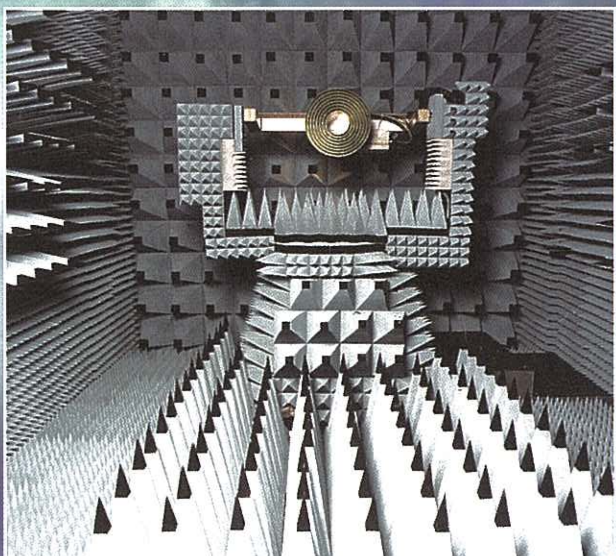
Annual Report 1996

Netherlands Foundation for Research in Astronomy



NFRA

Netherlands Foundation for Research in Astronomy

Annual Report 1996

Radiosterrenwacht Dwingeloo
P.O. Box 2
7990 AA Dwingeloo
Tel: +31 (0)521 595100
Fax: +31 (0)521 597332
E-mail: SECRETARY@NFRA.NL
Internet: www.nfra.nl

Radiosterrenwacht Westerbork
Schattenberg 1
9433 TA Zwiggelte
Tel: +31 (0)593 592421
Fax: +31 (0)593 592486

Cover: New antenna measurement chamber in Dwingeloo. This facility is being used for testing and characterizing prototype phased array antennas for the SKAI project. The photo shows an antenna setup in the surreal surrounding of absorbers that prevent unwanted reflections.
In the background a portrait of the famous 17th century scientist Christiaan Huygens, whose name is intimately associated with the physics of wave propagation through the well known Huygens Principle.

Contents

Report of the Board

Highlights of 1996

The year saw completion of several major activities begun in previous years. The radio observatory saw the delivery, installation and commissioning of the broadband, tunable receiver systems for the Westerbork synthesis radio telescope (WSRT). These receivers came on-line early in the fourth quarter, to give the telescope the unique capability of being able to observe at nearly any frequency between 250 MHz and 1,4 GHz. The Board was pleased to note that the project was completed within budget and following the time line set out in 1994.
First observations are discussed elsewhere in this Annual Report. These show in particular that the effects of man-made interference outside the frequency bands reserved for radio astronomy are substantial but in most cases not as debilitating as some had feared.

View of NFRA's new headquarters building in Dwingeloo.

Construction of the new headquarters building in Dwingeloo was also completed during the year, doubling the usable floor space and providing several new infrastructural facilities. The move to the new building took place in November, after which the older barracks construction was summarily demolished. Architecturally open and well lit by natural light, the new building provides not only office space for NFRA and JIVE personnel, but also new laboratory space for the JIVE correlator, for an anechoic antenna measurement facility, for EMC and climate controlled test chambers, for optical fabrication and test facilities, and for CAD/CAM capability in the mechanical workshop. This expansion of the technical capabilities of NFRA's laboratory will provide substantial new possibilities for instrumental development in the future.
New office and laboratory space also finally made possible the planned integration of personnel and equipment previously sited in Roden at the Kapteyn Observatory.
This university-based group was set up

in the early 1980 's to develop instrumentation for optical astronomy in general and for the optical telescopes on La Palma in particular. A decade of constant pressure on university budgets led unavoidably to a decision to move both personnel and laboratory infrastructure to Dwingeloo and to begin an optical instrumentation development program within the program of NFRA. The VISIR project for the ESO VLT is the first project in this program.
In previous years, Kapteyn Observatory personnel participated in the definition of the new workshop facilities in Dwingeloo, and with completion of the new building in 1996 the planned integration could be duly implemented. University technical staff formally joined NFRA and many of the machines and much of the test apparatus and library were moved and installed in the new building. In exchange for having NFRA assume the salary burden of Kapteyn Observatory technical staff, the university groups in Leiden and Groningen agreed to hire technically oriented astronomers to function as P.I. 's for NFRA technical projects.

On 16 April, NFRA's Board joined staff and guests to celebrate the fortieth year of continuous operation of the Dwingeloo 25m radio telescope. An historical film of the construction phase of the instrument, the oldest radio telescope still in active use, was shown for all to enjoy.

