digital Beamformer.

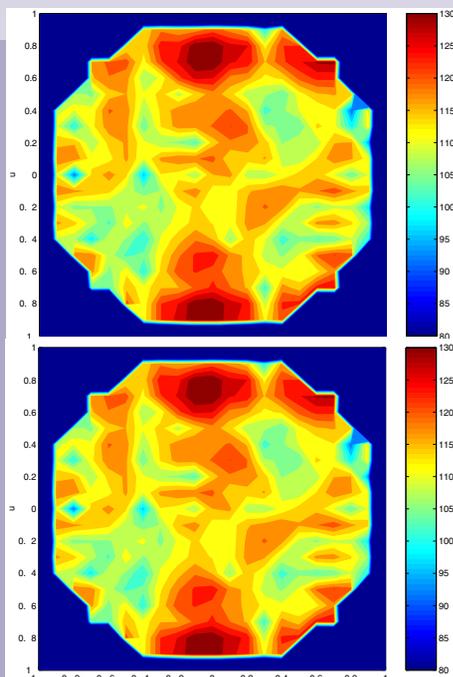


Figure 3. Plots showing results from calibration measurements for a single tile. The image on the left hand side show the measurements results before calibration. The right hand image presents the corresponding results after calibration, in which the satellite signal is clearly visible.

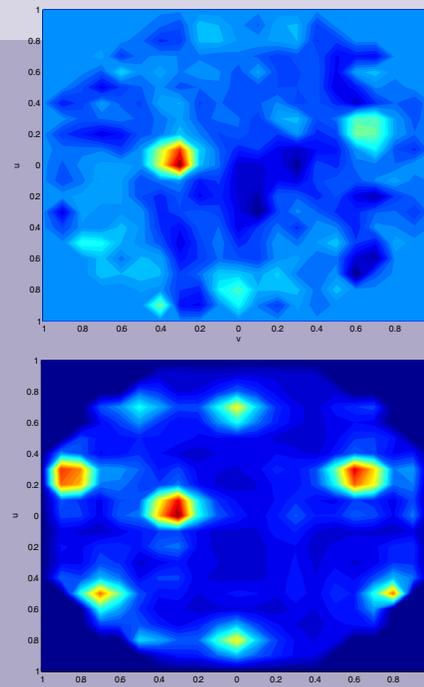


Figure 4. Intensity contour plots showing the distribution of GPS satellites over the sky measured at frequencies of 1227.6MHz (left) and 1575.5MHz (right) respectively.

## 2. Technical R&D

An intermediate step, after the initial calibration, towards the use of the complete system, is the measurement of fringes with two tiles. The sun has been used as a good strong far field noise source. Two tiles have been placed at 10m apart on an East-West baseline. The tiles were aimed at the meridian passage of the sun. Measurements were taken at 1440MHz, measurements have been taken on 30s intervals with 10s integration. The total measurement lasted five hours.

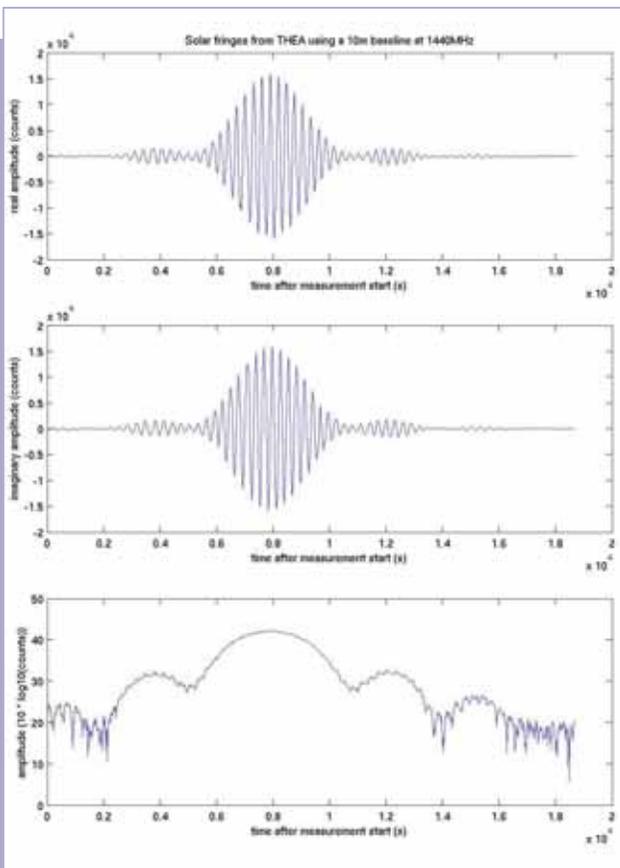


Figure 5 Results from solar fringe measurements. The upper plot shows the real part of the signal, the middle plot the imaginary part. The lower plot shows the total amplitude on a logarithmic scale.

Finally the complete 4-tile system has been evaluated with HI measurements on our own Galaxy. Imaging of the galactic neutral hydrogen was done using the array in a ff2-by-2 configuration with tiles placed directly next to one another. The phase delays due to slight differences in cable lengths were calibrated out on Afristar. A full-sky scan was made on a regular (u,v)-grid with a spacing of 0.05 between points, resulting in 1246 beam positions per

scan. With an integration time of 1 sec. per point a complete scan took 23 minutes. This produced a small distortion in the final image of the sky due to earth rotation. This effect is however hardly visible since neighboring points are still measured within 1 minute. Figure 6 gives one of the 31 full sky scans made in a 12 hour observation. The data has been compared with the Leiden Dwingeloo Survey (LDS) and a very good match has been found.

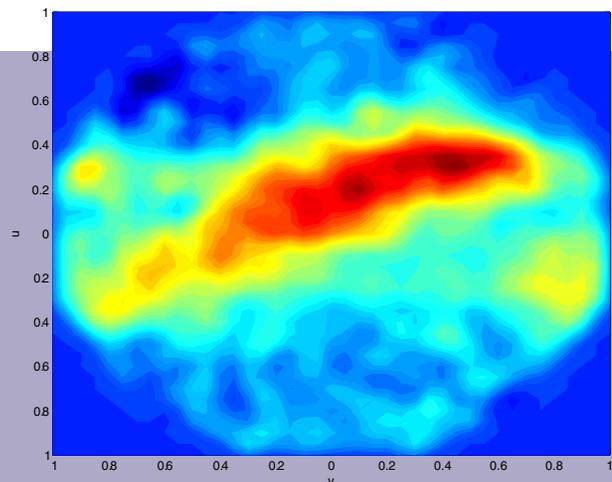
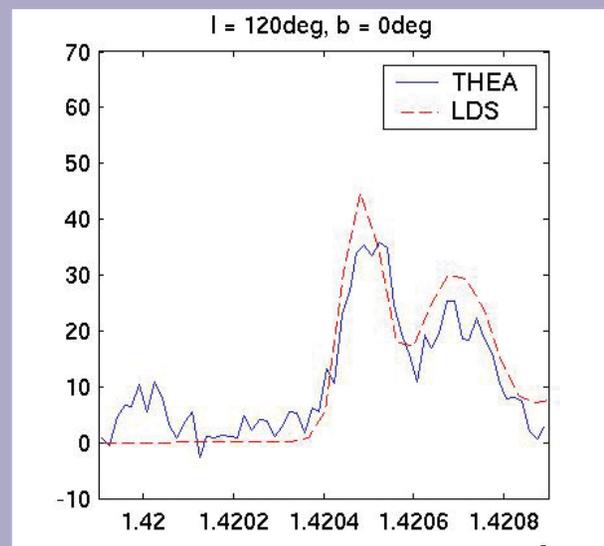


Figure 6 uv Plot of the HI radiation intensity of our Galaxy measured with 4 THEA tiles



The good match between the LDS data and the data measured with THEA is illustrated in Figure 7.

## 2. Technical R&D

### 2.3 Optical projects

#### a. MIDI ESO-VLTI project

##### Introduction

A consortium consisting of the Max Planck Institute for Astronomy, Heidelberg, the Netherlands Research School for Astronomy (NOVA) and the Observatoire de Paris has built MIDI, the MID-infrared Interferometric instrument for the ESO-VLT Interferometer. MIDI combines the light from two VLT telescopes for the N-band (~10mm) with provision made for the Q-band (~20mm).

ASTRON developed and produced the “cold optics” at the heart of the instrument. The two beams coming from the VLTI delay lines are re-imaged, spatially filtered, combined, dispersed and imaged onto the detector. The rest of the instrument, warm optics, cryostat, cooling system, detector unit and electronics, was produced by MPIA. The instrument control and data analysis software is being developed jointly by MPIA, NEVEC (Leiden) and Observatoire de Paris (Meudon).

The start of the project was when the Conceptual Design Review was passed successfully in December 1998, though MPIA had been working since 1997 on the concept of MIDI. MIDI then successfully passed the Final Design Review in 2001.

In 2002, the MIDI cold optics underwent extensive testing at MPIA, Heidelberg, culminating in a successful PAE (preliminary acceptance in Europe) in September. The entire system was then shipped to Paranal, Chile in October. It was installed on the VLTI in November, and achieved first light on the siderostats in December. On December 15th 2002, the first fringes were obtained using 2 UTs. The science program will begin in 2003.

##### The Optics

All the initial problems were successfully solved and the results of the tests performed in December 2001, showed that the overlap was excellent at approximately 95%. Some slight adjustments were started in September and then finished in November at Paranal, which resulted in an overlap of 97%.

##### Science

The MIDI science team met in October 2002 to further detail the observations to be carried out in the Guaranteed Time Observing (GTO) programme. At the end of September, abstracts and target lists for the first planned GTO run in June 2003 were submitted to ESO. During the AIV period in November-December 2002, several objects that are also in the MIDI GTO target list were observed, and fringes were successfully recorded. This data is now being analysed by the MIDI team to assess the performance of the instrument. The high quality of the optics in the VLTI structure has been demonstrated by an image taken with the MIDI field camera of the Eta Carinae nebula, resulting in the highest quality image of that object ever taken at 10 microns.

The MIDI instrument has successfully seen first fringes with the siderostats on the 10th December, and subsequently with the 8.2m Unit Telescopes on December 15th. The first star on which fringes were measured is the K giant Epsilon Carinae. Other sources that were detected are the pre-main-sequence star Z Cma and the peculiar massive star Eta Carinae.

MIDI commissioning will begin in earnest in February 2003 with the first scheduled commissioning session. Work is continuing on the calibration sources for MIDI. Tijn Verhoelst (Leuven) spent six months in Paris to work with Guy Perrin on IOTA observations of K giants and other late type stars that will be targets for MIDI. Geneva photometry of about seventy stars has been obtained, completing the photometric data set for about fourhundred potential targets.

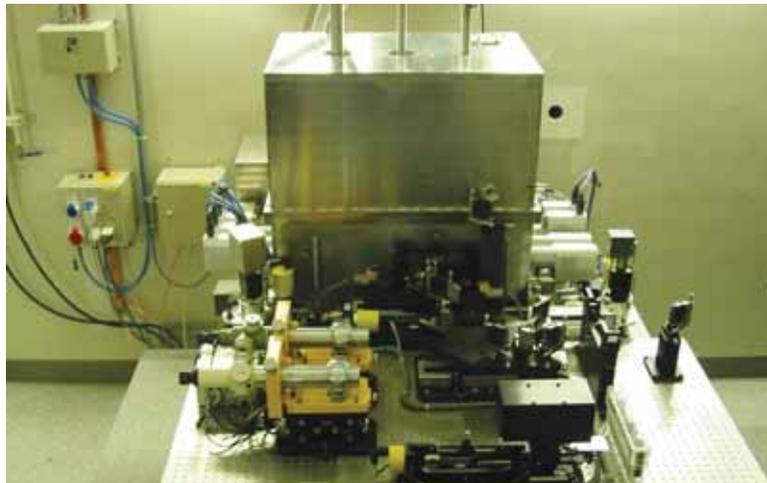


## 2. Technical R&D

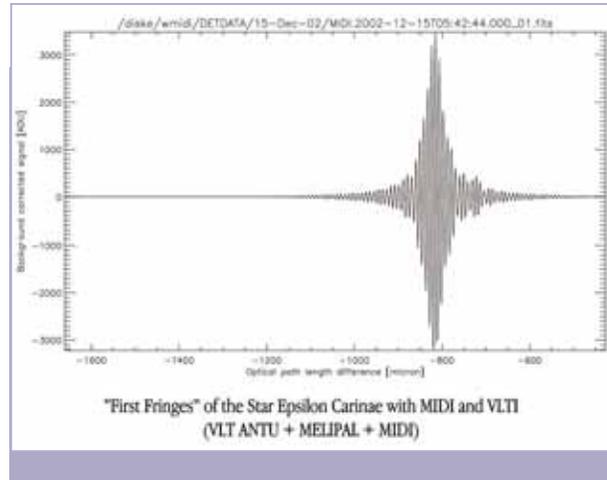
MIDI unpacked and undergoing initial tests in order to ascertain how the transport from MPIA, Heidelberg, Germany to Paranal, Chile had affected the optics. The alignment was found to be exactly the same as when the optics were packed!



The cold optics installed in the cryogenic chamber as seen from above. The cold-head can be seen top left and the vacuum pump is top right. The cold optics are dominated by the black filter wheel. To both the left and the right of the outer chamber, the eight motors that drive the mechanisms within the cryostat can be seen.



MIDI fully installed in the interferometric laboratory. The cryogenic chamber is closed and is ready to be pumped-down and cooled.



The first fringes obtained on a science object using two of the UTs. For these first fringes on a celestial object, the white-light mode was used on a bright object, so that basic integration time could be minimal. In this mode, there is no spectral dispersion, i.e. the images (photometric and interferometric) on the detector are just spots of light. Roughly speaking the telescope Airy disc, spatially modulated by the interferometric fringes (the Airy disc is optically matched approximately to the expected fringe width; depending on the camera in use, this spot of light is  $3 \times 3$  or  $3 \times 1.5$  pixels in size). The light in the spot-pixels is integrated and displayed as ordinate. The abscissa is optical path difference (OPD) for the two telescopes, using an arbitrary zero in engineering mode; the actual position of zero OPD is of course at fringe maximum. The OPD is scanned using the (warm) delay line of MIDI itself. The number of fringes between half-maxima is of order 5, so the bandwidth must have been of order 20% of the central wavelength.

### b. MIRI spectrograph camera

During 2002 the phase-A study of the Mid-Infrared instrument (MIRI) for the successor of the Hubble space telescope, the James Webb Space Telescope (JWST) was carried out. MIRI consists of a diffraction-limited camera and medium resolution integral-field spectrograph in the  $5\text{-}28 \mu\text{m}$  wavelength range. It will be built in a combined effort of a European consortium and parties in the US, headed by the Astronomy Technology Centre at Edinburgh, UK. The Dutch astronomical community contributes to this instrument by designing and building

## 2. Technical R&D

the optics and mechanical structure of the dispersive camera for the spectrometer. NWO, NOVA and all contributing institutes and partners fund the work. During the phase-A study, ASTRON's work focussed on the optical and mechanical design.

### Phase-A Study results

The phase-A study of MIRI that started in December 2001, has been finished in September 2002. During this phase a design emerged that demonstrated the feasibility of MIRI. In this design, the instrument consisted of fore optics guiding the light from the focal plane of the telescope to the instrument (part of the Italian work package) towards the camera (French) and towards the pre-optics of the spectrograph (designed by the UK). The pre-optics re-images the beam, separates the beam into four wavelength bands by dichroic filters and feeds these bands through four integral field units (see figure A) towards the slits.

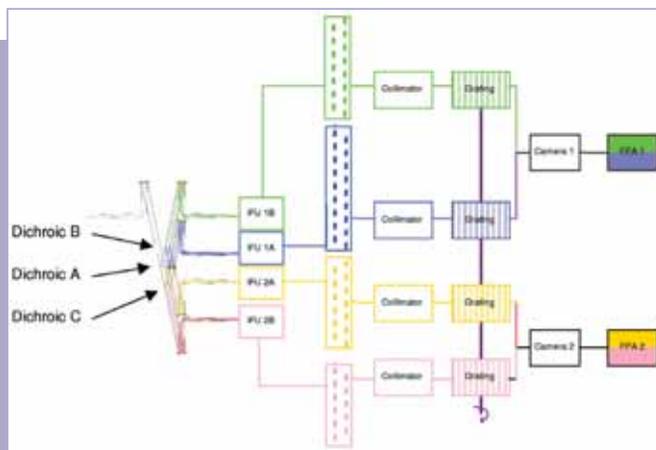
After the slits, the light enters the main spectrometer (the Dutch contribution). The light is dispersed using four gratings and subsequently by a three mirror camera imaged on two 1\*1 k infrared detectors, delivered by the United States.

coverage. The wavelength selection for the three exposures is implemented by a rotating wheel containing three sets of dichroic filters, optimised for the wavelength ranges of these exposures and by simultaneously tilting the gratings. The two three-mirror cameras both image two bands on the detector.

The interaction of the optical and mechanical design activities resulted in the phase-A study concept of the spectrometer. Design choice that we made comprises:

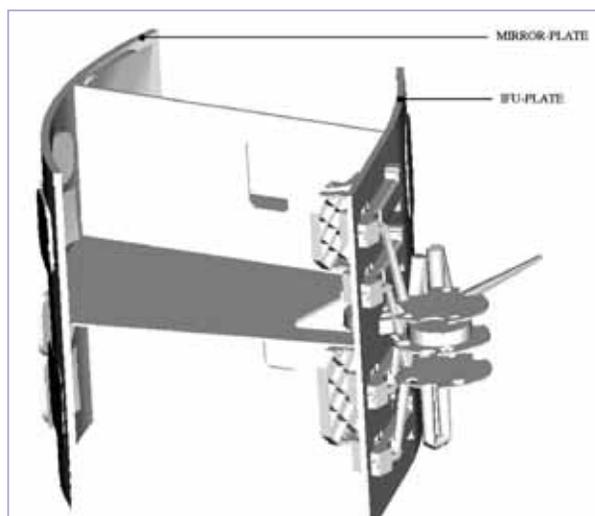
- an all-aluminium design, ensuring preservation of optical quality both at ambient temperatures and under cryogenic conditions, using a well known material both during design and manufacturing,
- monocoque, where the structure provides the baffling,
- optical elements on two wall of the spectrometer to reduce the complexity of the optical bench.
- two spectrometer halves on top of each other to obtain a compact stiff structure.

The resulting structure, figure .., has two stiff end-plates that act as 'optical benches' for the two groups of optical components, connected by a cross-shaped intermediate structure. The end-plates are very stiff light-weighted structures that carry all optical components and the two mechanisms. For convenience we will term the end-plate that carries the IFUs as the 'IFU-plate' and the end-plate on the opposite side as the 'mirror-plate'. Both end-plates are curved to follow the contours and positions of the optics. This curvature has the extra advantage of adding internal stiffness to the plates. Not shown in the figure are the four side walls which completely close the structure.



Schematic optical layout and principle of the MIRI spectrometer

For obtaining sufficient spectral resolution ( $R \sim 3000$ ) for 5-28.3  $\mu\text{m}$  on 2k pixels, at least 12 subspectra are needed. By splitting the full wavelength range into four bands (5-7.7, 7.7-11.9, 11.9-18.4, and 18.4-28.3  $\mu\text{m}$ ) these four bands can be measured simultaneously and only three separate exposures are needed to obtain full spectral

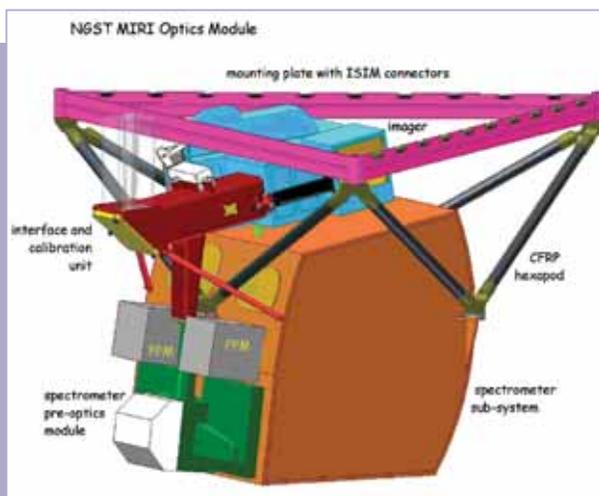


Mechanical layout, main structure of the MIRI spectrometer

## 2. Technical R&D

The cruciform structure not only acts as support between the two end-plates, but also as stray-light baffling between the two spectrometer channels and between the optics sections that contain the gratings (the main source of stray light) and those containing the cameras and FPMs. The intermediate images in the two spectrometer channels lie very close to one of these internal walls, which will carry a simple, but extremely effective aperture for baffling. Similarly, the IFU plate acts as a very effective baffle having only eight apertures – four are closed off by the IFUs leaving only a tiny slit for light entering the spectrometer, two are closed by the camera M2 mirrors, and two are covered by the FPMs which receive the light leaving the spectrometer.

A full layout of the phase-A study instrument is shown in figure .., where the mounting to the ISIM is shown in magenta, the grey rods are the hexapod structure that mounts MIRI mechanically to the satellite but isolates it thermally. The pickup mirror is shown in red, the imager is blue and the spectrometer is orange. The green parts are the pre-optics for the spectrometer and the grey boxes are the FPMs.



Mechanical layout, main structure of the MIRI spectrometer

### Pre-phase B

The phase-A study was completed well before the “kick off” of phase-B. The consortium requested ESA to fund an intermediate phase in which some alternative technical solutions could be studied and during which many organizational aspects of the project could be set up.

This request was granted and on the Dutch side, an alternative solution for the spectrometer, proposed by TNO-TPD will be studied.

### c. SPIFFI 2kx2k camera

#### Progress Summary Year 2002

The SPIFFI (Spectrograph for Infrared Faint Field Imaging) 2kx2k camera will be a new camera for an Infrared detector of 2kx2k pixels. It will replace the existing camera with 1kx1k pixel detector of the instrument SPIFFI. SPIFFI is a near IR spectrograph built by MPE for one of the 8 meter telescopes of ESO on Chili. It is a cassegrain instrument. It is a cryogenic instrument and it will be cooled to 77 K. It works under vacuum.

The SPIFFI 2kx2k project officially started in January with a contract sign between NOVA and ASTRON. A kick-off meeting has been held with MPIA, ESO and NOVA in Munich on 25 March.

In advance of the kick-off meeting and the signing of contracts, a small study on the special cryogenic lens mount was made. This lens mount is the most crucial mechanical part in this instrument. It has to overcome shrinkage of different materials from room temperature to 77K. It has to work under vacuum and should be extremely stiff to keep the lenses centred during operation of the telescope.

For the Preliminary Design Review, held early October, the optical design was worked out in detail. The cryogenic lens-mount was studied and calculated for the three most critical lenses and sketched for one lens. Also the principal design of the whole camera was sketched. The review was passed successfully. This material has a long time of delivery. The cryogenic lens-mount is designed more in detail, and final calculations on stiffness are done.

#### Progress Summary Q2 2004

One of the most important issues of previous quarter was the stop of the optical production, due to some required changes of the optical design. The optical design was changed slightly and finally all parties involved did agree to it. At Korth Kristalle the optical production was restarted.

