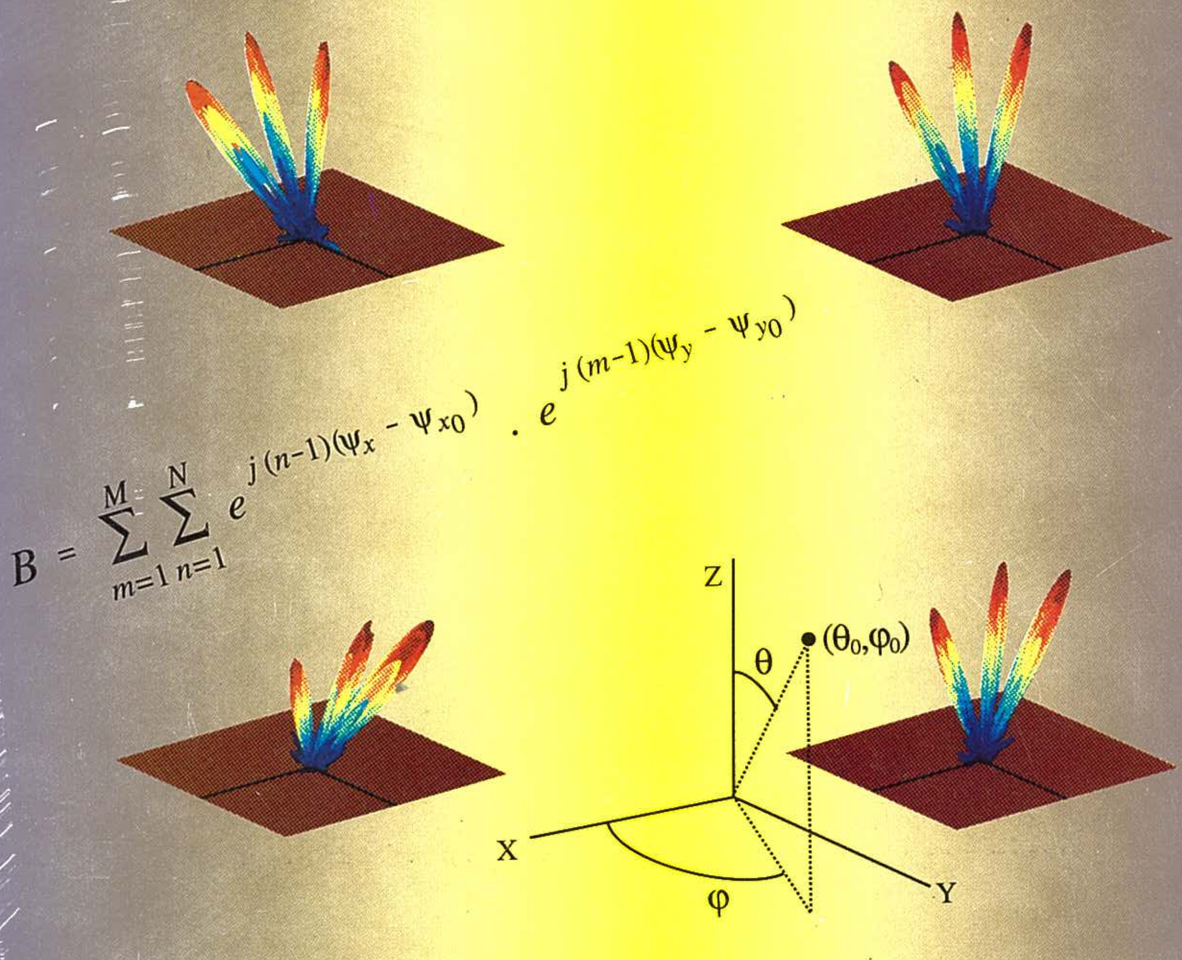
Netherlands
Foundation for Research
in Astronomy

ANNUAL REPORT 1995



Front cover

The beam patterns of a multibeaming planar phased array antenna are shown. They consist of 10 × 10 elements in the x- and y-directions. A color index indicates the sensitivity of the antenna in a specific direction, where red corresponds to maximum sensitivity.
The four images can be looked upon as four intervals of an electronic scan, starting at the upper left and going clockwise.
The sensitivity of a single beam, pointing with maximum sensitivity in direction (θ_0,ϕ_0), as a function of a specific direction (θ,ϕ), is calculated with the array factor B, given by

$$B = \sum_{m=1}^{M} \sum_{n=1}^{N} e^{j(n-1)(\psi_x - \psi_{x0})} \cdot e^{j(m-1)(\psi_y - \psi_{y0})}$$

where

$$\psi_x = \frac{2\pi}{\lambda} d_x \cos\phi \sin\theta \qquad \psi_{x0} = \frac{2\pi}{\lambda} d_x \cos\phi_0 \sin\theta_0$$

$$\psi_y = \frac{2\pi}{\lambda} d_y \cos\phi \sin\theta \qquad \psi_{y0} = \frac{2\pi}{\lambda} d_y \cos\phi_0 \sin\theta_0$$

In this relation N and M are the number of elements in the x- and y-direction, respectively. A uniform aperture distribution over the planar array has been assumed.

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Report of the Board

Highlights of 1995

The policy year began in the wake of the visit of the ASTRON Foreign Evaluation Committee at the end of 1994. The NFRA Board and the National Committee for Astronomy considered that committee's report in Vught on 13-14 February and reaffirmed community plans for gaining access to future forefront ground-based facilities -- in the visible and infrared via the European Southern Observatory's VLT, in the (sub)mm region via an initiative to be undertaken as quickly as possible to join the American MMA project, and in the radio region via an aggressive program of technical R&D at the NFRA Institute in Dwingeloo to lead ultimately to an instrument having a collecting area of a square kilometer (the SKAI project). During the year, a preliminary agreement was achieved with the US partners as to how Netherlands participation in the MMA might occur. During the fall a formal proposal for financing was submitted to NWO; at year's end no decision had yet been reached. Also during the fall, preparatory steps were taken in Dwingeloo to begin an R&D program focussed on the use of adaptive phased array antenna technologies to solve the main problems confronting any new large radio telescope: cost containment and suppression of external interference. An important aspect of this program will be to attract partners in Dutch technological research organizations and in industry.

The summer of 1995 saw the Silver Jubilee of the Westerbork Synthesis Radio Telescope (WSRT). A birthday party for the telescope and for some 300 staff and researchers involved in its operations over the years was held on 23 June, just one day short of twenty-five years since Queen Juliana officially opened the facility. An international scientific workshop on "Cold Gas at High Redshift" was hosted in Hoogeveen on 28-30 August, designed among other things to consider the research on the early universe that might be done with the telescope in the coming years. And a volume of essays, "The Westerbork Observatory, On-going adventure in radio astronomy," was prepared by Netherlands astronomers to commemorate the role the WSRT has played in the history of radio astronomy and also to speculate on how the subject is likely to evolve in the coming decades.

The summer also saw the start of construction of a new building in Dwingeloo for NFRA's Institute and for the Joint Institute for VLBI in Europe (JIVE). At a ceremony on December 12, attended by NFRA personnel, friends from the universities and from the local area, NFRA Board chairman Prof. dr. Piet van der Kruit formally set in place the first structural element to extend above ground level.

During the week of November 6, the NFRA hosted the annual NOVA Autumn School again.

The aims of this annual event are to round out the curriculum available to Dutch graduate students and to encourage them in a pleasant setting to get to know their colleagues from the other universities. This year two parallel courses were given on mass loss and stellar winds, and on structure and dynamics of galaxies.

For some years, preparations have been under way to bring the WSRT technically up to the state-of-the-art and to carry out a program of major maintenance. In 1995 many of the upgrade efforts moved from an R&D and prototyping phase into full production. Unfortunately, the final achievable bandwidth and the completion of the maintenance program are finance limited, so that an important task of the Board in the coming year will be to acquire the necessary finance to complete the total upgrade program.

New Statutes for the Foundation

During the year, NWO charged the NFRA Board to bring its statutes into conformity with model statutes being instituted organization wide. The principal changes with respect to the previous statutes include (a) appointment of members of the NFRA Board by NWO instead of by the Netherlands Academy of Arts and Sciences; (b) decision making as regards subsidies to university researchers by a specially created peer review committee rather than by the NFRA's Advisory Council (Raad van Advies); and (c) formal recognition that a single director (Algemeen Directeur) is charged with executive management of the Foundation. No role is formally defined for an advisory council nor for area committees (Landelijke Werkgemeenchappen) to advise the Board on matters relating to the NFRA program. Given that there was much discussion currently within NWO itself concerning the proper place and organization of its institutes, the NFRA Board chose to await events before proceeding to formulate bye-laws to define new advisory and policy development committees for its Institute.

Support for university research

Direct support for research at the Netherlands universities has for some years taken the form of grants to finance single graduate students or postdocs to work on specific research projects. The choice of research to be supported is made by peer review of submitted research proposals based on scientific merit and urgency and without regard for intended use of NFRA facilities. The Board moved during 1994 to make possible grants of up to about a million guilders over periods of five years to further particularly worthy programs of research. In 1995 the Board expressed its intention ultimately to increase such programmatic support until equality between the levels of project support and programmatic support is achieved.

Policy in the area of instrumental projects received much discussion during the year. In periods of limited finance it becomes important to focus investment on essential core programs in which the greatest impact can be achieved. However, because NFRA's Institute is a community resource and the only technical laboratory available to Dutch astronomers to develop new, ground-based instruments, it is imperative not to exclude the possibility of supporting specific research projects of almost any sort to achieve specific high priority goals. Management suggested that appropriate guidelines for its program should be (i) that up to 30% of the resources the development laboratory in Dwingeloo can go to non-core, non-infrastructural projects, and (ii) that non-infrastructural projects ought generally to be initiated and carried by project scientists from a university. In this way, NFRA can be more than a provider of funds and operator of observing facilities, but can act as a partner in promoting and optimizing university based research.

Specific efforts falling in this latter category of support for university research included four observational projects, three specifically instrumental projects and one project to host a facility. Manpower for data acquisition and reduction was provided for the Westerbork Northern Sky Survey (supporting research in Amsterdam, Groningen, Leiden and Utrecht; Miley and de Bruyn, project scientists), the Westerbork HI Survey of spiral galaxies Project (Groningen; van Albada, project scientist), the Dwingeloo Obscured Galaxy Survey (Leiden, Cambridge, Paris and New Mexico; Burton, local project scientist). And extraction and re-archiving of high time resolution data from the (now discontinued) solar radio emission research program using the 25m Dwingeloo telescope was carried out (Utrecht and Nijmegen; Kuijpers, project scientist). Technical and administrative support was provided for continued commissioning and enhancement of the Flexible Filter Bank for pulsar research with the WSRT (Amsterdam and Utrecht; van der Klis, project scientist) and for taking the Dutch Open Telescope to La Palma for commissioning (Utrecht; Hammerschlag and Rutten, project scientists). A substantial commitment was made to support development of the VLT Imager and Spectrometer for the mid-IR (Amsterdam, Groningen and Leiden; Pel, project scientist). And finally, NFRA negotiated with the Geodesy Faculty of the Technical University in Delft to support installation and operation in Westerbork of instrumentation for satellite laser ranging, GPS and gravimetric measurements, in the expectation that the observatory in future will become the fundamental geodetic station for the Netherlands.

International collaborations

An important strategy of the Board to promote Dutch astronomical research is to engage in specific international collaborations. The principle collaborations during 1995 were the following.

Participation in the European VLBI Network (EVN) and JIVE give Dutch astronomers access to the most sensitive VLBI (Very Long Baseline Interferometry) network in the world. In exchange for making WSRT observing time available to the EVN, Dutch observers gain access to the whole network of participating radio telescopes. Main developments during the year are summarized in the JIVE Annual Report, but included improvements in calibration and operational procedures, and preparations for the VSOP satellite radio telescope for VLBI, which is due for launch in August 1996. A small but steady stream of visitors visited Dwingeloo during the year to work with JIVE support scientists on preparing observing proposals or reducing and analyzing data.

The UK/NL collaboration to operate and to develop jointly the Isaac Newton Group of optical telescopes on La Palma in the Canary Islands, and the James Clerk Maxwell sub-mm telescope on Hawaii, continued during the year. The Dwingeloo Autocorrelation (digital) Spectrometer (DAS) in Hawaii became the spectrometer of choice for all observers, effectively displacing the acousto-optical spectrometer for all applications. The flexibility of the DAS was demonstrated repeatedly during experiments in collaboration with the Caltech Sub-mm Observatory to carry out single baseline interferometry. NFRA continued managing the Kapteyn Observatory Working group in Roden, as that group worked to complete the INT Prime Focus Camera and a series of CCD controllers for use on La Palma, before they move next year to join the NFRA technical laboratory in Dwingeloo. Separate annual reports for the ING on La Palma and for the JCMT on Hawaii are published by their respective boards.

The important technical collaborations are described in detail elsewhere in this Annual Report, but included especially the International Advanced Correlator Consortium to develop a new generation of hybrid correlator/spectrographs for radio astronomy; the AIPS++ Consortium to produce a reduction package for radio astronomical data that will be supported at nearly all major radio observatories in the world; the VISIR Consortium, to design and construct an instrument for the ESO VLT; and the IRAM-ESO-NFRA-OSO consortium, to carry out a program to study the feasibility of a Large Southern millimeter Array telescope at some time in the future.

Finally, international coordination of research and development efforts for the realization of SKAI proceeded in the context of the URSI Large Telescope Working Group (LTWG). The LTWG has members from Australia, Canada, China, France, Germany, India, Russia, the United Kingdom and the United States in addition to the Netherlands. Meetings have taken place once or twice a year at sites in the participating countries since the Working Group's inception in 1993. During 1995, a meeting was held in Guiyang, China, in particular to consider inexpensive Arecibo-like telescope structures in Karst formations such as are common in that province. NFRA staff members were involved as chairman of the Working Group and as consultant to a survey of interference in the region. The most active R&D efforts outside the Netherlands are taking place in Australia, Canada, China and India. At the request of representatives of these countries a "Memorandum of Agreement" is being drafted to formalize cooperation and coordination of research efforts.

Board membership

During the year Prof.dr. Ed van den Heuvel, University of Amsterdam, joined the Board as new member.

At the end of the year, Prof.dr. Piet van der Kruit (Groningen University) left the NFRA Board, having completed more than eight years of service as chairman. He saw the organization through two reorganizations, the first in 1988 when the ASTRON Foundation merged with the NFRA, and the second in 1992, when the management structure was extensively changed. He guided the decision making with respect to the major upgrade project now nearing completion at the WSRT and also with respect to the founding of JIVE. He was instrumental in obtaining the new building now under construction for NFRA's Institute and in arranging for the technical personnel of the KSW to integrate with NFRA's technical laboratory. He was central to the decision making that led to the long range plans for the community and for NFRA that is described at the beginning of this report. It has been a busy and productive eight years. NFRA in particular and the Netherlands astronomical community in general are indebted to Piet for his tireless efforts and successful promotion of our interests. Best wishes go out to him, whatever he may decide to do in future.

