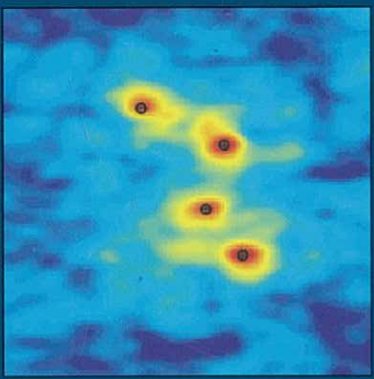

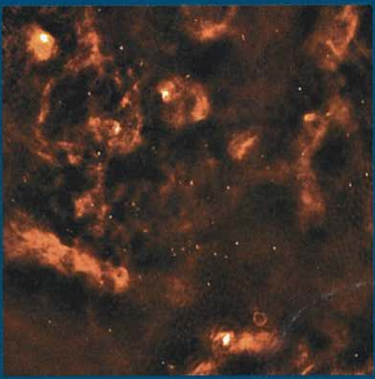

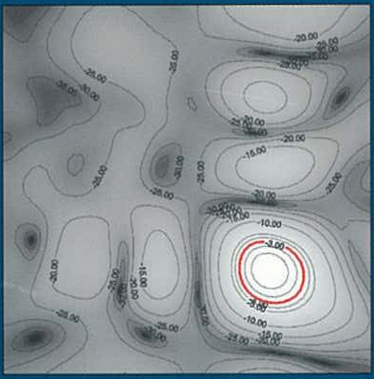

ASTRON

Annual Report 2000

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Contents

1. Report of the Director

The millennium year proved both turbulent and exciting at ASTRON. The turbulence derived from our having to adjust to a 30% decrease in our structural financing before 2002 while trying to ensure that at least the main lines of our program remain intact. The excitement came on several fronts and included an array of new scientific results from Westerbork and also our developing program of activities with commercial partners.

The budget decreases announced last year by our parent organization, NWO, take effect as we move into the final phases of several major technical projects – the broadband imaging system in Westerbork, to allow for surveys in redshift; the two thermal infrared instruments we are delivering in 2001 to the ESO Very Large Telescope (VISIR for imaging and spectroscopy and MIDI for interferometric fringe detection); and the Thousand Element Array demonstrator in our R&D program leading to the Square Kilometre Array (SKA) radio telescope. The resulting difficulties for these projects were brought into focus and at year's end we had begun consultations as to how they might be resolved.

We also made plans for a number of new projects. We contracted with ESO to study the feasibility of a next generation correlator for the Atacama Large Mm Array. We participated in discussions in our university community on the requirements for future optical-IR instruments, with a preference developing for interferometric applications.

We worked out plans for building and financing LOFAR, the new fully electronic telescope based on the array antenna concept being developed for SKA. This project will be carried out together with international partners at M.I.T. and at the U.S. Naval Research Lab. In the Netherlands it is being planned together with the Fokker Space company and is foreseen to involve local industry and research institutions from an early stage. In particular, LOFAR will provide a pre-competitive testbed for advanced ICT technologies including next generation digital network hardware and software, and then will give participating companies an opportunity to gain hands-on experience with implementing such technologies before they are fully ready for the market. We propose to pay special attention to the role the project might play in building up the infrastructure in ICT technologies in the Dutch provinces of Drenthe, Groningen and Friesland. At year's end we were awaiting word on the financing of the design phase of the project.

Research into innovative technologies for the design of a new generation of radio telescopes – in particular the array antenna concept for SKA – has become increasingly visible in Dwingeloo in recent years. The report year saw a formal evaluation of our SKA R&D program by a panel of international experts. Our efforts were put in perspective with respect to military and telecom developments and found to be both innovative and in important aspects unique. Our research council, NWO, was encouraged to continue financing the program and we were urged to work toward industrial partnerships to increase the scale of activities.

Our SKA R&D itself moved from design to production of the Thousand Element Array (THEA). This demonstrator is planned to incorporate multiple beams on the sky and adaptive beam forming, and to be installed out of doors so it can observe real astronomical sources in the presence of real world interference. During the year experimental data collected at the Westerbork telescope – 3C 48 absorption line in the presence of GSM mobile telephony signals – was used to verify the interference suppression algorithms being planned, which are based on space-time detection and blanking without a separate reference channel.

Internationally, the year saw important progress in organizing the global SKA effort. Thanks to funding from the European Union to help plan the future of radio astronomy, the European SKA Consortium was formed. At the General Assembly of the International Astronomical Union in August, amid much publicity, representatives from around the world formally signed an MoU setting up the International SKA Steering Committee, whose charge is to coordinate and promote activities in a global context. And the Global Science Forum of the OECD agreed a Task Force that will look into how future radio telescopes, including SKA, can make the very high sensitivity observations required of the early Universe while the use of the radio spectrum for commercial purposes is burgeoning.

And finally, as foreseen last year, we began a program of commercially oriented activities. We organized evening sessions for local businesses to present our technical capabilities and to discuss how we might play an effective role as centre of technical expertise in the north of the country. About a dozen local companies subsequently asked for technical advice and to perform feasibility studies and construct prototypes for planned new products. By year's end we had begun to discuss possible joint development projects. Particularly exciting is our conclusion that the technological developments required for radio astronomy so closely parallel those planned in the information and telecommunications industries that close collaboration should become a central element of our technical development strategy.

Of course, astronomical research has also remained an important focus of activity. The improved sensitivity now available with the Westerbork radio telescope makes it the most sensitive array in the world for the study of the 21-cm line of atomic hydrogen and very competitive for continuum studies. Several results published during the report year give a flavour of current research.

For example, standard theory considers that galaxies like our own are assembled gradually from smaller masses, which like most galaxies are probably dominated by dark matter. Because the galaxy formation process is unlikely to be very efficient, one expects many small masses to be left over from the main epoch of galaxy formation. Gas is expected to accumulate in these potential wells and become dense enough to withstand the ionizing influence of the ambient ultraviolet radiation field. Now sixty-five compact clouds of atomic hydrogen spread through our own Local Group of galaxies have been identified in the Leiden-Dwingeloo survey of atomic hydrogen in the Galaxy and are found to define a dynamically cold system infalling slowly toward the Group barycentre. Their properties are under study at Westerbork and seem to be similar in many respects to those of the Local Group dwarf irregular galaxies, except for the absence of a high surface brightness stellar population. Many show evidence of rotation that can be well fit by cold dark matter mass models. They are the best candidates yet for the remnant building blocks of galaxies.

Increasing evidence points to the assembly process continuing at a low level to this day. NGC 807, for example, is an apparently normal E3 elliptical galaxy that during the year was found to exhibit an extended low-density disk of neutral hydrogen that can only have resulted from the merger of one or more gas rich systems. Searches for other similar systems are in progress.

Studies of the emission from neutral gas in the early Universe must await the detection sensitivity planned with SKA, but current telescopes can perform absorption line measurements, where gas is in the line of sight to a background continuum source. An important if somewhat frustrating result from Westerbork was published during the year, namely that many existing measurements of absorption by atomic hydrogen in galaxies, in particular those using the Lyα line in the optical and ultraviolet, must involve unresolved blending of absorption from both the cold (~100 K) and the warm (~6000 K) components of the interstellar medium of the intervening galaxies. Unravelling the mixture is impossible in most cases and explains as erroneous the previously reported high spin temperatures of the gas in high redshift galaxies when the measurements relied on comparing Lyα optical-UV and 21-cm radio data. The consequences for our understanding of the evolution of the interstellar medium in galaxies are being reviewed.

If gravitational wells in space collect gas they also deflect radiation passing through them. The phenomenon is called gravitational lensing and has become an important tool for putting limits on concentrations of unseen matter. Of particular interest are cases where both the motions of atomic gas and gravitational lensing are observed in the same object. B1600+434 is an edge-on spiral galaxy where both kinds of data are available, atomic hydrogen in the disk of the galaxy and the image of a background quasar highly distorted after passing through the dark matter halo of the galaxy. During the year an extensive analysis of this system demonstrated that derivation of the distribution of dark matter in the galaxy is possible but will require a more accurate value of the Hubble constant. The available observations also reveal variability in the distorted quasar image on a timescale of days to weeks, which is interpreted as gravitational lensing by mass granularity (small substructure) in the galaxy's halo. Alternative causes of variability such as interstellar scintillation have been ruled out by Westerbork observations. A longer time series of observations promises to provide important constraints on the nature and distribution of the dark matter halo in this system.

The quasar J1819+3845 has also been found in new observations to vary on short timescales. In fact, during monitoring in Westerbork it has been observed to vary in intensity at 6cm wavelength by a factor of six in as short a period as an hour, making it the most extremely variable extragalactic source known. And just as stars twinkle and planets don't, this behaviour is interpreted as scintillation caused by turbulence in the intervening medium, in this case in the ionized gas between the stars in our own Milky Way galaxy, together with a source of extremely small angular diameter. By combining observations at different frequencies over more than a year it has been concluded that this kind of radio scintillation yields information about source structure at the micro-arcsecond level. This is about a thousand times the highest angular resolution that has been achieved by any other observational technique at any wavelength. During the year the first crude images of J1819+3845 at this exceedingly high resolution were produced, showing it to have an elongated core oriented approximately in an East-West direction. As the sensitivity of radio telescopes increases, interstellar scintillation should become a standard tool for probing ever closer to the black hole engines that power many radio sources.

The physics of J1819+3845 itself remains a puzzle of the first order, however. How can the source be so small, so hot and also on average so constant in flux? Clues from studies of the evolution of extragalactic radio sources may eventually help explain such objects. During the year an investigation of the largest radio sources known, which were found in a survey of the northern sky with the Westerbork telescope, revealed evidence for episodic outbursts in some sources, with a characteristic times between outbursts of several million years.

It has become customary in this report also to look to the coming year and note the main programmatic activities that are being planned. This is not possible this year because the program cannot be continued with the current funding prognosis. At some point during the coming year it may be necessary to make serious choices, but at year's end it was not possible to predict what those choices will be.

2. Technical Research and Development

2.1 SKA Research and Development

2.1.1 THEA

The Thousand Element Array (THEA) is the third in a series of demonstrator phased-array systems currently being developed at ASTRON. The two previous systems, the Adaptive Array Demonstrator (AAD) and the One Square Meter Array (OSMA) were described in the 1997 to 1999 Annual Reports. Detailed plans for THEA were also described in the Annual Reports over the last two years.

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 with conventional radio telescope designs: multi-beam operation, adaptive nulling, interference monitoring and reconfigurability of the sub-array units. THEA will also serve as a test-bed for new and advanced technologies which should lead to a higher level of integration and cost reduction. Examples are the use of a high-speed optical link and a new multi-beam analogue beamformer with a high level of integration including the antenna elements.

All major parts of THEA were involved in the realization of the first prototype in 2000. These major parts are not just the antenna and RF–IF electronics but also the THEA digital back-end processing. After stand-alone qualification and testing only minor modifications have been required to make these building blocks function according to specification. With these building blocks a limited integration has been performed so far, a full THEA proto-type will be operational in the first quarter of 2001, where the complete THEA with 16 tiles is scheduled for mid 2001. The remaining sections describe in short the characteristics and crucial performance features of each part of THEA - as well as results of a first proto-tile, a 64-antenna element Radio Frequency-only phased array antenna.

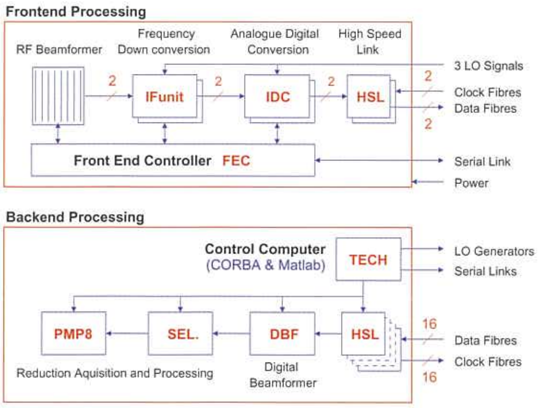


Figure 2.1 A block diagram outlining the various elements that make up the Thousand Element Array (THEA).

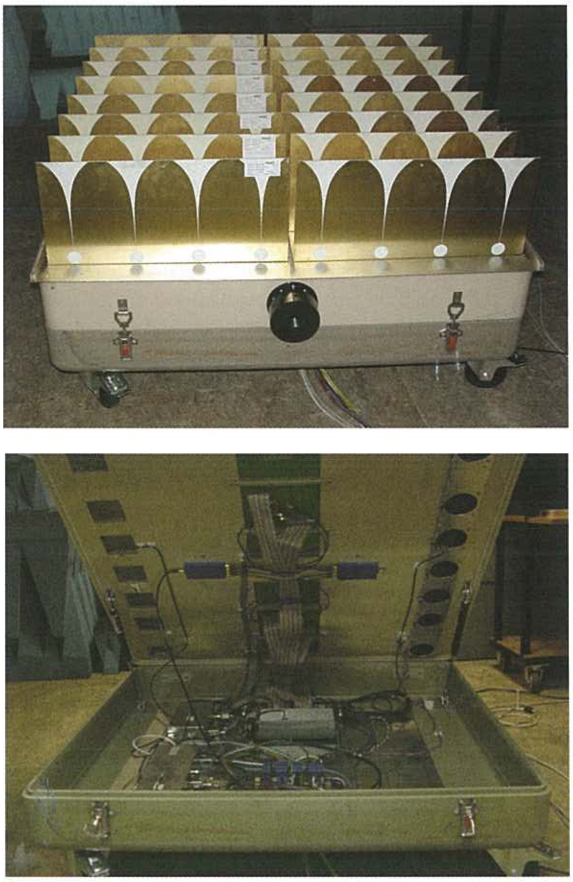


Figure 2.2 The first THEA tile being assembled in the Lab. The top image shows the 64 single polarized elements, the lower image the tile's electronics in a shielded area below the elements.

A block diagram of the THEA system is shown in Figure 2.1. One can distinguish two levels, the Front-end processing, which includes the RF-beamforming, frequency down conversion and analogue to digital conversion, at the tile level. The other level consists of the back-end processing, including the digital beamforming and data processing. The interface between the front-end, located outside the ASTRON building, and the back-end which is located inside is a fibre connection. A total of 16 tiles can be connected to the THEA back-end.

Figure 2.3 is a photograph of one of the column boards. This board contains four antenna elements and the corresponding Low Noise Amplification, phase- and amplitude control and signal combiners. The THEA antenna element has been build according to a design from the University of Massachusetts. This design meets an exceptionally high frequency bandwidth of nearly two octaves: 500 to 1800 MHz.

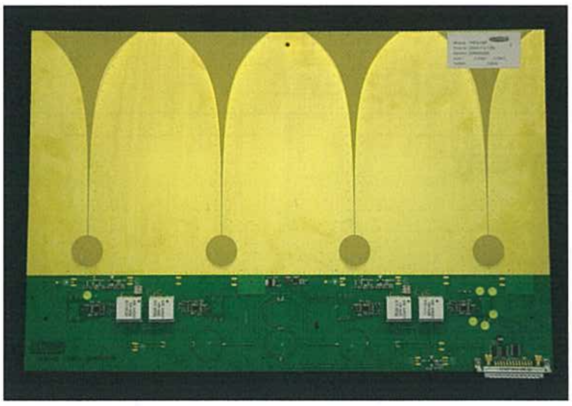


Figure 2.3 A single four element column board, showing the antenna elements, LNA and phase and amplitude signal combiners.

RF Beamforming

The requirement for a beamforming system is that phase shifts or time delays are available in order to electronically steer the beam, to a desired look direction. In THEA a compact phase control solution has been selected using a vector modulator. In principle two orthogonal vectors are controlled in amplitude and summed. A graph of the measured complex gain of the vector modulator (VM) with two 8-bit control words is given in Figure 2.4. An example phase-only calibration is shown where the gain is kept constant and the phase varied over one-degree increments. By comparing the desired and actual VM settings it is possible to determine the accuracy. In this example the accuracy is ±1 degrees in azimuth and ±0.1dB in amplitude. Given that it is too time consuming to calibrate each VM separately in the system for all digital control inputs (the required number of measurements would be 256x256 x number of frequencies per element) it is desirable to use a single calibration table which describes all VM's. Figure 2.5 gives the remaining phase and gain error of 8 receiver elements, when a single table is used with a complex offset for each element. The result is well within the THEA specifications.

The calibration of THEA can therefore be simplified to the determination of the complex offset of each element. Once again, the 'phase toggling' technique – which was successfully used with OSMA yielding good results – has been applied. Phase toggling, as the name suggests, is the process of changing the phase of each VM in such a way that a phase and gain offset can be measured. The basis of the technique is to toggle the phases of each element with a different step frequency. The beamformer output is recorded for each of the N measurements and then this data is transformed using a Fourier Transform. The resulting peaks occur at the appropriate step frequencies in the transformed data. The gain and phase at these points represent the average phase and gain offsets of each antenna element processing chain. This includes source delay, all circuitry and output cable delay. To calibrate the 64 elements of a tile using N=256 takes approximately five minutes for each frequency.

Proto Tile Results

A first integration of THEA realized in 2000 was the assembly and test of the RF beamformer in the prototile. This includes the cast housing, 16 column beamformer boards, two row combiner boards and the Front End Controller (FEC). For the characterization of this subsystem the recently installed Near Field Scanner was used. Near field measurements can be transformed in two directions; to the aperture (Holography) and to the far field. Figure 2.6a gives the beam pattern of a tile resulting from the transformation to the far field for broadside. The desired beam shape is obtained with nulls down to –40dB (the expected depth for a 64-element array with given phase and amplitude setting accuracy). A beam steered off broadside is given in Figure 2.6b and the correct direction is seen. These measurements demonstrate that a correct calibration of the RF front-end has been achieved and that a principle phase array operation of the THEA front-end design is feasible.

THEA Receiver Unit

The function of the receiver module is to provide gain and translate the desired input signal to an intermediate frequency band that can be processed by the subsequent IF-to-Digital Converter unit. It also has to suppress signals, which are not in the band of interest and might cause harmful interference. The THEA receiver consists of two double heterodyne receiving modules (one for each beam). Good noise performance and a high dynamic range are essential system requirements.

The first section of the unit forms a flexible remote-controlled filter- and amplifier bank for experimental purposes. The input frequency comprises the band from 600 to 1700 MHz, which is upconverted to 2.68 GHz and amplified in the first intermediate stage with an instantaneous bandwidth of 200 MHz. In the second stage this 200 MHz band is converted down to 210±10 MHz and again amplified. To handle a wide dynamic range, a variable attenuator was applied, that can be remotely controlled via the Front-End-Controller. The

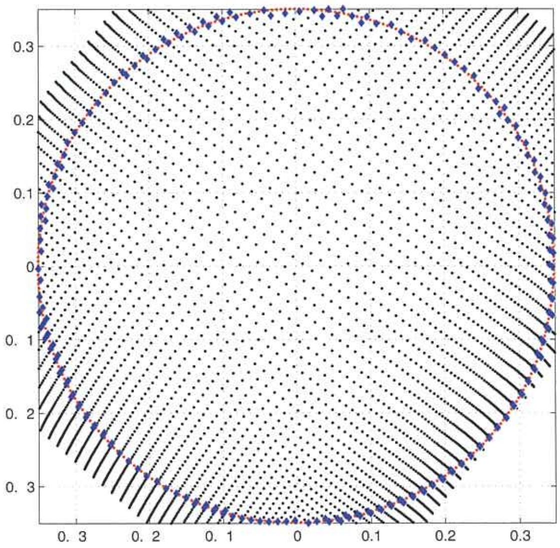


Figure 2.4 Plots illustrating the measured complex gain of a VM (black dots) and a desired complex gain (red dots) in one degree increments. This example illustrates the largest possible Complete gain contour (radius=2.65 x 10^{-3}).The closest match to the desired complex gain is also shown (large blue diamonds). Note the density of dots (calibration points) changes at ends of the plot. Calibration errors are thus smaller for some points.

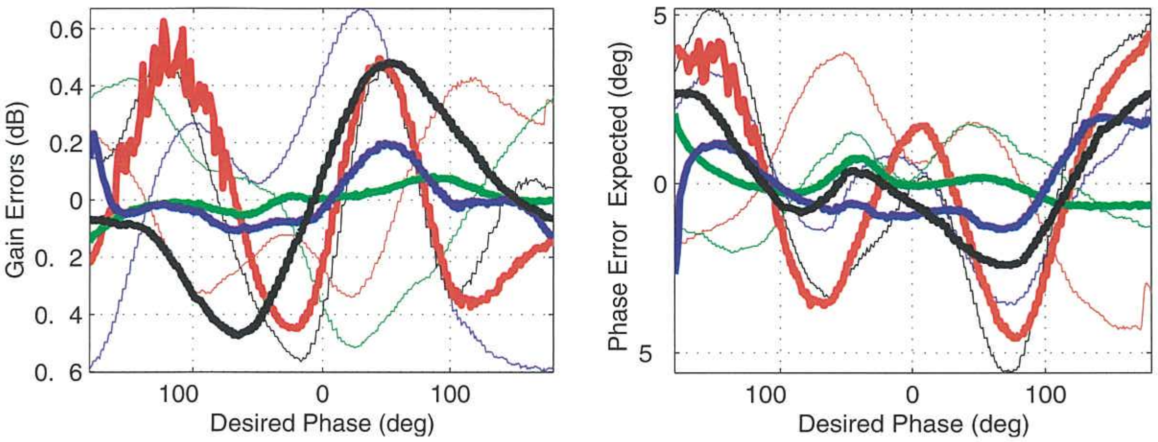


Figure 2.5 Two plots illustrating the result of subtracting the predicted Phase and gain errors from the measured data. The remainder is a set of smoothly varying functions of frequency and amplitude.

nominal gain of the entire unit is 31.5 dB. In view of future SKA developments, mass production considerations are becoming significant. The THEA receiver is also intended as a study object for the development of high volume units. High cost components and work-intensive production techniques like milling housings are not feasible in both SKA and LOFAR.

In 2000 the receiver unit was developed and a first prototype was built (Figure 2.7). First tests have shown that even with low-cost components a good system performance could be achieved. Techniques used in the THEA receiver modules might also be considered as a starting point for the development of the LOFAR receivers.

Adaptive Digital Beam Former

Beam forming in SKA is the process of spatially suppressing RFI-effects, thus cleaning up the celestial source information (before 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 and subsequently a spatial 4x4 point FFT, in order to convert the snapshot (a set of 16 concurrent, position-related signal samples) into a beam set (a set of 16 concurrent, direction-related signal samples). This set of base band-beams represents 16 predefined directions that completely cover the RF-beam created by the RF-Beam Former. The weighting operation does both beam shaping and direction fine-tuning.

The spatial weight factors are updated by the AWE every 10 ms. A dedicated adaptive algorithm in the AWE calculates the optimum values of the weight factors, according to the actual RFI-situation.

Research topics

System-oriented studies for the DBF focus on spatial weighting of the beam set, which remains an option for future SKA-demonstrators. Architecture-oriented studies for the DBF have focused on the fundamental trade-off between spatial processing capacity and temporal/spectral processing capacity. This has resulted in a DBF-board with a good balance between signal throughput and signal processing rate.