The testlens, testmount and testtooling for cryogenic testing of the mechanical design principle of lensmount is ready. Testing is planned for August.

The CTE tests (Coefficient of Thermal Expansion



## 2. Technical R&D



(shrinkage of material)) took some time to establish to a more reliable test and is almost finished. It is not yet clear if it has the required accuracy.

The drawings of the flat mirror are ready - production could get started. The 3D design of the detector unit is ready and sent to ESO for comment. The design seems to be accepted. The housing is ready, but waiting for the finishing of the lensmount 3D design of the last two lenses. The housing drawing should be finished early July to startup production as soon as possible. Some remaining 3D design is a cover for the detector and some baffles.

The projectplan for the Production and Integration Phase should be released soon.

### Progress Summary Q3 2004

Much effort was put in finishing the design of the several parts. Almost all parts are finished and just a few need last process of making drawings and final release. The housing design was the most important and was finished in August. The housing will be made out of one piece of aluminium and does have accurate interfaces to many parts: a surface for mounting the triplet, one for the doublet, for the flat mirror, the detector unit, the mounting plate and a large baffle. The production of the housing has been started and will require all skills of man and machine. The mechanical parts for the flat mirror are produced. Also the mirror itself is delivered, including coating by Antheryon and accepted.

The optics supplier Korth finished their production of the five lenses early September with one-week delay. During optical testing of the lenses at Astron it appears that two of the lenses were not correct and could not be accepted. They are shipped back for repair and should be finished soon. Two accepted lenses are sent already to Melles Griot for AR-coating. The other three will follow as soon as possible when the two repaired lenses are received and accepted.

Thermal expansion test (CTE) from room temperature to about 50 K are performed on S-TIM28 and POM (plastic) material and are partially successful. The CTE data of the POM material is used for an overall test of the cryogenic mount principal. This test will be done on the most critical lens, number 2, and will be done with a testlens of BK7 which shows almost the same thermal and mechanical behaviour as the original material S-TIM28. The first cryogenic run of this test has been done; a few others will follow.

### Progress Summary Q4 2003

The last quarter of the year was dominated in SPIFFI by the production of the housing. The production took much longer than expected, due to several facts like the more complex machining of the housing than expected, setback by essential tooling breakage and even machine failure. A review will be held on this subject with all people involved to evaluate and learn. Many other parts were produced in parallel.

The two incorrect lenses (of the five), which were delivered in September, are corrected by the supplier (Korth Kristalle) and delivered with a delay of about a month. They are tested in-house and forwarded to the supplier (Melles Griot) for the AR coating. The other lenses were already in process and Melles Griot delivered early December all the lenses conform schedule.

We finished the cryogenic test of lens 2 (dummy) and proved that the cryogenic lensmount principle works all right in static state. For the dynamic state a cryogenic flexure test will be done with the final housing and optics at ESO in Garching. This will be a crucial test.

Late December an integration test of the housing inside the SPIFFI instrument is done at MPE (Max Planck Institut für extraterrestrische Physik in Garching (Germany)), and passed successfully.

### Status Summary End 2003

All design reports and drawings are released.

Optics:

All optical parts, five lenses and a flat mirror are ready, coated and accepted and waiting for integration.

### Mechanics:

The most important part, the housing, is ready and black coated and ready for integration. As usual a measurement is needed to judge if the housing can be accepted (scheduled for week 2). Many parts are ready; just a few crucial parts like some lens-support rings need to be produced (scheduled for week2). A few lens-mounts need some finishing touch to be ready for integration, scheduled for week 3/4. Some remaining parts like a detector housing and a test-part are not critical and will be finished at the end of January.

### Testing:

All scheduled testing is done; mainly cryogenic testing of the lensmount principle. Based on these tests some crucial dimensions are defined. An extra cryogenic test with a rejected CaF<sub>2</sub> lens will be done (scheduled week 3)

## 2. Technical R&D

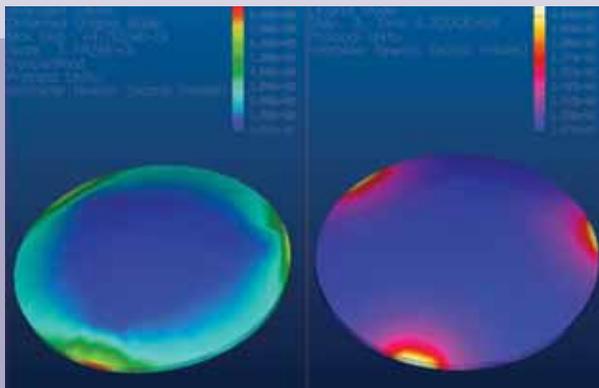
to ensure that no critical failures can occur during cryogenic test of the final camera. Reports to be written. Camera warm testing (in-house ASTRON) is scheduled for end of January and early February.

### Organisation and schedule:

The PI of the project at NOVA is now a joined cooperation of Paul van der Werf and Anthony Brown.

The major short time milestone is 'shipment of camera' and is scheduled for February 2004.

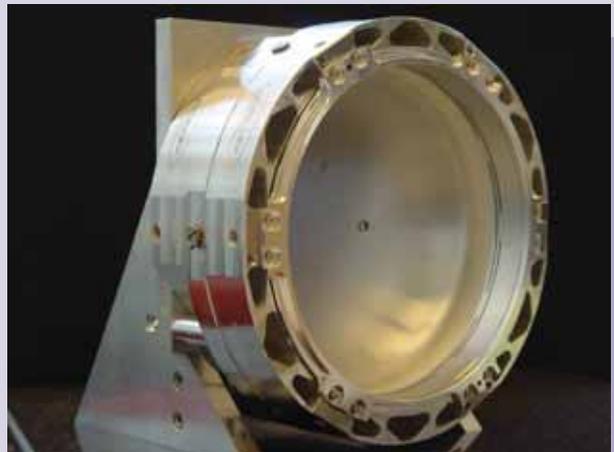
Succeeding workpackages are cryogenic optical test of the camera at ESO and integration and test in SPIFFI instrument at MPE. The major milestone is shipment of SPIFFI to Paranal, scheduled for May 2004. It is crucial to meet this date, otherwise integration and test into SPIFFI will be done at Paranal and will require an extra commissioning and extra manpower.



Thermal calculations. The picture on the right shows a temperature distribution during heating from 77K to 293 K within 12 hours. The left picture shows the worst-case stress distribution during heating. The stress is within the mechanical requirements.



The picture shows the triplet lensmount, with three lenses, two mounts and a few plates and spacers. Typical lens diameter 176 mm.



Cryogenic test setup for testing lens 2 and the lensmount principle. The partially polished lens is of BK7 material with almost the same thermal and mechanical behaviour as the original S-TIM28. The spot in the middle of the lens is a thermal sensor.



SPIFFI 2k camera housing (upside down) with black coating. In the circular opening at the right the triplet will be mounted. The view through the housing will be closed with the flat mirror. In the circular opening at the left the doublet will be mounted. At the inside there is a rough profile to prevent ghost images.

During the preliminary design phase it was already clear that we need accurate numbers of the shrinkage of materials at low temperatures. Of some of the materials these numbers are not available and should be measured. The most critical are S-TIM28 material and some type of plastics. The design of a test-tool for cryogenic CTE testing of plastic and other materials is in progress. A test lens will be cryogenically tested to verify the design principle of CTE compensation and to check the calculations and measurements.

## 2. Technical R&D

### d. VISIR

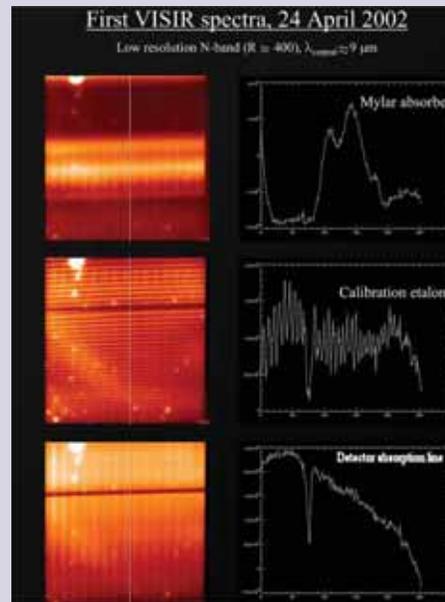
#### (Very Large Telescope Imaging and Spectroscopy in the Infrared (for ESO's VLT))

In April 2002 the VISIR instrument had first Infrared light in the lab in Saclay near Paris. VISIR is the Mid-Infrared Imager/Spectrometer for the ESO Very Large Telescope that has been developed by the French-Dutch consortium of SAP and ASTRON, under ESO contract.

SAP is responsible for the imager subsystem, the detectors, electronics, software and all peripheral equipment, ASTRON for the spectrometer. The team of ASTRON works in close collaboration with the instrument scientist for the Kapteyn Institute in Groningen. After several years of designing, prototyping, manufacturing, assembly, cryogenic testing and verification in the laboratory, the instrument has now entered the phase of final testing, acceptance and shipment to Chile. In combination with the 8 meter aperture of the VLT telescopes and the excellent observing conditions on Cerro Paranal in Chili, VISIR will offer unprecedented observing power in the relative unexplored mid-infrared wavelength range.

In 2002 the VISIR spectrometer has been located in Saclay in France. Assembly work related to testing and testing on the spectrometer itself was performed in the SAP laboratory during several expeditions of small teams of ASTRON. Some improved and repaired components were assembled early 2002, like the High Resolution Grating Unit (GUHR) with new motor-axle coupling and with some refurbished parts like the Echelle and yoke suspension. Flexure tests showed that the complex and time-consuming modifications to the GUHR Echelle and yoke suspension appear to have been successful. New High Resolution Collimator mirrors have been manufactured and delivered by Philips early January 2002 to replace the old mirrors that were out of specification. The optical quality was improved and the collimator is now within the requirements.

The first cryogenic tests with the fully integrated imager and spectrometer in the VISIR cryostat took place in April. The milestone of 'first VISIR laboratory spectra' was achieved on April 24 2002.



This test succeeded with a few other cryogenic tests over the year, to finalize all remaining tests of the spectrometer. The checked items are: functional tests of moving mechanisms, thermal behaviour, alignment of imager and spectrometer, detector performance and optical performance like straylight and ghosts, filter and grism quality.

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In the first half of December 2002, SAP reported that one of the cryogenic motors did not have delamination of the soldering of the clutch mechanism. The spectrometer does have seven of these types of motors. The repair of the motors is the responsibility of SAP. ASTRON will perform the exchange of the motors of the spectrometer to make them available for repair.

Further assembly and testing are planned for 2003.

### e. WYFFOS Wide Field Fibre Optical Spectrograph

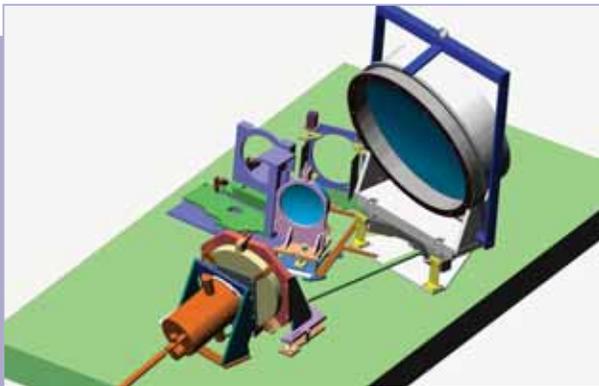
#### Verslag van 2002

For WYFFOS the year 2002 started with the Final Design Phase. The Preliminary Design Review was successfully closed in December 2001. The WYFFOS long camera is a

## 2. Technical R&D

new camera for the existing spectrometer on the Isaac Newton Group's (ING) William Herschel Telescope (WHT) on La Palma and will be located in a Nasmyth focus. The WYFFOS long camera will replace the existing camera and will have a larger focal length and a far better performance.

The year 2002 was a year full of designing, producing and assembling of the instrument. In a very early stage the optical drawings were released. Also the production of the huge spherical mirror and the rest of the optics was started as soon as possible, to have all optics available in the last quarter of the year. Most optics, including coatings, were outsourced to different companies. The field flattener lens and post-polishing of the flat mirror were done in-house. For short periods three designers in parallel worked on the mechanical final design to speed up the process. This resulted in a Final Design Review in June 2002. This has been passed successfully. The Final Design Review showed that the planned commercial available shutters did not fit and a special one should be designed. The detector mount was not correctly specified and needed some redesign.



Overview of the WYFFOS long camera design. Typical dimension of the big spherical mirror: 670 mm. The big mirror is produced of Zerodur (material with extreme low thermal expansion) and is mounted with a special construction with an 'invar' rod on the optical table, to prevent temperature effect of expansion of the table to the optical quality of the camera.

The production of the mechanical parts has been done mainly in-house by Astron and a few huge parts were outsourced. The production of all the optics was delayed. The big flat mirror was at the end of the year still not ready. Several companies, including ASTRON, processed the mirror and all companies shipped too late. The huge spherical mirror is delivered around Christmas time, which means a delay of four months.

The year 2002 ended with all the drawings released, including test equipment drawings.

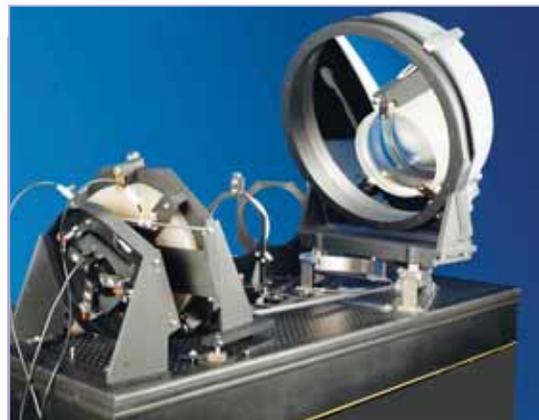
Almost all mechanical parts are ready, or need a final touch like a black coating. The boxes for optics shipment are produced. Some remaining parts as a dustcover, casing parts and remaining shipment parts will be produced during assembly and test of the instrument. Assembly of some subunits is started.

The meniscus unit, the field-flat-lens and the huge spherical mirror are ready for integration. The flat mirror is post-polished and outsourced for silver coating and expected to be back at the end of January.

Due to the delay in the optics production, the Acceptance Review will be delayed by about two months up to about February. This delay is communicated with ING. The commissioning date (June 2003) is not effected.

### Progress Summary Q1 2003

At the start of the year, all optical parts and mechanical parts were ready, except for the flat mirror, which was shipped in the first week of the year for coating. The WYFFOS long camera is fully integrated during February and installed on a temporarily optical bench in the integration room. A tent is installed over it to protect it as much as possible against dust. The flat mirror came in just a few days before the review of 20 March, due to errors of the supplier. First short tests did show good optical performance. The review with the Isaac Newton Group of La Palma has been passed successfully. We will finish the optical tests, but we don't expect any problems. There was some concern of ING about the shutter regarding vibration and we have to look for some solution to overcome this problem. We will do a life-test on the shutter to prove the quality of the mechanism, but don't expect any problems.



The picture is showing the fully integrated WYFFOS long camera as installed in the integration room.



## 2. Technical R&D



### Progress Summary Q2 2003

We finished the optical testing of the fully integrated camera successfully.

All documents like drawings and reports are sent digitally on CD to ING.

The instrument has been disassembled and packed and ready for shipment. We have finished the complete phase of the final design except for the shipment itself and on the issue of the shutter.

On the shutter we tested a system that showed that the issue of shock of the moving mechanism has been solved. Nevertheless the driving mechanism of the pneumatic cylinder construction is not yet stable enough. Some other type of cylinder was ordered to solve this problem. This will be proven by some kind of life test.

### Progress Summary Q3 2003

In September The WYFFOS long camera has been shipped to ING (La Palma) inside two boxes by our standard carrier. ING confirmed the complete and safe arrival of the instrument.

The shutter has been tested with an alternative pneumatic system on the issue of shock of the moving mechanism and on the long term performance by a 20k lifecycle test. The shutter passed these tests successfully. Delivery of the shutter will be done on site during the installation of the camera.

### STATUS Summary Q2 2003

The instrument is located by ING on La Palma, packed into two boxes, one with optics and one with mechanical units. Installation and commissioning is delayed by ING to probably Q2 2004, due to priorities of ING projects.

### f. X-SHOOTER

One of the four selected second-generation types of instrumentation for the Very Large Telescope of ESO (European Southern Observatory) is a so-called fast shooter, a medium resolution wide band (ideally 0.32 to 2.4  $\mu\text{m}$ ) spectrometer. This class of instruments aims to get maximum detectivity on stellar or small emission-line objects, while covering the largest possible wavelength range in a single observation. A particularly important requirement is the ability to get spectrographic data on

unpredictable and fast varying objects like supernova explosions or gamma ray burst optical counterparts, for the latter if possible in a matter of minutes.

At first four consortia showed interest in this instrument, of which some dropped out because the proposed technology is not yet mature and the last two consortia were merged into one new consortium. ESO asked this consortium, consisting of Denmark, Italy, the Netherlands and ESO, to perform a concept study for this type of instrument.

The large wavelength range of the instrument requires a multiple arm system, with for X-SHOOTER three spectrometers optimised for performance and sensitivity in their specific wavelength range. The division of work was divided along the spectrometers, i.e. the UV-spectrometer (300 to 550 nm) will be delivered by Denmark, the VIS-spectrometer (0,5 to 1,0  $\mu\text{m}$ ) by Italy and the NIR-spectrometer (1,0 to 1,95 or 2,4  $\mu\text{m}$ ) by the Netherlands. The central structure is functionally divided over the consortium: the optics taken up by Italy, the mechanisms by Denmark and the structure by the Netherlands. The decision to in- or exclude the K-band (2,0 to 2,4  $\mu\text{m}$ ) is postponed to future sessions of the Scientific Technical Committee (STC) of ESO.

The Dutch consortium consists of the University of Amsterdam, University of Nijmegen and ASTRON. The funding for the feasibility study comes from NOVA, ASTRON and the universities. For the funding of the project a proposal has been submitted to the NOVA-2 instrumental programme.

### 3. Radio Observatory

The full suite of fourteen front-ends has been available for virtually 100% of the available observing time. This implies that, again, the reliability of the front-ends has been quite good. In twentyone cases front-ends were replaced with one of the two available spares. The types of faults encountered during the year were defective or bad Ina's in six cases, defective LO's in two, three defecive noise sources, six cryogenics related complaints and the rest were miscellaneous faults.



## 3. Radio Observatory

### 3.1 Introduction

The Observatory celebrated a number of important milestones during 2002. The WSRT Upgrade activities have culminated in an efficient operation for the WSRT and some exciting first results. The work on the Upgrade has been officially closed during an October ceremony (see below). However, the Observatory staff continues to add more bells and whistles to the WSRT system in order to respond to the wishes of the astronomical customer community and to work on ironing out any obstacles that stand in the way of perfecting the WSRT data products.

Science output of the WSRT continues to be high as the instrument is producing high quality data. In addition, more innovative observing modes are being implemented as part of the commissioning program of the integrated IVC-DZB. Scientific productivity comparisons have been made with past years and with other world-class telescope and the WSRT still looks pretty good. If the WSRT continues to perform as it is now, it will make a certain impact on the radio astronomy of the 21st century.

Projects using data obtained with the new system clearly show that the WSRT is competitive with any equivalent astronomical instrument between 300 MHz and 4.8 GHz. Because of the increased operational bandwidth, the WSRT at L-band is even as sensitive as the current VLA that has twice the number of dishes. The new scientific results are breathtaking.

The WSRT Telescope Management System (TMS) has matured significantly during the year, and a number of milestones have been reached as part of the Upgrade activities. Implementation of the DZB nominal backend system (put into production mode on 1 April) into the TMS-6 software incorporates the complete multi-band 160 (8 x 20) MHz IVC (IF-to-Video Conversion) and the complete correlator capacity (250.000 complex channels) of the DZB backend system. The version of TMS that has been delivered at the time of the grand opening only contained a basic functionality for the WSRT operations. At the request of the astronomers other observing modes have been added to facilitate creative use of the WSRT capacities, such as various mosaic modes, multi-frequency (frequency-switching), multi-subarray mode and 90 degrees phase-switching of the IVC. At the end of 2003 the TMS-6 package also controlled the TADUmin (first version of the Tied Array Distribution

Unit) in support of VLBI operations using the phased WSRT, while commissioning observations are in progress to support TADUmin for pulsar operations. The TADUmin instrumentation is only the first step towards a final version of the TADU. NWO funding has been received for the TADUmax project to implement recent technological advances in order to do the adding process in a technically correct manner.

The maintenance record of the WSRT system is keeping up well, and few operational surprises are encountered during 2002. Preventive maintenance produced good news overall. The WSRT group continues to work on RRQ programs (Robust, Reliability and Quality of data) for the mechanical integrity, receiver operations, and the operational reliability of the fourteen antennas.

The Observatory is in the process of adopting the management practices that are used elsewhere in ASTRON. While astronomical institutes have traditionally been concentrating on science issues, some technical projects could have a tendency to have cost and time overruns. The Observatory has been working to map out manpower and material needs of the internal technical development projects as well as the projects done in collaboration with the Research Laboratory and external partners. Time accounting has now been introduced in the Observatory, and it is being used to monitor progress, and for internal accounting. The Observatory staff works together with the Research Laboratory on the projects: TADUmin and TADUmax, the 3.6 cm polarizer project, the prototype 110-170 MHz receiver project, and the IVC-DZB commissioning. Besides this the Observatory carries the following projects: a 6 GHz receiver for RT7, 3D visualiza-



The Westerbork Synthesis Radio Telescope

## 3. Radio Observatory

tion of radio astronomy data as part of an EU software projects initiated by the Bologna group, the RFIMS system described below for installation at the 14 WSRT telescopes, the TMS-6 telescope management system, as data flow and archiving projects for the WSRT data.

### Paper Production

As part of the management procedures of the Observatory, a number of indicators have been identified. In all aspects, the WSRT performs well compared with similar institutes. In particular, the number of scientific papers output of the WSRT and the Observatory staff remains high as a critical parameter. Some 58 refereed papers are produced by Observatory staff and outside PI's using WSRT data.



The Westerbork Synthesis Radio Telescope

### The WSRT Upgrade Party and the ASTRON Open House

On Friday 18 October 2002 ASTRON officially celebrated the end of the WSRT Upgrade. An opening ceremony with a large number of invited guests from the Netherlands academic community, the surrounding municipalities, the Province of Drenthe, and the Division of Exact Sciences of the Netherlands Foundation for Scientific Research. The program of the Upgrade Ceremony consisted of the following parts:

1. Welcome - Prof. Dr. Harvey Butcher
2. Welcome and introduction - Dr. Ir. Willem Baan
3. Technical Aspects of het WSRT Upgrade - Ing. Rob Millenaar
4. Astronomical Success Stories - Prof. Dr. Ger de Bruyn (ASTRON & RUG)
5. Looking back on the Upgrade - Prof. Dr. Piet van der Kruit (RUG Astronomy)
6. NWO and ASTRON - mw. Prof. Dr. A.C.J. Hulk (NWO Council)
7. WSRT in Drenthe - Mr. Relus ter Beek, Commissioner of the Queen in Drenthe

Assisted by Dr. Baan, Mr ter Beek inaugurated the WSRT by putting in a command to start a pulsar observation. Via a live connection from the Control Room, the guest in the big tent could follow the actions of Mr. Ter Beek. The most important message of the Upgrade Party was to say a **big thank you** to all people that worked on the Upgrade: the engineers and scientists of the ASTRON Research Laboratory (TL), the people of the WSRT, the astronomical colleagues, the friendly money givers at NOW, and the Dutch tax payers. The Head of the WSRT Electronics Group, Millenaar, presented a long list of TL/WSRT workers that contributed to the success of the Upgrade. Various speakers brought out various aspects and memories on the ten-year Upgrade project. The progressive science enabled by the upgraded WSRT was emphasized and three new posters were presented.