Technical Research and Development

A major fraction of the activities at NFRA's Institute at Dwingeloo and Westerbork centers around the development of innovative instrumentation and instrumental techniques for astronomy. During 1995, NFRA's technical laboratory focussed its efforts on outfitting the Westerbork telescope (WSRT) with (i) state-of-the-art receiver systems, (ii) a powerful new digital correlator/spectrometer based on a custom correlator chip, and (iii) new instrument control and data reduction software based on Object Oriented Programming techniques. Much of this work took place within the framework of national and international collaborations. All of it took place against a background of introducing modern project management techniques and up-to-date technical infrastructure to the laboratory.

Infrastructure

Project management

A major, largely successful effort was made during the year to bring planning activities for all technical projects into a unified planning and monitoring scheme. In this way, the progress and the future needs of the specialist R&D teams and of the supporting workshops can be optimized so that management can set priorities based on a clear picture of the available resources. Planning and monitoring of projects are now based on the Super-Project software package from Computer Associates, which allows manpower planning and monitoring, project progress compared to prognoses and financial resource management.

During 1995, all running projects were brought into the Super-Project planning system, and a system of manpower usage reporting was instigated. At year's end only the financial reporting remains outside the integrated planning system. NFRA also participated during the year in country-wide discussions on project management in medium and small enterprises

Procedures for farming fabrication work out to commercial firms were further developed and refined. NFRA personnel helped several companies develop their production techniques to be able to meet the exacting standards required for radio astronomy.

Mechanical engineering

Upgrades to NFRA capabilities were made on two fronts in the mechanical sector during the year. First, the Pro-Engineering mechanical engineering software package, introduced the previous year, was further integrated into production activities. This package allows 3-D design with not only ready interfacing to FEA, thermal analysis and other analysis packages, but also dramatically improves the documentation maintenance process.

Second, a semi-automatic lathe was installed and brought into use in the mechanical workshop, with a view to complementing the soon to become available CNC milling machine now at the Kapteyn Observatory in Roden.

Computing and networking

A major effort of the last several years at the Dwingeloo lab has been the transition from a central main-frame computer to a distributed network of workstations. This effort neared completion in 1995, so that essentially all computing is occurring either via a UNIX-based network of (some 26, mostly HP) workstations or via a Novell-based network of (more than 80) PC's. These two networks are coupled to each other and to systems in Westerbork and to the outside Internet world via dedicated 64 kbit/sec lines. Maintaining this workstation park will be essential in the coming years although in the current financial climate this will also be a serious burden for the organization.

The principle technical design software packages maintained at the NFRA Institute are:

- (i) *Academy/Touchstone*, for RF and microwave simulations, schematic entry and printed circuit layout;
- (ii) *Pro-Engineering* and *Auto-Cad* for mechanical design;
- (iii) *ANSYS* for both structural and thermal finite element analyses;
- (iv) *ViewLogic* for digital simulation and schematic entry;
- (v) *HP-VEE* for rapid development of test setups in the lab; and
- (vi) *OMTool*, a CASE tool for OO modeling and design using the OMT method.

During the year a dedicated World-Wide Web server was installed, and the NFRA's homepage (http://www.nfra.nl) is rapidly becoming the preferred source of up-to-date information about the organization and its activities.

Telescope maintenance

As noted in last year's Annual Report, a major program of repair and conservation has been started on the mechanical structures of the WSRT. The conservation work involves removal of the dishes from the equatorial mountings and the stainless steel mesh panels from the dish support structures, so that the build up of corrosion can be treated. Newly enacted legal restrictions on the permitted chemical procedures drove the costs of this treatment substantially at the beginning of the year. Repair work is being focussed on the support structures for the (33 tonne) counterweights, which were found in an analysis last year to be suffering from metal fatigue.

This work continued during 1995, taking about 3 months per telescope. Unfortunately, the available financing will not allow complete conservation treatment of the all the dishes.

Projects to re-write the software control systems for both the Dwingeloo telescope and the WSRT neared completion during the year. At the Dwingeloo telescope the venerable HP-1000 mini-computer has now been replaced by an HP-712 UNIX-based workstation and the software re-written in C++. A much improved user interface is one of the major results of this project. The PDP-11/53 at the WSRT has similarly been replaced by an HP-712 workstation. At year's end both of these systems were running in parallel to the old systems, with full transition planned for early in 1996.

Technical Projects

Receiver systems: Multi-Frequency Front Ends

Current work on receiver systems at NFRA is focussed on outfitting the 14 Westerbork dishes with frequency agile, state-of-the-art, low-noise receiver systems. Frequency bands available will be 92cm, 50cm, 18/21cm, 13cm, 6cm and 3.6cm. Two additional wide-band, tunable receivers will permit observing at random frequencies in the ranges 700 - 1200 MHz and 250 - 450 MHz (UHF-high and UHF-low respectively). These systems are being built into highly integrated front-end structures that will be placed at the prime focus positions of the element telescopes of the array. They will be operated remotely and fully automatically.

During the fall of 1994 the MFFE project moved from the prototyping phase into series production. In 1995, production proceeded apace, with the project split into two phases. Phase 1, to be completed late in 1996, will have the UHF tunable systems installed and tested. Phase 2 involves the large cryostat and remaining cooled and uncooled receivers and feeds, and is scheduled for completion and installation during the winter of 1997/8.

During 1995 a number of tests were also carried out with the single prototype front-end on the telescope. System noise performance and system stability were studied and the former better understood and improved. VLBI observations were successfully carried out and yielded high quality correlations. A new IF module in the front-end was successfully built and tested, allowing an on-line choice of either 10 MHz or 80 MHz instantaneous bandwidths.

Low Noise Amplifiers

NFRA's LNA team spent 1995 developing state-of-the-art designs for cryogenic and room temperature amplifiers for the MFFE project. A major constraint is that they should be able to be made for an affordable price. The large number of amplifiers (over 400) needed for the eight different frequency bands of the MFFEs also makes it necessary to aim for designs that can be easily produced, tuned and tested. Introduction of the Academy/Touchstone design package from HP/EEsof has made it possible to simulate and optimize the RF and microwave properties of the designs and to produce the layout of the printed circuit boards.

During 1995, development of six of the eight designs required was completed and production of the series was begun. Excellent designs have been achieved and initial difficulties with delivery of acceptable HEMTs (the active low noise devices) and of the necessary high performance printed circuit boards were resolved. In fact, the noise performance of all completed designs is better than the original specification.

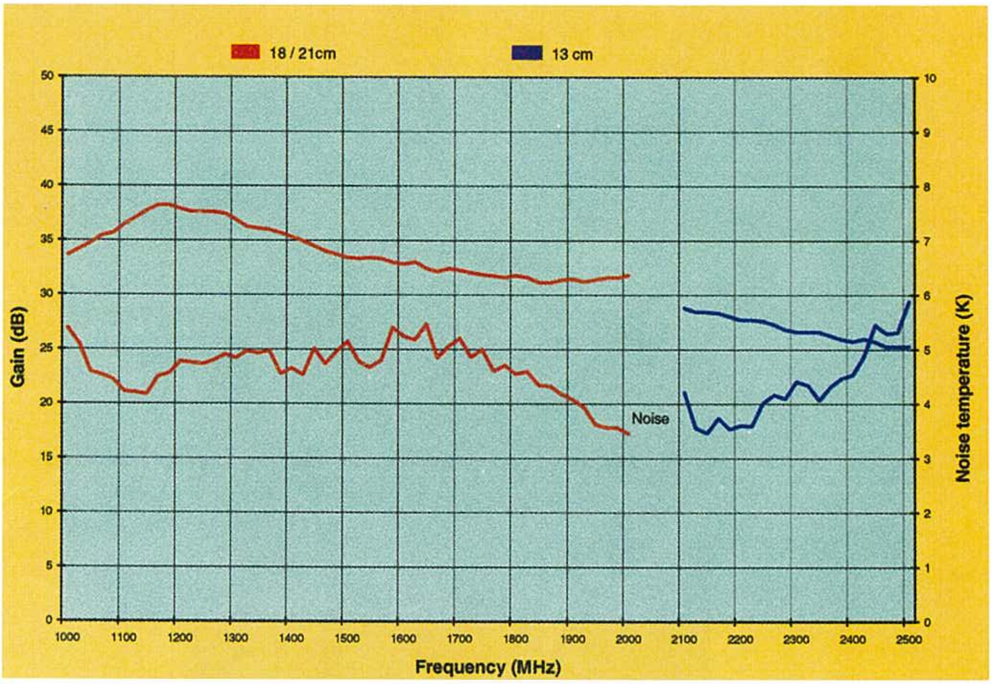


Figure 1.

Two cryogenic designs having state-of-the-art noise temperatures are shown in Figure 1. The typical noise performance of the 21/18cm LNAs is below 5 K across most of the 1 - 2 GHz frequency band. Typical results for the UHF room temperature amplifiers for the broad-band tunable receivers of the MFFE are 30 - 40 K, as shown in Figure 2.

Between the first and second stages of both amplifier types interference suppression filters are required, to eliminate the effects of TV signals from the nearby Smilde TV broadcasting tower. Results for the 92cm and 50cm room temperature prototypes are also shown in Figure 2.

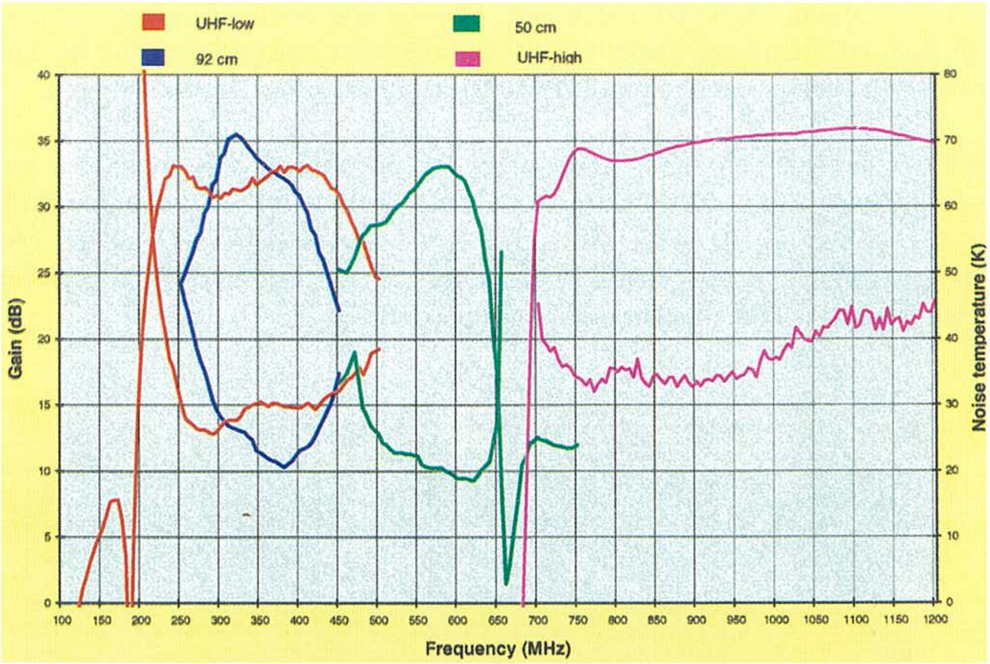


Figure 2.

Figure 3.

As all room temperature amplifiers will be used in the new double antenna configurations, special attention has been given to optimizing their differential phase and gain properties. Figure 3 shows a completed two-stage UHF-high amplifier, which employs a balanced configuration having two stages with input and output Lange couplers and filters for Smilde channels 2 and 3 in between.

High Speed Digital Signal Processing

Future study of the high redshift universe with the Westerbork radio telescope will require not only low noise, wide-band receiver systems, but also a substantially improved, highly flexible, digital correlator/spectrometer. This new back-end has been split into three separate projects: the correlator unit itself, an ADC (analog-to-digital converter) unit that also tracks the interferometric fringes, and an IF interfacing unit between the two that subdivides the total measurement band so as to avoid interfering signals from the local environment.

(i) Correlator/Spectrometer sub-system

NFRA's correlator team spent 1995 working to produce a VLSI (0.8 micron technology) full-custom correlation chip containing about a million transistors and supporting circuitry, together with the many circuits and software modules required to integrate the chip into a working correlator system.

These activities were carried out as part of an agreement between NFRA and the U.S. National Aeronautics and Space Administration (NASA), and a separate agreement with several institutes of the European VLBI Network, the Joint Institute for VLBI in Europe, and the Massachusetts Institute of Technology. This complex collaboration has been given the name, International Advanced Correlator Consortium. The work of the Consortium will ultimately result in a scalable correlator capable of correlating up to 32 input streams, each having a data rate of up to 4 Gbps. In its maximal implementation the machine will be able to achieve a sustained computing power of about 10^{12} multiplications per second. A total of 6 correlators for use with both connected arrays and VLBI networks of radio telescopes are planned.

At year's end prototypes of the chip had been successfully produced, including a second iteration that proved necessary to correct certain phase rotation circuitry needed for VLBI applications. Prototype printed circuit boards and Xylink DSP routines were ready for testing with the new correlator chips.

Current plans are to integrate the prototype correlator unit into the Westerbork system at the end of 1996.

(ii) ADC sub-system

This sub-system incorporates three functions: (a) it converts the 28 analog signals from the 14 receivers of the telescope into 2-bit digital signals; (b) it compensates for the arrival time differences of the wavefronts at the individual element telescopes (interferometer fringe delay tracking); and (c) it permits adding the signals from the whole array of 14 telescopes or from sub-arrays coherently, to allow the telescope to do VLBI and other observations whereby a radio telescope is created having a single beam on the sky with an equivalent collecting area of a single dish instrument of 93 meters diameter, making it one of the largest single dishes in the world.

During the year design and breadboarding was accomplished for many of the required circuits. Extensive software simulation prior to breadboarding has helped reduce the need for iterative redesign. Tests and development will continue through most of 1996, with delivery of a working prototype for installation in Westerbork at the end of the year.

(iii) IF sub-system

Recent observations of high redshift galaxies using the broad-band 92cm receiver system, which came into operation a year ago, have substantially increased the pressure to provide as wide an instantaneous bandwidth as possible with the new system. The original budget for the upgraded IF sub-system, which was proposed in 1990 and which will become available only in 1997, did not take this development into account. During 1995 collaborative studies were carried out together with local Dutch commercial companies of how one might be able to achieve the required performance at little extra cost, by increasing the level of integration substantially (put the circuits on a chip). At year's end it seemed likely that current technologies for analog circuitry on chips cannot yet easily provide the required suppression of interference. Studies will continue into 1996 until a technical or financial solution is found, or until one is forced to accept reduced functionality.

