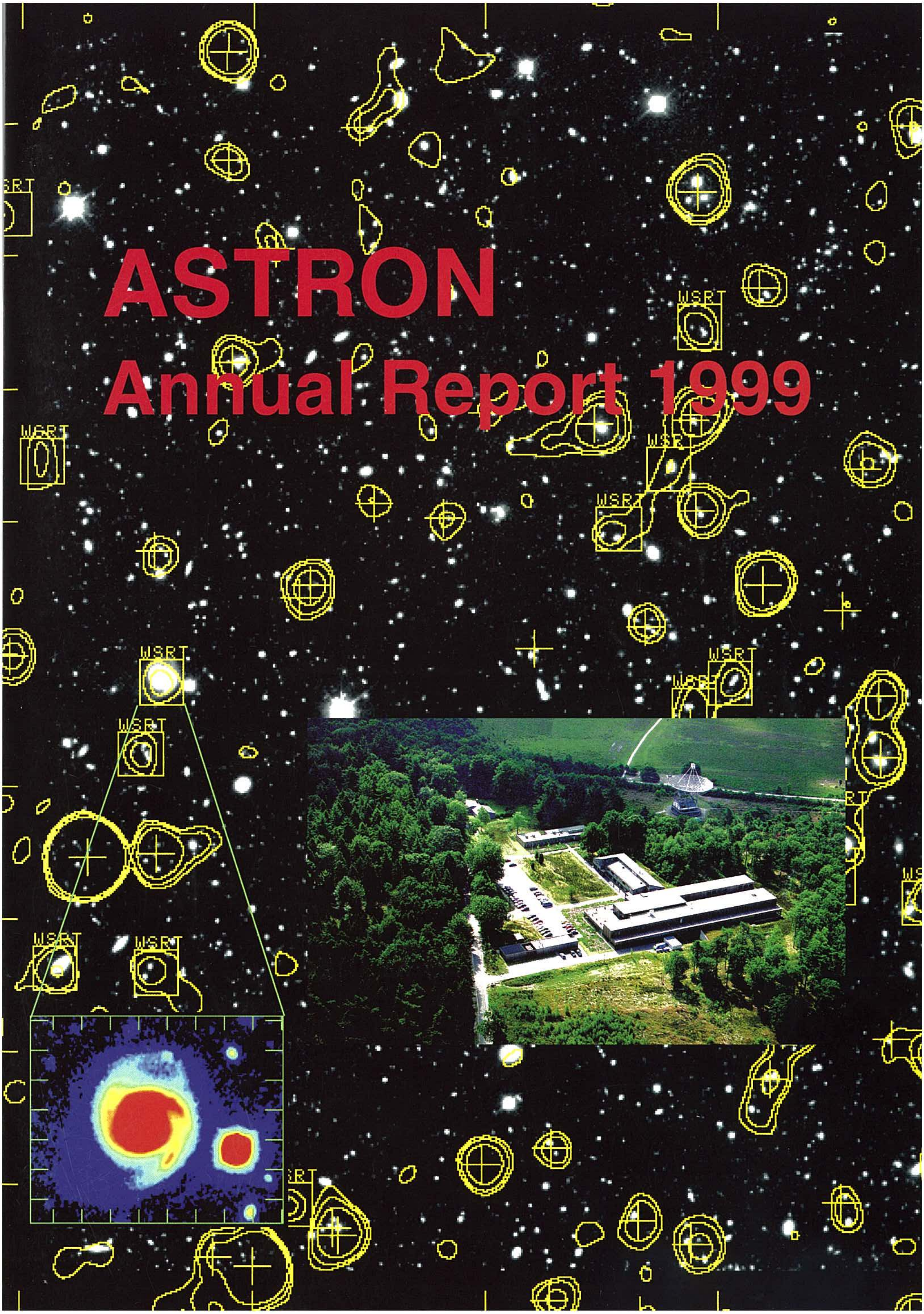
ASTRON
Annual Report 1999



ASTRON

Annual Report 1999

ASTRON/NFRA
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1 Report of the Director

1.1 Highlights of 1999

This year our Foundation celebrated its Silver Jubilee. Of course we held a birthday party – on 18 September we joined with friends from the region and retired colleagues to reminisce, to dance and to be entertained. But we also wanted collectively to look to the future, so we also invited friends and colleagues from around the world to join us for back-to-back scientific symposia. The first we held on 7–9 April at the Royal Netherlands Academy of Arts and Sciences in Amsterdam, to address the new science to be made possible by the next generation of radio telescopes. The second examined the required technologies and to show off the results of our technology program leading to the Square Kilometer Array as well as to hear of clever ideas from technical scientists in related disciplines. It was held at our Dwingeloo laboratory on 12–14 April. Great successes both, worldwide demand for the proceedings has remained strong many months after the events.

Other highlights during the year included the formal opening on 24 September of the Westerbork Astrometric-Geodetic Observatory. This facility, set up together with the Dutch geodetic community, combines in one location the principal techniques of modern geodesy – Global Positioning System measurements, VLBI, satellite laser ranging and gravimetry – thereby enabling precise comparison of results and discovery and suppression of systematic errors. A joint symposium emphasized both the new research to be undertaken and the cross-fertilization made possible by the new facility.

The entire complement of new front-end receivers on the Westerbork telescope went into routine operation early in the year. The increased sensitivity led quickly to a demonstration that among the faintest sources in the Hubble Deep Field at L-band are previously undetected extended objects, most probably the disks of distant starburst systems. The increased instantaneous sensitivity made possible discovery of a rapidly variable object that can only be interpreted as the interstellar scintillation of a source having structure on micro-arcsecond scales. And simultaneous measurements at widely separated frequencies and 100 nanosec time resolution of individual giant pulses from the Crab pulsar provided new constraints on the emission physics of these extreme events.

The year saw good progress in our R&D program leading to the Square Kilometer Array, SKA. The One Square Meter Array demonstrator, OSMA, was commissioned and used to demonstrate newly developed algorithms for internal element calibration and for spatial nulling of external interference sources while maintaining the gain pattern of the main beam. A full theoretical treatment of the calibration of polarization for non-homogeneous arrays exhibiting significant instrumental polarization was derived. The design of our next demonstration antenna, THEA, the Thousand Element Array, was begun and an array element antenna having a 7:1 frequency range and $\pm 50^{\circ}$ scan angle in the array environment was identified.

An essential requirement for the SKA to be able operate in the nano-Jansky regime will be a site largely free of man-made interference. Of particular concern will be the planned constellations of telecommunications satellites in low Earth orbits, which could leave no place on Earth free from strong interference. Our Minister for Education, Culture and Science, the Honorable Mr. L. Hermans, presented the case for action at a summit meeting of science ministers in June in Paris. He succeeded in convincing his colleagues of the necessity of setting up a high level Task Force to explore regulatory, technological and siting policy solutions that would both safeguard radio astronomy and permit continued growth of the telecommunications industry. This Task Force is expected to begin its work in 2000.

The year saw completion of an extensive analysis of the design and cost of a new low frequency radio telescope – to be called LOFAR and be based on insights developed in our SKA R&D program. LOFAR will make possible for the first time extremely sensitive, high angular resolution studies of the sky at frequencies just above the ionospheric cutoff. It will be designed to detect signals emitted during the epoch of cosmological re-ionisation at redshifts above six, and will have multiple simultaneous measurement beams, permitting it to excel at discovering and monitoring transient sources. By year's end, collaborations with the US Naval Research Laboratory and the Massachusetts Institute of Technology in the USA and with the Fokker Space company in Leiden as well as with our own university community had been established and a campaign for acquiring the necessary financing had begun.

Finally, during the year the European Southern Observatory decided to start studies leading to joint construction with the USA of ALMA, the Atacama Large Millimeter Array. We indicated our interest in participating in the development program and joined a consortium planning to investigate the design of the back-end electronics. Our initial focus will be on advanced correlator designs, which we will study together with groups at MIT in the US and IRAM and Toulouse in Europe.

1.2 International evaluation

As reported last year, our parent organization, NWO, has reorganized itself. At the beginning of the year, the university grants program previously administered by ASTRON was moved to NWO's Physical Sciences Research Council ("Gebiedsbestuur-Exacte Wetenschappen", GB-E), as was responsibility for our collaborations on La Palma and Hawaii. These changes will allow us to focus our attention on optimizing the operation of the Westerbork Radio Observatory and on maintaining forefront capability in our Technical Laboratory.

To obtain advice on the viability and required resources for the revised program, NWO organized a Visiting Committee of outstanding foreign researchers, which visited Dwingeloo in May. The committee judged both the content and management of the program as "excellent" but recommended that its effectiveness could be improved by a modest increase in our basic operating budget, in particular to fund essential infrastructure. We were admonished to complete the upgrade of the Westerbork telescope as quickly as finances allow and to take steps together with our university colleagues to promote the involvement of the younger members of the community in carrying out the program.

1.3 New program plan

Early in the fall we presented our formal response to the Visiting Committee's report in the form of a program plan for the coming six years. This plan presents two main kinds of activity:

1. A program in breadth. These efforts will involve developing innovative instrumentation for a variety of observing facilities. This program aims at ensuring that our university community continues to have steady access to forefront observing instruments that effectively address their short-term research goals. The focus in the coming years will be on optical-IR and radio frequency instrumentation that makes use of available technology. Much of this program will be defined in close cooperation with our community's university-based national graduate research school, NOVA.

2. A program in depth. Here ASTRON will continue to build on its extensive experience with developing and operating major research facilities in radio astronomy. Our goal will be to combine forefront astronomical and technological insights to play an important role in shaping the future of the field. In the short term we will exploit the improved sensitivity – unparalleled in the world for neutral hydrogen studies – and tunable receiver systems – allowing unique, deep surveys in redshift space – of the upgraded Westerbork array to set the stage scientifically for the SKA. In the medium term, we will exploit the new technical insights developed during our SKA R&D program to design and build together with international partners the new array radio telescope, LOFAR. And in the long term we will strive to make the Square Kilometer Array a reality.

In October, NWO informed us that it accepts the main lines of the proposed program but that it will be unable to meet even the current level of base funding. Indeed, a very substantial budget reduction is foreseen during the plan period. ASTRON's Board reaffirmed its commitment to the new program and tasked management with maintaining adequate personnel and infrastructure, even to the point of breaking with previous policy of undertaking projects only when they have a direct purpose in astronomy. By year's end, plans were in place both to carry out projects in support of groups outside astronomy and to begin a modest effort to develop income from commercial activities. These changes will come into effect gradually starting early in 2000. In the meantime discussions with NWO will continue on how we should proceed with financiering our primary program in astronomy.

1.4 NFRA/ASTRON becomes ASTRON

Since 1988 the Foundation has used two names: the Netherlands Foundation for Research in Astronomy – abbreviated to NFRA, and Stichting Astronomisch Onderzoek in Nederland – generally shortened to ASTRON. Both names have appeared on our letterhead and logo. During the year it became evident that our efforts to develop activities outside of astronomy frequently encounter confusion with this situation. Accordingly, we have chosen to migrate to the use in future exclusively of the name, ASTRON, and to implement the change gradually over a two-year period.

1.5 Personnel matters

During the year important personnel changes occurred at Board and senior management levels. At the beginning of the year, prof. dr. Bram Achterberg of the Utrecht University formally joined the ASTRON Board, replacing prof. dr. Jan Kuijpers. Board member dr. Roel Hoekstra assumed new and important responsibilities within the Netherlands Applied Physics Institute and at year's end felt it necessary to relinquish his seat on the Board. Prof.dr. Wim van Bokhoven, Dean of the Faculty of Electrical Engineering at the Eindhoven Technical University, joined the Board in December. And on 1 March, dr. Eugene de Geus assumed the post of Adjunct Director with responsibility for financial development and business affairs.

Finally, on 2 November we lost to cancer a good friend, ASTRON Board member and one of the most prominent members of our community, prof.dr. Jan van Paradijs. Jan was at the peak of his career, leading an international team that demonstrated the cosmological nature of gamma ray bursters and is now busy defining the astrophysics of these most extreme of objects. He embodied the policy of our community that the most effective way to get at the physics of cosmic objects is to observe them with instruments and observing facilities across the electromagnetic spectrum. He will be remembered for his dry wit, his ready willingness to help others and his phenomenal scientific productivity. We will miss him.

1.6 Financial Management

The year 1999 was the first in which ASTRON itself became fully responsible for its annual budget, to be controlled by an independent external accountant. The divested budget responsibility has led to a new system of reporting to NWO and has necessitated a change in the supporting role of the financial division. New forms of reporting and forecasting were found to be necessary for externally funded projects as well as for the organization in which these projects are embedded. The implementation and execution of an ambitious scheme of reporting and forecasting of institute and project budgets was initiated in 1999.

The financial statement in this annual report will, therefore, also differ quite substantially from those in previous years, with a balance sheet and profit and loss statement. It will become clear from the financial statements that a number of issues regarding the reorganization of ASTRON's position within NWO remain unresolved, such as the position of fixed assets. These issues should be resolved in the coming budget year.

1.7 LOFAR

Last year, at the request of the university community, ASTRON started investigating the possibility of building a radio telescope that would use the "phased array" techniques being developed for the Square Kilometer Array in an astronomical instrument that could be operational by the middle of the next decade. The choice of operating frequency for such a telescope quickly fell on one of the most poorly explored regions of frequency space accessible from Earth: the band just above the ionospheric cut-off frequency (around 10 MHz) up to approximately 200 MHz. A pre-feasibility study was concluded in April 1999, which revealed that the instrument would need to be somewhat larger than originally anticipated if it was to allow a significant step forward to be made compared with both past and present telescopes operating at these frequencies. A preliminary design consisted of ~8,000 low frequency antenna elements in 40-50 stations distributed over a region 200-400 km in diameter. The strong wavelength-squared frequency dependence of effective aperture of the active antenna elements result in a total collecting area of almost a square kilometer at the low frequency end. The study also concluded that the computing power, which is required to process the considerable amount of data that is produced by such a telescope, will be available and affordable in 3-5 years time.

Discussions with colleagues at the US Naval Research Laboratory (NRL) revealed that there was also interest elsewhere in such an instrument. Several years before, an NRL team had demonstrated that self-calibration techniques enabled ionospheric correction at 74 MHz and they began taking images with the US National Radio Astronomy Observatory's Very Large Array (NRAO-VLA). They showed that the low frequency sky can now be explored at angular resolutions at least two orders of magnitude higher than previously possible. A wide spectrum of scientific studies looks set to become possible if the sensitivity can be increased by large factor over that afforded by the VLA. The million square meters of ASTRON's preliminary design certainly seemed to be appropriate for such a facility. A memorandum of agreement was subsequently prepared by ASTRON, NRL and NRAO to further develop a conceptual design for a radio telescope now named LOFAR (short for Low Frequency Array).

A compilation was made of the Scientific Drivers identified by the Dutch Astronomical community and by interested astronomers at NRL and NRAO. LOFAR's primary scientific goals were selected as:

- The Epoch of Reionization: to detect and map the signature left by the reionization of the Universe at redshifts probably between 6 and 10.

- Coherent emission processes in the Universe: for delineating the interaction between nonthermal emitting plasmas and thermal absorbing gas, and for differentiating between self-absorption processes. The objects and processes that will be targets of LOFAR include: (1) The distribution and spectrum of the Galactic cosmic-ray electron gas; (2) High-redshift radio galaxies and quasars; (3) Shocks driven by infalling matter in clusters of galaxies; (4) Pulsars and other transients in the Milky Way and in external galaxies; and (5) Radio emission from extrasolar planets.

Potentially important non-astronomical applications include:

- Detecting and imaging Earth-ward bound Coronal Mass Ejections for geomagnetic storm prediction.

- High spatial- and temporal-resolution studies of the ionosphere for the detection and study of both natural and artificially-produced ionospheric structures.

Furthermore, LOFAR hardware and software will be a key stepping stone for the development of the advanced digital signal processing technology required for the Square Kilometer Array.

In the course of the year, ASTRON brought Fokker Space, a company based in Leiden, into the project. Their role is to help define the Dutch side of the LOFAR program, focussing in particular on system design, project management and setting up an industrial consortium capable of participating in future phases.

In at least one respect LOFAR is quite different from most other (radio) telescopes, namely the cost of the antenna elements compared with the cost of signal transport and signal processing. In most conventional telescopes (including for example ALMA) the balance is heavily skewed towards the antenna. In LOFAR, the exact opposite is the case. The (relatively small and lightweight) active antenna element that has been proposed for LOFAR is therefore an important ingredient in keeping the cost down. Previous low frequency radio telescopes have used passive antennas which are by nature not capable of reaching the decade or so in bandwidth required in this case. ASTRON has teamed up with German company Rohde & Schwarz for the development of a breadboard antenna for LOFAR that could meet the requirements. First results are expected early in 2000.

By the end of the year, several meetings between astronomers and engineers of the three institutes and Fokker Space had taken place. These discussions resulted in a slightly modified version of the original preliminary design. The most striking changes were made to the configuration of the stations, which was now fully two-dimensional. A number of outstanding issues still remain to be resolved. Staff from MIT's Haystack Observatory have also indicated an interest in joining the LOFAR consortium. Further study looks set to take place next year, in preparation for submission of proposals to funding agencies in the second half of 2000.

2 Technical Research and Development

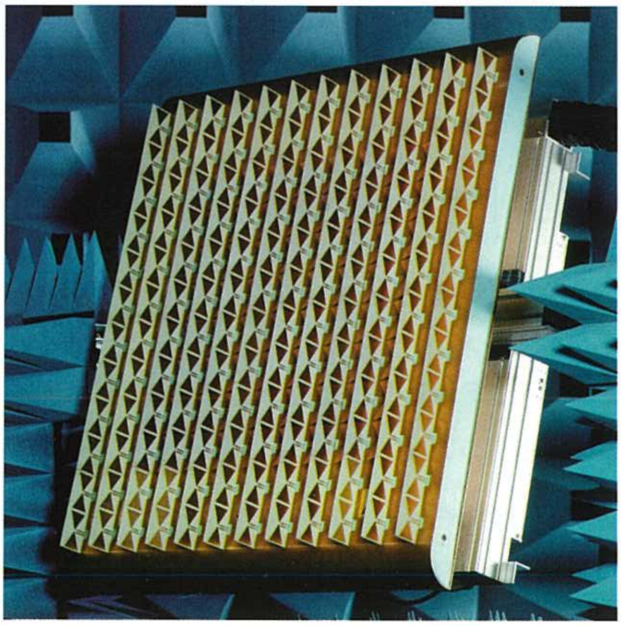
ASTRON's program of innovative instrumentation and facilities development now involves technologies for both radio astronomy and optical-IR astronomy. At the Westerbork radio telescope 1999 saw the full complement of Multi-Frequency Front End receivers go into routine operation, and the new IF system aimed at enabling surveys in redshift space move into production in our Technical Laboratory. R&D for developing the array antenna technologies required for the next generation of radio telescopes (specifically for LOFAR and SKA) achieved a number of interesting results during the year, and our two optical-IR projects – VISIR and MIDI for the ESO VLT – approached the ends of their design phases. In this section the details of these projects are presented together with other work carried out in ASTRON's Technical Laboratory in Dwingeloo.

2.1 SKA R & D – Development

2.1.1 OSMA (One Square Metre Array)

As a lead up to the new radio telescope SKA, several prototype phased-array systems are being defined and built at ASTRON. The Adaptive Antenna Demonstrator was completed in 1997 and followed by the One Square Metre Array (OSMA). The third stage is the THousand Element Array (THEA) which is currently being developed. In the first part of the 1999 the OSMA system became operational. Since then, various experiments have been performed in the anechoic room at ASTRON. These measurements show that phased-arrays offer new opportunities for radio astronomy, e.g. suppression of interfering sources and multibeaming. The OSMA results were presented at various conferences and in journal papers. During the SKA Technology Symposium at ASTRON in April 1999, demonstrations were given of the capabilities of OSMA. The major features of the system are:

- Full electronic beamsteering with a mixed RF and Digital beamforming architecture.
- Multi-beam operation.
- Real-time 16-channel digital beamforming
- Interference suppression with an adaptive digital beam former
- Octave operational bandwidth from 1.5 GHz to 3 GHz.
- Wide-band time-delay units in the RF Beamformer.



System Overview

OSMA is a planar phased-array receive-only antenna with a mixed analogue and digital adaptive beamforming architecture, operating in the frequency range from 1.5 to 3 GHz. The linearly polarised array consists of an 8 by 8 element active centre region surrounded by two rows of passive elements. The total number of antenna elements is therefore equal to 144.

The array is built up from broadband bow-tie elements with an integrated balun printed on a low-cost substrate. The elements are placed on a square grid with an inter-element spacing of 75 mm. The array is backed by a ground plane which is rounded at the edges to reduce diffraction effects. The top-level beamforming architecture of OSMA is illustrated in Figure 2.2 as well as the measurement configuration.

The first stage of the beamforming hierarchy is when the 64 active antenna elements are connected to 16 RF beamformer units (RFBF I). Each RF beamforming unit processes data from four antennas. The passive elements are terminated with matched impedance loads. The outputs of the RFBF I units can be connected to both a 16-channel adaptive digital beamforming (ADBF) unit or to a second stage 16-channel RF beamforming unit (RFBF II). The OSMA system can be used in two different modes: an RF beamforming mode, or a mixed RF and digital adaptive beamforming mode. Both modes of operation can be used simultaneously, either generating two RF beams or alternatively one RF and two digital beams. The control and data acquisition of the OSMA system is managed by Matlab in conjunction with an experimental measurement system ECHO, from which all system devices can be controlled.

In the ADBF system of OSMA a snapshot (simultaneous digital sample) from each of the 16 RF-signals of the RFBF I modules is combined into a single digital beam. The digital beam can be manipulated by applying a complex weight vector to the input data. In this way the digital beam can be

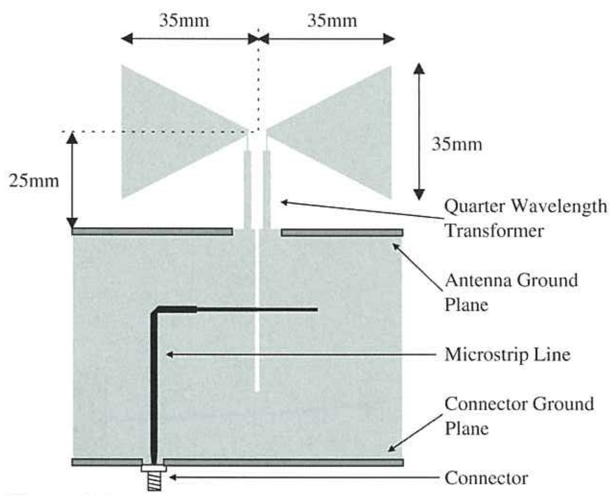


Figure 2.1 : (a) A photograph of the OSMA array inside the ASTRON anechoic chamber. OSMA is mounted on a positioner which can orientate it in two directions, azimuth and elevation, with respect to a transmit horn. (b) A single element of the bow-tie array showing the integrated microstrip balun. The antennas are not manufactured individually, but in multiples of four.

steered within the half-power zone of the RF beam. In the ADBF system, narrowband signals (4 MHz) are processed. The ADBF is duplicated twice in OSMA in order to generate two independent digital beams. The first part of the ADBF is the conventional real-time digital beamformer (DBF) while the second part is the adaptive weight estimator (AWE) that determines the optimal weights used by the real-time beamformer. A set of 16 complex 8-bit analogue-to-digital convertors provides data at 8 Msamples/second to the real-time beamformer ASICs. Some of the snapshots are used in the AWE for calibration and to calculate the required adaptive weights for the real-time beamformer. The AWE is implemented in software on a DSP. Alternatively, the so-called OSMA-Chip can be used to generate the weight vectors with a higher update rate. The OSMA-Chip was developed in conjunction with the TU Delft and DeDris as part of a STW program. It uses a CORDIC core to rapidly calculate adaptive weights.

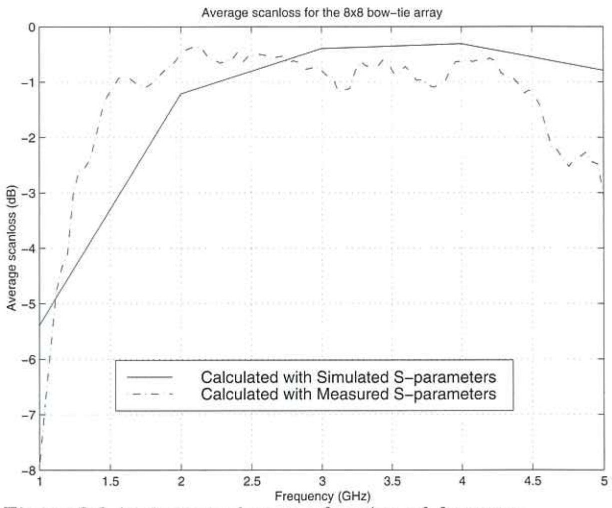


Figure 2.3 Average scanloss as a function of frequency.

Results

Detailed descriptions of the results obtained with OSMA can be found in a number of papers that were written (see NFRA Publications). A short summary is given below.

Antenna

A single element of the bow-tie array is shown in Figure 2.1b. Measurements with the bow-tie array showed that the array can be used over a 3:1 bandwidth with an average scan loss smaller than 1 dB for scan angles less than 50 degrees w.r.t. broadside. This is illustrated in Figure 2.3.

Multi-Element Phase-toggle (MEP) Calibration

A new calibration procedure was developed which allows groups of elements to be calibrated simultaneously by using FFT signal processing techniques. The purpose of the calibration procedure is to correct for all amplitude and phase errors that occur in the analogue beamforming structure of the OSMA system. The technique is referred to as Multi-Element Phase-toggle (MEP) and shows a significant improvement over other techniques which typically calibrate elements individually. The MEP method has two other main advantages. The first being that an average amplitude and phase offset of each element is measured, not just one particular phase setting. The other is that all interfering signals from other array elements (which are not phase-toggling) are located in bin zero of the FFT spectrum.The MEP technique allows there to be reduced isolation between the channels whilst not affecting the desired result. Figure 2.4b illustrates the measured amplitude and phase errors after a MEP calibration. The remaining errors are less than half a quantisation step of the TDU (22.5 degrees at 2 GHz).