The occasion of the WSRT Upgrade was used to stage two other activities. That same evening there was a successful Upgrade Party for all of ASTRON and JIVE. And on the following Sunday, there was an ASTRON-WSRT-JIVE Open House with an estimated number of 5000 visitors. The party tent was utilized as an exhibition hall of educational, technical and astronomical exhibits staged by the various ASTRON and JIVE groups and astronomy amateur groups. Outside there was a cherry-picker to bring people to the focal box of RT7, the geodetic Group from the Technical University of Delft showed gravitational measurement techniques, RT6 could be moved around with a joy-stick, and the THEA en LOFAR antennas were exhibited and explained. And a good time was had by all.



## 3. Radio Observatory

### 3.2 Science

#### 1. Gas and Dark Matter in the Outskirts of M31

R. Braun (ASTRON), E. Corbelli (Arcetri), R.A.M. Walterbos (NMSU) and D. Thilker (JHU)

The outer regions of spiral galaxies are important tools for understanding the basic processes of galaxy formation and the influence of the environment on their evolution. The lack of star formation due to the low gas column densities implies a quiescent gas which more closely reflects the primordial gas distribution. Moreover, outer disks enable direct measurement of the properties of the dark halo through the HI kinematics. Far from the optical edge, the dark matter halo becomes the only dynamically important component and many ambiguities present in the inner regions become less severe (e.g. the M/L ratio). Knowledge of the halo density profile in the outermost regions is essential for solving crucial issues at the heart of galaxy formation theories including the extent and the nature of the dark matter itself. Numerical simulations of structure formation in a Cold Dark Matter scenario predict, for example, a well-defined radial density profile for the collisionless particles from the center of the galaxy out to its virial radius (e.g. Navarro et al., 1997, ApJ 490, 493). On the other hand, a strong link between the radial distribution of the gas and of the dark matter could unveil a possible baryonic nature of the latter.

The nearby spirals M31 and M33 form especially unique targets, due to their obvious relevance for understanding the formation and evolution of the Local Group, but also because (1) their distances are well known, independent of  $H_0$ ; (2) the high angular resolution that can be obtained; and (3) the extensive information that exists at other wavelengths on the gas and stellar distributions. An example of the information that can be obtained from a careful analysis of the HI disk of M33 is given by Corbelli & Salucci (2000, MNRAS 311, 441) where, in the framework of CDM theories, the measured extended rotation curve implies a halo virial radius of about 100 kpc. If the dark matter halo of M33 extends this far, it is quite plausible that the M31 and M33 halos overlap. However, no such comparable study can be done for M31 without a new HI survey. A second important result obtained for the nearby galaxy M33 is the demonstration that the outer HI disk cuts off abruptly over only 1 kpc due to ionization by the extra-galactic radiation field (Corbelli & Salpeter 1993, ApJ 419, 104).

M31 is the largest and plausibly dominant member of the Local Group. We have obtained new WSRT HI observations of the M31 HI disk at high spatial and velocity resolution, with uniform sensitivity, to address the following issues.

1. The extended HI rotation curve and warp, and implications for the dark matter halo of M31.

Our survey is the first to combine high spatial and velocity resolution (50 pc and 2 km/s) across the entire 80 kpc extent of the HI disk, allowing for a detailed determination of the core and extended structure of the dark halo. For a proper determination of the rotation curve, it is essential to have a detailed understanding of the HI warp in the outer disk. Previous modeling of the HI warp (e.g. Henderson 1979, A&A 75, 311, Brinks & Burton 1984, A&A 141, 195) has been based on a combination of high resolution inner disk HI data and much lower resolution and sensitivity outer disk HI data. The models have all assumed a flat rotation curve, but no independent fit of rotation curve and warping of the disk has been attempted. In the case of M31, HI was previously detected out to 150' (31 kpc at 740 kpc), while the optical radius is  $R_{25}=95'$ , or 20 kpc. The column density limit of the earlier surveys was only  $5 \times 10^{19} \text{ cm}^{-2}$ , while our new WSRT total power data reach down to about  $1 \times 10^{18} \text{ cm}^{-2}$  for emission filling the 30 arcmin beam. Our synthesis survey region was chosen accordingly.

2. The radial decrease of the outer HI disk: measuring the extragalactic UV radiation field.

As the column density decreases, HI gas no longer remains optically thick to the external UV ionizing radiation and a sharp HI-HII transition occurs. This can be inferred from sensitive, high resolution HI maps of the HI decline in outer disks. Complementing these maps with dynamical information on the dark matter distribution in those regions makes it possible to estimate the intensity of the UV background radiation field in the local universe, which is otherwise unmeasurable. Very few galaxies have been mapped at 21-cm with sensitivity as high as  $5 \times 10^{18} \text{ cm}^{-2}$  and even fewer have been observed with sufficient resolution to infer the sharpness of the HI-HII transition. Only in the nearby galaxies M33 (Corbelli & Salpeter 1993, ApJ 419, 104) and NGC3198 (Maloney et al. 1992, ApJ 398, 89) have previous 21-cm observations resolved the sharp truncation (about 1 kpc) of the HI disk.

## 3. Radio Observatory

Our M31 survey will give a new determination of the local UV field, thereby testing the M33 result and the derived constraints on the dark matter halos of both galaxies, because the derived background ionizing radiation fields should be the same in both cases. The SW side of M31 is the ideal place for this, as the velocities are well offset from Galactic HI and our deep total power observations have demonstrated that the edge will be well-sampled with our survey coverage.

3. HI morphology and velocity structure in M31: the two-phase medium in the inner and outer disk.

The VLA HI survey by Braun (1990, ApJS 72, 761) has delineated the two-phase HI medium in M31 through detection of a high brightness, highly filamentary cool HI medium over the inner HI disk with an increasing temperature with radial distance from the center (Braun 1997, ApJ 484, 637). The new data will allow us to study the radial distribution of the two phase medium i.e. how far out in the disk large HI cloud complexes exist as part of the high density phase of the ISM inside a warmer and diffuse gas. The presence and the size of the clouds depend on the gas thermal pressure (especially outside star forming regions such as in outer disks) and on metal abundances (e.g. Wolfire et al. 1995, ApJ 443, 152). Therefore, information on the cloud distribution can be used to trace the metal enrichment process and the heating mechanism in the absence of stars. Related to this subject is the overall question of HI morphology and small-scale velocity structure in- and outside the starforming disk; is the outer HI disk as structured as that at smaller radii, and if so, what shapes and stirs it?

4. A search for HI clouds and streams: continuing gas accretion in the outer disk?

A search at the 7.5 kpc spatial resolution of our WSRT autocorrelation data for faint cloud complexes has recovered a previously discovered extended HI cloud near M31 (the "Davies cloud" (1975, MNRAS 170, 45p)) and a new extended HI tail on the other side of the disk. How are these features related to M31? A stellar counterpart to our HI tail has been found by Ibata et al (2001, Nature 412, 491). Continuing accretion of gas in galactic disks has become one of the standard assumptions in understanding the chemical evolution of spiral disks (e.g. Chiappini et al. 1997, ApJ 477, 765, Cuillandre et al 2001, ApJ 554, 190), yet concrete observational evidence for this process is absent.

Smoothing the proposed survey data to 0.5 kpc spatial resolution will give us information on the extent of the gas at column densities approaching  $10^{18} \text{ cm}^{-2}$ , comparable with high redshift Lyman Limit Systems, and therefore will give us information on whether LLS are more likely progenitors of isolated clouds and of low luminosity dwarf galaxies, or if they were extended faint outer disks connected with the bright luminous part of galaxies.

In short, our observations provide the most detailed view yet of the HI disk of any galaxy ever observed (50 pc beam over a 80 kpc source) and may shed significant new light on these important questions.

The synthesis data were acquired in the WSRT maxi-short configuration during the period Aug. 2001 to Jan. 2002. A Nyquist sampled (15 arcmin spacing) pointing grid was defined in the M31 (major,minor) axis coordinate system. A total of 162 pointing positions were chosen from this grid to provide good coverage of the region of HI emission indicated by our previous WSRT total power survey of a 6x6 degree field, as well as sufficient (empty) background. A total of 27 tracks of 12 hour duration were acquired, each sampling 6 different pointing positions. Each 12 hour track consisted of cycling through the 6 relevant pointing positions with a series of 10 minute snap-shots. Calibration and flagging of the data were done in Classic AIPS. After external band-pass and gain calibration, each pointing was self-calibrated using the continuum emission which happened to be present. The continuum model of each field was subtracted from the visibilities and residual continuum was removed with UVLIN. A joint deconvolution of all 162 pointings was done with Miriad's MOSSDI, after forming a weighted sum of the combined dirty synthesis image with a relevant total power image. The large physical memory (2 GByte) required to carry out joint processing of even a single spectral channel was found in a Dec Alpha machine operated by the PuMa II group in Amsterdam purchased with NOVA funding. Individual channels required about 5 CPU hours processing. The 300 independent spectral channels (each of 2 km/s width) containing M31's HI emission therefore required some 1500 CPU hours. This was carried out in parallel using the 4 CPU's (and 8 GByte total memory) of the PuMa II machine over a period of several weeks.



### 3. Radio Observatory

A first glimpse of the resulting HI database is given in Figure 1, where an image of peak brightness temperature is presented at the full spatial and velocity resolution (of about 50 pc and 2 km/s). Displayed brightnesses range from about 2 to 145 Kelvin and are presented with a square-root transfer function to accommodate the large dynamic range. Intricate detail is apparent in the inner disk, while warping and streamers are seen at larger radii. The diffuse feature located about 2 deg. to the NW of the M31 nucleus is Davies' compact high velocity cloud. Recent WSRT imaging of this source (De Heij et al. 2002, A&A 391, 67) suggests that this object may currently be undergoing a tidal interaction with M31. HI streamers extend more than 3 deg. to the South of the M31 nucleus. Some of these are coextensive with the optical streams seen by Ferguson et al. (2002, AJ, astro-ph/0205530). These streams presumably represent ongoing gas accretion onto the M31 disk from disrupted or stripped satellites. Extensive analysis of the M31 database is now underway.

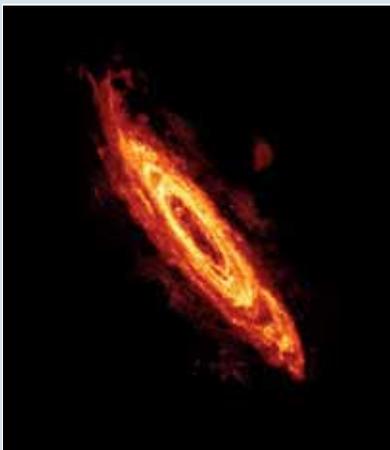


Figure 1

#### 2. Subpulse Drifting in Radio Pulsars

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In the thirty years since their discovery, drifting subpulses have featured in many discussions about the nature of pulsars and the pulsar's emission mechanism. The subpulse-drifting phenomenon in itself is simple: when comparing adjacent individual pulses, the subpulses that

comprise them are seen to shift regularly through the average pulse window. The left panel of the figure, for example, shows a recent WSRT/PuMa observation of radio pulsar B0809+74 in which these subpulses form their driftbands.

The drifting subpulse phenomenon can be explained with radio emission being formed in discrete locations ('sparks') on a circle around the pulsar's magnetic pole. We observe each spark as a single subpulse and their carousel-like rotation around the pulsar magnetic pole causes the subpulse drifting.

Occasionally however, the pulsar ceases to emit. In the figure, it does so from pulse 30 to 40 — but the mechanisms behind these so-called nulls are still not clear at all. It is interesting to note that the position of the subpulses is identical before and after the null. Furthermore we see that the drift rate is less after a null. We have used this drifting-nulling interaction to probe the mechanisms of pulsar emission and nulling.

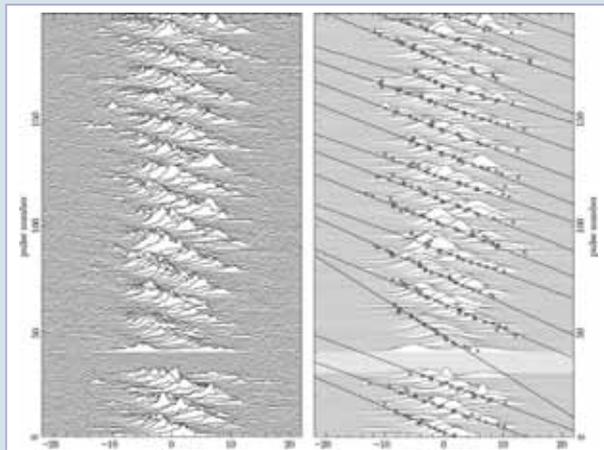


Figure 1 Example of the fitting of the subpulses for radio pulsar B0809+74. Left panel: stacked pulses, observed with WSRT/PuMa, in the on-pulse region (one whole pulse period is 360off). Right panel: after finding nulls (lighter colour), and fitting subpulses (crosses at the base of the fitted Gaussians), we fit the driftbands (black lines).

#### Recent discoveries with WSRT/PuMa

Over the last two years, we have built a set of high quality 0809+74 observations, all taken with WSRT/PuMa. We find that the drift pattern of the 0809+74 subpulses comes in two modes: the first one is the normal one we see in the figure (although it is disturbed by the null there). The second one is much more rare, and stable

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only on a timescale of about two minutes; in it, the subpulses drift less fast, but they are also wider and more closely spaced. To cause these changes in the subpulse behaviour, clearly something must have changed on or near the pulsar.

Yet to infer the actual emission region changes from this new drifting pattern we need to solve the so-called alias order problem: when all subpulses are identical, the shift of an individual subpulse cannot be determined. Looking at the figure, we see that if we compare the subpulses in pulse 1 with those in pulse 2, they may have moved either a little to the left, or much to the right.

For  $\text{PSR-B0809+74}$  we devised a new method that exploits the aforementioned drifting-nulling interaction to solve for the alias order. We find - contrary to the expectations of many - that the subpulse drifting in  $\text{PSR-B0809+74}$  is not aliased. That means the 'sparks' rotate only very slowly around the pulsar magnetic pole, taking approximately 200 seconds to finish one revolution.

With this,  $\text{PSR-B0809+74}$  is only the second pulsar for which the carousel rotation time is known. It is interesting to note that the rotation time is about two orders of magnitude larger than was predicted by theories on pulsar emission, indicating these theories are not yet correct. With a rotation time now actually observed, we expect to improve emission theories.

We can now use the absence of aliasing to determine the underlying changes in the subbeam-carousel geometry, and show that after nulls, the subbeam carousel is reduced in size, suggesting that it originates lower in the pulsar magnetosphere. The many striking similarities with emission at higher frequencies, thought to be emitted lower too, indicate that after nulls we look deeper in the pulsar magnetosphere than we do normally.

That means we have also come one step closer to understanding the nulling mechanism: this change in emission height indicates an increase of the particle velocity and/or a decrease in plasma density after nulls.

### Further reading

van Leeuwen, Kouwenhoven, Ramachandran, Stappers & Rankin "Null-induced mode changes in  $\text{PSR-B0809+74}$ ", *A&A*, 387, 169-178 (2002).

van Leeuwen, Stappers, Ramachandran & Rankin

"The subpulse-drift alias order of  $\text{PSR-B0809+74}$ ", *A&A*, submitted.

### 3. The shroud around the twin radio jets in NGC 1052

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The LINER elliptical galaxy NGC 1052 has an unusually prominent central radio source (1 to 2 Jy). It is variable on timescales of months to years and has a fairly flat spectrum between 1 and 30 GHz, which has sometimes been classified as Gigahertz peaked. The overall radio structure is core-dominated, and has two lobes spanning only about 3 kpc, so that NGC 1052 meets the traditional size limit for Compact Steep-spectrum Sources (CSSs), but not for Compact Symmetric Objects (CSOs). We have used the powerful multi-channel, wideband IVC/DZB on the WSRT as well as VLBI observations which reach sub-pc scales (1 mas  $\sim$  0.1 pc with  $cz=1474$  km s<sup>-1</sup> for  $H_0=65$  km s<sup>-1</sup> Mpc<sup>-1</sup>) for a detailed study of the active nucleus and its inner environment. A more extensive analysis of the results presented below is in Vermeulen et al. (2002a *A&A* submitted, 2002b *PASA* submitted).

Ten epochs of 15 GHz VLBA data show a two-sided source, with oppositely directed, slightly curved jets and a prominent gap 0.1 to 0.2 pc west of the brightest feature in most images. Features on the two sides move in opposite directions with roughly equal apparent velocities of  $0.26 \pm 0.04c$ . Using these error margins, the jets must be oriented at most 33° from the plane of the sky.

In the inner parsec, VLBA observations at seven frequencies between 43 and 1.4 GHz, show spectral shapes which proceed in both jets from steep, through convex, to highly inverted towards the middle, and are connected with low brightness temperatures and the distinctive central hole. This can only be reasonably explained by free-free absorption, probably due to a geometrically thick disk- or torus-like ionised region which is likely to be more or less perpendicular to the jets, with the eastern jet approaching and the western jet receding, because the latter shows more absorption. The deepest absorption seen,  $\tau \sim 1$  at 43 GHz over the central region, would imply a volume density of  $n_e \sim 10^5$  cm<sup>-3</sup> if free-free absorbing gas at  $T=10^4$ K were distributed uniformly along a path-length of 0.5 pc.

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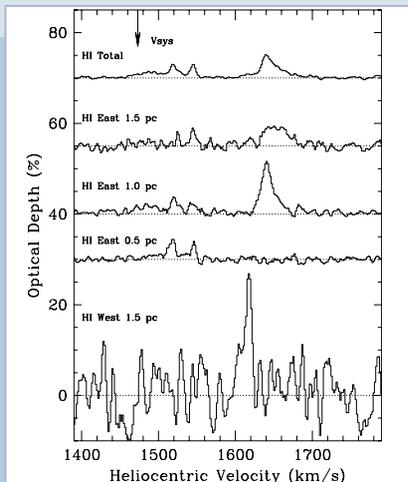


Figure 1 (label spectra)  
 Left: HI optical depths at various locations along the VLBI jets of NGC 1052; dotted lines show the zero levels. Right: WSRT optical depth measurements (negative is emission) for all four 18 cm OH lines. The offset zero lines are indicated; also note the different scale for our integrated VLBI HI spectrum, shown convolved to the same resolution for comparison.

We think there are three different HI absorption systems towards NGC 1052, at least two of which are probably due to atomic gas on parsec or sub-parsec scales, local to the AGN environment, rather than distributed on galactic scales. The most remarkable one is redshifted by 125 to 200 km s<sup>-1</sup> with respect to the stellar systemic velocity. Our VLBI spectral imaging shows “high velocity” atomic gas only at 1 to 2 pc along both jets ( $\tau=5-20\%$ , Figure 1 left panel). This could well be in an annulus around the ionised, free-free absorbing gas, as one might expect given that the innermost region and/or the surface of an accretion disk or torus receive the most intense ionising radiation. An HI optical depth of 20% with a FWHM of 20 km s<sup>-1</sup> implies a column depth of  $N_{\text{H}}=1021 T_{\text{sp},100} \text{ cm}^{-2}$ , but conditions close to an AGN may well raise  $T_{\text{sp}}$  by one or two orders of magnitude.

We used the multi-channel wideband IVC/DZB backend on the WSRT to establish that the 1667 MHz and 1665 MHz OH absorption recently discovered over a limited velocity span by Omar et al. (2002, A&A, 381, L29) extends over at least as wide a range as HI (see Figure 1 right panel). The peak 1667 MHz depth, 0.4% in the high velocity system, suggests a column depth of order  $10^{14} \text{ cm}^{-2}$ . The 1667/1665 ratio ranges from near 1 at low velocities to approximately 2 in the high velocity system. The “high velocity” profile is remarkably similar to that of

total HI, and we suggest co-location of these atomic and molecular gas components. Interpretation of a tentative velocity gradient in HI across the nucleus as evidence for a rotating structure is contradicted by the fact that the centroid is redshifted by 150 km/s or more from the systemic velocity. But if this is instead infalling gas, the nature of the central hole in HI is unclear. The OH and HI gas probably does not coincide with the H<sub>2</sub>O masers at 0.1 to 0.2 pc along the receding jet (Claussen et al. 1998, ApJ, 500, L129), even though these are at the same velocity.

We have also discovered with the WSRT that the satellite OH lines are present: 1612 MHz in absorption and 1720 MHz in emission. Their conjugate profiles probably result from excitation in a far infra-red radiation field when the OH column density is sufficiently large; competing pumping mechanisms determine which line is in emission and which one in absorption in specific density and temperature regimes; we will model this with planned global VLBI OH observations in hand.

### References

- Claussen, M.J., Diamond, P.J., Braatz, J.A., Wilson, A.S., and Henkel, C. 1998, ApJ, 500, L129  
 Omar, A., Anantharamiah, K. R., Rupen, M., and Rigby, J. 2002, A&A, 381, L29  
 Vermeulen, R. C., Ros, E., Kellermann, K. I., Cohen, M. H., Zensus, J. A., and van Langevelde, H.J. 2002a, A&A, submitted  
 Vermeulen, R. C., Ros, E., Kellermann, K. I., Cohen, M. H., Zensus, J. A., and van Langevelde, H.J. 2002b, PASA, submitted

### 4. The Effervescent HI Disk of NGC 6946

R. Boomsma (Groningen), T.A. Oosterloo (Dwingeloo), R. Sancisi (Bologna/Groningen), J.M. van der Hulst (Groningen) & F. Fraternali (Groningen)

In our Galaxy, most of the interstellar matter is found in the disk. However, a significant amount of gas is present in the halo. This halo is found in a broad range of physical states, ranging from ionised gas at very high temperatures to large complexes of neutral gas. For most of this gas, its presence in the halo is thought to be related to the star formation in the disk. This star formation drives, through supernova explosions and stellar winds, large-scale flows of gas from the disk into

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the halo. In the halo, this gas cools and falls back to the disk. Such a large-scale gas circulation is commonly referred to as a galactic fountain. The intermediate-velocity HI clouds, and some of the high-velocity HI clouds, are related to such a galactic fountain occurring in the Galaxy. Apart from such fountain-related clouds, some of the HI clouds in the halo are thought to be of external origin and are small gas-rich objects that are being accreted by the Galaxy.

Although many of the basic processes involved in galactic fountains are understood, many fundamental questions remain. Moreover, not much is known about the characteristics of such gas flows in other normal spiral galaxies. The main obstacle is that very sensitive observations are required to detect such gas in normal spiral galaxies, given the faintness of the HI in the haloes of normal spiral galaxies. Recent deep HI observations of a small number of nearby normal spiral galaxies have started to reveal some of the properties of the neutral gas in the haloes of normal spiral galaxies and have demonstrated that very deep HI observations are very useful in understanding the physics of gaseous haloes in spiral galaxies.