Periodically, the work of the Foundation is recognized by outside organizations. During 1996 the Board was pleased to note two events of this kind.
First, a ceremony was held on 4 December at Cerro Paranal in Chile, to seal a time capsule into the foundation of the Very Large Telescope (VLT). In the capsule was included one copy of a fundamentally important research article in recent decades from each member country. The Dutch contribution was selected to be "A High Resolution Radio Continuum Survey of M51 and NGC 5195 at 1415 MHz" by D.S. Mathewson, P.C. van der Kruit, and W.N. Brouw, Astronomy & Astrophysics, **17**, 468 - 486 (1972). This paper announced the discovery, using the WSRT, of spiral density waves in the gas of disk galaxies.

NFRA staff member Dr. Albert Bos receiving the Veder Prize of the Netherlands Society for Electronics and Radio Science.

Second, the Netherlands Society for Electronics and Radio Science recognized the outstanding achievements of NFRA staff member, Dr. Albert Bos, for achievements in the field of digital signal processing. At a ceremony on 29 May, Dr. Bos was presented the prestigious Veder Prize of the Society for his work on high speed, massively parallel, digital correlator systems in radio astronomy.

Finally, on a more somber note, it must be recorded that the proposal reported in last year 's Annual Report to obtain funding for participation in the U.S. MilliMeter Array project failed to receive the requested support of the research council NWO. The importance of gaining access to one of the coming generation of such telescopes is acknowledged in science policy circles, but the costs were perceived as high in relation to other needs of Dutch science. The lack of a decision in the U.S. on the project would in any case delay any definitive decision in the Netherlands, and the lack of a European dimension to the proposal was deemed a weakness.

Forward look

Agreement was reached with the Physical Sciences Board of the research council that the two main thrusts of NFRA's work program in the coming years will be (i) scientific exploitation of the WSRT, following completion of the modernization activities, and (ii) R&D on adaptive phased array technologies, to ramp up starting in late 1997 and with a view to the adoption of these technologies for the Square Kilometer Array Interferometer (SKAI) project.

Given the combination of ambitious future plans and a generally difficult budgetary situation, NFRA's Board and management began considering a major reorganization of NFRA's Institute as the only practical way forward. To focus future activities effectively, the radio observatory will be provided with separate staffing and financial resources. The technical laboratory will acquire additional staff, both to enhance available expertise and to provide support for a move to project based financing that must increasingly include resources from outside the research council. Administrative and maintenance activities will be streamlined and optimized for the new situation. At year 's end, preparations were started to allow a reorganization to begin during the autumn of 1997.

Policy regarding direct support in future of university research was altered in detail. NFRA recognizes three types of support to university groups: "projects", which generally involve the financing of a single graduate student or postdoc; "programs", which increase the scale of support and which try in particular to guarantee the continuity of major programs of research; and administrative and technical support by the staff in Dwingeloo for specific projects. During the year, the Board formally expressed its intention to change the ratio of grants for "projects" to those for "programs" from the current 70:30 to 50:50 by the year 2000.

In addition, in another break with past policy, the Board formally decided that it should be possible in future for the specific observing instrumentation to be at least partially financed via the "program" line.
The Board also reconsidered its future requirements for independent policy advice. The bodies currently providing advice to the National Astronomy Committee (NCA), the ASTRON Foreign Advisors and the ASTRON Foreign Evaluation Committee each deliberate on selected aspects of NFRA's activities. A more coherent approach was deemed desirable and the Board decided to institute in their place a Scientific Advisory Council (Wetenschappelijke Adviesraad). This body will meet once every two years to evaluate NFRA's program in its entirety, including future policy plans and the effectiveness of the organization in carrying out its current program. Its membership will consist of four foreign and two national astronomers, and two persons from outside the field but having broad experience operating research organizations.

International activities

An important strategy of the Board to increase the effectiveness of existing research efforts and to create opportunities for new lines of research is to engage in specific international collaborations. These collaborations include those providing access to observing facilities outside the Netherlands and ones set up to develop new types of facilities and instrumentation that would otherwise not be possible.

Of signal importance in this regard during 1996 was the signing of a Memorandum of Agreement to "cooperate in a technology study program leading to a future very large radio telescope". Eight institutes in six countries – ATNF, Australia; HIA, Canada; BAO, China; NCRA, India; NFRA, Netherlands; SETI Institute, USA; NAIC, USA; and OSURO, USA – agreed to study the various scientific and technical opportunities and problems associated with developing a radio telescope having a million square meters of collecting area – the Square Kilometer Array Interferometer (SKAI) project. This agreement will provide the basis for the major part of NFRA's technical R&D efforts in the coming years.