RFI suppression with deterministic RF nulling

Spatial nulling can be done using the analogue beamformer or with the digital beamformer. Both approaches were explored in OSMA. The RF deterministic nulling performance

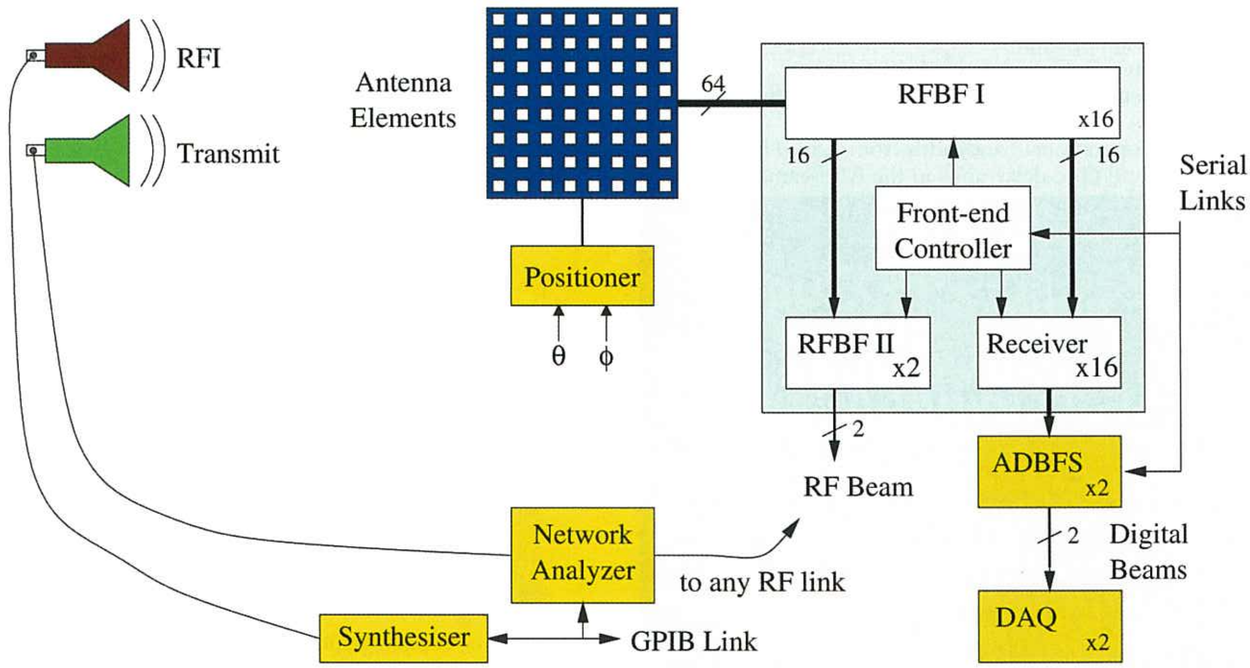


Figure 2.2 Top-level beamforming architecture of OSMA including the measurement setup. A network analyzer and synthesizer generate the required source signals. The 64 array outputs are combined into 16 signals using the first stage RF beamformers (RFBF I). The two identical outputs of this beamforming stage can be used to generate either RF or digital beams. The receiver contains frequency down-conversion and ADC circuitry. The adaptive digital beamforming system (ADBFS) outputs are connected to a data acquisition (DAQ) system.

of the OSMA RF beamforming system was measured in the frequency range from 1.5 to 3 GHz. Figure 2.5a shows an example of the measured H-plane antenna pattern at f=2 GHz, with and without a null placed at $\theta_{RFI} = 10°$. The broadside direction (or location of the transmit horn) of the array is at $\theta = 0°$. The main beam direction is given by θ_{LOOK}, which in this case was set to –10°.

The measured null depth is more than –43 dB w.r.t. the main beam. Compared with the sidelobe level of the original beam the signal-to-interferer ratio has been improved by more than 30 dB. Figure 2.5(b) compares the theoretical and measured results in the case of a null placed at $\theta_{RFI} = 10°$. The agreement between measured and predicted data is excellent.

RFI suppression with adaptive digital nulling

With the adaptive digital beamformer it is possible to suppress unknown or/and moving interfering sources. An example of an antenna beam pattern measured with OSMA at 2 GHz using Minimum Variance nulling is shown in Figure 2.6. A single RFI source was located at broadside. The main beam was steered to 12°. The obtained null-depth is better than -30 dB w.r.t. the main beam. Note that the first sidelobe is significantly higher (-8 dB) as compared to sidelobe level (-13 dB) obtained with a Fourier beamformer with uniform weighting.

2.1.2 THEA – The Thousand Element Array

The Thousand Element Array (THEA) is the third demonstrator phased-array system that is currently being developed at ASTRON. THEA consists of 1024 receiving antenna elements and will be used as an outdoor phased-array system to detect (known) radio sources in the frequency band ranging from 600 to 1700 MHz in the presence of several strong RF Interfering (RFI) signals. The THEA phased-array system has various new features compared to conventional radio telescope designs:

Multi-beam operation - THEA will have 32 digital beams available simultaneously. The 32 beams are clustered in two groups of 16 beams. Each group of beams can be directed to any point on the sky without loss of sensitivity.

Adaptive nulling - Interfering sources can be eliminated with a real-time adaptive digital beamformer.

Interference monitoring - A real-time map of the interfering sources can be made.

Re-configurability by using sub-array units - THEA is built up of 16 tiles, each tile consisting of 64 elements. The construction is flexible in the sense that the distance between the tiles can be changed. In that way, experimental

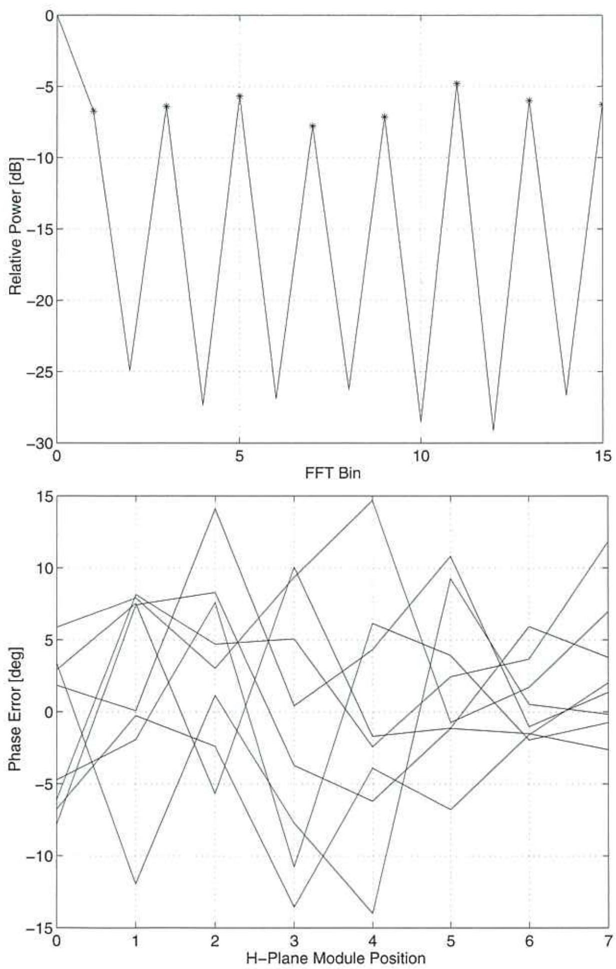


Figure 2.4 (upper panel) Fourier Transform of Measured Calibration Data: Measured FFT spectrum with 8 elements calibrated simultaneously. The contribution of the other elements fall into bin 0. Frequency is 2 GHz. (lower panel) Phase Error After Calibration: Measured phase errors after MEP correction (f=2 GHz) are less than ±0.5 LSB.

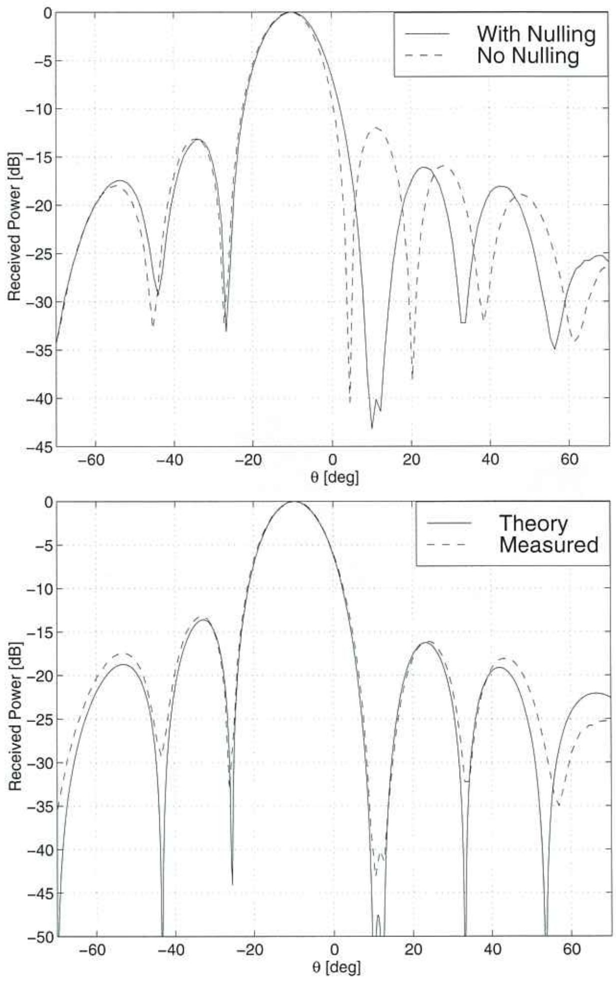


Figure 2.5 (upper panel) Measured H-plane antenna patterns with and without a null placed at $\theta_{RFI} = 10°$, $\theta_{LOOK} = -10°$, f=2 GHz. (lower panel) Measured and predicted H-plane beam patterns for a null placed at $\theta_{RFI} = 10°$, $\theta_{LOOK} = -10°$, f=2 GHz. The array was calibrated using the MEP technique for the measured beams, however the simulation uses ideal weights.

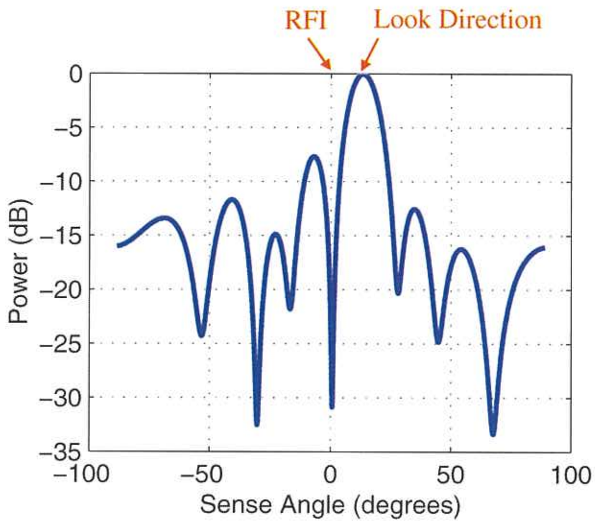


Figure 2.6 Measured OSMA antenna pattern with a single RFI source at broadside. The beamformer look direction is 12°. Frequency is 2 GHz.

research on array configuration can be done, e.g. sparse random arrays. In addition THEA could be set up as a two-antenna interferometer.

Besides these additional functionalities, THEA also serves as a test-bed to exploit new and advanced technologies which should lead to a high level of integration and cost reduction. Examples are the use of a high-speed optical link with a capacity of 30.72 Gbit/s and a new multi-beam analog beamformer with a high level of integration including the antenna elements.

THEA system

The lay-out of the complete THEA system is shown in Figure 2.7. It consists of 16 tiles covering a total surface of approximately 16m^2. The total number of receiving antenna elements is 1024. The tiles are located on a remote outdoor platform. The digital back-end electronics and the control system are located in the Dwingeloo building of ASTRON. The distance between the building and the THEA platform is 200m. High-speed optical links are used to transport the data from the tiles to the back-end electronics and vice versa. LO generation is done with standard synthesizers located near the platform. The functional layout of a tile is shown in Figure 2.8b. The corresponding mechanical structure of a tile is illustrated in Figure 2.8a. Each tile is build up from 64 linearly-polarised antenna elements grouped in 16 subarrays.

Within each tile two fully independent RF beams are made with the analog beamformer. The analog RF beamformer has a high-level of integration: it supports both the antenna as well as a dual-beam RF beamformer. Each beamformer board consists of four channels. The main features of the RF beamformer boards are that 1) the four broadband antenna elements are integrated with the RF electronics on a single board; 2) Each board produces two independent beams; 3) Expensive and lossy connectors and/or cables are avoided. The column RF beamformer is implemented as a multi-layer board with a total of eight layers. The layout of the prototype beamformer board is shown in Figure 2.9. The prototype board contains bow-tie elements.

The two RF signals from the analog beamformer are converted to a baseband signal with an instantaneous bandwidth of 20 MHz. Finally, the signals are digitised with a 40 MHz 12 bit A/D convertor. A novel conversion scheme is used in the IF unit to minimise the influence of out-of-band interfering signals. The 32 digital output signals of the tiles are distributed to the digital beamformer in the back-end unit by means of an optical high-speed link with a total capacity of 30.72 Gbit/s. A 32-channel real-time digital beamformer converts the 32 input signals into two sets of 16 digital beams using FFT beamforming. Further processing and data reduction (e.g. spectral analysis) is done in the RAP (Reduction, Acquisition and Processing) unit. The spectral analysis is implemented on a special processing board consisting of nine C67 DSP's.

Wideband Antenna design

In cooperation with the University of Massachusetts a wideband antenna array was developed based on Vivaldi notch antennas. These elements can be used in single- or dual-polarized arrays to achieve multi-octave bandwidths for scanning to 50 degrees in all planes. Elements have been designed for single- and dual-polarized arrays with an ex-

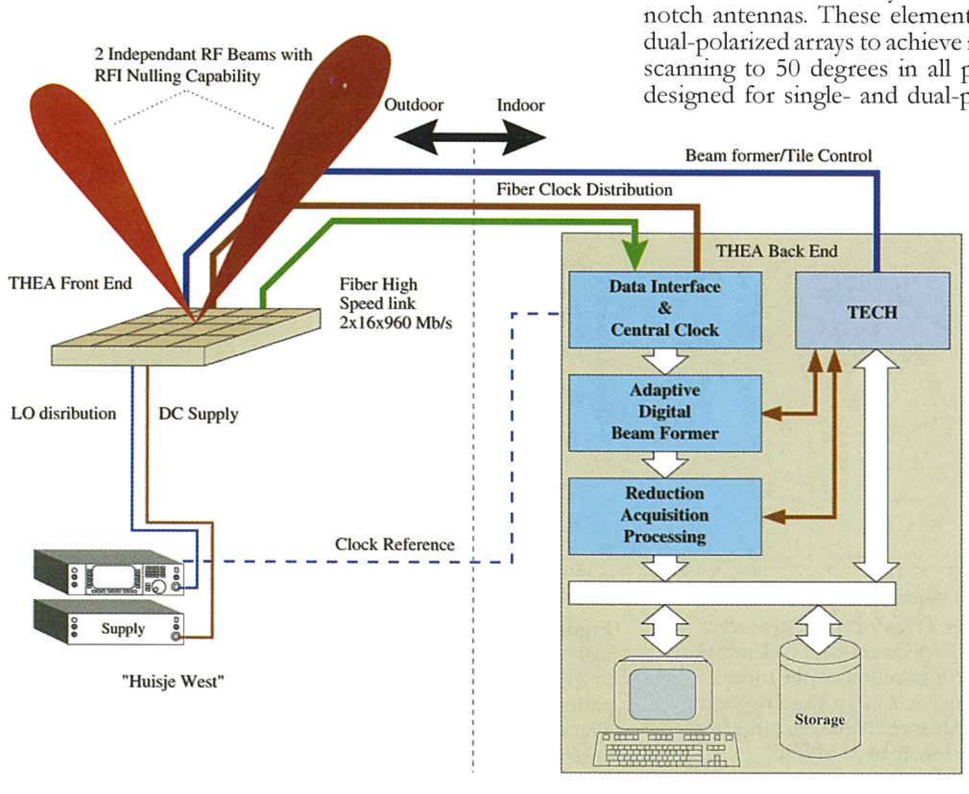


Figure 2.7 THEA system lay-out, consisting of 16 tiles with a total collecting area of approx. 16m^2. The tiles are located on a remote outdoor platform. The digital back-end electronics are placed in the Dwingeloo building. High-speed optical links are used to transport the data from the tiles to the back-end over a distance of 200m. THEA will operate in the 600-1700 MHz band with an instantaneous bandwidth of 20 MHz.

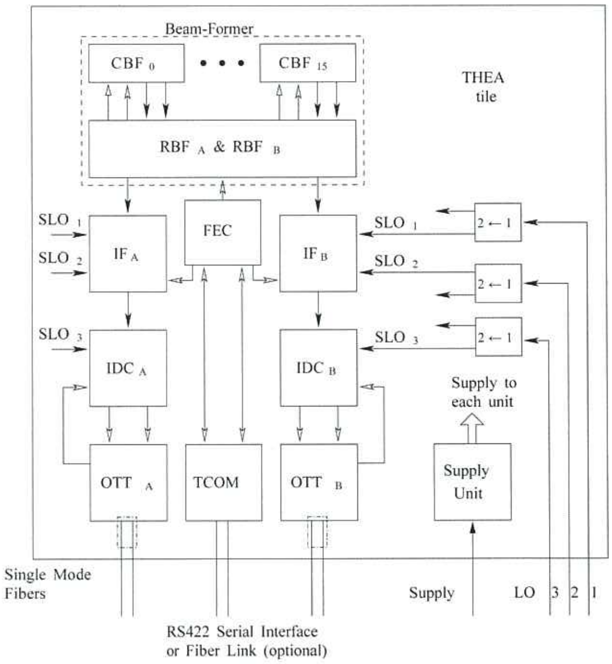


Figure 2.8 (a) Mechanical structure of a tile. The housing is made of low-cost foam. (b) Functional lay-out of a tile. It consists of 64 antenna elements creating two independent beams. Both signals are converted to baseband and digitized with a 40 MHz 12-bit AD convertor.

pected bandwidth of 5:1 for Standing Wave Ratios (SWR) < 2 and scanning to 50 degrees in all planes. The arrays that have been designed to operate without grating lobes throughout their entire frequency band and scan range of THEA. Thus, the element spacing is less than 0.5 wavelength at the highest frequency, and less than 0.1 wavelength at the lowest frequency. Efficient operation of elements with such a small aperture relies heavily on mutual coupling to neighboring elements. Effective design of Vivaldi notch antenna arrays, therefore, requires careful treatment of mutual coupling.

The final THEA array will use Vivaldi notch elements like the one depicted in Figure 2.10a. The exponentially flared slotline is etched in both ground planes of the stripline circuit board that comprises the feed line. An open-circuited stripline stub at the transition provides beneficial reactance that enhances the bandwidth of the element. The circular slotline cavity terminates the slotline, but its impact on the elements' radiation cannot be ignored. The full-wave MOM analyses correctly account for these effects as well as other mutual coupling effects in the array. In an infinite array, the element SWR is predicted in Figure 2.10b. The expected performance over the optimised band of 0.5 - 1.5 GHz is similar for θ up to 45° in the E-plane. The Vivaldi antennas will be integrated with the RF beamformer boards of Figure 2.9.

RF and digital beamforming architecture

In each tile two fully independent RF beams are made with the RF beamformer. RF beamforming is done in two stages. Firstly, the signals from four antenna elements are complex weighted and coherently combined with a four-channel column beamformer (CBFi) as indicated in Figure 2.8b. The complex weighting is done with an integrated vectormodulator. Each column combiner generates two output signals, corresponding to the two beams. Secondly, the 2*16 output signals from the column beamformers are combined in the row beamformer unit (RBFi). Finally, we obtain

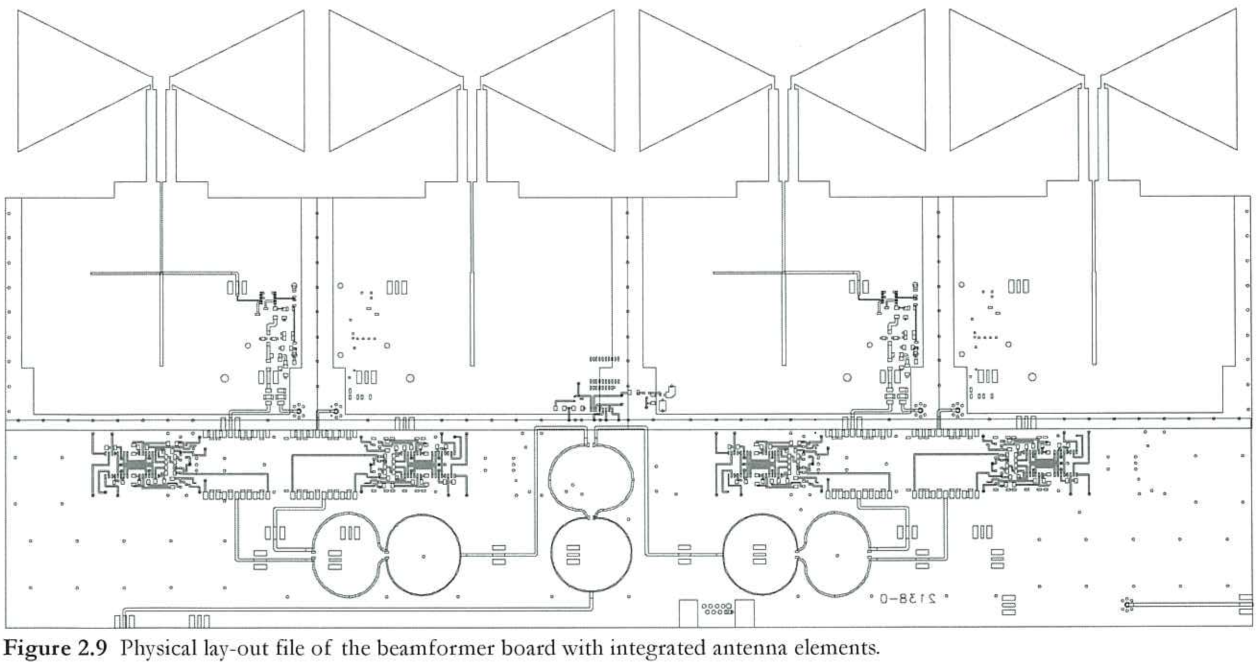
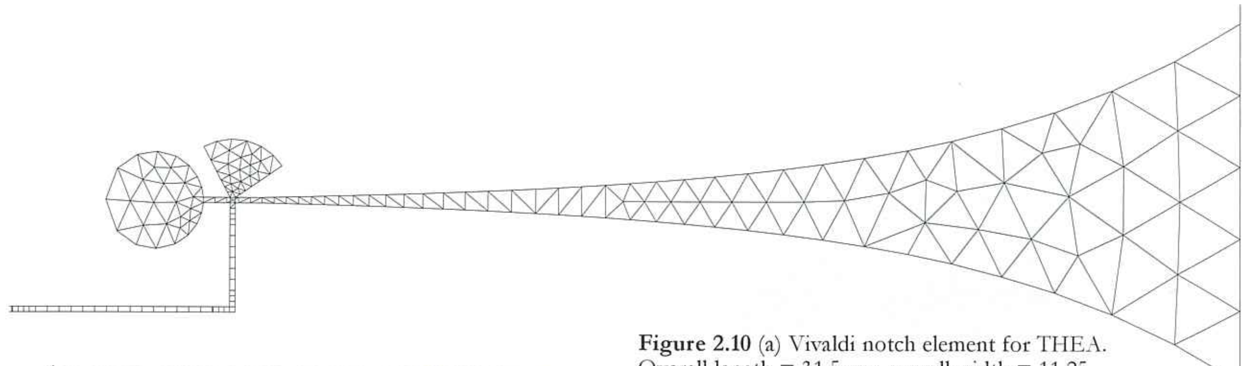


Figure 2.9 Physical lay-out file of the beamformer board with integrated antenna elements.



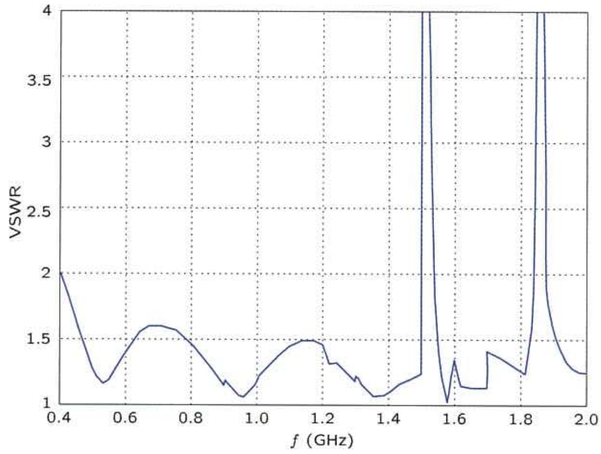


Figure 2.10 (a) Vivaldi notch element for THEA. Overall length = 31.5 cm; overall width = 11.25 cm. Notch aperture is 9.25 cm wide. Triangles indicate grid for Numerical analysis. (b) Predicted SWR of THEA element in infinite array radiating broadside. Optimised band is 0.5 - 1.5 GHz.

two signals that are converted to baseband and digitised by the IF-unit and the IF-to-Digital Convertor (IDC). In the digital back-end the 32 digital signals from the 16 tiles are processed in two groups of 16 by the Adaptive Digital Beam Former (ADBF) (see Figure 2.7). The digital beamformer converts each group of 16 input signals into 16 simultaneous digital beams using efficient FFT processing. The digital beamformer is controlled by the Adaptive Weight Estimator (AWE). The AWE is the intelligent part of the ADBF unit. In the AWE an "intelligent" sub-space tracking algorithm (developed in collaboration with colleagues at Ohio State Univ.), determines the optimal complex weights of the digital beamformer from snapshots of the raw data. The algorithm can also generate information (e.g. locations of strong RFI sources) that can be used by the control system (TECH) to modify the complex weights of the RF beamformer in each tile. The adaptive algorithm is implemented on a DSP platform, whereas the real-time digital FFT beamformer is implemented on FPGA devices. With the planned design of the ADBF unit it will be possible to make 16 digital beams within each RF beam. Figure 2.11a shows an example of the 16 digital FFT beams as produced by the digital beamformer at 1GHz. A cut in the v=0 ($\phi=0°$) plane is plotted in Figure 11b. The update rate of the ADBF is 10 msec.