To obtain a full observational view of the halo gas, observations are needed of a number of galaxies of various inclinations since projection effects allow to detect only certain components of the distribution and kinematics in a single galaxy. Edge-on galaxies provide information about the vertical structure and about the tangential motion. Observations of galaxies of intermediate inclination supply valuable additional information about the kinematics and the spatial distribution of the halo gas. However, to study the vertical motions of the HI and the correlation with other features in the disk of the galaxy, such as sites of star formation, observations of face-on galaxies are required. An excellent candidate for such a study is the galaxy NGC 6946. Previous WSRT observations (Kamphuis & Sancisi, 1993, *A&A*, 273, 31) had shown the presence of HI with large vertical motions. However, the limited sensitivity did not allow a detailed study of this gas. In the spring of 2002, NGC 6946 was observed for 16 x 12 hours with the WSRT, using the full capacity of the new IVC+DZB system. This resulted in one of the deepest HI datasets ever obtained of a nearby galaxy (and about a factor 5 deeper than the previous observations of NGC 6946).



Figure 1 The optical image of NGC 6946, as taken from the Digital Sky survey (left) and, on the same scale, the total HI image of NGC 6946 (right) as obtained with the WSRT

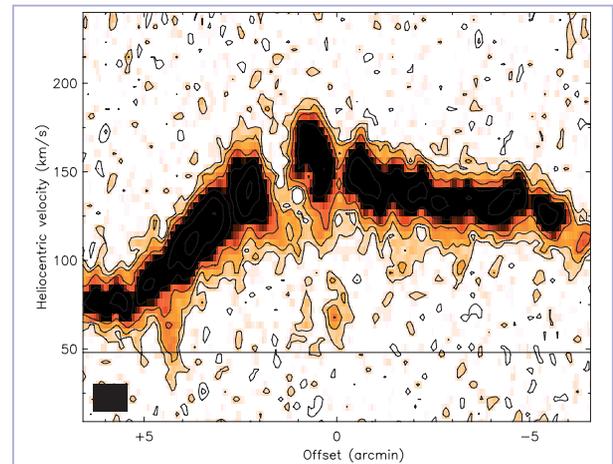


Figure 2 Position-velocity slice taken across one of the holes in the HI disk of NGC 6946. The hole is clearly visible as a gap in the HI of the disk. A small cloud of HI is detected with a velocity different by about 100 km/s from the local rotation velocity. The line profiles of the HI in the disk are asymmetric, indicating the presence of a diffuse HI component in the halo. The horizontal line indicates the systemic velocity

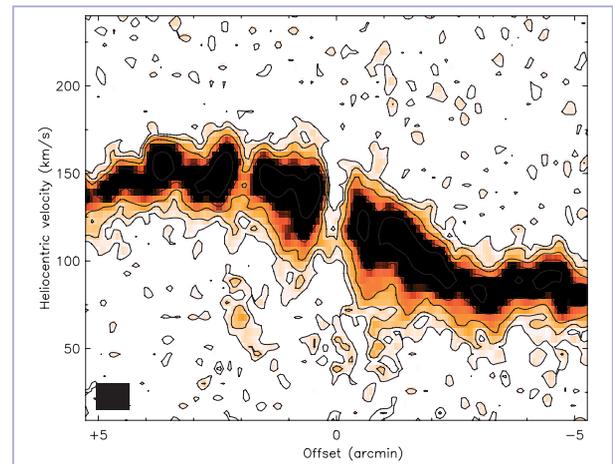


Figure 3 Position-velocity diagram slice taken across the large hole present about 10 kpc W of the galaxy centre. The diameter of this hole is about 3 kpc. Small clouds of HI with anomalous velocities are detected in the vicinity of this hole.



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The total HI image derived from the observations is given in figure 1, together with the optical image at the same scale. This image shows the intricate structure of the HI in great detail. It shows a beautiful spiral pattern that extends to well beyond the boundaries of the bright optical disk. It also shows the presence of many holes in the HI disk. Most of these holes are caused by star formation blowing the gas out from the disk into the halo. In many cases, clouds of HI are found near such holes. This is illustrated in figure 2 where the position-velocity diagram across one of the HI holes in the disk of NGC 6946 is given. Apart from HI in the regularly rotating disk, a hole in the disk is present as well as a cloud at an anomalous velocity. The velocities of such clouds are observed, as in figure 2, to deviate up to 100 km/s from the gas in the disk, indicating vertical outflows of that magnitude. In most cases, the HI clouds are found at velocities towards the systemic velocity, although in several places gas is detected away from the systemic velocity. The large number of holes and associated flows will allow to study the statistical properties of these features. A particularly interesting object is the large hole, of about 3 kpc in diameter, detected about 10 kpc W of the centre. The position-velocity diagram taken through this hole (figure 3) shows several small clouds of HI that probably originate in the hole. Not only in HI, but also in other wavebands, such as the radio continuum and optical bands, this hole is empty.

Not all features in the HI appear to be associated with star formation. An interesting example is a small hole near the southern edge of the HI disk. It is located well outside the optical disk and there are no optical features visible at the location and it is unlikely to be related to star formation. Near this hole, a small HI cloud with a velocity deviating 40 km/s from the disk gas is observed. Perhaps this feature is caused by the accretion of a small object. At a few other locations there is evidence for accretion of small HI clouds.

Apart from the clouds that are associated with individual holes, a more diffuse halo component is also detected. This component can be inferred from figure 2 by the asymmetric shape of the line profiles of the HI in the disk. This component is probably similar to the diffuse halo gas (a.k.a. the “beard”) detected in NGC 891 (Swaters, Sancisi & van der Hulst 1997, *ApJ*, 491, 140) and NGC 2403 (Fraternali et al. 2001, *ApJ*, 562, L47). As in these two galaxies, this diffuse halo gas shows lower rotation velocities than the gas in the disk. Given the large number

of holes with associated outflows detected, the observations of NGC 6946 will enable us to study, for the first time, the relationship between the outflows with the more diffuse HI halo and will allow us to build a more complete picture of the fountain flows in an external galaxy.

The observations of NGC 6946 show that very deep HI observations can reveal the HI in the haloes of nearby galaxies and that the properties of such halo HI can be studied in great detail. They also show that the much improved sensitivity and correlator capacity, combined with its traditionally excellent imaging characteristics, make the WSRT a very competitive instrument for doing very deep HI observations of nearby spiral galaxies.

### 5. A Serendipitous Search for HI Emission in Deep Radio Continuum Surveys

Raffaella Morganti (ASTRON), Michael Garrett (JIVE)

The superb sensitivity and wide-field capabilities of the upgraded WSRT, make it a very attractive instrument to conduct deep radio continuum surveys. The introduction of the new 160 MHz IVC/DZB backend now permits a 1-sigma noise level of ~10 microJy/beam to be obtained in a single 12 hour observation at L-band. Previous deep field studies using the old system (e.g. the HDF-N, Garrett et al. 2000, *A&A* 361, L41) could only attain these sensitivity levels by employing long integration times (several days), targeting relatively small regions of the sky. The impressive observing “speed” of the upgraded WSRT permits significantly larger areas of sky to be surveyed. This is an important advantage in carrying out detailed studies of the clustering properties of radio sources and the nature of the faint radio source population more generally. Even before the 160 MHz system was in place, the trend towards observing much larger areas of the sky had begun. In particular, de Vries et al. (2002, *AJ* 123, 1784) recently published a catalogue of over 3000 faint radio sources in an ambitious survey covering ~7 square degrees of the NOAO Deep Wide-Field Survey in Bootes. These observations reached a 1-sigma noise level of 28 microJy/beam - the new system permits areas of this size to be surveyed to much deeper sensitivity levels.

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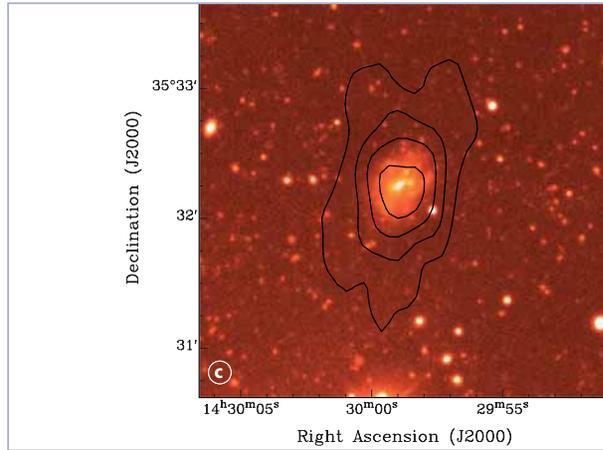


Figure 1 - WSRT 1.4GHz continuum image (contours) superimposed upon the NOAO optical image. The lowest contour is 40 microjy/beam.

The new system covers the full 160 MHz observing band (including all the polarisation products) with eight 20 MHz bands. Each of these bands can be independently tuned - the optimal continuum band thus avoids known areas of RFI (e.g. 1380 MHz at L-band) as well as galactic emission. Even in continuum mode, each band consists of 64 (or 128) channels - this is useful for RFI rejection but an interesting by-product is the possibility of detecting HI.

We have conducted a deep survey at the edge of the Bootes field. The WSRT observations were made in support of a deep, sub-mJy wide-field VLBI survey of a small area of the field, that includes a possible in-beam VLBI “calibrator”. Figure 1 presents a continuum WSRT contour map superimposed upon the NOAO optical image of the same field. The measured r.m.s. (1-sigma) noise level is ~13 microjy per beam - close to the limit that is expected from the thermal noise characteristics of the array and various problems that arose during the observations (in particular solar radio emission in the last few hours of the observations).

#### A Serendipitous Search For HI Emission

For these observations we used the default continuum set-up that is now being adopted with the new 160 MHz system. Six of the eight 20 MHz bands are then located at frequencies below 1421 MHz, thus covering a range of frequencies where emission from neutral hydrogen redshifted up to  $z \sim 0.1$  (i.e.  $\sim 28000$  km/s) may be observed. The 64 channels used for each 20 MHz band

ensure a velocity resolution of about 60 km/s. This velocity resolution is good enough to distinguish between single or multiple galaxies, and, for the more massive ones, even measure the rotation velocity. The noise that is reached for every channel in a 12 hour observation (using natural weighting and Hanning smoothing of the data) is about 0.1 mJy/beam. A standard continuum observation is therefore well suited to a serendipitous search for HI emission in the observed field.

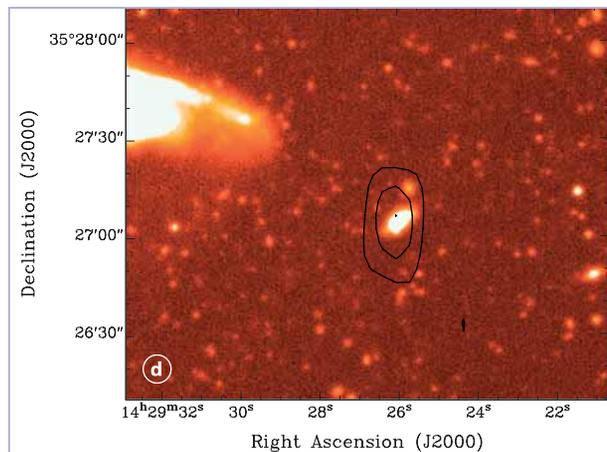


Figure 2 - An example of position (r.a.) vs velocity plot obtained for a constant declination in the continuum-subtracted cube. One of the HI detections is shown in the plot.

The presence of HI emission can be detected by generating a data cube from the full visibility data set, after subtracting all the associated continuum CLEAN components. We have performed this for our observations of the Bootes field, and at least four HI detections have indeed been found in a radius within  $\sim 15$  arcmin of the field center. In Figure 2 we present an example of a position (r.a.) vs velocity plot obtained for a constant declination in the continuum-subtracted cube. One of the detections is shown in the plot, and the rotation of the galaxy is clearly visible.

The HI distribution, superimposed on the optical image of the four detections, is shown in Figure 3. Only for one nearby object, NGC 5656, was the presence of HI already known (Figure 3a). This galaxy is situated at a velocity of 3150 km/s and includes about 5 times  $10^{10}$   $M_{\odot}$  of neutral hydrogen. Extended radio continuum is also detected in this galaxy. A second detection was found coincident with the faint galaxy MCG+06-32-054 at  $\sim 4080$  km/s (Figure 3b). Here the radio continuum is much

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weaker with a peak flux density of only  $\sim 60$   $\mu\text{Jy}$ . At 4500 km/s neutral hydrogen was detected corresponding to an anonymous galaxy (Figure 3c). No radio continuum (to a  $\sim 3$ -sigma level of 40  $\mu\text{Jy}$ ) has been detected in this case. Finally, neutral hydrogen was also detected at a velocity of 9500 km/s (Figure 3d). The peak of this HI emission is only about 0.8 mJy. A rough estimate of the HI mass gives  $\sim 4 \times 10^8 M_{\text{sun}}$  (for  $H_0=65$  km/s/Mpc). The bright galaxy visible in the optical image next to this HI detection is NGC 5646. HI emission from NGC 5646 is not detected - with a velocity of 8576 km/s it falls within a gap between two of the 20 MHz bands, a known region of RFI.

An estimate using the HI mass function (Zwaan 2000, PhD thesis), suggests that every field observed with a similar depth, should contain a handful of objects with detectable HI emission. The majority of the expected objects will be  $M^*$  galaxies, i.e. galaxies with an amount of neutral hydrogen between 109 to 1010  $M_{\text{sun}}$ . The bias toward the detection of massive systems is partly due to the coarse velocity resolution that is obtained using the “default” continuum set-up, which normally would be done with full polarization (note that the velocity resolution can be improved by a factor of two by sacrificing two polarisations).

### More Possibilities With the New System

The new IVC/DZB backend at the WSRT provides a number of new possibilities for deep surveys. The default continuum configuration using the 160 MHz band, permits very sensitive observations to be made, reaching  $\sim 10$   $\mu\text{Jy}$  in 12 hours (L-band). The impressive observing “speed” of the new instrument allows vast areas of the sky to be surveyed in relatively modest integration times. As described above, the default spectral line mode used for all standard continuum observations, permits, without adversely affecting the continuum observations in any way, to search for HI emission in the field. In the example described here, the optimal set-up (in terms of frequency coverage and the RFI environment) has been employed, but nothing really prevents the user from centering the bands at even lower frequencies. For very deep continuum observations (many times 12h), a search for much more distant HI emission can then be conducted.

In addition, the 160 MHz-wide band combined with the spectral line capability permits both spectral index and

rapid changes in the rotation measure to be determined for continuum sources in the field. Like the HI capability, such measurements also come “for free”, and are useful by-products that can now be extracted from every continuum observation.

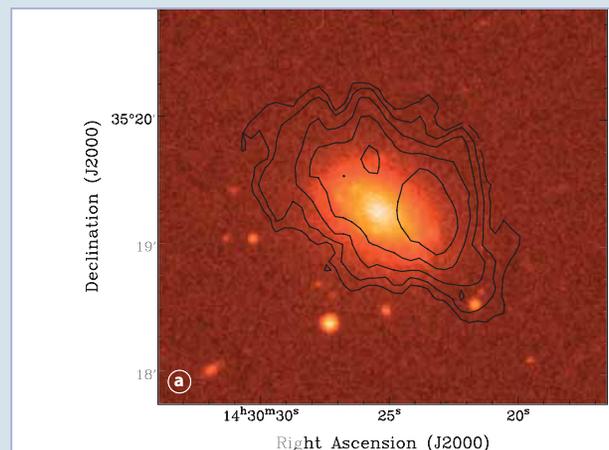


Figure 3 - The HI distribution, superimposed on the optical image, of the four detections in the Bootes field.

Finally, we note that as the WSRT archive becomes populated with new data from the IVC/DZB system, there will be an important opportunity to automatically extract a wide-range of information from standard continuum data sets. Such developments are timely, and are particularly interesting in the context of Virtual Observatory tools and applications. In any case, it will be wise to “mine” such archives with the understanding that various products can be derived, not only the total intensity or polarization images.

### 3.3 WSRT Activities

#### 3.3.1. WSRT Software group

In 2002 a major part of the efforts of the software group at the WSRT has been aimed at making the new DZB-Nominal system fully operational, and at expanding the possibilities for using this new backend, with TMS, for astronomical observations.

The year 2002 has seen many highlights in the WSRT software group. Many of these were related to the successful integration of the DZB-Nominal system into the TMS-software (Telescope Management System).



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The DZB-Nominal system allows the use of 250.000 complex channels, which can be divided over 8 eight bands of maximum 20-MHz bandwidth each. After initial test observations, the first successful 160-MHz production observation was carried out in the first week of April. Thanks to this rapid deployment of the software control, the astronomical commissioning phase could be started swiftly. As a result of the commissioning work, various bugs still residing in the IVC/DZB hardware, as well as some flaws in the control software, were found, isolated and repaired.

After delivering full control of DZB-Nominal, TMS efforts concentrated on enabling various observing modes with the DZB-Nominal system. By the end of the year, TMS supported the following observing modes: position-mosaicing observations, so-called drift-scan observations (i.e., observations with fixed telescope positions) and observations in which the telescope array is split in several independent subarrays observing at either different frequencies (the so-called multi-frequency mode) or at different positions on the sky (multi-pointing mode). Also, 180-degree phase switching in the IVC, which suppresses artifacts ("ghosts") in spectral line observations, and the subsequent demodulation in TMS, was enabled in the summer of 2002 and has been operating ever since. In 2003, TMS will deliver, among other modes, 90-degree IVC phase switching, front-end phase switching, so-called frequency mosaicing (regular switching between separate observation frequencies during an observation) and the ability to divide the correlator capacity into up to eight independent correlator subarrays. This will make the WSRT an even more flexible and versatile instrument.

After the delivery of the new Tied Array Distribution Unit (TADU-min) in 2002, as part of the Westerbork upgrade, much effort was put into integrating the setup and control of this instrument in TMS. As a result, specification, scheduling and controlling observations with VLBI and PUMA can now be fully handled by TMS. For PUMA, this has the great advantage that remote operation has become possible. As soon as the remaining issues with TADU-min have been solved, the old Adding box can be removed. This will most likely occur in early 2003.

Enabling full control of the DZB-Nominal system was marked by TMS release 5 on April 15th 2002. The next TMS release, TMS 6, will occur when TADU-min control has been fully enabled in TMS.

The WSRT off-line software has been developed further as well. Several databases, which used to be implemented as AIPS++-tables, have been ported to the MySQL database system, which has proven to be a fast and highly reliable freeware database system. Also, we have enabled a new pipeline that makes products, such as plots and data decomposition files, intended for data quality inspection. The pipeline has been build built largely with components of the in-house developed IWOS package. We have made the pipeline products available to local users (such as inspectors, observers, friends of projects) on the intranet, so that these can have a quick look at the quality of the data shortly after an observation has been finished.

The archiving and exporting facility has seen several enhancements in 2002. We have enabled archival and export of data products to the astronomical community on DVD-R. A plan has been made to migrate the data archive from the current CD/DVD-based archive to a disk-array based archive. Two 4-Tbyte disk systems have been purchased, each of which will be filled with all Measurement Sets produced by the WSRT since 1998. As more data is produced in the future, this archive will be expanded with more storage capacity. The main advantage of having a disk-based archive system is the direct access to all stored datasets, which is a first step in making the WSRT data archive available on-line in a Virtual Observatory-like environment. The disk-based archive will be fully operational in 2003. One of the two systems will be moved to Dwingeloo once the Gbit-connection between Dwingeloo and the WSRT is operational (half 2003). This is required for improved data security and rapid access to the data archive for local Dwingeloo users.

The TMS software embodies many AIPS++ modules and much of its functionality. This requires a constant effort since AIPS++ is still very much a developing package. In 2002 we have upgraded our local AIPS++ distribution four times. The version numbers we have used are 18.000.00 (June 10th), 18.127.00 (August 12th), 18.277.00 (October 26th) and 18.322.00 (December 2nd). The use of AIPS++ within TMS gives rise to occasional problems. The main problem areas are the stability of the table system, the handling of coordinate and IERS information and the support for AIPS++ on HP-UX systems. Also, there is an ongoing discussion on the contents of a WSRT Measurement Set (the AIPS++ data format). In 2003, it is planned that an AIPS++ programmer will be added to the WSRT software group, who should bring some relieve in



## 3. Radio Observatory

these areas. An effort will be made to decrease dependence on the AIPS++ package by gradually phasing out the use of AIPS++ tables, and by removing AIPS++ dependence as a whole on the HP-UX machines.

After being TMS project leader for 3 three years, Mark Bentum has accepted a position elsewhere in the organization. Arno Schoenmakers has taken over Mark Bentum's role as TMS project leader as of October 1st 2002.

### 3.3.2. WSRT Computer systems and network

A new central switch, the Nortel Passport 8600, replaced all existing switches and routers, and all internal network connections. All internal network connections are fiber based and 100 Mbit/s. The high-performance back plane of the Nortel switch allows us to easily upgrade the network to 1 Gbit/s, as is envisioned to be connection speed between the WSRT and Dwingeloo buildings at the end of 2003.

The DZB data acquisition machine HP9000/C200 has been replaced by a C3600. This was required to be able to control and read out the DZB-Nominal system. For the moment, it operates with HP-UX 10.2. Furthermore we have purchased several fast new PCs running Linux (wop10 – wop17), which allow us to produce automatic plots and inspection reports for the larger datasets coming from the DZB-Nominal system. To minimize the burden of maintaining many Linux hosts at the site, we are planning to migrate user's PCs to Windows 2000 so that system management in Dwingeloo can maintain these centrally. A fast PC running Linux, in combination with the Exceed remote connectivity software, will then be used as a Linux host and window manager for several users.

We have put quite some effort in separating the on- and off-line parts of the network, by limiting the number of NFS mounts between these two areas. This should ensure that an observation is not influenced because of a system or network problem in the off-line area.

The TMS web environment has been moved from the HP-UX 10.2 machine wawo3 to the Linux PC wop17. This move was instigated by the better availability of web-design tools for Linux systems, and the improved security

of the newer Apache servers for Linux.

In 2002 we have also seen an increase in the demand for network connections for laptop computers. Unfortunately, this has led to an increase in the use of (copper) UTP network cables, fiber-to-UTP devices and UTP network hubs with the increased risk of RFI production. This development is not reconcilable with the effort and money that was put in making a fiber network available in the building for RFI suppression reasons, and we will have to decide in the coming year how to deal with this situation.

### 3.3.3. Multi Frequency Front Ends (MFFE)

The full suite of 14 front-ends has been available for virtually 100% of the available observing time. This implies that again, the reliability of the front-ends has been quite good. In 21 cases front-ends were replaced with one of the two available spares. The types of faults encountered during the year were defective or bad LNA's in 6 six cases, defective LO's in 2 two, 3 three defective noise sources, 6 six cryogenics related complaints, and the rest were miscellaneous miscellaneous faults. In previous years components in the LO system have been a source of trouble involving high repair cost. During the past year this seems to have been less of a problem. No significant changes to the system were made during 2002.