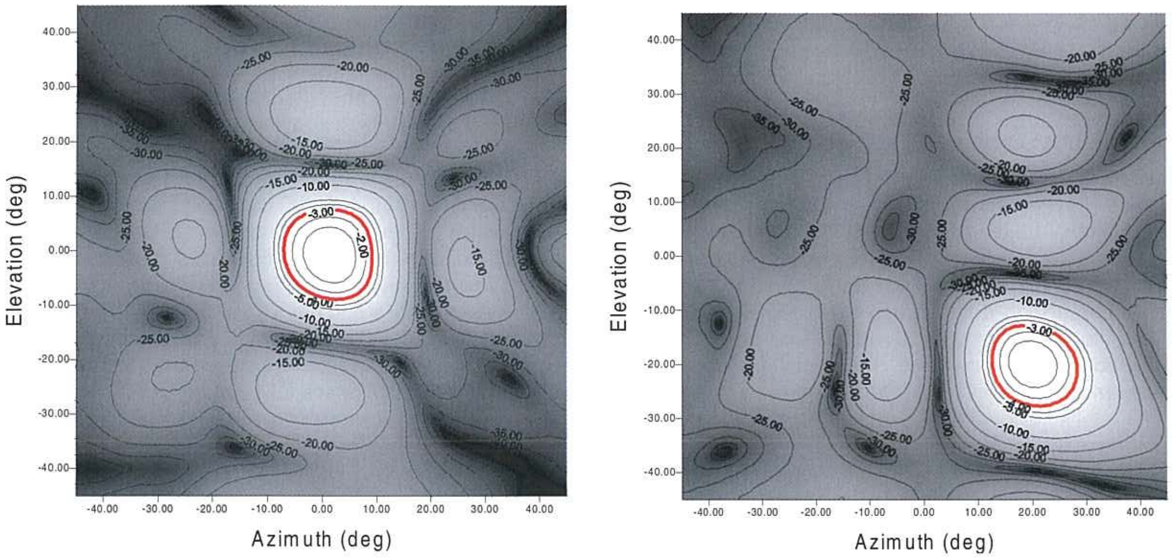


Figure 2.6 Measured far-field responses of the THEA tile steered to two different look directions. Panel a) is for a broadside beam, panel b) is for a beam steered off by 20 degrees in both elevation and azimuth.

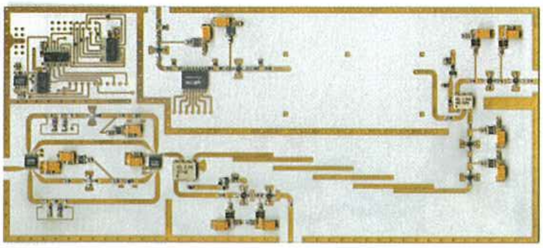


Figure 2.7 Prototype THEA Receiver module

The essentially non-linear behaviour of adaptive algorithms in the AWE 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 studies will focus on comparing different candidate algorithms and the accurate processing of wideband signals. Actual measurements will take place in the new ABES-room (ABES is the Adaptive Beam former Experimental System, based on OSMA and described below), in cooperation with Eindhoven University of Technology. Another challenge lies in the processing of signals descending from a sensor-array with non-linear spacing.

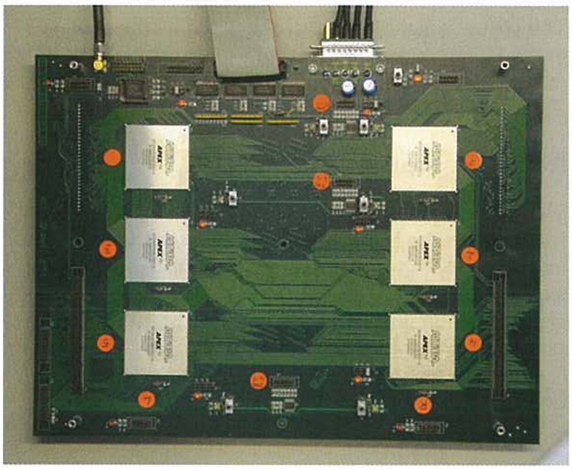


Figure 2.8 The DBF board – a complex multi-layer board with 6 high speed FPGAs – is completely reprogrammable and reconfigurable.

Development Topics

Realisation of the DBF has resulted in a 12-layer high-speed-digital custom-made PCB. On this board, 6 FPGAs (from Altera's APEX20K-family) are interconnected to enable optimal mapping of the DBF-functionality. But other hardware-functionalities, too, can be configured on it. Top-down design of the DBF-functionality itself (i.e. weighting operation plus 4 x 4 point FFT) has resulted in a parameterized VHDL-model, technology-independent and re-usable for future.

The DBF-board operates at the moderate clock rate of 40 MHz, it combines 384 bit parallel input with 384 bit parallel output. The data-throughput performance is 15.36 Gbit/s, the real-time data processing performance is 7.68 G operations/s. These numbers respectively exceed and equal the best available DSP (Texas Instruments' C64)!

For the AWE, an off-the-shelf PCB (Daytona-board with two DSPs from Texas Instruments' C67-family) is being prepared, before the Minimum Variance algorithm (C-code from OSMA, for functional reference test), can be programmed on it. Both DBF- and AWE-board will be fully tested, before being integrated with the other THEA-subsystems.

The IF- to Digital Converter

The IF- to Digital Converter (IDC) converts an IF frequency band of 200-220 MHz to a digital base band of 0-20 MHz. This is done in multiple steps. First the IF frequency band is down converted to base band via analogue mixing using a quadrature scheme. Both signals are filtered with anti-alias filters to reduce the alias components after A/D conversion. Then the analogue base band signals are digitised using 12 bit A/D converters with a sample rate of 40 MHz. From here the desired frequency band is finally filtered in the digital domain in order to reduce image frequencies and spurious signals. Two mixer principles are implemented: the Hartley and the Weaver scheme. The Front End Controller controls which scheme is used. The resulting digital output signals are transported via an optical interface card which is connected directly on top of the IDC board as shown in Figure 2.9.

Development of the IDC continued this year and resulted in two prototypes of which the layout and the assembly was been done by an external PCB company. After extensive tests at ASTRON, the final design was completed. For the IDC's housing a low cost custom-made metal box has been used.

Optical High Speed Digital Link

The Optical High Speed Digital Link is responsible for transport of data from the tiles to the central adaptive digital beam former. The total required data rate, for the case of sixteen tiles and two independent RF beams, is more than 30 Gbit/s. The data transport system consists of custom developed optical network interface cards based on low cost Gigabit Ethernet technology interconnected by means of fibre cables. Since only point-to-point connections are required for this application, a synchronous transport service is being implemented directly on top of the Data Link Layer (Layer 2 of the OSI Reference Model). This way the full bandwidth offered by the physical layer can be used.

Each IDC unit in a tile is equipped with a Tile Network Interface Card (TNIC). A TNIC has a 2x12 bit parallel interface which connects directly to the I & Q outputs on the IDC board as is shown in Figure 2.9. The input data is 8/10 coded, multiplexed and the resulting serial signal is used to drive a 850 nm VCSEL laser. This results in an optical signal at a fibre data rate of 1.2 Gbit/s. This way, 32 fibres are used to transport the total data stream and by means of Space Division Multiple Access the 32 fibre channels are transported over one fibre cable to the digital back end.

At the digital back end, two 16-Channel Network Interface Cards (16-CNIC's) are being designed, one for each RF beam. Each 16-CNIC has an optical input bandwidth of more than 19.2 Gbit/s and it provides the required optical to electrical conversion and de-

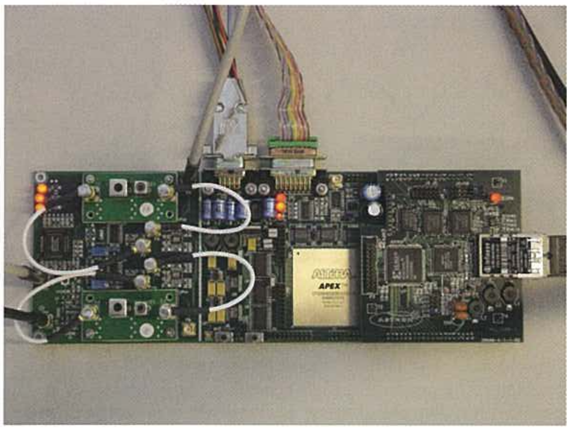


Figure 2.9 The IDC unit: the analogue IF input signal enters the board on the left hand side where the analogue part is laid out. The digital part is situated from the middle to the right hand side of the board. The optical network interface card can be distinguished at the right edge of the picture.

multiplexing, resulting in a parallel interface which can be connected directly to the Adaptive Digital Beam Former. Furthermore, it is possible to connect a 16-CNIC directly to a Selection Board of the RAP-unit (Figure 2.11). A one channel fibre network interface card prototype is depicted in Figure 2.10. Point-to-point links have been successfully tested using the developed hardware. Sustained data rates up to 1.6 Gbit/s over a 400 m graded index multimode fibre have been demonstrated.

RAP Unit

The RAP (Reduction, Acquisition, Processing) unit, as designed for THEA, is a compact solution for optimum flexibility and integration within a single industrial PC. It provides a unique input bandwidth at a board level and processes selected data at very large data rates. This new back-end is based on widespread PC technology, the new generation of Digital Signal Processor (DSPs) and a custom designed memory selection board. The purchased DSP board contains 9 DSP processors and is capable of 8 Gflops peak processing power. The memory board is capable of handling an input data rate of 16 Gbit/s and stores 2 GByte on RAM. A picture of the realised Selection Board is given in Figure 2.11.

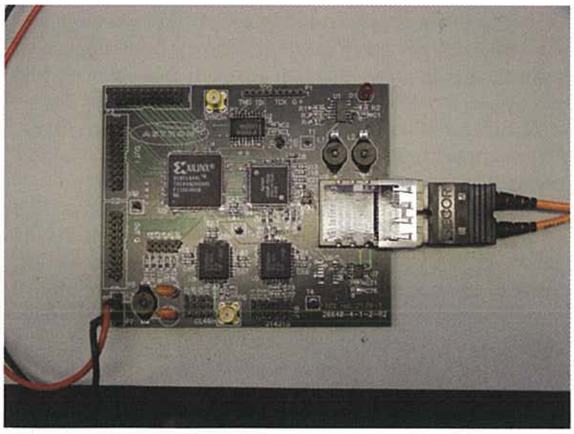


Figure 2.10 Optical High Speed Link interface module.

The RAP unit's application's are:
- Spectrum analysis
- Beam forming
- Interferometry
- Fast signal processing real time or off-line
- Very high bandwidth acquisition

For THEA, the RAP-unit can run a real time 1000 point Fast Fourier Transform. RFI sources will be detected and rejected with a spectrum resolution of 38kHz at a signal bandwidth of 20MHz. Preliminary tests with the RAP-unit have been performed successfully and basic control software has been implementated. The full capabilities will be programmed and tested with the complete THEA.

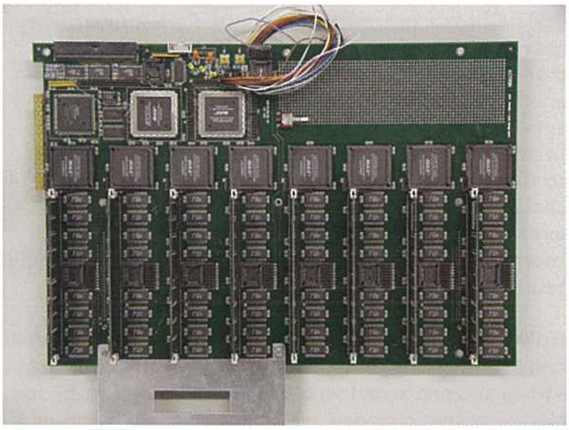


Figure 2.11 The Selection Board – part of the RAP Unit – which can accept an input data rate of 16 Gbit/s and has a storage capacity of 2 GB (on normal PC-RAM).

2.1.2 Adaptive Beamforming Experiments

Within the different SKA demonstrator projects (AAD, OSMA and THEA) beamforming has been researched thoroughly. This research was mainly implementation oriented because of the demonstrative nature of the projects. In order to accommodate an ongoing research activity focussing on beamforming; suitable infrastructure was required. ABES, the Adaptive Beamformer Experimental System, consists of the One Square Meter Array (OSMA, described fully in previous annual reports) in operation in a newly installed second anechoic chamber.

During the year, the coating of the anechoic room was completed. A start was made with the improvement of the support construction for the transmit horn and the OSMA-tile (consisting of 64 bow-tie elements), as well as the cable connection to the observation platform ECHO (the Experimental Chassis for OSMA). This observation platform is being rebuilt in the corridor adjacent to the new anechoic room. Its installation is expected to be completed in August 2001.

At this point ASTRON will have at its disposal a fully operational measurement system, dedicated to the 2-4 GHz band. It will support various research projects that deal with antenna technology and adaptive signal processing, applicable in the fields of astronomy or mobile communication.

2.1.3 Antennas for SKA

Antenna research at ASTRON is focussed on the design, feeding and modelling of actively scanned phased array antennas. This R&D activity is partly embedded in the development projects and LOFAR. The focus is on developing simulation tools and knowledge that are needed to make antenna systems for the various projects. Novel calibration schemes have been developed for phased array antennas. Important items are: (a) Interconnections and feeding of antennas; (b) 3D electromagnetic simulation tools; (c) Experimental verification of antenna performance; (d) Calibration and (e) Mechanical aspects.

In February 2000 the indoor measurement facility at ASTRON was upgraded with a near-field scanner. The near-field scanner can be used to measure far field patterns for the situation that the dimensions of the anechoic chamber normalised to the wavelength are small compared to the case of a far field antenna measurement set-up. The near-field facility is being used to test and calibrate THEA. In this way, tiles can be characterised without the need for a very large and expensive anechoic chamber. Also a second anechoic room was furnished. This room will be used for adaptive beam-forming research.

Collaboration with the University of Massachusetts continued this year. Research concentrates on broadband Vivaldi antenna arrays with dual polarisation. Accurate electromagnetic models are being developed in order to analyse and optimise such arrays. Initial parameter studies have resulted in an array design that is predicted to have an operating bandwidth of approximately 5:1 while scanning up to 45 degrees from broadside. The main goals of the current research activities are: a) Enhancement of the operational frequency bandwidth to a decade; b) Improvement of the scan range; c) Truncation effects in finite arrays; d) Integration of antenna elements with the RF electronics ("active antenna"); e) Effect of dual polarisation and f) Optimising the mechanical construction for costs. In THEA a single polarisation Vivaldi array, designed by the University of Massachusetts, is being used.

Non-regular array configurations (e.g. quasi random arrays) are being investigated in a joint project with the Eindhoven University of Technology. When antenna elements are placed in a phased array on a grid with an element spacing of at least half a wavelength at the lowest frequency, grating lobes will appear over the whole frequency band. By placing the antenna elements on a random or quasi-random grid, it is possible to suppress grating lobes. However, for some applications (such as radio astronomy), grating lobes are not always fatal. Nevertheless, it is preferred not to have grating lobes. One of the additional advantages of a sparse array is a strong reduction of mutual coupling and an elimination of blind scan regions. The antenna elements themselves can also be larger compared to antenna elements in conventional arrays. Key items of research are: (a) development of a generic simulation tool to optimise the element location in sparse (random) arrays; (b) Array configuration studies; (c) Adaptive nulling in sparse random arrays; (d) Mechanical design of sparse arrays and (e) Minimisation of costs.

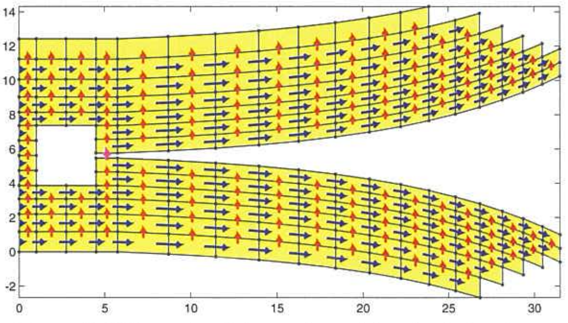


Figure 2.12 Example of the mesh used for simulating the Vivaldi broadband antenna. The mesh controls the number of unknown currents to be calculated, 340 in this case, and is a measure of the accuracy of the result but also of the computational time needed.

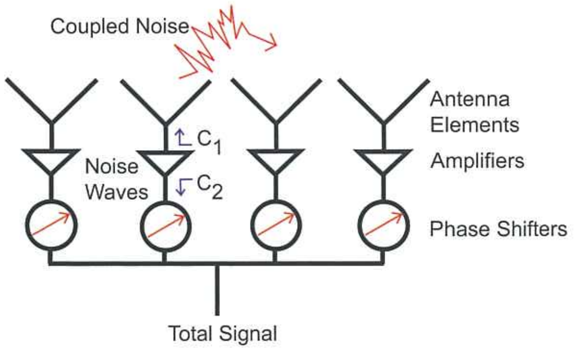


Figure 2.13 A schematic view of the analysed noise coupling problem. The noise coupling between antenna elements is, besides amplifier and antenna characteristics, a factor of the scan angle of the array. Equations have been developed which give new design criteria for minimization of noise in an array.

Together with the University of Colorado in Boulder nested array structures are being investigated. They can be used either for phased array applications as well as for frequency selective surfaces. Special tools are being developed for analysing such structures, based on computational electromagnetism. Key items here are: (a) Broadband antenna elements; (b) Dipole fractal arrays and (c) Noise coupling in arrays.

The antennas under test for THEA and those under development for SKA must have very broadband characteristics. These characteristics are usually optimised using an infinite-by-infinite array approach, which automatically takes all the coupling effects into account. However, for arrays of small or intermediate dimensions, the antennas along the edges may present strong deviations from the infinite array characteristics. Part of the research carried out in collaboration with Eindhoven University of Technology has focused on these truncation effects. The approach taken is based on finite-by-infinite array solutions, and it was first applied to arrays of broad dipoles, and then to arrays of Vivaldi antennas, with the finite array direction parallel to the plane of the antennas. Up to now, idealized antennas have been considered, i.e. they were made of metallic plates fed by a delta-gap source. To simulate the truncation effects, a fast code has been developed that is based on a triangular decomposition of the antenna surface and on a tabulation of the potential Green's function. Large time savings for the calculations were also achieved by decomposing the current distribution on each antenna into a limited set of standard distributions, corresponding to infinite-by-infinite and semi-infinite array distributions. For the latter case, a fast scheme has been developed for the computation of the related Green's function.

In parallel, a number of other studies have been carried out. They concern the coupling of noise generated by the amplifiers, reciprocity applied to phased arrays, and the mitigation of grating lobes in large sparse arrays. The latter study has been carried out via the final project of a undergraduate student and it showed that a gradual space tapering approach is much more efficient than perturbing the positions of the antennas of a regular array.

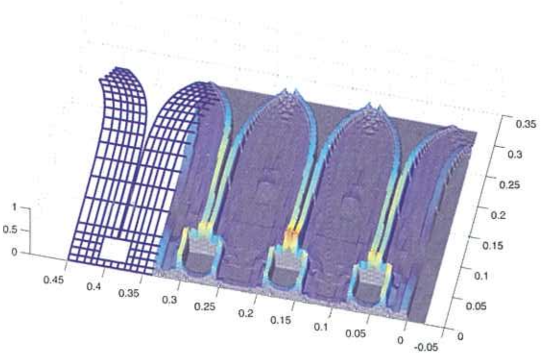


Figure 2.14 Simulated currents on a small array of three Vivaldi antennas. Left: the antenna surface, as it is discretised for the simulation. Right: the total amplitude of the currents on the three antennas. The currents are concentrated along the rectangular cavity (bottom) and along the tapered slots of the antennas. They can flow from one antenna to the next, so contributing to the very strong couplings between the elements of the array.

2.1.4 RF-IC's

RF-IC Developments for SKA

As a continuation of the work started in 1999, a Radio Frequency Integrated Circuit (RF-IC) has been design for implementation in a SKA front-end. In order to be able to meet the cost targets for SKA, a (potentially) mainstream technology has been chosen: Silicon Germanium (SiGe). SiGe is an up-coming low cost silicon process, which in the future might be able to compete with (expensive) high performance processes in Gallium Arsenide.

On the IC, a microphotograph is given in Figure 2.15, a number of different test circuits have been designed, three different Low-Noise-Amplifiers, a poly-phase filter (a phase shift network) and a vector modulator. The vector modulator can provide the phase-shifting required in the frond-end of a phased array antenna. A success of these components will be a step closer to a single chip low cost front-end.

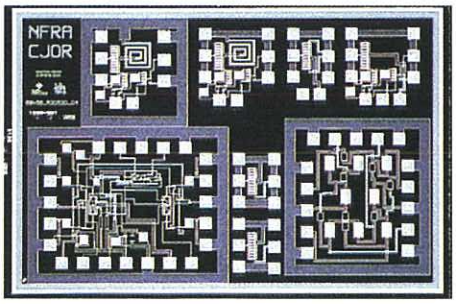


Figure 2.15 Microphotograph of a SiGe RF-IC chip.

SETI RF-IC Development Work

The SETI institute is building a telescope array, called after the major sponsor, the Allen Telescope Array. The array consists of 500 5 meter diameter dishes. For receiving and down converting the signals of these 500 dishes, ASTRON has been asked to develop the up-down converter's unit. In order to be able to build this at reasonable cost and with good performance, an integrated circuit mixer has been designed, processed and tested. Figure 2.16 gives the drawing of the mixer IC. The IC has been processed in high performance Gallium Arsenide (GaAs) material. The IC handles RF input signals in de range of 0.5 to 11GHz, with a local oscillator signal between 13 and 26 GHz. An (active) mixer IC which can handle these signal bandwidths is unique.

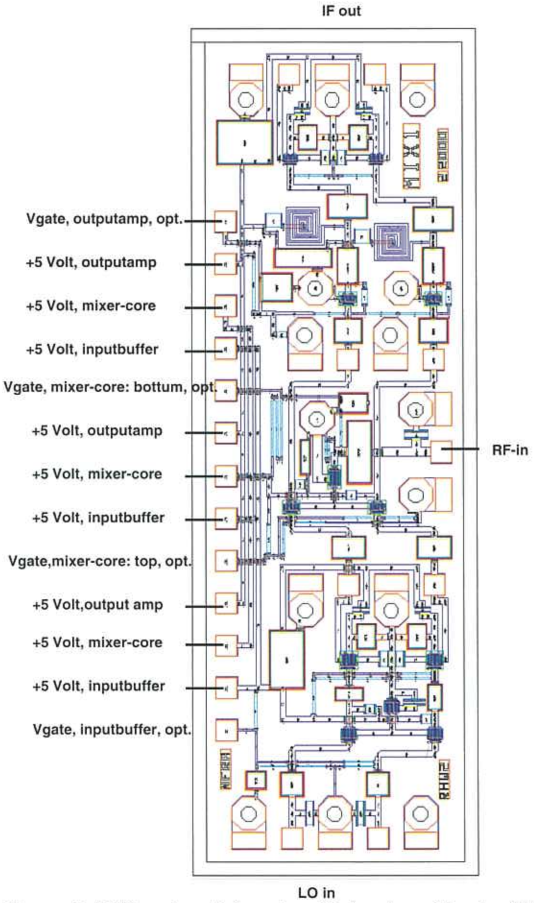


Figure 2.16 Drawing of the mixer IC developed for the SETI Institute's Allen Telescope Array

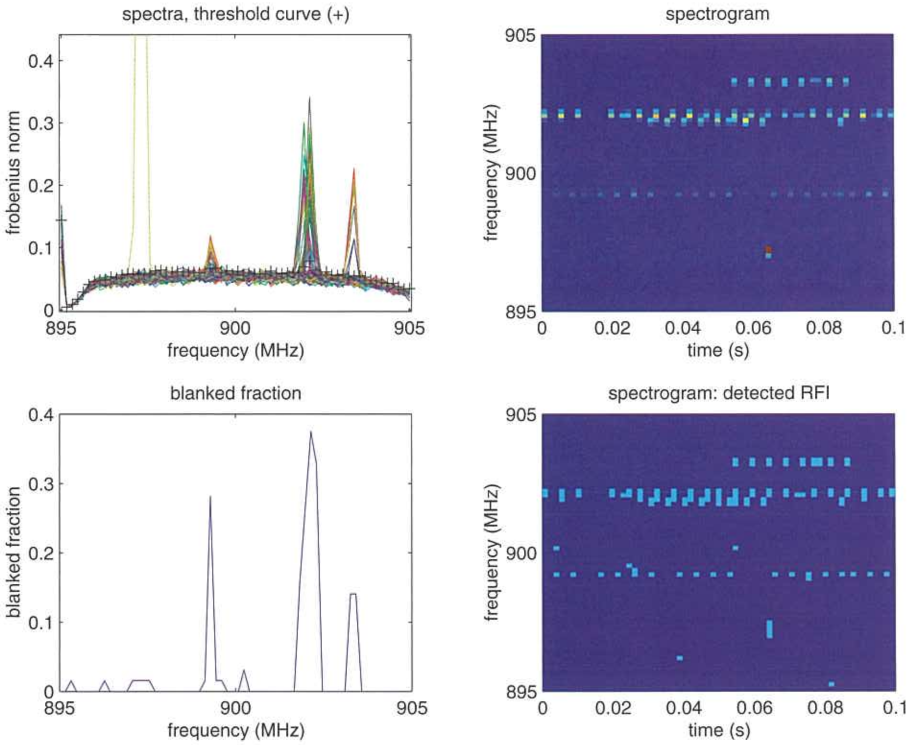


Figure 2.17 Detection of GSM mobile phone signals

2.1.5 NOEMI

The use of the electromagnetic spectrum is changing rapidly due to an increasing demand for bandwidth, especially from the communications industry. Although there is a trend to the use of higher frequencies, the UHF and L bands remain in great demand due to constraints on antenna size for personal mobile communications. Another change in the spectrum is the increasing use of digital broadband modulation. Radio astronomy is a passive service – it does not transmit signals, but only receives them from outer space. These signals are usually many orders of magnitude weaker than communications signals. This means that there is an increasing risk that spectrally adjacent spectrum users cause a deterioration in the astronomical signals by transmitting residual signals (RFI) in the bands allocated to radio astronomy. New RFI mitigation techniques are being studied and developed, in order to meet the RFI challenge with these new techniques. ASTRON has been active, for several years now, in all fields relevant to the RFI mitigation issue. One of the RFI mitigation projects ASTRON is involved in, is the Nulling Obstructing Electromagnetic Interferers (NOEMI) project.