Spatial nulling with THEA

Spatial nulling is implemented in THEA on two levels:
(i) Determinstic analogue nulling in the RF Beamformer, and
(ii) Adaptive digital nulling in the digital beamformer (ADBF).
Deterministic nulling in the RF beamformer is used to suppress strong and fixed RFI sources, e.g. TV signals, prior to A/D conversion. Information obtained with the digital beamformer on the location of strong RFI sources is used to optimise the nulling performance of the RF beamformer. The results obtained from the OSMA system have been used in the design of the RFI-rejection concept of THEA.

Test Facilities

The indoor antenna measurement facility at ASTRON was upgraded with a near-field scanner. A photograph is shown in Figure 2.12. The near-field facility will be used to test and calibrate each THEA tile, before the tiles are placed on the outdoor platform. The near field scanner measures the near field of a THEA tile over a certain plane. By using an Fourier Transformation it is then possible to determine the far-field pattern of a tile. In this way, tiles can be characterised very accurately without the need of a very large and expensive anechoic chamber.

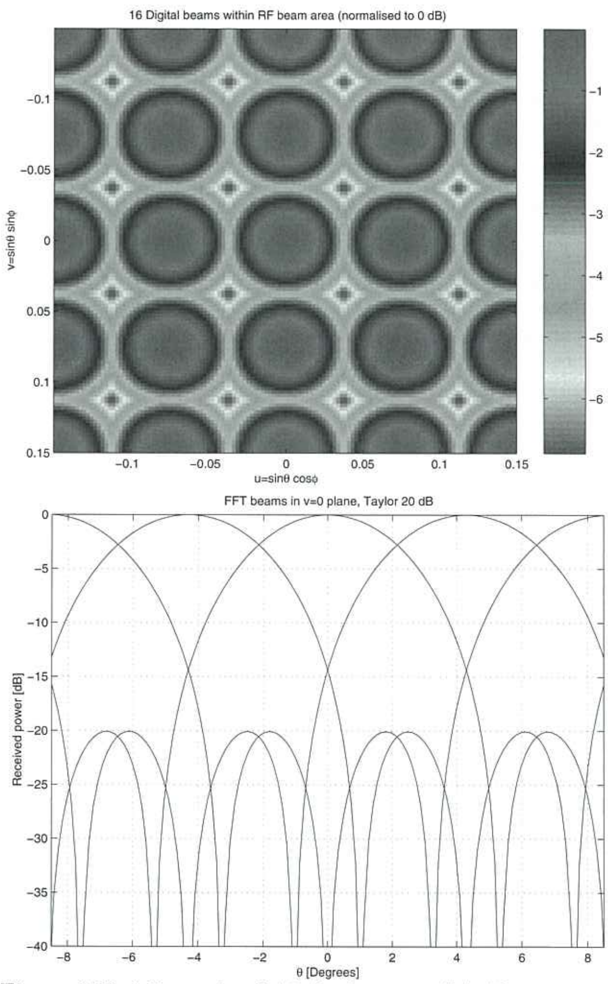


Figure 2.11 a) Example of 16 simultaneous digital beams produced by the digital beamformer in the (u,v)=(sinθ cosϕ, sinθ sinϕ)-plane b) Cut in the v=0 ($\phi=0°$)-plane. Beam area plotted is the 3dB beamwidth of the RF beam of the tiles. Beamwidth of each digital beam is 4.5°. RF frequency is 1 GHz.

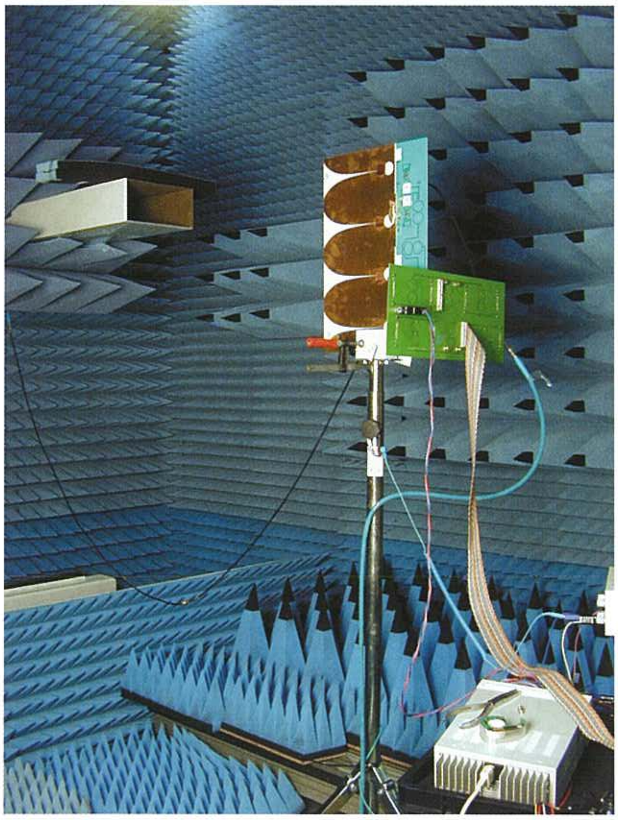


Figure 2.12 New indoor Near Field antenna test facility at ASTRON.

2.2 SKA R & D – Research

2.2.1 Antennas for LOFAR

In January 1999 a formal collaboration between Rohde & Schwarz and ASTRON started with the secondment of an ASTRON senior project manager, to their antenna development laboratories in Munich, Germany. Rohde & Schwarz is an international company active in the areas of professional communications technology and measurement equipment with main office in Munich. They employ approximately 4400 people worldwide and have subsidiaries or representatives in more than 70 countries.

The collaborative effort focused on research and development of broadband antennas in the framework of the SKA technology roadmap. The first 5 months were spent on research in the area of broadband reflector antennas. Interesting results were obtained for these systems that enabled operation over a frequency range of more than a decade, e.g. 1 GHz to 20 GHz with high performance. The results can be directly applied to the high frequency SKA. In April, a presentation on this work was held at the ASTRON Conference "Technologies for Large Antenna Arrays".

Within the ASTRON the Low Frequency Array (LOFAR) project became more concrete in the spring of 1999. The antenna technology needed for this instrument matched the capabilities of Rohde & Schwarz. After an initial assessment of possible antenna options that could fulfil the LOFAR system requirements, the choice was made for an active antenna configuration. Although Rohde & Schwarz has a long tradition in the area of active antennas, no suitable off the shelf device was available that would meet all LOFAR requirements. Instead a plan was established along which lines the development was to take place. In several phases, breadboard models were created, using advanced CAD simulation tools, to measure and evaluate the design. Results of passive radiator and active circuitry obtained so far are encouraging. The active antenna performance can be well predicted by the simulation tools and fit the LOFAR requirements. It is expected that several LOFAR breadboard prototype active antennas will be available for long-term field-testing purposes early in the year 2000.

Initiated by ASTRON, agreements between Rohde & Schwarz and other partners in the LOFAR project were established. These agreements enabled LOFAR partners to take note of the LOFAR active antenna research and development efforts and results. In this framework, especially the agreement between Rohde & Schwarz and Fokker Space must be mentioned because it can form the basis of the industrial consortium that will play an important role in the realisation of the LOFAR project. In the long-term future it might also be beneficial to the SKA project.

2.2.2 RF-IC's

In 1999 the Radio Frequency-Integrated Circuit (RF-IC) plans and ideas, required for future large scale telescopes (e.g. SKA), really started. Three different Low Noise Amplifiers (LNA) where designed in the 0.25mm PsHEMT Gallium Arsenide process from Philips Microwave Limeil. In each of the designs a different aspect of a low noise front-end amplifier has been tested. The outcome of the Low Noise Active Antenna (LNAA) study, described in the 1998 annual report, which was a discrete design, has been integrated in one of the three amplifiers. The three designs where processed and first samples could be tested in October 1999.

For the testing of the IC's a wafer-prober, a precision instrument which enables the testing of the bare chips, has been purchased and installed. With the wafer-prober IC's can be tested without the disturbance and difficulties of a package around the chip.

With the wafer-prober the LNA designs where tested for gain, noise figure and other critical parameters. The IC's performed very well, a very good match between what was simulated and expected and the measured results has been established. In the first months of 2000 more tests on the LNA's will be performed. A complete active antenna will be built in order to test the IC's in the correct environment. And one of the THEA boards will be equipped with samples of the integrated LNA's.

The wafer-prober was also used to perform the testing of a wafer from DIMES (Delft University). This wafer contained Low Noise Amplifiers designed by a Master student from Delft University. These measurements where successful as

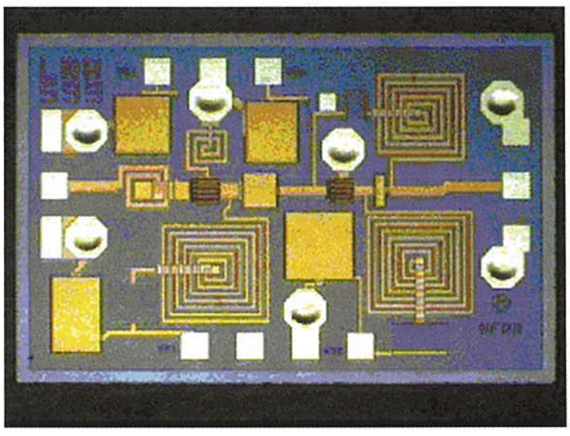


Figure 2.13 A micro-photograph of one of the IC's developed at ASTRON. The IC measures 1.5 by 1.0 millimeter.

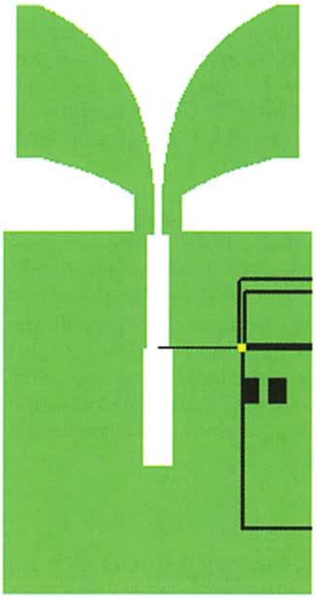


Figure 2.14 The design of the new Low Noise Active Antenna with the IC visible as a small yellow dot at the intersection of the microstrip and bias lines on the right.

well, they showed a very good match with the simulations, although the performance itself was, due to the limitations of the Silicon 1 mm process, not sufficient for SKA.

In order to extend the ASTRON IC activities from expensive GaAs to more affordable (silicon) processes, Cadence tooling has been purchased and installed. Silicon foundries tend to base their libraries on different tooling than GaAs foundries. With the Cadence software high frequency Silicon Germanium (SiGe) and CMOS circuits will be designed. This can lead to a lower component cost for SKA.

2.2.3 Adaptive Digital Beam Former

Beam forming in SKA is intended to suppress adequately the time-dependent Frequency Interference (FI)-effects, thus cleaning up the celestial information before the actual image processing by the correlator. The Adaptive Digital Beam Former (ADBF)-system in THEA consists of two sub-systems: the Digital Beam Former (DBF) and the Adaptive Weight Estimator (AWE).The DBF performs a spatial weighting operation on the snapshot (a set of concurrent signal samples), thus creating a baseband-beam that is narrower than the RF-beam created by the RF-Beam Former. The AWE calculates the optimum value of the weightvector according to the actual RFI-situation, before updating it in the DBF at regular intervals.

Research topics

Applying an FFT-based DBF opens up the possibility of constructing a set of baseband-beams (rather than a single baseband-beam) that fills a sub-space of the RF-beam. Future investigations will focus on this so-called sub-space beam processing. Another interesting area is the fundamental trade-off of spatial processing capacity versus temporal processing capacity. This appears in the DBF-development as finding the balance between input-/output- interconnectivity and clock rate

Because of the essentially non-linear behaviour of adaptive models, a time-dependent weighting operation can offer a significant improvement in ADBF-performance (accuracy, convergence speed, stability), at the same time making it more difficult to predict the exact degree of this improvement.

Future investigations will focus on comparing different candidates for AWE-modelling: as an alternative to the Minimum Variance Derivative Constraint (MVDR) algorithm, the Subspace Tracking algorithm is being considered.

Development topics

Implementation of the DBF faces extreme demands concerning input/output-connectivity, processing speed, number of CMOS-transistors and power consumption. The cause is the extremely high bitrate (15.36 Gbit/s for THEA). Fortunately, the data-flow oriented character and the single-task functionality of the DBF lends itself well to partitioning into a regular structure of identical, more elementary functions. Especially for THEA, the 16-point FFT-function can be partitioned into four identical 4-point FFT-blocks, each without the CMOS-transistor-consuming multipliers. At the moment, the DBF is being developed as a VHDL-model (VHDL is a Very high speed integrated circuit Hardware Description Language), before being realised as a reconfigurable hardware platform (i.e. a custom-made printed circuit board (PCB), with FPGA's from the Altera APEX20K-family).

Implementation of the AWE faces far less extreme demands concerning processing speed, because the weightvector update rate in the AWE is much lower than the snapshot sampling rate in the DBF.

However, the control-flow oriented character and the multi-task functionality (complex matrix calculus) puts extreme demands on the scheduling of (and the data transport rates for) the various array-processing subroutines. At the moment, existing 'C'- coded software modules from OSMA (representing the AWE-model) are being adapted for fitting into an embedded software platform (an off-the-shelf "Daytona"-PCB, with DSPs from the Texas Instruments TMS320C67xx-family).

Realisation and verification of both DBF and AWE depends heavily on the quality of the vendor-dependent, highly complex development environments, like "WorkViewOffice" and "Quartus" for the DBF and "Code Composer Studio" for the AWE.

2.2.4 Nulling Obstructing of Electromagnetic Interferers (NOEMI)

The use of the electromagnetic spectrum is currently subject to major changes due to an increasing demand for bandwidth, especially from the communications industry. The requirement for bandwidth of the new users is not completely compensated for by the phasing out of out-of-date communication systems. One effect is that the spectrum occupancy, both in time and frequency, increases. Another aspect is that new transmission modulation schemes are being developed. There is a trend towards higher transmission frequencies and the use of wideband digital modulation schemes. Exceptions to the trend of moving to higher frequencies are the personal mobile commucation systems which are linked to the UHF and L band because of the constraints on antenna sizes.

Radio astronomy is a passive service as it does not transmit, but only receives signals. These signals are from outer space and are generally, in contrast to the signals used in the majority of the current communication systems, much weaker than the instantaneous noise levels. This means that for radio astronomy there is an increasing risk that spectrally-adjacent spectrum users might transmit residual signals (RFI) in the radio astronomy bands. However, it is believed that with new RFI mitigation techniques, which are currently being studied, these challenges can be met, thus keeping radio astronomy a fruitful branch of science. ASTRON plays a leading role in RFI mitigation techniques as it has been active, for several years now, in all relevant RFI mitigation areas.

One of these areas is mitigation of RFI by exploiting the spatial, frequency, and time behaviour of interference. As this behaviour often distinguishes interference from the desired astronomical signal, it can be used to suppress the interference. One of the ASTRON projects in this particular

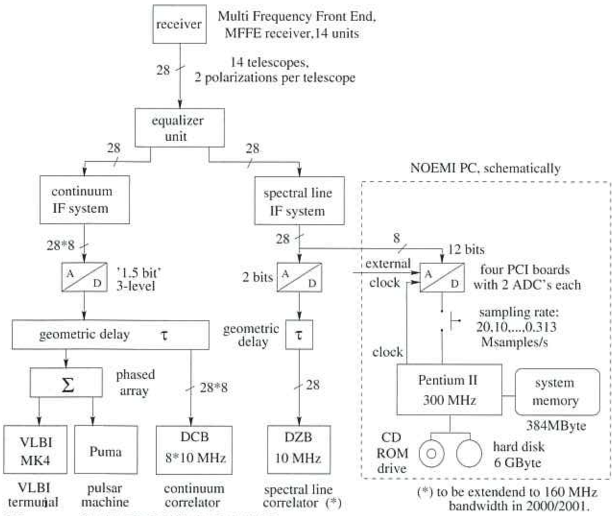


Figure 2.15 WSRT-NOEMI measurement setup

field is the Nulling Obstructing of Electromagnetic Interferers (NOEMI). This four-year project, described in the following sections, is a collaboration between ASTRON and the Technical University Delft, supported by the Dutch technology foundation, STW.

Project goal and status

The purpose of the NOEMI project is to investigate the merits of RFI mitigation in radio astronomy telescope systems by digital array processing techniques. These techniques are studied theoretically, and the aim is to apply the acquired knowledge in an RFI suppressor demonstrator at the Westerbork Synthesis Radio Telescope. The three main objectives of the project are first to study the characteristics of interference and to investigate the optimal array signal processing algorithms for the mitigation of the interfering signals, secondly to build a small-scale interference mitigation demonstarator at the WSRT, and finally to report the implications which the acquired knowledge has for the interference mitigation aspects of the SKA design.

Last year the project focused on the algorithm research and the theoretical characterization of interference. This year the NOEMI data recorder was installed and used, and the algorithms were tested on WSRT data taken with the data recorder. The detection and blanking algorithms were successfully used on intermittent interference, such as GSM uplink data. Suppressing time-continuous signals, and their influence on the astronomical map, was studied mainly theoretically. Continuous signals, taken by the NOEMI data recorder at the WSRT, were suppressed by the algorithms, but more research is needed in order to quantify the results properly in terms of system noise effects and residuals in the map.

Data recorder installation and measurements

The NOEMI data recorder mentioned in the previous section consists of a personal computer (Pentium II) equipped with eight 12 bit analog-to-digital converters (ADC's). These ADC's are connected to eight of the twenty-four telescope channels, see Figure 2.15. The data, which contains both astronomical and interfering signals, are stored on disk and on CD-ROM for offline processing. The computer memory size allows consecutive recordings of about 268 Mbytes, which corresponds, depending on the bandwidth used, to about one second to one minute. As can be seen from the figure, the data recorder is connected to the WSRT before the geometric delay system. As the NOEMI data reduction is done in small sub bands there is no need for delay compensation.

Before the data recorder was transported to the telescope, addditional software was written in order to be able to control the subsystems and store the data on the hard disk. In June the system was installed at the telescope and the first successful measurements were done. The resulting data ranges from time slotted interfering signals such as GSM, to continuous signals, such as GPS. Although radio astronomy has no frequency allocations in the two bands mentioned above, these data sets are very useful for testing the algoritms. In all interference recordings the telescope was pointed at a well-known astronomical source in order to investigate the influence of the algorithms also on the desired astronomical signals. In the process of mitigation of the interference, the properties of the astronomical signals should be maintained.

Detection and blanking of intermittent RFI

In case the observed interference is time slotted or intermittent and if the interference on-off ratio is not too high, blanking is a good option. In the NOEMI project this was tested with the GSM uplink around 900 MHz. The detection algorithm is based on eigenvalue analysis because this is more sensitive for interference than detecting the channel powers only. Figure 2.16 shows as an example spectogram of GSM uplink channels, measured with the data recorder and WSRT telescope number 6. Clearly visible is the 0.5 ms time slotted character of three 200 kHz wide channels at 902.4, 904.4, and 907.2 MHz. The continuous interference at 902 MHz is not part of the GSM uplink, and is generated elsewhere. The array-processing techniques are applied successfully to GSM data sets. In order to investigate their effect on the astronomical signal, GSM datasets were superimposed onto a measurement of 3C48 with a galactic HI absorption line at 1420.4 MHz. In this way it was verified that the algorithm did not affect the astronomical signal. Figure 2.17 shows the combined dataset before and after detection and blanking, both with single channel detection and detection based on array processing techniques.

Spatial filtering

In addition to intermittent interference analysis, mitigation techniques were studied that are based on the spatial array structure. First results show that, as was already expected on the basis of other work, that strong interferers can be sup-

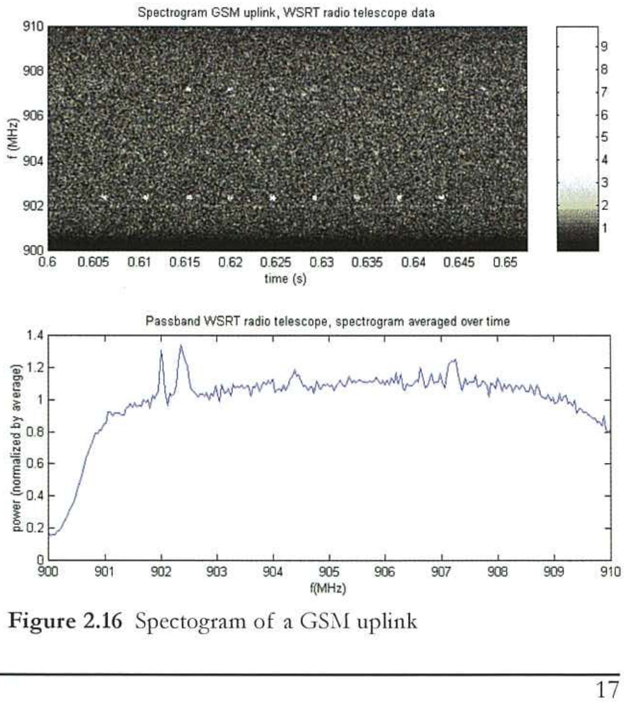


Figure 2.16 Spectogram of a GSM uplink

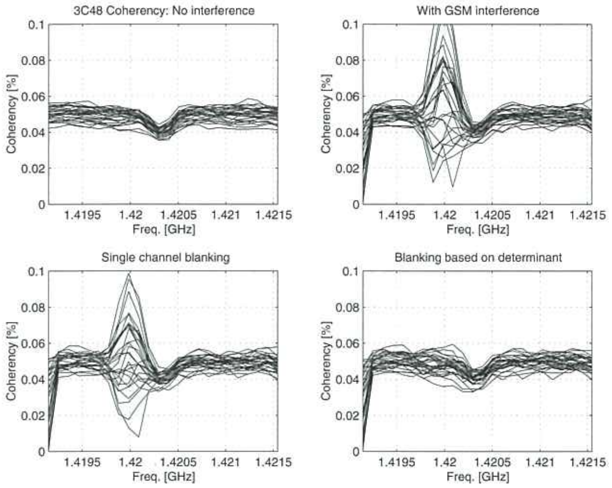


Figure 2.17 Superposition of GSM-uplink data at 905 MHz on galactic absorption data of the source 3C48 at 1420.4 MHz, before and after blanking.

pressed close to the level of the channel noise level. Interference which has comparable or less power than the instantaneous telescope channel system noise is hard to detect and suppress. But as telescope systems usually have very long integration times, which are necessary to make maps, these interference signals will pop up in the map. This issue will be given more attention in the next phase of the project. Another aspect which became clear is that after the spatial filtering process, the interferometer data set (the so called UV-data) becomes a linear tranformation of the initial data set. This makes straight-forward map making impossible and in the NOEMI project an alternative map-making scheme is being investigated, which takes into account the mixing of the UV dataset. As datasets taken with the NOEMI data recorder are not suited to map-making, a WSRT data converter was written. It converts the WSRT measurement sets to a mathematical spreadsheet format (Matlab). In this way 12-hour datasets containing RFI as well as astronomical signals can be investigated offline. The converter has been tested and this type of investigation will start at the beginning of next year.

Plans for the following project phase

The choice of the DSP board was coordinated with other groups within ASTRON/JIVE. The advantage of the board that was chosen is that it can be connected to the 10ms output of the WSRT-DZB correlator in order to obtain and process 10ms astronomical data. At JIVE, the VME version of this board is currently being prepared for reading out the 10ms data of the JIVE correlator.

2.2.5 A/D Converter Techniques

This year there were several programs that focussed on Analog-to-Digital converter techniques. One of the activities that had already started in 1996 was an investigation of the integration aspects of A/D converters. As part of this program, an integrated version of the A/D converter which was developed for the DZB, has been designed and realized. This single-chip DZB sampler was called Integrated DZB Sampler (IDS). Testing the circuit was not successful because of instabilities in either the signal path or the biasing circuits. This year the project has been evaluated. In order to make the chip work, a new version of the IC has to be made, meaning that the layout of the chip has to be redone because the process in which the IC was fabricated is not available anymore. It has been decided not to do so, because the IDS is not a crucial part of either the DZB or of SKA. The research concerning integrated 2-bit samplers with power-dependent reference levels is therefore concluded. The project has been very useful because a lot of technical knowledge and insight has been gained concerning mixed-signal Integrated Circuits and just as important is the experience gained concerning the design process. Furthermore the theoretical results of this project have been elaborated in a second project which was also concluded in 1999.

The subject of this project was the use of Multi-bit A/D Converters in Radio Astronomy. The aim was to investigate the usage of standard, commercially available multi-bit A/D Converters within Radio-Astronomy. Using standard A/D Converters is advantageous because this enables single-chip solutions without the costly IC-development trajectory. The requirements on standard A/D Converters for Radio-Astronomical correlation measurements have been deduced within this project. Furthermore a start has been made to investigate the effects of the presence of a strong interferer on the quantization process. Both above mentioned projects were conducted in cooperation with the IC-Technology & Electronics Group of the Faculty of Electrical Engineering of the University of Twente.

The work was mainly done by students in order to obtain their Masters degree. Starting a new project with the same group has been discussed and a possible subject is the applicability of sigma-delta A/D converters. These type of converters offer big advantages because they can easily be implemented in silicon and they can operate at low voltages. However, the bandwidths which can be reached nowadays lie in the range of several kilohertz which is at this moment not sufficient for Radio-Astronomical applications. It is expected that the bandwidth will be increased to several tens of megahertz within a few years. By then a new project will be initiated.

A very promising A/D conversion technique is 'harmonic subsampling'. According to the Nyquist criterion, the sampling rate of an A/D converter must be twice the bandwidth of the signal to be sampled. There are no conditions concerning the absolute frequency of this signal. If the band of interest does not start at 0 Hz (i.e. it is not a baseband signal) but at a multiple of half the sampling frequency, the signal after sampling is at baseband, so the A/D converter performs some form of mixing plus sampling. This is called harmonic subsampling and in order to gain experience with this technique an evaluation board containing a High Speed A/D converter (1 GS/s, 8 bits) with a large analog input bandwidth (2.2 GHz) has been purchased and a test set-up has been built.The results of this project will become available at the beginning of the year 2000.

2.2.6 Photonics for SKA

The photonics activity covers three complementary approaches in cooperation with three external groups. The ASTRON activity concentrates on signal distribution over fibre stretches up to of order a hundred metres using RF as well as digital modulation techniques with up to a few Giga-Hertz of bandwidth.