A study was started to investigate the feasibility of building a single front-end dedicated to single dish VLBI work in the methanol line. A preliminary design for a cryogenically cooled circular polarization receiver, operating from 6.0 to 6.8 GHz was made. The project was started up and will be finished in 2003.

### 3.3.4. VLBI operation

#### Observing sessions

During 2002 the Westerbork tied-array took part in VLBI observing sessions in February, May and November.

#### Tied array interface

For the first 2 VLBI sessions the VLBI system used the old (WADDS) tied array interface to the DCB continuum system. After finishing the upgrade (October 2002), the VLBI system was connected to the new (TADU-min)

## 3. Radio Observatory

tied array system. The advantages of this are:

- The new tied array is part of a line correlator, so the parallel data stream allows for better checking of delay offsets and bandpasses.
- The IVC works with 20MHz bands instead of 8MHz (folded) bands in the DCB IF system. Hence recording of 16MHz VLBI bands becomes possible as well as simplifying the interface to observe both 8MHz of lower sideband and 8MHz of upper sideband for the same recording channel.
- The conversion of linear polarization in the receivers to circular polarization for the VLBI recording takes place at an earlier stage in the signal path, and can in principle be adjusted more accurately. This also avoided the old IF/Polarization selection box, which was known to have significant crosstalk problems.
- The data taken in parallel by the DZB correlator can be used for spectral line observations.

In order to get this working we needed the new (IVC) IF system and (DZB) correlator to be operational, and the adding board to be connected into the back of the A/D conversion system after delay compensation. The output also needed external signal equalization and filtering. The cabling and final local oscillator and mixer systems were also modified. The adoption of this new hardware also involved new online software and major changes to the mixing scheme and schedule preparation software, as well as debugging parts of the telescope control system (TMS) that were only relevant to the TADU-min system. The switching of telescopes in and out of the tied array is now under software control, and so can be logged.

### Field system

For 2002 Westerbork continued to update to the latest versions of the VLBI Field System (FS) software. This was necessary to follow developments in recorder technology and calibration software.

After the November VLBI session we also upgraded the Field System's linux kernel to Debian 3.0. Although this was not strictly necessary for the field system computer, it allowed us to setup a newer reserve computer. It was difficult to support newer computer hardware on the old linux kernel.

### Recording system

All observing sessions in 2002 continued to use both the Mark4 acquisition system and tape recorder. Westerbork also cooperated with JIVE in evaluating the disk based Mark5P recording system, from Haystack, and the PCEVN

system from Metsähovi. Both connected to the Mark4 formatter outputs and were observed in parallel with tape recordings, and both gave positive results with a minimum of operational and setup problems.

### Operations

A landmark for the operations this year was the start of DZB "Nominal/160MHz System" production observations. All of the spectral capabilities of the half-million channel correlator and the full sensitivity of the 160 MHz IF bandwidth are available; the WSRT 21cm line and continuum facilities are now of world-class. They account for the most heavily used observing modes of the telescope. In addition, the frequency agility of the MFFEs was once again put to good use, for rapid switches between observing bands both within and between observations: the WSRT is thereby able to cater efficiently to a suite of observing request with a breadth that would have been impossible to accommodate in the past.

At the end of 2002, the DCB remained in occasional use for projects with the highest demand on amplitude stability (pending further work in this area on the IVC), and for PuMa observations. Most continuum users have made the switch from the DCB to the IVC+DZB. This has the advantage of more sensitivity provided by the wider total bandwidth; it also offers superior spectral resolution, which can be useful to minimise the fraction of data lost to RFI, as well as for polarisation position angle rotation measurements.

PuMa observations were conducted regularly throughout the year, for many individual targeted observing projects, as well as a long-term timing programme. The WSRT has come to play the central role in Multi-Frequency Observations in which a number of telescopes around Europe observe pulsars simultaneously at many frequencies.

The November VLBI session was conducted for the first time with the TADU-min system. Performance was satisfactory, except for polarisation handedness errors in some bands, which can be easily rectified in future, and impurities in the polarisations, which will be improved with planned X, Y gain balancing inside the DZB. Various factors external to the WSRT have led to a fairly modest VLBI load in 2002.



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Given that commissioning work (DZB, IVC, TMS, TADU-min) continued to occupy a significant fraction of the available "office hours", the net time spent on production observations, close to 60%, is quite satisfactory. This production rate was reasonably well estimated ahead of time, and there was a normal throughput rate, so that the appropriate total load of project hours was admitted at each of the time allocation committee meetings.

Increasingly, there is a need for frequent reconfigurations of the array (telescope motions), resulting from requirements to observe at night, particularly at 92cm, in order to avoid RFI and solar fringes, combined with desires for multiple specific spacings, for instance for optimal wide-field imaging. The impact on the one hand on the work schedule of the mechanical group, and on the other hand on the mechanical condition of the telescopes, drives, connectors, and tracks, has to be carefully monitored; these may become boundary conditions on time allocation, and hence on overall telescope production efficiency.

With the use of the nominal IVC+DZB system has come a large increase in the data volume to be archived and exported. This has led to some logistical strains in the operations group. It is hoped that archiving on DVD instead of CDROM, which became available shortly before Christmas 2002, will provide some relief in the interim period until permanent online archiving can be implemented.

As of November, the operations group has been considerably strengthened by the full-time presence of the data quality analyst/inspector, who was previously charged part-time with user support in Groningen. The necessary dedicated person-hours are now available to circumvent the incompleteness of TMS databases, and to set up a robust administration of all observations in various stages of progress (preparation, scheduling, inspection, export). It is expected that this will also lead to more constant throughput rates in the future.

### 3.4 Geodesie

#### Activities on the Westerbork Astrometric Geodetic Observatory (WAGO).

##### Permanent GPS tracking

Time series of permanent GPS observations in the framework of the International GPS Service (IGS) and the Dutch Active Reference System (AGRS.NL) are built up since May 1997 and are still in progress. For the control of the antenna's vertical position, two GPS Turborogue 8-channel receivers were installed since January 2001 of which the antennas were placed on nearby situated stable locations, just above ground level. First careful analysis of these time series meets the expectations of the constructed vertical control assembly on the mm.-level.

##### Tidal gravity observations

Ocean tide loading is the deformation of the solid Earth due to the varying weight of the ocean tides. This is observed in GPS measurements where it is considered noise if one studies long term station motion or if one wants to estimate the water vapour contents in the atmosphere. Ocean tide loading is also visible in continuous relative gravity measurements, even much better than in any other measuring technique. Therefore, it has been decided to measure this gravity signal to study loading effects and if possible, to improve the ocean tide loading corrections for GPS observations. Westerbork is a very suitable location to perform this experiment because it is about 50 km away from the North Sea. This is far enough to avoid large influences of the ocean tides directly bordering the coast. Ideally one wants to measure the loading effect due to the whole of the North Sea, not only due to the first few kilometres of water north of Holland. On the other hand, Westerbork is close enough to the coast to observe a measurable loading signal and detect differences in the computed loading values when different ocean tide models are used as input. The loading signal will be around 5 mGal (5 10<sup>-8</sup> m/s<sup>2</sup>), which still requires very sensitive instruments. For that purpose a LaCoste & Romberg gravimeter specially designed to measure tidal phenomena was borrowed from the Proudman Oceanographic Laboratory, Liverpool, United Kingdom. This instrument has been transported to Delft in June 2002 by car and ferry. To operate this instrument, named ET15, two new large batteries with chargers and a data acquisition system have been purchased. After initial testing the ET15 was moved in

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October to Westerbork. Since the data acquisition system is able to measure 20 signals, the LaCoste & Romberg gravimeters G-785 owned by the Delft University of Technology and the G-971 of the Survey Department of Rijkswaterstaat were also installed in the bunker.



Fig. 1. Set-up of the 3 gravimeters, from left to right the ET15, the G-785 and the G-971.

The output of the LaCoste & Romberg gravimeters is given as a voltage. Naturally, it is desired that these voltage changes are linear with gravity variations. To test it known gravity variations were simulated by changing the screw of the instruments by a fixed amount. This changes the spring force that on its turn is compensated by the feedback system. When these steps cover the whole range of the feedback system, the linearity of the system can be investigated. For the instruments G-971 and G-785 a large quadratic dependency was found which will need to be included in the transformation from voltage to gravity variations. For the ET15 the quadratic dependency could be eliminated by changing the drive offset voltage. To separate the different computed ocean tide loading values using different ocean tide models, a resolution of about 0.2 mGal is needed. The largest signal in the observations is due to the Earth tides causing an amplitude of about 200 mGal. This results in a required accuracy for the calibration value of 0.1% in amplitude and phase. The ET15 has been calibrated to this level in 1988. To check if this calibration value is still the same, Olivier Francis of the European Center for Geodynamics and Seismology (ECGS), Luxembourg, was invited to come to Westerbork in October 2002 with his absolute gravimeter of the type FG5. By parallel measuring for seven days the variations in the data of the ET15 could be scaled to the variations in the data of the FG5.

Unfortunately, Holland experienced that week the biggest storm for a decade. This resulted in high noise levels and only an accuracy of 0.83% in amplitude could be achieved.

To monitor the progress of the measurements, the PC in the bunker that is logging the data has been connected to the internet. This has been found extremely helpful because we have experienced some trouble with earthquakes. These are small quakes but they cause the beam of the gravimeters, of the ET15 in particular, to oscillate and it happens that they get stuck on the top or bottom of their range. By remotely checking the progress of the measurements these events can be spotted and action can be taken to get the instruments back in proper working conditions.



Fig. 2. The ET15 set-up in the Westerbork bunker, in front the gravimeter and in the back its feed-back system.

#### Gravity and atmospheric loading

One of the activities in the Westerbork gravimetry bunker has been performed within the framework of a student's graduating project. A study was drawn up to quantify the effect of atmospheric loading on gravity at the Westerbork measurement site. Atmospheric mass variations imply a varying gravity value. These atmospheric mass variations can be represented by air pressure variations, so the relationship to be sought is one between local air pressure variations and gravity measurements. The gravity measurements were performed by two gravimeters of the Scintrex CG-3M Autograv type. These gravimeters were measuring simultaneously during a time span of 80 days. The measurements were adjusted for several unwanted effects, both originating from geophysical and instrumental sources. Corrections were made for the Earth tides, the ocean loading effect and several spikes in the data. The most difficult part was estimating a proper function to model the long-term



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instrumental drift, which did certainly not show a linear development.

After the gravity signal was corrected for these disturbing effects, the residual was compared to the pressure signal by means of a linear regression. Results similar to the standard -0.3 mgal/mbar were found. A more precise relationship could not be derived, because the residual signal was heavily dominated by another disturbing effect, which could not be traced at that time. Research is still being performed to explain this residual disturbance in the gravity signal. In this, use is made of combining the gravity signals of both Scintrex gravimeters.

Because the Westerbork station is a fundamental station - in being a first-order point in the Dutch gravity datum and being a site at which several types of geodetic measuring techniques are collocated-, a precise correction factor for air pressure variations is indispensable.

### 3.5 Spectrum Management

#### Relations with the Government

Baan participated in various Netherlands coordination meetings on the national use of spectrum in the NFC forum (Netherlands Frequency Commission) as advisory group to the Minister of Traffic and Waterworks and since July 2002 part of the Ministry of Economics. Baan represents the Ministry of Education, Culture, and Science (OCW) in the area of scientific spectrum management. In addition, ASTRON staff participated in the NVC forum (Netherlands Conference Preparation Committee), which prepares the Netherlands position for the ITU-R World Radiocommunication Conference (WRC-03) in 2003. Regular contacts have also been maintained with the Radiocommunications Agency Netherlands (Agentschap Telecom, former RDR) of the Ministry of Economics on current spectrum issues and the protection of passive bands, and for keeping track of announcements of new satellite systems from the ITU.

Observatory staff members also participated in various meetings on PLT (Power Line Transmission), which is a system using less than 30 MHz modulations of the existing power grid. Such a system would have a strong impact on LOFAR.

The Conference Preparatory Meeting (CPM-03) for the upcoming WRC-03 was held in November in Geneva.

Spoelstra (CRAF Spectrum Manager) and Baan actively participated in this meeting. During 2002 Task Group 1-7, chaired by Baan and Steven Doiron (Intelsat), held two meetings and finished its work on Passive Service ^ Satellite Service band-by-band studies (270 pages) in preparation for Agenda Item 1.8.2 of WRC-03. During 2002 also a large number of CEPT Project Team meetings and ITU-R Study Group meetings were attended by Baan and Spoelstra.

#### RFI Environment and Monitoring

For a radio observatory like the WSRT the awareness for and battle against Radio Frequency Interference is a constant burden. Last year has seen continuous monitoring of the RFI environment at the WSRT site, the assembly of a mobile RFI monitoring facility and some dedicated actions.

The system located in the construction hall at the WSRT site has been in full operation and has produced a constant stream of spectrum occupancy data. It consists of two relatively inexpensive commercial receivers and a set of omni-directional antennas on the roof. The data is transferred to the central building and is processed into spectrograms, occupancy and signal strength graphs. One receiver is used to routinely scan the frequency range from 200 to 2600MHz and the other can be used for ad hoc measurements.

Together with LOFAR,s RFI Monitoring Team a mobile monitoring station has been assembled and put into action. A utility vehicle was equipped with a high quality receiver (9 kHz to 3 GHz), and a range of directional and non-directional antennas was selected, together with auxiliary equipment, like notebook computer, power generator, GPS, trailer with a 12 meter high mast and antenna rotators and tripods. Using an additional amplifier and assorted filters, the mobile monitoring station is able to produce high quality spectrum measurements. The station has been collecting data around the countryside for LOFAR site evaluations, and proves to be a very useful tool for tracking down local RFI sources that pollute the WSRT,s observations.

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### RFI Mitigation System at the WSRT

The work on active RFI mitigation strategies has continued. Extensive experience has been gained at the Observatory with RFI mitigation algorithms using a DSP demonstrator system that ran up to 50 Msamples/sec. Among the algorithms that were implemented are:

- 1) time-frequency analysis and outlier,s excision using thresholding;
- 2) RFI suppression with a „RFI estimation & subtraction" method;
- 3) adaptive RFI cancellation using a reference channel, and
- 4) higher-order statistics analysis. These DSP processing efforts of the real astronomical signals resulted in considerable RFI suppression both for continuum and spectral observations [1, 2]. The Observatory has received a grant from NWO to build an FPGA-based digital signal processing system that would be installed at all fourteen telescopes (NWO grant 614.061.006).

Figure 1 shows a block-diagram of the RFI Mitigation System (RFIMS) as it is being implemented at the WSRT. The baseband signals are digitized, processed in the FPGA, and then transformed back to analog form to be processed further in the correlator. A real-time processing system will be installed in each of the 28 IF channels that is built around the new ALTERA STRATIX programmable logic device (PLD) EP1S80B956-6. The baseband signals are digitised at the output of the IF-to-video converter (IVC), using a 12 bit analog-to-digital converter with the maximum sampling frequency of 125MHz. The maximum bandwidth of the baseband signals is 20MHz. The actual real-time RFI signal-processing device has 79,040 logical elements and 7,427,520 RAM bits and works with clock frequencies up to 200MHz. It contains also 176 embedded multipliers (9x9). Subsequent digital-to-analog conversion is done using a 14-bit converter with maximum conversion frequency of 165 MHz. All equipment is based on off-the-shelf VME modular components (COTS). The processing modules are connected with each other and exchange data in order to allow the application of spatial filtering algorithms and for synchronization of calculations in different parallel channels.

The time-frequency presentations of WSRT cross-correlation amplitudes are given for source 3C48 on 29 Jan 2003, frequency 337MHz, bandwidth 10MHz, DZB correlator, 60s integration time for each of the 131 records (approx. 2h). The RFI has been suppressed at channels RT5X and RT7X (left panel) and not suppressed at channels RT4X, RT6X (right panel).

During a particular observation, an appropriate configuration of RFI mitigation algorithm is loaded in the FPGA,s (Field Programmable Gateways) that can be adapted to the type of observations and the particular RFI environment. Based on monitoring data, the observatory staff will have control over this process and will be able to estimate the effectiveness of the particular RFI mitigation algorithm. Alternatively the RFIMS processing may be bypassed totally. In first instance, just one of the eight 20 MHz frequency channels within each of the 14x2 IF,s can be processed before correlation. Eventually the system may be expanded up to 224 channels to cover eight 20 MHz frequency bands from each antenna.

[1] P. Fridman, „DSP experimental system for radio frequency interference mitigation at WSRT", ASTRON, ITR- 221, pp. 1- 250, 2000.

[2] P. A. Fridman, and W. A. Baan, ``RFI mitigation methods in radio astronomy", Astronomy& Astrophysics, vol. 378, pp. 327-344, October IV.

### CRAF 2002 report

#### Committee on Radio Astronomy Frequencies, CRAF

ASTRON hosts the clearing house of the Committee on Radio Astronomy Frequencies (CRAF). CRAF is an expert committee of the European Science Foundation (ESF) in Strasbourg, Germany. This facility, the administrative frequency management center of CRAF, is managed by the CRAF secretary/frequency manager, Titus Spoelstra. Observatories from seventeen European countries participate in CRAF. Also the European Incoherent Scatter Facility (EISCAT), the European Space Agency (ESA) and the Institut de Radio Astronomie Millimétrique (IRAM) are CRAF member.

The mandate of CRAF is to

- provide scientific advice for the co-ordination of a common European policy on frequency protection for radio astronomy, passive remote sensing, and related sciences;
- “promote understanding on the issue of passive frequency



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use for scientific observations;

- provide a discussion forum on interference issues in passive frequency use, and increase public awareness of these fields at the European level and the international level.”

In the pursuit of these tasks, CRAF interacts with the relevant major bodies and supranational entities at the European and international level. These parties are inter alia the Conference of European Post and Telecommunication Administrations (CEPT), the European Commission, European Administrations/Regulatory Authorities, Industry, International Telecommunication Union (ITU).

CRAF has formal observer status in CEPT and is member of the ITU Radiocommunication Sector (ITU-R).

In 2002, CRAF participated actively in various working groups and project teams in CEPT and ITU-R and had regular communication with European Administrations.

The main issues discussed and studies in 2002 include

- Mobile-Satellite Service including the Aeronautical Earth Stations in this service at ~1.6 GHz.
- Fixed-Satellite Service in the band 10.7-11.7 GHz
- Ultra-Wide Band technology
- Short Range Radar at ~24 GHz
- Power line communications
- Preparations for the World Radiocommunication Conference 2003 (June 9 - July 4, 2003)
- Broadcasting-Satellite system in the band 620-790 MHz and its impact in radio astronomy
- Global Transmission System experiment on the International Space Station
- Interference from GPS L3 space-to-Earth transmissions (1381 MHz)
- Local issues in European countries with the aim to “to keep the frequency bands used for radio astronomical observations free from interference”.

## 4. LOFAR

More sensitive telescopes see stars, galaxies, black holes and other objects that are farther away. Because the speed of light is limited, they also 'see' further back in time. The next generation of telescopes should be able for the first time to see the entire history of the Universe. A hundred-fold increase in sensitivity is required.



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### LOFAR

LOFAR (Low Frequency Array) will be the first telescope of a new generation of essentially digital radio-telescopes. LOFAR uses a large number of low-cost antennas and relies on broad-band datalinks and advanced digital signal processing to implement the majority of its functionality in (embedded) software.

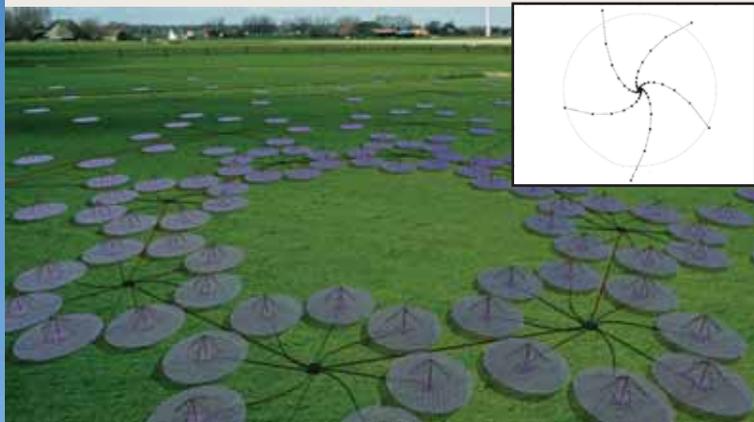


Figure 1 Artist impression of a LOFAR Station in a generic landscape, and a possible geometry for the total LOFAR configuration, with 25% of all antennas in a Central Core.

The instrument will be realized as an aperture synthesis array composed of phased array stations. Figure 1 gives an artists impression of such a LOFAR Remote Station. The antennas in the station form a phased array, producing one or many station beams on the sky. Multi-beaming is a major advantage of the phased array concept.

It is not only used to increase observational efficiency, but will be vital for calibration purposes. The physical size of the Remote Stations will be roughly 200m. Stations will be equipped with three types of antennas optimised for 10-40, 40-90 MHz and for 110-240 MHz respectively. The use of these antennas in the FM band is not explicitly ruled out, but no special effort is being made for getting sensitivity in the frequency range between 90-110MHz. All sets of receptors share the same digital signal path. Detection and mitigation of interfering signals (Radio Frequency Interference or RFI) is an essential part of the processing at station level.

The phased array stations are combined into an aperture synthesis array. The Remote Stations are distributed over a large area with a maximum baseline of 360 km as

illustrated in the Figure, yielding a maximum angular resolution of about 0.6 arcsec at the highest LOFAR frequencies. The collecting area will be laid out in a roughly scale-free configuration, with 25% of the area within a 2km diameter, 50% within 12km, and 75% within 75km. The layout will be two-dimensional in order to yield good instantaneous UV coverage, and may be somewhat elongated in the N-S direction to yield roughly circular synthesized beams over a wide range of source declinations. The total number of stations will be between 60 and 160, with 100 as the nominal figure. The concentration of antennas in the central 2km, called the Compact Core, can be operated as a single large station. Contrary to the Remote Stations data will be transported to a central location at full Field of View. This makes the Compact Core suitable for all-sky monitoring programs, including the detection of cosmic ray air showers. The Compact Core can also be used to calibrate the large ionospheric phase fluctuation, that would otherwise lead to severe decorrelation when correlating Remote Stations. The adopted calibration scheme is not dependent of this approach, but the Compact Core has sufficient sensitivity to leverage sensitivity of the much smaller Remote Stations for the calibration of the ionospheric phase screen.

LOFAR implements a distributed FX correlator, with the F-part implemented in filterbanks at the Remote Stations and the X-part implemented in a flexible Central Processor. The Central Processor can also be operated in Tied Array mode, and has extensive pre-processing capabilities. In addition to this primary correlator/processor LOFAR will have a dedicated All-Sky Monitor system, correlating all signals within the Compact Core. Note that the central processing facilities need not be co-located with the centre of the array. Also note that for the LOFAR frequencies bands, sufficiently stable local frequency standards can be maintained, so there is no need to distribute a central LO signal to the remote stations.

Over 2002, engineering activities for LOFAR reached their full momentum. By the end of the year, some forty people were involved in the project for a significant fraction of their time. This resulted in a major progress in all areas of the design. The remainder of this section highlights the progress in the subsystems where ASTRON has the main responsibility.