Project Goal

The purpose of the NOEMI project is to investigate the effectiveness of digital array signal processing techniques for RFI mitigation. The main goals of the project are to study the RFI mitigation algorithms theoretically, to measure and characterise the interfering signals, and to demonstrate the effectiveness of the algorithms in a small scale demonstrator at the WSRT. Finally, the implications of the acquired knowledge for the RFI mitigation aspects of the Square Kilometre Array (SKA) radio telescope design will be reported. The project is a four-year joint effort of ASTRON and the Technical University Delft, supported by the Dutch technology foundation, STW.

Online RFI Mitigation System

In a previous project phase, interfering signals at the WSRT were recorded using a personal computer based data recorder. The signals of eight telescope channels were recorded with a maximum recording length of a minute. In order to investigate some subtle effects of the RFI mitigation algorithms on the astronomical signals, longer integration times were needed. This was the reason for installing an online digital processing system (DSP) in the NOEMI data recorder. The system can do sub-band processing (FFTs), short term correlation, sub-band-detection and temporal blanking, and further integration to second/minute level. Due to this data compression, online RFI mitigation was made possible instead of off-line processing on limited size CDROM data. The system was used for mitigation of time slotted RFI such as mobile telephone signals (GSM) and aeroplane radar (DME).

Figure 2.17 shows a test of the DSP system on previously recorded GSM data obtained at the WSRT. The upper left figure shows the pass band with the GSM 0.5 ms – 200 kHz communication bursts. The spectra obtained at different times are also plotted. The spectrogram of the same measurement is shown in the upper right panel. The strength of the signals are indicated by different colours, four GSM users can be distinguished. Using a threshold detector, the GSM bursts are detected, and shown as light green rectangles in the lower right figure. Finally, the fraction of detected (and blanked) signals is shown in the lower left panel.

The NOEMI data recorder and DSP system were also used for the detection and online removal of an aeroplane radar (see Figure 2.18). Both the non-blanked and blanked spectra were stored on disk. In this way, the effect of the algorithms on both the RFI and on the astronomical signals could be studied. For time slotted interfering signals the RFI can be removed up to (or better: down to) the detection limit, which is dependent on the integration time.

Gain Calibration

In the RFI mitigation models developed by the NOEMI team, the assumption is usually made that the noise power of all telescope channels is the same (spatially white noise). In the real world this does not hold exactly, the models for detecting intermittent RFI were

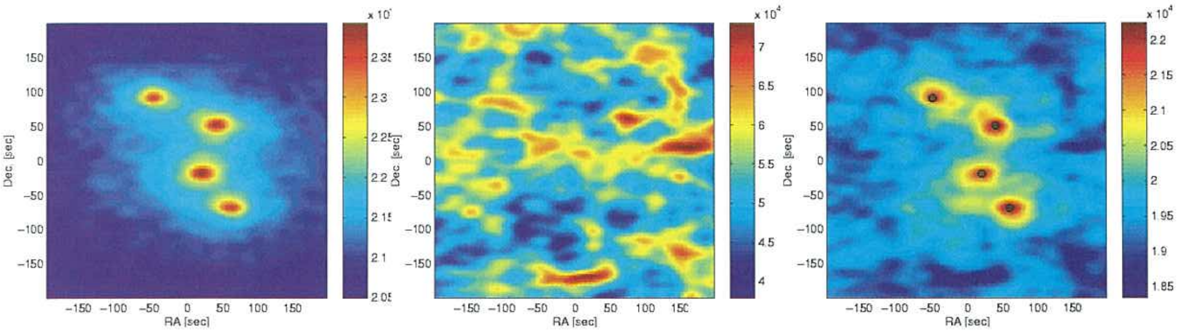


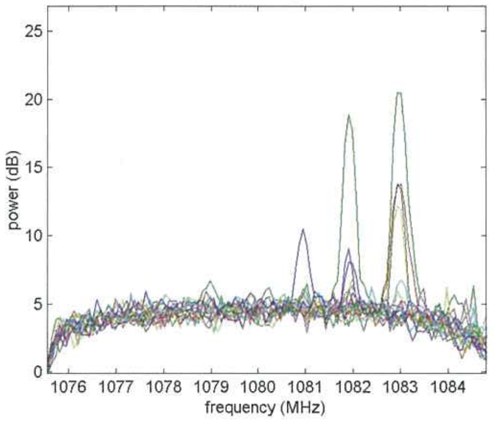
Figure 2.18 Effect of spatial filtering on an artificial sky with four sources affected by RFI

adapted, taking this into account. Also a study was done on new, efficient methods for the estimation of gain parameters using astronomical observations.

Spatial Filtering and Imaging

In order to analyse new imaging and spatial filtering algorithms, an implementation was made in the mathematical software package MATLAB. The complete sequence of imaging steps was implemented: starting with synthesis of an artificial sky and including all co-ordinate transformation, correlation steps and standard map point source calibration/subtraction (CLEAN). It was shown that with spatial filtering and RFI mitigation techniques that alter the (u,v) data, good maps can be produced using new imaging algorithms, for example adapted CLEAN. Figure 2.18 shows a synthesized sky map (left figure) with four sources. The middle figure shows what happens if interference with a signal to noise ratio of 5 is present: the sources are invisible. The figure to the right shows a reconstructed map after spatial filtering and applying adapted CLEAN. The new spatial filtering and map making software was applied to a WSRT measurement set which was converted to a MATLAB readable format, and a first raw image was made using the new software.

(a) nonblanked spectrum



(b) blanked spectrum

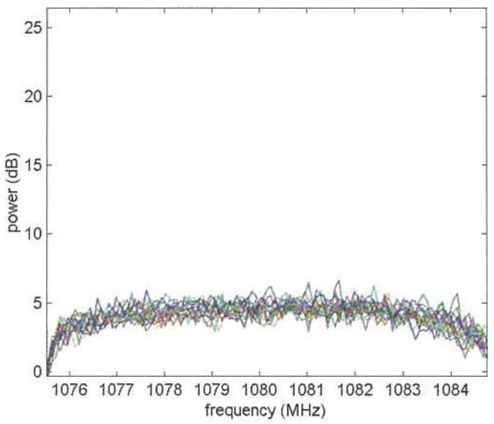


Figure 2.19 Non-blanked (top) and blanked (lower) aeroplane radar spectrum (DME)

Search for the Mars Polar Lander

At the WSRT, the NOEMI team helped look for NASA's lost Mars Polar Lander (MPL). The NOEMI data recorder was put into action as it can provide spectral resolution of a few Hz, which was needed for detecting the two MPL carrier signals at 401.39 MHz and 401.64 MHz. As NASA had no equipment sensitive enough to find the lost Mars probe, assistance was requested. On February 4th and 8th observations were performed to try to find the probe, alas without detecting it. Figure 2.20 shows an observed spectrum in which with a dashed line indicates where one of the MPL carrier signals was expected. At a slightly higher frequency two interfering signals (RFI) are visible, not originating from the MPL. The MPL was not found and the MPL was considered definitively lost, but the observations gave the NOEMI team the opportunity to test their detection algorithms and to extend their database with RFI signals.

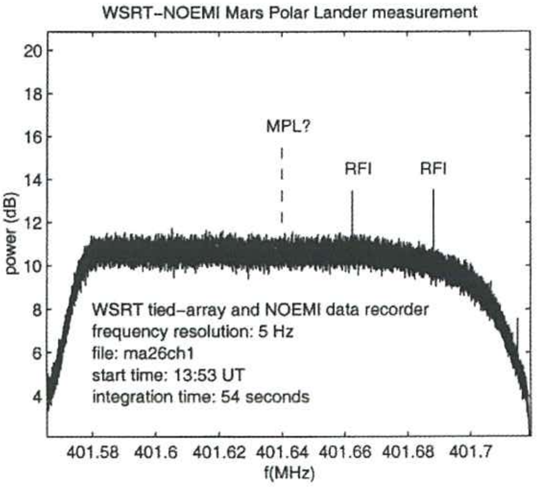


Figure 2.20 The observed spectrum of one of the MPL carrier signal frequencies. There was no detection at the expected frequency, although two RF Interferers were detected.

2.1.6 Signal Processing

The activities concerning signal processing research have concentrated around the following topics: A/D converters and quantisation effects, embedded systems (the Massive project), facilities for beamforming research (ABES) and RFI mitigation techniques (NOEMI).

For the analysis of high-speed Analogue-to-Digital converters an evaluation board was purchased. With this board, sampling at 1 Gsample per second with a resolution of 8 bits was achieved. Another very important feature of the evaluation board was that the analogue input bandwidth was 2.2 GHz which enabled harmonic sub sampling. During his training period, a student from the Technical College in Enschede built a test set-up and measured several relevant parameters. This was a very important step in acquiring knowledge concerning high speed A/D converters and harmonic sub sampling. The research concerning quantisation effects in interferometers and phased arrays using multibit A/D converters, resulted in the submission of 2 papers: "Modelling correlation of quantised noise and periodic signals" which was submitted to "IEEE Transactions on Signal Processing" and "Degradation due to Quantisation Noise in Radio Astronomy Phased Arrays" which was submitted to and accepted by "Experimental astronomy". In the first article an expression was found for the correlation function in case the input of the two receivers of an interferometer consists of noise and a periodic signal. In the latter document, the sensitivity of a digital multi-element receiver (1- or 2-bit) is compared with the sensitivity of a completely analogue multi-element receiver.

During the year a project called "Modelling, Mapping and Simulating Scalable Hierarchical Embedded Signal Processing Systems" was begun. It is part of a government sponsored program to stimulate research on Embedded Systems and Software in the Netherlands. The project is a cooperation between Leiden University, Frontier Design, TNO-FEL and ASTRON and the project name is abbreviated as "Massive". The aim of the project is to explore in a structured manner, implementation alternatives for large signal processing systems in general and the Square Kilometre Array in particular. Because of the many alternatives available both in software (on General Purpose Processors and on Digital Signal Processors) and in hardware (Application Specific Integrated Circuits, Reconfigurable Logic) many options are possible. By introducing a hierarchical structure the complexity can be reduced because optimum solutions found can be reused at different levels of the hierarchy.

2.1.7 Photonics for SKA

The photonics activities at ASTRON cover three complementary approaches all in collaboration with external groups. The in-house studies concentrate on signal distribution via fibre over various ranges, for example within equipment like phased array antennas, between subsystems such as antennas in a station as for SKA and LOFAR, and between antenna stations up to hundreds of kilometres apart. The latter uses amplitude modulation of the optical carrier by digital signals and a study program is in a definition phase with partners from industry considering an application requiring extensions reaching for a few kilometres. This matches quite well our requirements for the remote LOFAR stations as well as for the connectivity between the central processing facility and the elements forming the central core of that instrument.

For the signal interchange between subsystems up to about a kilometre, a prototype link has been developed operating at 1.6 Gbit/s based on commercially available components intended for the Gigabit Ethernet market (see section 2.1.1 Optical High Speed Digital Link). A next generation system will be developed for THEA and a study has started on implementation of this technology in routing nodes for a hyper-ring network linking large numbers of microprocessors in a cluster.

RF signal distribution via optical carriers allows coherent and incoherent detection schemes. One application, pursued by the MURI team at the University of Colorado in Boulder, aims for coherent optical processing where signals from different antennas are combined by a dynamic hologram. ASTRON was visited by the team from Boulder and a return visit also took place. The visit to Boulder coincided with one of the MURI review meetings; among the topics discussed were the system aspects of optical processors for beam-forming, beam-steering and cross-correlation for radio astronomical (phased) arrays. For such coherent optical processing applications the investigation of the phase stability continued using standard telecom single mode fibres with 9 micrometer core diameter. Although single mode at 1550 nm wavelength, a few modes are supported at the 633 nm wavelength of our interferometer test set-up. A piece of 4 micron fibre was used to select a single mode for making a fringe pattern of which polarization and coherence is determined, improving our understanding of these matters. Differential phase stability between two fibres in a 200 m cable is shown to be sufficiently slow that it can be tracked and corrected by the proposed optical processors based on photo-refractive crystals.

Incoherent optical processing is being pursued within a Navy-supported joint study with TNO-FEL on key components in photonic architectures for phased-array receivers. A true time delay beam-former was developed which combined the signals from the four sections of the 64 element OSMA phased array. By switching pieces of fibre, additional delay is used to obtain a full hemisphere of scanning range. In contrast to most applications the 1550 nm optical carriers are added incoherently on a single photo diode, resulting in coherent summation of the modulating signals over the 1 to 4 GHz range. 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. Details on the design can be found in a TNO report and the resulting beams as measured in the antenna room at ASTRON are presented in a conference paper. In the final year, optical amplification will be investigated to improve the dynamic range of the beam-former, which is currently limited by the attenuation of the optical path of splitters and combiner.

2.2 Technical Activities for LOFAR

Technical activities at ASTRON in support of the LOFAR project concentrated on system design, architecture and calibratability. On all these issues the concepts and required technologies took shape over the year. ASTRON, MIT/Haystack and NRL agreed on a baseline specification in August. Detailed architectural studies took place at ASTRON based on this baseline, leading to a more fully worked out model for the instrument.

Complementary to these design activities, a second iteration costing was done. Also a formal risk assessment was carried out together with the Fokker Space company. A Design, Development and Verification plan, with a first order planning and work breakdown, was made based on the results of these activities.

2.2.1 LOFAR Architecture and High Level Design

LOFAR is a high-sensitivity astronomical imaging and detection instrument for low radio frequencies (10-240 MHz). LOFAR can be considered the first facility of a new generation of radio-telescopes where the major emphasis is on a flexible data processing. LOFAR employs a large number of simple, low cost antennas. Signals are digitised immediately after the antenna and are treated in a highly configurable data processing chain. The processing architecture is scaleable and allows for an optimum distribution of the total processing power over signal processing and calibration tasks. This is achieved by trading processed signal-bandwidth for advanced processing, such as interference rejection, multi-beaming, pulsar processing, and decade-wide chirp processing.

Initial calibration will take place at a Data Processing Cluster. The calibrated and compressed data are then available to scientists who may choose to process their data further on the cluster or handle them on their own processing platforms. LOFAR will be operated remotely over the Internet, giving transparent access to the functionality without need for detailed knowledge of the geographical location of the antennas or processing facilities. LOFAR will support multiple simultaneous beams making it a true multi-user instrument.

The LOFAR antennas are grouped in stations with a physical size of order 200m. Of the total of about one hundred stations, 25% is concentrated in an area about 2 km in diameter. The remaining stations are organized along spiral arms to get optimal imaging properties. The instrument is equipped with a total of 13,000 receptors for 10-90 MHz and 13,000 compound receptors for 110-240 MHz. Each receptor produces two independent signals, one per polarization. Both sets of receptors share the same digital signal paths, either the low frequency signals or the high frequency signals are processed. In both cases, a 32 MHz band is Nyquist sampled and digitised with 14 bits (per polarization). The time samples are then Fourier transformed into sets of spectra, allowing for parallel processing of spectral data later in the processing chain. The resulting data rate including overhead is 2 Gbit/sec per receptor. The maximum total data rate from LOFAR will thus be more than 26 Tbit/sec.

For the stations in the inner 2 km, the full digitised bandwidth (about 7 Tbit/sec) is transported to a central processing facility. These stations form the so-called "virtual core", since all receptors can be processed as if they belonged to a single large station. The virtual core contains 25% of all receptors.

For the other stations (called remote stations) the maximum output data rate is 160 Gbit/sec. Given a Wide Area Network with sufficient bandwidth and with sufficiently powerful processing platforms, this full rate could be transported to the central processing facility as well. Otherwise several options are available to reduce the data rate:

- Spectral selection (down to 2..4 MHz in 4096 RFI-free spectral channels)
- Spatial filtering (beamforming and selection of 2..8 beams)
- Bit compression (down to 4..8 bits after removal of man-made interference)

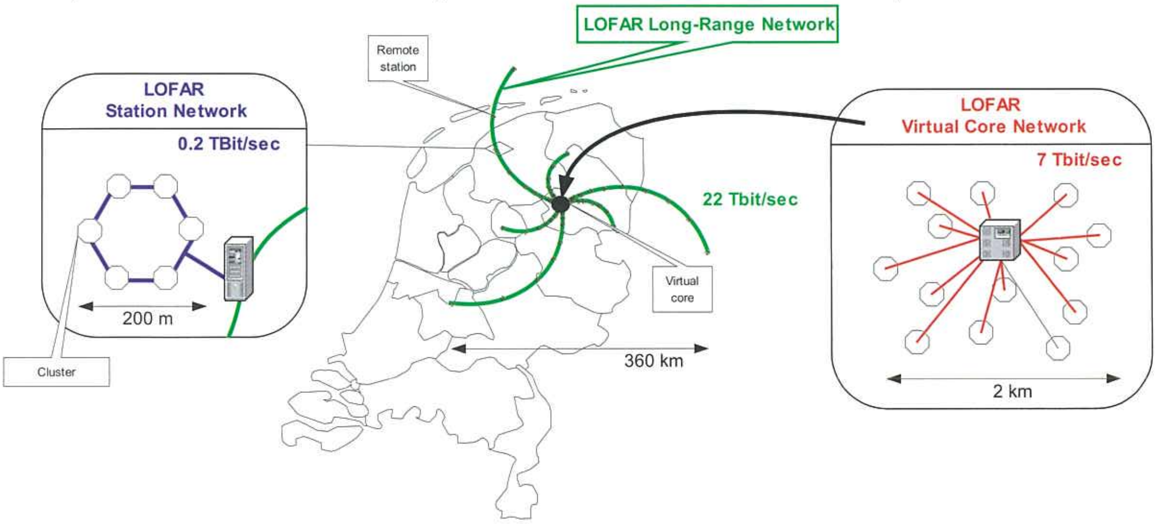


Figure 2.21 Impression of the LOFAR instrument when located in the northern provinces of the Netherlands. Stations are located along the long range network (shown in green). Stations in the inner 2 km are connected directly to the central processing site.

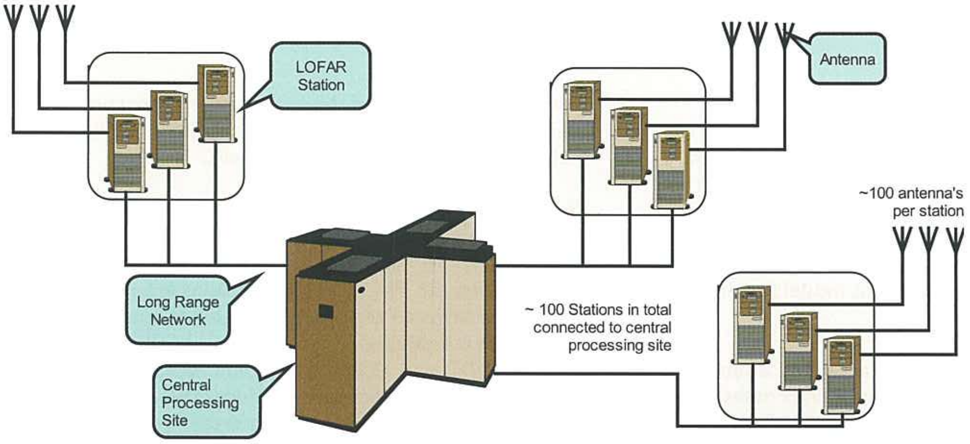


Figure 2.22 LOFAR sites. Of order 100 stations are distributed over the country. Each station contains about 100 antennas, connected to processing machines on location. All station outputs are sent to a central processing site for further processing.

These functions are then implemented at a station level processor facility. The minimum output bandwidth of a remote station that is scientifically useful at the lower frequencies is 1 Gbit/sec (32 MHz with 2 beams or 4 MHz with 16 beams, both Nyquist sampled at 8 bit, dual polarization). This lower limit increases with frequency, up to roughly 16 Gbit/sec for the highest frequencies. These values will be properly determined in the system engineering process.

Data are framed and time-tagged based on GPS receivers and rubidium clocks at station level. The combination of a GPS receiver and a rubidium clock permits < 1 nanosecond time accuracy at station level. This allows synchronization to be maintained within the system even if data transport is not fully deterministic (using reframing in the central facility).

At the central processing site, beams are correlated and corrected to first order for ionospheric phase fluctuations (see below). The data can then be integrated and stored in an on-line data store with a capacity of 630 TByte. This data store facility is read out during the successive calibration loops needed for further data reduction. User interaction during the calibration process can be carried out within a period of a few days. Meanwhile all data of the observation is kept in the data processor while new data is being acquired.
After the calibration process, the 16 PByte of raw data per day that enters the data processor is further reduced to 33 TB/day of final data products available for users. LOFAR will produce 100 PByte of observation data for the astronomical community per year.

2.2.2 Calibration and Configuration

Calibratability is one of the dominant design drivers for LOFAR. A firm consensus has emerged among the partners that the signals from the 20-30 central stations of the array should also be combined into a single large station with a diameter of about 2 km. The narrow beam of the resulting 'compact core' is needed to probe the ionospheric phase screen, and the variable shape of individual station beams with sufficient spatial resolution. An additional condition is that each station/core combination must have enough dipoles to give a S/N of 3 or more on at least 20 bright calibrator sources per station beam in 10 sec (the exact numbers depend on the severity of the ionospheric disturbances, which vary with frequency). Given the density of bright sources at LOFAR frequencies, this condition is met for 100m stations with about 100 dipole elements each.

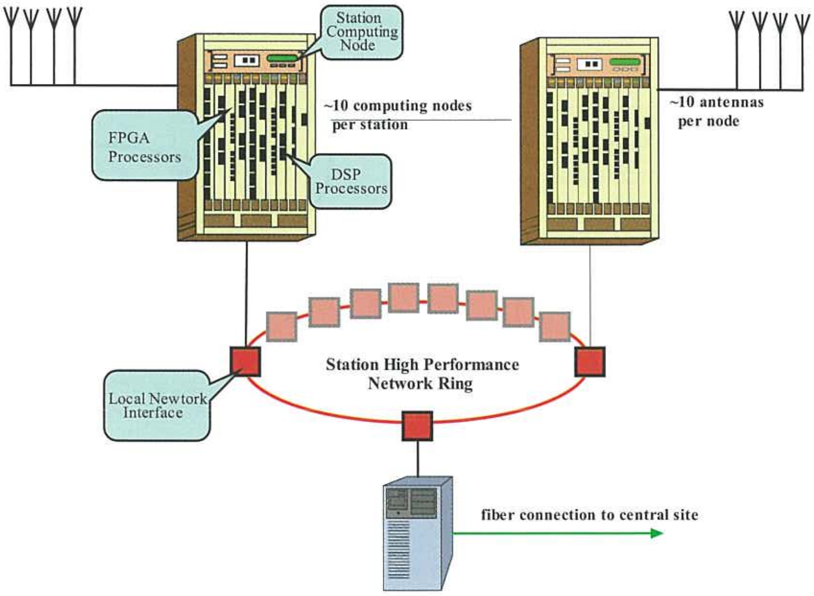


Figure 2.23 Impression of Station level processing. Sets of antennas are connected to station computing nodes. In those nodes a series of Fourier transformations and other processing steps will be performed on dedicated hardware (Digital Signal Processors, Field Programmable Gate Arrays etc.). A high bandwidth local network is needed for data transport between the station processing nodes. The reduced output data from all station processing nodes is collected and sent to the central processing site over the long range network.