To investigate the phase stability of single mode optical fibres a physics student of Hogeschool Enschede has built an interferometric setup using a HeNe laser. Fringe patterns are recorded with a CCD camera and analysed on a PC. The differential phase stability between two stretches of fibre of about a metre length turns out to be sufficient to do coherent optical processing at 633 nm. This research will be continued by a new student measuring longer stretches of cable. Also a new setup will be made using a modulated laser diode for the 1550 nm band, which allows the evaluation of commercial multiple fibre telecom cables over lengths up to a few hundred metres.

Systems for coherent optical processing of phased arrays have been proposed and are being prototyped by the MURI team at the University of Colorado in Boulder. In the course of the year three visits were made to the Boulder group to attend MURI review meetings and to discuss the system aspects of radio astronomical phased arrays.

A key element in any RF approach is the modulator for which a design was made in 1999 by a graduate student of the Department of Electrical Engineering in Boulder during an intern-ship at ASTRON. Currently a group at the Royal Melbourne Institute of Technology is interested in our proposed strategy to integrate active components on a lithium niobiate substrate, and is working on realization of a prototype.

A joint study with TNO-FEL on key components in photonics architectures for phased-array receivers, supported by the Dutch Navy, has started and good progress has been made in surveying the literature of the last five years. Since the main emphasis in current photonics R&D is on incoherent (commercial) applications it was decided to develop a true time delay beam-former in incoherent technology. RF signals up to 3 GHz will directly modulate laser diodes in the 1550 nm range, after which the signals are delayed by switched optical fibres. The application is to combine the signals of the four quadrants of the 64 element OSMA phased array, such that by extending the delay range with two more bits the full hemisphere can be scanned. In contrast to most applications the signals are added optically on a single photo diode. This reduces the detector dynamic range requirement, since strong interfering signals are cancelled in the detector by appropriate phasing of the elements in the array.

Development activity concentrates on serial interfacing of optical transceiver modules developed for the low cost Gigabit Ethernet market. The THEA application requires two 12-bit A/D sample streams of 40 MHz to be combined and transferred over tens of metres by multi-mode fibres. There are also single mode versions to be used for LOFAR where 14-bit at 60 MS/s is required to bridge up to 10 km.

2.3 WSRT Projects

2.3.1 Correlator Systems

One quarter of the correlator hardware for the DZB forms (together with the old IVC hardware) the 10 MHz system that has been operating reliably and has been used successfully for regular astronomical observations. In parallel the work on the final system continued in the lab. The data distributor (a unit that provides for the signal routing of input signals and the recirculation option) has been tested and integrated in the JIVE correlator, although delays have been encountered due to the changeover of the Viewlogic design environment to a different hardware platform. Combined with the new configuration software, it allows full 16 station correlation and flexible routing of playback unit signals to the correlator. Both the JIVE and DZB correlators operate with a limited capacity. The full capacity will become available next year when the DSP sofware on the correlator boards becomes available. A pilot project has been started to read the 10 msec data from correlator boards and process it before integration. The installation of the remaining DZB hardware awaits completion of the IVC system (see below). The required test- and control software for the integration of the IVC system is partially ready.

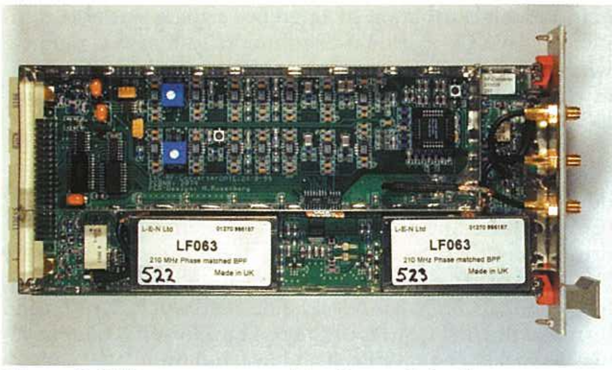


Figure 2.18 The component side of one of the Converter modules of the production series

2.3.2 The IVC-system

The IF-to-Video Convertor (IVC) system provides the interface between the Multi Frequency Front Ends and the new digital correlator (DZB). It serves to convert the 160 MHz bandwidth received from each Front End (in total 16 inputs x 2 polarizations are available) to the video bandwidth at the input of the correlator. This year was characterized by the development and completion of two important parts of the system, the Converter module and the Local Oscillator (LO)-system, including the synthesizer modules. Production of a series of modules was started in 1999 and a number have already been completed. The system has been completely defined. First successful system tests have been performed with one prototype signal chain, which was subsequently coupled to a correlator module in the lab, producing the first passband spectra for one complete DZB-channel.

The development of the Converter module was effectively stopped for almost 6 months due to the lack of suitable 200-220 MHz filters in the RF-signal chain. That period was used for a time consuming search for an adequate supplier, followed by an extensive development track with the English company LEN, specialized in filter design. It was concluded with an agreement on the tight specifications and order for the production of a series of over 500 filters, with delivery starting in December. With the properties of the filters fixed, the design of the Converter module could be completed and production was started at the end of the year. Figure 2.18 shows a photograph of the component side of one of the Converter modules of the production series.

The development of the LO-system was originally farmed out to industry, but this was not successful, because the required stability specifications could not be met by our industry partner (see the Annual report of 1998). An assessment by ASTRON staff of the underlying technical problems revealed that the required improvements could be made on the basis of the existing design. To do this in a controlled, cost efficient way, it was decided at the beginning of the year, to do further development and redesign at ASTRON's Technical Lab. This approach proved to be successful, thanks to the dedication and competence of the designers involved. Besides stability and phase noise specifications of the synthesizers, special attention was given to the control of frequency and phase settings and their synchronization, which also turned out to need a redesign with respect to the original design. After an intensive development period under strong time pressure, a successful prototype and pilot modules for the production series were demonstrated in September. The 256 LO-modules were taken in production at the end of October, with expected delivery in January 2000. Figure 2.19 shows a photograph of one of the assembled LO-modules on a six-layer printed circuit board. The development of other parts of the LO-system, mainly for generation and distribution of reference signals, was also completed. An LO- and time-distribution system was defined, which generates reference signals for other parts of the DZB as well and fits well within the concept of the new WSRT LO- and time-distribution system.

The control system for all IVC-functions was completely defined and has been tested on prototype modules. Hardware for the control system has been ordered. The first software layers of the DZB software for local control of the IVC-system have been written and tested. The next layer, interfacing to TMS, has been defined and will be written and tested in the first quarter of 2000. The 256 video filter modules have all been produced and tested during 1999 and are available for use in the system. The same is true for the 32 Splitter/selector modules. The Equalizer system, comprising 4x16 Equalizer modules, was completed early in the year and is also available for use.

At the end of the year prototype modules were used to assemble the first IVC-unit, processing the IF-signals from one telescope. This unit serves as a prototype for the series of 16 units and for first system tests with an IF-channel of a complete IVC-signal path. Figure 2.20 shows a photograph of the prototype IVC-unit, mounted in one of the EMC-shielded cabins of the system. Extensive system tests were being performed at the end of the year and will continue in January 2000. One test involved the ADC- and correlator part of the DZB and showed the operation of one complete channel of the DZB for the first time.

Fabrication and tuning of the remaining IVC-modules and system parts, as well as construction of the mechanical housing and cabling, will last until the end of the first quarter of 2000. From then onwards the complete system will be assembled, eventually consisting of four fully equipped Cabins like the one in Figure 2.20 and two additional cabins, one for the Equalizer system, the other for the Control system and the central LO-generation and distribution system. After assembly the entire IVC will be tested for a period of two months in the Technical Lab in Dwingeloo. The final tests will be done including DZB ADC-units and correlator, under control of TMS-software. The IVC-system is anticipated to be available for installation in Westerbork in June 2000. The actual installation and the start of commissioning will depend upon the progress of two other parts of the WSRT upgrade (TADU and TMSmax) and will be carefully planned for minimal interference with ongoing WSRT- operations.

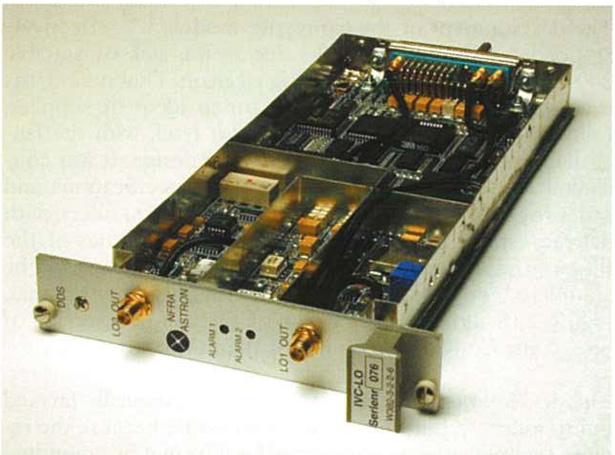


Figure 2.19 An assembled LO-module on a six-layer printed circuit board.

Figure 2.20 One of the IVC-units in the lab, mounted in one of the EMC-shielded cabins of the system.

2.3.3 Local Oscillator and Time Distribution

Installation of the new Datum maser was an important step in upgrading the time and phase stability of the Westerbork Radio Observatory. The phase stability it provides allows geodetic VLBI observations to reach an accuracy of 0.1 mm in principle, which requires distribution of the LO signals with a stability of 0.3 ps per hour. To play our role as the Dutch geodetic reference station and to fulfil the requirements for pulsar timing observing, time distribution hardware with a stability of 0.3 ns over years is needed. However, even more important are the appropriate calibration procedures and associated hardware tools to reference our local receiver time to universal time as distributed by GPS.

Early in the year it became clear that realization according to the project plan as defined in 1998 could not continue without change. Technically, interfacing to the new maser had to be included, while at the same time manpower had to be reallocated. The latter arose because it turned out that the LO distribution within the IVC system was a too challenging a design issue for the company that was supposed to do the bulk of the IVC production. When it was decided to do that design at ASTRON it was realized that much synergy could be obtained by combining these efforts with those for the LO part of the LO and Time distribution System. So, a Target Team was formed to review the requirements for the distribution system, taking into account the new situation with the Datum maser as the primary reference source and emphasis on the distribution of the LO signal to the IVC and from there to MFFE and ADC systems. A set of three reports was made covering the basic specifications and layout principles, scope and definition for a project, and an inventory of work packages. With this information in hand the next steps can be made.

2.3.4 TADU

TADU stands for Tied Array Distribution Unit and will be the interface between the DZB on one side and the VLBI Mark IV recording system and the Pulsar Backend on the other side. The basic functionalities of TADU are to convert the digital signals out of the DZB Tied Array Adders into analog signals and to multiplex multiple analog baseband signals onto the 2 IF inputs of the Mark IV.

The project has been split into 2 separate parts: TADU-MIN and TADU(-MAX). The TADU-MIN project concerns the development and production of 16 Digital-to-Analog converter modules which can be located directly on the Tied Array Adder boards within the DZB-ADC subsystem. The analog output signals can than be connected to a modified version of ASTI+, the system which is currently being used for the multiplexing operation of the analog baseband signals. It is expected that TADU-MIN can be realized in the year 2000 and it offers the possibility to use the DZB for VLBI observations immediately after the DZB-IVC subsystem becomes available, without having to use the DCB. This offers the possibility of using a bandwidth as large as 18 MHz for VLBI observations. For pulsar observations, the bandwidth becomes 20 MHz. There are some risks involved: the Tied Array Adder was not designed to be equipped with D/A converters and the clean analog power supply voltages are in principle not available, so a significant amount of crosstalk can be visible. Furthermore, there is no galvanic isolation between the DZB and the Mark IV system which bears the risk of creating groundloops.

The TADU-MIN project will not offer all the desired functionality. This will be realised within the TADU(-MAX) project. This project will offer a bandwidth of 20 MHz instead of 18 MHz and the Local Oscilator signals, which are used to mix the baseband signals onto the IF channels, will be freely programmable. Also the usage of separate analog power supplies and optical interconnections between the DZB-ADC units and TADU have been planned. Because of the use of a digital switching matrix, the configurations of the DZB become independent of the modes of the VLBI Field System. It is expected that the D/A converter modules developed for the TADU-MIN project can be reused within the TADU(-MAX) project.

2.3.5 AIPS++

A major milestone was reached this year with the First Release of the package. Hundreds of CD's have been distributed from the AIPS++ Centre in Socorro with versions for Sun Solaris and Linux Red Hat and SuSe. At this stage the main strength is still as a toolbox with a powerful scripting language (Glish), and for imaging, deconvolution and image analysis functions which are not offered (or less well) by other packages. However, astronomers will only start using AIPS++ as their main data reduction package when it offers more uv-data processing functions (editing, visualisation, calibration). This is now the highest priority. ASTRON is contributing to this in the person of a new programmer, who has started with ionospheric calibration, building on the preparatory work done over the last few years.

ASTRON's AIPS++ team has continued to work on important infrastructure modules like the table system and lattices, but has also improved and extended the set of uv-data converters to and from the main AIPS++ Measurement Set. Apart from the vital link to the UVFITS format there are now also converters to the older WSRT IWOS programs, and to MATLAB for the benefit of RFI research in Delft.

In the meantime, some AIPS++ modules (tables, measures) have continued to perform reliably as essential parts of the new WSRT control system (TMS). Off-line, some of the uv-data processing needs of the upgraded WSRT have been covered by a temporary local 'mini-package' written in Glish. A serendipitous by-product of this activity is a new way to determine the socalled 'X/Y Phase Zero Difference' of the WSRT. Among other things, the mini-package is used to produce automatic plots of all observations, and automatic reduction of short calibrator observations.

The latter can be regarded as the first step towards the processing pipeline that will be needed to deal with the increasing data-volume produced by the WSRT. The next step has been made at the Radio Observatory, using Glish scripts to combine the already available tools in the AIPS++ release to make automatic maps of all observations. This will be gradually extended to a fully-fledged 'calibration pipeline', partly building on experience at other telescopes like the ATCA and the ESO VLT. Eventually such pipelines will also become available to astronomers for off-line data processing in AIPS++.

An informal group (LOCOM) has been set up to exchange information between the various and increasing AIPS++ activities at ASTRON (Technical Lab and Radio Observatory), JIVE and the Dutch universities (mainly Groningen at the moment). One of its first actions was to identify a few suitable datasets that will be used to exercise AIPS++ and make sure that it deals properly with our specific concerns (e.g. many spectral lines, and WSRT polarisation).

It cannot be emphasised enough that one of the most unique aspects of AIPS++ over other packages is the ease of accessing data in tables, using Glish. This capability will enable a wide range of users to develop new data reduction techniques and strategies, and also to use AIPS++ as a powerful environment for research. This will become even more attractive after AIPS++ has changed over to CORBA next year. At this moment AIPS++ is being used in research projects to investigate crossed dipoles, a new formulation of the Measurement Equation and for the development of strategies to deal with image-plane effects for both LOFAR and SKA.

In summary it can be said that AIPS++ turned an important corner in 1999, even though it will be some time before it can truly replace the existing packages (and lure its users away). But parts of it are increasingly being used for various purposes around the world. In this sense, AIPS++ is an evolutionary step away from a traditional reduction package. One of the challenges will be to find the right balance between serving traditional users, and offering an open environment in which 'a hundred flowers can bloom'.

2.3.6 TMS

Most parts of the Telescope Management System for the WSRT were delivered this year. TMS was required to make use of the increasingly larger datastreams and more demanding control requirements. TMS makes use of object-oriented design and programming techniques. In its current form the package consists of 54 modules with over 300,000 lines of C++ and Perl code. Applications in all areas are in production operations.

The main architecture of TMS is a distributed control system around a central real-time database. The control system uses a well-defined communication framework to allow generic interfacing to very hybrid components. The real-time database contains all high level control information (required pointing, fringe stopping and delay position, frequency mixing scheme), calculated at the 0.1 Hz heart-beat of the WSRT. This information is transfered to controller applications which make the translation to device units and protocols. The control system is supported by many administrative functions ranging from preparation of observations to the export of measurements.

During the past year a lot of effort was spent in increasing the robustness of the DZB control and readout. Several major problems regarding e.g. the synchronization of delay control and the noise-source calibration were solved. DZB observations suffered from several problems related to AIPS++ tables which had to be solved by the local AIPS++ team. The control of the MFFEs was improved in several ways to support fast frequency switching and give more engineering information. Vital periferal systems like the Maser and GPS receiver are now fully monitored by TMS.

An important step made in 1999 was the addition of the GPS as a full secondary system clock (including several synchronization mechanisms). The GPS will be the main TMS clock when the existing on-line computers have been phased out. In the summer the final TMS observation infrastructure was taken into production. This software takes care of the starting and halting of observations and takes care of exception handling. The remainder of 1999 the OcsManager application just mimiced the schedule running on the existing on-line system, next year it will take full responsiblity of the schedule and the on-line control of the WSRT.

An SMS (Short Message Server) based alarm system and extensive WWW access was implemented to further support unmanned operations. Most TMS databases are available on-line now (with several security restrictions, though). Administrative support software was continuously improved, and a major database repair operation was performed in December to recover observations that were lost because of table-crashes. The Specification Module, originally glish-based, was rewritten in perl to increase flexibility and platform independence. Export of data was long hindered by damaged Measurement Sets and inconsistencies in the conversion to UVFits. Most of these problems were solved by the end of the year, and with streamlined and updated export procedures the WSRT is now in a good position for routine export during 2000.

Early 2000 the final transition from the HP1000 based on-line system to TMS will be made. Although all subsystems have been tested in isolation, several integration problems have been forseen. Therefore a prolonged integration and test period has been planned, in particular for the DCB hardware and the observation infrastructure. When the control system has been fully integrated, the new observation specification software will be taken into production. This will allow for full specification and control of PuMa, the IVC system and the nominal DZB system.

2.3.7 WSRT RFI Mitigation Demonstrator

Project description

The aim of the project is to investigate the effects of modern signal processing algorithms for radio interference (RFI) rejection in radio telescope systems, specifically in the WSRT. The focus is on single and dual channel processing techniques, like e.g. RFI excision and adaptive noise cancellation (ANC). For this purpose, a four-channel input RFI mitigation system was installed and tested. The mitigation system can be used offline, but it can also be used together with the WSRT-DZB correlator to form a single interferometer. The purpose is to compare measurements with and without the suppression algorithms in order to quantify its effect both on the RFI as well as on the astronomical signals. Array processing techniques are not considered in this project as this topic is covered by the NOEMI project.

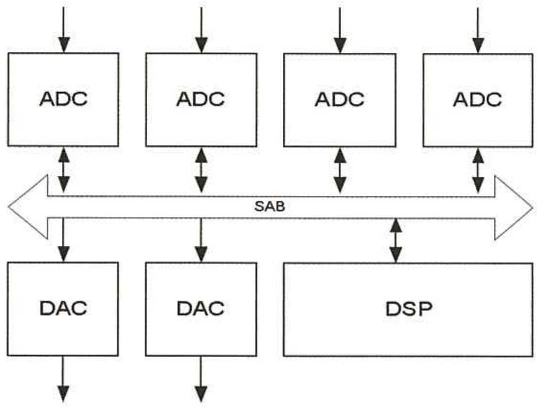


Figure 2.21 WSRT RFI mitigation demonstrator setup

The WSRT RFI mitigation demonstrator (Figure 2.21) is an industrial PC based system, consisting of four ADC's, two DAC's and of a board with 9 DSP's (PMP8) from Signatec. Each of the DSP's (TMS3206201) has a processing capacity of 1.6 billion instructions per second. The ADC's can be connected to the video channels of the WSRT, and to reference antennas. The bandwidth used is typically 10 MHz. Data tranfer is done via a fast (500 MByte/second) bus, the Signatec Auxiliary Bus. The processed data can be stored offline for further processing. Another option is to direct the processed data to the WSRT DZB correlator system. This is done by converting the data back to analog and feeding it to the correlator ADC's. In this way RFI suppression algorithms can be tested online in a single interferometer using the DZB correlator.

RFI mitigation results

In the second half of 1999 the RFI mitigation demonstrator was installed and used for testing RFI excision and adaptive noise cancellation with the WSRT.

For RFI excision, the interference signals were removed from the data stream after detection. It was shown that the excision system works well with the radio telescope signals. The next step in the research is quantifiying the effect of the excision both on the amount of suppression of RFI and on the astronomical sensitivity of the systems.

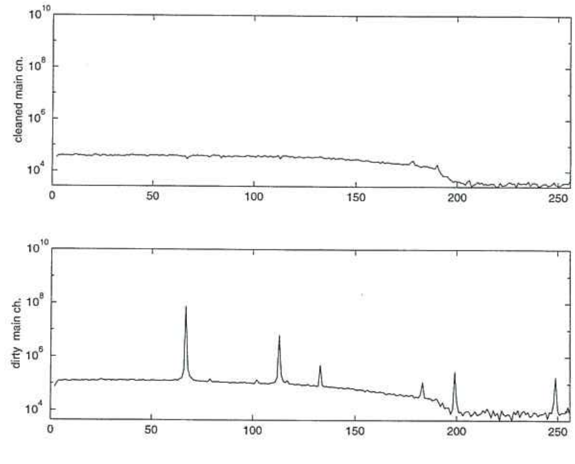


Figure 2.22 Adaptive noise cancellation of RFI at 361 MHz

Adaptive noise cancellation was applied as well. This is a technique to suppress RFI by subtraction of a reference signal from the telescope signal. This reference contains RFI but no astronomical signal (or at a low level). Before the reference is subtracted, it is filtered by a tunable digital filter. After subtraction, the output power is minimized by adapting the digital filter parameters. This leads to a spectrum in which the RFI is suppressed. Figure 2.22 shows an example of this technique applied at the WSRT. The lower figure shows RFI, centered at 361 MHz and with at bandwidth of 10 MHz. Horizontally, the bandpass of a (baseband) telescope channel is given, the numbers are the frequency channel numbers. The vertical scale is the output power in dB. The upper figure shows the band after applying the adaptive noise cancellation algorithm. It clearly shows that the interference can be suppressed with an amount of 30 dB. The effect on the sensitivity is still to be investigated.

2.4 Optical Projects

2.4.1 VISIR ESO-VLT project

Organisation

As part of a French-Dutch Consortium, ASTRON participates in the ESO-VLT with the construction of VISIR: VLT Imaging and Spectroscopy in the InfraRed, an instrument to be installed in the Cassegrain focus of VLT unit 3 in 2001. The Service d'Astrophysique (SAp) of CEA/DAPNIA at Saclay is responsible for the imager part and the instrument infrastructure while ASTRON is developing and building the spectrometer. Smaller participants in the project are NIKHEF (Amsterdam) and SRON (Groningen) for the design and production of specific modules. The formal kick-off was in December 1996 and the first phase ended with a Preliminary Design Review (PDR) at the end of 1997. The Final Design Review (FDR) was held in March 1999 and officially closed during the summer. Most of the year 1999 has therefore been devoted to production of parts and testing of prototypes. The next milestone for ASTRON will be the delivery of the spectrometer to Saclay in 2000 with the Consortium delivering the complete VISIR instrument to ESO in 2001.

Optical Design

The optical design of the spectrometer has been fixed for some years: it should provide long-slit spectrometry in the N and Q bands in different (low, medium and high) resolutions. Since the FDR there has been a change in the design of the High Resolution mode. To avoid excessive cost for a large number of order-selection filters, order separation will now be done by means of cross-dispersion grisms. With these low-dispersion grisms three echelle orders are imaged simultaneously on the detector.

Mechanical Production

The spectrometer is a rather compact instrument (85x60x35 cm, 70 kg) with a considerable number of subsystems and mechanisms. It is built almost entirely out of the same 6061 aluminium alloy. To improve the stiffness to weight ratio and thermal behaviour, structures and mirror blanks are light weighted as much as possible (see e.g. Fig.1). For the 13 mechanisms there are two types of actuators. Most mechanisms (wheels, selection mechanisms, detector focus) are driven by the VISIR cryogenic motor developed at Saclay. Fine-positioning of the five gratings is done with high-precision motor/encoder servo systems (linear motor, LVDT encoder) developed by SRON-Groningen from the scanner systems used successfully in the ISO SWS/LWS spectrometers. Prototypes of both types of motors have been built and tested extensively.

Opto-mechanical production

The optical laboratory started making the final etalons for VISIR, following the successful tests done on the prototypes with glass and germanium plates. The polishing of CdTe plates is now also well under way. Meanwhile there was a strong involvement in the production of mirrors and mirror blanks by the ASTRON workshop: flat mirrors are polished to optical quality, curved mirrors verified and their mounting pads polished (see Figure 2.23). Special positioning equipment has been built to verify the optical properties of subsystems like the re-imager and the collimators as soon as they are ready.

Test equipment and modelling

The integration support for position dependent measurements has been automated to be used in combination with the RASNIK alignment system. Tests in the small cryostat have continued: especially wiring for heaters and fixation of sensors have been studied. Meanwhile a second (existing) cryostat has been adapted so it can house the two most complicated mechanisms of the spec-

Figure 2.23 One of the mirrors blanks of the TMA collimator/camera system of the High Resolution spectrometer arm. This mirror has a strongly off-axis aspherical surface that will be diamond-cut directly into the Al-6061 blank by Philips Optical Products in Eindhoven (Netherlands). The photo shows the light weighted structure on the back of the mirror. Also shown are the special mounting 'ears' for stress-free isostatic mounting.

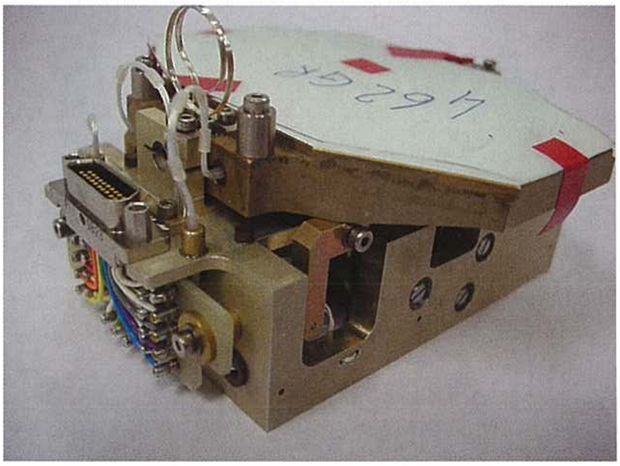


Figure 2.24 The first of the small Low/Medium Resolution grating scanners. The grating surface (not yet ruled) is on top. It measures 94x58 mm. To its left one of the flex-pivot grating suspensions can be seen. The thermal link above the flex-pivot is only temporary. The linear motor and LVDT encoder are mostly hidden underneath the grating.

trometer: the grating subsystems (see below). The thermal modelling of these and other systems has continued to guide the mechanical design and the positioning of heaters and sensors. The cabling of moving subsystems has turned out to be difficult as often many connections with screening have to move in tight spaces at cryogenic temperatures. An experimental setup has been made to test the fatigue of cables at liquid nitrogen temperature.