Software Engineering

The software engineering group at NFRA is charged on the one hand with maintaining and extending existing software for operating the Westerbork telescope and reducing its data, and on the other with developing next generation software capabilities. A strategic decision several years ago, to join in a world-wide development effort that should ultimately lead to the same basic data analysis system being used at all major radio observatories (with local enhancements and special elements, of course), and that would employ the modern methods of Object Oriented Programming and software engineering, will guide NFRA developments for the coming years.

Data reduction and analysis: AIPS++

The program to produce an internationally supported reduction and analysis package is called the "AIPS++ project". It involves programmers and scientists at seven institutes in six countries. A major review at the end of 1994 resulted in a reorganization of efforts early in 1995, after which the project has moved ahead well. NFRA engineers have provided the so-called tiled, table handling library routines as well as have worked toward the design of east-west synthesis array specific calibration and analysis routines.

In particular, during 1995 NFRA contributed a major conceptual breakthrough in the project. Each different kind of radio telescope allows one to make specific approximations when calibrating and reducing data. But to produce a generic approach that will allow ready extension in future to as yet unforeseen instrumental configurations, one requires a generic mathematical formalism within which all radio observations can be fit.

NFRA staff achieved and published such a formalism during the year, which is called the Measurement Equation (Figure 4) formalism. The Measurement Equation is based on a matrix description of each separate part of the signal detection process. Both single dish and synthesis array interferometers, including VLBI, can be handled, and new and improved calibration procedures for radio telescopes based on the Measurement Equation seem within reach. The Measurement Equation should make it possible to combine and calibrate data from conventional mechanically steered dishes with data from adaptive phased array antennas having electronically steered and variably shaped beams.The AIPS++ project has adopted the formalism and will promote its use world-wide.

Instrument control: Telescope Management System

The new front-ends and new back-end provide a dramatically more flexible system at the WSRT than has previously been possible. New and more powerful instrument control computers will add to the power and adaptability of the telescope system. Design of the new control software necessary to operate the new hardware and to exploit its potential for new observing modes has begun and has been given the project name, Telescope Management System.

Early in 1995 a concept study was completed, which indicated that Object Oriented Programming technology would be well suited for the purpose, as well as would promote common discussion and activities with the AIPS++ group. The goals of flexibility, extendibility and robustness are to be achieved by using OOP technology in combination with commercial class libraries and toolboxs. Design and implementation started in August and the framework for communication and persistence was essentially completed by the end of the year.

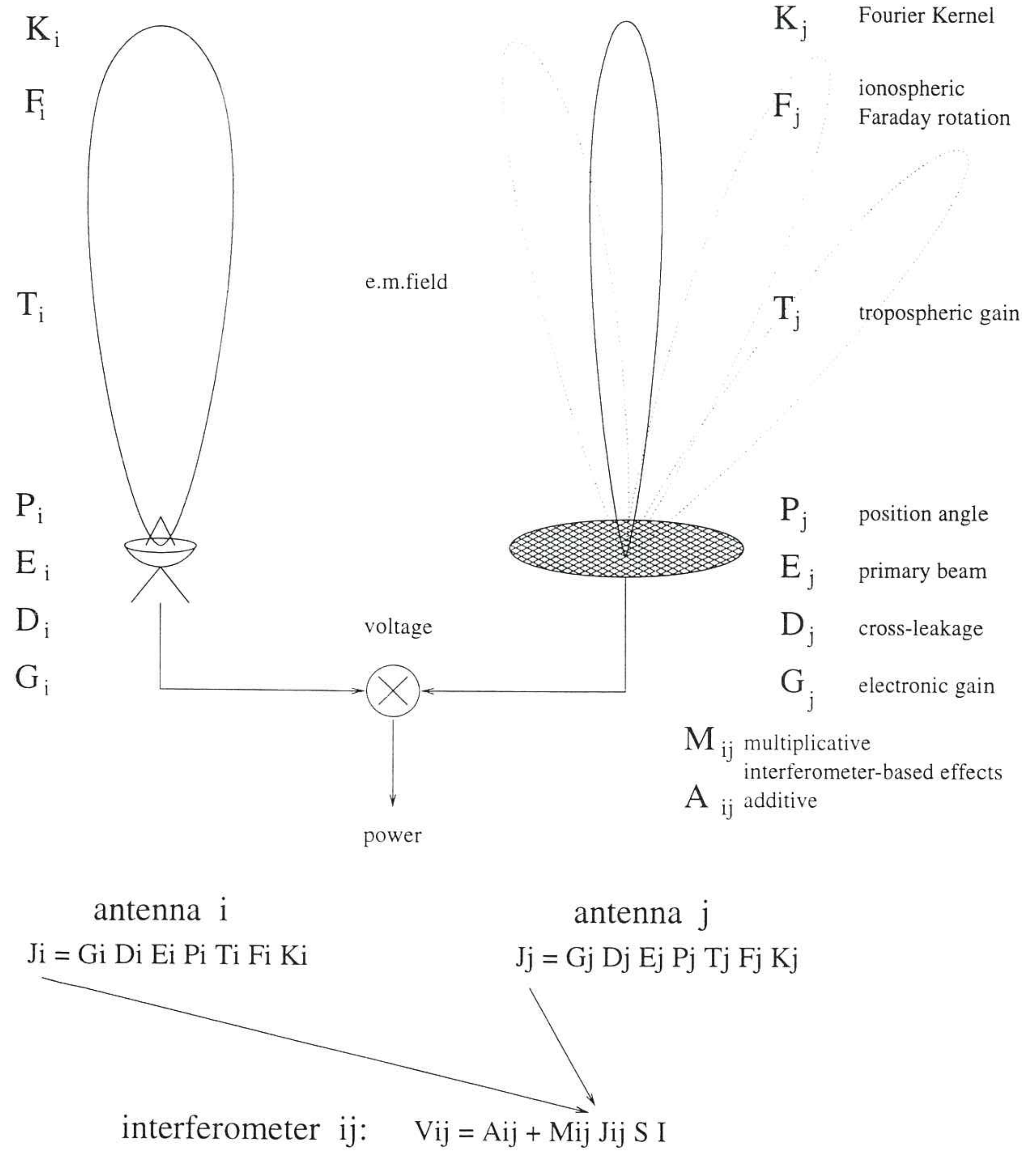


Figure 4. The Measurement Equation.

TMS is planned to be delivered in three releases, characterized by the notions "encapsulation," "integration" and "optimalization". The encapsulation phase is due for completion in the fourth quarter of 1996. A simple interface to AIPS++ will allow rudimentary data handling with the new software as soon as the first phase MFFEs are installed.

The system design for TMS follows the usual lines of complex, distributed control systems. A central or supervisory control process has knowledge of all sub-systems. Sub-systems may range from dumb hardware devices to complex embedded software systems. In all cases the central TMS process is in charge of their behavior, resulting in reliable and synchronized operation. The control process itself is driven by a repository device and specification information. The repository, implemented as a collection of object libraries, contains all the knowledge needed to specify and schedule observations and to find and access output data. Other clients of the repository are applications for observation specification, post-processing and inspection.

Adaptive Phased Array Antennas

The technologies to be employed in the next generation of very large radio telescopes must solve both the problem of cost and suppress external interference from the environment. General considerations of the evolution of the costs of highly integrated electronics and of the demonstrated ability of planar phased array radars in military applications to adapt to severe levels of unwanted signals led during the year to a decision to focus the efforts of the NFRA technical laboratory on the development of inexpensive versions of such antennas. This program will take form during the coming two years, and begin in earnest following completion of the upgrade activities in Westerbork in 1998.

Antenna design is a new area of technical research for NFRA. By year's end several new staff had been recruited and plans for installing an antenna test setup were well advanced. Software for antenna design was acquired and the first calculations were carried out on idealized antennas (see cover of this report).

Additional projects

At NFRA, technical projects take two forms: (i) major infrastructural developments such as those described above, and (ii) special efforts of more limited scope. The former has a long term character and remains focussed on the techniques of radio astronomy. As the only technical group in the country for ground-based astronomy, however, the latter projects are of importance to support the more short term research programs of the community. Management has set as goal that up to 30% of the effort of the technical staff should go projects of the latter sort. During 1995 the following several specific projects received significant attention.

High Temperature superconducting filters
As use of the radio spectrum increases it becomes ever more important to be able to filter out unwanted signals originating in adjacent frequency bands. A promising possibility for constructing very sharp and very clean RF filters is under study in the electrical engineering and technical physics departments of the Technical University in Delft with support from NFRA. This technology will ultimately lead to compact filters having very low loss (and hence low noise contribution) combined with the required high selectivity. At the end of 1995 a first prototype band rejection filter was demonstrated.With input from NFRA a similar filter is being developed that can be used in the 18/21cm signal chain of the MFFEs.

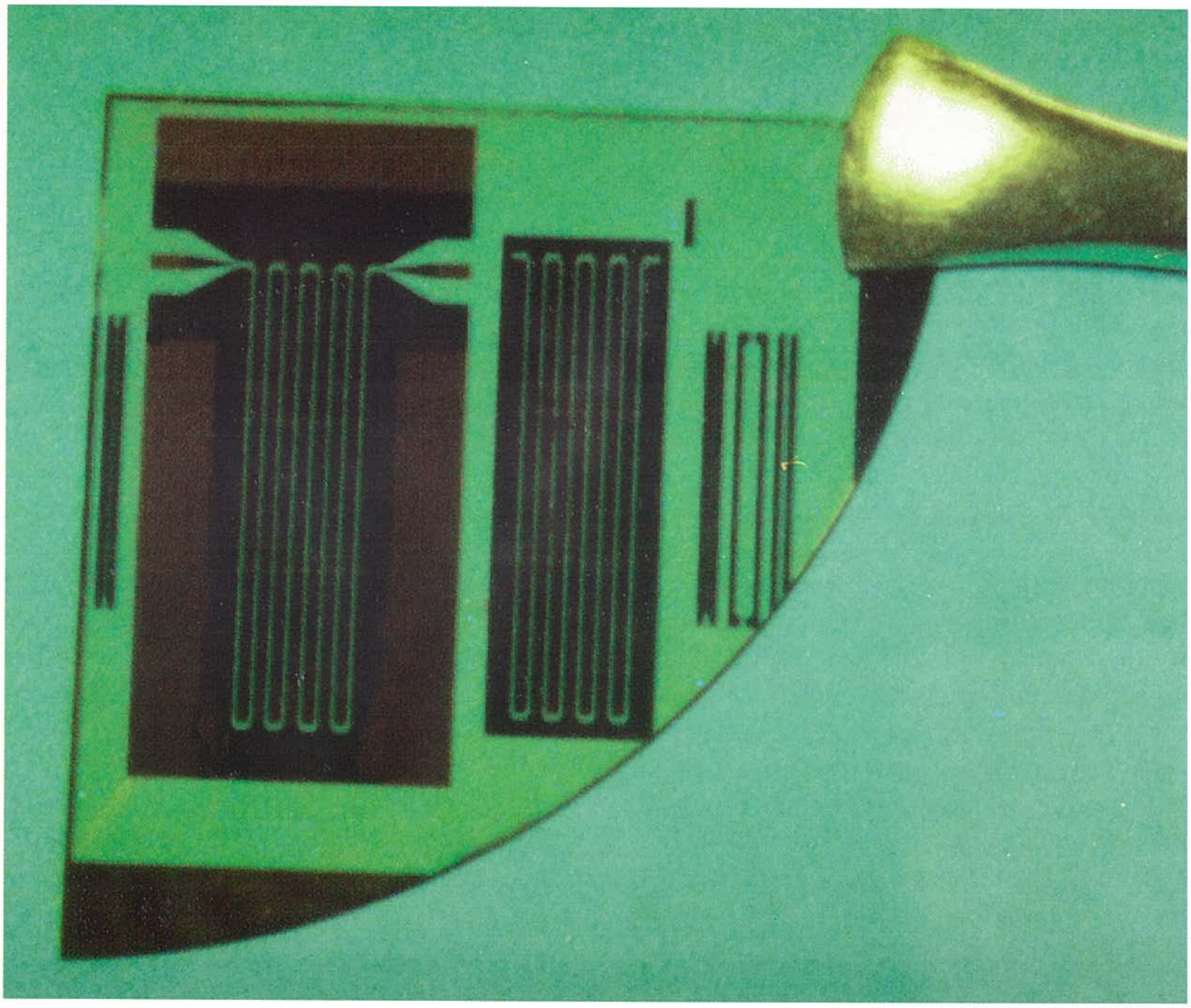


Figure 5. Prototype of a High Temperature Superconductor band stop filter (1450 - 1610 Mhz, 7th order Chebyshev response): a future countermeasure against interference in radio astronomy receivers. (Courtesy Sven Wallage).

Flexible Filter Bank for Pulsar Searches and Timing

Neutron stars are dead stars having a very high mass density (a solar mass in a star of 20 km radius) and a very strong remnant magnetic field. As these objects rotate they emit pulses of radio emission, the characteristics of which can be used to study a variety of phenomena, including the death of stars in supernova explosions, the evolution of the Galaxy and the predictions of General Relativity.

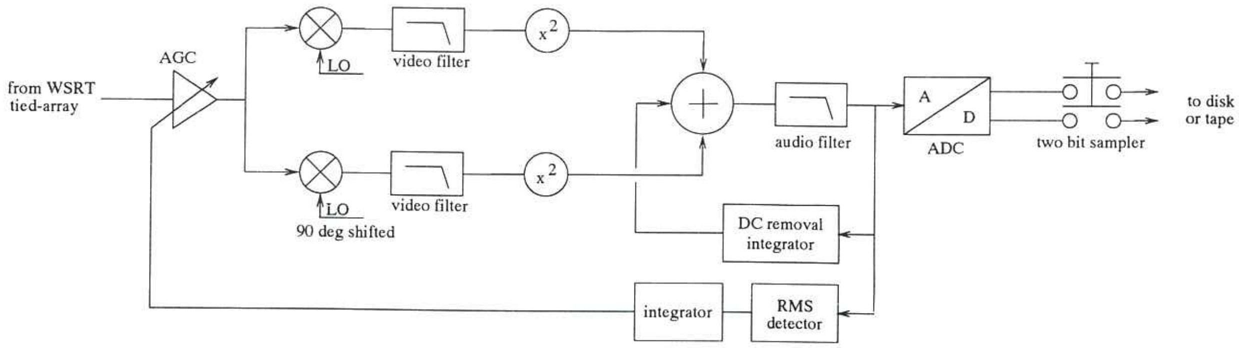


Figure 6. Flexible Filter Bank layout. The signal from the WSRT tied-array is attenuated in the AGC to the proper power level. It is then fed to a mixer (quadrature type receiver) which downconverts it to a double sideband (DSB) baseband signal. Next the video filter reduces the bandwidth to the desired value. The output of the squaring device is a measure of the signal power. Before digitisation and two-bit sampling the signal has to be smoothed with the audio filter in oder to comply with the Niquist sampling criterion.