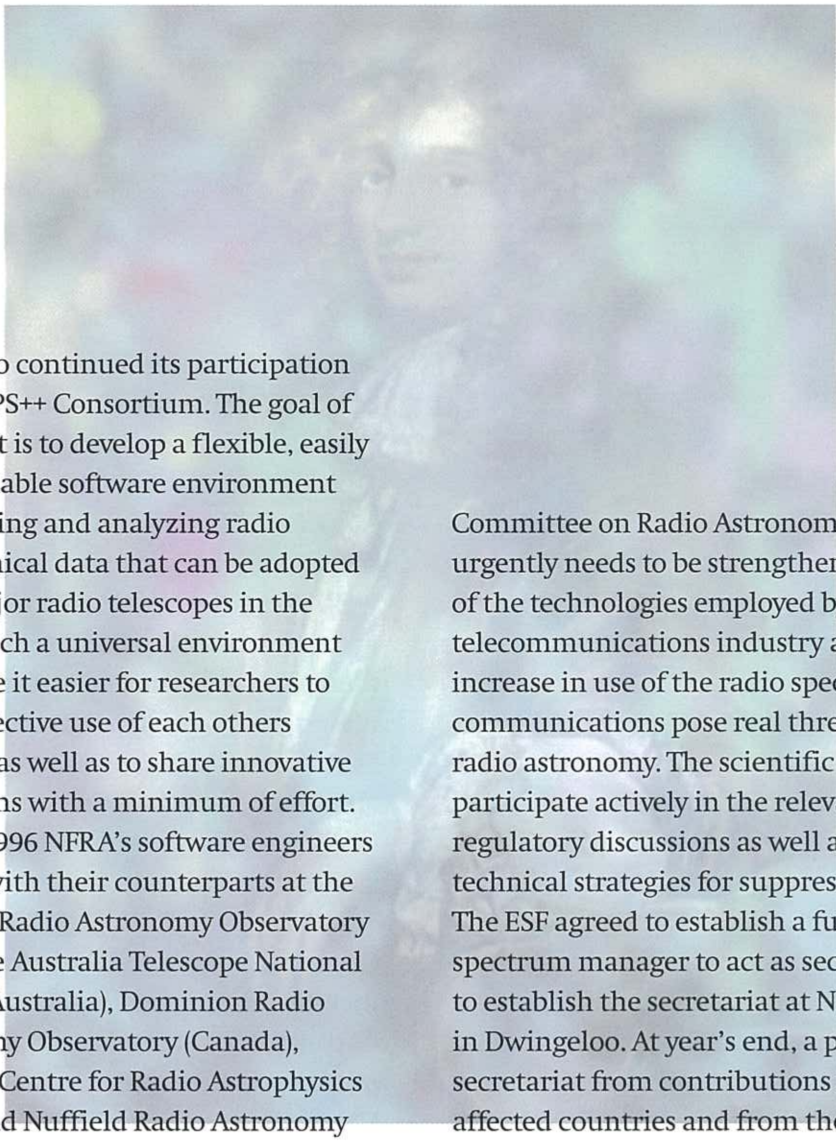
A number of collaborations were formalized during the year to develop specific observing instruments. A Memorandum of Understanding between NFRA and the Direction des Sciences de la Matiére, DAPNIA/Service d'Astrophysique, CEA Saclay was developed to formalize the collaboration to develop the VISIR mid-infrared imager and spectrometer for the ESO VLT. An MoU was also prepared to define

the SAURON collaboration between universities of Durham, Leiden, and Lyon, with NFRA as funding partner. This collaboration will produce a wide field spectrograph for the William Herschel Telescope specifically designed for the measurement of galaxy velocity fields. And an MoU was prepared between NFRA and the Instituto de Astrofysica de Canarias to permit the installation and testing on La Palma of the Dutch Open Telescope of the Astronomy Institute of Utrecht University.

The collaboration continued during the year with the UK to operate the optical telescopes of the Isaac Newton Group at the Roque de los Muchachos Observatory on La Palma in the Canary Islands, and with the UK and Canada to operate the James Clerk Maxwell sub-mm radio telescope on Hawaii. These activities are described extensively in the annual reports of each facility and will not be repeated here.