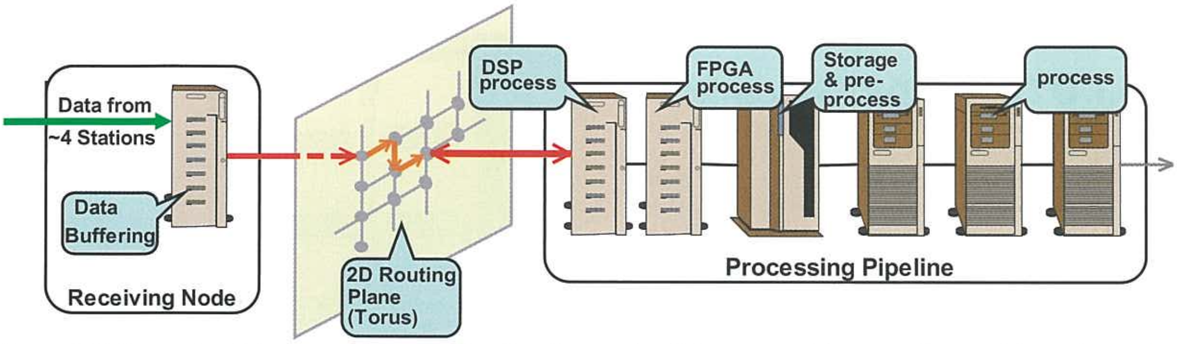


Figure 2.24 Impression of the Central Processing Site. Data from stations is input to receiving nodes. The receiving nodes use the routing plane for distribution of data towards the processing pipelines. Each pipeline will process a subset of all data with minimal interaction with other pipelines. In total, of order 200 pipelines will be needed to fulfil all processing power requirements.

There is also consensus about the need for full u,v-coverage. This is partly to avoid side lobe confusion caused by (very) crowded fields, and partly to allow reduction of the field-of-view to the size of an 'iso-planatic patch', i.e. an area over which the ionospheric phase does not change by more than a radian. Full u,v-coverage can be achieved in a few hours with an array of 100 stations placed along log-spiral arms with a maximum baseline of 200-400 km (depending on observing wavelength), assuming the use of multi-frequency synthesis over a modest relative bandwidth of 10-20%. The tentative conclusion is that, in principle, LOFAR will be calibratable for deep imaging down to the thermal noise level.

2.2.3 Functional Simulations

A functional simulation program supports the development of the LOFAR instrument. LOFARSim is a framework for functional end-to-end simulations of generic radio telescopes. The functionality of actual modules in the instrument, whether they are hardware and/or software modules, is simulated accurately by implementing the required functionality in building blocks that are combined by the framework into a simulation.

The vast number of elements in the LOFAR instrument requires extensive computational power for the end-to-end simulation tool. Therefore, LOFARSim is based on parallel computing techniques running on a Beowulf type cluster computer. The simulation environment will play a major role in architecture studies during the system design, interface definitions, prototype testing and integration of the instrument.

Figure 2.25 LOFAR engineering model antenna.

The LOFAR system architecture has been successfully implemented in this framework. This includes routing and beam forming blocks in the central processing site of the LOFAR instrument. Further refinement of architectural building blocks into detailed designed blocks is ongoing.

2.2.4 RFI Monitoring

Man-made radio frequency interference is quite severe at LOFAR frequencies, and is likely to have a major impact on the final design of the instrument. RFI monitoring observations are a vital tool for both the design studies as well as for the final decision on siting of the instrument. In the course of the year, some questions related to dynamic range and spectral occupancy were addressed and preliminary spectrum measurements were carried out. This was done both with an engineering model LOFAR antenna, developed by ASTRON in collaboration with Rhode & Schwarz, and with a quarter wave dipole antenna. The set-up that was used for the measurements is depicted in Figure 2.26. The results so far indicate that low frequency observations with LOFAR should be feasible in a hostile RFI environment, as it was encountered during the experiments, especially if in the telescope design RFI mitigation is an integral part of the system design.

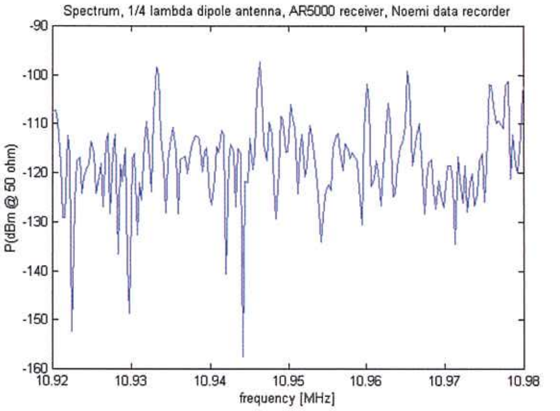


Figure 2.26 Spectrum at 10.95 MHz, clearly showing the sky background noise between the RFI signals. The sky background was calculated to be at –117 dBm for the set-up used.

2.3 WSRT Upgrade Projects

2.3.1 DZB and IVC Systems

The final element of the WSRT upgrade program is a broadband (160 MHz) IF-system, that will allow surveys in redshift space. It provides the interface between the Multi Frequency Front Ends and the new digital correlator (DZB). The project received funding in 1998 and goes by the name IVC (short for intermediate frequency (IF) to video conversion system). In 2000 the production and assembly of the IVC-system hardware was completed.

Delivery of production series of Local Oscillator (LO)- and Converter modules were completed in the second quarter of the year. The first production IVC-unit (IF-system for one telescope) became available for tests at the end of March, followed by the first complete IVC-cabinet (four telescopes) in April. In June all four cabinets were assembled and ready for placement and testing of the LO-, Converter and Filter modules. During this period, testing of the control of the functionality of the system from the DZB-software also started. By the end of the year the complete system was available for integration and testing at the WSRT. A number of modifications on individual modules in the signal chain still have to be implemented before the system can be used at its full specification. At the beginning of 2001 integration and commissioning of a 20 MHz system will start, full capability will be reached later in the year.

The two figures show the installed IVC-Cabinets in the basement in Westerbork, four Cabinets with the actual IF-systems for 14 telescopes plus two spare inputs.

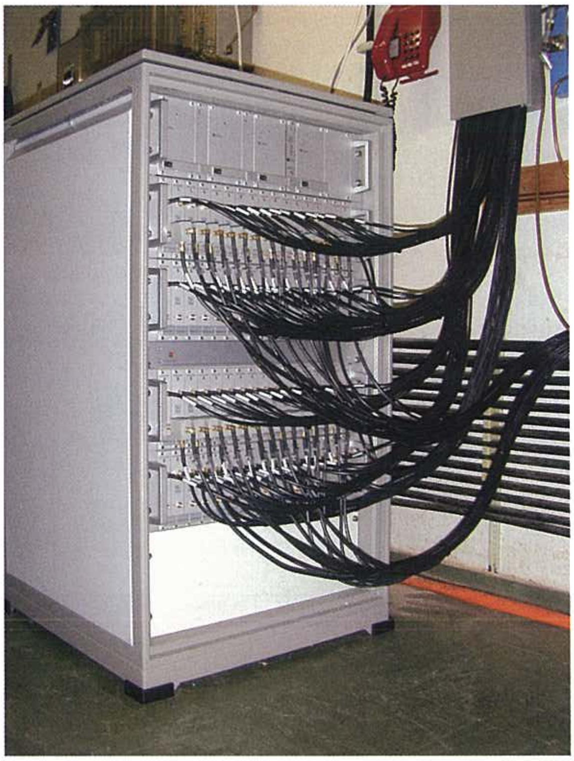


Figure 2.27 The Equalizer Cabinet, located near the incoming telescope IF-cabling.

Figure 2.28 The four IVC-Cabinets and central Control and LO-distribution Cabinet, installed in the basement of the WSRT main building.

2.3.2 TADU – a New Tied Array Mode

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 PuMa Pulsar Machine on the other side. The basic functionalities of TADU are to convert the digital signals out of the DZB Tied Array Adders into analogue signals and to multiplex multiple analogue base band signals onto the two IF inputs of the Mark IV recorder. The project has been split into two separate parts . The first (TADU-MIN), concerns the development and production of 16 digital-to-analogue converter modules which can be located directly on the Tied Array Adder boards within the DZB-ADC (Analogue to Digital Converter) subsystem. The analogue output signals can then be connected to a modified version of the system which is currently being used for the multiplexing operation.

In 2000 the hardware for this phase of the new tied array mode was delivered to Westerbork. The first stage will become operational in 2001 in parallel with the new IF system. For the second stage (TADU-MAX) of the new tied array mode new design options are being investigated. The feasibility phase for TADU-MAX started in the last quarter of 2000.

2.3.3 AIPS++

This year has seen release 1.3 (April) and 1.4 (October) of AIPS++. These releases represented major steps towards 'scientific completeness', i.e. the possibility for the astronomer to do the entire data reduction in AIPS++. In practice this meant a significant increase in the functionality for reading, editing, calibration and visualisation of u,v-data – the package was already strong in imaging and image analysis. In addition, the robustness and speed have been improved. A major ASTRON contribution to the general package is the implementation of ionospheric calibration, building on preparatory work done over the last few years. This is particularly important for the WSRT 300 MHz observations, and for the design of LOFAR. Work has also started on the implementation of a u,v-data editing (flagging) module.

2.4 Optical and (Sub-)mm Projects

2.4.1 VISIR ESO-VLT Project

As part of a French-Dutch Consortium, ASTRON participates in the ESO-VLT instrumentation program 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 2002. 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 were 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 that summer. Most of 2000 has been devoted to production and testing of parts of the final instrument. The next milestone for ASTRON will be the delivery of the spectrometer to Saclay in May 2001 with the Consortium delivering the complete VISIR instrument to ESO in 2002. This is about half a year later than foreseen, due to a fire in Saclay and the general complexity of the instrument. More details on both the design and development of VISIR can be found in previous annual reports.

Mechanical Production

Several parts of the spectrometer were completed this year. All the structural components and the reflective optics are made out of the same 6061 aluminium alloy. To improve the stiffness to weight ratio and thermal behaviour, structures and mirror blanks are as lightweight as possible. The biggest part of the spectrometer is its structure (85x60x35 cm, 70 kg) which was contracted out due to its size. It was delivered, checked, approved and installed on the installation support near the end of the year (see Figure 2.29). Meanwhile, many substructures had also been made and the re-imager was completely integrated – including optical and electrical elements. This was the first sub-system completed according to the principles of using the smallest number of parts which are all made very accurately and then put together without any adjustments. The optical properties were measured at ASTRON (see Figure 2.30) and fulfilled the specifications, both in terms of optical quality and alignment. By the year's end integration of the fixed optics was almost completed and assembly of moving systems (scanner mechanisms) had started.

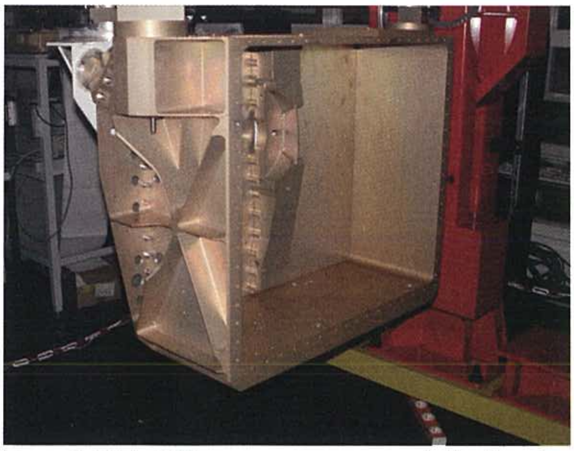


Figure 2.29 The VISIR spectrometer structure (gold coloured aluminium) mounted on the integration support (red) together with the dummy imager (white). The cover of the spectrometer structure has been taken off so the inside is visible.

Opto-Mechanical Production

Filter substrates (germanium) and etalon plates (germanium and cadmium telluride) have been made in house. The technique of polishing aluminium was developed and production of all the flat mirrors was done on the lap master. The same aluminium polishing technique was also used to make interface surfaces of structural elements flatter than is possible with milling. This was necessary to ensure the correct orientation of (optical) components, the reduction of stresses when integrating systems and to improve the thermal contact. The non-blanks of the non-flat mirrors were made in house and the last step, the diamond tooling of the surfaces to a micro-roughness sufficiently low for infrared light, was done externally. The test of the re-imager has proven this technique to be successful. Similarly, the blanks for the gratings were made in house and the ruling was applied elsewhere.

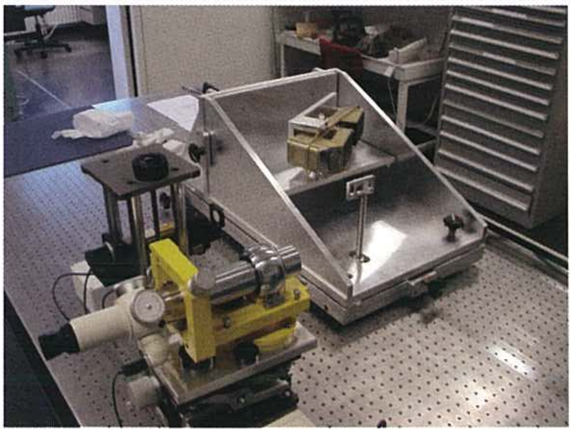


Figure 2.30 The re-imager (gold coloured aluminium) as mounted on the positioning table for the verification of the optical properties. The optical quality is checked with the interferometer which is not visible on this picture. The alignment was checked with the telescope (on the left in the yellow holder). The absolute position of the focal plane was verified with the crosshairs mounted in the plate in front of the re-imager.

Test Equipment, Verification and Modelling

A second cryostat for testing subsystems was finished as well as the positioning table for which the degrees of freedom can be adjusted independently. This table has already been used extensively in testing the re-imager. The integration support was extended with a dummy warm flange which is in fact an optical table that can be turned into any position. The thermal model was run with the parameters of the cryogenic tests with closed cycle coolers and the Mass and Thermal Models in Saclay. The experimental and modelled results agreed remarkably and showed a nice gradual decrease in temperature to operational conditions in about 36 hours.

These results make pre-cooling with liquid nitrogen unnecessary, thus making future VISIR operations simpler.

Integration

Near the end of the year, the spectrometer structure was ready for installation of the sub-systems. The fixed optics was already more or less integrated and some of it had already been fitted and taken off again to be stored safely. For the moving optics, some cryogenic tests of individual subsystems remain to be done. The general assembly of all the components will start in March 2001 for transfer of the spectrometer to Saclay in April. Tests and characterisation of the fully integrated and cooled VISIR system will then continue at Saclay before the instrument is shipped to Chile for commissioning on the VLT in the second quarter of 2002.

2.4.2 MIDI ESO-VLTI Project

A consortium consisting of the Max Planck Institute for Astronomy (MPIA), 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 ($10\mu m$) with provision made for the Q-band ($20\mu m$).

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 Conceptual Design Review was passed successfully in December 1998. Since then, MIDI has successfully passed both the first and second part of its FDR. The third and final part involves the software and is due to be closed in March 2001.

Optical and Mechanical System

In 2000, both the optical and mechanical designs were completed. Also production and assembly began. The base plate was assembled and placed on its dummy feet, the real feet having been sent to MPIA, Heidelberg for cryogenic testing. A dummy sliding mechanism was designed and manufactured in order to test the accuracy of the mechanical positioning, which removes the need to accurately transfer the encoder positioning into the vacuum vessel. The dummy slider was tested at room temperature and was found to have a repeatability of better than $0.6\ \mu m$.

Integration of MIDI at MPIA, Heidelberg was started in November 2000 with the set-up of the MIDI optical table, the installation of the 5-axis mount for the cryogenic box and the integration and installation of the dewar. The first optical subsystem assembly is due to start in January 2001, with delivery for the cold bench to MPIA in April next year.

MIDI Science

There is a well-developed science program available for MIDI, which can be split into 3 programmes. The first is on AGNs (active galactic nuclei), the second on YSOs (young stellar objects) and the last on AGBs (asymptotic giant branch stars). Details of these programmes will be confirmed in 2001 with the help of Sim-MIDI, a MIDI simulator that can estimate the amount of observing time required per object. A list of calibrators for MIDI has been made and several observing proposals were submitted in 2000, in order to obtain photometric and spectroscopic data for the calibrators. The angular sizes of all but 100 are already known, work is continuing on obtaining sizes for the remainder.

2.4.3 ALMA

The Atacama Large Millimetre Array (ALMA) is a 64 station wideband (sub-)millimetre interferometer that will provide astronomers with extremely high sensitivity and high spatial resolution and several GHz total bandwidth. ALMA is currently planned as a joint USA and European instrument. The project may well turn into a three-way partnership if Japan joins in 2001. The European ALMA Design and Development Phase (Phase 1) defines a joint program to construct and operate ALMA. For this purpose feasibility and prototype design studies have been defined for all subsystems. This work is being carried out in seven project teams, one of which is the ALMA Backend Electronics subsystem (ALMA BEE) team, led by the Observatoire de Bordeaux. ASTRON is participating in the ALMA BEE Team with the main target of carrying out a feasibility and prototype design study for an ALMA correlator: the ALMA Future Correlator (ALMA FC). These activities are partly sponsored by ESO and NWO-GBE.

In the same timeframe, NRAO is developing a Baseline Correlator for the initial ALMA stations. The experience with this development and the results of the ALMA FC study will be used to define the final correlator design at the end of Phase 1. The rationale behind this two step approach is that a large facility like ALMA should make optimal use of the rapid developments in digital signal processing technologies. On the one hand there has to be an initial correlator when the first antennas arrive. On the other hand the full correlator capacity can probably be realized more optimally by using newer technology and more scalable designs.

The ALMA FC study follows a two track approach. In the first place the European concept of a Digital Hybrid Correlator (HXF) is being worked out in full detail, including prototypes of critical subsystems. Secondly a broad range of correlator architectures is being compared in a generic correlator study. This study aims at a parameterised comparison in terms of cost, power consumption and functionality.

The HXF approach (as illustrated in Figure 2.31) handles the wide input band by splitting it in several sub-bands using Finite Impulse Response filters. Fringe and delay tracking are integrated within the filter section. The sub bands can be handled by correlator sections running at a 150 MHz clock, enabling the use of low-power circuits. The correlator sections offer sufficient on-board gen-

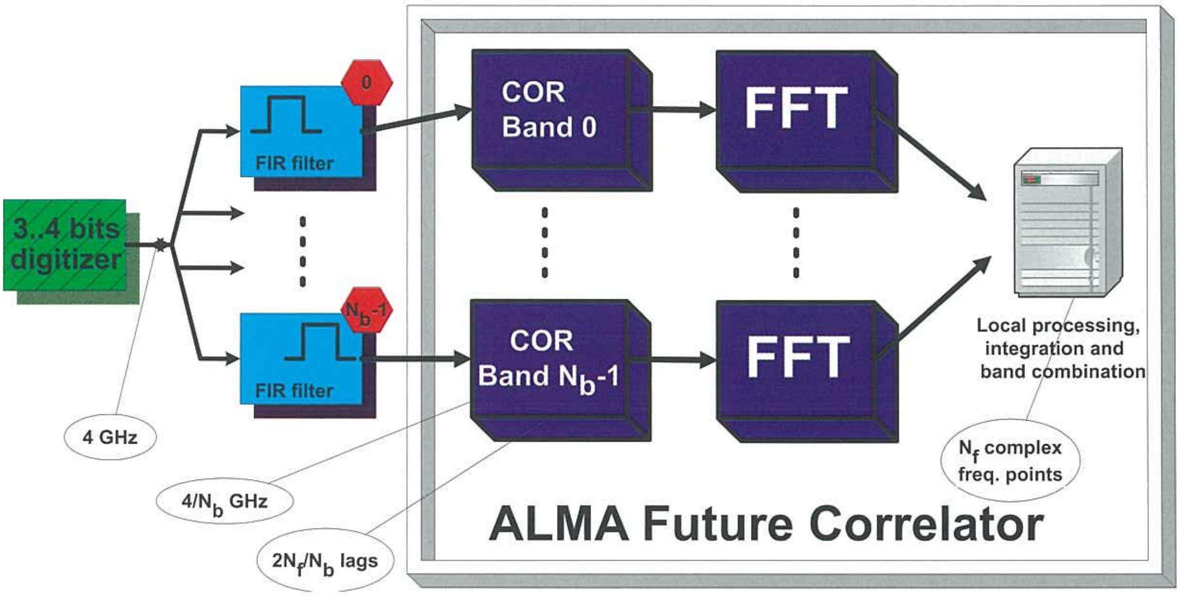


Figure 2.31 Schematic lay-out of the major elements in the ALMA Future Correlator design.

eral purpose processing power to handle the time-to-frequency FFT and on-line calibration. This could include the compensation for phase fluctuations based on water vapour radiometer data, provided this information is routed to the correlator on-line. The correlator will be four-bit, leading to >10% sensitivity improvement over a two-bit system. The correlator will provide at least 256 spectral channels over the base band (2 GHz) in full polarization, which is a factor of four improvement over the Baseline Correlator.

The ALMA FC study is being carried out in a multi-disciplinary team consisting of correlator experts, digital designers, signal processing engineers and software architects. The study requires a strong interaction with potential users of ALMA, in order to drive the study with the proper requirements in terms of performance and flexibility. There are close contacts with especially the Dutch astronomical community to ensure that the Future Correlator will indeed optimise the scientific output of ALMA. The ASTRON Future Correlator was presented at the international ALMA Science Advisory Committee meeting in September.

An inventory of the processing requirements for various design approaches was compiled during the year, in collaboration with the signal processing group at Leiden University. A study of the effects of requantisation is being performed in collaboration with the Arcetri Observatory. Component and technology studies have been initiated on fast back plane technology, commercially available interconnects (at correlator level) and implementation platforms for the various signal processing steps. The latter will involve simulations in VHDL and possibly pre-prototyping using technology developed for the ASTRON Thousand Element Array (THEA). MIT/Haystack will, as a subcontractor, carry out a study on the implementation of the 4-bit multiplication scheme. A Statement of Work has been negotiated for this subcontract.

A simulation platform has been developed for end-to-end system simulations. The platform can be run on a Beowulf cluster using MPI and on a standalone PC. The platform will be used to verify system and subsystem features including signal flow and requantisation effects. An inventory of correlator data flows and (semi-)on-line processing requirements has been started and will be further pursued together with the ALMA software teams.

In 2001 prototypes for critical components will be built. This will include the then adopted back plane technology and digital signal processing design. Prototypes will be integrated into an operational mock-up, with non-critical parts implemented in software.

3. Radio Observatory

3.1 Highlights of the Year

The year 2000 was an exciting one for the Observatory. Besides discoveries and much media attention, the Observatory has succeeded in bringing new hardware and software on-line that greatly improves the performance and capability of the Westerbork Observatory.

3.1.1 The Mars Polar Lander

During the early weeks of February, NASA requested the Observatory's help in searching for the Mars Polar Lander (MPL), which would operate in conjunction with the Mars Orbiter, but which had not been heard of since it landed on Mars. After a weak signal was found (which later was turned out not to be related to the MPL) with a telescope in Stanford, California, the Observatory participated in three coordinated observations, at a time when the MPL had been programmed to transmit in the 401 MHz band. Although there was hint of a signal with apparently the right characteristics during the first run, the subsequent runs did not succeed in finding signals with the correct signature. At the time of writing of this report it is not certain whether the MPL crashed on the surface of Mars or is standing inoperable on the surface.