(Sub)Systems

After VISIR passed the FDR in 1999, the spectrometer - like the imager - is now fully in the manufacturing phase and the first subsystems are taking shape. Figure 2.24 shows the first small grating scanner of the Low/Medium Resolution grating unit. An overview of the complete unit is shown in Figure 2.25. The selection mechanism is a carrousel that carries the four grating scanners. In addition, there is a fifth position for a return flat. By turning the carrousel to this fifth position and opening the spectrometer entrance slit fully, the LMR arm becomes a camera for direct inspection of the selected source in imaging mode. Apart from the ruling of the two echelle gratings, the High Resolution unit (see Figure 2.26) is now nearly complete. In the meantime the echelle blank has been replaced by a dummy to allow testing while the echelles are being ruled by Hyperfine Inc. (Boulder). The fine-positioning servo has been tested and optimised at room temperature; cryogenic tests will start soon.

Verification

The spectrometer Mass and Thermal Model (spectro-MTM) is an aluminium box with the same outer dimensions and weight as the instrument itself. This spectro-MTM (together with the imager MTM provided by the French partners) has been used extensively in Saclay to test the mechanical stability of the support system and to do tests in the prototype VISIR cryostat. The results of these tests have confirmed the validity of the design in most cases (e.g the hinges) or

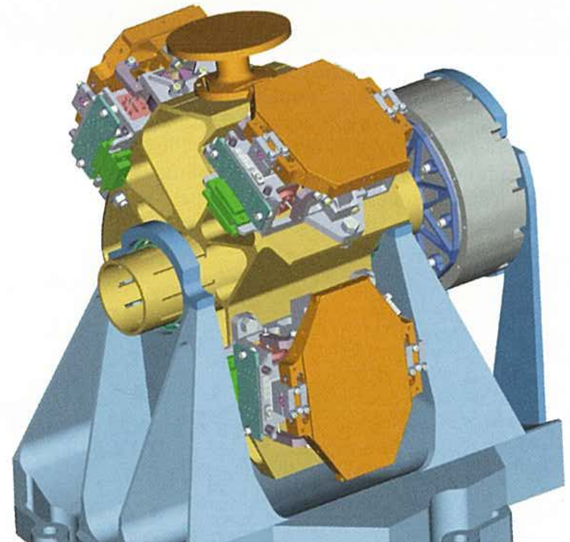


Figure.2.25 The Low/Medium Resolution grating unit. This assembly drawing shows the final design of this complex subsystem. The central carrousel carries the four grating scanners that can be selected by means of the cryogenic motor/clutch unit (on the right). A fifth position selects the return flat (here on top) that can be used for behind-the-slit viewing. The carrousel and the outer support structure are machined out of monolithic pieces. For simplicity, some details (bearings, electric and thermal connections) have been omitted.

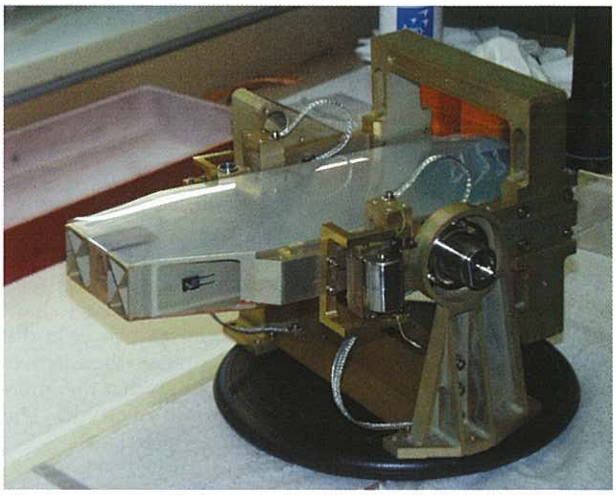


Figure 2.26 The High-Resolution 'duo-echelle'unit. The large light weight grating blank (here still without rulings) is suspended by flex-pivot bearings in the inner 'yoke'. This yoke can be rotated over about 50° between the two selection positions by the cryogenic motor/clutch unit (not mounted here) on the outside of the support frame. The linear motor for fine-positioning of the grating is visible on the front arm of the yoke; the LVDT encoder is on the opposite side. The four flexible thermal links are only temporary.

led to improvements in the design (stiffness of structures). A nice example are the hinges that connect the imager and the spectrometer: they are difficult to test as individual elements: following instructions from ASTRON, the design and FEM calculations were done at NIKHEF, the hinges were produced at ASTRON and, as a set, tested at Saclay to be within specifications.

Integration

At the same time, the execution of these tests provides a good training for working with "the real thing": by mid 2000 most of the spectrometer manufacturing will be complete. After integration and verification of all components (cryogenic tests only for individual subsystems) in the ASTRON laboratory in Dwingeloo the spectrometer will be transferred to Saclay in the fall of 2000. Tests and characterisation of the fully integrated and cooled VISIR system will then continue for several months in the laboratory of Service d' Astrophysique, before the instrument is shipped to Chile for commissioning on the VLT in 2001.

Science with VISIR and MIDI

As mentioned above, there has been a design change in the HR spectrometer arm. To avoid very high filter costs order separation will now be done by cross-dispersion with grisms. The cross-dispersed orders cover only one third of the full slit length, but for a number of astrophysically important spectral features the long slit option will remain available by means of special filters. The scientific capabilities of the HR mode are thus not significantly compromised.

The design of MIDI, the mid-infrared VLTI instrument under development by MPIA Heidelberg, NOVA/ASTRON and Obs. de Meudon, is now frozen. Like VISIR, MIDI has entered the manufacturing phase. While both instruments are heading for 'first light' in 2001, it is becoming more and more clear that the complementary capabilities of VISIR and MIDI offer great scientific potential. For studies of warm dust and molecular clouds with high spectral and spatial resolutions the combination of VLT/VLTI, VISIR and MIDI is unique. The Dutch science teams for VISIR and MIDI are taking this combined potential explicitly into account and have started the preparation of joint VISIR/MIDI observing programs. Closely related to these programs, appointments of two 'MIDI/VISIR' PhD-students have been initiated.

2.4.2 MIDI ESO-VLTI Project

Organisation

A consortium consisting of the Max Planck Institute for Astronomy, Heidelberg, the Netherlands Research School for Astronomy (NOVA) and the Observatoire de Paris is building MIDI, the MID-infrared Interferometer for the ESO-VLT Interferometer. MIDI is the beam-combining instrument for the N-band (10 micron) with provision made for Q-band (20 micron).

ASTRON is producing the "cold optics" at the heart of the instrument. The two beams coming from the delay lines are re-imaged, spatially filtered, combined, dispersed and imaged by the detector. The rest of the instrument, warm optics, cryostat, cooling system, detector unit and electronics, will be produced by MPIA.

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. At the end of July 1999, MIDI successfully passed the first part of the FDR. The second part will take place at the end of February 2000.

Optical Design

The optical design underwent many changes in the first part of 1999. The angle of the beam combiner was changed from 45° to 30° in order to minimize polarisation effects. The space between elements was increased to allow for baffling mechanisms and structures. The camera lenses were optimised to produce sharp images and to reduce the absorption of radiation longer than 12 micron within the lenses. Both a tolerance analysis and ghost analysis have been performed. The full N-band grism has been designed and ordered and preliminary design for the low-resolution prism is available. All of this has led to an optical design that was frozen in November 1999 (see Figure 2.27).

The optical laboratory has developed a way of polishing aluminium mirrors. This means that all the flat mirrors can be made in house with a very high optical quality much better than that achieved by diamond cutting. Four of the camera lenses can also be made in house.

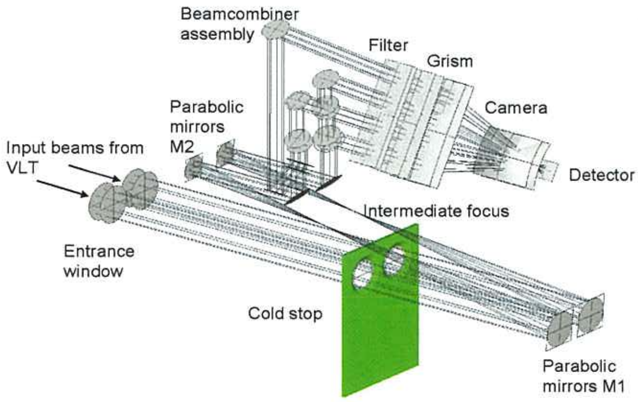


Figure 2.27 The optical model of the MIDI cold bench in one of the configurations with an indication op the optical components. There will be mechanisms for the exchange of filters (wheel), grism/prism, and different cameras.

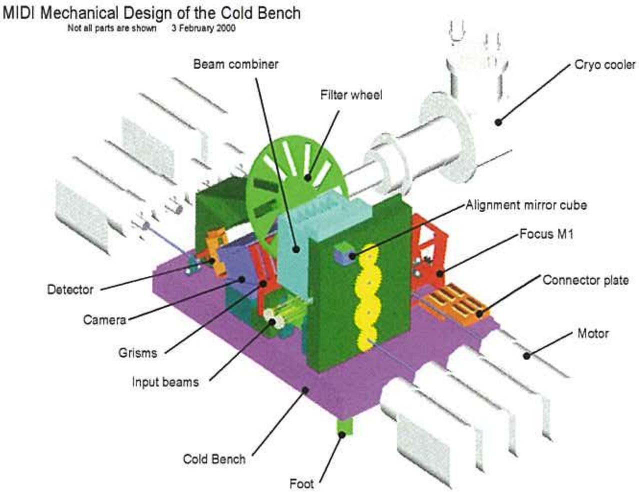


Figure 2.28 The mechanical design of the MIDI cold bench. For each system either the space envelope is included or the detailed design if finished (focus M1 and filter wheel).

Mechanical

The mechanical design started in June with the arrival of the first mechanical designer, supplemented by a second in November. The space envelope for the entire cold optics has been fixed and almost all the interfaces with the outside world have now been established. It has proved to be extremely useful that the two main partners for the hardware (MPIA and ASTRON) work with the same software for optical design (ZEMAX) and mechanical design (Pro-Engineer). Exchange of designs, checks of interfaces and the general communication are greatly facilitated. At ASTRON, the space for the cold bench has been split up in space envelopes for the different optical systems (see Figure 2.28). The detailed design at ASTRON is progressing well, with 4 mirrors detailed and ready for milling. Detailing of the 2 focussing mechanisms and the flat mirrors are almost complete. MIDI will be able to operate in different configurations and rolling mechanisms are foreseen to exchange cameras (for example) while the cold bench is at operating temperature. A prototype rolling mechanisms has been designed and produced. The first test results at room temperature are due in January 2000.

Science

There is a well developed science program available for MIDI together with the groups in Heidelberg and Meudon. A list of filters for the N-band has been agreed and a consortium of several instrument groups, including VISIR, has been formed to purchase the filters at a reduced cost. There is a large overlap with scientific activities for VISIR, benefiting both instruments (see also science under VISIR).

3 Radio Observatory

3.1 WSRT Upgrade Projects

In 1999 upgrade of the WSRT saw major progress being made in many of the projects. Although the Westerbork upgrade as a whole is not yet finished, significant progress has been made with regards to the technical capabilities of the telescope. Many incomplete systems were completed in the course of the year, and several longstanding problems have now been solved.

3.1.1 Multi Frequency Frontends

All sixteen MFFE's have now arrived at the WSRT and are fully operational. The frontend systems offer improved sensitivity, with eight frequency bands being available at any time and a large tuning range. During the year a couple of minor problems were solved. One of the most serious problems encountered was with the helium tubes. Since the MFFE's can be tuned to another band in less than a minute, a multi-frequency experiment on quasar variability was done, switching between frequency bands every 5 minutes. Frequent rotation of the feed assembly put too much strain on the original flexible helium tubes which led to damage. After a number of leaks were encountered it was decided to limit the number of frequency changes per 12 hour observation. A new type of helium tube was recently found which can better accommodate repeated flexure and the retrofitting of all tubes is partially implemented. After completion, a 5 minute switching time will again be supported.

At the end of the year, with all the new telescope microprocessors implemented as well, continuous observing with 14 telescopes was once again possible. If a frontend causes problems, two spare MFFE's are available. Other difficulties, such as oscillating 92cm LNA's and broken noise sources are all solved now.

3.1.2 Telescope Control System

In 1999 the renewal of the telescope control systems was completed. All telescopes are now equipped with this new microprocessor system, giving a much higher pointing accuracy especially for mosaicing.

3.1.3 New Hydrogen Maser

In april a new Datum (formerly Sigma Tau) hydrogen maser was installed at the WSRT. This new maser clock replaces the original 30 year old maser (a reconditioned prototype EFOS maser), which had developed aging problems. After only two weeks, the new maser started serving as the WSRT clock and has been performing perfectly since. The frequency stability is $2x10^{-15}$ in a 1000 seconds interval.

3.1.4 The DZB Correlator System

Since September 1997, the first components of the new digital backend have been in use at Westerbork. The IF system of the old DLB was connected to one of the ADC units of the DZB. The ADC unit is capable of handling 20 MHz of input bandwidth. The current IF system, however, is limited to only 10 MHz bandwidth. For this reason this part of the DZB is referred to as the "10 MHz System". Although it is only 1/16th of the total bandwidth at the end of the project, it already outperforms the old DLB system by a large margin.

First Light with the 10 MHz System was achieved in the autumn of 1997. However, the data acquisition software was still in quite an early state of development at that time. In 1999 extensive development and de-bugging of both the on-line and off-line software took place. In the course of the year a slow shift took place from technical commissioning to astronomical commissioning and finally progressing to an increasingly large fraction of astronomical observing. Major problems with delay tracking, phase jumps and the noise source calibration were all resolved along the way.

Total bandwidths of 10, 5, 2.5, 1.25 MHz can be chosen at this time. The basic set of correlator modes provides all auto- and cross-correlations of 16 telescopes. Although the WSRT array still consists of only 14 equatorially mounted paraboloids of 25-m diameter in an East-West configuration of 2.7 km extent, the additional IF and correlator inputs can be used in conjunction with new or test elements. An examples is THEA now under construction, or in the future one or more LOFAR prototypes.) Configurations are available for 256, 128 or 64 spectral channels in combination with 1, 2 or 4 polarization products.

A second set of correlator modes provides cross-correlations of 12 antennas, but with twice the number of spectral channels noted above. This mode was particularly useful during the first half of 1999, when the mechanical and receiver upgrade was still underway. For that reason, the last two telescopes to be retro-fitted, RT0 and RT7, were excluded from these correlator configurations. In this mode, configurations are available for 512 or 256 spectral channels in combination with 2 or 4 polarization products.

Figure 3.1 The New Hydrogen maser of the WSRT.

A special correlator mode is also available for the exclusive observation of auto-correlations. In this case, auto-correlation spectra of 2048 spectral channels can be provided for up to 32 IF inputs (for example 14 telescopes with 2 polarizations each).

3.1.5 The Telescope Management System (TMS)

The focus of activities this year was the completion of Release 3. The control of all the hardware at the WSRT was realized. The MFFE's are now completely controlled by TMS. This was a major improvement over the old sequential control. The software is no longer the limiting factor in the speed of changing to another band.

Monitoring of various pieces of hardware was also implemented in TMS (besides the MFFE's, the Maser and Meteo station). Besides archiving monitor data, alarm points were also placed, e.g. the monitoring of the cryogenic temperatures of the MFFE's. If the temperature exceeds a certain limit, a SMS call to the cryogenic engineer is sent. This has saved a frontend from warming up on several occasions.

In July, a new coordinate system for the telescopes and visibility data was adopted. Unfortunately the introduction of the new system was not as smooth as was anticipated. After a few weeks however, all the errors were repaired. Observations performed in the intermediate period were repaired during the export procedure.

After a long period of solving problems, the exporting of data is now once again possible. Astronomers can elect to receive their data in a number of formats: such as the original Measurement Set, in UVFITS format or as Newstar Scanfiles. The data is archived in Westerbork in MSFits format on CD's.

3.1.6 RFI at the WSRT

As many observatories, the WSRT also suffers from RFI. Especially for the bands below 1 GHz there are many sources of RFI. One of the major sources in the past was the Observatory's own equipment. Although most of the digital equipment was placed inside a Faraday-cage, a lot of RFI came from devices that remained outside the cage, like printers, computers, modems and especially the digital network. One of the most significant reductions of RFI was achieved by replacing the coaxial computer network by a fiber network. By the end of the year the entire WSRT computer network had been replaced with fiber connections (and of course the main switch was placed inside the Faraday cage). For example, this made observations at 92cm with all telescopes at the WSRT possible for the first time.

A TV-tower is located at about 13 kilometers from the WSRT site. This tower supplies the three northern provinces of Holland with the three Dutch TV-channels, as well as the local TV-station: TV-Drenthe. These four very strong signals influence the receivers in the telescopes. In fact, due to the strength of these signals, intermodulation products appear. Especially the combinations with TV-Drenthe give products, which appear in all bands below 1400 MHz. To reduce the effect of this interference, there was only one real solution: to develop filters, which attenuate the original signals. For 3 receiver bands (UHF-low, 92cm and UHF-high) such filters have been developed and implemented in the frontends. Results are very good: almost all intermodulation products are gone at the cost of only a very modest increase in system noise. Problems in the 49cm band itself are worse. A more distant TV station, TV-Noord (with a transmitter some 28 km north of Westerbork) is located in the middle of the band, so filtering is not possible. At this moment contact has been established with the local TV-stations to talk about switching the transmitters off during certain hours at night, thus making night-time observations possible in the 49cm band.

After implementing the intermodulation reduction filters, small intermodulation artefacts were still present at a very low level in some products. It was discovered that the residuals are produced at the TV-tower itself. At this moment ASTRON engineers are in close contact with Nozema (the Dutch company responsible for the TV transmitters) to look at solutions (e.g. Filters in the output circuit of the transmitters).

The second most prominent signals come from GSM traffic. To reduce the amount of RFI that is produced the car-free zone that surrounds the WSRT is now also a GSM-free zone.

3.1.7 VLBI

During the final session of 1998 the first observations were done with the MFFEs in the Westerbork tied-array. In 1999 all four network sessions had the tied-array available for observing. Westerbork also took part in a few VLBI observations outside the network sessions. Thick and thin tape recording continued with the MkIV tape drive. During 1999 most of the array control and monitoring software was changed. This is part of the project to run observations with an object-orientated Telescope Management System (TMS) and meant replacing the outdated HP-1000 based hardware and software. This project continues into 2000.

3.2 System upgrades at the WSRT

Frequency Flexibility

During 1999 the software for controlling the MFFEs was upgraded to allow parallel setting of wavebands and frequencies. This allows new wavebands to be chosen in about 1 minute, and re-locking to another frequency in the same waveband in about 15 seconds. It is now possible to do true dual frequency observations with the tied-array in the following bands:

- 3.6 cm and 13 cm ('S/X')
- 3.6 cm and 92 cm
- 3.6 cm and UHFlow
- 6 cm and 49 cm
- 6 cm and UHFlow
- 18/21 cm and UHFlow

However these setups have not been tried in real VLBI sessions, and only one linear polarization would be given by the tied-array at present.

New Field System

The field system is a pc with special software that controls the VLBI recorder at the WSRT. In 1999 the computer was replaced and its software was updated, partially to ensure Y2K compliance.

More filters

A 'standard' set of MkIV filters were placed in the first 8 baseband converters (BBCs). These give 0.5 MHz and 0.125 MHz bandwidths (USB only) for some spectral line observations. All 15 BBCs have 16, 8, 4 and 2 MHz in both sidebands. Some other filters are available for attaching via the 'external' connectors.

3.3 WSRT Hardware repairs

Diodes for bandwidth switching

In the baseband converters the bandwidths are switched with diodes. However the diodes initially used were unsuitable for wider bandwidth switching (8MHz and 16MHz). These were replaced during 1999.

Tape unit

Several problems occurred with the VLBI tape unit during 1999. Most of these could be attributed to mechanical wear, and in particular the write-only headstack was badly worn during session 4. It will be replaced at the beginning of 2000.

3.4 Future Prospects

New Tied-Array Mode

A new tied-array is planned to go with the new IF system for Westerbork. This will be implemented in stages, to allow the old tied-array to be retired as soon as possible. When implemented:

- Total Bandwidth need no longer to be limited to 80MHz, but will allow up to the full 160MHz from MFFEs above 1GHz.
- 16MHz per sideband will be available as the new IF will have 20MHz filters.
- Circular polarization will be made at an earlier stage, and will hopefully have less crosstalk.

Circular polarizers for the 3.6cm band

Before mid 2000 there will be circular polarizers for the 3.6cm band, so that these receivers can be used in geodetic experiments.

Recording with 2 headstacks

With 2 headstacks (write-only and read-write) recording simultaneously the recording bandwidth from the current VLBA standard of 256 Mbit/s can be increased to 512 MBit/s without increasing tape speed. This mode has been locally demonstrated, but scheduling software will not be available until 2000.

3.5 The Astrometric-Geodetic Observatory in Westerbork

The task of mapping out our spatial environment is shared between the geodetic and astrometric communities. Since space operations started in 1957, the spatial precision of the measurements has steadily improved, which has been utilized by the geodetic community to determine the motions of the Earth and inside Earth such as its rotation, surface deformations, and changes in sea-levels. Since 1970 the use of interferometry with independent clocks has been developed with comparably high precision within the radio-astronomy community. Since the interferometer baseline of sometimes thousands of kilometers enters as a geodetic unknown, this aspect has led to the field of space-geodetics. In The Netherlands satellite-geodetics was developed within the Technical University of Delft (TUD) in collaboration with the Space Research Organization (SRON) in Utrecht, and currently uses transportable and highly automatic field-instrumentation. Very Long Baseline Interferometry (VLBI) was developed in the Netherlands by ASTRON in Dwingeloo and Westerbork and has culminated in the Joint Institute for VLBI in Europe (JIVE) in Dwingeloo.

In recent times, a geographic concentration of satellite-geodetic equipment and radio-astronomy instrumentation was called for and a bundling of knowledge and experience. For this reason the Astrometric - Geodetic Observatory Westerbork (AGOW) was initiated, which brings together the technical systems for VLBI, laser-ranging of satellites, a Global Positioning System (GPS), gravity measurements, as well as position and height measurements. AGOW is beginning to play a central role in national and international geodetic networks such as the Normal Amsterdam Height network, the Active GPS Reference system in The Netherlands (AGRS.NL), the International GPS Service (IGS), and the worldwide VLBI networks.

The AGOW as national reference station represents a collaboration between ASTRON, JIVE, the TU in Delft, and the Measurement Service of the Dutch Ministry of Transport, Public Works and Water Management. A plan of action for the coming years has been set up by the geodetic community in order to exploit the added value of having the various instruments co-located in Westerbork and tying together the measurement characteristics of this instrumentation. While VLBI techniques achieve extreme accuracies in spatial directions, they cannot tie these to the center of mass of Earth. On the other hand, laser ranging to satellites does tie the orbits to this center of mass (when the skies are clear). GPS works well under all weather conditions but is less precise over long distances. Gravity measurements detect extremely small changes in height independently from the space measurements through the atmosphere. The combination of these qualities makes AGOW the premier reference station for accurate studies of the mobility of the little piece of Earth on which it stands, which by continuous measurements will dynamically anchor The Netherlands to the international coordinate systems.

The topic of worldwide change in the sea level is of particular interest for The Netherlands. How does the country as a whole move relative to its neighborhood and how does the sea level change, and especially how fast does this happen? The vertical positioning determined by AGOW is critically important for answering these questions. It requires millimeter accuracies to do this.

On 24 September ASTRON and the TU in Delft hosted a festive meeting on the occasion of the opening of the Astrometric – Geodetic Observatory Westerbork, which was attended by some 60 representatives from the scientific community. A scientific program in the morning highlighted the vast scientific potential of AGOW with talks on "Astronomy applied to Land Surveying",

"Length, Width and Height with Satellites", "Height, a Worry for the Department of Water Management", and "The Observatory as fundamental Reference Station". The afternoon program consisted of a visit to Westerbork and the AGOW facilities. During the day a cooperation agreement was signed by TUD, ASTRON, JIVE, and the Measurement Service of the Ministry of Transport, Public Works and Water Management.

Bringing the geodeticists and astronomers in close contact with geophysicists, oceanographers, and meteorologists through the experiments at AGOW provides invaluable research possibilities for the community.

4 Spectrum management

4.1 Observatory Activities

Spectrum Management and radio interference matters are significant items of the ASTRON and WSRT Agenda. The Radio Observatory has participated in spectrum activities at the local, national and international levels during 1999.

4.1.1 International Activities

The secretariat of IUCAF, the Commission on the Allocation of Frequency for Radio Astronomy and Space Science, was located at ASTRON, because the Observatory Director served as chair of IUCAF until April 1999. At that time Dr. Klaus Ruf became chair of IUCAF and the secretariat moved to the Max Planck Institut für Radioastronomie in Bonn. Much of the international coordination of spectrum activities in the various parts of the spectrum for the passive services are done from the IUCAF secretariat. Observatory staff actively participated in meetings of ITU-R Working Party 7D on Radio Astronomy, ITU-R Task Group 1-5 on Unwanted Emissions, and various European and ITU-R meetings in order to present and defend the scientist's view on spectrum issues. Also active participation was given at the General Assembly of the URSI, the International Union of Radio Scientists, in Toronto. Besides various presentations on spectrum issues related to general spectrum issues and the preparations for the upcoming World Radio-communication Conference (WRC) in 2000, a general presentation was also given on the topic of Spectrum Congestion.

4.1.2 National Activities

Observatory staff participated regularly in discussions on the Dutch position on Agenda Items for the WRC-2000 Conference. In this manner ASTRON has become a discussion partner of the government agencies dealing with spectrum issues. For instance, the Annual Report of the RDR, the National Service for Radiocommunication of the Netherlands Ministry of Transport, Public Works and Water Management, contained an interview with the Observatory director as one of the spectrum customers of the RDR. Discussions were also held in order to facilitate spectrum coordination of the Radio Observatory with TV stations, mobile telephone providers, and the military.