Participation of the radio observatory in observing sessions of the European VLBI Network (EVN) also continued during 1996. Staff of the EVN 's Joint Institute for VLBI in Europe (JIVE) moved into NFRA'snew headquarters building in Dwingeloo in November, and immediately began to receive an increased number of visiting astronomers. A specially built tape handling carousel was installed and commissioned; this machine provides storage for up to 2000 VLBI tapes as well as computer activated transport between a loading dock at street level to the correlator laboratory in the building 's basement. Development work on the EVN/JIVE Mark IV VLBI correlator and tape units moved into the basement laboratory as well. These and other, network wide activities are described in the EVN/JIVE annual report. A formal Memorandum of Agreement was prepared to govern the joint and separate responsibilities and interactions between the NFRA and JIVE organizations in the new situation.

Other continuing collaborations included the International Advanced Correlator Consortium, in which scientific and engineering staff at Haystack Observatory (Westford, Massachusetts), Nuffield Radio Astronomy Observatory (Jodrell Bank, UK), Institute for Radio Astronomy (Bologna, Italy), the University of New Mexico (USA), JIVE and NFRA are working together to develop the world's most powerful correlator for radio astronomy. The activities of the consortium are governed formally by an agreement between NFRA and NASA. An overview of activities during 1996 relevant to the VLBI implementation is provided in the JIVE annual report for the year. Activities related to the Westerbork implementation of the correlator are given elsewhere in this report.



NFRA also continued its participation in the AIPS++ Consortium. The goal of this effort is to develop a flexible, easily maintainable software environment for reducing and analyzing radio astronomical data that can be adopted by all major radio telescopes in the world. Such a universal environment will make it easier for researchers to make effective use of each others facilities as well as to share innovative algorithms with a minimum of effort. During 1996 NFRA's software engineers worked with their counterparts at the National Radio Astronomy Observatory (USA), the Australia Telescope National Facility (Australia), Dominion Radio Astronomy Observatory (Canada), National Centre for Radio Astrophysics (India) and Nuffield Radio Astronomy Observatory (UK) to finish the core system, with a view to beginning development of user applications in late 1997.

Finally, the Council of the European Science Foundation (ESF) decided, following a formal evaluation of past effectiveness, that support for the ESF's Committee on Radio Astronomy Frequencies (CRAF) urgently needs to be strengthened. Rapid evolution of the technologies employed by the telecommunications industry and the explosive increase in use of the radio spectrum for communications pose real threats to the future of radio astronomy. The scientific community must participate actively in the relevant international regulatory discussions as well as work to develop technical strategies for suppressing interference. The ESF agreed to establish a full-time European spectrum manager to act as secretary to CRAF, and to establish the secretariat at NFRA's headquarters in Dwingeloo. At year's end, a plan to finance the secretariat from contributions from the most affected countries and from the ESF's own budget was being worked out in detail.

Board membership

On 1 January, Prof. Ed van den Heuvel (Amsterdam) took over as chairman of Board, and during its meeting on 7 February Prof. Jan Kuijpers (Nijmegen) was appointed as the Board's secretaris/penningmeester. Prof. Renzo Sancisi (Groningen) and Dr. Frank Israel (Leiden) left the Board on 1 September, to be replaced by Prof. Tjeerd van Albada (Groningen) and Prof. George Miley (Leiden).

Also on 1 September, Prof. Walter Hoogland joined the Board as an external, that is, non-astronomical, member. Prof. Hoogland's background is in high energy physics. He has been director at the NIKHEF institute for nuclear and high energy physics in Amsterdam and served as scientific director at

CERN in Geneva. He is currently at the University of Amsterdam.

Finally, the Foundation's Director, Prof. Harvey Butcher, serves as the Boards's Executive Secretary. At its meeting on 2 February the Board formally recommended that Prof. Butcher's term of appointment as Director be extended for a second term of five years.