The WSRT has a large collecting area, so it is a sensitive instrument well suited to the study of pulsars. A new back-end for the WSRT went into operation at the end of 1994 for this purpose, and was described in that year's Annual Report. The novelty compared to similar instruments elsewhere is that the bandwidth of its 64 channels can be tuned between 6.25 kHz and 2.8 MHz and the band positions in frequency can be adjusted to avoid external interference.

During 1995, the Filter Bank became fully operational and preparations were made to automate it such that it can run many hours and observe many different objects without attention. A major project to discover new milli-second pulsars is under way, using highly polarized, steep spectrum point sources identified from the WENSS. Plans were also made for upgrading and improving the system to enable detection of rapid pulsars having such high dispersion measures that the pulses would normally be smeared out.

Cluster-cluster VLBI

At radio wavelengths one can record the electric vector of the light waves directly, making it possible to perform interference experiments with telescopes too far apart to be connected physically. This technique is termed Very Long Baseline Interferometry (VLBI), and the major radio observatories in Europe regularly perform coordinated observations and cooperate to correlate the resulting data later off-line. In this way a telescope is simulated which has a resolving power on the sky equivalent to a single telescope the size of Europe. The technique of VLBI yields the highest resolution of any technique in astronomy. The WSRT regularly participates in VLBI observing as part of the European VLBI Network.

Cluster-cluster VLBI is a natural extension of standard VLBI, in which the limitations of the latter are largely eliminated by arranging for sub-arrays of two synthesis array telescopes such as the WSRT to look simultaneously at nearby radio sources in the sky. Such an interferometric configuration should allow greatly improved measurement of the following:

(i) three spatial components of the baseline vector (positions of the two array telescopes) and the relative clock offset.
(ii) radio source positions without the need for invoking models for precession-nutation or for the equatorial system.
(iii) extremely precise relative positions and proper motions of sources close together on the sky.
(iv) Earth orientation parameters at a high rate.

During 1995, the first tests of this new technique were made between the only two array telescope facilities currently having compatible VLBI recording equipment, the WSRT and the Very Large Array in the USA. Joint observations were made at 21cm for 4.5 hours on a series of strong sources. The VLA system was not configured to allow scientific results, but a proof-of-concept demonstration was carried out successfully. At year's end an error analysis was still in progress to compare results obtained with the new mode with those by more conventional VLBI techniques.

Compound Interferometer spectroscopy

Gas-rich objects in the early universe can in principle be studied without the bias of obscuration by local and/or internal dust by using the redshifted 21cm line of neutral hydrogen. Spectroscopy of this line in randomly selected galaxies using current radio telescopes, however, is restricted to the narrow, protected bands made available by international treaty, and requires either that the redshift be known from optical observations (possibly biasing the statistics) or that one have a sufficiently broad radio band-width that the location of the line can be determined directly from the radio data.

During 1995 a new observing mode was introduced at the WSRT, that caters for just the latter requirements: large instantaneous band-width, large number of high resolution spectral channels and unresolved spatial structure. The mode is being called the Compound Interferometer mode, and is achieved by reconfiguring existing hardware to provide up to 5120 channel spectrometry with the equivalent of a 93m radio dish. The main difference with single dish spectroscopy is that the latter samples the image at the origin of the Fourier plane, whereas the CI mode with an east-west array such as in Westerbork samples the sky in a fan beam. As the earth rotates sources away from field center move in and out of the beam, making it necessary to make a map of the field to aid data reduction. In compensation for this extra effort in reducing the data, an interferometer such as the WSRT is typically a hundred times less sensitive to interference from the environment than an equivalent single dish telescope.

At year's end an unbiased (blind) search for H I absorption towards several high redshift (near z = 3.4) galaxies was in progress. When the UHF systems come on-line in late 1996 this mode will permit extension to lower and higher redshifts).

VISIR

An important field of Dutch astronomical research concerns the physics and chemistry of cool gas clouds in star forming regions. The Very Large Telescope (VLT) of the European Southern Observatory (ESO) will shortly be the largest optical facility in the world. The VLT program for developing new instrumentation is also well under way, although until now without an instrument optimized for the study of cool, dense gas clouds.

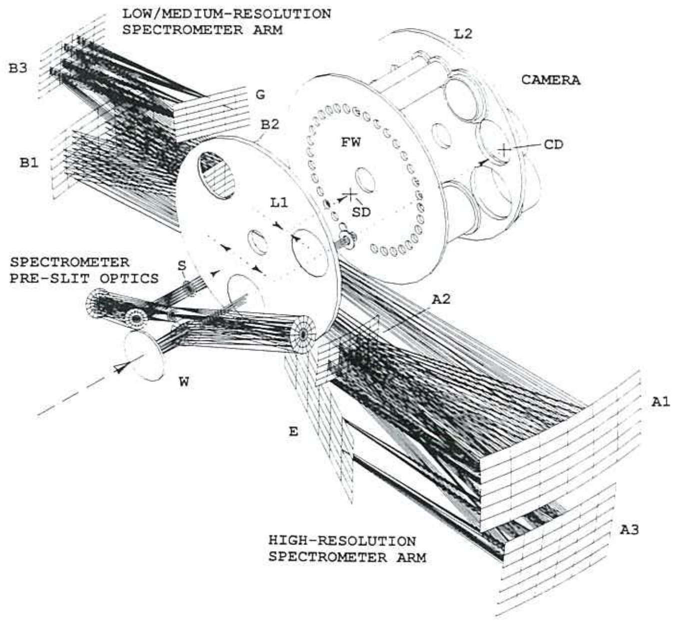


Figure 7. Schematic 3-D view of the optical layout of VISIR. W - cryostat entrance window; S - spectrometer entrance slit; A1-A2-A3 - 3 mirror collimator/camera for the high resolution spectrometer arm; E - duo echelle grating; B1-B2-B3 - 3 mirror collimator/camera for the low/medium resolution spectrometer arm; G - low/medium resolution grating; SD - spectrometer detector; L1 - collimator lens wheel; L2 - camera lens Wheel; FW - filter wheel; DC - camera detector.

During the autumn, financial approval was granted for a joint French-Dutch project to develop a diffraction limited spectrometer and imager for observations with the VLT in the 7.5 to 14 micron (N-band) and 16 to 28 micron (Q-band) atmospheric windows. At year's end detailed contract negotiations with ESO were under way.

The instrument received the name VISIR: VLT Imager and Spectrometer for the mid-IR. The development effort will be a collaboration between NFRA and the Service d'Astrophysique of the CEA/DAPNIA at Saclay, in which NFRA will be responsible for the spectrometer sub-system. A preliminary overview of the optical train is shown in

The spectrometer will in fact be a dual system, with one arm for the low- and medium-resolution modes and the other for high resolutions. The former will deliver resolutions in the 150 - 10000 in the N-band and 1000 - 2000 in the Q-band. In the high resolution mode, two large echelle gratings, mounted back to back yield resolutions of 20000 - 30000 in the N-band and about 10000 in the Q-band. All spectroscopic modes will employ a long slit, having lengths up to 40 arcsec on the sky. Both spectrometer arms use the same detector, a 512x512 array having 50 micron pixels.

The combined VLT-VISIR system, together on the one hand with the superb atmospheric conditions at the Cerro Paranal site and on the other with the new array detectors now available at these wavelengths, will yield a substantial step forward for the study of phenomena visible only in the mid-infrared. When completed in 4.5 years, VISIR will be an ideal follow-on to the ISO satellite!

Rotation Measure mapping

At low frequencies the wide field of view and good off-axis polarization performance combine to make the Westerbork radio telescope an effective instrument for locating and studying polarized radio sources. Scientific applications range from the search for millisecond pulsars, the study of fine scale structure in the inter-stellar medium in the Galaxy, the study of thick disks and halos of cosmic rays in spiral galaxies, the investigation of giant radio galaxies and the search for Thomson scattered halos originating in the inter-galactic medium around high redshift radio sources. Most radio sources have steep radio spectra, so that they are stronger at low frequencies, making these frequencies attractive for their study. Unfortunately, very small amounts of magneto-ionic medium along the line of sight -- including in the ionosphere -- cause the polarization to rotate with frequency. This rotation is called the Rotation Measure of a source and scales quadratically with wavelength.

During the year, NFRA software engineers and astronomers worked together to produce a new procedure for mapping the RM in a WSRT field. Essentially, the technique searches at each position on the sky for the maximum of the complex polarization vector as a function of trial

RM value. In practice a three dimensional data cube is constructed having two spatial coordinates and one RM axis, with the data being the complex polarization values. A CLEAN-like search for maxima then yields a spatial map of RM values across the field of view.

Initial tests show that the sensitivity of this technique should be in the region of 0.1 rad/m^2, which may be compared to typical values of the galactic foreground RM of 5 - 10 rad/m^2 at low frequencies. Differential measurements relative to this (very stable) foreground should permit one to eliminate the effects of the ionosphere. The technique should be particularly powerful with the broad bandwidth MFFEs and new back-end.

SCUBA

A major new instrument planned for use on the JCMT is the so-called "Submillimeter Common User Bolometer Array". It provides two arrays of bolometers that can observe simultaneously continuum radiation in bands around 450 and 850 microns. The long wavelength arrays consists of 37 bolometers, the short wavelength array of 91. The system will provide a spectacular improvement in the efficiency of mapping the sky at submillimeter wavelengths.

The detectors sample the sky sparsely, however, so that at least 16 measurements with the arrays shifted slightly between each are required to obtain complete sampling in a map. Depending on the behavior of the sky background radiation, one can consider performing single integrations at each of the 16 positions or repeated rapid scans through all 16 positions. If the sky background is rapidly varying the latter mode should yield superior quality maps, but it is also more complex to implement. The SCUBA development team has implemented the former mode, and NFRA will implement the latter. A design study to this end was carried out in 1995 with a view toward implementing the scheme at the telescope in 1996.

Institute Science

NFRA's Institute in Dwingeloo and Westerbork is primarily dedicated to providing observing facilities and innovative technical R&D for researchers at Dutch universities and in the international astronomical community. Essential to the success of the program is a small research staff to provide liaison between NFRA's internal program and the research efforts of the wider community. These staff are asked to carry out active research programs with NFRA's facilities, wherever possible in collaboration with external users. This section reports a selection of interesting results obtained by NFRA staff astronomers and colleagues during 1995.

Unique binary millisecond pulsar

Rapidly rotating neutron stars emit radio waves from their polar magnetospheres that are observed as a series of pulses. Studies of the pulse characteristics and arrival times provide information on the evolution and interior structures of these strange objects. The most rapid pulsars have rotation periods in the millisecond range. These most rapid rotators are slowing down only very, very slowly, and are therefore extremely stable natural clocks. When found in binary systems they can be used for sensitive tests of general relativity.

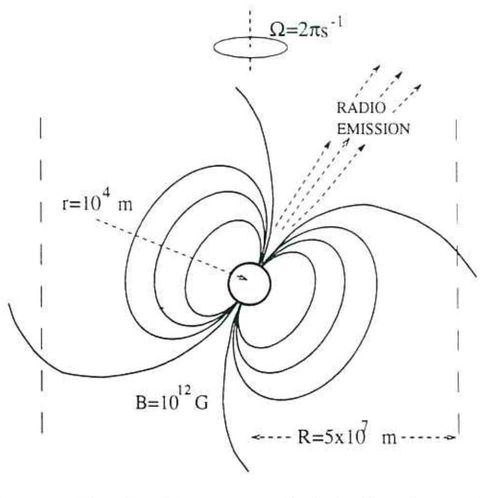


Figure 8. Schematic of a typical 'normal pulsar' (not to scale!) indicating typical parameters. The dashed lines depict the light cylinder - the representative distance from the pulsar beyond wich magnetic field lines are open and corotation of the magnetosphere must break down. Radio emission is presumed (on the basis of many observations) to emanate from a narrow band of fieldlines near the magnetic pole. (Courtesy E. Rowe).

Most millisecond pulsars have been discovered in blind searches, that is by slowly scanning the sky and analyzing the incoming signals for the presence of pulses. The first millisecond pulsar, B1937+21, however, was found in integrated imagery taken with the Westerbork telescope, as an unresolved steep spectrum object. Subsequent studies have suggested that a good way to find more of these objects could be to select highly polarized, steep spectrum, unresolved sources from surveys such as the WENSS and then examine their signals for rapid pulsing.

During the year, an international team from NFRA, NRAO, Caltech, and Jodrell Bank reported that one of the first of such sources to emerge from WSRT low frequency survey data, does indeed turn out to be a member of the class of millisecond pulsars. Designated J0218+4232, the object has a pulse period of 2,3 msec and is located in a binary system of orbital period of 2,0 days. Its distance of more than 5,7 kpc makes it the most distant field millisecond pulsar known.

The advantage of imaging searches to locate these objects is emphasized by the fact that its intrinsic luminosity is significantly higher than the maximum found for pulsars in recent blind searches with the Arecibo and Parkes telescopes. Also, first indications are that there is emission from the source at all pulse phases, possibly making it the first pulsar ever seen in which the viewing angle is aligned with the axis of rotation.

Head-tail radio sources

Sijbring (Groningen) and de Bruyn (NFRA) finished their extensive study of head-tail sources in the Perseus cluster during the year. These sources are galaxies whose radio emitting plasma is swept out from the galaxy as it moves through a hot intra-cluster gas.

Wide field WSRT observations at 21, 49 and 92cm provided total intensity maps of five of the sources and spectral index and polarization maps of NGC 1265 and IC 310. The observations achieved high dynamic range using redundancy and self-calibration techniques and reveal a large extension to the tail of NGC 1265 at 49 and 92cm. The projected tail bends through an angle of almost 360 degrees. Along the tail, within a distance of one or two resolution elements, the intensity decreases by more than an order of magnitude and the spectral index steepens dramatically. The simplest model for these tails is that they delineate the orbit of the galaxy as it moves through the intra-cluster medium, with faint perpendicular extensions caused by the effects of a cluster wind or by buoyancy of the radio plasma in the intra-cluster medium.