Figure 3.1 The Mars Polar Lander (Image JPL)

This experiment was equivalent to looking for a signal with only a few Hertz bandwidth from a mobile phone on the surface of Mars. Besides using the standard WSRT back ends to search for the weak spectral line with the ultimate sensitivity, the WSRT used the PuMa (Pulsar Machine) backend to get the highest spectral resolution. While the operational system was still being developed as part of the Upgrade, this period was used as a major tryout of the system. As such the experiment was a *grand success,* and the press covered the event on all major TV channels.

3.1.2 Science Highlights

In June NWO issued a press release entitled *"Westerbork discovers reincarnating radio galaxies".* This release relates to the double-double radio structures discovered among the giant radio galaxies that were found in the WENSS survey and had been followed up by Arno Schoenmakers and Ger de Bruyn as part of Schoenmaker's dissertation work in Leiden. These objects can be up to 20 million light-years in size and they represent renewed nuclear activity as evidenced by a set of radio lobes inside a set of much larger and much older radio lobes, that were formed during an earlier period of activity.

As reported in last year's annual report, the WSRT has been used for a deep survey of the Hubble Deep Field (a deep optical imaging field for the Hubble Space Telescope) in order to find the radio counterparts of the optical images. A total of 72 hours of WSRT observing time were used to produce the deepest image ever produced with the WSRT having an rms noise of 8 microJy/beam. During the year, Michael Garrett (JIVE) and collaborators presented the results on the HDF in several publications, in which they described the galaxy population in the field. The WSRT HDF image contains some 25% more sources than a similar image made with the VLA, which can be explained by the fact that the smaller beam of the WSRT makes it more sensitive to extended objects. These extended objects represent most likely a population of starburst galaxies that occur in the redshift range of one to two. Three of the most compact sources in the field were subsequently detected with the European VLBI Network and these constitute the AGN population among the HDF sources. It is expected that with the arrival of the full bandwidth capacity of the IVC the ultimate sensitivity of the WSRT will be some 40% higher.

3.1.3 System Highlights

During the year, the Westerbork Observatory assumed responsibility for the new Telescope Management System (TMS) software, and initiated a major effort to make the whole observing process more robust. This concerted *RRQ (Robustness, Reliability and Quality of Data) effort* has taken a significant amount of time but it has also produced the great improvement in the operational efficiency at the Observatory that was desired. During most of the year the WSRT ran routine production observations. An efficiency evaluation during the course of the year suggested that the mechanical parts of the data production process had an availability rate of between 96% and 99% depending on how long repairs last and how much redundancy has been built into the system. Because the WSRT is an east-west array, it observes in basic 12-hr time slots and the resulting scheduling efficiency can only be about 70%. During the November VLBI session the WSRT observing system had a failure rate of 3.5% in the first 40 hours and a rate of 0.3% during the last 100 hours.

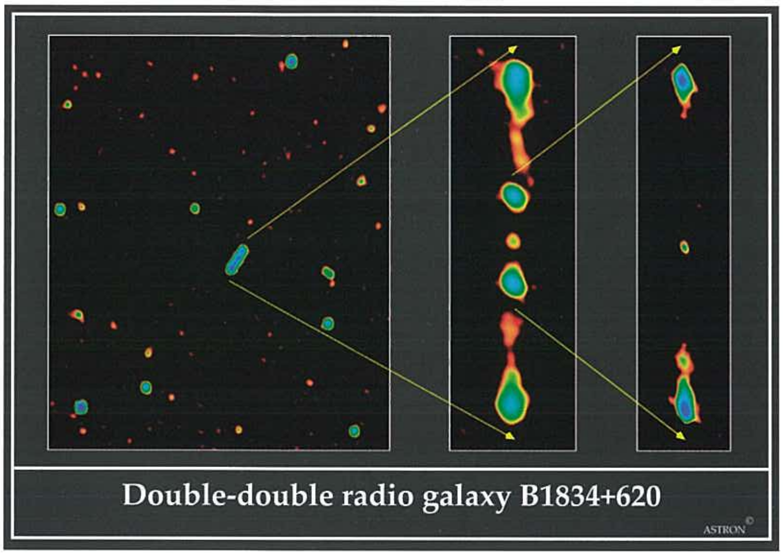


Figure 3.2 One of the giant double-double radio galaxies which was discovered. The left-most image shows an area of the sky, about twice the size of the full moon, observed with the WSRT. The extended source in the middle, when looked at in more detail, consists of four bright components (middle panel, observation with the VLA). The outermost components are a 'normal' pair of radio lobes, which span a distance of roughly five million light-years. An even more detailed view of the inner components (right-most panel, also VLA) resemble the outer radio lobes remarkably well. They clearly form a separate pair of radio lobes, which is smaller than the outer pair, and which most likely result from a temporal halting of the two jets. The central radio core is too small to show any details. This is the place of origin of the two jets and thus the location of the central black hole.

3.2 WSRT Activities

In this section the emphasis lies on the enhancement projects at the WSRT. Some of these projects have been done together with ASTRON's Technical Laboratory.

3.2.1 Telescope Management System

The year 2000 has been a very important year for the Telescope Management System (TMS). In March the HP1000 system which had been the main computer controlling the telescopes for more than 20 years was finally phased out.

The most important TMS project in 2000 was the RRQ Effort (Robustness, Reliability and Quality of data). Much time was spent in optimising observations – with very good results so far. In the summer a utilization of production observations of about 70% was achieved and an efficiency close to 85%. Utilization is defined as the quotient of real output (good production observations) and total capacity (365 days a year, 24 hours a day). The efficiency is defined as the quotient of real output and the allocated time for doing production observations. The numbers achieved in the summer are the goals for the upcoming years, which means that still some 30% of the capacity is available for system time. Over the whole of 2000 the fraction of system time was higher because of the major upgrade activities taking place. In 2001 the emphasis will be on the implementation of the 8 x 20 MHz IVC system, the nominal DZB correlator backend and the initial version of the tied-array distribution unit TADUmin.

The output format of WSRT data is in AIPS++ Measurement Sets. That is the case for DZB as well as for DCB (the old continuum backend) observations. After the observations the data is converted to MSFITS, the WSRT archive data-format. All the data in this format is stored on CDs. This year the archiving and exporting trajectory has been optimised. By the end of the year the archiving backlog had been eliminated. One task still to perform is re-archiving old data still present on DAT-tape format. This will be done in the first half of 2001 (there are almost 300 tapes). Also the export process has been optimised. Depending on the astronomer's wishes, the data in MS-format is converted to either UVFITS or NEWSTAR SCN-files. After conversion the data is send to the astronomer on either CD or DAT. The maximum 'waiting time' is two weeks but if needed data can be exported within a day. Almost all data has indeed been exported within this time frame.

3.2.2 Computer Systems and Network

The year-2000 problem was prepared for successfully last year. Not a single problem occurred during the millennium change.

The current WSRT data output rate exceeds 1 GByte per hour for standard imaging observations. This year the new archiving and exporting system was completed with the addition of 4 Linux workstations of which two have a 0.5 Terabyte disk array system (RAID) for storage. In principle, it is possible to store two weeks of data in all the standard formats. That means that once the data conversions are done, data can be archived directly and exported within two weeks.

3.2.3 Front Ends

Again the Multi-Frequency Front Ends (MFFE) proved to be very reliable instruments for the WSRT. There was no situation in which any telescope could not be used for observations. In total about 30 MFFE exchanges were made this year, half of them because of cryogenic maintenance. New flexible helium tubes were installed to allow continuous rapid front end rotation during observing.

3.2.4 RFI at the WSRT

Modifications were made to the WSRT RF-chain to reduce the effect of intermodulation products caused by a new TV channel in the region. Excellent cooperation was achieved with the commercial broadcast operator Nozema, who installed an additional filter in the TV-broadcast tower at Smilde.

3.2.5 PuMa

The pulsar observing backend, PuMa, was used very successfully during this year. PuMa played a crucial role in the Mars Polar Lander experiments in January. It demonstrated that spectral observations with 2 Hz channels are possible using this instrument. Furthermore, software was developed for high-resolution polarimetry with the PuMa observations, including polarimetry with the base band recorded voltage data. Programs have also been developed for studying the high-resolution temporal fluctuation behaviour of pulsar radiation.

3.2.6 Public Relations

The year has been good for the public visibility of Westerbork. In January NASA asked the WSRT to help search for the lost MARS Polar Lander, resulting in much interest from the media and the general public. A second item was the recording of a music video clip by the artist Dilana Smith, which prominently featured the WSRT.

In September the WSRT facilitated the making of the film 'Discovery of Heaven'. Jeroen Krabbe, Edwin de Vries and Ate de Jong are producing the film based on the novel "De ontdekking van de hemel" by Harry Mulisch, in which astronomy and the WSRT play a major role.

3.2.7 WSRT Projects and Time Awards

The backlog in the completion of allocated projects built up during the installation and commissioning of new hardware and software have been eliminated over the course of 2000. Hardware stability has been good, but there are some concerns about the reliability of some ageing systems, such as the DCB and the phased-array Adding Box, that will be phased out after the DZB and TADU are operational. In short, the WSRT user community has begun to get the benefits of the strong and sometimes unique capabilities of the WSRT after the Upgrade. ASTRON astronomers are leading the way in designing innovative observing programs, which build on the greatly improved flexibility of the WSRT and stretch the bounds of the capabilities of the WSRT. Examples are the requests for improvements in the simultaneous multi-frequency modes, and the design of complex mosaicking patterns.

The demand for the WSRT has been steady in 2000 with 25-30 proposals in each semester, which were very diverse in scientific topic, size and scope, and instrumental demands. The L-band (1150-1800 MHz) receivers, with their state-of-the-art sensitivity, combined with the spectral resolution afforded by the DZB, continue to be the single most heavily used sub-system (30-40 percent). On the upgraded, flexible WSRT these programs are easily interspersed with substantial radio continuum programs (20-30 percent), and Tied Array pulsar observations (10-15 percent), and are often conducted at multiple frequencies simultaneously.

Figure 3.3 The film crew at work during the filming of scenes of the film 'Discovery of Heaven'.

3.2.8 VLBI with the WSRT

The WSRT participated in all sessions of the European VLBI Network and in several ad-hoc sessions during the year. As a tied-array system the WSRT has an effective surface area of 94 m diameter. This makes it the second largest telescope in Europe and it helps form the central sensitive triangular core of the EVN, together with the Effelsberg (near Bonn, Germany) and Lovell (near Manchester, UK) telescopes.

3.3 Spectrum Management

The complexity of spectrum management at the radio observatories has increased significantly during recent years. While the range of frequencies used for a variety of applications has been enlarged, also the commercial stakes have become much higher. While only thirty years ago the radio spectrum was not yet allocated above 1000 MHz, presently commercial applications compete for frequencies up to 60 GHz and beyond. The number of conflicts for the radio astronomy community has increased dramatically, while the susceptibility of radio telescopes has increased due to increased sensitivity. ASTRON considers it part of its mission to help in shaping the spectrum use of today in order to preserve the future for passive use for scientific purposes.

Local Issues

Locally the town governments and the Provincial government have supported the Observatory to maintain the radio quiet zones in Dwingeloo and Westerbork. The town governments of Midden-Drenthe, Westerveld, and Aa and Hunze have supported this effort and have modified the local regulations to forbid the use of GSM mobile phones in the Radio Quiet zones around both sites. Anti-GSM boards have now also been placed at the entries to both national parks in Dwingeloo and Westerbork. There is also regular communication about locations for mobile communication towers in the neighbourhood of the two observatories.

In addition to regular contacts with the national government agencies, the Observatory also has regular contacts with the Provincial government of Drenthe on topics relating to spectrum use. In particular the provincial policy on the placing of transmission towers is of interest for the observatory. In addition, regular discussions are taking place on the planning of the locations and infrastructure required for a possible LOFAR telescope in the northern part of The Netherlands (and Germany). LOFAR has the interest of various provincial planning agencies dealing with the developments in industrialization and agriculture, of recreation and tourism, as well as the development of the telecommunication highway.

National Issues

ASTRON has entered into regular discussions with the Government Service for Radio communication (RDR) and the Directorate-General for Telecommunication and Post (HDTP), which are part of the Ministry of Traffic, Public Works and Water management and deal with spectrum management and policies for spectrum use in The Netherlands. With these discussions it is possible to contribute to the national policies but also to the international positions on spectrum management and policy.

ASTRON is also working together with the RDR on spectrum monitoring. In particular the preparatory work for siting LOFAR in The Netherlands requires regular spectrum monitoring in order to make an inventory of the use of the spectrum. There is a regular exchange of spectrum information and on experimental techniques for monitoring the spectrum.

International Issues

ASTRON staff members regularly serve as member of the national delegations to meetings of the ITU-R (Radio communication sector of the International Telecommunication Union) and the CEPT (European Commission for Post and Telecommunication). There has been regular participation in ITU-R Working Parties on scientific use (WP 7D on radio astronomy) and the Task Groups on unwanted emission of Study Group (SG1 on spectrum management), as well as a number of CEPT project teams and Task Forces.

Study Group 1 has set up two Task Groups (TG 1-3 and TG 1-5) to study the issues of unwanted emission produced by transmitting services. Besides preparing regulation on unwanted emissions, these Task Groups also considered the important issue of passive (non-transmitting) services receiving unwanted emissions produced by transmitters in nearby or adjacent bands. While no general regulation was produced that would protect the passive operations from unwanted emission, the general attention of national administrations has been drawn to this issue and there appears to be a general desire to find solutions. To address the particular issue of satellite downlinks close to radio astronomy bands, a new Task Group 1-7 was created by SG1 in order to address this issue and bring out advise to the ITU-R at the next WRC in 2003. the Westerbork director is co-chairing this Task Group together with a member from the satellite community.

In particular, ASTRON participated actively in the National Preparation Committee for the preparation of the ITU-R World Radio communication Conferences in 2000 and already for the 2003 meeting. During these meetings the national positions are prepared on the agenda items for the conference. Three ASTRON staff members participated in the 2000 WRC in Istanbul. During this meeting in May-June new allocations were made for the use of certain parts of the spectrum and new regulations were adopted to facilitate the peaceful coexistence of the large variety of services in the electromagnetic spectrum.

One agenda item of WRC-2000 of particular interest for astronomers was the review of the spectrum allocations between 71 and 275 GHz. The end result of this exercise was very favourable for the science services, radio astronomy and Earth remote sensing. A large fraction of the spectrum in the atmospheric window in this range was allocated to the radio astronomy service. While the international radio astronomy community in all regions of the world worked very effectively with their administrations to achieving these results, it is worth noting that the basic ideas and the first schemes on how to divide up this spectral range originated in Dwingeloo. These original ideas have almost exactly been translated into ITU-R spectrum allocations.

WRC-2000 also dealt with spectrum allocations for a new European global positioning system called Galileo, which will operate next to the GPS system of the USA. A major worry of the astronomers is the need for a satellite downlink just above the 5 GHz Radio Astronomy band. Because of strong political pressure on the conference, this downlink frequency band was allocated against the wishes of the astronomers and it is now up to the radio astronomers to make sure that there is sufficient protection for the radio astronomy receivers at 5 GHz.

IUCAF

The Commission on the Allocation of Frequencies for Radio Astronomy and Space Science (IUCAF) operates under the umbrella of the UNESCO via the ICSU, the International Council for Science. IUCAF continues to coordinates the regulatory effort for the radio astronomy community in the international arena and particularly in the work in the ITU-R and its working groups. The IUCAF membership consists of 10 members from observatories and organizations in eight countries around the world. As former chair of IUCAF the Westerbork director still participates in the group.

Within the framework of ITU-R WP 7D on radio astronomy, IUCAF is helping to coordinate the work on creating an inventory of interference mitigation techniques to be used at radio telescopes.

CRAF

The Committee on Radio Frequencies (CRAF) and its Frequency Manager operate under the European Science Foundation and coordinate the spectrum management activities of the European observatories. CRAF works as member of the Radio communication Sector of the ITU, and in 2000 it also got a formal observer status under the CEPT European Radio communications Committee umbrella. As a result CRAF can function effectively within the European and international spectrum scene in serving the interests of the European radio astronomy community. The CRAF membership consists of staff members of the European observatories. Much of the day-to-day work of CRAF is being coordinated by the CRAF Frequency Manager, who is an ASTRON staff member.

Because the range of issues for protecting radio astronomy observatories is widening steadily, the number of meetings where attendance is required is also increasing. Presently the CRAF Frequency Manager participates in 8 different project teams of the CEPT on issues that vary from applications in the Mobile Satellite Service, with systems like Iridium and Globalstar, to the introduction of digital video and sound broadcasting.

During the year, the activities of the CRAF Frequency Manager required approximately 97000 Euro, which was supported for 70% by ASTRON. The national research councils in France, Finland, and Italy have contributed the other 30% of the operational cost for this activity. A plan has been proposed to the ESF and the directors of the EVN institutes during their November meeting in Madrid in order to establish permanent support for this activity by the national research councils in a more equitable distribution.

The development of the new generation radio telescope, the Low Frequency Array, LOFAR, requires especially that the frequencies in the range 10-240 MHz be adequately protected for radio astronomy. This frequency range is already well used at several European radio astronomy stations. New developments such as power line transmissions, cable transmissions and ultra-wide band transmissions using bandwidths of a few GHz, require special attention in this respect.

4. Institute Science

4.1 Radio-Loud Gravitational Lenses

During the year ASTRON staff remained involved in the exploration of the CLASS database in search of new radio-loud gravitational lenses. These lenses are suitable for determining the Hubble 'constant' and detailed mass modelling of galaxies. Several new candidate lenses successfully passed all tests and will be investigated for variability. One of the highlights in a Groningen thesis (successfully defended in February 2000) was the discovery of rapid radio variability of the CLASS quasar B1600+434 (a double lens system) which is ascribed to radio-microlensing by MACHO's in the dark matter halo of the edge-on lens galaxy at z=0.4. These observations came out of several long-term multi-frequency monitoring campaigns with the VLA and WSRT, which continued into spring 2000 and recommenced in the fall of 2000. A spectacular event observed in VLA-data taken in September-October 1999 is very hard to explain by any mechanism other than radio microlensing.

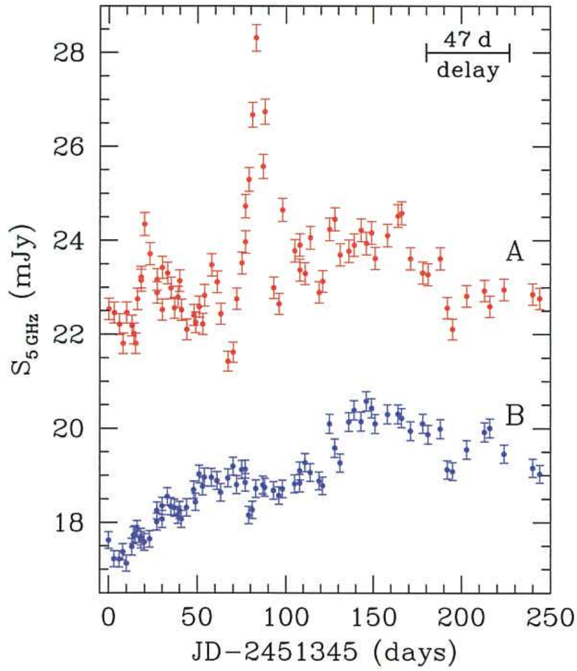


Figure 4.1 A textbook case of a radio microlensing event in the gravitational lens B1600+434? Observations of B1600+434 with the VLA at 6cm in the second half of 1999 revealed extraordinary variations in component A, which may only have a weak counterpart in component B, about 47 days later. The event strongly supports the explanation for radio-microlensing advanced by Koopmans and de Bruyn on the basis of earlier WSRT and VLA observations.

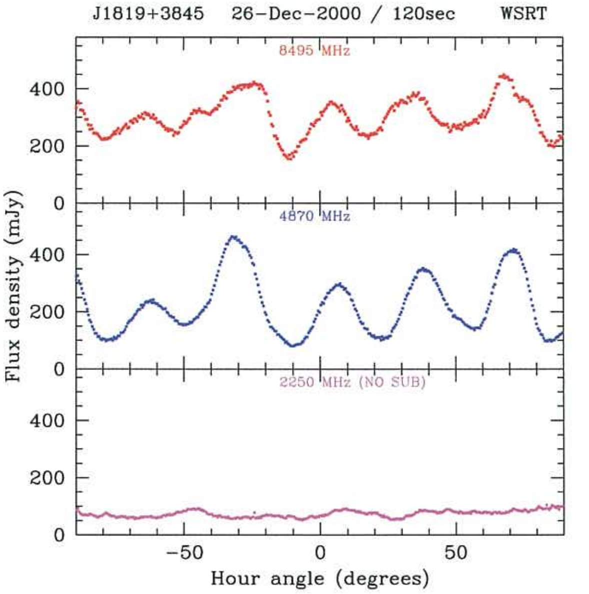


Figure 4.2 The radio light curve of the quasar J1819+3845 as observed with the WSRT the day after Christmas. By splitting the array in three parts the intensity could be recorded at three frequencies simultaneously and continuously. The intensity modulations are observed to be strongest around 5 GHz which marks the transition frequency weak to strong interstellar scintillation for this source and direction.

4.2 Rapidly Varying Extragalactic Radio Sources

Work continued on the long term monitoring at 6cm with the WSRT of the quasar J1819+3845. This is the most rapidly variable extragalactic radio source. Its variations are due to scintillation by interstellar plasma turbulence. The light curves, now spanning more than 1.5 years, beautifully show the predicted annual modulation of the scintillation timescale. The plasma giving rise to the scintillation may be at a distance of only 20 pc. It has a transverse velocity, relative to the Local Standard of Rest, of about 20 km/sec. The data also provide evidence for anisotropy in either the scattering medium properties and/or the background quasar. The quasar has now maintained its extraordinarily high brightness temperature (in excess of 10^{12} K) for several years, yet shows surprisingly little intrinsic variation; the source is only very slowly getting brighter (20 percent/year) which must be intrinsic. At the end of the year J1819+3945 was successfully observed with the WSRT split into three sub arrays each observing at a different frequency (2.3, 4.9 and 8.5 GHz). The remarkably strong frequency dependence of the scintillation modulations is a powerful constraint on the properties of the screen and the source. A collaboration has been started with a colleague from the University of California in San Diego to interpret this behaviour.

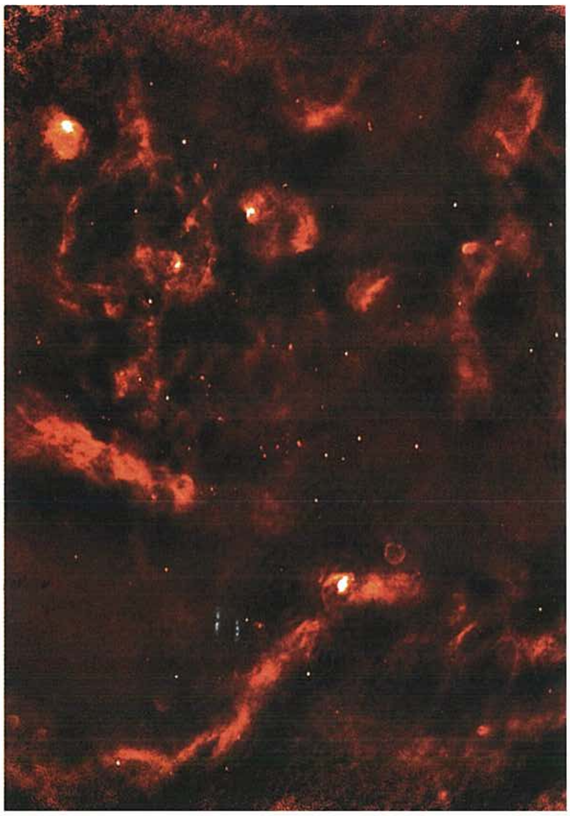


Figure 4.3 An area of 1.5x2 degrees in the part of the Galactic plane containing the Cyg OB2 association. The image was made by using the WSRT with a mosaic of 35 fields at 1400 MHz. The area is filled with structures emitting thermal radio emission. The displayed part also shows at least 3 discrete sources associated with radio emitting WR+OB binaries as well as at least 4 other radio stars (among whom Cyg X3, which happened to be radio faint during the observations). The ring nebula just above the 'knee' of the 'boot' (= CXR11) in the lower part is associated with a Luminous Blue Variable, one of only a handful of such stars known in our galaxy.