## 4. Lofar

### Low Band Antenna

After an intensive research and simulation trajectory, the first mechanical prototypes of the Low Band Antenna were built in October 2001. These mechanical prototypes proved to be a good example of a strong, but relatively low cost, antenna structure. They can be (dis)assembled in about 15 minutes and can be carried by a single person. The material costs of a single antenna (without any electronics, but including a ground plane) is about € 115. It is estimated that industrialization can reduce this price with approximately 70% to about € 35.



Figure 2: Photo of the LF Antenna prototype.

The antennas have been equipped with amplifiers based on the amplifier prototypes that were used for the noise verification experiments. It should be noted that these amplifiers are not optimised for low-noise performance. First spectra were measured at the ASTRON measurement platform in Dwingeloo. Evaluation of the results confirmed the expected noise behaviour and gave a lot of insight in the environment in which LOFAR has to operate, as illustrated in figure 3 and 4.

After solving some stability problems, four prototypes were built and sent to the LOPES (LOFAR prototype

station) project at the Max Planck Institute in Bonn. They were used there to develop the algorithms for the detection of cosmic rays with LOFAR.

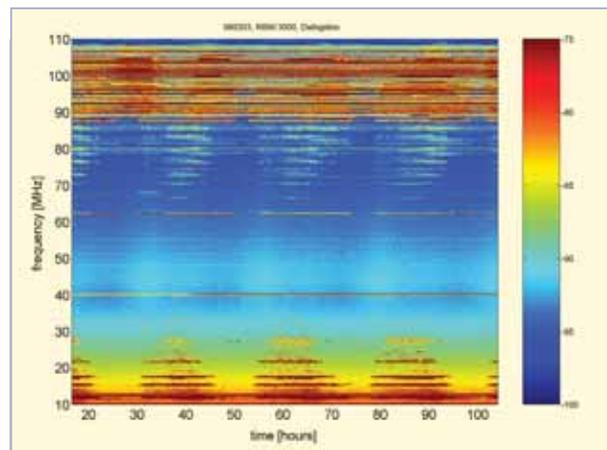


Figure 3: Spectrogram taken with the first Low Band prototype antenna, clearly showing the FM band (90-110 MHz), short wave transmitters (around 20MHz) and interference from the neighbouring THEA (Thousand Element Array) instrument (40MHz). The repeating feature between 40 and 50MHz is the Galaxy.

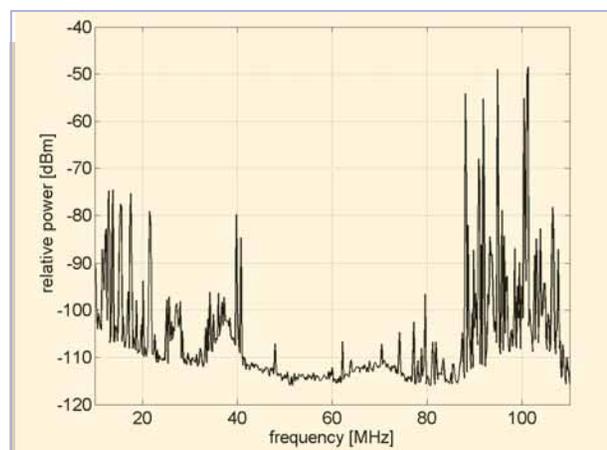


Figure 4: First spectrum measured with the Low Band Antenna prototype.

### Receiver, Clock and Analog/Digital convertor

Different receiver architectures were compared, ranging from direct sampling to heterodyne receivers. The research focused on the required ADC clock purity (the effects of jitter), the noise budget and the required selectivity of the receiver. The effect of the sample clock,

## 4. Lofar

especially clock jitter was analysed both theoretically and with experiments. From analysis a general model was made to analyse jitter in high-speed, high resolution ADCs. The focus of the research was on a 14-bit 80MHz ADC, which was also used in the experiments. The experiments were done with 12 and 14-bit 80MHz ADCs. From theory and experiments it has been concluded that the jitter of the clock becomes more prominent when signals are sampled at higher frequencies, i.e. sampling in the second Nyquist zone puts a tougher requirement on the clock than when sampling a signal in the first Nyquist zone. This makes a direct sampling receiver also less attractive. An aspect which will get more attention is the distortion behaviour of the receiver.

Separate research was on the distribution of the clock and LO signals between and within LOFAR stations. The performance difference between distribution over copper and fibre interconnects regarding clock and LO signals was studied. It has been concluded that the Relative Intension Noise (RIN) of a fibre distribution system makes an optical solution less attractive.

For practical measurements and assessments of different AD converters, a dedicated acquisition PCI card was developed, the so called Twin Input Memory (TIM) board. A single TIM board card is capable of storing 2 channels of 16-bit data sampled at 80 MHz in up to 4 GByte mainstream Dynamic RAM modules. This results in a memory buffer capable of storing 13 seconds of signal data from both signal inputs. Software has been developed and the complete system has been tested successfully. A key issue of a board is that each incoming sample is stored in memory (no sample loss). This required a novel memory controller design to realize storage of the continuous input stream for the case of Dynamic RAM. Different sampling modes are available.

Prototype receivers and TIM boards were used to collect data from the Low Band Antenna described above, both at ASTRON and for the LOPES project.

### Station Digital Processing

Once digitised, the LOFAR antenna signals have to be processed in the digital domain. At station level this involves filtering and beamforming, combined with RFI mitigation. An intensive research trajectory was started to study techniques and technology for filtering, beam forming, RFI Mitigation and data compression. The focus was on the specifications for the digital processing platform. This work was done in collaboration with the MASSIVE project to cope with the exploration of a large design space for the platform architecture.

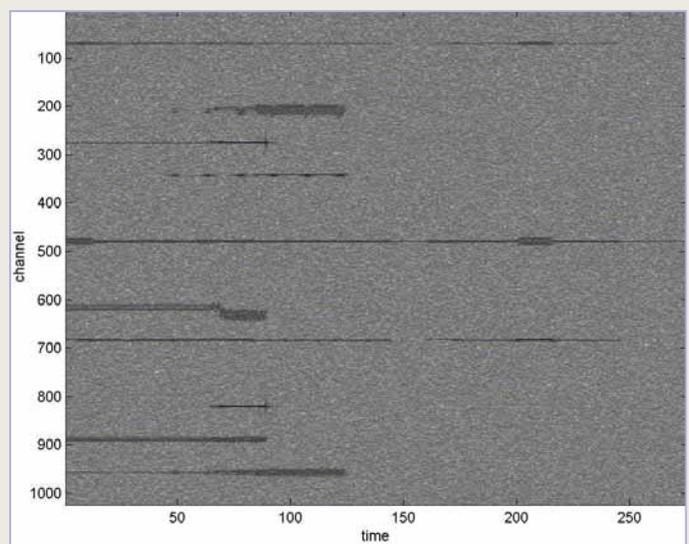
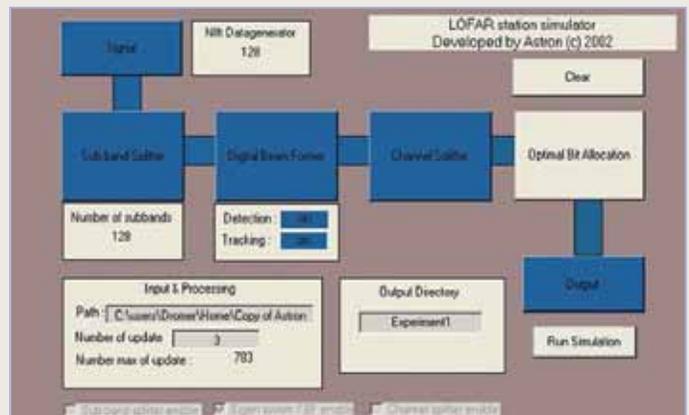


Figure 6 An artificially generated RFI environment. The data generators now allow for controlled mitigation experiments

# 4. Lofar

A prototype poly-phase filterbank was implemented, running at 65MHz compliant with current LOFAR specs. This prototype provided the necessary estimate of the required chip resources and feasible clock rates. An interface between FPGA and PC through RS-232 was implemented, facilitating validation of implementation and quality measurements. Statistics for RFI mitigation and compression - using a DSP Core - were implemented on the FPGA. The filterbank, together with spectral RFI detection and blanking, have been implemented both in Matlab as well as in the LOFARSim simulation framework. A data generator was developed in Matlab, to provide well-conditioned input signals modulated in several ways to create a realistic RFI environment. This has been used for controlled experiments on RFI mitigation and filter quality used. Figure 8 shows the RFI mitigation results for the artificially generated spectrum. The beam forming has been verified by comparing theoretical and actual positions of the beams lobes (Figure 9) the PASTd algorithm has been implemented in Matlab.

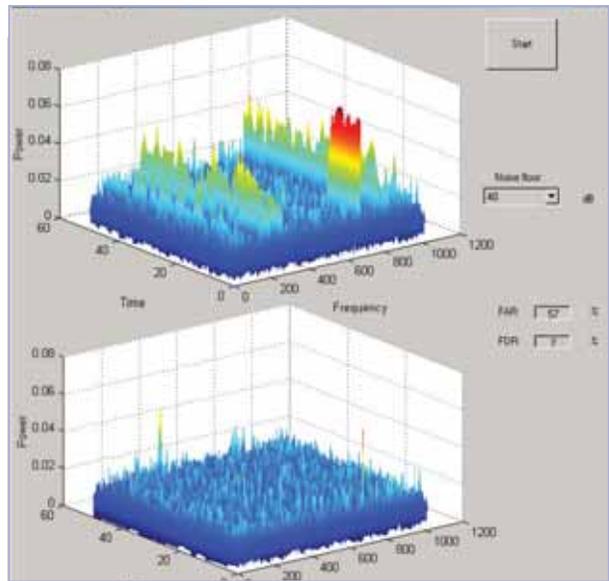


Figure 8 Channel outputs (above), and mitigated (below)

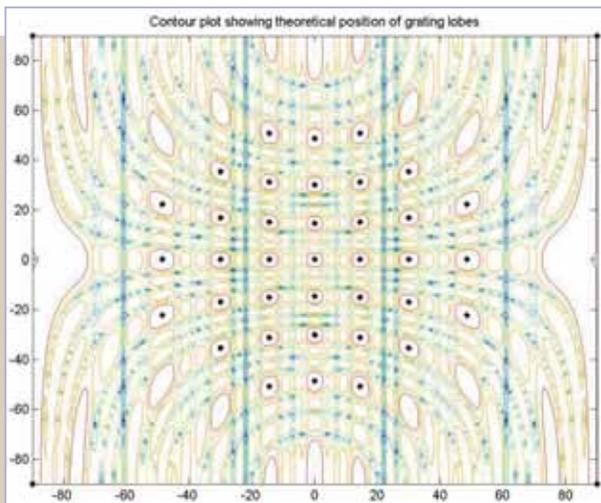


Figure 9 Simulated Beam pattern, with predicted lobes ( $^{\circ}$ 's)

Databases were developed for storing techniques, components and platform architectures. Actual mapping results were obtained for e.g. the integral Polyphase filterbank structure that was ported from the APEX/STRATIX family to the Xilinx Virtex II Pro. Mapping information of this kind allows for a proper selection of technologies and platforms. A performance model for the digital processing platform provided a coarse estimate of cost, power consumption and data transfer for a first design. A technology survey was made to provide realistic input data for this analysis. This resulted in an initial LOFAR Station Architecture as illustrated in Figure 7.

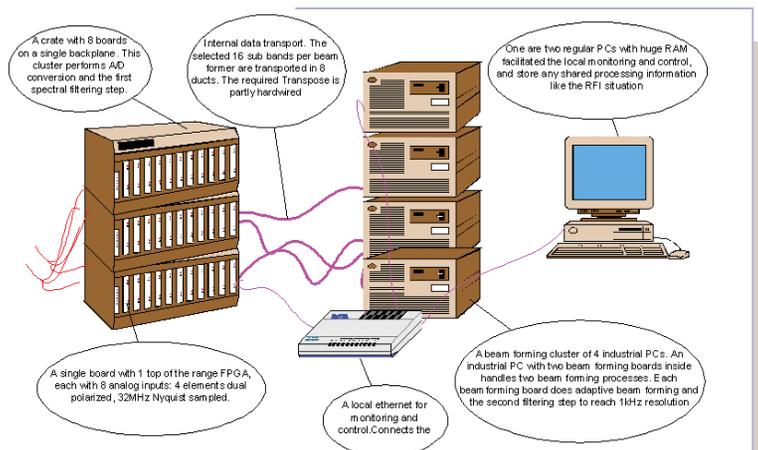
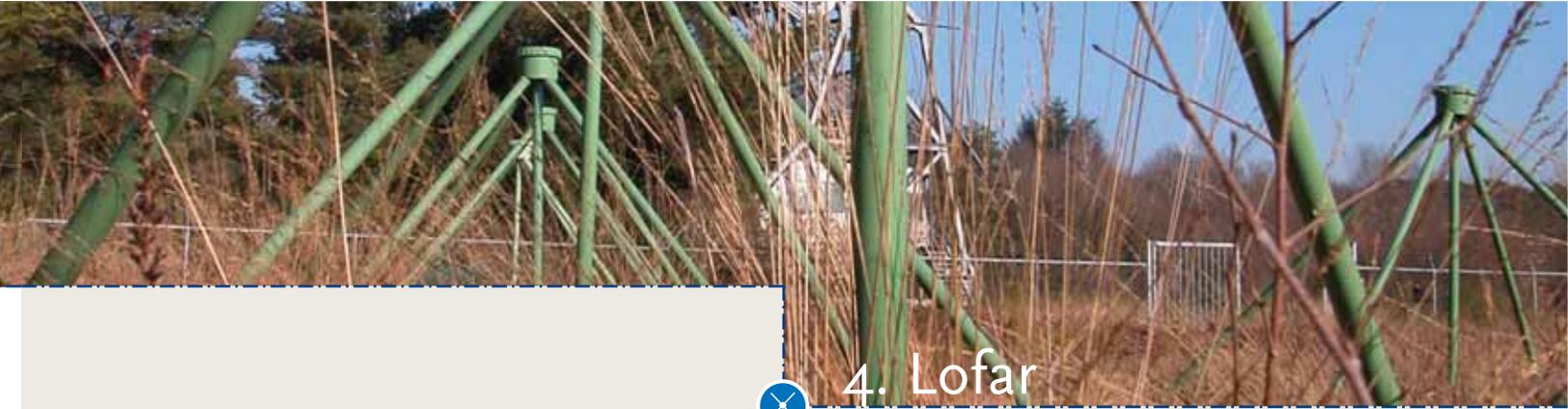


Figure 7 An impression of the digital processing platform for LOFAR remote stations



## 4. Lofar

Studies of RFI detection and mitigation techniques were done in collaboration with the NOEMI (Nulling Obstruction Electromagnetic Interferers) project. Extensive simulations of spectral and spatial mitigation were made to allow for a proper selection of algorithms.

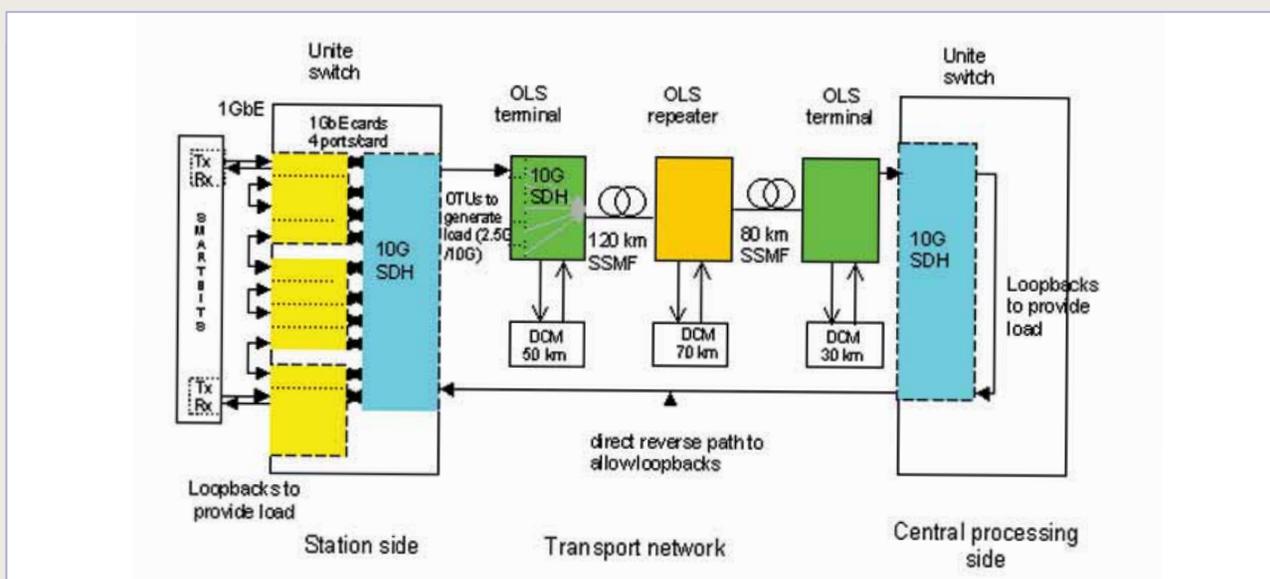
There are several issues that remain to be studied. Particularly: re-quantization effects, polarization, station calibration, constrained beam forming, real-time operation and synchronization, interfaces and operational modes. A proper analysis and design depends on the availability of baseline model and baseline of algorithms. Only when simulations and prototypes confirm theoretically derived results, we can expect the feasibility of station digital processing.

### Wide Area Network

The objective of the activities on this subsystem was to specify and design the LOFAR networks for datatransport and for monitoring and control. Due to the high bit rates and relatively long distances to be covered by the WAN, it will be one of the main cost driving elements. It will be important that the final design is suitable for implementation at low cost, including a simple and reliable installation of network equipment on the sites. These activities were to a large extent carried out as part

of the RETINA project (together with KPN Research, Lucent and the Technical University Eindhoven). RETINA aims specifically at the realization of a 40Gbps demonstrator and the development of 160 Gbps network equipment. As part of these activities a demonstrator was realized in Lucent Labs with existing equipment achieving 160 Gbps using WDM of 16 \* 10Gbps over 200 km (see Figure). PMD compensation units were used and a single repeater. LambdaUnite™ MSS were used to merge many 1 Gbps streams into 16 10Gbps (TDM), and WaveStar® OLS 1.6T systems were used to WDM the 10Gbps streams onto a single fibre and back. The OLS can handle 1.6 Tbps, but the setup was sufficient to demonstrate the datarate for remote station. There are various options to get multiple stations on the same fibre, but it may be just as cheap to give each station its own fibre.

In addition to these research activities, a blueprint was developed for a cheap, 10GbE based architecture. Together this gives a good overview of possible implementations for the LOFAR network. Several demonstrators have been built, so hands-on experience is available now. The network requirements are sufficiently clear (as function of the distribution of the processing budget over the various subsystems).



Blueprint 10GbE bases architecture.



# 4. Lofar

## Central Processor

The LOFAR Central Processor (CEP) can combine the functions of Correlator, Tied Array adder and Transient Detector. To meet the different requirements from these operational modes, the CEP has been designed as a large cluster computer with a fast backbone to solve the large datatransport problem implied by, in particular, the correlation mode. An initial architecture for the CEP was completed, describing the design of the CEP system and programming environments based on COTS cluster computer hardware, added co-processors and a middleware-based approach to the software. Various aspects of the design were verified on a breadboard cluster, which was extended with six new nodes (Dual AMD PCs). With the new nodes high bandwidths on the SCI interconnect system were observed. Bandwidths of >250 MB/s were measured for point-to-point connections, using the LOFARSim/CEPFrame programming environment, see Figure 11. The breadboard cluster was also used for scalability measurements on the interconnect system. The feasibility of executing a data transpose function on a routing network, has been demonstrated for a small cluster containing six nodes (0.8 Gbps per node). For these performance measurements a Transpose operation was implemented

in the CEPFrame application development framework. The measurements show the scalability of the interconnect system to large number of nodes, when extra link dimensions are added to the switch fabric. In Figure 10 a measurement on the saturation of the interconnect system is shown. The blue dots show the saturation of the interconnect system when the cluster becomes larger as seven nodes. The brown dots show the same data distribution, but now on a 2-dimensional interconnect system, which clearly does not saturate for up to ten nodes.

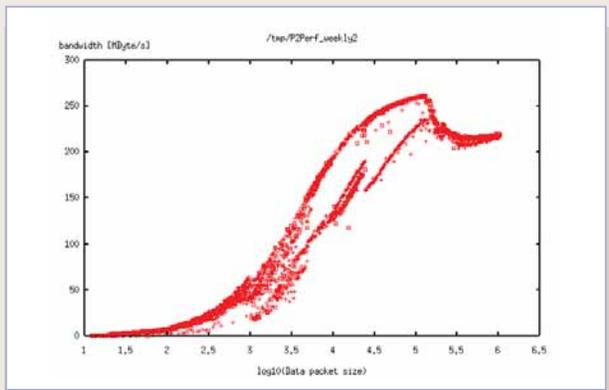


Figure 11 Example of point-to-point bandwidth measurement as function of packet size.

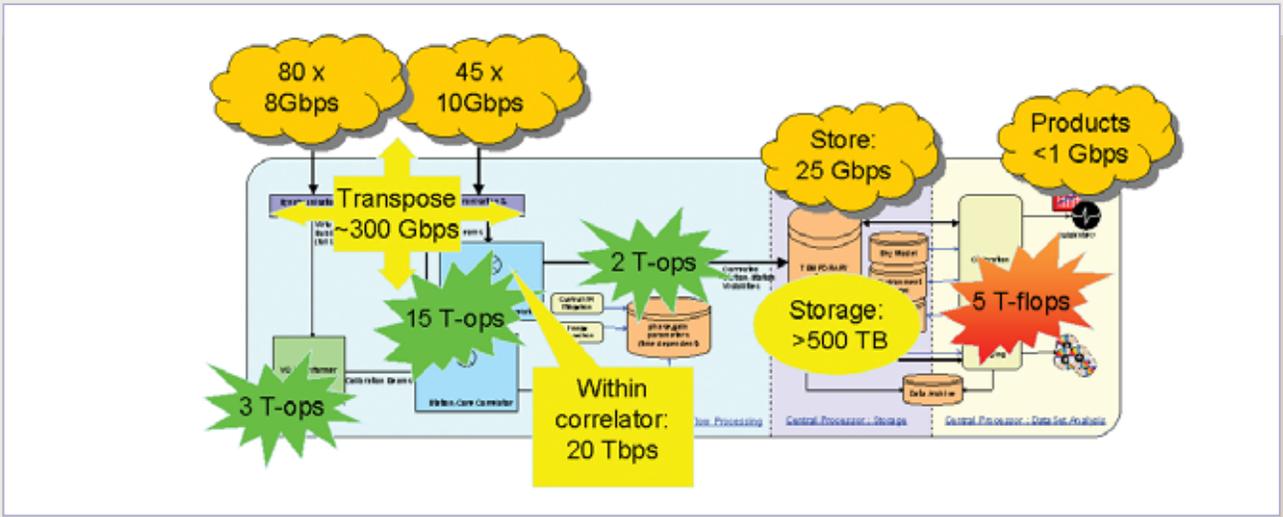


Figure 10 CEP breadboard cluster interconnect scalability measurements

## 4. Lofar

A programming and run-time environment for CEP applications was developed and used for demonstrators and performance measurements. This platform is the predecessor of the production version (CEPFrame). The platform uses some middleware implementations for the actual data transport on the cluster computer. Some features are:

- Integrated parallel execution through wrapped middleware libraries
- Optimized transport for SMP nodes
- Data buffering available in every processing step
- Control to processing step through a Corba client

### Calibration

A first version of the Prototype Selfcal System (PSS-1) was implemented to verify the adopted calibration approach. The heart of the system consists of MeqTrees, which are used to predict values of visibility samples for selfcalibration. AIPS++ tables were used to store the various parameters of the Measurement Equation (including the Sky Model), and AIPS++ fitting classes were used to solve for them. A simple demonstration solved for the position of a small number of sources. The subsequent exercising of PSS-1 by the 'testing group' led to new requirements for user access to M.E. parameters and fitting results.