4.1.3 Local Activities

The Observatory is very thankful for the good relations with the provincial and municipal governments. With provincial authorities the placing of GSM towers throughout province was discussed and a start was made with in preparing for the identification of LOFAR sites throughout the northern provinces. With the municipalities that encompass the Radio Quiet Zones of Westerbork and of Dwingeloo, there has been regular contact about the placing of various transmitters but also about forbidding the use of GSM mobile phones in the Quiet Zones. The use of GSM is not allowed any more close to the WSRT and the same rule is under consideration for the Dwingeloo site.

4.2 CRAF

ASTRON is host to the Secretariat and Frequency Manager of the European Science Foundation's (ESF) Committee on Radio Astronomy Frequencies, CRAF.

4.2.1 CRAF Secretariat

The CRAF secretary was involved in correspondence on various issues related with meeting activities (e.g. with ITU, CEPT, European Commission, Federal Communications Commission [USA], administrations in different European countries and advice to the Korean administration on GSM coordination between France and the United Kingdom).

The CRAF secretariat organized two regular CRAF meetings and one CRAF workshop. The latter addressed in particular the issue of the definition of tolerated data loss due to interference.

4.2.2 CRAF Frequency Manager

In 1999, the CRAF frequency manager participated in various meetings working on:

a) The protection of radio astronomy against interference from space-to-Earth transmissions of the Iridium satellite system;
b) Coordination with the GLOBALSTAR mobile earth stations;
c) Preparation of the World Radiocommunication Conference 2000, WRC2000, in the context of the International Telecommunication Union, ITU, and in European context;
d) Various activities of the Conference of European Telecommunication and Post administrations, CEPT, affecting radio astronomy.

The CRAF Frequency Manager attended a total of 47 meetings.

The following issues required special attention in 1999 and will require this in 2000 as well:

Iridium - European radio astronomy

In 1999 the CRAF frequency manager participated in 9 meetings to work on the protection of radio astronomy at 1.6 GHz against harmful interference from the Iridium Mobile-Satellite System (Earth-to-space and space-to-Earth). The Earth-to-space transmissions are addressed at national level by the administrations of the different CEPT countries. The space-to-Earth transmissions require a Europe wide solution (e.g. because of the dimensions of the satellite footprints).

Under the auspices of the CEPT Milestone Review Committee, MRC, CRAF and Iridium worked on an agreement to solve the downlink issue. The MRC adopted on March 27, 1998, a recommendation for all CEPT countries which stated that from 1 January 2006 the level of unwanted emissions from the Iridium system must be below the levels given in ITU-R Recommendation RA769-1 (which gives such numbers for radio astronomy). In May 1999, the European Science Foundation (on behalf of CRAF) and Iridium signed an agreement to handle during the period 1 May 1999 – 1 January 2006 the protection of European radio astronomy stations against unwanted emissions from the Iridium satellite system complying with MRC Recommendation 4 and the ESF-Iridium LLC framework agreement of 1998.

This 2nd ESF-Iridium framework agreement is used by CEPT administrations in the conditions on Iridium in the authorization of the Iridium system.

The ESF-Iridium interim agreement guarantees radio astronomy low interference levels for up to 50% of the year, thus allowing Europe's extensive 1612 MHz research programs to continue, with operational restrictions. This 50% fraction of time is more than was achieved elsewhere.

World Radiocommunication Conference 2000

In the year 2000 the next ITU-R World Radiocommunication Conference, WRC2000, will be held. More than in the previous WRC (WRC97) the agenda contains many items which are of great importance for radio astronomy. CRAF and its frequency manager works on these issues at a European level in various CEPT project teams, e.g. SE21, PT33 and PT34.

On the WRC2000-issue of the allocation of frequencies above 71 GHz (with the intention to go as high as 1 THz) the results are at present quite satisfactory for radio astronomy. Basically all CRAF views have been brought into the CEPT position.

Work for the next WRC after 2000 is already slowly starting, especially in PT33 where the allocation of frequencies between 71 GHz and 1 THz may need further elaboration. Special attention for a WRC in near future is needed for the band 1400-1427 MHz, on which the pressure from space and broadcasting services is rapidly increasing.

New Radio Astronomical Developments

ALMA and SKA are international projects for new radio astronomy instrumentation. It has been proposed to introduce the idea of an internationally recognized radio quiet zone around these facilities. Substantial lobby work is required of CRAF members with their own administrations, while the CRAF frequency manager follows also the discussions in OECD context. The time-scale is at present not clear, but the year 2000 may see increasing activity on this issue.

The discussions of SKA are currently gaining momentum and the problems of an international radio quiet zone and of satellite downlink interference is much greater than for the planned mm-astronomy facility ALMA. CRAF discussed aspects of this issue in the course of 1999.

European Issues

Special attention required the CEPT Detailed Spectrum Investigation, DSI, Phase-III addressing and evaluating the spectrum needs for the frequencies between 867 MHz and 3400 MHz. Radio astronomy input is given by CRAF to safeguard astronomical work in this frequency domain and CRAF participates actively in the evaluation process.

Other issues are:

• The coordination process between radio astronomy stations and the GLOBALSTAR system (1.6 GHz).

• Coordination issues concerning the introduction of terrestrial Digital Video Broadcasting, DVB-T, in particular in Belgium, France and the United Kingdom.

5 Institute Science

5.1 Radio microlensing by galaxy halo dark matter at high redshift

The study of gravitational lenses can be used to probe the material content and the scale of the Universe. These applications have enjoyed tremendous attention during the last decade. The new lenses discovered in the CLASS survey (started in 1994) have made a major contribution to this development. Dutch members of the CLASS collaboration (at ASTRON and in Groningen), have been very active in the use of these lenses, of which about 15 have now been detected.

An unexpected discovery during these studies was the very rapid uncorrelated radio variability in the two components of the gravitational lens source B1600+434. VLA and WSRT observations at frequencies of 1.4, 5 and 8.5 GHz yielded very strong indications that these variations are due to radio microlensing by compact halo objects.

The variations are believed to be caused by the motion of features in a radio jet (of a quasar at redshift z=1.6) behind a fine-fibered foreground pattern of microlensing caustics. This pattern is due to objects in the halo of the intervening edge-on lens galaxy (at redshift z=0.4). For rapid variations to be detectable there must be extremely compact structure (on a level of 5-10 microarcseconds) and transverse motion at super-relativistic speeds.

The discovery was discussed in Science and was one of the highlights a Groningen PhD thesis.

5.2 Discovery of a Microarcsecond Quasar

VLBI studies have revealed that the radio nuclei of powerful active galaxies and quasars poor out their energy in the form of highly collimated jets linked to an unresolved core. The smallest features that have been studied are on a scale of about 0.1-0.5 milliarcseconds – corresponding to a linear scale of typically lightyears. To understand the collimation process, and what goes on within the radio core, one needs to go to higher angular resolution. Investigators from the Kapteyn Institute in Groningen and ASTRON set out to find the smallest sources using a radio spectral index criterion. They did find a very small source but via an unexpected route. In fact they had to call in the help of the interstellar medium.

Due to turbulence in the ISM, the planar wavefront of the quasar is distorted in such a way that rays can reach us from a broader range of directions than normal. This scattering and focussing, in fact, provides the extra resolution. But due to the relative motion of source, plasma screen and the earth, transverse to the light of sight, the source intensity will change in a sort of random way. This is equivalent to the twinkling of stars by the higher layers in the earth's atmosphere. Using the new MFFE's on the WSRT in a 96 hour long campaign in May 1999 they discovered unprecedentedly fast and large variations in the quasar J1819+3845. Variations of 5-10% on a 1 minute timescale were no exception. Three important conclusions could be drawn from these observations: a) the source must be smaller than 30 microarcseconds, b) the source is unusually hot or fast (or both) yet has survived for at least a year and, c) the screen giving rise to the turbulence must be rather local (distance only 20 parsec).

The screen could be related to the edge of the local Hot Bubble. Further studies during the year revealed systematic changes in the intensity modulations that are believed to be due to the changes in the projected earth velocity. By May 2000, one year after the observations began, this will allow a precise measurement of the transverse plasma velocity.

5.3 WSRT's longest and deepest look yet: at the Hubble Deep Field

In the spring of 1999 the WSRT used its new sensitive MFFE's to take a deep look at one of the best studied spots on the sky: the Hubble Deep Field. The group – made up of astronomers from both Dwingeloo institutes (JIVE and ASTRON) – used the WSRT in a 72^h integration at 1.4 GHz and reached a noise level of about 8 microJy; this is the expected thermal noise level. At the 15" resolution of the WSRT (at 1.4 GHz), it appears as though we may now have come close to the confusion limit (where there is about one source for every 10 beams). The WSRT detected more than 200 sources above 45 microJy in a 16x16 arcmin area centered on the 3x3 arcminute HDF. Eight of these sources fall in the HDF; two of them had not been seen before. They are identified with relatively nearby galaxies. They were not detected by the VLA in a similarly deep survey with 10 times better angular resolution, presumably because of resolution effects. The WSRT, in fact, detected about 20% more sources than the VLA, many of which may be starburst systems resolved out at higher resolution.

5.4 Dark Matter and Cool Gas in Local Group Sub-dwarf Galaxies

Six examples of the compact, isolated HI high-velocity clouds (CHVCs) identified by astronomers from Dwingeloo and Leiden (reported in last year's annual report and published this year in A&A), but only marginally resolved in single-dish data, have been imaged with the Westerbork Synthesis Radio Telescope. The 65 confirmed objects in this class define a dynamically cold system, with a global minimum for the velocity dispersion of only 70 km/s, found in the Local Group Standard of Rest. The population is in-falling at 100 km/s toward the Local Group barycenter. These objects have a characteristic morphology, in which one or more compact cores is embedded in a diffuse halo. The compact cores typically account for 40% of the HI line flux while covering some 15% of the source area, as illustrated in Figure 5.2. The narrow line width of all core components allows unambiguous identification of these with the cool condensed phase of HI, the Cool Neutral Medium (CNM), with kinetic temperature near 100 K, while the halos appear to represent a shielding column of warm diffuse HI, the Warm Neutral Medium (WNM), with temperature near 8000 K. A core was detected with one of the narrowest HI emission lines ever observed, with intrinsic FWHM of no more than 2 km/s and 75 K brightness, as shown in Figure 5.3. From a comparison of column and volume densities for this feature a distance in the range 0.5 to 1 Mpc was derived for the object, placing it in the outer reaches of the Local Group. A determination of the the metallicity of this object yielded

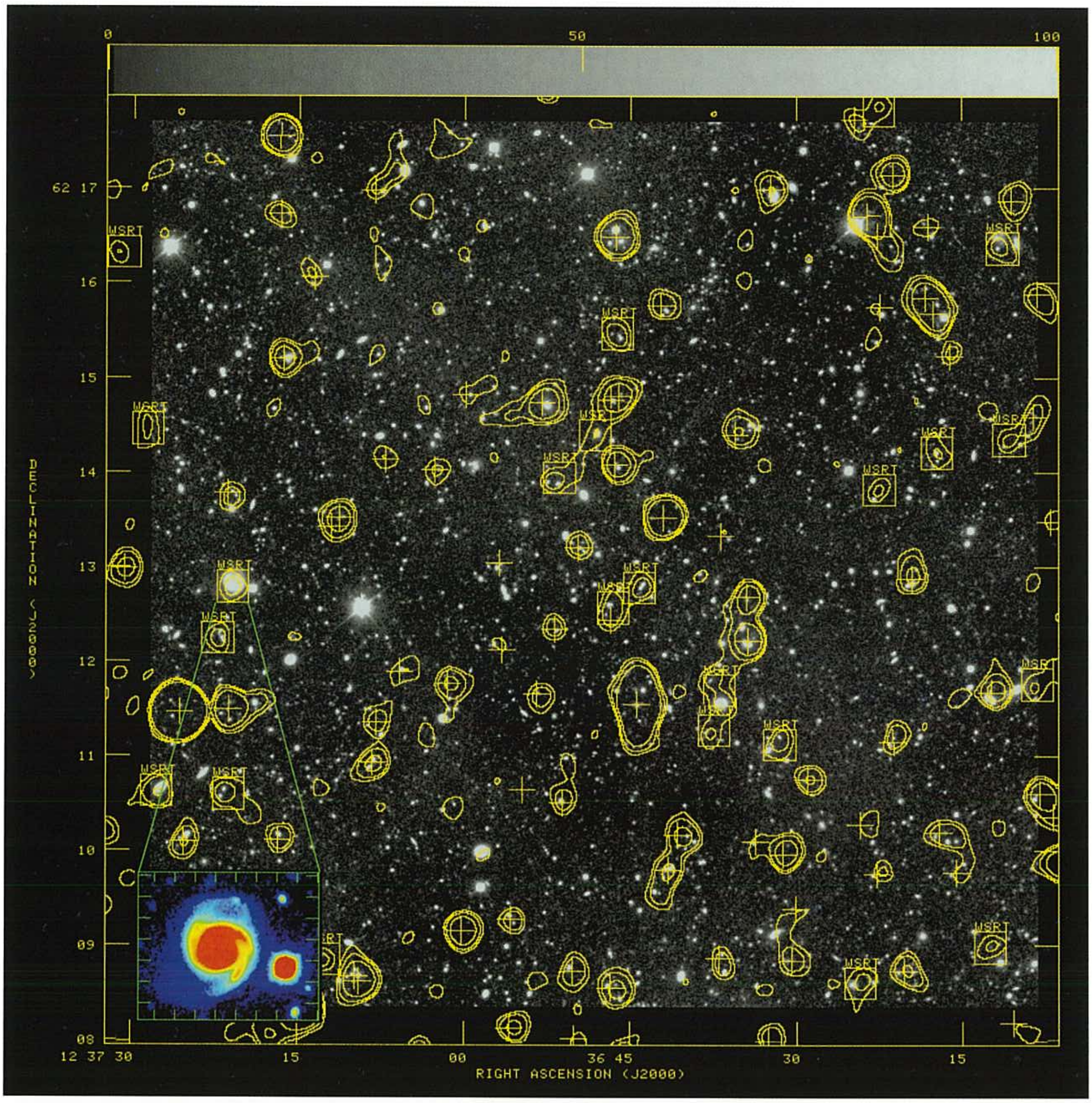


Figure 5.1 The WSRT's deepest image yet: 72 hours of 1.4 GHz observations centred on the Hubble Deep Field (HDF) region. The image was restored with a 15 arcsecond circular beam and superimposed upon the deep CFHT I-band image of Barger et al. (1998). The 1 sigma rms noise level is 7 micro-Jansky/beam at the edge of the field, rising to 9 micro-Jansky per beam at the centre. Contours are drawn at -3, 3, 5 and 10 x 9 microJy/beam. Crosses represent sources detected previously by the VLA (Richards 2000). Sources detected by the WSRT (but not the VLA or MERLIN) are boxed and appropriately labeled. Some of these new WSRT detections (see inset - bottom left-hand corner), are associated with nearby, disk galaxies ($z < 0.1$). The fact that they are resolved out by the VLA and MERLIN, implies star-formation evenly distributed across a major fraction of the optical disk

value of 0.04 to 0.07 times the Solar abundance. This determination was performed by comparing the HI column density to that of MgII seen in absorption toward the background active galaxy Mrk 205 (as marked in Figure 5.2). This is comparable to the lowest metal abundance dwarf galaxies known, and clearly indicates a far extragalactic origin for the material.

Comparably high distances (greater than about 500 kpc) are implied by demanding the stability of objects with multiple cores, which show relative velocities as large as 70 km/s on 30 arcmin scales. Many of the compact cores show systematic velocity gradients along the major axis of their elliptical extent which are well-fit by circular rotation in a flattened disk system. Two out of three of the rotation curves we derive are well-fit by the Navarro, Frenk, and White cold dark matter profiles. These kinematic signatures imply a high dark-to-visible mass ratio of 10–50, for D=0.7 Mpc, which scales as 1/D. The implied dark matter halos dominate the mass volume density within the central 2 kpc (10 arcmin) of each source, providing a sufficent hydrostatic pressure to allow CNM condensation.

The CHVC properties are similar in many respects to those of the Local Group dwarf irregular galaxies, excepting the presence of a high surface brightness stellar population. Deep searches for a low surface brightness stellar population will be carried out during 2000.

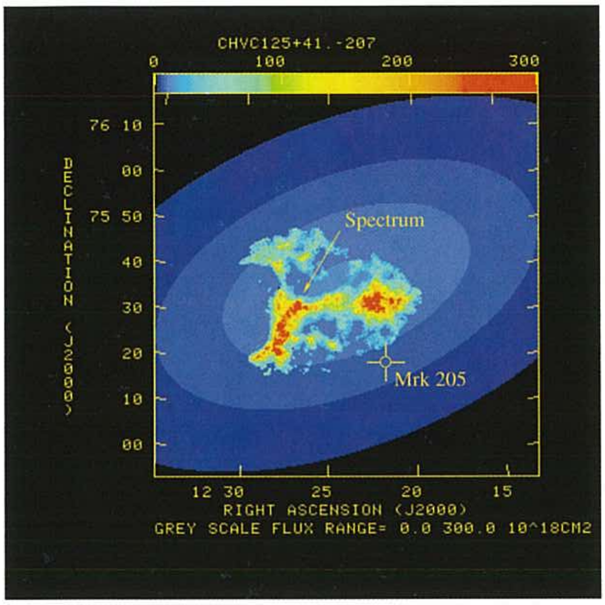


Figure 5.2 Column density distribution of HI in CHVC 125+41–207 at 28 arcsec resolution reconstructed from the Leiden Dwingeloo Survey and WSRT data. A linear pseudo-color-scale extends from 0 to 300x1018 cm^{-2}. The location of the background galaxy Mrk205 is indicated with the open symbol, while the compact clump, for which a spectrum is shown is indicated with the arrow.

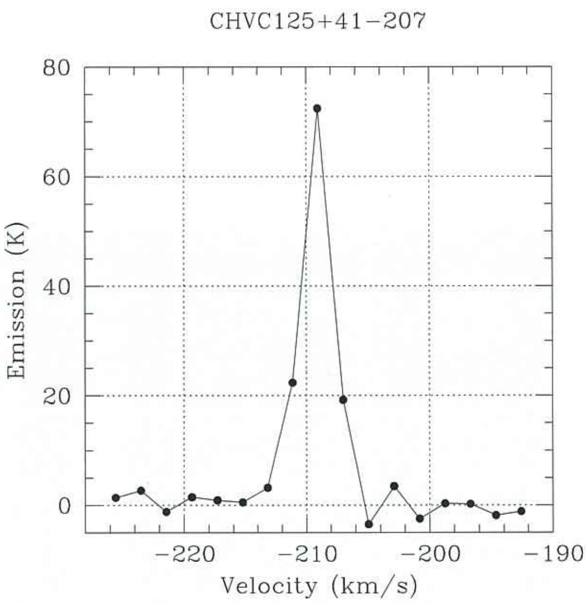


Figure 5.3 Brightness temperature spectrum of a compact clump in CHVC 125+41–207. The extremely narrow linewidth is one of the narrowest HI emission lines ever observed – robustly constraining the kinetic temperature.

5.5 HI Super-shells in Nearby Spiral Galaxies

Together with a colleague at NRAO, a systematic, automated search was conducted for expanding HI super-shells in 4 nearby spiral galaxies. A large and diverse sample of expanding structures in NGC 300, NGC 2403, M81, and M101 were accurately characterized using the model-based, 3D object recognition method which was developed previously. It was found that the galaxies in the sample each contain from 21–204 detectable, expanding shells with a diameter 300 pc or larger; this number is thought to be more than 50% complete. The distribution of 98 expanding shells found in NGC 300 is shown in Figure 5.4, overlaid on the stellar continuum and Hα emission. Taken as a whole these structures embody 10^{53}–10^{54} erg of kinetic energy, and a substantial fraction of each galaxy's HI mass. Undetected shells (below the resolution limit of 300 pc) also contribute significantly to the total mass and energy of the bubble populations. Note the rather dramatic association of some HI shells with prominent star forming regions within NGC 300. As expected, a relatively small fraction of the total shell population has embedded Ha emission, since bubbles should generally outlive their progenitor HII regions by a large margin. However, some bubbles are detected in which the HI shell appears to precisely contain a parental star forming (SF) region. Some especially notable examples are just to the west of the galaxy nucleus. Evidence was also found for ionized shells, rather than just an ordinary HII region, within expanding HI bubbles.

Predictions were made of the ensemble properties of HI superbubbles formed by OB associations and potential GRB (Gamma Ray Burst) explosions in disk galaxies. Monte Carlo simulations have been used to describe a steady-state population of expanding shells and determine integrated photometric characteristics of the stellar clusters responsible for mechanical energy deposition. The procedure that was developed makes it possible to identify systematic changes in the global properties of the superbubble population, resulting from variations in the overall cluster membership function (CMF) and relative spatial distribution of OB associations versus HI gas. The simulations were tested against observational data by generating predictions for the four galaxies listed above for which HI catalogs were available. The results for NGC 300 are presented in Figure 5.5.

The predicted population of HI super-shells, based on a steady-state stellar population which provides the current number and luminosity distribution of the observed HII regions, is indicated with the dashed histograms in the top

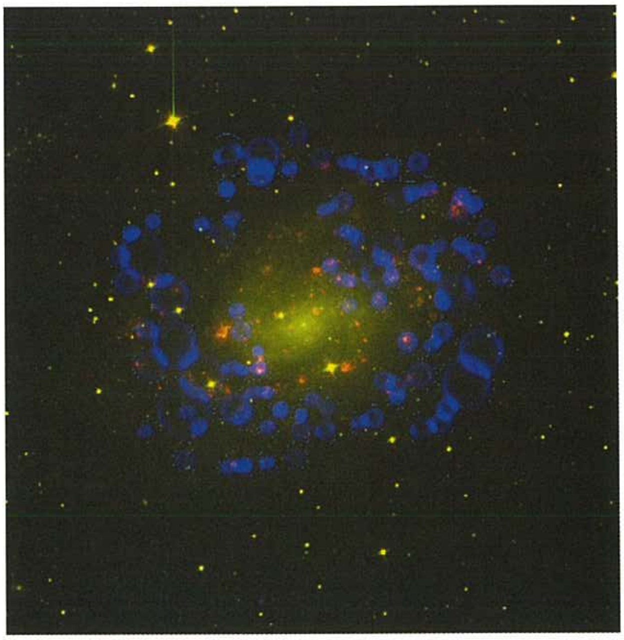


Figure 5.4 Colour composite image of NGC 300. The red channel was used to display an Hα line+continuum image, green shows the continuum only, and blue presents the velocity integrated representation of our HI shell population. The sky background appears to have a red and green character because the blue image has no sky contribution, as it is constructed from the best-fitting HI shell models.

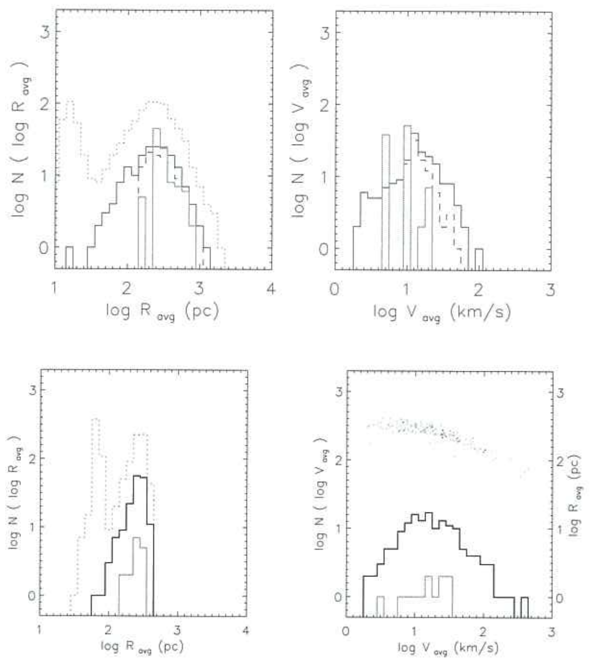


Figure 5.5 Top Panel: Comparison of population synthesis predictions with the observed radii and expansion velocities of HI superbubbles detected in NGC 300. The dotted line in the left-hand panel shows the size distribution for stalled shells, whereas solid black lines in both panels present predicted radii and expansion velocities for model shells which have not yet stalled. These histograms are plotted without regard to the details of our HI survey. After filtering out those shells which could not be detected given the limiting resolution of our datacube or properties of our survey parameter space, modified predictions are shown with the dashed line in each panel. For comparison with observations, the actual size and expansion velocity distributions are also shown using solid grey lines

Bottom Panel: Predicted characteristics of superbubbles formed via GRB explosions with an energy of 10^{53} erg. Panel (a) shows the synthetic mass-averaged radius distribution for steady-state GRB forming at the rate of 100 per Myr and per galaxy and 1 per Myr per galaxy (solid and grey histograms, respectively). The dotted histogram is the distribution of radii for stalled GRB shells in the case of 100 per Myr and per galaxy. Because GRBs seem to occur at least 10^4 times less frequently than SNe, the formation rate of 1 per Myr per galaxy is more appropriate for comparison with observations. The 100 per Myr and per galaxy calculations are presented for the sole purpose of better illuminating GRB remnant properties by defeating small number statistics. Panel (b) plots the distribution of mass-averaged GRB SB expansion velocities and includes a scatter plot of radii versus expansion velocity. .

panel of the figure. This can be compared with the actual histograms of detected HI super-shells which are represented by the solid grey lines. There is generally very good agreement between the number predicted and that seen, except for an excess of detected shells with a radius of about 300 pc. This narrow peak in the distribution near 300 pc radius is similar to the characteristic predicted signature of a population of GRB events as shown in the lower panel of the figure. The magnitude of the excess in the shell distribution seen in NGC 300 is comparable to that expected for a realistic GRB rate of about 1 per Myr and per galaxy. A similar excess of 300 pc radius shells is seen in all of the galaxies analyzed and may be a general indication that GRB events contribute a detectable signature to the HI super-shell population.

5.6 Influence of Shoemaker-Levy 9 impacts on Jovian radiation belts

In July, 1994, the comet Shoemaker-Levy 9 collided with the planet Jupiter, with explosive results for the Jovian atmosphere. Also in the radiation belts, significant changes occurred, with a dramatic

increase in the decimetric radio emission, and other changes in the structure. These were observed by a number of radio telescopes, including the WSRT, and they have been reported in the astronomical literature. Now the WSRT data have been reanalyzed by a colleague at the University of California at Berkeley in a joint project with ASTRON staff. They have made use of tomographic software developed at the ATNF in Australia. Because the WSRT beam only provides good east-west resolution, the tomographic method has been used to map the brightness distribution in two dimensions only, projected onto the Jovian equatorial plane.