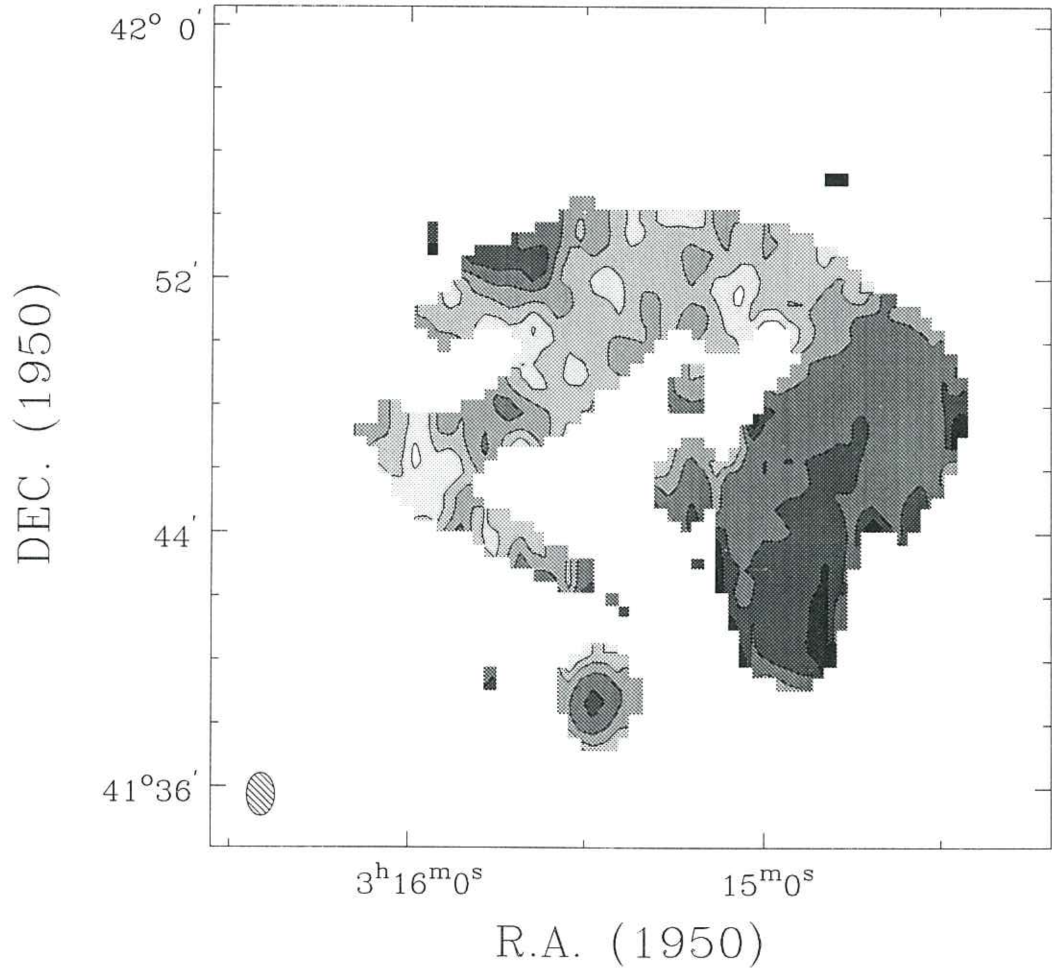
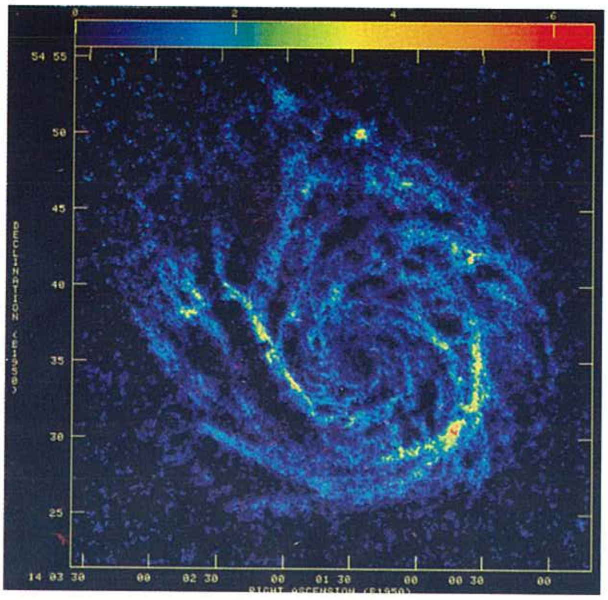


Figure 9. The spectral index distribution between 49 and 92 cm along the tail of NGC 1265. (Courtesy of D. Sijbring).

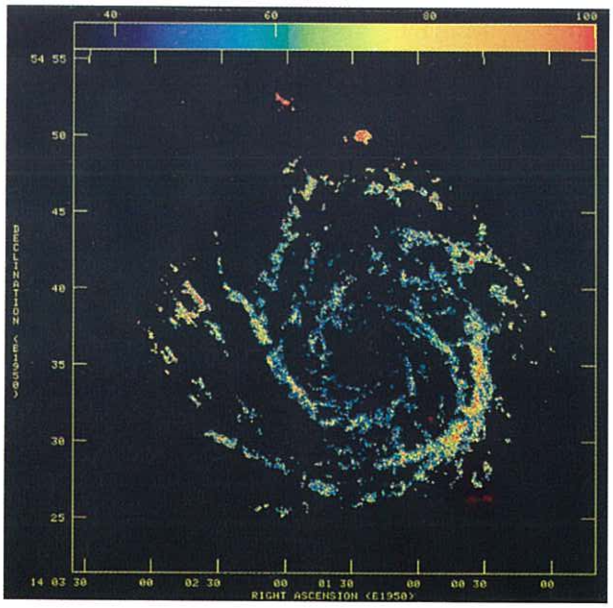
The very long tail of NGC 1265 at low frequencies makes it possible to test theories for the aging of relativistic electrons in radio sources. The best fit to the spectral distribution is given by a model in which electrons are injected at the head of the source, energy is subsequently lost by synchrotron radiation, and no continuous isotropization of the electron pitch angle distribution takes place. This model is also consistent with the relatively constant spectral index in the faint and old part of the tail. When inverse Compton losses are included in the spectral aging models an upper limit estimate of the magnetic field of five times the equipartition value is obtained. The calculated electron ages in the tail are 3 - 4 times younger than the age of the tail at corresponding positions, possibly indicating the presence of bulk streaming motions of the electrons in the tail.

Nature of the atomic interstellar medium in spiral galaxies

Braun (NFRA) has been studying the topology, phase balance, temperature and line opacity of the atomic interstellar medium in the discs of spiral galaxies using HI emission and absorption data. Two phases of the neutral gas may be distinguished, a Cool Neutral Medium (CNM) and a Warm Neutral Medium (WNM). During the year he completed a major study of twelve nearby spiral systems.



panel a



panel b

Figure 10. The large fractional HI line flux from CNM complexes with substantial HI opacity is illustrated in this pair of panels. The integrated HI emission of NGC 5457 (M 101) is shown in panel (a), while the peak emission brightness is shown in panel (b). The filamentary CNM complexes which account for more than half the HI line emission within R_{25} have peak brightnesses in excess of about 100 K and a high modelled opacity.

The CNM phase has been found to occur in a filamentary network of atomic super-clouds which have a characteristic narrow dimension of 150 pc and which in velocity show a narrow core (< 5 km/sec) superposed on a broad base (30 km/sec FWHM). The fractional H I line flux in the CNM phase decreases with galactic radius from more than 80% at small radii, to about 50% at R_{25}. The face-on surface covering factor decreases from about 20% to less than 10%. At about R_{25}, the CNM super-cloud population disappears altogether, and with it all traces of star formation. The kinetic temperature of the CNM rises continuously with radius from less than 50 K at small radii to in excess of 200 K at large radii. At the same time the CNM H I opacity is continuously declining, although in some galaxies it remains significant (greater than one) out almost to R_{25}.

The WNM appears to have a fully complementary distribution, increasing the flux fraction with radius and taking over entirely beyond R_{25}.

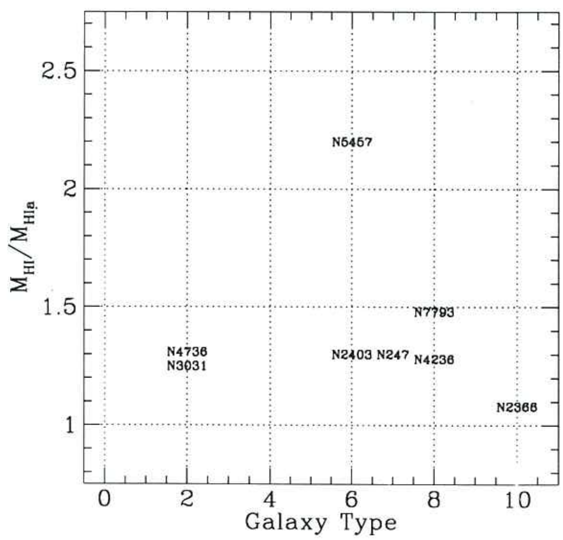


Figure 11. Correction factors for the ratio of actual HI mass to apparent HI mass are plotted for the eight modelled galaxies. The correction factor is of order 20 % for low gas mass spirals of all types. High gas mass systems may have more than twice as much atomic hydrogen as deduced under the usual assumption of negligible opacity.

Gas mass estimates in galaxies

Braun's demonstration that much neutral gas mass in the discs of spiral galaxies is in the form of dense filamentary structures raises the question of the reliability of gas mass estimates based on integrated H I line fluxes. He finds local corrections to the column density of super-clouds are typically a factor of two but may exceed a factor of five. Total H I mass corrections seem to depend on galaxy type, varying from less than a factor of 1,1 in the SBm galaxy NGC 2366, to a factor of 2,2 in the Sc I system NGC 5457.

Neutral gas in the early universe

Neutral hydrogen gas between the galaxies can be studied via absorption lines of the Lyman series or of the 21cm hyperfine structure line. At high redshift, Lyman-alpha lines are commonly seen in the optical region of the spectrum against bright background quasars. Indeed, the so-called damped Lyman-alpha systems seen in the ultraviolet and optical spectra of quasars are believed to be the main depository of neutral gas at early epochs. But what are these systems? And can we be certain that significant mass is not being overlooked because many galaxies contain moderate to significant amounts of obscuring dust? Observations in the 21cm radio line promise answers to these questions.

During 1995, NFRA astronomers Braun and de Bruyn collaborated with colleagues from Texas, Cambridge (USA) and Leiden to combine results of 21cm line studies of nearby spiral galaxies with first observations of 21cm absorption in known damped Lyman-alpha systems. The high redshift systems are found to be characterized by spin temperatures of about a thousand degrees, much higher than is found for gas in the visible discs of local galaxies, including our own (see section on "Nature of the atomic interstellar medium in spiral galaxies"). But such conditions are found in the most outer regions of local spirals, suggesting quite reasonably that the absorption at high redshift derives from intervening galaxies having extended H I discs. Could the absorbing objects be the large (10^{15} $M_{\odot}$) proto-clusters predicted by some theories of structure formation? Checks for emission signals in the same fields reveal no emission, effectively ruling out such super-clusters.

To constrain the amount of intervening gas in a way unbiased by dust obscuration in galaxies and quasars one can resort to blind surveys for 21cm absorption against the outer lobes of distant radio sources. During the year, Chengalur (NFRA) carried out the first high sensitivity, large instantaneous bandwidth, high spectral resolution observations of this type with the new broad band 92cm and compound interferometer system at the WSRT. He observed a redshift interval of 2,8 towards 4 high redshift radio galaxies. No absorption was seen, to a four sigma limit (assuming $T_{spin} = 10^3$ K) of 9×10^{20} cm^{-2} column density. At this sensitivity one would have expected to have less than one detection, so no serious conclusions can yet be drawn. The coming wide band tunable UHF front-ends should provide some real constraints on this problem.

SKAI and the early universe

Our ideas of the structures that matter assumed in the early universe have evolved dramatically in the last few years. Initially it seemed probable that very massive proto-cluster "pancakes" of neutral atomic hydrogen might be the first structures to condense from the nearly uniform background of matter emerging from the Big Bang. Deep observational searches, however, with the Westerbork telescope and later with other facilities, have failed to detect such massive pancakes. Now theoretical arguments have been advanced suggesting it may be more likely that much smaller structures are the first to form and that these later coalesce to produce the large scale structures we see around us today.

To better understand what might be observed in this new scenario, Braun and Butcher (NFRA) have collaborated with Lake, Katz and Ingram (Washington), and Weinberg (Ohio), to make available and to analyze state-of-the-art numerical simulations of structure formation in the early universe. An extensive series of super-computer simulations have been transformed to produce maps and velocity fields of the predicted atomic hydrogen emission at various redshifts (that is, epochs in the history of the universe). These images were then compared with the imaging ability of the proposed Square Kilometer Array Interferometer (SKAI) radio telescope operating at the required frequencies.

In Figure 12 is shown the neutral hydrogen emission predicted by these simulations at a redshift $z = 2.0$ (for a cosmological model in which the dynamics are dominated by Cold Dark Matter and with $\Omega = 1$, $\Omega_B = 0.05$, $H_0 = 50$ kms^{-1}, $\sigma_{16} = 0.7$). Overlaid on the simulation are five sigma detection contours after 1600 hours of integration with a strawman SKAI. Within a single pointing, and in each 25 MHz of spectral bandwidth, one would expect several tens of detections at $z = 4$, perhaps 500 at $z = 3$ and some thousands at $z = 2$. Rather than investigating different epochs using separate, individual long integrations, it will be an instrumental goal of the SKAI project to provide frequency bandwidth and spectral resolution sufficient to observe as much as possible of the entire redshift interval $2 < z < 4$ simultaneously. Based on the detection frequencies noted above, one would then expect such a single experiment to allow the study of some 8000 high redshift systems.

These results demonstrate the unique potential of a Square Kilometer radio telescope to determine empirically the evolution of galaxies from the earliest epochs, to tell us how and when large scale structures came into being and thereby also to reveal the nature of the unseen matter we know is all around us.