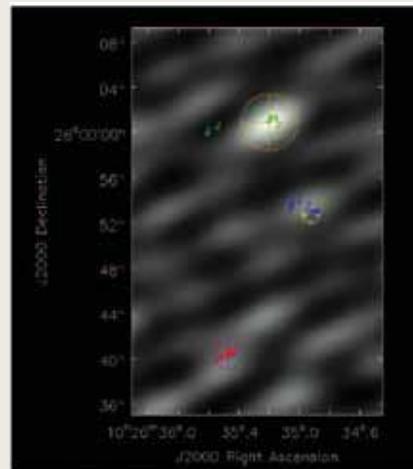


Figure 10 CEP breadboard cluster interconnect scalability measurements

## 5. Commercial Activities and Public Relations

The commercial activities of ASTRON are increasingly sustained. BTT, the front office of ASTRON is guiding the projects on technology transfer and coordinates the relationships and collaborations with industrial parties.



# Commercial Activities and Public Relations

## 5.1 Bureau Technology Transfer

The course in "Applied RF technology" is one of the activities of BTT. After the successful start of the short course on RF-technology in 2001, this series of courses were continued in 2002. Three of these courses have been held in this year. A total of 47 students from a variety of Dutch companies were registered.

The number of commercial relations with the industry increases; the consultancies are in the field of core technologies of ASTRON. Some examples:

- A study on an antenna of a communication system for a satellite modem has been carried out.
- A very specific test unit for testing at cryogenic temperatures was made available to an external company for testing an RF amplifier.
- Some lenses were tested for an external party.
- For a research institute in Groningen, ASTRON did a short advisory project concerning wireless measurement of high temperatures.
- A company, mainly active in logistics, asked ASTRON for support in designing and measuring some magnetic loop antennas for usage in a RFID application.

One of the companies that used ASTRON knowledge was BASIC. ASTRON was consulted to introduce automation technology in the production process. The advisory trajectory was very successful. ASTRON accompanied BASIC in buying a 5-axis milling machine and in the introduction of computer aided design and manufacturing software. ASTRON trained some personnel and guided the process of implementing the CAD-CAM procedure for automation of the production process.

### Exposure on exhibitions

In order to extend the network of industrial partners, BTT prepared different presentations throughout the year on conferences and business shows. The main presentations were: The URSI conference in Maastricht, the ICT Kenniscongres 2002 in Den Haag, and the exhibition "Het Instrument 2002" in Utrecht our 12 m2 booth. The exhibition on: "Het Instrument" was the first time ASTRON presented its Technology Transfer policy so explicitly for the industrial community. About 45 contacts were registered. This presence on this exhibitions has shown to be very valuable for BTT exposures.



Exposure on exhibitions

### NorthStars

NorthStars is a project that is aimed at enlarging the collaboration between ASTRON and industrial parties (SME's) in the Northern part of the Netherlands. NorthStars is funded by the EU through SNN (Samenwerkingsverband Noord Nederland), a collaboration between the three Northern Provinces of the Netherlands. In the NorthStars project, a prototype of flat antenna system, based on phased array technology used for receiving satellite TV, will be developed. Part of the project is structuring the industrial cooperation for developing and producing the system; this is carried out by BTT staff. Although still no final grant was received from the SNN in 2001, a small project team was founded to carry out the work consisting of system-design aspects of FAST (Flat Antenna System Technology).

### Intellectual Property Rights

The awareness on IPR is growing, two new patent applications were submitted. An international patent (PCT) was submitted, for a patent idea of Albert Jan Boonstra on Gain Calibration of a phased array sensor system. An idea of Niels Tromp on a light weight construction was briefly investigated for novelty, and the patent was submitted in the Netherlands. The patent on the phased array antenna of Arnold van Ardenne (Dutch patent) was submitted in the PCT countries.

## 5.2 Public Relations

ASTRON's word in 2002 has not gone unnoticed thanks to our public relations efforts. The various visits, press releases and interviews have had a positive effect. Often of course it was ASTRON that sought publicity to announce a new achievement, or to convey a specific message. The institute was also visited many times by groups, interested in the work at ASTRON. In particular, our ambitions for the future, notably LOFAR, were at the centre of attention. Our public relations effort has two main goals. One is the general PR goal of bringing ASTRON's work and products to the attention of a wider audience. Second is the more specific and focussed job of informing and involving the various relevant networks in ASTRON's activities.

### General PR

Below is a list of all organisations and groups that visited ASTRON. In general the programme consisted of a general introduction to ASTRON and astronomy, a description of the LOFAR project, a tour through our laboratory facilities and of course a visit to JIVE. Whenever possible, groups also visited the radio telescopes in Westerbork.

### Visits

- (01/02) Studenten Hanze Hogeschool
- (05/02) KPN Telecom
- (06/02) THOR, Electrotechnische Studentenvereniging TUE, ook WSRT
- (01/03) Scholieren LAPTOP Leiden (advanced pre-university programme for top students, ook WSRT
- (19/03) Kivi/Niria
- (23/03) Journalistengroep olv Govert Schilling, alleen WSRT
- (03/04) Belangstellenden via medewerkers ASTRON/JIVE
- (16/04) ICT mbo scholieren Alfa College Assen
- (18/04) FMF Fysisch Mathematische Faculteitsvereniging Groningen, alleen WSRT
- (23/04) Studievereniging vd Waals, TUE, ook WSRT
- (23/04) Rotary en andere serviceclubs Hoozeveen
- (01/05) Amateur astronomen uit België, ook WSRT
- (17/05) Gemeente Aa en Hunze, alleen WSRT
- (30/05) 3e jaars sterrenkunde studenten Leiden, ook WSRT
- (31/05) Sterrenkundige vereniging Euroster Rotterdam, ook WSRT

- (26/06) Agere en Lucent
- (28/06) Rijkswaterstaat NN
- (30/08) Directeuren RO provincies
- (04/09) Medewerkers KPN techniek, ook WSRT
- (04/09) Kamerheren HM Koningin
- (04/09) Opleiding Management van Administraties
- (14/09) NVWS, alleen WSRT
- (20/09) Achterhoekse Radio Amateur Club
- (30/09) Drentse en Overijsselse Burgemeesters
- (02/10) Firma Mogema
- (07/10 tot 11/10) Nova Herfstschool
- (10/10) VVD prov. Statenfractie
- (14/10) Studentenvereniging Leidsche Flesch (RUL)
- (25/10) Ambassadeur USA en Commissaris vd Koningin Drenthe
- (29/10) Docenten Regiovakgroep Electrotechniek
- (30/10) Relatiedag Reclamebureau Turksma & Partners
- (20/11) Handelsvereniging Dwingeloo x
- (18 en 19/11) TNO Industry
- (21/11) Eems Dollard Regio Raad
- (29/11) VVD kamerleden

### Press and publicity

General press attention was given to ASTRON on the following occasions:

- (18/4) ASTRON medewerker Boonstra wint KiVi Telecommunicatieprijs
- (3/6) Drentse Hightech samenwerking brengt toekomst dichterbij (ASTRON-Bysky)
- (juli) Samenwerking Global Crossing-Surfnet-Astron
- (12/8) Verleden te bekijken met 'radiobril' (SKA Workshop Groningen)
- (9/9) ASTRON en KU Nijmegen benoemen LOFAR Hoogleraar
- (9/10) Radiotelescoop Westerbork opnieuw 's werelds beste
- (11/10) Turbulente Ontwikkelingen rond Radiosterrenstelsel 3C 445
- (14/10) Lucent Technologies demonstreert multi-terabit glasvezelnetwerk voor LOFAR-telescoop
- (14/10) Telescoop Westerbork zet deuren open voor publiek
- (18/10) WSRT officiële officiële ingebruikname door Relus ter Beek
- (26/11) VVD Kamerleden overtuigd van LOFAR
- (18/12) Eerste superscherpe beelden van MIDI bij de ESO Very Large Telescope: een mijlpaal in de infrarood astronomie



# Commercial Activities and Public Relations



## Exposure in the media

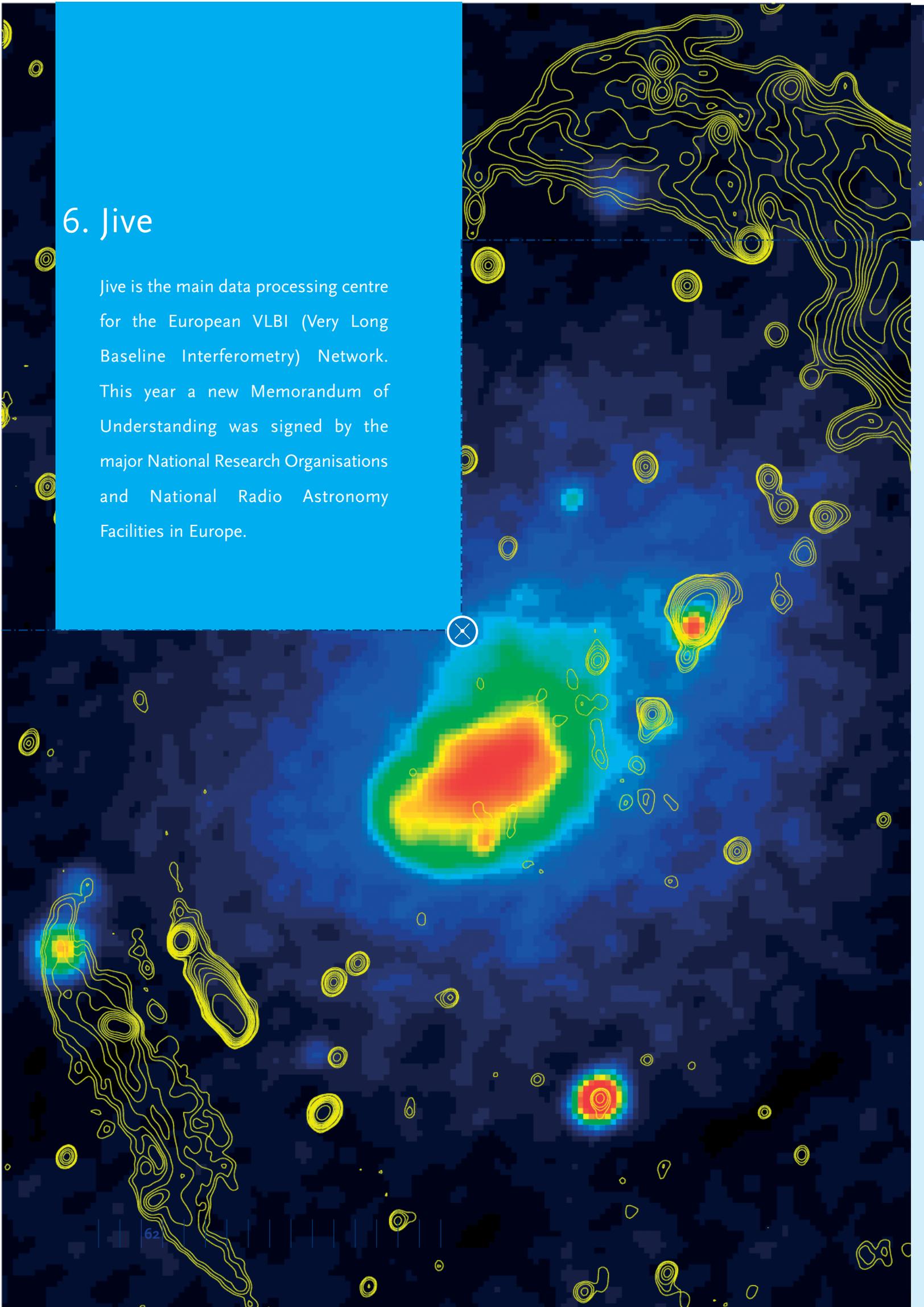
- (16/01) Reportage 2Vandaag
- (april) Artikel Kamer van Koophandelkrant voor bijeenkomst LOFAR
- (04/06) RTV Drenthe interview Nico Alblas en Arnold Van Ardenne voor BySky
- (13/8) Artikel Dagblad vh Noorden over samenwerking Emmen
- (13/08) Uitzending TV Noord over SKA meeting Groningen
- (13/08) Interview Radio Drenthe over SKA meeting Groningen
- (13/08) Interview Stadsomroep Groningen over SKA meeting Groningen
- (17/08) NOS-journaal, 20.00 uur
- (17/08) Artikel Volkskrant
- (04/09) Interview Radio Nederland Wereldomroep (Ned) over LOFAR met Marco de Vos
- (05/09) Interview Radio Nederland Wereldomroep (Fra) over LOFAR met Sylvain Alliot, uitzending 7 minuten in Frankrijk en Afrikaanse landen
- (14/09) Interview met Eugène de Geus en artikel AD (sept) Telecommagazine (interview Jack Verhoosel van Lucent)
- (23/09) Interview Ed v.d. Heuvel bij WSRT voor programma 'De Ontdekking' van de Vara
- (08/10) RTV Drenthe nieuws Interview Willem Baan over upgrade
- (15/10) RTV Drenthe Drents Diep reportage (8 min) over upgrade
- (18/10) Radio 1 'Het Filiaal', 3 maal live interviews over upgrade
- (18/10) RTL 4 nieuws over upgrade WSRT
- (18/10) RTV Drenthe nieuws officiële ingebruikname
- (23/10) Interview Eugène de Geus voor VPRO radio thema week geluid
- (04/11) Interview Eugène de Geus voor VPRO radio 'Noorderlicht'

## Specific pr:

- Brochure Instrumentmakerij
- (10/04) KC films opnames voor reclamespot
- (16/04) LOFAR informatiebijeenkomst
- (13/05) Ondertekening contract samenwerking Ordina
- (04/06) Ondertekening contract samenwerking ASTRON-BySky
- (03/06) JBF producties voor promotiefilm NOM
- (09/07) Filmen Pavlov Media WSRT voor film tijdens Utrechts Filmfestival
- (20-24 aug.) Stand tijdens URSI Maastricht
- (5 en 6 sept.) Stand tijdens ICT Kennis Congres Den Haag
- (19/10) Bijeenkomst Kivi in Westerbork
- (19/10) Halve finale wetenschapsquiz Rug-krakers Westerbork
- 20/10 Open Dag ASTRON te Westerbork

## 6. Jive

Jive is the main data processing centre for the European VLBI (Very Long Baseline Interferometry) Network. This year a new Memorandum of Understanding was signed by the major National Research Organisations and National Radio Astronomy Facilities in Europe.



## 6. Jive

### Jive

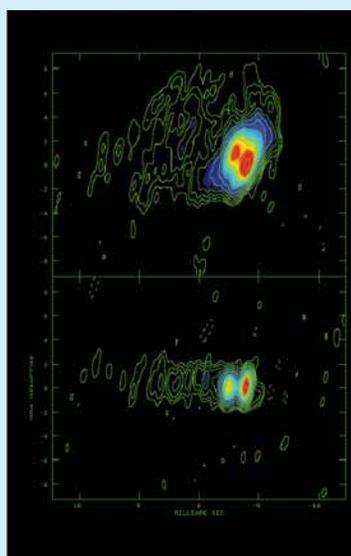
In 2002 JIVE's role as the main data processing centre for the European VLBI (Very Long Baseline Interferometry) Network and Global VLBI, was further reinforced by the conclusion of a new Memorandum of Understanding (MoU). The MoU was signed (or in the process of being signed) by the major National Research Organisations and National Radio Astronomy Facilities in Europe, including NWO (the Dutch "Nederlandse Organisatie voor Wetenschappelijk Onderzoek"), PPARC (Particle Physics and Astronomy Research Council, UK), CNR (the Italian National Research Council), MPIfR (Max Planck Institute for Radio Astronomy, DE), IGN (National Geographical Institute, ES) and the Swedish National Facility for Radio Astronomy at Onsala Space Observatory (SE). The new agreement secures a stable and long-term funding profile for the institute.

In the area of technical development, the capabilities of the Data Processor were further enhanced, and in particular a significant improvement in the efficiency of production data correlation started to emerge in the second-half of the year. A significant upgrade to the correlator began with the integration and testing of the new Mk 5 playback system. Mk 5 is a new PC Disk-based VLBI recording (and playback) system, that replaces the Mk4 longitudinal tape-based systems that have been the mainstay of EVN (European VLBI Network) operations for almost two decades. At the end of the year Mk5 fringes were obtained; the quality of the data was impressive with essentially no errors reported.

While the introduction of the new PC disk-based playback systems was the main focus of technical developments at JIVE in this year, significant progress was also made in the realization of eVLBI i.e. a real-time VLBI system with the EVN telescopes connected to the EVN correlator at JIVE via optical fibres. In August 2002, work began on the installation of the SURFnet fibre optic link connecting JIVE to the Amsterdam Internet Exchange at SARA (the Dutch "Expertise Centrum voor Reken- en Netwerkdiensten, [www.sara.nl](http://www.sara.nl)). Three 1 Gigabit per second lines are currently available, but this can be easily expanded to provide virtually unlimited capacity to the EVN Data Processor. The first international eVLBI fringes were presented in a live demonstration at the iGRID 2002 meeting in Amsterdam.

The enthusiasm of the Research Networks for eVLBI is considerable, and after iGRID a eVLBI Proof-of-Concept Project was set-up, including the major European Research Networks; the Pan-European Research Network, GEANT (The GÉANT project is a collaboration between

26 National Research and Education Networks, representing 30 countries across Europe, the European Commission, and DANTE); and a number of EVN institutes as equal partners.



JVAS B0218+357

High-Fidelity Global VLBI Images of the Gravitational Lens B0218+375 (Biggs et al. 2002).



In August 2002, work began on the installation of the SURFnet fibre optic link connecting JIVE to the Amsterdam Internet Exchange at SARA.



Richard Schilizzi's Farewell Party at JIVE.

Astronomical activity at JIVE continued to flourish. Highlights included the successful write-up and defense of Wouter Vlemmings' (Leiden) thesis, high-fidelity Global VLBI images of the gravitational lens 0218+357, the first investigation of the FIR-Radio (Finite Impulse Response) correlation at high- $z$ , the discovery of high velocity jet outflows from the evolved star W43A, and the VLBI detection of a faint quasar (J0836+0054) at  $z = 5.5$ . During the period of this report 45 papers were published in astronomical journals or conference proceedings. The institute was happy to host 40 visitors during the year, many of whom made extensive use of the support and data analysis facilities at JIVE.

At the end of the year Prof. Richard Schilizzi resigned as director of JIVE, in order to take up a new position as the International Project Director of the Square Km Array. As institute director for almost a decade, Richard played a fundamental role in the initial foundation of JIVE and the successful development of the EVN MkIV Data Processor. By the end of the year, the JIVE Board had set-up a search committee for a new director.

## 7. Facts & figures

In this Chapter ASTRON presents an overview of general publications, as well as publications based on WSRT-observations, and by astronomical staff. Also, read all about the joint ASTRON-Jive colloquia, the short Annual Account, the compound of the Board, and the highlights of this Annual Report 2002.