The panel of images shows the radio emission from the Jovian radiation (Van Allen) belts in the equatorial plane as seen from the north pole of Jupiter (the planet is the dark blob in the center). The images have been constructed by tomography from WSRT 21 cm observations made in July, 1994. The first panel (upper left, labelled 8-15) shows the average emission, extending out to several Jovian radii (R_J), over the period 8-15 July.

In the remaining eight images, the average emission has been subtracted from the daily tomographic image reconstruction on the dates indicated. The twenty-odd fragments of comet Shoemaker-Levy 9 impacted Jupiter in the period 16-22 July. Localized enhancement of emission features seen in the radiation belts is apparent during the impact period, especially on 20-22 July. The total flux density of Jupiter at 21 cm increased by about 25% as a result of the impacts.

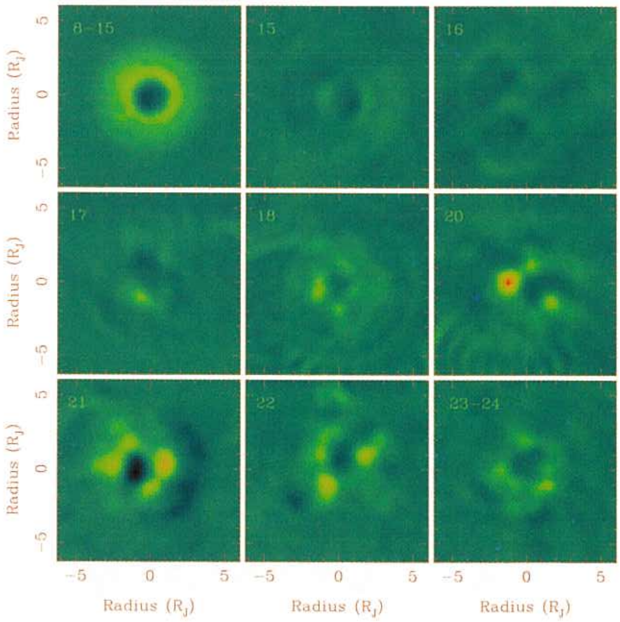


Figure 5.6 Tomographic images of the impact of Shoemaker-Levy 9 on Jupiter in July 1994 as observed with the WSRT at 21 cm.

5.7 HI in early-type galaxies: signature of a long-lived cold ISM.

Early-type galaxies constitute quite a heterogenous group of galaxies. A key element for explaining the range in their observed properties is the differences in gas content. ASTRON astronomers, in collaboration with an Australian colleague, started a study of the distribution and kinematics of the neutral gas in such systems a few years ago. A number of surprising objects have so far been detected.

The renewed interest in the study of the cold ISM, and in particular of the neutral hydrogen, in early type galaxies has brought the realization that some of these galaxies have a surprisingly large amount of HI. Even more interestingly, this gas can be distributed in very regular structures (i.e. disks or rings). Two of the best examples that have been found so far by this group are shown in Figures 5.7 and 5.8. A very good example is NGC 807. Deep HI observations reveal a low-surface brightness HI disk with more than 10^{10} $M_{\odot}$ of neutral gas extending to 60 kpc radius (see Figure 5.7). The disk shows very regular rotation. Another example is NGC 3108, a dust-lane galaxy with almost 10^{10} $M_{\odot}$ of neutral gas extending to 40 kpc each side of the nucleus. Figure 5.8 shows the position-velocity map taken along the major axis of this galaxy.

Two striking results are coming out from this work:

The large amount of neutral gas in these objects suggests that they are the result of a major mergers, i.e. a merger of two spiral galaxies. However the regularity of the HI observed in these systems suggest that these disks, if originally accreted, are the result of very old accretion and therefore they are long lived structures. This long-lived cool interstellar medium must play an important role in the evolution of these galaxies.

The other result is the great similarity of the rotation curves of these objects with the rotation curves of luminous late-type spirals. If one would not know that e.g. NGC 3108 is an elliptical galaxy, one would not be able to infer it from the position-velocity data only. The HI in these objects will be used to trace the mass distribution of the galaxy and to determine the properties of the dark matter in early-type galaxies in particular at large radii.

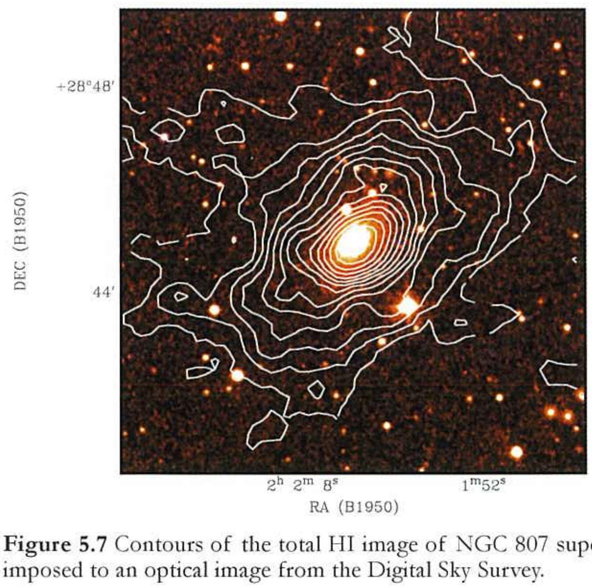


Figure 5.7 Contours of the total HI image of NGC 807 superimposed to an optical image from the Digital Sky Survey.

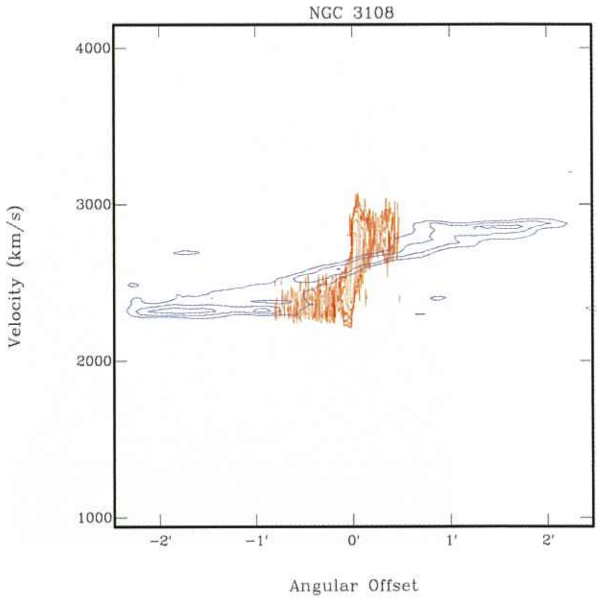


Figure 5.8 Position-velocity map taken along the major axis of NGC 3108 from the HI disk (blue contours, VLA data) and from the optical data (red contours, from the 3.6 ESO telescope at La Silla).

5.8 Warm ionized gas around Coma A

Powerful radio galaxies are frequently associated with extended emission line nebulosities extending up to tens of kpc from the nucleus. The morphological and kinematical properties of these nebulae provide important clues on the origin of the gas and the origin of the activity as a whole.

In order to investigate the intrinsic distribution of the warm gas in powerful radio galaxies, astronomers from the United Kingdom, France have – in collaboration with ASTRON staff – obtained deep Hα images with the Taurus Tunable Filter on the WHT for the well-known radio galaxy Coma A.

The image (Figure 5.9) shows a spectacular system of interlocking emission line arcs and filaments, and a striking match between the ionized gas and the radio structures. The match between part of the ionized gas and the radio structures, in particular the optical filament that curves around the northern radio lobe, suggests that in Coma A the direct interaction with the radio jet is not the only source of ionization of the gas, but that also the expansion of the lobe into the environment plays a role. This makes Coma A a quite unusual object.

One possible explanation for these uncommon features is that Coma A has a particularly gas rich environment and that the close morphological association is due to the radio lobes expanding into the gas-rich environment. Powerful radio galaxies are believed to be the result of recent galaxy mergers or tidal interactions between galaxies. The Coma A system has indeed the appearance of an interacting group of galaxies. Also the Hα filaments bear a resemblance to the HI tails detected in 21-cm radio observations of interacting groups. Further study of this object is planned by looking for neutral gas to investigate the nature of its environment.

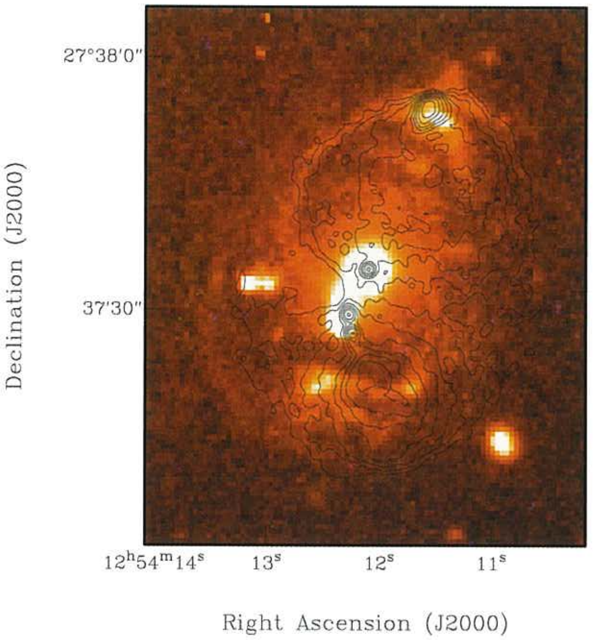


Figure 5.9 Hα image of Coma A (colours) with superimposed the radio image (contours) from the VLA.

5.9 Investigations of Giant and Double-double radio sources

Work is proceeding on WSRT observations of a large sample of Giant Radio Sources (GRSs). With a linear size exceeding 1 Mpc (H_0 = 50 km/s/Mpc) these are the largest radio sources in the Universe associated with Active Galactic Nuclei (AGN). Mainly two frequencies are used for these observations: 1.4 GHz and 325 MHz. Figure 5.10 shows an example of a 1.4 GHz WSRT observation of the GRS B1918+516, which was recently discovered by a group of astronomers based in Dwingeloo, Leiden and Utrecht. This radio map is the result of a single 12 hr observation with the old frontends. With the new MFFE frontends, which have much more sensitive L-band receivers, a considerable improvement in sensivity is possible. This allows one to investigate the extended diffuse radio bridges more accurately and to search for possible relic halos around these sources. Further, the observations at 325 MHz, which were done using eight different 5-MHz wide channels between 300 and 380 MHz, provide direct information on the Rotation Measures and depolarization towards the lobes of these sources.

The recent compilation of a complete sample of GRSs was further used to provide observational constraint on the evolution of large FRII-type radio sources in the Linear Size – Radio power (P–D) diagram. Theoretical models predict a decline in the radio power as radio sources increase in size. The rate of decrease of radio power is expected to grow for sources larger than 1 Mpc, but this predicted effect could never be properly tested observationally due to the lack of decent samples of such large sources. With Schoenmakers' sample of GRSs it has been possible to include sources larger than 1 Mpc in size in a fitting procedure to investigate the behaviour of the radio power of such sources. It was found that in order to fit the observed number of sources with linear sizes larger than 100 kpc, steep evolutionary tracks are necessary with a downward bend at a linear size of about 1 Mpc, much like those predicted by the theoretical evolution models.

The group has also investigated the optical emission-line properties of their sample of GRSs, and the correlations of these with radio properties. For this purpose extensive use of the 2.5-m INT telescope on La Palma was made. It was found that the emission-line properties of GRSs are not different from those of smaller sized (but larger than 50 kpc) radio sources. There were no significant correlations between emission-line strengths or ratios and either linear size, radio core power or total radio power in these sources. Furthermore, although a most careful analysis of the emission lines strength was performed, the measured emission-line ratios did not make clear what the ionization mechanism of the emission-line gas is. Still, this study provided a valuable database of emission line properties of a complete sample of Mpc-sized radio sources which will be used for comparison purposes in the future.

Another fascinating group of radio sources is that of the class of Double-double radio galaxies (DDRGs, see also NFRA Newsletter 15). These are radio sources consisting of a well aligned, co-centered, double-lobed radio sources of different size (see Figure 5.11 for an example). The favoured explanation for this strange morphology is that of a radio source which underwent an interruption of its central jet-forming activity. In this model, the inner radio lobes are the youngest, and the outer radio lobes are currently fading because they are cut-off from the energy supply of the jet. These sources allow us to investigate several poorly understood issues of radio source evolution, among which the following. First, what happens to radio lobes when the energy supply by the jet is stopped? An investigation of the outer lobes of the DDRGs can clarify this issue since they most likely are in this evolutionary stage. Second, what is the

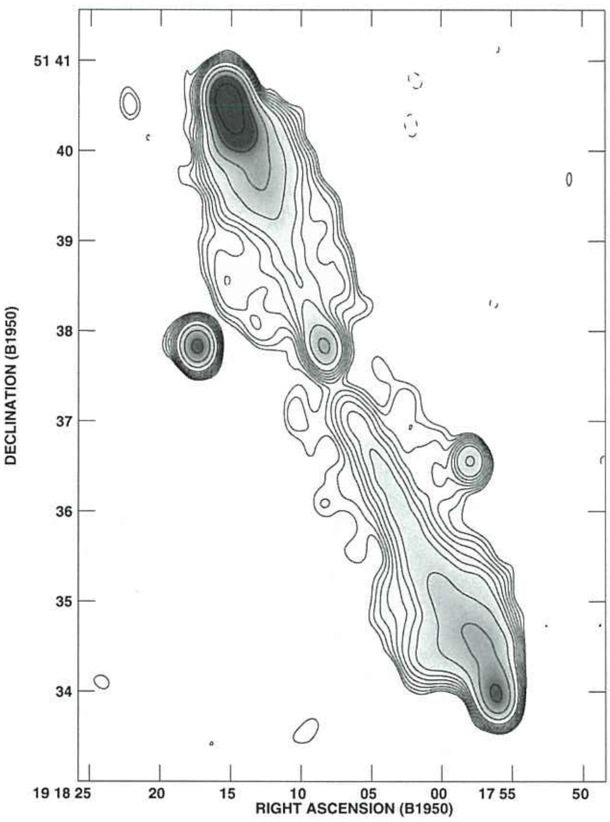


Figure 5.10 Radio contour plot of the giant radio galaxy B1918+516. This source has a redshift of 0.284 and a projected linear size of 2.3 Mpc (H_0 = 50 km/s/Mpc). This map is the result of a 12hr WSRT observation at 1.4 GHz. It beautifully shows the extended radio lobes, the radio core and two jet-like structures emanating from this core. The two unresolved sources alongside the giant are most likely unrelated radio sources.

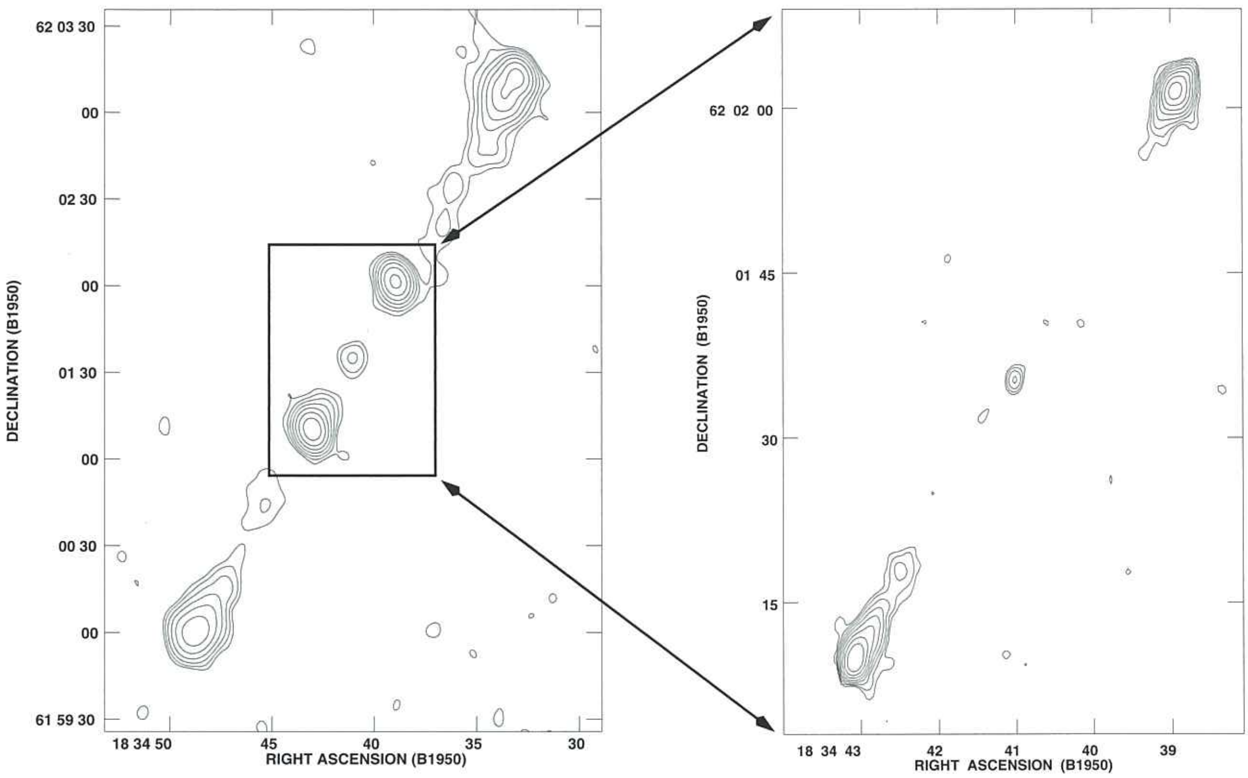


Figure 5.11 Radio contour plots of the DDRG B1834+620. The figure on the left shows the source as a whole, observed with the VLA in its D-configuration at 8.4 GHz (8 arcsec resolution). The plot on the right shows the inner part only, observed with the VLA in its A-configuration at 1.4 GHz (1 arcsec resolution). It shows that the inner structure is a double-lobed radio source itself.

contents of a radio lobe? Is it only jet material, or is there mixing with the surrounding intergalactic medium? In the DDRGs, the inner radio lobes are expanding within the cocoons of the outer radio lobes. Therefore, any information on the (environment of) the inner lobes is highly interesting. Third, how often do such interruptions of the jet occur and how long do they last. Again, the DDRGs are excellent candidates to study this behaviour. Finally, is there any relation between DDRGs and the so-called "X-shaped", or winged radio sources? Perhaps the DDRGs are those sources where the restarted jet has not drastically changed its outflow direction. The DDRGs are a fascinating group of radio sources that should be studied in high detail. The upgraded WSRT will play a crucial role in these investigations.

5.10 Globular Cluster Searches

A group of astronomers from Amsterdam, Utrecht and Dwingeloo have observed 11 globular clusters with the WSRT to search for radio pulsars in these clusters. This survey is capable of reaching a sensitivity of about 50-60 microJy (10 sigma limit) at the 1420 MHz band. This is roughly ten times more sensitive than the earlier surveys on most of these clusters. These clusters have been selected on the basis of their core density and the interaction probability in the core. The analysis of four clusters (Ter 5, NGC 6624, NGC 6342, NGC 7078) has been completed, so far, there has not been a confirmation of the presence of any radio pulsars in these clusters. The analysis on the other clusters is continuing.

5.11 Observational evidence of 'kick' mechanisms in neutron stars

In collaboration with colleagues from India, an examination has started of available observations on pulsars in search for evidence pertaining to mechanisms proposed to explain the origin of their velocities. Conclusions so far are:
1) that mechanisms predicting a correlation between the rotation axis and the pulsar velocity are ruled out
2) that there is no significant correlation between pulsar magnetic field strengths and velocities

If asymmetric impulses are responsible for both spin and velocities of pulsars (Spruit & Phinney 1998; Cowsik 1998; Burrows et al. 1995), then:
3) single impulses of any duration appear ruled out!
4) multiple impulses of long duration are also ruled out!

5.12 Search for "Single Scattering Events"

Radio signals, during their passage through the intervening medium, are scattered due to the irregularities in the density of free electrons in the interstellar medium. Signals from distant sources undergo, most often, strong & multiple scattering while the signals from nearby sources may be only weakly scattered even at meter wavelengths. It is also likely that the scattering of the signals from some of the close-by sources is possibly non-multiple in nature and hence may show a distinct signature of single or discrete Scattering Events, where we receive, along with a direct unscattered signal only a few discrete delayed versions of the signal. In such a case, it appears possible to probe the properties (such as the size and density contrast) of the discrete density-irregularities responsible for the scattering, if the associated delays can be measured.

The source PSR B0950+08 has been observed with the WSRT at 382 MHz by astronomers from Dwingeloo and Amsterdam, together with a colleague from India, with the aim of detecting these single scattering events. A search was made for significant discrete features in the Autocorrelation (AC) function computed from the baseband-recorded voltage series. Analysis has shown no indication of the presence of such discrete scattering events. With the minimum measurable delay of about 100 nanoseconds in the present analysis, this gives an upper limit to the density fluctuation and the size of any possible cloud present in the vicinity of the line of sight. For instance, suppose we have an electron cloud of size 100 AU, the upper limit to the number density fluctuation of this cloud is about 2x 10^{-3} cm^{-3}.

5.13 The kinematics of the CJ-F sources

The CJ-F, is a complete flux-limited sample of 293 flat-spectrum radio sources, drawn from the 6 cm and 20 cm Green Bank Surveys. Continued VLBI observations of the CJ-F sources have been performed by a large group since 1990. It is believed that for the unambiguous determination of the jet component position and motion parameters it is necessary to have at least three observing epochs (spread over roughly 4 years). In the last two years, considerabl improvements have been made to the observational and data-analysis status of the CJ-F survey. The most recent observing session was in November 1999; this 3-day run served as the second or third epoch for 64 CJ-F sources. The current status of the survey is as follows: 259 sources in CJ-F have at least three epochs of observations and 34 sources have two epochs, as summarized in Figure 5.12. All together 872 observations have been obtained so far. The observational part is now complete to 88%. A paper describing the model-fitting results for these sources is in preparation.

A major goal of the CJ-F survey was to make a statistical study of the apparent speeds in order to understand the general properties of the phenomenon rather than the details of an individual object. The great majority of CJ-F sources show a parsec-scale jet on one side of a flat-spectrum, compact core. Many of the observed jets are curved, and in some cases quasi-oscillatory trajectories or ridge lines have been observed. Components show a wide range of apparent velocities – different components in the same source can show different velocities; components can accelerate, decelerate, merge, or split; and in some cases a stationary component can coexist with moving components. As an example for a source with a "straight" jet, four VLBA observations of the galaxy 0309+411 (redshift: 0.14) are shown in Figure 5.13. Four jet features can be traced through the epochs and separate with apparent superluminal motion of value ~2.4 c (taking H_0=50 h km/s/Mpc and q_0 = 0.5) from the core which is assumed to be stationary. To our knowledge, this is the first evidence for superluminal motion in this source.

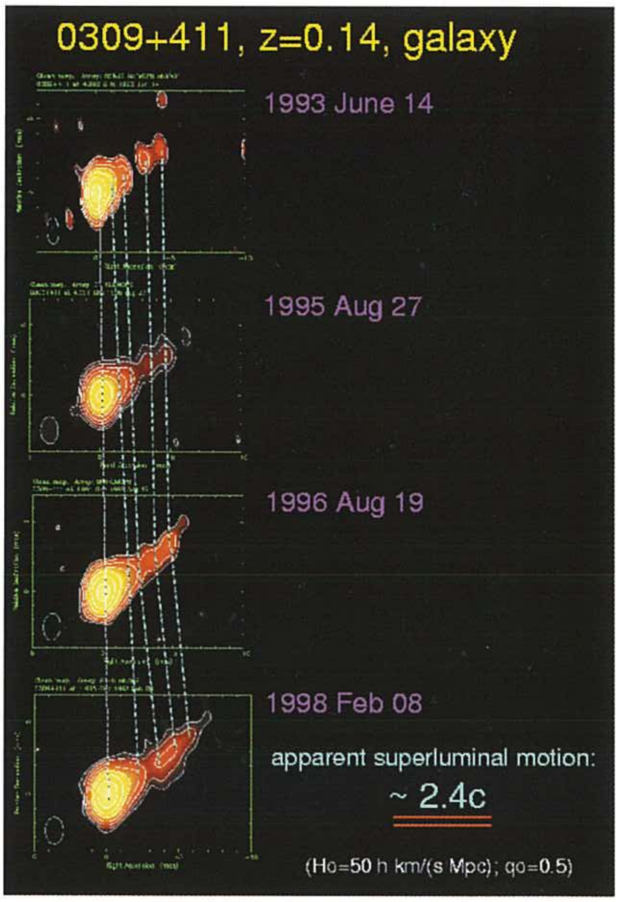


Figure 5.13 Composite picture showing one object selected from the CJ-F survey. The galaxy 0309+411 has been observed at four different epochs (between 1993 and 1998) with the VLBA. Jet features separate from the core with apparent superluminal speeds of ~2.4 c. The dot-dashed blue lines mark the position of the jet features.

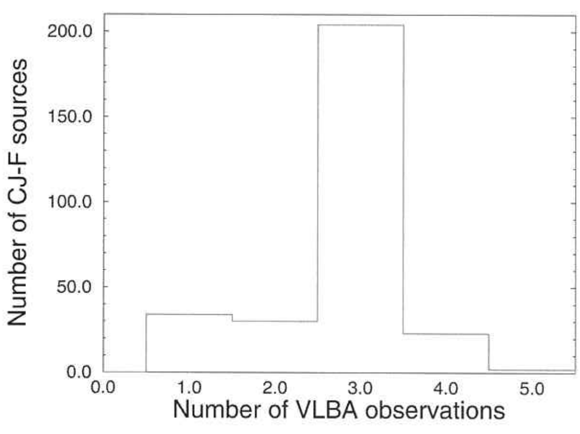


Figure 5.12 Histogram describing the status of the VLBA observations performed on the sources of the CJ-F sample.

6 ASTRON FACILITIES

Library

Since the number of books and other media has grown considerably, a remodeling of the library was necessary. More racks have been added and the floor plan changed to be more efficient. The forecast is that there is now enough room for about three to four years. The Biblio database was converted to Access and can now be used on every NT-desktop. The library has about 4500 books classified in twelve subject-groups and about eighty sub-categories. The trend to electronic publishing on the Web continues, much work was carried out to get subscriptions of available electronic periodicals and other data. This is often cumbersome since many publishers use their own unique system. As such books and periodicals will not disappear for some time to come.