4.3 Radio Studies of the Cygnus Region

The Cygnus region in the Galactic plane, around l=80°, is one of the richest parts of the Galactic plane. In this direction we see a substantial part of a Galactic spiral arm. The region is, however, filled with highly variable optical extinction, easily 5-10 magnitudes, making the radio band one of the best ways to study its contents. The brightest radio stars in this region are only 1-2 kpc away. They are associated with colliding wind binaries in which the fast dense wind of a Wolf-Rayet star collides with that of a massive (OB) companion. Several of these stars (WR146 and WR147) have been monitored with the WSRT for more than a decade by astronomers from Utrecht, Groningen and others. The brightest object WR146, nearly 70 mJy strong at 21cm, shows modulations on a variety of timescales suggesting that there may be a third body in the system. An EVN image shows the emission to consist of a thinnish 'shell' that may wrap itself around the O-star. A small area, 2x2 degrees, was imaged using the WSRT, aiming to find more radio stars. Figure 4.3 shows the resulting image. Many candidate stars were detected. One was confirmed in follow up observations in early 2001. The work was written up last year in several papers in Astronomy and Astrophysics, but all results will appear in a Groningen thesis which will go to press early in 2001.

4.4 Compact High Velocity Clouds

Ten isolated compact high-velocity clouds (CHVCs), discovered with Dwingeloo and Westerbork observations, have been imaged with the Arecibo telescope. They were found to have a nested core/halo morphology that can only be accurately reconstructed with a combination of high-resolution filled-aperture and synthesis data. The halos are identified as Warm Neutral Medium (WNM) surrounding one or more cores in the Cool Neutral Medium (CNM) phase. These halos are clearly detected and resolved by the Arecibo filled-aperture imaging, which reaches a limiting sensitivity (1 sigma) of N_{HI} about 2×10^{17} cm^{-2} over the typical 70 km/s line width at zero intensity. The FWHM line width of the halo gas is found to be 25 km/s, consistent with a WNM thermal broadening within 10^4 K gas. Substantial asymmetries are found at high $N_{HI} > 10^{18.5}$ cm^{-2}) levels in 60% of the sample, as shown for example in Figure 4.4. A high degree of reflection-symmetry is found at low N_{HI} $< 10^{18.5}$ cm^{-2}) in all sources studied at these levels as seen in Figure 4.5. The column-density profiles of the envelopes are described well by the sky-plane projection of a spherical exponential in atomic volume density, which allows estimating the characteristic central halo column density, $N_{HI}(0) = 4.1\pm3.2\times10^{19}$ cm^{-2}, and characteristic exponential scale-length, $h_B=420\pm90$ arcsecond. For plausible values of the thermal pressure at the CNM/WNM interface, these edge profiles allow distance estimates to be made for the individual CHVCs studied here which range between 150 and 850 kpc.

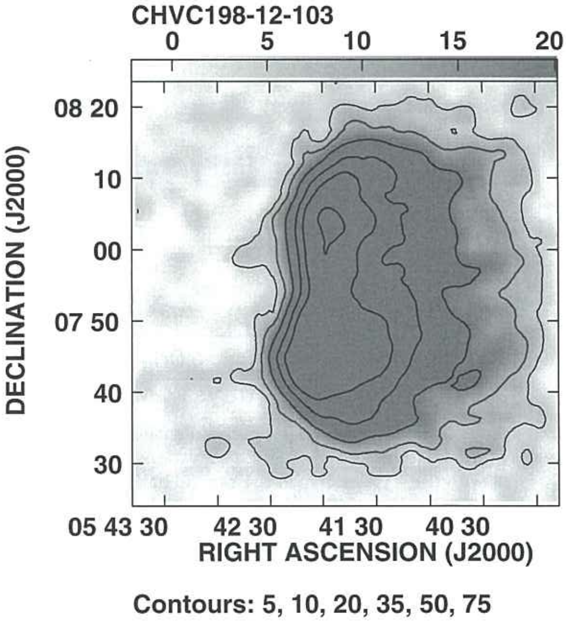


Figure 4.4 Integrated HI distribution observed with the Arecibo telescope for CHVC 198-12-103. The indicated contours represent units of 10^{18} cm^{-2}. This is the most asymmetric example of the 60% of sources in the sample which displays a substantial asymmetry at high column densities.

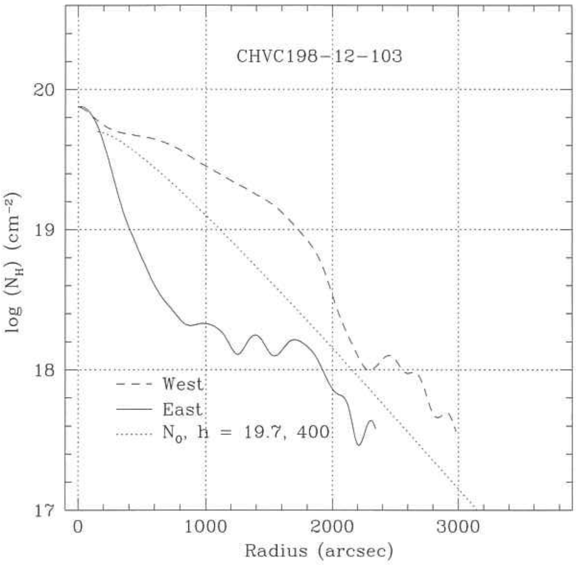


Figure 4.5 Column-density profiles of CHVC 198-12-103. The logarithm of HI column density is plotted against distance to the East and West of the emission peak. The dotted curve overlaid on the observed log(N_{HI}) values corresponds to the sky-plane projection of a spherical exponential distribution of atomic volume density, with the indicated central log(N_{HI}) and scale height in arcsecond. Even this source shows a remarkable degree of reflection symmetry at low column densities.

4.5 HI in Galaxy Clusters

In a project carried out with colleagues from NCRA (India) and ATNF (Australia) the Australia Telescope Compact Array (ATCA) was used to obtain HI 21cm data for the nearby galaxy cluster A3128 at z=0.07, which has been studied extensively in optical and X-ray wavelengths. For 148 of the galaxies the redshifts are such that the HI emission (if any) would lie within the data cube, as illustrated in Figure 4.6. The known redshifts of these galaxies were used to co add their spectra and thus improve the sensitivity to HI emission. The technique is fairly successful – the co added spectra allow detection of an average mass content of ~9x10^8 M$_\odot$, almost an order of magnitude lower than for direct detection of individual objects.

By dividing the total galaxy sample into sub samples, it was found that the gas content of late type galaxies that lie outside the X-ray emitting core of the cluster is substantially higher than that of those within the core. The fact that for disk galaxies the average gas content is higher for galaxies outside the X-ray emitting region compared to those inside implies that these galaxies are not well mixed in the cluster potential. Even outside the X-ray emitting region the distribution of gas-rich galaxies in the cluster is not uniform; gas-rich galaxies are concentrated in the east of the cluster as illustrated by the spectrum in Figure 4.7. This is consistent with earlier analyses of the kinematics of the galaxies in A3128 which indicate the presence of sub clustering. Co adding spectra with known redshifts is a powerful tool for the study of HI in cluster galaxies. This technique could be applied to substantially increase the redshift range over which such observations can be carried out.

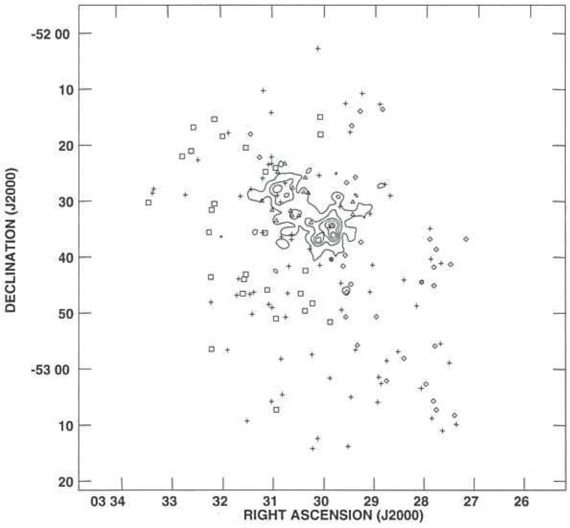


Figure 4.6 Position of galaxies in A3128 that have measured redshifts and lie within the HI data cube. The X-ray emission (from a ROSAT HRI broadband image) is shown as contours. The two galaxies whose HI emission has been tentatively detected are shown as stars. Neither of these two galaxies has an optically measured redshift. Late type galaxies are shown as open squares, open diamonds and open triangles. The open squares are "gas rich" on the average, while the open diamonds are "gas poor" on the average. Galaxies which are regarded as lying within the X-ray emitting region are shown as open triangles. Crosses are either early type galaxies, or galaxies whose morphological type is unknown.

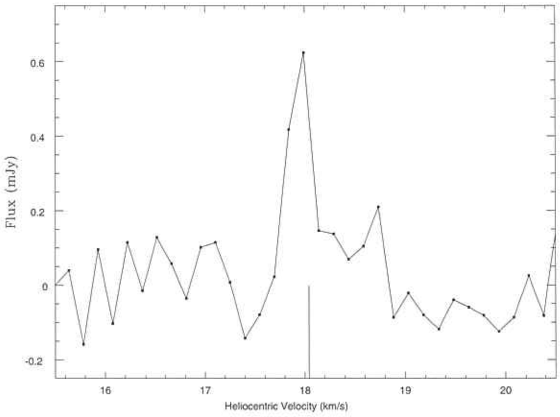


Figure 4.7 The co added spectrum smoothed to 140 km/s velocity resolution for the group of 20 galaxies with the most significant HI emission signal. Groups are defined purely on the basis of proximity in projected separation and independent of HI content of the individual galaxies.

4.6 Supernova Remnants

A long term research programme into the origins and evolution of Supernova remnants (SNR) continued during the year. MSH 14-63 is a typical shell SNR, a strong radio emitter, but also prominent in the infrared, optical and X-ray bands. In the 21 cm mosaic (Figure 4.8), the shell consists of several curved ridges which do not appear to have a common centre, in a manner reminiscent of the young SNR associated with the supernova Tycho Brahe observed some 430 years ago. This and several other characteristics suggest a "young" (<2,000 year old) object, though there are other strong indications that the age may be nearer to 10,000 years. The nature of the bright feature at the south-western edge remains a particular enigma. Among the possible explanations, it may be where the blast wave encounters a region of high ambient density, or it could be the remnant of high-density ejecta.

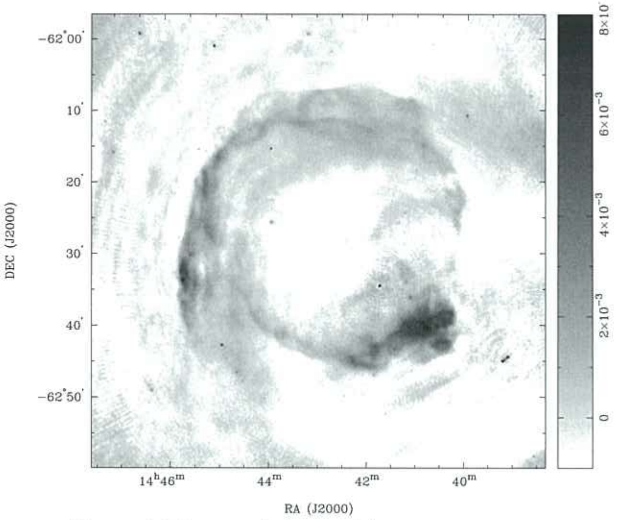


Figure 4.8 A greyscale image of the supernova remnant G315.4–2.3 (MSH 14-63) and surroundings at a frequency of 1.34 GHz, observed with the Australia Telescope Compact Array. The scale for the wedge is in Jy/beam. The 8-arcsec beam is shown as the tiny dot in the lower right corner of the plot.

MSH 15-56 is one of the most striking examples of a shell associated with a centre-brightened, non-thermal flat-spectrum object. While the shell looks pretty standard, the interior component, which is not well-centred in the shell, has anything but the amorphous shape often attributed to such objects. Its main body seems to consist of a bundle of slightly curving ridges which bulge out at the ends, forming a distinct ring at the north-western extremity. What is also peculiar about this component is its lack of detectable X-ray emission, notwithstanding its prominence in the radio band.

4.7 Interstellar Medium in Galaxies

Neutral hydrogen situated in front of a radio source can be revealed and studied via absorption observed on the radio continuum emission. Apart from the galactic interstellar medium (ISM), HI absorption may also be used for the study of the direct environment of the Active Galactic Nucleus (AGN). In the past, HI absorption has mostly been interpreted as coming from a torus or from gas falling into the AGN. These observations indicate that this is likely to be the cause only for a particular kind of radio sources. Other phenomena, like interaction of the radio plasma with the ISM seem to occur.

The work done by ASTRON astronomers in collaboration with colleagues from the United Kingdom and at NRAO has shown that the causes of such absorption can, instead, be quite varied and the phenomena quite complicated. HI absorption has been searched for in a sample of radio galaxies using the Australia Telescope Compact Array (ATCA), the Very Large Array (VLA) and the Westerbork Synthesis Radio Telescope (WSRT). The detections have been related to the different radio and optical properties of the galaxies.

The HI absorption in Fanaroff-Riley type I (i.e. edge-darkened) radio galaxies is likely to come from a circumnuclear *thin* disk, as deduced also from optical work. However, in the case of Fanaroff-Riley type-II (i.e. the most powerful radio galaxies) the indication in favour of the circumnuclear disk being the only cause of absorption is not very strong. In particular, it was found that in two of the three detected objects the HI is blue shifted compared to the systemic velocity, thus indicating a gas outflow. In the third galaxy, two velocity systems have been found: this object is believed to be a young radio galaxy where the radio plasma is still expanding into a rich ISM.

Moreover, by also considering data available in the literature, a tendency was found for radio galaxies with a strong components of young stellar population and far-IR emission to show HI absorption. The overall richer ISM and a young, small radio source that is likely to be present in these galaxies may have a role in producing the absorption.

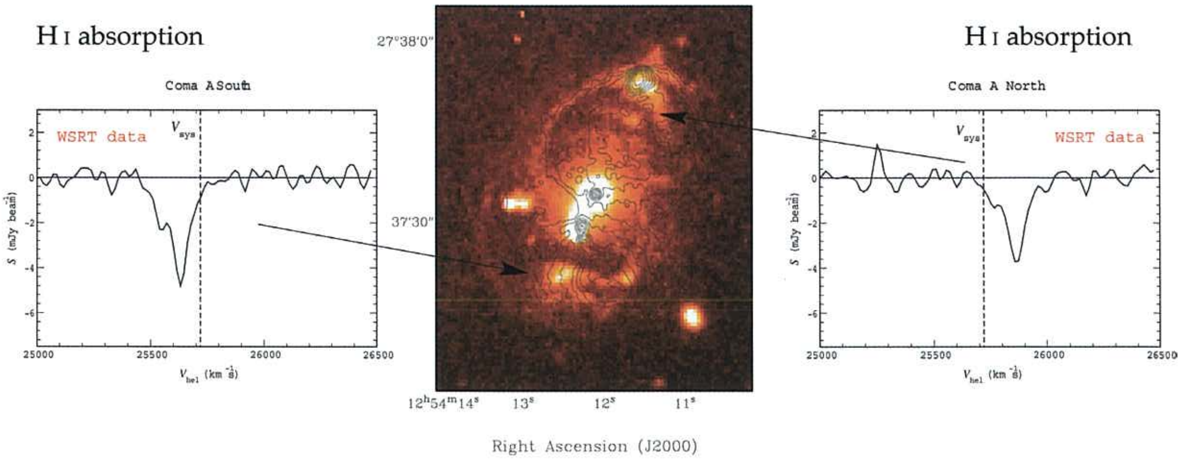


Figure 4.9 Panel showing the approximate location of the HI absorption in the radio galaxy Coma A. In the plots, the dashed line represents the systemic velocity. In the middle is the Hα image with superimposed the contours from a 20cm VLA image.

Even more interesting is the discovery of two radio galaxies where HI absorption can be seen against the kpc-scale radio lobes. The most spectacular case is Coma A. Using the WSRT, HI absorption was detected against both radio lobes (see Figure 4.9) that extends up to 25 kpc from the nucleus. Compared with the systemic velocity, the absorption is red shifted by about 200 km/s in the northern lobe and blue shifted by about 150 km/s in the southern lobe. The HI appears kinematically associated with the ionised gas that has a particularly complicated morphology in this galaxy (colour image in Figure 4.9). This is explained as the radio lobes expanding into a gas-rich environment. Coma A could be the result of interactions/mergers between the dominant giant galaxy and less massive galaxies in the same group. Thus, in Coma A we will have the rare opportunity of getting information on both the neutral and ionised gas around a radio galaxy.

4.8 HI Disks in "disk-less" Galaxies

ASTRON astronomers have continued a long term study of the interstellar medium (ISM) in elliptical galaxies, in particular the neutral hydrogen, in a collaboration with colleagues from ATNF and NRAO. The characteristics of the ISM can tell us about the formation of these galaxies, their evolution and the role of the environment in these processes.

For example, the properties of neutral hydrogen in luminous and low-luminosity elliptical galaxies appear to be clearly different. All low-luminosity galaxies observed show similar characteristics: the distribution of neutral hydrogen is quite regular and centrally concentrated. For luminous elliptical galaxies the situation is more complicated and a variety of amounts of HI (from more than $10^{10} M_{\odot}$ to upper limits of 10^{8} $M_{\odot}$) and morphology are observed. This suggests a different evolution of the gas in these two groups and that mergers and accretion play a different role in these galaxies compared to the more luminous ellipticals. The reason for such a variety can be found either in the evolution of the galaxy or in the effect of the environment or both.

A few galaxies have been imaged in HI with the WSRT. In particular, for the elliptical galaxy NGC 807 new data with higher velocity resolution than previously available have been obtained (see Figure 4.10). A simple model of the velocity field, done as part of a summer student project, has shown that the inner part of the HI distribution can be described as a regularly rotating disk while deviation from this are seen in the outer part. In this galaxy, as in many others with similar characteristics, the surface density of the disk is low and therefore, unlike in spiral galaxies, an optical disk failed to form from the HI disk ("disk-less" disk galaxies).

The HI disk in NGC 807 is very large (60 kpc radius). Because the galaxy is quite isolated, such a large disk can survive for a long period. That such environmental effects are important is underscored by observations of NGC 759. This is an elliptical that is in a much denser environment than NGC 807. NGC 759 has, like NGC 807, a large amount of molecular gas in the central regions. This, together with optical features, indicates that NGC 759 has experienced significant accretion in the past. While in NGC 807 the amount of molecular gas is similar to the amount of HI, the WSRT observations reveal that in NGC 759 the amount of HI is at most 5% of the molecular gas. If the HI in NGC 759 was originally found at large radii, as it is the case in NGC 807, frequent tidal interactions with neighbouring galaxies will have destroyed the HI disk in NGC 759.

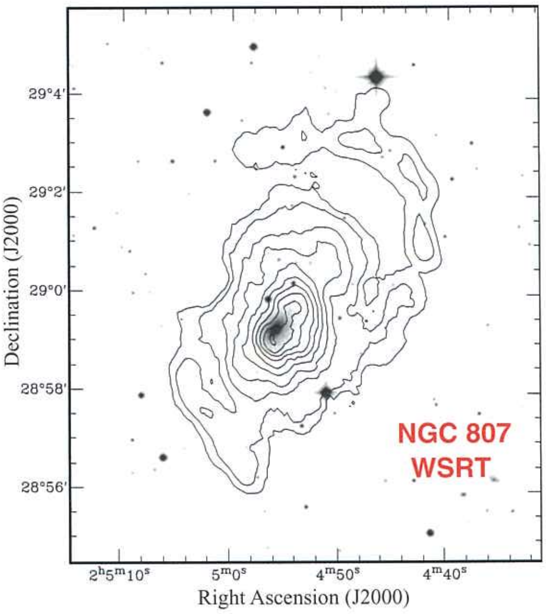


Figure 4.10 A map of the HI gas in NGC 807, taken with the WSRT and superimposed on an optical image of the galaxy.

4.9 Giant and Double-double radio sources

Sources belonging to the class of Giant Radio Sources (GRS) are characterized by a linear size which exceeds 1 Mpc ($H_0 = 50$ km/s/Mpc). These are extreme radio sources in many respects. They are the largest radio sources in the Universe associated with Active Galactic Nuclei (AGN), the AGNs themselves are experiencing an extremely long period of radio-activity in order to produce such large radio structures, and the jets they produce are so stable that they can transport particles almost without dissipation over distances of at least 500 kpc. Eventually, these jets terminate in a shock and inflate an enormous expanding bubble of shocked jet material (traced by the radio lobes). As such, the jets are a strong source of energy and magnetic field input for the hot intergalactic medium. The results from both radio and optical studies into a large sample of GRSs which were selected from the WENSS survey on the basis of their large angular size are gradually being published now. Furthermore, effort has been put into the investigation of a sample of giant sources at much higher redshifts (z > 0.4). For this project a request for observation time on the WSRT has been successful. This allows multi-frequency polarimetric radio imaging of the extended radio lobes of these fascinating sources (see Figure 4.11 for an example).

Detailed radio studies of three radio sources of the class of Double-Double Radio Galaxies (DDRGs) with both the WSRT and the VLA have been started up. DDRGs are radio sources consisting of a well aligned, co-centred, double-lobed radio sources of different size. 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. The DDRGs allow us to investigate several poorly understood issues of radio source evolution.

In order to observationally constrain the ages of the different structures and the properties of the environment, so that these can be compared with the proposed model, an observational campaign has been started, aimed at studying their radio structure as completely as possible using a variety of frequencies and resolutions. Observing time has been granted on the VLA to obtain the high-resolution data and on the WSRT to investigate the faint, extended lobe structures. These results are eagerly awaited. In the near future, it is hoped that the GMRT can provide additional low-frequency data of these sources.

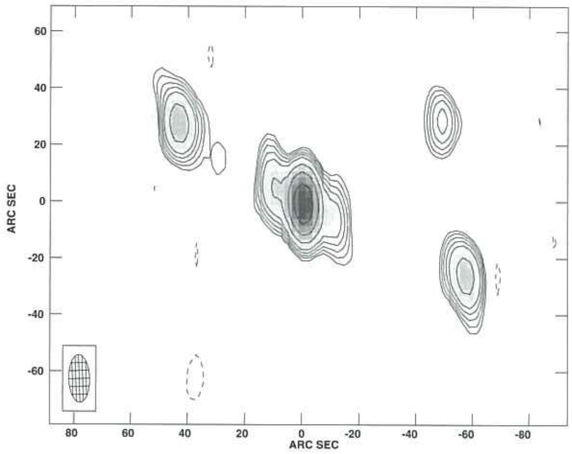


Figure 4.11 Radio map of the high-redshift giant radio galaxy J0927+295. This map is the result of a 6 hour WSRT observation at 2.3 GHz. The source has a redshift of 2.72 (based on a single Ly-α line in its optical spectrum) and thus a projected linear size of 0.9 Mpc (H_0 = 50 km/s/Mpc), which is astonishingly large at such a redshift. The map shows the outer ends of the extended radio lobes, the radio core and two jet-like structures emanating from this core. The source towards the north-west is an unrelated radio source associated with a nearby spiral galaxy. Contours are at 0.22 x (-1, 1, 1.41, 2, 2.82, 4, 8, 16, 32) mJy/beam.

4.10 Pulsar Studies

Discrete Scattering Events

A powerful technique has been developed to search for discrete refractive scattering events (including effects due to possible non-multiple diffractive scattering) at meter wavelengths. A search was performed in the direction of two close by pulsars B0950+08 and B1929+10, looking for spectral signatures associated with the multiple imaging of pulsars due to scattering in the interstellar medium. In the epoch of these observations, no signatures of such events were detected in the direction of either source over a spectral periodicity range of 50 KHz to 5 MHz. Analysis puts strong upper limits on the column density contrast associated with a range of spatial scales of the interstellar electron density irregularities along these lines of sight.