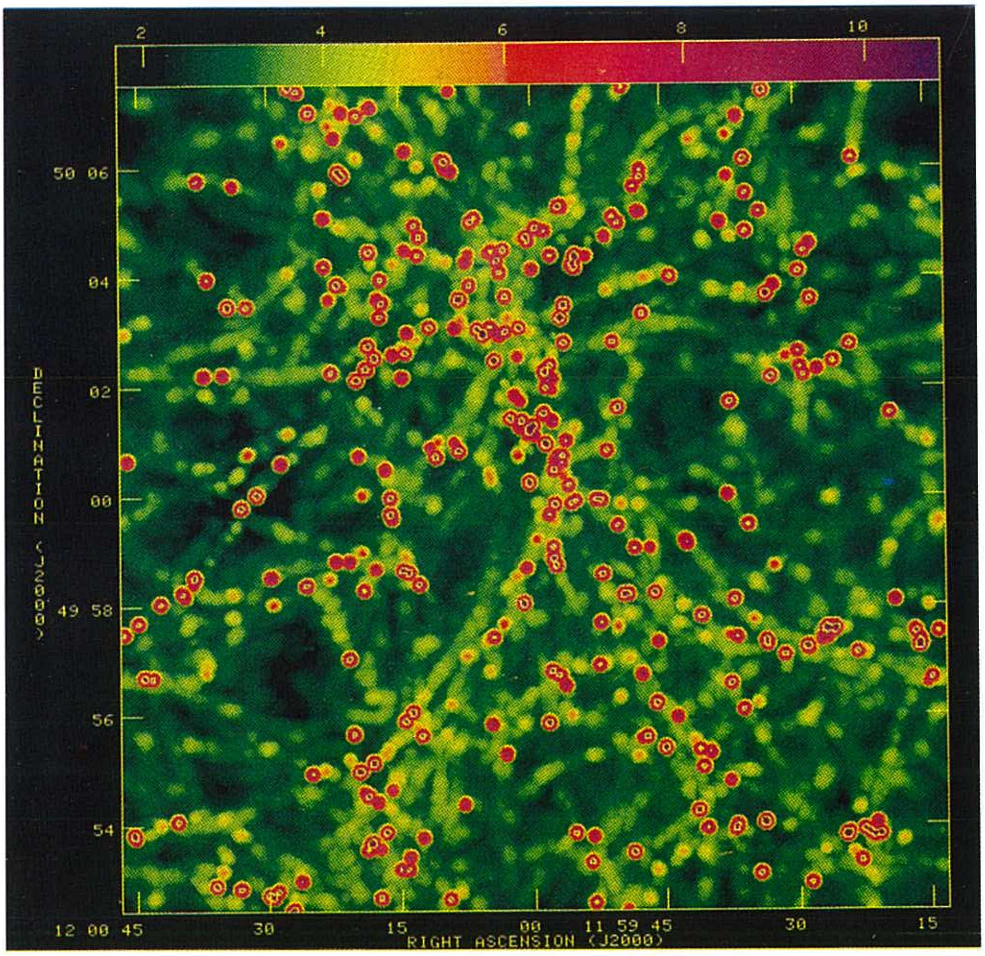


Figure 12. HI emission at $z = 2$ with SKAI detections overlaid. The linear grey-scale indicates the predicted peak brightness of HI emission in a $22.2/(1+z)$ Mpc cube and extends from $\log(M_{\odot}/\mathrm{Beam}) = 1.7 - 10.8$. The single white contour at $\log(M_{\odot}/\mathrm{Beam}) = 9.22$ is the 5σ SKAI detection level after a 1600 hour integration.

Testing models for cosmic ray acceleration

Recent work on the origin of cosmic rays suggests three main production sites: stellar explosions into the interstellar medium, stellar explosions into a former stellar wind, and powerful radio galaxy hot spots. Strom (NFRA) collaborated with Biermann and Falcke (MPIfR) during the year to test model predictions for particle acceleration by strong, fast shocks in a stellar wind using observations of the non-thermal radio emission from the cataclysmic variable binary star GK Persei.

GK Persei is a nova that exploded in 1901. Its radio spectrum at high frequencies is a power law with spectral index close to that predicted for synchrotron emission from a shocked region in a stellar wind, in the case where the shock is much faster than the wind speed. The object should therefore provide a good testing ground for the theory of particle acceleration in this situation.

High dynamic range WSRT data at 49 and 92cm were combined with data from other telescopes to define the radio spectrum between 0,15 and 6 GHz. Strom and colleagues find that a consistent picture can be developed, in which fast shock fronts in a strong stellar wind produce the observed radio luminosity, the geometric shape of the source, the radio spectrum including the observed low frequency cutoff, and the observed polarization properties. In particular, the observed polar cone emission regions can be reproduced in this model, and the gradual low frequency cutoff in the radio spectrum is a natural consequence of nucleus-nucleus interactions between cosmic ray particles and interstellar matter (mostly proton-proton collisions producing secondary electrons and positrons with a characteristic energy distribution). All other proposed explanations for the low frequency behavior of the radio properties fail in one way or another when compared to the observations. This work provides convincing confirmation that at least some fraction of cosmic ray particles can originate as secondaries from nucleus-nucleus interactions.

Rapid variability of quasars at low frequencies

Some extra-galactic radio sources are observed to vary in luminosity at low frequencies. If this variability is a phenomenon intrinsic to the source, the timescales of variability and implied brightness temperatures ($T_B > 10^{12}$ K) suggest bulk relativistic motions of the emitting plasma with Doppler factors of 10 to 20. Such factors are similar to or higher than those derived from the apparent super-luminal motion of milli-arcsec components in some radio galaxies and quasars seen in VLBI studies.

In 1995, Peng (Beijing) and de Bruyn (NFRA) reported on their study with the WSRT of the 92cm variability of the quasar 4C 38.41. An 18% variability was seen over a period of 36 days with clear indications of variability on the timescale of a week. The computed brightness temperature is $7{,}5 \times 10^{18}$ K, dramatically exceeding the inverse Compton limit, and the inferred Doppler factor for bulk motion is nearly 200! The study emphasizes that variability studies can put strong limits on phenomenological models, and that refinements to current relativistic beaming models may be necessary to understand the phenomenon of low frequency variability.

Giant radio galaxies

Extragalactic radio sources with dimensions greater than 1,5 Mpc are rare in the cosmos, but provide in principle a good laboratory for studying both the physics of the radio galaxy phenomenon and the nature of the intergalactic medium. It is uncertain whether these sources attain such large sizes because the ratio of jet power to the density of the surrounding medium is unusually large, or because the sources are simply much older than the average radio source of the type and so have had time to expand to unusually large dimensions.

The low frequency WENSS project is yielding some 250.000 radio sources in the northern sky, among which are many good candidates for this class of giant source. As part of the Early Universe program subsidized by NFRA, Röttgering (Cambridge UK), de Bruyn (NFRA), Bremer (Leiden), Tang (NFRA) and colleagues have established that Mkn 1498 (B1626+5153) belongs to the class. A classical double, the source has a maximum dimension of at least 1,6 Mpc, a flux density at 325 MHz of 1,9 Jy and spectral index of -0,66. Optical spectra with the 4,2m William Herschel telescope on La Palma by the team show a narrow line emission spectrum typical of many radio galaxies and yield a redshift of z = 0,056. The H-alpha line clearly has a broad line component, making Mkn 1498 the third known giant radio galaxy exhibiting broad permitted lines.

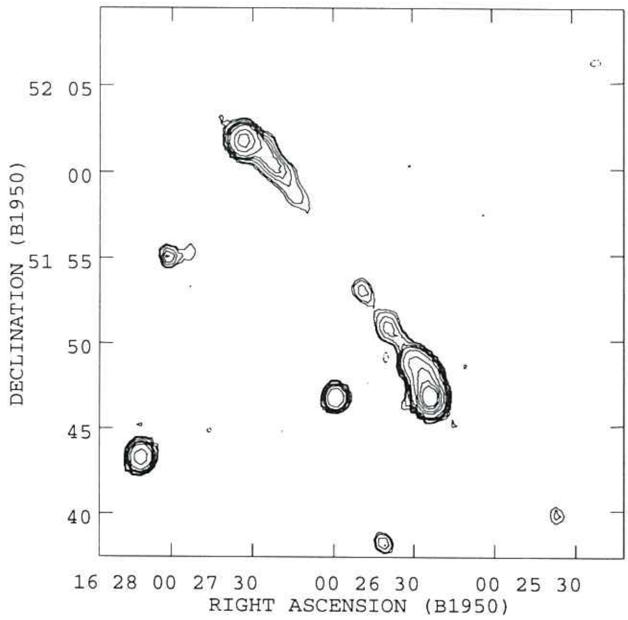
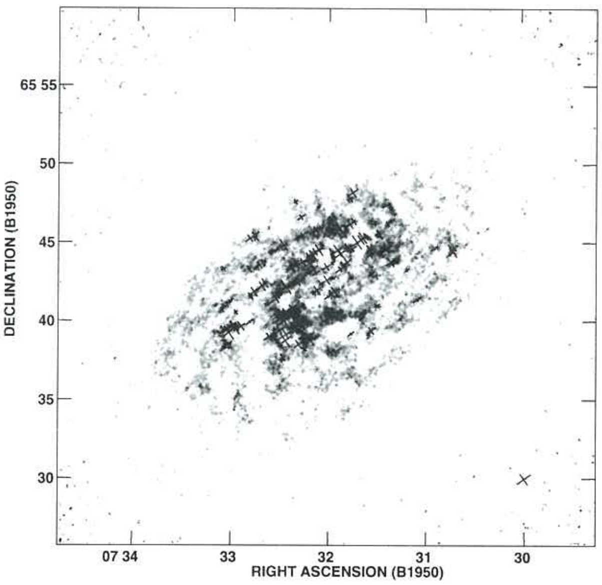


Figure 13. A contour map of the giant radio source B1626+5153 from the WENSS survey. (Courtesy of H.J.A. Röttgering).

Most available evidence supports the view that the main differences among radio galaxies and radio quasars may be understood as an orientation effect (Barthel, Groningen). At some orientations one can see the central source directly, including the broad permitted lines, while at others the center is hidden and only the larger scale narrow emission line gas and large scale radio emission is visible. Of the dozen or so giant radio sources known, three (including Mkn 1498 now) show broad optical permitted lines, broadly consistent with the predictions of this orientation unification model. The expectation is that the WENSS survey ultimately will provide sufficient giant sources to improve the statistical weight of these comparisons such that convincing conclusions can be drawn concerning unification models.

Expanding HI shells in spiral galaxies

Energy input to the interstellar medium in spiral galaxies is usually dominated by supernova explosions and by stellar winds from very young stars. The latter phenomenon often leaves large cavities in the medium, which can be detected as expanding super-shells of neutral gas. Maps of the positions and velocities of the neutral gas in the 21cm line should allow detailed study of the energy balance in spiral disc systems. To identify super-shells reliably, Braun (NFRA), Thilker (NFRA summer student) and Walterbos (UNM) developed a method of automatically correlating theoretical model data cubes of super-shells with observational cubes of real systems.



The method cross-correlates the observed HI data with a series of three dimensional kernals that are designed to match the predicted appearance of super-shells at a range of in-disc radii and with a range of initial expansion velocities. In practice the correlation data often do show peaks of high statistical significance, and provide estimates of the mean ambient density, shell age, mass and kinetic energy, and the internal wind velocity.

Figure 14. Detected atomic super-shell structures in NGC 2403. The 146 super-shells detected at high significanceare indicated by the crosses superposed on an image of the integrated HI emission.

NFRA Institute

Financial report 1995

Received funds	*(kf)*	*total*
Operations		15,670
NWO	12,273	
NWO beleidsruimte GB-E	1,200	
Credit balance 1994	1,413	
UK/NL non-recurring expense	519	
Others	15	
Expertise Centrum	250	
Capital Outlay subsidies		5,683
NWO basis instituut	1,000	
NWO middelgroot	2,499	
NWO groot	1,800	
Credit balance 1994	384	
Total		**21,353**

Expenditures	*(kf)*	*total*
Operations institute + WSRT		11,961
Staff	8,635	
Exploitation	2,598	
Credit balance 1995	728	
Grants program		2,175
Projects	1,398	
Programs	650	
Credit balance 1995	127	
WSRT construction maintenance		809
WSRT development projects		2,120
Multi Frequency Front Ends	1,049	
New digital backend	1,044	
Software: AIPS++ project	17	
WENSS	10	
R & D Phased Array Study		210
UK/NL Cooperation		3,432
Staff and overhead	823	
NL share operations	2,609	
Infrastructure new building		290
Expertise Centrum ECAB		250
General credit balance 1995		106
Total		**21,353**

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Number	Proposer(s)	Title	Inst.	Researcher
Stellar systems				
781-71-040	Prof.dr. H.J.G.L.M. Lamers Prof.dr. E.P.J. v.d. Heuvel Dr. L.B.F.M. Waters	The evolution of Low-Mass Binaries from AGB, through Post-AGB into Planetary Nebulae	UU	Drs. E.J. Bakker
781-71-041	Dr. P. Hoyng Prof.dr. M. Kuperus Prof.dr. H. van Beijeren	Stochastic excitation of global magnetic modes	ROU	Drs. A.J.H. Ossendrijver
781-71-042	Prof.dr. J.A. van Paradijs Dr. W. Hermsen	Gamma-Ray production in galactic compact objects	UvA	Drs. R.C.A. van Dijk 50% NFRA 50% SRON
781-71-043	Dr. H.F. Henrichs	Seismology of O stars	UvA	Drs. J.H. Telting
781-71-044	Prof.dr. J.M.E. Kuijpers	Radio pulsars and linear acceleration emission	UU	Dr. E.T. Rowe
781-71-045	Dr. R.J. Rutten	Radiation hydrodynamics of the quiet chromosphere	UU	Drs. N.M. Hoekzema
781-71-046	Dr. G.J. Savonije	Non-linear Tides in Early type Binary Stars	UvA	Drs. F. Alberts
781-71-047	Dr. G.H.J. van den Oord Prof.dr. M. Kuperus	The effect of retardation on MHD-configurations	UU	Drs. N.A.J. Schutgens
781-71-048	Prof.dr. H.J.G.L.M. Lamers	A study of the variability of Luminous Blue Variables	UU	Drs. R. Noordhoek
781-71-050	Prof.dr. A. Achterberg	The Highest-Energy Cosmic Rays	UU	Dr. Y.A. Gallant
781-71-051	Prof.dr. H.J.G.L.M. Lamers	The winds of B[e]-supergiants and B-supergiants	UU	Dr. T.M. Lanz
781-71-052	Dr. L.B.F.M. Waters Prof.dr. T. de Jong Prof. C. Waelkens	The evolution of Post-AGB stars	UvA	Drs. F.J. Molster
781-71-053	Dr. H.F. Henrichs	Origin of wind variability in massive stars	UvA	Drs. J.A. de Jong

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781-72-032	Dr. J.M. van der Hulst Dr. R. Braun	The interaction between star formation and the interstellar medium M33 and M31	RUG	Drs. O.M. Kolkman
781-72-033	Dr. J.M. van der Hulst	A theoretical study of the Infra Red spectra of planetary nebulae, galactic nuclei and HII regions	RUG	Drs. P.A.M. van Hoof

781-72-034	Dr. E.F. van Dishoeck Prof.dr. H.J. Habing Dr. Th. de Graauw	Nature and evolution of interstellar dust studied by laboratory infrared spectroscopy	RUL	Dr. W. Schutte NFRA/SRON/RUL
781-72-036	Prof.dr. H.J. Habing	The selection of a dynamical model for the inner disk and the bulge of our Galaxy based on an upgraded sample of OH/IR stars	RUL	Drs. M. Sevenster
781-72-037	Prof.dr. W.B. Burton	Scientific exploitation of the Leiden-Dwingeloo HI survey; physical characteristics of galactic HI	RUL	Drs. S.R.D. West
781-72-038	Dr. J.B.G.M. Bloemen Prof.dr. H.J. Habing	Gamma-ray spectroscopy of the interstellar medium using COMPTEL	ROU	Drs. R.D. van der Meulen