Purchasing department:

All purchase orders leaving ASTRON are now routed through the purchasing department. In general the purchasing procedures were sharpened and formalized, a general purchase document is now used with the more expensive orders. Highlight of the year was the purchase of a CNC-milling machine for which much negotiating was done.

System-management group:

The millennium change passed, without trouble for the users. However much work was necessary and has been carried out, mainly the OS-upgrades and loading of additional patches on HP- and SUN workstations. The old VAX computer was switched off with some ceremony and the central UNIX fileserver was replaced also.

The Internet-line upgrade from 64 kb to 512 kb was completed in early 1999, for the moment this solved the slow-access problem to Internet facilities. Since this was very expensive, further upgrading to 2 Mb is not possible in the coming years without special grants. Since ASTRON is located in a rural area, costs for leased-connections are many times higher than in the more densely populated areas in the west of the country. This is difficult to explain to people, located in the more centralized areas.

Color printing was added for presentation and publishing purposes, two color printers are available now to the general user.The trend toward LINUX machines instead of SUN and HP workstations also continued: there are now over twenty LINUX-stations in use. The number of PC's networked under NT has grown to over 220 stations, served by four central servers. Due to safety problems, all E-mail has been rerouted to a central POP3/IMAP mailserver. Through the so-called "Web-access" system, users can read and answer e-mail whenever a browser on the internet is available. The firewall that was promised last year was ordered in the last quarter, but had not yet been installed at the end of the year.

Prototype shop

Since the merge with the "Kapteyn Sterrenwacht Roden", ASTRON has been heavily involved in opto-mechanical projects. The shift to complex optical machinery called for a different approach in mechanical engineering. This has led to the change of the mechanical shop to a so-called prototyping shop where CNC milling and rapid-prototyping are the main techniques. A tight coupling between mechanical design and the available CNC-machine has been achieved; this was used with success in the milling of many complex-shaped mirrors for the VISIR project.

In the course of 1999 it became clear that (the almost ten year) old 3-axis CNC machine from Roden can no longer fulfill all of the complex workload, that is now needed. The decision was made to buy a second (5-axis) CNC-machine and a second CAM-technician was added to keep the machines busy.

The new machine will be available in May 2000.

Emergency Procedures

Just before the year's end, ASTRON's Emergency procedures were brought in line with applicable guidelines. ASTRON and JIVE now have a professionally trained emergency team. Provisions that were also made include an internal emergency phone number, signposts around the building, and a set of emergency procedures – a copy of an emergency plan is now available at both locations. Every member of staff received basic training in how to react in case of an emergency.

7 The ASTRON Program Committee

Membership:

Dr. J.M. van der Hulst	Groningen	Chair
Dr. P. Best	Leiden	
Dr. P.P. van der Werf	Leiden	(Semester 99b)
Dr. J. Luu	Leiden	(Semester 00a)
Dr. L. Kaper	Amsterdam	
Prof. Dr. F. Verbunt	Utrecht	
Dr. R. Vermeulen	Dwingeloo	
Prof. Dr. F.H. Briggs	Groningen	(Semester 99b)
Dr. J. Higdon	Groningen	(Semester 00a)
Prof. Dr. M.G. Edmunds	Cardiff	(Semester 99b)
Prof. Dr. U. Klein	Bonn	(Semester 00a)

There were three changes in the PC composition in 1999. Dr. U. Klein from the University of Bonn replaced Dr. M.G. Edmunds from Cardiff as foreign member. The Leiden member Dr. P.P. van der Werf was replaced by Dr. J. Luu and the Groningen member Dr. F.H. Briggs was replaced by Dr. J. Higdon.

In 1999 NWO reorganized and as a result a change in responsibilities occurred. The WSRT remains under the direction and responsibility of ASTRON. The UK/NL collaboration (and associated finances and telescope time allocation) now is the responsibility of the "Gebiedsbestuur Exacte Wetenschappen" (GBE) of NWO. Despite this change the NFRA PC continued to evaluate both WSRT proposals and proposals for the UK/NL telescopes (the JCMT and the ING telescopes at La Palma). Both the ASTRON board and the NWO GBE board agreed that the astronomical community is served best if a single committee continues to evaluate proposals and allocate time for both the UK/NL telescopes and the WSRT.

The WSRT continues to be in its upgrade phase where new hardware (correlator, front-ends) and software (the Telescope Management System TMS) are being developed and tested and hence has not yet reached its full capacity. The timescales are longer than anticipated despite the dedication of the persons involved. Nevertheless the observing efficiency in 1999 came close to 50%. The proposal pressure has steadily increased with the new capabilities coming slowly on-line and the average oversubscription rate is more than 1.5. The submitted proposals are a mix of short (< 30 hours) and long projects (>130 hours). With the new capabilities and new spectral windows opening up the PC expects that the proposal pressure will increase even further, possibly also as a result of larger programs.

The instrument of interim proposals for small programs, urgent observations, and the like has not been used extensively in the past year. Because the regular deadline is only semi-annual the interim allocation possibility offers extra flexibility to users which the PC is willing to support.

WSRT Allocations Semester 1999a

Proposal	PI	Title	Time (hr)
r99a001	Dwarakanath	WNM of the Galaxy	78
r99a002	Chengalur	The lowest redshift damped Ly alpha system	with r99a008
r99a003	Zwaan	HI survey of Abell 2218 at z = 0.18	240
r99a004	Rivers	ZoA Survey follow up	20
r99a005	Pottasch	Observations of Planetary Nebulae	55 backup
r99a006	Fender	Magnetic white dwarf in AE Aqr	14
r99a008	Lane	Damped Ly alpha absorber at z = 0.0912	53
r99a010	Braun	Compact HVC's in the Local Group	78
r99a011	Braun	The newly discovered galaxy Cepheus 1	26 backup
r99a012	Galama	GRB follow-up	325
r99a013	Galama	Late radio emission from GRBs	52
r99a014	Hagiwara	Detecting OH in the radio-loud QSO 3C48	14
r99a015	Stappers	High precision pulsar timing program	50
r99a016	Dennett Thorpe	Low frequency spectra of "10 GHz peakers"	24 backup
r99a018	Ramachandran	Single scattering events in pulsar signals	16
r99a020	Stappers	Eclipsing Millisecond Pulsars	30 backup
r99a022	Schoenmakers	HI absorption toward two giant GPS sources	28 backup
r99a023	Tian Wenwu	Millisecond pulsars in WENSS/NVSS sources	7 backup
r99a026	Peck	Circumnuclear tori in 3 faint CSOs	38
r99a027	Tauris	Search for radio pulsars in NGC 7654	26
r99a029	de Bruyn	Variable HI and OH absorption in 1830-211	51
r99a031	de Bruyn	Preparation for a Zeeman splitting experiment	14
r99a032	de Bruyn	RM synthesis in Faraday-depolarized sources	24
r99a033	Pickering	HI observations of giant LSB galaxies	28 backup
r99a034	Baan	OH emission and HI absorption at high z	24
r99a036	Taylor	NGC 3521: A hidden merger?	14 backup
r99a037	v. Albada	WHISP	110
r99a038	v.d. Hulst	HI survey of the Coma cluster	220

JCMT Semester 1999a

Proposal	PI	Title	Time hr/queue	
		Contingency for 98A overflow	24	
m99an02	Smith	SCUBA Observations of GRB Counterparts	24	ToO
m99an03	Hogerheijde	Molecular entrainment in bipolar outflows	46	C2
m99an08	Waters	Debris disks in evolved binaries	24	B3
m99an11	Stacey	SPIFI Investigations of the Barred Spiral M83	32	A2
m99an12	Tielens	D2CO/H2CO ratio towards IRAS16293-2422	48	C1
m99an14	Tilanus	Sub-mm imaging of M51 and M83	32	B2
m99an16	van Dishoeck	Phys. and chem. structure of circumstellar disks	48	B1
m99an17	Röttgering	Dust and formation of massive galaxies at z > 3	13	B4
m99an19	Papadopoulos	The CI line as a tracer of starburst activity	56	A1
m99an21	Roelfsema	Submm imaging of ultra compact HII regions	15	C3
m99an23	Barthel	Star forming QSO host galaxies	14	D1

WHT Semester 1999a

Proposal	PI	Title	Time (nights)
w99an001	Salamanca	Circumstellar medium around SNR's	6h override
w99an002	Galama	Imaging and spectroscopy of GRBs	override for 3 GRB
w99an004	Higdon	Taurus study of starburst nuclear rings	2G
w99an005	Ehrenfreund	DIBs and large molecules in single clouds	2B+1B backup
w99an007	Neeser	Damped Ly alpha survey of a z ~ 2 QSO sample	2G
w99an008	de Zeeuw	SAURON observation of giant ellipticals	2D+1G
w99an009	Miley	Search for forming clusters at z > 2.5	2D
w99an010	Best	Evolution of z~1 6C galaxies	1D+1G
w99an012	van Woerden	Distance and metallicity of HVC complexes	2B+1B backup
w99an013	Galama	Imaging and spectroscopy of GRB afterglows	override for 2 OTs
w99an014	Kuijken	Weak lensing survey of high z clusters	2D+1B

INT Semester 1999a

Proposal	PI	Title	Time (nights)
i99an001	Tschager	Redshifts of the host galaxies of young radio sources	2G
i99an002	Foing	Surface structure and flares on active stars	6B
i99an003	Stempels	High resolution spectroscopy of T Tauri stars	4B
i99an004	v. Dokkum	Photometric survey of the Coma cluster	2D+2G

JKT Semester 1999a

Proposal	PI	Title	Time (nights)
j99an001	Le Poole	Photometric calibrators for the 2nd GSC	2D+6G
j99an002	Tschager	IDs of young radio source hosts	5D
j99an003	Groot	Disk and halo cataclysmic variables	2x6B

WSRT Semester 1999b

Proposal	PI	Title	Time (hr)
r99b001	Mohan	HI 21 cm line absorption from the fast clouds in the Galactic disk	14
r99b003	Rol	Rapid follow up of GRBs	440
r99b004	Nan	High sensitivity imaging of X-ray-emitting quasars	14
r99b006	Braun	Primordial Sub-dwarfs in Galaxy Groups (allocated time for NGC 628)	228
r99b007	Crutcher	Excited CH Zeeman Observations of Dense Molecular Gas	76
r99b008	Gibson	Small scale cold HI structures in the Perseus arm	72
r99b009	Katgert	Distributions of ISM Rotation Measure in a region at l=145, b=-20	78
r99b010	Snellen	Testing self similar evolution in young radio sources	24
r99b011	Stappers	Radio pulsar microstructure study of four pulsars	15
r99b012	Garcia Ruiz	The asymmetric warp of the galaxy UGC 7774	52
r99b013	Stappers	A high precision timing program	36
r99b014	Stappers	Simultaneous multi-frequency observations of eclipsing msecpulsars	45
r99b015	Dickel	The relation of supernova remnants and pulsars (allocated for 114.3+0.3)	15
r99b016	Ramach	A study of mode-changing and emission cone geometry of 1822-09	14 backup
r99b018	Ramach	Observations of NGC 7078	24
r99b020	Kouwenhoven	Drifting subpulses and pulse nulling of pulsars B0031-07 & B0809+74	16
r99b021	Dennett-Th.	Measuring microarcsecond sources	97
r99b022	Rottmann	Low-frequency observations of X-shaped radio galaxies	65 backup
r99b023	Lane	HI 21cm Absorption in Damped Ly alpha Systems	70
r99b024	Burton	Distances and physical conditions from narrow HI lines in compact HVCs	69
r99b025	Koopmans	Radio scintillation or microlensing in the gravitational lens	107
r99b027	Strom	High time-resolution optical/radio observations of Crab giant pulses	10
r99b029	Garrett	WSRT observations of the HDF	91

JCMT Semester 1999b

Proposal	PI	Title	Time (hr/queue)
m99bn03	Cimatti	850 micron photometry of extremely red galaxies	14 B5
m99bn04	v.d. Werf	A deep submillimetre survey in the NTT Deep Field	24 A1
m99bn05	Stark	Deuterium chemistry in young stellar objects	25 A3
m99bn07	Henning	A search for massive protostellar objects	32 C3
m99bn08	Papadopoulos	Deep sub-mm imaging of a very warm and a very cold IRAS galaxy	24 B6
m99bn10	Tielens	Using methanol lines to trace infall	46 C1
m99bn12	Waters	Evolution of circumstellar disks in young clusters	56 B1
m99bn13	v.d Werf	Completion of the SCUBA survey for distant galaxies (MS1054/A1689)	32 A2
		Completion of the SCUBA survey for distant galaxies (MS1358/A520)	32 B4
m99bn14	v. Dishoeck	Physical and chemical structure of star forming regions	48 B2
m99bn15	v. Dishoeck	CO 2—1 profiles toward translucent clouds	16 D1
m99bn16	Rottgering	Dust and the formation of massive galaxies at z > 3.2	30 B3
m99bn17	Bolatto	The ISM in NGC 891	32 SPIFI
m99bn18	Hogerheide	The morphology of the cloud cores surrounding YSOs	25 C2
m99bn19	Smith	SCUBA Observations of Gamma-Ray Burster Counterparts	ToO

WHT Semester 1999b

Proposal	PI	Title	Time (nights)
w99bn001	Vreeswijk	Imaging and spectroscopy of GRB error boxes	ToO
w99bn002	Luu	Spectroscopy of Outer Jovian Satellites	1D+1G
w99bn003	Luu	Rotational Properties of Kuiper Belt Objects	3B
w99bn004	de Zeeuw	SAURON observations of galaxies along the Hubble sequence	3D+1G
w99bn005	v.d. Berg	Spectroscopy of peculiar X-ray stars in NGC 752 and NGC 6490	1B
w99bn006	Swaters	Stellar velocity dispersion measurements of late type dwarf galaxies	3D
w99bn007	Ehrenfreund	Environment dependence of diffuse interstellar bands in Perseus OB2	2B
w99bn008	Gerssen	Pattern speeds of bars	1D
w99bn009	Higdon	Metal abundance in extragalactic tails and bridges	2G
w99bn012	Groot	Spectroscopy of variable sources detected in INT WFC variab. survey	1D+1G

INT Semester 1999b

Proposal	PI	Title	Time (nights)
i99bn001	Tschager	The optical hosts of young radio sources - redshifts	2G
i99bn003	Le Poole	Assessing the quality of the GSC-II photographic photometry	1D+2G
i99bn004	Sackett	The MEGA survey: mapping microlensing in M31	3D

JKT Semester 1999b

Proposal	PI	Title	Time (nights)
j99bn001	Tschager	The optical hosts of young radio sources - optical identification	2D+2G
j99bn002	Le Poole	Photometric calibrators for the 2nd generation Guide Star Catalogue	1D+5G+2B
j99bn003	Barthel	Completion of a multi-color search for very high z QSO candidates	7D

8 ASTRON Institute

8.1 Financial Report of 1999

Expenditure	Budget	Actual	Difference
Grants/Expenditure	20,703,600	20,683,970	19,630
Other Expenditure	0	0	0

Income	Budget	Actual	Difference
Government Grants/Min. of Education, Culture & Science	17,926,600	17,926,600	0
Subsidies/Contributions by third parties	2,008,000	2,019,628	-11,628
Cash Management	140,000	151,919	-11,919
Other Income	629,000	515,376	113,624
Total Income	**20,703,600**	**20,613,523**	**90,077**
Balance	**0**	**-70,447**	**-70,447**

(all amounts in Dutch guilders)

8.2 ASTRON Organization

8.2.1 Board

Prof.dr. A. Achterberg	University of Utrecht
Prof.dr. T. van Albada	University Groningen
Prof.dr. E.P.J. van den Heuvel	University of Amsterdam, Chair
Dr. R. Hoekstra	Applied Physics Laboratory, TNO (until 25/11/1999)
Prof.dr. W. Hoogland	University of Amsterdam
Prof.dr. G.K. Miley	Leiden University
Prof.dr. J.A. van Paradijs	University of Amsterdam (deceased 2/11/1999)
Prof.dr. H.R. Butcher	ASTRON
	Executive Secretary

Management Team

Ir. A van Ardenne	Head of Technical Laboratory
Prof.dr. H.R. Butcher	General Director, chair
Dr. W.A. Baan	Head of Radio Observatory
Dr. E.J. de Geus	Head, Administrative Affairs (from 1/4/1999)
Prof.dr. R.T. Schilizzi	Director JIVE
B.A.P. Schipper	Head of Facilities Management

Employees Council

J.P. Hamaker, chair
M.J. Arts
A. Bennen
J.W. Beuving
R. Boesenkool
L. Nieuwenhuis
H. Verkouter

8.2.2 Personnel/Staff

(status at 31/12/1999)

8.2.2.1 Policy and Administration

H.R. Butcher	General Director
E.J. de Geus	Deputy Director/Head, Administrative Affairs
K.A.A. Oving	Secretary

M.P. van Haarlem

Spectrum Management

T.A.T. Spoelstra

Finance and Personnel

A. Bennen
C. Boon
P. Hellinga
A. Koster
F.H. Wekking

8.2.2.2 Technical Laboratory

A. van Ardenne	Head of Technical Laboratory
C.B.M.B. Bartelds-Jager	Secretary

Low Noise Amplifiers

L. Nieuwenhuis
J.G. bij de Vaate
E.E.M. Woestenburg

Digital Signal Processing

A. Bos
A. Doorduin
A.W. Gunst
A.B.J. Kokkeler
G.W. Schoonderbeek
R. de Wild
S.T. Zwier

Antennas

M.J. Arts
P.H. Riemers

Software/Image Processing

A.H.W.M. Coolen
G.N.J. van Diepen
J.P. Hamaker
G.M. Loose
J.E. Noordam
K. van der Schaaf
O.M. Smirnov
H.W. van Someren Gréve
C.M. de Vos

System Engineering

S.A. Alliot
J.D. Bregman
S. Damstra
G.W. Kant
Y.J. Koopman
G.H. Tan

Optical/Infrared Instrumentation

B.D. Bos
A W Glazenborg-Kluttig
J.C.M. de Haas
H.H. Hanenburg
A.P.M. de Jong
R.E.A. Ottow
J.A.P. Pul
A.A. Schoenmaker

Mechanical Design

R. van Dalen
W. van Emden
J.W. Kragt
G. Kroes

Development Support

N. Ebbendorf
I.J.H. Formanoy
A.M. Koster
E. Mulder
H. Snijder

Planning Support

J.W. Beuving
R. Kiers

DZB-IVC Production

A. Eybergen
J.A.E. Rosenberg

SKA Research and Development

O.S.O. Apeldoorn
W. Cazemier
M. Drost
K.F. Dijkstra
G.A. Hampson
J. Morawietz
A.B. Smolders
R.H. Witvers

Industrial Liaison

R.G.B. Halfwerk

8.2.2.3 Radio Observatory

W.A. Baan — Head of Radio Observatory
N. Csonka-de Wolf — Secretary

Science Support

R.G.L. Braakman
R. Braun
A.G. de Bruyn
A.R. Foley
B.M. Harms
D.J.J. Moorrees
R. Morganti
G. Kuper
T.A. Oosterloo
R. Ramachandran
J.J. Sluman
R.G. Strom
Y. Tang
R.C. Vermeulen

Postdoctoral Fellow

S.H. Britzen

Operations Group

M.J. Bentum
A.J. Boonstra
K. Brouwer
P. Donker
P. Fridman
T. Grit
P.G. Gruppen
L.H.R. de Haan
R.P. Millenaar
J.P.R. de Reijer
A.P. Schoenmakers
H.J. Stiepel
J. Stolt
J. Weggemans

8.2.2.4 Facilities Management

B.A.P. Schipper — Head of Facilities Management
J.E. van den Berg-van der Veen — Secretary

Mechanical Workshop

J. Bakker
M. Bakker
J.S. Dekker
G. Hagenauw
J. Idserda
T.J. de Jong
G.J.M. Koenderink

J.H. Nijboer
M.R. Schuil

Computer Systems

R. Boesenkool
J. Slagter
K.J.C. Stuurwold
H.J. Vosmeijer

General Facilities

H. Bokhorst
H.J. Borkhuis
D.J. Haanstra
P.C. Jager
D.P. Kuipers
R.H. Stevens-Kremers
N.H. Vermeulen-Bouman
M.W. Vos
B.J. Vriezenga
R.J. Wagner
A. Wieringh

Cafeteria/Cleaning

H. Braam-Piel
H. Eising-Zoer
I. Grit
I. Hoek-de Weerd
G. Hofman-Sterk
L.J. Lenten-Streutker
E. Oosterloo-Scheffer

Miscellaneous

P. van den Akker
K. Weerstra

9 PUBLICATIONS

9.1 Astronomy Publications in 1999

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Braun, R. and Burton, W.B., "The kinematic and spatial deployment of compact, isolated high-velocity clouds", Astronomy and Astrophysics, v.341, p.437-450.

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Chengalur, J.N., **de Bruyn, A.G.** and Narasimha, D., "HI and OH absorption at z=0.89", Astronomy and Astrophysics, v.343, p.L79-L82.

Deshpande, A. A., **Ramachandran, R.**, Radhakrishnan, V., "The observational evidence pertinent to possible kick mechanisms in neutron stars", 1999, A&A, 351, 195

Fassnacht, C.D., Blandford, R.D., Cohen, J.G., Matthews, K., Pearson, T.J., Readhead, A.C.S., Womble, D.S., Myers, S.T., Browne, I.W.A., Jackson, N.J., Marlow, D.R., Wilkinson, P.N., Koopmans, L.V.E., **de Bruyn, A.G.**, Schilizzi, R.T., Bremer, M. and Miley, G., "B2045+265: A New Four-Image Gravitational Lens from CLASS", The Astronomical Journal, Volume 117, Issue 2, pp. 658-670.

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Galama, T.J., Wijers, R.A.M.J., Vreeswijk, P.M., Groot, P.J., van Paradijs, J., Kouveliotou, C., Robinson, C., Bremer, M., **Strom, R.G**, Tanvir, N., "Physical parameters of GRB 970508 from its afterglow synchrotron emission", Astronomy and Astrophysics Suppl. 138, 451.

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Healy, K.R., Hester, J. J., **Braun, R.** and Raymond, J.C., "VLA Observations of the Cygnus Loop 'Spur'", American Astronomical Society Meeting 194, #85.03

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Koopmans, L.V.E., **de Bruyn, A.G.**, Marlow, D.R., Jackson, N., Blandford, R.D., Browne, I.W. A., Fassnacht, C.D., Myers, S.T., Pearson, T.J., Readhead, A.C.S., Wilkinson, P.N. and Womble, D., "A new radio double lens from CLASS: B1127+385", Monthly Notices of the Royal Astronomical Society, Volume 303, Issue 4, pp. 727-735.

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10 ASTRON/JIVE Colloquia

15/01 Jiri Stulemeijer (Technische Universiteit Delft) - Optical Integrated Circuits for Microwave
29/01 Enzo Branchini (RU Groningen) - Modeling the Cosmic Peculiar Velocity Field
12/02 Dap Hartmann (University of Bonn) - An all-sky Galactic CO
19/02 Leon Koopmans (RU Groningen) - The CLASS gravitational lens survey: current results and ongoing project.
12/03 Denise Gabuzda (JIVE) - The Small-Scale Magnetic Field Structure of 1803 + 784 from 5 and 1.6-GHz VSOP Polarization Observations.
19/03 ASTRON + JIVE – Open Podium
25/03 Christophe Craeye (Leuven Univ.) - Radar signature of the sea surface perturbed by rain
26/03 Tim de Zeeuw (Sterrewacht Leiden) - A HIPPARCOS census of nearby OB associations, with a preview of GAIA
06/04 Rick Perley (NRAO) - Recent developments at the VLA: new 20 cm feed designs, the 74 MHz system and more.
23/04 Felix J. Lockman (NRAO) - The Green Bank Telescope: History, Progress and Scientific Program
14/05 Moshe Elitzur (Univ. Kentucky) - Dust Emission form Young Stars - Evidence for Disks and Envelopes.
21/05 Dion Kant (ASTRON) - Television Tuners, "an example of an industrial cost driven development"
28/05 Nikolaus Neininger (University of Bonn) - Andromeda's molecular arms at scales Of 10 kpc to 10 pc
04/06 Geoff Bower (NRAO) - Circling the Ellipse: High Frequency Very Long Baseline Interferometry and Circular polarimetry of Sgr A*
11/06 Dave Jauncy (ATNF) Beyond VLBI: The Microarcsecond Structure of Intra-Day Radio Sources
18/06 Bob Campbell (ASTRON) - Those pesky first few pico-parsecs
25/06 Grant Hampson (ASTRON) - Multiple Beams for THEA
10/09 A. Deshpande (Raman Research Institute) - Pulse-sequence cartography and pulsar polar-cap weather.
17/09 Y. Gupta (NCRA) - Size and Location of Pulsar Emission Regions from Scintillation Studies.
01/10 A. Bakkers (Univ. Twente) - A distributed real-time Java system based on CSP
01/10 Jan Peeters-Weem (Univ. Colorado) - Noise Coupling of Broad-Band
05/10 Young Chol Minh (Korea Astronomy Observatory) - "Korea Astronomical Observatory: review of radio astronomical and VLBI scientific activities"
08/10 Rob Swaters (RU Groningen) - Dark Matter in Late-type Dwarf Galaxies
12/10 S. Ellingson (Ohio State Univ.) - RFI Suppression: A multidomain Perspective
15/10 Arno Schoenmakers (Univ. Utrecht) - A Population Study of Giant Radio Galaxies
22/10 Dipanjan Mitra (Raman Research Institute, Bangalore, India) - Signatures of Non-dipolar Magnetic Fields in Radio Emission from Pulsars.
29/10 Helene R. Dickel (University of Illinois/ASTRON/Univ. van Amsterdam) - Molecules in Interstellar Space
10/11 Ramesh Bhat (GMRT / MPI, Bonn) - Constraints on the Interstellar Plasma Turbulence Spectrum from Pulsar Observation
12/11 T. Cornwell and A. Kemball (NRAO) – An introduction to AIPS++
19/11 John R. Dickel (University of Illinois and ASTRON) - Supernova remnants and their neutron stars
26/11 Willem Cazemier (ASTRON) - Low Dimensional Description of the Main Lobe of Phased Array Patterns
10/12 Tim Cawthorne (University of Central Lancashire) - Jets in active galaxies: models for trajectories and relativistic effects on polarization.
17/12 Titus Galama (Caltech) - Gamma-Ray Burst Afterglows

11 Abbreviations

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

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