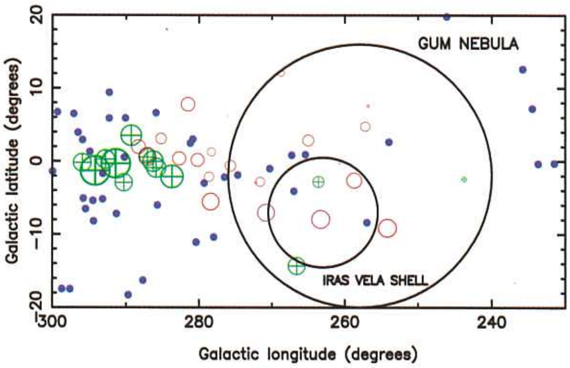


Figure 4.12 Observed scatter broadening (τ_{sc}) of pulsars at 327 MHz plotted as a function of the galactic coordinates. The green circles with crosses correspond to pulsars for which earlier τ_{sc} measurements are available. The open circles are the pulsars observed using the Ooty Radio Telescope. The size of these symbols is proportional to log(τ_{sc}), where τ_{sc} is in milliseconds. Pulsars indicated as blue dots are those for which the scatter broadening measurements are not available. The Gum nebula is indicated by the big circle with radius of ~ 18° with morphological centre at l=258° and b=-2°. The smaller circle indicates the IRAS-Vela shell, with a radius of ~7.5°, with centre at l=263° and b=-7° (adopted from Sahu 1992). The present sample consists even of pulsars outside the "main body" of the Gum Nebula, as it is possible that the faint diffuse and filamentary extensions are possibly part of the nebula itself.

Scattering in the Gum Region

Measurements have been made of the scatter broadening of pulsars in the direction of the Gum nebula. For the first time, these observations show clear variations of scattering properties across the Gum nebula. The IRAS-Vela shell is shown to be a high scattering region. Revised estimations of distances to these pulsars are consistently lower by a factor of 2-3 than was previously found, which has very important consequences for the deduced values of radio luminosity and transverse velocity of pulsars.

Acceleration Searches

Pulsars are intrinsically faint sources. Detection of pulsars becomes even more difficult when they are in close binary systems, where the signals emitted by them undergoes a time-dependent Doppler shift with respect to the observers' frame. Many researchers have tried developing fast algorithms for compensating for this effect, so that the detection probability is maximised. However, so far, there is no algorithm for doing a full coherent recovery. An extremely efficient (partially coherent) algorithm has been developed for doing this job. To date tests of its high efficiency have been performed with simulations, and with some real data.

4.11 The Dusty Torus in Markarian 231

The study of molecular megamaser emission in galaxies has become an area of research that has delivered spectacular new insights into their nuclear regions. Some H_2O Megamasers, in particular, have revealed in great detail the dynamics and the structure of compact disk structures surrounding the black holes in galactic nuclei. OH megamaser emission occurs in Ultra-Luminous Far-Infrared Galaxies (ULIRGs) but it has been more difficult to determine the structure of the maser emission regions. There has always been a suspicion that the OH molecules are also part of a donut-like "torus" structure ranging in scale from 20 to 100 parsecs. It has also been clear for a long time that the Far-Infrared radiation field pumps the molecules so they may amplify radiation rather than absorb it. The pumped molecules may do some fancy image processing of the background radiation passing through the masering clouds.

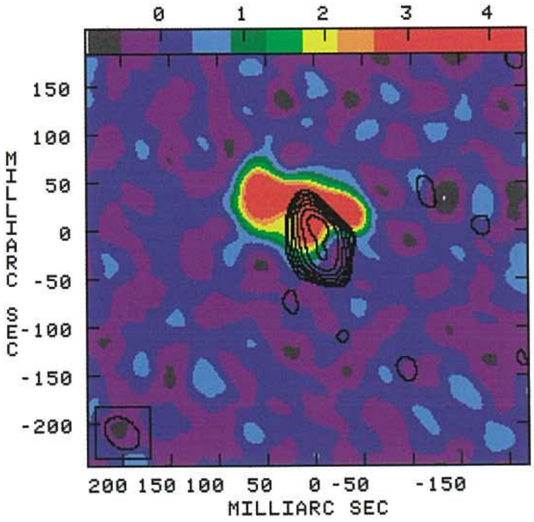


Figure 4.13 Markarian 231 – the colours show the OH Megamaser emission, the contours give the radio continuum emission from the nucleus itself.

Observations of the Ultra-Luminous Infrared Seyfert I galaxy Markarian 231 using the European VLBI Network have revealed the presence of a dusty torus in the nucleus of the galaxy. Mrk 231 was one of the first galaxies in which an OH megamaser was found in 1985. Mrk 231 is known as a prominent Seyfert type I galaxy, with a massive black hole at its centre. Almost all other OH megamasers were found in galaxies with intense star-formation in progress in their nuclei. The recent observations show that there is a dusty molecular torus around the nucleus of Mrk 231. Only the upper section of the torus of OH emission is seen from below (like one sees a wide-rimmed sun-hat on a persons head). In the figure, the intensity of the emission is given in colours, while the radio continuum emission of the nucleus itself is depicted with contours.

These observational results confirm the suspected torus structure for the molecular material in megamaser galaxies. It is even possible to see the rotation of the torus around the nucleus. Furthermore, the OH emission is located outside the nuclear centre of the galaxy, but lies on top a larger radio halo. It seems that the original picture for OH megamasers works well for Mrk 231: the far-infrared radiation field pumps the molecules in the torus structure such that they amplify the radio continuum radiation coming from behind.

There are now some one hundred OH megamasers known and some of these show very peculiar OH line emissions, which may indeed be explained by rotating disks. Mrk 231 may serve as an example in interpreting the phenomena of all these other galaxies.

5. ASTRON Facilities

Library

More and more publishers are making the content of their periodicals available on the Web, unfortunately they all work with different access methods. Some of them use a combination of IP-number and password, others work with free access, in general all access methods do differ and transparent access for all members of the institute has not been accomplished so far. The number of subscriptions in the ASTRON library is about 185. Forty new books were added last year; in the forthcoming year an attempt will be made to find a better match of the library's content with the demand of the readers. This will require co-operation of the readers themselves.

Millennium Transition

The much feared millennium transition passed without significant problems. It was however necessary to switch off the old VAX 780, still in use as the ASTRON mail server. It was replaced by a GroupWise Novell server with Internet gateway. With a small ceremony in the computer room, where it had resided for so many years, the VAX was switched off. The opportunity was seized to clean the lists of mail recipients before it was transferred to the new system.

As for Unix workstations, many patches had to be collected from the Internet and loaded on to the workstations, in some cases over forty patches were necessary on a single machine. One should not think too lightly about the impact that the millennium transition had. It was only as a result of much work beforehand that the event passed smoothly.

Computer Network and Security

Halfway through the year, a firewall was added as a security measure and the secure shell (SSH) was adopted as the login method of choice. Installation of the firewall also made it possible to redesign the IP-numbering system. The choice was made for a private network behind the firewall which gives the opportunity of dividing the network over several number ranges, eliminating the shortage in IP-numbers.

To bring 100 Mbit to the individual workstations, only an upgrade of the switch configuration was needed. The Bay-Networks switch was replaced with a 3Com switch with a 27 GHz backbone fabric. This switch can carry the much heavier load of today, in fact it can switch all its channels at wire speed without buffering. The backbone of the network transfers the IP-packets at 1 Gbit/s, there are four backbone connections to the different network switch cabins. 100 Mb is has now been accomplished at 20% of our machines; this will be brought to 100 % during 2001. No changes to the wiring is needed, because in the design phase of the network (back in 1996) this was already part of our specifications.

During 2000 many machines were replaced by newer and faster ones, the total number of machines increased only slightly, from 220 to 244. About 30 PC's were replaced by newer systems.

Guesthouse

The number of nights spent in the Guesthouse was 1333, which is about 27% of the available capacity.

Workshop

Highlight of the year in the mechanical workshop was the installation of the new 5-axis CNC milling machine for which a special room has been built. The machine has been practically in full-time used from day one, this is a big achievement. Combining a variety of computer- and mechanical techniques has allowed the workshop to produce very complicated parts with a very high degree of precision.

Facilities Management

The flooding experienced in 1998 led to the installation of a pump system to prevent surface water from entering the building. This has worked well and no further problems have been encountered,. In the meantime, the building contractor has made provisional repairs to the concrete foundations of the building to make it more waterproof. Real flood conditions did not occur during the year.

6. ASTRON Programme Committee

6.1 Report and Membership

The Program Committee serves to review proposals for observing time at the WSRT, which is under the direction of ASTRON, and the telescopes of the UK/NL collaboration (JCMT, WHT, INT and JKT), which are the responsibility of the Gebiedsbestuur Exacte Wetenschappen (GBE) of NWO.

The PC conducts two reviews per year for the standard proposal stream. Delegates of the PC then subsequently coordinate the scheduling of the Dutch proposals with the programs of the other members of the Isaac Newton Group and the JCMT consortium. During the autumn of 2000, there was also a review of proposals to the Wide Field Survey Program that is being conducted with the INT at La Palma; the Dutch PC served as an advisory board to the joint UK/NL WFS review board that made the final judgement of the proposals.

The PC is composed of eight members – seven from Dutch Institutes plus one foreign member. Members normally serve a term of three years.

Membership:

J.M. van der Hulst	Groningen	Chair (Semester 00b)
F.H. Briggs	Groningen	Chair (Semester 01a)
H.F. Henrichs	Amsterdam	(Semester 01a)
J.L. Higdon	Groningen	
L. Kaper	Amsterdam	(Semester 00b)
U. Klein	Bonn	
J. Lu	Leiden	
H.J.A. Röttgering	Leiden	(Semester 01a)
F. Verbunt	Utrecht	
R.C. Vermeulen	ASTRON	
P.P. van der Werf	Leiden	(Semester 00b)

6.2 Allocation of Observing Time

WHT Semester 00a

Proposal	Proposer	Subject	Allocation
w00an01	Luu	Rotational Properties of Kuiper Belt Objects	1G 3B
w00an02	van der Werf	Distant submillimeter galaxies	3D
w00an03	Vreeswijk	Rapid imaging and spectroscopy of GRBs	ToO
w00an05	Douglas	Planetary nebulae in Virgo cluster galaxies	2G
w00an07	Best	Emission line gas in CSS radio sources.	0.5D
w00an08	Best	Evolution of z~1 6C galaxies.	1.5D
w00an11	van den Berg	Spectroscopy of blue straggler binaries in M67	1.5B
w00an12	Pickering	Near-IR imaging of LSB galaxies	2.5B
w00an13	Koekemoer	Probing AGN fuelling in powerful radio galaxies	2G
w00an15	Kregel	The stellar velocity distribution in NGC5529	1D
w00an16	de Zeeuw	Mapping galaxies along the Hubble sequence	3D

INT Semester 00a

Proposal	Proposer	Subject	Allocation
i00an01	Tschager	The optical hosts of young radio sources	2D 3G
i00an05	Bezecourt	R and Z band imagery of cluster A2219	1D 1G
i00an08	Jimenez	Stellar library for stellar population synthesis	5B
i00an11	Orosz	Atmospheres of Subdwarf Binary Stars	5B

JKT Semester 00a

Proposal	Proposer	Subject	Allocation
j00an01	van der Hulst	R band imaging of WHISP galaxies	5D 5G
j00an02	Pickering	B-band imaging of LSB galaxies	4D 1G
j00an03	Van den Berg	An X-ray blue straggler in M67	5x0.5B
j00an04	Van den Berg	An X-ray blue straggler in NGC752	1.5B
j00an07	Le Poole	Photometric calibrators for the 2nd GSC	2B
j00an09	Orosz	Multicolor light curves for HZ22	3B

JCMT Semester 00a

Proposal	Proposer	Subject	Allocation
m00an01	van der Werf	Warm, dense molecular gas in the Antennae	56h C2/8h C3*
m00an02	Israel	12CO/13CO ratios in galaxies	17h D1*/22h C5*
m00an03	Israel	Dust Emission from NGC 1569	6h B5
m00an05	Henning	Magnetic fields in Bok globules	48h B2
m00an06	Stark	Warm gas in the inner envelopes of YSO's	32h A5
m00an08	Rottgering	Star formation in the early Universe	24h B4
m00an09	Kemper	Mass loss history of oxygen-rich AGB stars	12h A3/24h B3/20h C1
m00an13	Barthel	Fraction of starbursts in the FIRST survey	25h B1
m00an14	Stark	Deuterium chemistry in YSO's	20h A4/5h C4*
m00an15	Boonman	Structure of massive protostars	25h A2
m00an16	Smith	SCUBA observations of GRB counterparts	24h ToO
m00an22	Best	Star forming galaxies in clusters at z=1	64h A1
m00an23	Pickering	Dust in LSB galaxies	40h B6
			* backup

WSRT Semester 00a

Proposal	Proposer	Subject	Allocation
r99a38	v.d. Hulst	HI survey of the Coma cluster	440h
r00a03	Witzel	Extreme Tb in flat spectrum radio sources?	53h
r00a04	Kloeckner	Hydroxyl emission in ultraluminous IR galaxies	18h *
r00a05	Sjouwerman	Search for OD in the galaxy	40h
r00a06	Oosterloo	HI in and around the radio galaxy Coma A	56h
r00a07	Morganti	HI absorption in radio galaxies	36h *
r00a08	Rol	Rapid follow-up and monitoring of GRB's	450h
r00a09	van Albada	WHISP	585h
r00a10	Liang	Origin of cluster-wide radio halo sources	4 8h *
r00a11	Kouwenhoven	Pulsar magnetospheric emission mapping	30h
r00a12	Ramachandran	Coherent radiation patterns in pulsar emission	6h
r00a13	Camilo	Scattering timescales for galactic pulsars	12h *
r00a14	Stappers	High precision timing program	144h
r00a15	Galama	Monitoring of SNe with suspect central engines	169h
r00a17	Lane	Candidate 21cm absorption systems at 0.2<z<1.0	80h
r00a18	Mitra	Non-dipolar magnetic fields in neutron stars	9h
r00a19	de Bruyn	Limiting Tb of flat spectrum radio sources	60h
r00a20	Jouteaux	Survey for pulsars in the Cygnus region	135h *
r00a21	Briggs	Test method for measuring global reionization	24h
r00a22	de Bruyn	Microlensing in B1600+434: macho's at z=0.4	44h (60h *)
r00a23	de Heij	Confirming observations of new CHVC candidates	27h
r00a24	Dennett-Thorpe	The ISM towards J1819+3845: the local bubble?	73h *
r00a25	Dennett-Thorpe	Continuation of Monitoring of J1819+3845	117h
r00a26	Dennett-Thorpe	Microarcsecond extragalactic radio sources	40h *
r00a28	Jaffe	HI in the supergalaxy toward the Virgo cluster	40h
			* backup

WHT Semester 00b

Proposal	Proposer	Subject	Allocation
w00bn001	Bottema	Distributionof Dark Matter in late-type spiral galaxies	3D
w00bn002	van Kerkwijk	The anomalous X-ray pulsar 4U 0142+614	2D
w00bn005	Tschager	The optical hosts of faint CSS radio sources	2G
w00bn006	de Zeeuw	Mapping early-type galaxies along the Hubble Sequence	3D
w00bn007	van Woerden	Distances of HVC anticenter complexes and HVC Complex H	1G 2B
w00bn009	Kregel	Dynamics of the thin disk of NGC891	2D
w00bn010	Rutten	The distance to cataclysmic variables	1B
w00bn011	Vreeswijk	Imaging of GRBs &spectroscopy of GRB-related optical/IR transients	ToO
w00bn014	Oosterloo	The origin of the gaseous halo of NGC 2403	3G
i00bn002	Orosz	A dynamical study of KPD 1930+2752	12B

INT Semester 00b

Proposal	Proposer	Subject	Allocation
i00bn001	Jimenez	Much-improved stellar library for stellar population synthesis	6B
i00bn003	Sackett	The MEGA survey: mapping microlensing in M31	1D 2G 2B
w00bn008	Noordermeer	Optical spectroscopy of galaxies in the WHISP sample	4D2G

JKT Semester 00b

Proposal	Proposer	Subject	Allocation
j00bn001	Noordermeer	R band imaging of galaxies in the WHISP sample	10D 6G
j00bn002	Orosz	A photometric study of KPD 1930+2752	8B

JCMT Semester 00b

Proposal	Proposer	Subject	Allocation
m00bn004	Israel	12CO/13CO ratios in galaxies	39h C3
m00bn006	Henning	Massive protostellar objects towards luminous IRAS sources	20h C2
m00bn007	Tielens	Using methanol lines to trace infall	46h C1
m00bn009	Higdon	The radial distribution of molecular gas in M33	60.5h D1,11.5h+
m00bn011	van der Werf	Gravitational lensing of high-redshift starburst galaxies	32h B2
m00bn012	van der Werf	Completion of the SCUBA cluster survey	24h B1 *
m00bn015	van der Werf	Completion of the SCUBA survey of the NTT deep field	24h A2 *
m00bn016	Thi	Physical &chemical structure of circumstellar disks in TW Hyd	24h C4
m00bn017	Best	Star forming galaxies in clusters at redshift one	48h A1 *
m00bn018	Israel	Very warm gas in NGC 6946 and IC 342	36h B4
m00bn019	Kemper	Mass loss history of oxygen-rich AGB stars	13h A4, 17h B3
m00bn022	Smith	SCUBA observations of Gamma-Ray Burster counterparts	24h ToO
m00bn025	Stark	Deuterium chemistry in young stellar objects	15h A5
m00bn026	Boonman	Physical and chemical structure of the inner regions	17.5h A3

*: proposals which will continue in 01a if not finished in 00b; +: backup

WSRT Semester 00b

Proposal	Proposer	Subject	Allocation
r00b005	Rottgering	Radio observations of candidate proto-clusters	13h
r00b006	Oosterloo	HI observations of dusty radio galaxies	13h
r00b010	van Albada	WHISP	474h
r00b012	Rol	Continuation of rapid follow-up and long-term monitoring of GRB	192h
r00b013	Walker	Lensing of radio pulsars	76h
r00b015	Klockner	Hydroxyl megamaser galaxies	34h
r00b016	Stappers	High precision timing program	114h
r00b018	de Bruyn	Microlensing in the double lens B1600 + 434: constraining macho	159h
r00b019	Lane	Time variability of the z=0.313 21cm absorption towards B1127-1	36h
r00b020	Paragi	Searching for HI absorption by the excretion flow in SS433	26h
r00b021	Braun	The HI edges of spiral galaxy disks	26h
r00b022	Dennett-Thorpe	Second epoch monitoring of J1819+3845	46h
r00b025	Perez-Torres	The low-frequency radio emission of SN 1993J	2h

7. Commercial Activities

The main goal of the SKAI-high project is to seek co-operation with Small and Medium sized Enterprises (SMEs) through two knowledge-based clusters. One cluster focuses on technologies at radio frequencies, while the other is centred on optical technology. The main goal for ASTRON is to secure the availability of knowledge and technology suppliers for future projects at ASTRON. The process of knowledge dissemination can be illustrated by some examples of collaborations in the past year. From these examples we may conclude that knowledge and technology of ASTRON is easily accessible.

A manufacturer of so called "intra ocular lenses" (*which are inserted surgically*) called upon ASTRON for assistance in their drive for continuous improvement of production quality and test procedures. ASTRON was able to suggest a test set-up based upon pattern recognition techniques. The proposed tests could be implemented in parallel with the company's current testing methods, which quickly led to a set of objective test results without infringing upon production schemes.

ASTRON also performed a study of the behaviour of so-called radio based tagging responders. Radio Frequency Identification transponders (RFID) use radio frequencies to provide an energy field which powers up transponder(s) in the field, enabling them to return their identity back to the reader. The transponders can be attached for instance to articles in a store, with the aim of theft prevention. RFID has numerous applications. In this case, RFID is applied in a logistics environment. The business that requested the study is using a commercial off-the-shelf reader coupled to an antenna. The technology challenge posed to ASTRON was to provide optimal detection range. ASTRON's antenna modelling tools and techniques, specifically developed for astronomical applications, turned out to be very useful to model and solve the problem.

On November 23rd a workshop was organized on the subject: "Integral design in practice". Through a mixture of lectures and tours of our facilities various design subjects were presented. In total 30 participants from SMEs, technical schools and scientific institutes from the northern part of the Netherlands attended the workshop.

Figure 7.1 A group of visitors being shown round ASTRON's facilities. These images show a tour of the VISIR integration room, with (top) a description of the mirrors being produced and (bottom) a full scale dummy of the mechanical interface to a unit VLT telescope.

8. ASTRON Organization and Personnel

8.1 Members of the Board

Prof. dr. T.S. van Albada, University of Groningen
Prof. dr. E.P.J. van den Heuvel, University of Amsterdam – Chair
Prof. W. Hoogland, University of Amsterdam
Prof. dr. A. Achterberg, Utrecht University
Prof. dr. G.K. Miley, University Leiden
Prof. dr. ir. W.M.G. van Bokhoven, Technical University of Eindhoven

Prof. dr. H.R. Butcher, ASTRON, Executive Secretary

8.2 Personnel

8.2.1 Management Team

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

8.2.2 Employees Council

J.P. Hamaker, Chair
J. Beuving, Secretary and Deputy Chair
M. Arts
A. Gunst
L. Nieuwenhuis
N. Schonewille
J.G. bij de Vaate

8.2.3 Personnel/Staff

(status at 31/12/2000)

8.2.3.1 Policy and Administration

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

M.P. van Haarlem

Spectrum Management
T.A.T. Spoelstra

Finance and Personnel
A. Bennen
C. Boon
A.H. Doek
P. Hellinga
A. Koster

8.2.3.2 Technical Laboratory

A. van Ardenne	Head of Technical Laboratory
C.A. Leering	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
M. van der Meulen
G.W. Schoonderbeek
R. de Wild
S.T. Zwier

Antennas
M.J. Arts
G.W. Kant
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

Various Projects
S.A. Alliot
J.D. Bregman
S. Damstra
Y.J. Koopman

Optical Projects
B.D. Bos
E.J. Elswijk
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
J. Tinbergen

Mechanical Design
R. van Dalen
J.W. Kragt
G. Kroes
J.H. Pragt

Development
N. Ebbendorf
A.M. Koster
E. Mulder
H. Snijder

Project Management/Planning
J.W. Beuving
A.J.J. van Es
R. Kiers

DZB-IVC Production
A. Eybergen
A.P. Schoenmakers

SKA Research and Development
O.S.O. Apeldoorn
M. Drost
K.F. Dijkstra
G.A. Hampson
J. Morawietz
R.H. Witvers

Industrial Liaison
H.J. Boer
R.G.B. Halfwerk

8.2.3.3 Radio Observatory

W.A. Baan	Director 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

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
F.J. Nijenboer
J.P.R. de Reijer
H.J. Stiepel
J. Stolt
J. Weggemans

8.2.3.4 Facilities Management

B.A.P. Schipper	Head of Facilities Management

Mechanical Workshop
J. Bakker
M. Bakker
J.S. Dekker
G. Hagenauw
J. Idserda
T.J. de Jong
G.J.M. Koenderink
S.J. Kuindersma
J.H. Nijboer
M.R. Schuil
N. Tromp

Computer Systems
R. Boesenkool
R.M. Luichjes
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. Financial Report of 2000

ASTRON Institute

Financial Report of 2000 compared with 1999

	2000			1999
	Budget	Actual	Difference	Actual
INCOME				
Government Grants-Min of Education,Culture & Science	17,262,700	17,262,700	0	17,926,600
Subsidies/Contributions by third parties	3,091,000	3,218,026	127,026	2,019,628
Cash Management	140,000	288,640	148,640	151,919
Other Income	295,000	344,586	49,586	515,376
Total Income	**20,788,700**	**21,113,952**	**325,252**	**20,613,523**
EXPENDITURE				
Grants/Expenditures	20,788,700	21,149,328	360,628	20,683,970
Other Expenditures (Alloc to Provisions)	0	3,400,000	3,400,000	0
Total Expenditure	**20,788,700**	**24,549,328**	**3,760,628**	**20,683,970**
BALANCE	**0**	**-3,435,376**	**-3,435,376**	**-70,447**

(all amounts in Dutch guilders)

10. Publications in 2000

10.1 Publications by Astronomical Staff

Axon, D.J., Capetti, A., Fanti, R., **Morganti, R.**, Robinson, A., Spencer, R., "The Morphology of the Emission-Line Region Of Compact Steep-Spectrum Radio Sources", The Astronomical Journal, Volume 120, Issue 5, pp.2284-2299. (2000)

Baan, W.A., "Megamasers and their host galaxies", Galaxies and their Constituents at the Highest Angular Resolution, International Astronomical Union. Symposium no.205. Manchester, England, August 2000.