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781-73-053	Prof.dr. T.S. van Albada	Standard candles and the physical basis of the Tully-Fisher relation	RUG	Drs. M.H. Rhee
781-73-055	Dr. W. Jaffe	The dynamics of teh nuclei of elliptical galaxies	RUL	Drs. F.C. van den Bosch
781-73-056	Prof.dr. G.K. Miley Prof.dr. A.G. de Bruyn	Search for superclustering in the early universe	RUL	Drs. R.B. Rengelink
781-73-057	Dr. P.D. Barthel	The ELF - QSO connection: superstarbursts as origin of QSO activity?	RUG	Drs. J.P.E. Gerritsen
781-73-058	Dr. P.D. Barthel Dr. P.A. Shaver Dr. J. Surdej	Structure and composition of early epoch gas clouds and galaxies	RUG	Dr. A.J. Smette
781-73-059	Prof.dr. P.T. de Zeeuw Dr. M.A.C. Perryman	HIPPARCOS study of the structure of OB Associations	RUL	Drs. R. Hoogerwerf

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781-76-010	Prof.dr. G.K. Miley, Prof.dr. A.G. de Bruyn, Dr. P. Katgert, Prof.dr. R.T. Schilizzi	Studies of the early universe using radio sources	RUL	Dr. H.J.A. Röttgering
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781-76-013	Prof.dr. T.S. van Albada, Prof.dr. R. Sancisi	Dark Matter, Dynamics and Evolution of Spiral Galaxies: discussion of the first results of the Westerbork survey of HI in spiral and irregular galaxies (WHISP)	RUG	Drs. M. Vogelaar (research assistent)
781-76-014 MPR	Prof.dr. J.P. Goedbloed, Prof.dr. A.G. Hearn, Prof.dr. H.A. van der Vorst	Magnetohydrodynamics: parallel computation of the dynamics of thermonuclear and astrophysical plasmas	RUU	Dr. G. Toth
781-76-015	Prof.dr. H.J. Habing Dr. E.F. van Dishoeck Dr. R. Waters Dr. P. Wesselius	Physical and chemical evolution of young stellar objects	RUL	Dr. C. Dominik

Publications

Publications by NFRA staff

Bohringer, H., Nulsen, P.E.J., **Braun, R.**, Fabian, A.C. *The interaction of the radio halo of M87 with the cooling intracluster medium of the Virgo cluster*, MNRAS 274, L67-71

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NFRA Notes & ITRs

Notes

626	M. de Vos	Towards a TMS for the WSRT.
627	A. Bos	The DAS maintenance and test procedures. R.P. Millenaar.
628	A. Bos	Draft: EVNFRA Correlator Software. Part 1: The correlator control interface.
629	C. Slottje	Nieuwbouw Jive operationele Condities en Ruimtebehoefte voor opslag en Expeditie bij het gebruik van Paternostersystemen voor de Tape logistiek van JIVE.
630	P. de Jong/ S. Zwier	The EVN correlator: the control board hardware description.
631	C. Slottje	Zijn paternosters geschikt voor JIVE.
632	C. Slottje	Nieuwbouw JIVE, A benchmark voor JIVE operations.
633	C. Slottje	Locatie en Tape logistiek van Jive en goederen logistiek van Astron. Een haalbare en flexibele oplossing.
634	C. Slottje	JIVE benchmark, Tape storage capacity demand for JIVE operations.
636	R. Millenaar	The EVNFRA data distributor unit: Functional description.
637	B. Woestenburg	Concept studie van het IVC-system voor het DZB.
640	B. Woestenburg A. Gunst	Calibratie voor de dubbele LNA-configuratie van de UHF-banden in het MFFE.
641	J. Bregman	WADDS upgrade project documentation

ITRs

205	B. Woestenburg L. Nieuwenhuis	A 230 - 460 Mhz HEMT- amplifier with extremely low noise at room temperature.
208	Ren Xu	A two stage cryogenically coolable S-band amplifier.
209	A. Kokkeler	ADC subsystem documentation set.

210	M. de Vos	Scissor User Manual
212	G. Van Diepen	General C++ Cooking Standard at the NFRA.
213	F. Olnon	NFRA standard for configuration management.

Publications of NFRA supported research projects

Savonije, G.J., Papaloizou, J.C.B., **Alberts, F.**, *Non-adiabatic tidal forcing of a massive, uniformly rotating star*, MNRAS 277, 471-496

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Radio Observatory

Facilities

The Westerbork Synthesis Radio Telescope

The Array

The WSRT consists of an East-West array of fourteen equatorially mounted 25-m dishes. Ten of them are on fixed mountings, 144 metres apart; the four (2 x 2) remaining dishes are movable along two railtracks, one, 300 m long, adjacent to the fixed array and another, 180 m long, 9 x 144 m more towards the East. The movable dishes can be used at any position of the rail tracks. The pointing accuracy of the dishes is 15 to 20 arcseconds, the surface accuracy is of the order of 2 mm.

Observing modes

In its 'normal', local mode of operation the WSRT is used as an aperture synthesis array with a total length of 2.8 km. It then consists of a basic set of 40 interferometers, each interferometer comprising one fixed and one movable dish, and a variable number of 'redundant' interferometers (fixed-fixed and/or movable-movable). The redundant interferometers are generally used to calibrate the short term phase and amplitude variations caused by instabilities in the atmosphere. This method, in combination with self calibration techniques, allows very high dynamic ranges to be obtained in continuum observations in particular. The redundant interferometers can, of course, also be used to contribute to aperture-synthesis maps.

A new method of using the WSRT in local mode was developed in 1990. This mosaic method allows mapping of large areas of the sky in a relatively short time. During one 12-hour period the telescopes along with the fringe-stopping and delay centers cycle through a grid of positions a number of times. The grid may contain as many as 120 positions; it can be arranged in a flexible way. If done sensibly no more than 10 seconds are required to change positions within the grid. This allows large surveys of continuum or line radiation which are not limited by the ultimate sensitivity of a full 12-hour observation per position. Part of the time the WSRT is used for Very Long Baseline Interferometry (VLBI) along with other radiotelescopes in Europe and elsewhere (mainly the USA). The fourteen WSRT dishes are then used as a 'tied array', together yielding the equivalent of one 93-metre single dish in the VLBI network.

Receivers and backends

wavelength (cm)	6	18	21	49	92
frequency range(MHz)	4770-5020	1590-1730	1365-1425	607-610	300-380
field size HPBW (degr)	0.17	0.5	0.6	1.4	2.6
max. bandwidth (MHz)	80	40	40	2.5	80
synth. beam in RA (arcsec)	3.7	11	13	30	55
cont. sensitivity (r.m.s. in 12-hour obs. mJy/beam)	0.07	-	0.06	0.6	0.5

Table 1. Characteristics of the WSRT and its receivers.

Table 1 summarizes the characteristics of the WSRT at each of the five wavelengths for which receivers are available. At 18 cm there are only five (cryogenically cooled) receivers. At this wavelength the WSRT is generally used in the VLBI tied-array mode. For the other four wavelengths a complete set of 14 receivers can be used. All receivers have two polarization channels.

Two digital correlators and two VLBI recording systems can be used to combine the signals from the array for different types of observations. A summary of their characteristics is given in table 2. Note that the Mk2 VLBI mode is from 1994 no longer a standard mode supported by the European VLBI Network. Below we give some additional information.

The spectral line backend (DXB)

The basic number of independent 1-bit correlation products the DXB can produce simultaneously is 2560. In 2 bit mode the correlator produces half the number of products (1280) with a sensitivity improved by approximately 1.2. When the observed spectrum can be covered adequately with an overall bandwidth (B) narrower than its maximum value (10 MHz), the clockrate of the correlator (20 MHz) allows the number of correlation products obtained in one integration time to be increased by a factor 10/B to a maximum of 40960 (10/B is a power of 2). The number of complex channels, obtained after Fourier transform of the correlation functions, may be distributed over interferometers and polarization channels of the array. How one chooses to do this depends not only on the spectral resolution required, but also on the sensitivity needed per frequency point (=complex channel) on each interferometer.

Sensitivity may be increased by changing the correlator's bit-mode, but also by observing the same spectrum simultaneously in two independent polarization channels. The number of independent frequency channels F in each observed spectrum depends on the overall bandwidth B (MHz), the correlator bit-mode M (1 or 2), the number of interferometers I, and the number of polarization channels P by the relation: $F \times M \times I \times P = 2560 \times 10/B$

DXB spectral line backend								
bandwidth options (MHz)	10	5	2.5	1.25	.625	.313	.156	.078
# complex ch. (2 bit)	1280	2560	5120	10240	20480	40960	40960	40960
(3 bit)	2560	5120	10240	20480	40960	40960	40960	40960
spectral resolution (kHz)								
40 interf. 2 polariz. 2 bit	625	156.3	39.1	9.8	2.4	0.6	0.3	0.15
10 interf. 1 polariz. 1-bit	39.06	9.77	2.44	0.61	0.31	0.15	0.08	0.04
DCB continuum backend								
total bandwidth (MHz)	8x10	40						
bandwidth options (MHz)	10	5						
# complex channels	2048							
MK2 VLBI backend								
max. total bandw. (MHz)	2							
bandwidth options (MHz)	2	1	.5	.25	.125	.0625		
MK3 VLBI backend								
max. total bandw. (MHz)	14x4							
bandwidth options (MHz)	4	2	1	.5	.25	.125		

Table 2. Characteristics of the WSRT backends.

As an example the spectral resolution is given for each of the eight possible overall bandwidths available and for two rather extreme choices: (i) use of 40 interferometers in two polarization channels and 2-bit correlation mode for maximum sensitivity, and (ii) use of all possible correlation products on, for instance, 10 interferometers in one polarization channel and in 1-bit correlation mode for high spectral resolution.

The Continuum Backend (DCB)

The DCB has eight independent bands, each with a width of either 10 MHz or 5 MHz. The central frequencies of the eight bands may be chosen independently within an overall range of about 90 MHz. This choice can be useful to avoid interference at a particular frequency.

Very Long Baseline Interferometry (VLBI)

Any combination of the WSRT dishes can be used as a 'tied array' to serve as one station in a VLBI network. Two types of VLBI backends are available: the narrow-band Mark2C system and the wide-band Mark3A system. In front of the recording terminals one of the normal WSRT backends is used: the DXB in combination with Mk2 and the DCB in combination with Mk3. It is possible to observe two polarization channels simultaneously with the Mk3 system. With the Mk2 system one can switch between polarization but one cannot observe them simultaneously. Again, from 1994 Mk2 observations will only be supported on an ad hoc basis.

The 25-metre Dwingeloo telescope
Unlike the WSRT the Dwingeloo telescope is available for use by astronomers who are able to schedule and to carry out their observations themselves. Although a schedule can be prepared for periods of the order of a week, the astronomer's monitoring of the progress will generally require some physical presence in Dwingeloo.

The characteristic parameters of the telescope are given below:

Diameter	25 m
Mount	alt-azimuth
Pointing accuracy	~ 1 arcmin
Surface accuracy	2 - 2.5 mm
Aperture efficiency	0.64 (λ = 18 or 21 cm)
	0.40 (λ = 6 cm)

Frontend receivers are available for 21 cm and for 18 cm wavelengths (and, upon request for 6 cm). Their parameters are:

System temperature	36 K
Frequency range	1375 - 1425 Mhz (λ = 21 cm)
	1580 - 1725 Mhz (λ = 18 cm)

Sensitivities (5 × rms noise) in 60 min integration time:

cont., bandwidth 10 Mhz	20 mJy (2 mK)
line channel, 78 kHz wide	150 mJy (17 mK)

As a backend a prototype of the Dwingeloo Autocorrelation Spectrometer (DAS), developed for the JCMT, is used. It has 1024 channels (if desired to be used with two Ifs as 2 × 512 channels). It operates at overall bandwidths of 10, 5, 2.5 ..... 0.067 Mhz. If desired, observations with a time resolution of 0.1 sec can be done.

Projects

Number	*Name*	*Subject*
515	Bruyn, G de	Nauwkeuriger bepaling positie bronnen
1027	Strom, RJ	Cyg X-1
1030	Wakker, BP	HVC-distance
1043	Hucht, KA van der	Variable non-thermal wolf-rayet binaries
1046	Verheijen, MAW	Dark matter in spiral galaxies
1103	Albada, TS van	WHISP
1121	Braun, R	Nearby starburst systems
1135	Pater, I de	Shoemaker/Levy-Jupiter encounter
1136	Geller	Intergalactic ionized medium
1138	Nordgren, TE	HI Morphology & kinemathisc of galaxy pairs
1140	Hanlon, L	Rapid radio observations of gamma-ray burst error boxes
1141	Carilli	Damped Lya absorption system
1153	Braun, R	Molecular gas in the early universe
1154	Burton, B	The opacity of neutral atomic gas in the galacxy
1155	Klis, M van der	Filterbank commissioning time
1160	Bremer, M	Scattering halos around CYGA & 3C295
1161	Johnston, H	Search for pulsars in WENSS candidates
1162	Strom, R	SGR 1900+14
1163	Brunner, H	Survey of an optical/X-ray quasar field
1165	Strom, R	SNR DA 530
1166	Briggs, F	Steep low-freq turnover in high-z quasar
1172	Chengalur, JN	Unbiassed search for high-z HI absorption
1173	Carilli, C	HI 21cm absorption towards high-z radio galaxies
1175	Paradijs, J van	Lobes around soft X-ray transients
1177	Breuck, C de	Synchrotron halo of spiral galaxies
1179	Sanghera, H	A sample of low luminosity 'WENSS' giant radio sources
1180	Dallacasa, D	Extended emission in BL-LAC objects
1181	Braun, R	Search for pulsed emission near Cygnus loop
1182	Albada, TS	HI in highly inclinated galaxies
1184	Chengalur, JN	DW1 companions & galactic HI fine scale structure
1185	Progrebenko, S	QSO 2022+171 Radio spectrum and variability
1189	Schoenmakers, AP	Deep 92 cm observations of nearby giant radio galaxies
1191	Vasisht	Young Pulsars in Perseus
1192	Schoenmakers, AP	A unique sample of high redshift giant radio galaxies
1196	Briggs, F	Interaction of an HVC with galactic HI
1197	Schoenmakers, AP	21 cm observations of nearby giant radio galaxies
1201	Sanghera, H	A sample of low luminosity giant radio sources from WENSS
1203	Henrichs, HF	The stellar wind of Per
1204	Boriakof, V	Measurement of the interstellar field towards pulsars
1205	Schoenmakers, AP	Interim observations of high redshift giant radio galaxies
1206	Bruyn, G de	Onderbouwing voor 21 cm waarnemingen in GRB940301
1208	Deich, W	Polarisation & scintillation of pulsars
1209	Bruyn, G de	Hooks & filaments in the galactic lineair polarisation

1210	Spoelstra, TATh	Galactic contiuum polarisation
1214	Paradijs, J van	Search of phase reference sources near SCOX1
1215	Paradijs, J van	Study of rapid periodic variations of GRS1915+105
1216	Barthel, PD	Parsec-scale jet emission in the Sombrero Galaxy
2000	Bruyn, G de	WENSS