## 7. Facts & figures

### 7.1 Publications, posters and presentations

#### 1 Technical presentations, posters and publications

##### 1.1 Presentations

1. Alliot, S, Deprettere, E., Ardenne, A. van, "A scalable platform for large scale array signal processing systems specification and prototyping", Proceedings of the System, Architecture, Modeling and Simulation, SAMOS workshop, July 2002.
2. Ardenne, A. van, "Wideband arrays on SKA", University of Colorado, Boulder, USA, February 8, 2002.
3. Ardenne, A. van, "SKA phased array technologies and concepts", ATNF-CSIRO, Australia, May 23 2002.
4. Ardenne, A. van, "The European SKA Strawman Approach, SKA Workshop Groningen, August 2002.
5. Ardenne, A. van, "The SKA Concept and Technologies", 27th URSI General Assembly, Maastricht, August 2002.
6. Ardenne, A. van, "Square Kilometer Array Project: Concepts and Technologies", 27th URSI General Assembly, Maastricht, August, 2002.
7. Ardenne, A. van, "ALMAMADE, Industrializing the production of ALMA receiver cartridges, SRON, October 2002.
8. Ardenne, A. van, "European - Square Kilometre Array, FP6 Design Study Partners from E-SKA Consortium", SKA Study Meeting (SSM), November 27 2002.
9. Ardenne, A. van, "European Square Kilometer Array, FP6 Design Study Partners from E-SKA Consortium", European SKA Consortium Meeting, Dwingeloo, December 18, 2002.
10. Ardenne, A. van, "The URSI General Assembly", NERG-URSI dag, Utrecht, December 2002.
11. Ardenne, A. van, "ASTRON, its Technical Capabilities and ESTEC", ESTEC Noordwijk, December 2002.
12. Boonstra, A.J., "RFI mitigation methods, enhancing sensitivity", TVS Colloquium, Delft University of Technology, January 2002.
13. Boonstra, A.J., "Spatial filtering of continuous interference in radio astronomy". SKA Study Meeting (SSM), February 2002.
14. Boonstra, A.J., "Sensor array RFI mitigation ", KIVI Telecommunications Spring Event, Winner of the KIVI Telecommunication Award 2002, Eindhoven, April 2002.
15. Boonstra, A.J., "Polarisation gain calibration", Seminar, Delft University of Technology, May, 2002.
16. Boonstra, A.J., Veen, A.J. van der, "Gain estimation for polarized radio telescope arrays", In Proceedings International Union of Radio Science (URSI), 27th General Assembly, Maastricht, The Netherlands, August 2002.
17. Bregman, J.D., "Development of an optical network for LOFAR", University of Colorado, Boulder, USA, March, 18, 2002.
18. Bregman, J.D., Kant, G.W., Ou, H., "Multi-terabit routing in the LOFAR signal and data transport networks", 27th URSI General Assembly, Maastricht, August, 2002. (invited)
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20. Craeye, C.V.G., Vaate, J.G. bij de, "Effects of array truncation on the depth of deterministic nulls obtained with a broadband phased array", IEEE proceedings Antennas and Propagation Soc-Intern-Symposium, July 2002.
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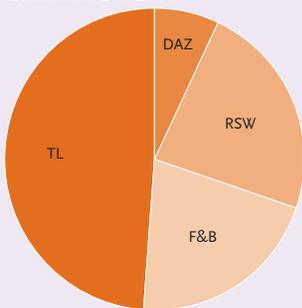
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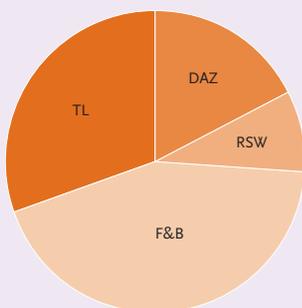
# 7: Facts & figures

## 7.2 P & O

**Personeelsbestand**  
december 2002

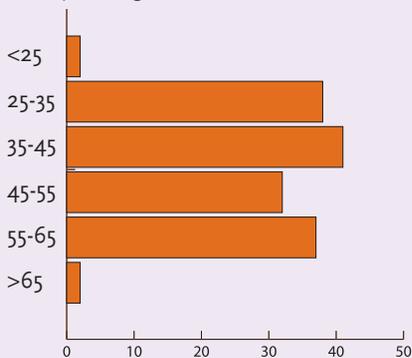


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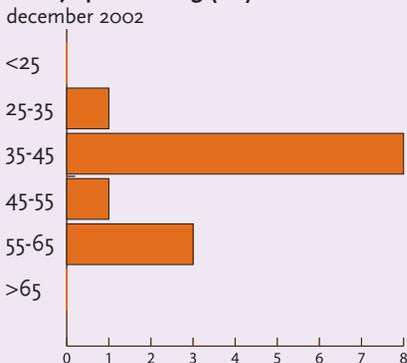


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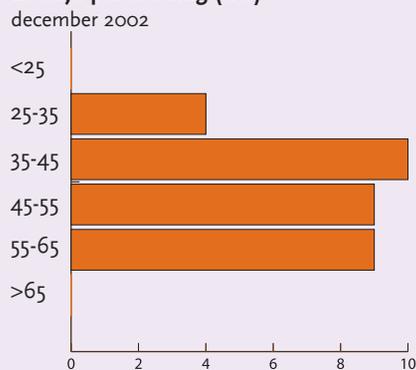
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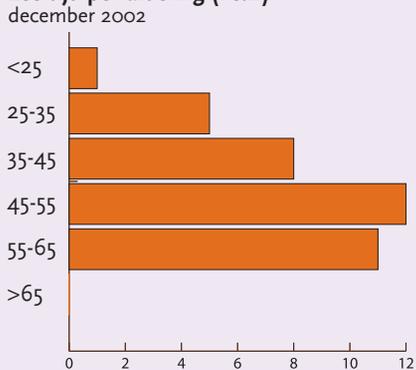
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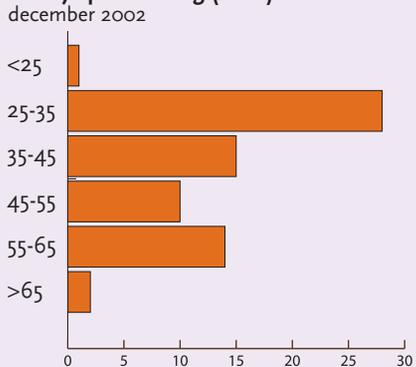
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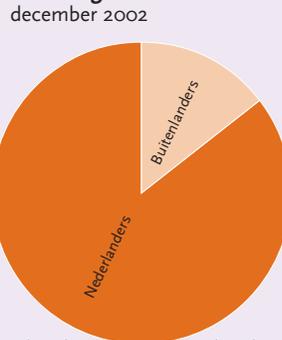
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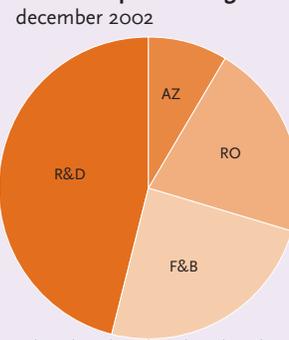
**Leeftijd per afdeling (R&D)**



**Verdeling ASTRON**



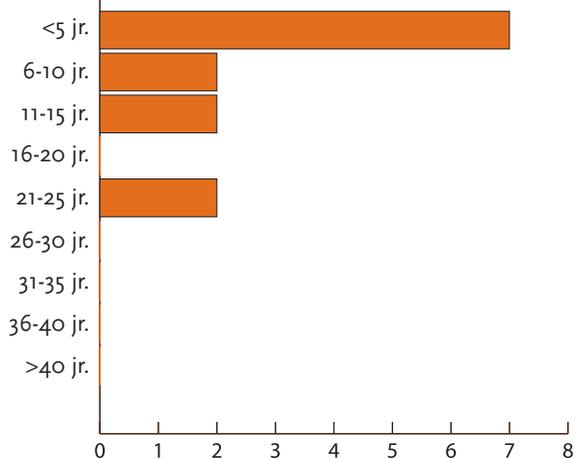
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# 7. Facts & figures

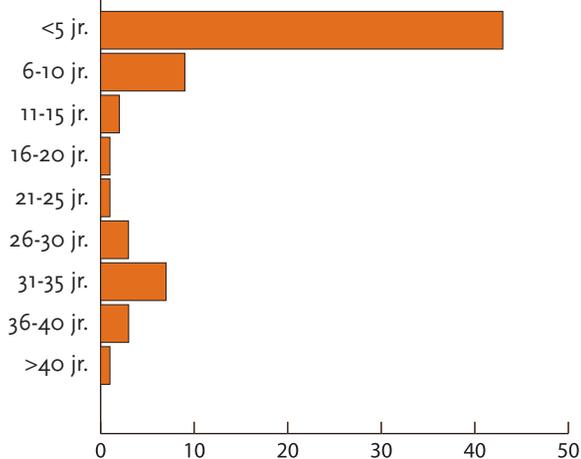
## Dienstjaren (AZ)

januari 2003



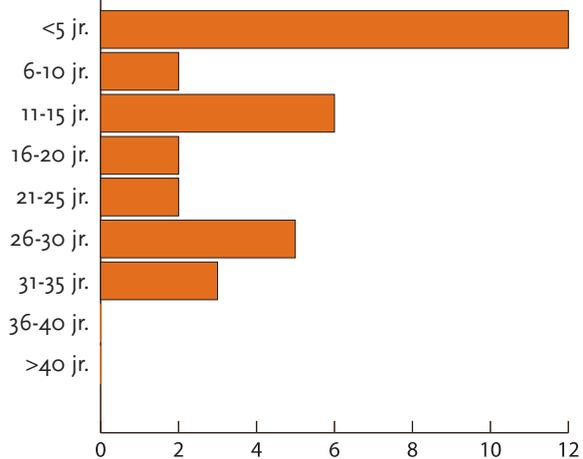
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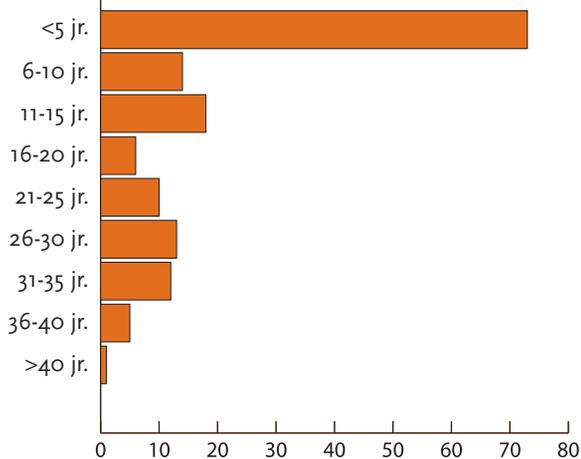
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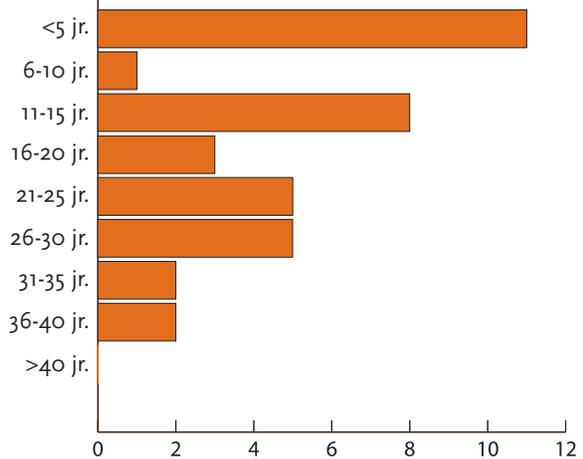
## Dienstjaren ASTRON

januari 2003



## Dienstjaren (F&B)

januari 2003



## 7 Facts & figures

### 7.3 Financial Report

#### Financial Report of 2002, compared with 2001

	Budget	Actual	2002 Difference	2001 Actual
<b>INCOME</b>				
Government Grants-Min. of Education, Culture & Science	7.389.534	8.870.165	1.480.631	7.719.214
Subsidy/contribution by third parties	3.128.686	2.692.572	436.114-	4.106.893
Cash Management	56.500	81.212	24.712	101.472
Other Income	55.000	83.854	28.854	187.555
<b>Total Income</b>	<b>10.629.720</b>	<b>11.727.803</b>	<b>1.098.083</b>	<b>12.115.134</b>
<b>EXPENDITURE</b>				
Grants/Expenditure				
Operations	11.069.000	10.897.320	171.680-	8.281.856
Provisions	34.034	34.034	-	34.034
Projects	473.314-	968.668-	495.354-	3.626.056
<b>Total Expenditures</b>	<b>10.629.720</b>	<b>9.962.686</b>	<b>667.034-</b>	<b>11.941.946</b>
<b>BALANCE</b>	<b>-</b>	<b>1.765.117</b>	<b>1.765.117</b>	<b>173.188</b>

all amounts in EURO's (ff)

## 7. Facts & figures

### 7.4 Joint ASTRON and Jive Colloquia

Date	Speaker	Institute
January 18	Konrad Kuijken	Kapteyn Institute, Groningen
February 1	Peter Shaver	ESO, Munich
February 8	Jean-Pierre Macquart	Kapteyn Institute, Groningen
February 15	Gijs Verdoes Kleijn	University of Leiden
February 22	Annette Ferguson	Kapteyn Institute, Groningen
March 1	Marianna Ivashina	ASTRON
March 8	Johan Bleeker	SRON
March 22	Padeli Papadopoulos	ESA, Estec
April 5	Hiroshi Imai	JIVE
April 12	Andy Biggs	JIVE
April 18	Edwin Valentijn	Kapteyn Institute, Groningen
April 19	Johan Hamaker	ASTRON
May 17	Filippo Fraternali	Kapteyn Institute, Groningen
May 24	Roel Bergsma	Macaw
May 31	Nick van Eijndhoven	University of Utrecht
June 7	Alan Roy	MPIfR, Bonn
June 13	Arjan Jaspers	Modernisering van een cryogeen ruismeteersysteem
June 14	Zsolt Paragi	JIVE
June 21	Joanna Rankin	University of Amsterdam/University of Vermont, USA
July 5	Andrzej Marecki	Torun Observatory, Poland
August 9	Rendong Nan	BAO, China
August 16	Rick Perley	NRAO, USA
August 23	Anish Rohi	NRAO, USA
August 26	Mareki Honma	NAO, Japan
August 27	Ravi Subrahmanyam	ATNF, Australia
September 13	Yoshiaki Hagiwara	ASTRON
September 20	Aris Karastergiou	MPIfR, Bonn
September 27	Mercedes Filho	Kapteyn Institute, Groningen
October 11	Russell Edwards	University of Amsterdam
November 8	Dipanjan Mitra	MPIfR, Bonn
November 15	Henrik Svensmark	Danish Space Research Institute, Copenhagen
November 22	C. Brügmann	Lambda (the cosmological constant): Ugly or Beautiful?
November 29	Wouter Vlemmings	University of Leiden
December 6	Sandor Frey	Institute of Geodesy, Cartography and Remote Sensing, Satellite Geodetic Observatory, Hungary
December 17	Ed Churchwell	University of Wisconsin, USA



## 7: Facts & figures



### Titel

Galactic bulges, large and small

The Atacama Large Millimeter Array

Circular polarization in AGN

The Nuclei of Nearby Radio Galaxies with HST

Gas and Stars in the Outskirts of Galaxies

Optimization of geometrical parameters of elliptical helical antennas for mobile satellite communication systems

Space Research at SRON: Astrophysics and Earth system science

Dark matter in galactic disks, the case for H<sub>2</sub>

A collimated jet from an Asymptotic-Giant-Branch star

Improving the H<sub>0</sub> estimate from the gravitational lens system B0218+357.

An ASTRO-WISE Observatory

Zesendertig jaar Sterrenwacht: Een dozijn ambachten en een paar ongelukken

Hot and cold gas in the disk and halo of the spiral galaxy NGC 2403

The company dashboard on the Web

A Visit to the Cosmic Disco : The Photon House Party and the Neutrino Breakdance

Seyfert Galaxies with VLBI: Tori and Jets

Outflows in SS433

Rotating Subbeam Patterns, the Eur-Asian Multifrequency Observation Project, and the Pulsar Emission Problem

Weak Compact Steep Spectrum Sources: what stage of the evolution of radio loud AGNs do they represent?

FAST Project- a new possible solution for the FAST active reflector

What the EVLA will do for you!

C+ lines from cold HI regions in the Galaxy

Current status of the VERA project

ATCA images of the restarting phenomenon in giant radio galaxies

Extragalactic H<sub>2</sub>O maser -- Recent observational results

Simultaneous single-pulse observations of radio pulsars

Searching for weak AGN in Nearby Galaxies

Circular Polarization in Pulsars

Pulsars as probes to the Galactic Magnetic field: Towards the Perseus Arm

Solar Activity and Global Warming

VLBI astrometry of circumstellar masers

The edge of the visible Universe as seen by the EVN

Hypercompact HII Regions: A New Evolutionary Stage of O-Star Evolution?

# 7. Facts & figures

## 7.5 Highlights

### January 2

New year reception  
Speech ASTRON by H.R. Butcher  
Speech JIVE by R.T. Schilizzi.

### February 19

Delivery of the new precision milling machine Fehlman P54

### March 4 till 6

Course "Applied RF technology"

### April 1 till 5

Springschool

### April 5

Farewell reception George Koenderink

### April 8 and 9

CRAF-Meeting

### April 16

LOFAR Informationday

### April 19

Farewell reception Johan Hamaker

### May 31

Farewell reception Geert Hagenauw in de kantine

### August 16

International SKA Steering Committee Meeting

### September 30

Course applied RF-technique  
Visit of municipalities of Drenthe and Overijssel

### October 1 and 2

Course "Applied RF technology"

### October 3

LOFAR station processing demonstration

### October 7 till 11

NOVA Fall school

### October 10

Visit of Provincial Council of the People's Party for Freedom and Democracy, VVD

### October 18

Official opening Westerbork including a party

### October 20

Open Day

### October 25

American Ambassador and the Queens Commissioner of the rovince of Drenthe

### December 9, 10 and 11

Course "Applied RF technology"

### December 13

Retirement of Arie de Jong

### December 16

College B&W Gemeente Westerveld

### December 17

Farewell party Richard Schilizzi of JIVE

### December 18

European SKA Consortium meeting

### December 20

"High Tea"



## 7 Facts & figures

### 7.6 ASTRON Organisation

#### Board

Prof. Dr. A. Achterberg	Utrecht University (until May)
Prof. Dr. Ir. W.M.G van Bokhoven	Technical University of Eindhoven
Prof. Dr. H.R. Butcher	ASTRON, director
Prof. Dr. E.P.J. van den Heuvel	University of Amsterdam, chair
Prof. Dr. W. Hoogland	University of Amsterdam
Prof. Dr. H.J.G.L.M. Lamers	Utrecht University (from May)
Prof. Dr. G.K. Miley	Leiden University

#### Management Team

Ir. A. van Ardenne	Head of Technical Laboratory
Dr. W.A. Baan	Director Radio Observatory
Prof. Dr. H.R. Butcher	Director, chair
Dr. E.J. de Geus	Head Administrative Affairs
B.A.P. Schipper	Head of Facilities Management

## 8. Abbreviations



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ADBF	Adaptive Digital Beamforming	MIDI	Mid-Infrared Interferometry Instrument for ESO's VLTi
ADC	Analogue to Digital Convertor	MIRI	Mid-InfraRed Instrument
AGN	Active Galactic Nucleus	MIT	Massachusetts Institute of Technology
ALMA	Atacama Large Millimeter Array	NICMOS	Near Infrared Camera and Multi-Object Spectrometer
ASIC	Application Specific Integrated Circuit	NIR	Near Infrared
AWE	Adaptive Weight Estimator	NRL	Naval Research Laboratory
COR	Correlator	NOEMI	Nulling Obstructing Electromagnetic Interferers
CORDIC	Coordinate Rotation Digital Computer	NOVA	Nederlandse Onderzoekschool voor Astronomie
CRAF	Committee on Radio Astronomy Frequencies	NRAO	National Radio Astronomy Observatory
DBF	Digital Beam Former	NWO	Nederlandse organisatie voor Wetenschappelijk Onderzoek
DCB	Digital Continuum Back-end	OSMA	One Square Meter Array
DDRG	Double-Double Radio Galaxies	PCB	Printed Circuit Board
DLB	Digital Line Back-end	PuMa	Pulsar Machine
DSP	Digital Signal Processor	RF	Radio Frequency
DWDM	Dense Wavelength Division Multiplexinginterfacing	RF-IC	RF Integrated Circuit
DZB	Latest WSRT Back-end (correlator)	RFBF	RF Beam Former
ESO	European Southern Observatory	RFI	Radio Frequency Interference
EVN	European VLBI Network	SENSE	SKA End-to-End Simulation Environment
FARADAY	Focal Arrays for Radio Astronomy, Design Access and Yield	SKA	Square Kilometer Array
FFT	Fast Fourier Transform	SRON	Space Research Organisation of the Netherlands
FIR	Far Infrared	STW	Stichting voor de Technische Wetenschappen
FPGA	Field Programmable Gate Array	TADU	Tied Array Distribution Unit
GRB	Gamma Ray Burst	TDU	Time Delay Unit
HEMT	High Electron Mobility Transistor	TECH	THEA Experimental Chassis
HST	Hubble Space Telescope	THEA	Thousand Element Array
HVC	High Velocity Cloud	THEP	Thousand Element Array Experimental Platform
IACC	International Advanced Correlator Consortium	TMS	Telescope Management System
IAU	International Astronomical Union	UHF	Ultra High Frequency
IF	Intermediate Frequency	URSI	International Union For Radio Scientists
IRAM	Institut de Radio Astronomie Millimetrique (Grenoble)	VHDL	VHSIC Hardware Description Language
ISO	Infrared Space Observatory	VHSIC	Very High Speed Integrated Circuit
ITU	International Telecommunications Union	VISIR	VLT Imaging and Spectroscopy in the Infrared
IUCAF	Commission on the Allocation of Frequencies for Radio Astronomy and Space Science	VLBA	Very Long Baseline Array
IVC	IF-to-Video Convertor System	VLBI	Very Long Baseline Interferometry
JCMT	James Clerk Maxwell Telescope	VLT	ESO's Very Large Telescope
JIVE	Joint Institute for VLBI in Europe	VLTi	VLT Interferometer
JWST	James Webb Space Telescope	VSOP	VLBI Space Observatory Program
LNA	Low Noise Amplifier	WENSS	Westerbork Northern Sky Survey
LNAA	Low Noise Active Antenna	WHT	William Herschel Telescope
LO	Local Oscillator	WSRT	Westerbork Synthesis Radio Telescope
LOFAR	Low Frequency Array	WYFFOS	Wide Field Fibre Optical Spectrograph
MEP	Multi-Element Phase-toggle	ZOA	Zone of Avoidance
MFFE	Multi Frequency Front End		



# Colofon

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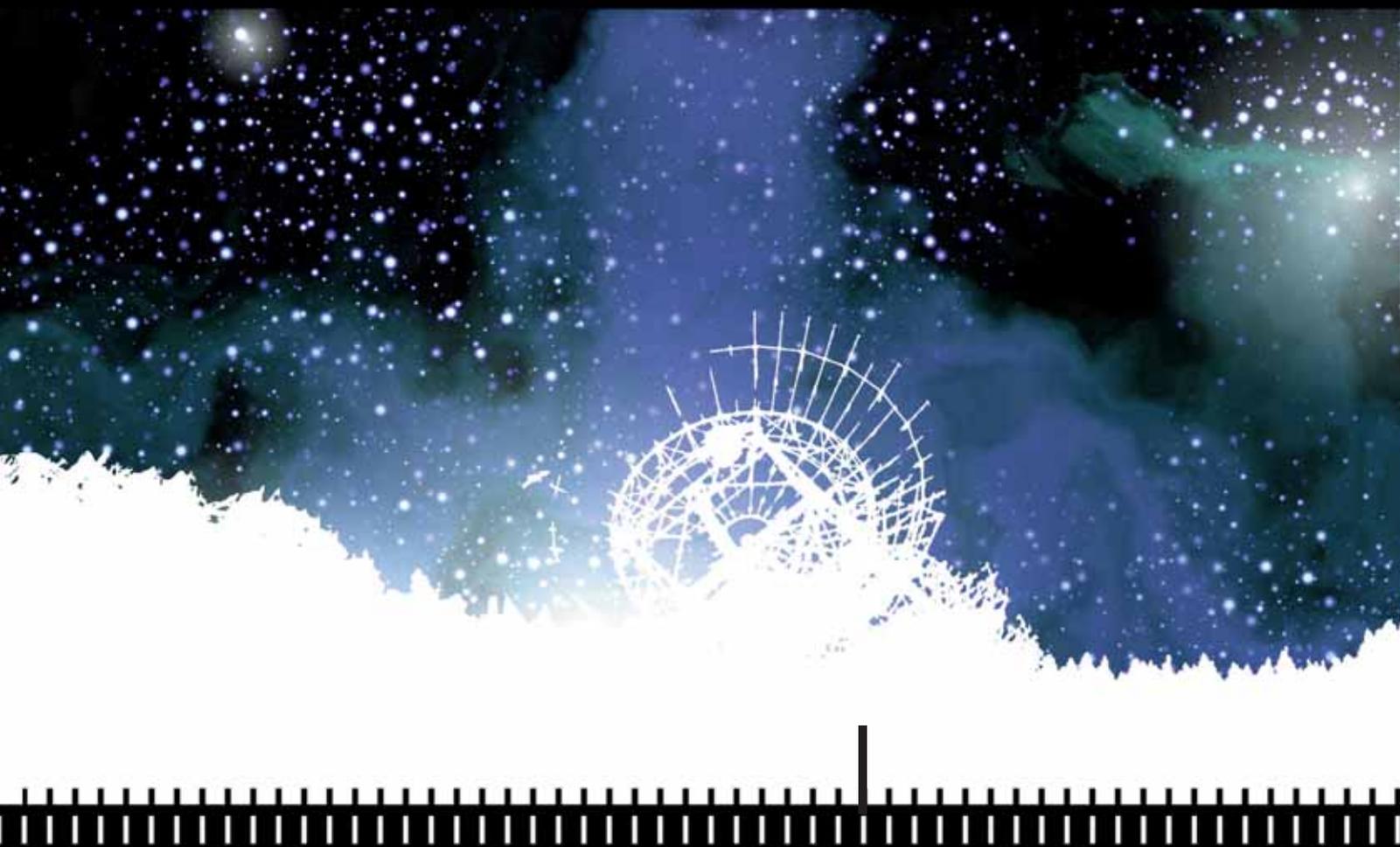
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