Bradley, L.D., Kaiser, M.E., **Baan, W.A.**, Crenshaw, D.M., "Radio Observations of the Near-nuclear Region of M51", American Astronomical Society Meeting **197**, 108.08, (2000)

Braun, R., Burton, W.B., "High-resolution imaging of compact high-velocity clouds", Astronomy and Astrophysics, v.354, p.853-873 (2000)

Britzen, S., Vermeulen, R.C., Taylor, G.B., Pearson, T.J., Browne, I.W., et al., "CJ-F: The kinematics of 242 AGN", Galaxies and their Constituents at the Highest Angular Resolution, International Astronomical Union. Symposium no.205. Manchester, England, August 2000.

Britzen, S., Witzel, A., Krichbaum, T.P., Campbell, R.M., Wagner, S.J., Qian, S.J., "Three-year VLBI monitoring of PKS 0420-014", Astronomy and Astrophysics, Vol.360, p.65-75, (2000)

Burton, W.B., **Braun, R.**, "Morphological Characteristics of Compact High-Velocity Clouds Revealed by High-Resolution WSRT Imaging", Small Galaxy Groups: IAU Colloquium 174, ASP Conference Series, Volume 209.Held in Turku, Finland, 13-18th June 1999.Edited by Mauri J.Valtonen and Chris Flynn. Published by Astronomical Society of the Pacific, San Francisco, CA, P.136., (2000)

Butcher, H.R., "Radio Telescopes", Proc. SPIE Vol.4015, 4015, (2000)

Capetti, A., de Ruiter, H.R., Fanti, R., **Morganti, R.**, Parma, P., Ulrich, M.-., "HST snapshot survey of the B2 sample of low luminosity radio-galaxies: a picture gallery", Astronomy &Astrophysics, v.362, p.871-885 (2000)

Carilli, C.L., Menten, K.M., Stocke, J.T., Perlman, E., **Vermeulen, R.**, Briggs, F., **de Bruyn, A.G.**, Conway, J., Moore, C.P., "Astronomical constraints on the cosmic evolution of the fine structure constant and possible quantum dimensions.", Phys. Rev. Lett., 85, 5511-5514 (2000)

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12. ASTRON/JIVE Colloquia

Name	Institute	Title	Date
M. Putman	Mount Stromlo and Siding Spring Observatory	High-Velocity Clouds: Tidal Debris or baby galaxies?	07-01-00
D. Werthimer		Is anybody out there?	14-01-00
J. Higdon	RUG Groningen	The Neutral ISM and Massive Star Formation in Ring Galaxies.	28-01-00
L. Pentericci	MPIA Heidelberg	The most distant radio galaxies: probes of massive galaxy formation.	04-02-00
L. Koopmans	RUG Groningen	Strong & Micro-lensing in the radio.	11-02-00
R. Millenaar, M. Bentum, R. Vermeulen, M. Kouwenhoven, W. Baan	ASTRON/UU Utrecht	The Mars Lander Project at WSRT	17-02-00
J.G. bij de Vaate	ASTRON	First NFRA RF Integrated Circuits Results and Future Plans.	18-02-00
O. Apeldoorn	ASTRON	First NFRA RF Integrated Circuits Results and Future Plans.	18-02-00
H. Hanenburg	ASTRON	Presentation mechanical design MIDI and Video presentation of VISIR hardware in Saclay.	24-02-00
R. Ortiz	UL Leiden	AGB stars in the bulge detected by ISOGAL.	25-02-00
A.J. Boonstra	ASTRON	Radio interference mitigation: the challenge, current NFRA activities, and plans.	10-02-00
G. de Bruyn	ASTRON	Rapid Radio Variability of AGN.	17-03-00
R. Taylor	Galgary	Canadian Galactic Plane Survey.	24-03-00
N. Evans	University of Texas and UL Leiden	Can we prove that stars form by Gravitational Collapse?	31-03-00
J. de Haas	ASTRON	VISIR	14-04-00
J. W. Pel	ASTRON	VISIR	14-04-00
R. Hoogerwerf	UL Leiden	The origin of runaways stars.	28-04-00
U. Klein	University of Bonn	Neutral Hydrogen Bubbles in galaxies.	12-05-00
J. Hamaker	ASTRON	Coherency-matrix Self- 'Calibration'.	19-05-00
R. Fender	UVA Amsterdam	The disc: Jet coupling in X-ray binary systems.	26-05-00
E. Sadler	University of Sydney	Radio Sources in the 2dF Galaxy Redshift Survey.	06-06-00
B. Cotton	NRAO and UL Leiden	The Environment of the CSS Quasar 3C138.	09-06-00
D. Melrose	University of Sydney	Scintillations and circular polarization in compact extragalactic sources.	16-06-00
P. Best	UL Leiden	The nature, environments and interactions of powerful radio galaxies at redshift z - 1.	27-06-00
R. Allen	Space Telescope Science Institute	Crowed-Field Astrometry and Imaging with the Space Interferometry Mission.	30-06-00
A. Leshem	TU Delft	Spatial interference mitigation and imaging.	07-07-00

Name	Institute	Title	Date
A. Parfitt	ATNF	The Luneburg Lens as a SKA Element	01-08-00
K. Wills	Sheffield University	Probing the Centre of the Starbust Galaxy M82	04-09-00
L. Ligthart	TU Delft	International Research Center for Telecommunication, Transmission and Radar of the TU Delft	08-09-00
J. Chengalur	NCRA/TIFR	21-cm observations of Damped Ly alpha systems.	15-09-00
R. Walterbos	University of New Mexico	The warm Ionized medium in Spiral Galaxies.	28-09-00
H. Hoekstra	RUG Groningen	Weak lensing by low mass groups: implications for Omegacam	29-09-00
W. Lane	RUG Groningen	HI 21 cm Absorbers at Moderate Redshifts	06-10-00
D. de Boer	SETI Insititute	The new project engineer for the SETI ATA will talk about the state of the project.	13-10-00
M. Bureau	UL Leiden	SAURON: Overview and first science results	20-10-00
W. van Breugel	University of California	The Highest Redshift Radio Galaxies	02-11-00
C. de Breuck	UL Leiden	High redshift radio Galaxies: Search Techniques and Emission Line Properties	10-11-00
M. Kouwenhoven	UU Utrecht	Pulsar observations with the Westebork Synthesis Radio Telescope	17-11-00
C. Craeye	TU Eindhoven	Phased-array simulation algorithms	17-11-00
F. van der Tak	UL Leiden	The embedded phase of massive star formation	24-11-00
J. Tinbergen	ASTRON	Optical vs radio aperture synthesis: principles and implementation	01-12-00
P. Fridman	ASTRON	RFI suppression at WSRT: experimental system, algorithms, test observations	08-12-00
A. Tarchi	University of Bonn	Radio observations of starbust galaxies: the case of NGC2146	14-12-00
C. Craeye	TU Eindhoven	Phased-array simulation algorithms	15-12-00

13. Visitors

Name	Institute	Arrival	Departure	Contact
H. Xiaoyu	Shanghai Astronomical Observatory	01-01-00	20-01-00	M. Garrett
V. Tornatore	Plitecnioc Milano	01-01-00	13-01-00	D. Gabuzda
H. Hagiwara	MPIFR Bonn	17-01-00	24-01-00	R. Vermeulen
A. Stirling	University of Lancaster	20-01-00	31-01-00	M. Garrett
C. de La Force	Jodrell Bank	20-01-00	31-01-00	M. Garrett
E. Rol	UVA Amsterdam	24-01-00	04-02-00	R. Strom
J. Dennett - Thorpe	RUG Groningen	24-01-00	25-01-00	D. Gabuzda
S. Garrington	Jodrell Bank	24-01-00	28-01-00	M. Garrett
R. Spencer	Jodrell Bank	25-01-00	30-01-00	M. Garrett
R. Noble	Jodrell Bank	16-02-00	18-02-00	H.J. van Langevelde
A. Mc. Donald	Jodrell Bank	20-02-00	27-02-00	M. Garrett
A. Stirling	University of Lancaster	27-02-00	12-03-00	D. Gabuzda
H. Kollen	Fokker Space Leiden	02-03-00	03-03-00	M. de Vos
L. Fuhrmann	MPIFR Bonn	08-03-00	10-03-00	S. Britzen
B. Scott	University of Calgary	12-03-00	18-03-00	L. Gurvits
E. Fomalont	NRAO Charlottesville	12-03-00	18-03-00	L. Gurvits
Z. Paragi	FOMI Hongarije	12-03-00	25-03-00	L. Gurvits
L. Fuhrmann	MPIFR Bonn	16-03-00	18-03-00	S. Britzen
W. Brouw	ATNF Australie	19-03-00	26-03-00	J. Noordam
P. Snoeij	Fokker Space Leiden	20-03-00	21-03-00	M. van Haarlem
R. Taylor	University of Calgary	23-03-00	25-03-00	G. de Bruyn
R. Taylor	University of Calgary	27-03-00	30-03-00	G. de Bruyn
S. Gibson	University of Calgary	27-03-00	06-04-00	G. de Bruyn
W. Brouw	ATNF Australie	31-03-00	07-04-00	J. Noordam
P. Hazell	Avonsoll Ltd Bristol	02-04-00	12-04-00	H.J. van Langevelde
M. Haverkom	UL Leiden	04-04-00	06-04-00	G. de Bruyn
A. Lecacheux	RIR Frankrijk	17-04-00	18-04-00	S. Alliot
M. Rosolen	RIR Frankrijk	17-04-00	18-04-00	S. Alliot
L. Denis	RIR Frankrijk	17-04-00	18-04-00	S. Alliot
V. Clerc	Observatoire Meudon	17-04-00	18-04-00	S. Alliot
A. Gregoor	NWO The Hague	01-05-00	02-05-00	C. Boon
C. Leinert	ESO Munich	02-05-00	04-05-00	A. Glazenborg
K. Wagner	ESO Munich	02-05-00	04-05-00	A. Glazenborg
R. Rohloff	ESO Munich	02-05-00	04-05-00	A. Glazenborg
W. Laun	ESO Munich	02-05-00	04-05-00	A. Glazenborg
R. Ramachandran	UVA Amsterdam	02-05-00	03-05-00	
J. W. Pel	RUG Groningen	03-05-00	04-05-00	A. Glazenborg
R.Waters	UVA Amsterdam	03-05-00	04-05-00	A. Glazenborg
A. Korlenkov	Logics Unlimited Scandinavic AB	05-05-00	04-06-00	L. Gurvits
A. Gregoor	NWO The Hague	08-05-00	09-05-00	C. Boon
D. Thilker	NRAO Socorro	10-05-00	21-05-00	R. Braun
N. Killeen	ATNF Australie	10-05-00	12-05-00	G. van Diepen
W. Tschager	UL Leiden	10-05-00	13-05-00	R. Vermeulen
W. Vlemmings	UL Leiden	10-05-00	13-05-00	H.J. van Langevelde
M. Caillat	Observatoire de Paris	10-05-00	11-05-00	G. van Diepen
N. Gizani	University of Madeira	11-05-00	20-05-00	M. Garrett
U. Klein	University Bonn	11-05-00	15-05-00	R. Morganti
A. Gregoor	NWO The Hague	15-05-00	16-05-00	C. Boon
J. Dennett - Thorpe	RUG Groningen	16-05-00	19-05-00	D. Gabuzda
A. Gregoor	NWO The Hague	22-05-00	23-05-00	C. Boon
R. Weber	University of Orleans	24-05-00	25-05-00	S. Alliot
A. Gregoor	NWO The Hague	29-05-00	30-05-00	C. Boon
E. Sadler	University of Sydney	29-05-00	10-06-00	R. Morganti
K. Wagner	University of Colorado	29-05-00	30-05-00	J. Bregman

Name	Institute	Arrival	Departure	Contact
M. Giroletti	University of Bologna	29-05-00	14-08-00	M. Garrett
A. Donar	Wesleyan University	03-06-00	14-08-00	G. de Bruyn
J. Donkers	UU Utrecht	04-06-00	09-06-00	N. Vermeulen
A. Gregoor	NWO The Hague	05-06-00	07-06-00	C. Boon
J. Smoker	Queen's University	05-06-00	09-06-00	R. Braun
N. Bastian	University of Wisconsin	05-06-00	14-08-00	R. Braun
X. Marguerettaz	University of Orleans	05-06-00	28-09-00	S. Alliot
N. Garnich	Moscow State University	07-06-00	26-08-00	D. Gabuzda
B. Cotton	UL Leiden	08-06-00	09-06-00	R. Morganti
A. Gregoor	NWO The Hague	19-06-00	21-06-00	C. Boon
V. de Hey	UL Leiden	20-06-00	30-09-00	R. Braun
G. Delgado	ESO Chile	21-06-00	23-06-00	H. Butcher
A. Gregoor	NWO The Hague	26-06-00	28-06-00	C. Boon
P. Augusto	University of Madeira	03-07-00	13-07-00	D. Gabuzda
J. Lazendic	University of Sydney	05-07-00	12-07-00	J. Dickel
M. Brentjens	University of Utrecht	05-07-00	05-08-00	R. Strom
J. Chengalur	NCRA/TIFR, Pune, India	07-07-00	30-09-00	G. de Bruyn
K. Weiler	Naval Research Laboratory USA	09-07-00	12-07-00	M. van Haarlem
A. Roy	MPIfR Bonn	10-07-00	14-07-00	D. Gabuzda
C. Reynolds	JIVE	10-07-00	07-08-00	M. Garrett
E. Middelberg	Bonn University	10-07-00	14-07-00	D. Gabuzda
F. Hommes	Fokker Space Leiden	10-07-00	12-07-00	M. van Haarlem
P. Snoeij	Fokker Space Leiden	10-07-00	12-07-00	M. van Haarlem
Y. Jiyune	Onsala Space Observatory	17-07-00	14-10-00	C. Phillips
W. Brouw	ATNF	21-07-00	02-08-00	J. Noordam
G. Swarup	TIFR Pune University	30-07-00	02-08-00	W. Baan
V. Clerc	Observatoire Meudon	31-07-00	11-08-00	S. Alliot
A. Kus	TRAO Polen	05-08-00	06-08-00	R. Schilizzi
Fam. Aller	Unversity of Michigan	18-08-00	26-08-00	D. Gabuzda
S. Ananthakrishnan	TIFR Pune University	18-08-00	25-08-00	W. Baan
L. Pustilnick	SAO	20-08-00	27-08-00	P. Fridman
C. Walker	NRAO	20-08-00	23-08-00	L. Gurvits
M. Avruch	ISAS Japan	21-08-00	01-01-01	H.J. van Langevelde
I. Fejes	Satellite Geodetic Observatory	28-08-00	08-09-00	L. Gurvits
G. Comoretto	Arcetri	03-09-00	07-09-00	M. de Vos
I. Snellen	Institute of Astronomy, Cambridge	04-09-00	06-09-00	G. de Bruyn
R. Plante	Institute of Astronomy, Cambridge	04-09-00	06-09-00	J. Noordam
R. Calders	TU Delft	04-09-00	08-09-00	A.J. Boonstra
K. Wills	University of Sheffield	06-09-00	13-09-00	R. Morganti
A. Singal	University of Bonn	11-09-00	23-09-00	R. Strom
C. Craeye	TU Eindhoven	12-09-00	13-09-00	B. Smolders
A. Pushkarev	Astro Space Center	22-09-00	17-10-00	D. Gabuzda
E. Corbelli	Arcetri	26-09-00	29-09-00	R. Braun
A. Gunn	Jodrell Bank	28-09-00	01-10-00	C. Reynolds
F. Sluiter	LIACS	02-10-00	04-10-00	A. Kokkeler
M. Haverkorn	UL Leiden	10-10-00	12-10-00	G. de Bruyn
D. de Boer	SETI	12-10-00	14-10-00	J.G. bij de Vaate
M. Bremer	UL Leiden	19-10-00	20-10-00	R. Morganti
T. Carozzi	Swedish Institute of Space Physics	22-10-00	23-10-00	H. Butcher
M. Ribo	University of Barcelona	23-10-00	01-12-00	D. Gabuzda
W. Vlemmings	UL Leiden	23-10-00	27-10-00	J.H. van Langevelde
T. Wilklind	Onsala Space Observatory	24-10-00	29-10-00	R. Morganti
M. Haverkorn	UL Leiden	31-10-00	02-11-00	G. de Bruyn
V. de Hey	UL Leiden	07-11-00	09-11-00	R. Braun
Dhr. Chang	NRAO Socorro NM	12-11-00	14-11-00	W. Baan
Dhr. Magnum	NRAO Socorro NM	12-11-00	14-11-00	W. Baan
R. Freund	NRAO Socorro NM	12-11-00	14-11-00	W. Baan
A. Stirling	Unversity Central Lancashire	17-11-00	27-11-00	D. Gabuzda

Name	Institute	Arrival	Departure	Contact
C. de La Force	Jodrell Bank	17-11-00	27-11-00	D. Gabuzda
E. Ros	MPIfR Bonn	27-11-00	01-12-00	D. Gabuzda
A. Tarchi	University of Bonn	05-12-00	20-12-00	D. Gabuzda
C. Leinert	MPIA Germany	05-12-00	08-12-00	J. de Haas
U. Graser	MPIA Germany	05-12-00	08-12-00	J. de Haas
W. Laun	MPIA Germany	05-12-00	08-12-00	J. de Haas
V. de Hey	UL Leiden	05-12-00	07-12-00	R. Braun
J.W. Pel	RUG Groningen	06-12-00	07-12-00	J. de Haas
W. Tschager	UL Leiden	11-12-00	21-12-00	D. Gabuzda
G. Durand	Saclay	13-12-00	14-12-00	J. de Haas
P.O. Lagage	Saclay	13-12-00	14-12-00	J. de Haas
C. Lyrand	Saclay	13-12-00	14-12-00	J. de Haas
Y. Rio	Saclay	13-12-00	14-12-00	J. de Haas
P. Galdermard	Saclay	13-12-00	14-12-00	J. de Haas
Fam. Richett		18-12-00	19-12-00	G. de Bruyn
I. Snellen	Institute of Astronomy, Cambridge	18-12-00	22-12-00	D. Gabuzda
W. Vlemmings	UL Leiden	19-12-00	20-12-00	H. J. van Langevelde

14. Abbreviations

A/D	Analogue/Digital
AAD	Adaptive Antenna Demonstrator
ABES	Adaptive Beamformer Experimental System
ADBF	Adaptive Digital Beamforming
ADC	Analogue to Digital Converter
AGB	Asymptotic Giant Branch
AGN	Active Galactic Nucleus
AIPS	Astronomical Image Processing System
AIPS++	New version of AIPS
ALMA	Atacama Large Millimetre Array
ATCA	Australia Telescope Compact Array
ATNF	Australia Telescope National Facility
AWE	Adaptive Weight Estimator
BEE	Backend Electronics
CEPT	European Commission for Post and Telecommunication
CHVC	Compact High Velocity Clouds
CLASS	Cosmic Lens All-Sky Survey
CNC	Computer Numerically Controlled milling
CNIC	Channel Network Interface Cards
CNM	Cold Neutral Medium
CRAF	Committee on Radio Frequencies
DAT	Digital Audio Tape
DBF	Digital Beamforming
DCB	Digital continuum Backend
DDRG	Double-double radio galaxies
DIFMAP	Software for Reduction of Radio Interferometry Data
DSP	Digital Signal Processor
DZB	New Digital Backend for the WSRT
ECHO	Experimental Chassis for OSMA
ESF	European Science Foundation
ESO	European Southern Observatory
EVN	European VLBI Network
FC	Future Correlator
FDR	Final Design Review
FEC	Front End Controller
FFT	Fast Fourier Transform
FITS	Flexible Image Transport System
FWHM	Full Width at Half Maximum
GaAs	Gallium Arsenide
GBE	Gebiedsbestuur Exacte Wetenschappen
GULMR	Grating Unit Low and Medium Resolution
HXF	Digital Hybrid Correlator
IC	Integrated Circuit
ICT	Information and Communications Technology
IDC	IF to Digital Converter
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency
INT	Isaac Newton Telescope
IRAS	Infrared Astronomical Satellite
ISM	Interstellar Medium
ITU-R	Radio communication sector of the International Telecommunication Union
IUCAF	Commission on the Allocation of Frequencies for Radio Astronomy and Space Science
IVC	IF-to-Video Converter
JCMT	James Clerk Maxwell Telescope
JIVE	Joint Institute for VLBI in Europe
JPL	Jet Propulsion Laboratory
LNA	Low Noise Amplifier
LNA	Low Noise Amplifier
LO	Local Oscillator
LOFAR	Low Frequency Array
MACHO	Massive Compact Halo Objects
MATLAB	Mathematical Modelling Tool
MFFE	Multi Frequency Front Ends
MIDI	Mid-Infrared Interferometry Instrument for ESO's VLT
MIRIAD	Multi-channel Image Reconstruction, Image Analysis and Display
MIT	Massachusetts Institute of Technology
MoU	Memorandum of Understanding
MPIA	Max Planck Institute for Astronomy, Heidelberg
MPL	Mars Polar Lander
MS	Measurement Set
MSFITS	Program to make Measurement Sets FITS files
NASA	National Aeronautics and Space Administration
NCRA	National Centre for Radio Astrophysics
NEWSTAR	Westerbork Data Processing Software System
NIKHEF	Nationaal Instituut voor Kernfysica en Hoge-Energiefysica
NOEMI	Nulling Obstructing Electromagnetic Interferers
NOVA	Nederlandse Onderzoeksschool voor Astronomie
NRAO	National Radio Astronomy Observatory
NRL	Naval Research Laboratory
NWO	Nederlandse Organisatie voor Wetenschappelijk Onderzoek
OECD	Organization for Economic Cooperation and Development
OSMA	One Square Metre Array
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PuMa	Pulsar Machine
RAID	Redundant Array of Inexpensive Disks
RAP-Unit	Reduction, Acquisition, Processing unit
RF	Radio Frequency
RFI	Radio Frequency Interference
RF-IC	Radio Frequency Integrated Circuit
RFID	Radio Frequency Identification transponders
RRG	Robustness, Reliability and Quality of Data
RT	Radio Telescope
S/N	Signal to Noise Ratio
SCN	Newstar File Format
SETI	Search for Extraterrestrial Intelligence
SG	Study Group
SiGe	Silicon Germanium
SKA	Square Kilometre Array
SME	Small and Medium size Enterprises
SNR	Supernova Remnant
STW	Stichting voor de Technische Wetenschappen
TADU	Tied Array Distribution Unit
TG	Task Group
THEA	Thousand Element Array
TMS	Telescope Management System
TNIC	Tile Network Interface Card
UHF	Ultra High Frequency

UNESCO	United Nations Educational, Scientific and Cultural Organization
UVFITS	Program to make (u,v) FITS files
VAX	Computer made by Digital Equipment Corporation (DEC)
VCSEL	Vertical Cavity Surface Emitting Laser
VHDL	VHSIC Hardware Description Language
VHSIC	Very High Speed Integrated Circuit
VISIR	VLT Imaging and Spectroscopy in the Infrared
VLA	Very Large Array
VLBI	Very Long Baseline Interferometry
VLT	Very Large Telescope
VM	Vector Modulator
WENSS	Westerbork Northern Sky Survey
WHT	William Herschel Telescope
WNM	Warm Neutral Medium
WRC	World Radio communication Conferences
WSRT	Westerbork Synthesis Radio Telescope
YSO	Young Stellar Object

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