Time awards

Project	92cm	50cm	21cm	18cm	6cm	Total (hours)
515					4.5	4.5
1027			7.3			7.3
1030			54.7			54.7
1043	51.0	1.8	150.7		26.9	230.5
1046			48.0			48.0
1103			758.6			758.6
1121			11.8			11.8
1135	15.5					15.5
1136			132.0			132.0
1138			23.9			23.9
1140	48.0		10.5			58.5
1141	30.7					30.7
1153	24.0					24.0
1154			73.2			73.2
1155	2.2					2.2
1160			12.0			12.0
1161			83.1			83.1
1162	12.0		24.0			36.0
1163			24.0			24.0
1165			12.0			12.0
1166	7.3					7.3
1172	76.6					76.6
1173	66.3					66.3
1175			13.9			13.9
1177	33.8					33.8
1179			10.5			10.5
1180			15.3			15.3
1181	24.0					24.0
1182			76.5			76.5
1184			26.4			26.4
1185	3.9	5.1	1.0		10.0	20.0
1189	84.1					84.1
1191	38.9					38.9
1192			36.8			36.8
1196			48.0			48.0
1197			12.5			12.5

1201			13.2			13.2
1203			45.1		34.0	79.1
1204	19.9					19.9
1205					8.5	8.5
1206			14.2			14.2
1208	22.4					22.4
1209	30.5					30.5
1210	58.2					58.1
1214	9.1					9.1
1216	7.7					7.7
2000	945.5	397.3	10.9			1353.7
Total	1611.6	404.2	1750.1		83.9	3849.8
VLBI	138.0		0.9	71.5	249.3	459.7
Total	1749.6	404.2	1751.0	71.5	333.2	4309.5

ING Dutch Projects and Time Awards

WHT

Semester 95A (February-July 1995)

Ref No.	PI		Award (nights)
W/95A/N2	Smette	UV-bright high-*z* quasars	1D+3G
W/95A/N3	Miley	Ultra-steep spectrum sources	2D
W/95A/N4	Katgert	Structure magnetic field hot ISM	2D
W/95A/N5	Butcher	Butcher-Oemler galaxies	3D
W/95A/N11	Balcells	Velocity field elliptical cores	2B
W/95A/N12	Smette	Quasar haloes	1G
W/95A/N14	Oudmaijer	Mass losing high-*b* carbon stars	1G
W/95A/N16	van Woerden	Distance HI HVC-c	1G+1B
W/95A/N17	Telting	Determination *v*sin*i*	2B

Semester 95B (August 95- January 1996)

W/95B/N1	Franx	Dark matter distorted galaxies	3D
W/95B/N2	Bremer	Evolution cluster galaxies	3D
W/95B/N3	Kuijken	Bars in bulges	1D
W/95B/N7	Prins	Spectroscopy M31 SNRs	2G
W/95B/N8	Kuijken	Kinematics bulges disk galaxies	2G
W/95B/N9	Voors	LBV G79.29+0.46	1G
W/95B/N10	Favata	Lithium in Stock 2	1B
W/95B/N11	van Winckel	Post AGB stars	2B
W/95B/N12	van der Werf	IR spectroscopy high-z galaxies	3B
W/95B/N13	Telting	*v*sin*i* early type stars	2B
W/95B/N15	van der Werf	ISM cooling flow galaxies	1B

INT

Semester 95A

I/95A/N1	van der Kruit	Surface photometry WHISP galaxies	3D+2G
I/95A/N2	van der Hulst	Ionized gas in edge-on spirals	2D
I/95A/N5	van Paradijs	Accretion disks cataclysmic variables	7B
I/95A/N6	Spruit	Enigmatic dwarf nova WZ Sge	4G
W/95A/N10	Martin	Be and Li in Her X-1 and Cyg X-1	1B
J/95A/N2	Dieters	Search black hole candidates	3B

Semester 95B

I/95B/N1	Sackett	Low surface brightness galaxies	3D
I/95B/N2	Sprayberry	HI selected galaxies	2D
I/95B/N5	van Paradijs	Cataclysmis variables	6B
I/95B/N6	de Bruyn	Spectroscopy giant radio galaxies	3G
I/95B/N8	van der Kruit	Surface photometry WHISP galaxies	3D+3G
I/95B/N10	van Hoof	CNO in Pns	2B

JKT

Semester 95A

J/95A/N1	Stil	Stellar population dwarf galaxies	4G
J/95A/N3	Augusteijn	Disk and halo cataclysmic variables	5G
J/95A/N4	de Blok	Low brightness galaxies	7D
J/95A/N5	Gunawan	Wolf-Rayet stars	8B

Semester 95B

J/95B/N1	Augusteijn	Cataclysmic variables	6D
J/95B/N2	Stil	Stellar population dwarf galaxies	3G+3B
J/95B/N3	Jaffe	Educational images	2D+1G
J/95B/N4	Zaal	Spectroscopy OB stars	11B

Dwingeloo Colloquia 1995

Dr Holland Ford (STScI, Baltimore)
"Polar Stratospheric Telescope (POST) Dutch participation?"

Dr Maria Massi (Florence/MPIfR)
"Errors in EVN VLBI measurements due to instrumental polarisation"

Drs Pek van Andel (RU Groningen)
"Anatomy of the unsought finding. Serendipity : Origin, History, Domains, Traditions, Appearances, Patterns and Programmability"

Drs Matthijs van Boxsel
"Over de Domheid"

Gautam Vasisht (Caltech
"Soft Gamma Ray Repeaters Unveiled"

Dr Jaap Tinbergen (KSW Roden)
"Polarization Perspectives"

Dr Bob Sault (NFRA/ATNF)
"Interferometric Mosaicking"

Dr Lorraine Hanlon (ESTEC, Noordwijk)
"Gamma Ray Bursters"

Dr John Conway (Onsala Space Obs, Sweden)
"HI Absorption toward the Nucleus of Cygnus A: Implications for the Obscuring Torus"

Eddie Szulc, MSc (HighTech Automation BV)
"Applied Artificial Intelligence"

Dr Wim van Driel (Nancay Obs, France)
"Radio astronomy in France"

Dr Luigina Feretti (Bologna Univ, Italy)
"The Magnetic Field of the Coma Cluster"

Dr Andrea Hin (RU Groningen)
"Visualisation of turbulence: particles and clouds in motion"

Dr Vera Rubin (Carnegie Institution, Washington DC)
"A Century of (mostly optical) Galaxy Spectroscopy"

Prof Tor Hagfors (MPI aeronomie, Lindau)
"Lunar Reflection Interferometry: Is It Useful?"

Dr Duncan Campbell-Wilson (Molonglo Obs, Australia)
"The Molonglo Observatory Synthesis Telescope (MOST)"

Dr Colin Lonsdale (Haystack Obs, USA)
"VLBA Images of a Jet Terminus"

Dr Marat Mingaliev (Russian Acad. of Science)
"The RATAN-600 Radio Telescope: Current Status and Investigations."

Prof Ray Offen (Macquarie University, Sydney)
"How Do We Make Software Engineering More Like Engineering?"

Dr Huib-Jan van Langevelde (JIVE/NRAO)
"Phase referencing VLBI observations of U Her"

Dr Chris O'Dea (STScI, Baltimore, USA)
"A Multi-Wavelength Perspective on GHz Peaked Spectrum Sources"

Freek Benning (Waterschap Hoogeveen)
"Terugdringen van de verdroging in het Dwingelerveld, en de taakstelling van het Waterschap"

Dr Ewine van Dishoeck (Sterrewacht Leiden)
"Probing the earliest stages of star formation with molecular observations"

Jan Noordam (NFRA, Dwingeloo)
"The Measurement Equation for a Generic Radio Telescope"

Dr Penny Sackett (Kapteyn Lab, Groningen)
"The Distribution of Dark Mass in Galaxies"

Dr Phil Diamond (NRAO, Socorro)
"Rings around stars: SiO masers in the extended atmosphere of M-type giants" fri Oct 20 (11:00):

Dr Istvan Fejes (Satellite Geodetic Observatory, Penc, Hungary)
"Space VLBI Geodesy"

Jan Slagter (NFRA Dwingeloo)
"Demonstratie van het gebruik van Product Data Management (PDM) en WorkFlow".

Andrew Hopkins (University of Sydney)
"The Phoenix Deep Survey: the nature of the sub-mJy radio population and IRAS-type galaxies"

Drs Carina Olij, Dr Roel Hoekstra (TNO/TPD, Delft)
"GOME: Monitoring of Atmospheric Ozone from Space; Technical, Results, Project Management Aspects"

Prof Frank Briggs (Kapteyn Lab, Groningen)
"A radio selected deuterium line at redshift 0.7"

Dr Huub Rottgering (Sterrewacht Leiden)
"Recent Observations of Distant Radio Galaxies"

Dr Jan Willem Pel (KSW, Roden)
"VISIR: Mid-IR imaging and spectroscopy with the VLT."

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Abbreviations

AAT	Anglo Australian Telescope
ADAM	Astronomical Data Analysis & Management system
AGB	Asymptotic Giant Branch
AGN	Active Galactic Nuclei
AIPS	Astronomical Image Processing System
AOS	Acousto Optical Spectrograph
ASTRON	Stichting Astronomisch Onderzoek in Nederland
ATNF	Australia Telescope National Facility
AU	Astronomical Unit (= afstand aarde - zon)
BLR	Broad Line Region
Caltech	California Institute of Technology
CAT	Coudé Auxiliary Telescope
CCD	Charge Coupled Device
CCI	Comité Cientifíco Internacional (La Palma/Tenerife)
CCIR	Comité Consultatif International Radio Communication
CESRA	Committee of European Solar Radio Astronomers
CIT	California Institute of Technology
CLRO	Clark Lake Radio Observatory
CRAF	Commission on Radio Astronomical Frequencies
CSIRO	Commonwealth Scientific & Industrial Research Organization
CSS	Compact Steep Spectrum source
DAS	Dwingeloo Autocorrelation Spectrometer
DCB	Digital Continuum Backend
DLB	Digital Line Backend
DMA	Direct Memory Acces
DRAO	Dominion Radio Astronomy Observatory
DWARF	Dwingeloo/Westerbork Astronomical Reduction Facility
DWOFS	Dwingeloo/Westerbork OFfline System
DXB	Extended Digital Line Backend
EFOSC	ESO Faint Object Spectrograph and Camera
ESA	European Space Agency
ESF	European Science Foundation
ESO	European Southern Observatory
EVN	European VLBI Network
FAST	Fundamental Astronomy by Space Techniques consortium
FET	Field Effect Transistor
FFT	Fast Fourier Transform
FITS	Flexible Image Transport System
FK4	Vierde Fundamentele Katalogus van sterposities
FWHM	Full Width Half Maximum
GB-E	Gebiedsbestuur Exacte wetenschappen NWO
GHRILL	Ground based High Resolution Imaging Laboratory

GIPSY	Groningen Image Processing System
GPS	Gigahertz Peaked Spectrum
HPBW	Half Power Beam Width
HVC	High Velocity Cloud
IAC	Instituto de Astrofysica de Canarias
IACG	Inter Agency Consultative Group
IAU	International Astronomical Union
IC	Integrated Circuit
IFA	Institute For Astronomy, Hawaii
IKI	Space Research Institute, Moskou
ING	Isaac Newton Group of telescopes
INT	Isaac Newton Telescope
IPCS	Image Photon Counting System
IRAF	Image Reduction and Analysis Facility
IRAS	InfraRed Astronomical Satallite
IRS	Intermediate Resolution Spectrograph
ISM	InterStellar Matter
ITR	Internal Technical Report
IUCAF	Inter Union Commission for the Allocation of Frequencies
IUE	International Ultraviolet Explorer
IVS	International VLBI Satellite
JCMT	James Clerk Maxwell Telescope
JIVE	Joint Institute for VLBI in Europe
JKT	Jacobus Kapteyn Telescope
JPL	Jet Propulsion Laboratory
Jy	Jansky
KPNO	Kitt Peak National Observatory
LBDS	Leiden Berkeley Deep Survey
LINER	Low Ionazation Nuclear Emission Regions
LMC	Large Magellanic Cloud
LO	Locale Oscillator
LST	Local Sidereal Time
LWG	Landelijke WerkGemeenschap
MIDAS	Munich Image Data Analysis System
MIT	Massachusetts Institute of Technology
MOST	Molonglo Synthesis Telescope
MPIfR	Max Planck Institut für Radioastronomie
MWLCO	Mount Wilson & Las Campanas Observatories
NAC	Nederlandse Astronomen Club
NASA	National Aeronautics and Space Administration
NCA	Nederlands Comité Astronomie
NFRA	Netherlands Foundation for Research in Astronomy
NGC	New General Catalog
NLR	Narrow Line Region
NOAO	National Optical Astronomy Observatories (USA)
NRAO	National Radio Astronomy Observatory (USA)
NRC	National Research Council (Canada)

NSF	National Science Foundation (USA)
NWO	Nederlandse organisatie voor Wetenschappelijk Onderzoek
OVRO	Owens Valley Radio Observatory
PATT	Panell for Allocation of Telescope Time (UK/NL)
PC	Programma Commissie
pc	parsec
PSS	Palomar Observatory Sky Survey
QSO	Quasi Stellar Object
Quasar	QUAsi StellAr Radio source
RAL	Rutherford Appleton Laboratories
RAS	Royal Astronomical Society (UK)
RGO	Royal Greenwich Observatory (UK)
SKAI	Square Kilometer Array Interferometer
ROG	Ruimte Onderzoek Groningen (SRON)
ROL	Ruimte Onderzoek Leiden (SRON)
ROU	Ruimte Onderzoek Utrecht (SRON)
RSN	Radio Super Nova
RUG	Rijks Universiteit Groningen
RUL	Rijks Universiteit Leiden
SATSI	Segmented Aperture Tilted Shearing Interferometer
SCASIS	Seeing Cell Aperture Synthesis Imaging Spectrometer
SERS	Science and Engineering Research Council (UK)
SEST	Swedish ESO Submillimetre Telescope
SMC	Small Magellanic Cloud
SNR	Super Nova Remnant
SRON	Stichting Ruimte Onderzoek Nederland
SRT	Synthese Radio Telescoop
ST-ECF	Space Telescope European Coordinating Facility
STScI	Space Telescope Science Institute
TAP	Technical Advisory Panel (JCMT)
TNO	Toegepast Natuurwetenschappelijk Onderzoek
TWG	Technical Working Group (VLBI)
UCB	University of California at Berkeley
UGC	Uppsala General Catalog
UKIRT	United Kingdom Infrared Telescope
URSI	Union Radio Scientifique International
UU	Universiteit Utrecht
UV	Ultra Violet
UvA	Universiteit van Amsterdam
VLBI	Very Long Baseline Interferometry
VUA	Vrije Universiteit Amsterdam
WARC	World Administrative Radio Conference
WENSS	WEsterbork Northern Sky Survey
WGAR	Working Group on Astronomical Refraction
WHT	William Herschell Telescope
WSRT	Westerbork Synthesis Radio Telescope
YERAC	Young European Radio Astronomers Conference