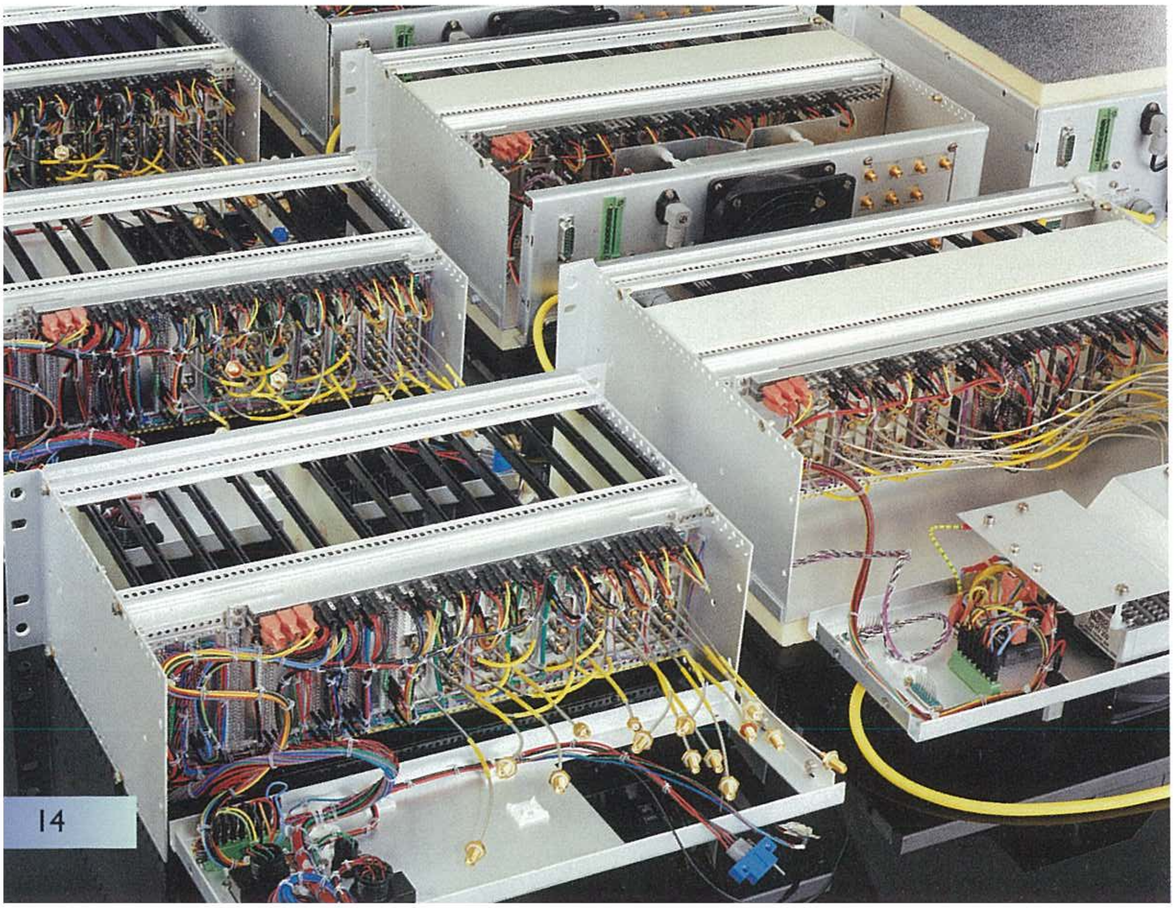
Technical Research and Development

A major fraction of the activities at NFRA's Institute involve the development of innovative instrumentation and new observing techniques for astronomy. During 1996, NFRA's technical laboratory focussed its efforts on outfitting the Westerbork radio telescope (WSRT) with state-of-the-art receiver systems, a powerful new digital correlator/spectrometer, and new instrument control and data reduction software. In addition, technical studies were begun and necessary infrastructure was installed to allow development of broad band, adaptive phased array antenna systems for the SKAI project. These various developments are summarized in this section.

Receiver systems

Multi-Frequency Front Ends

The Multi-Frequency Front Ends (MFFE) project is providing the WSRT with state of the art receivers for 9 different wavebands in the range 3.6cm to 1.2m (250 MHz to 8.6 GHz). For each band a dual super-heterodyne receiver is combined with a feed system matched to the focal ratio of the 25-m element telescopes of the Westerbork array. These systems are integrated into a rotating unit that is mounted at the prime focus of the element



Series production of the MFFE 19 inch racks at Philips PBF, Almelo. Photo: Smit Set

telescopes, such that frequency changes can be effected rapidly and fully automatically. At frequencies above 1.2 GHz, receivers are cooled to 20 K, those below are operated at ambient temperature. Unique are the two UHF broad-band receivers, that allow observations at any frequency in the ranges 250 - 460 MHz and 700 - 1200 MHz. With these receivers, the line of neutral hydrogen at 1420 MHz rest frequency can be observed over redshift intervals $0.18 < z < 1.0$ and $2.0 < z < 4.7$.

During 1996, the project completed construction of the UHF systems and installed and commissioned them on the telescope. During 1997 and early 1998, the remaining systems will be fabricated, with a view to having the entire system fully operational in mid-1998.

Low noise RF/IF technologies

Low noise amplifiers

Almost 500 state-of-the-art (HEMT-based) amplifiers are required for the MFFE systems. Designs optimized not only for low noise but also for ease of production, tuning and testing, translating directly into cost, are required. Prototyping of designs for all bands was completed during the year and the project moved into series production. Final gain and noise temperature figures for each of the MFFE 's wavebands, averaged across the band, are shown in the table.

Superconducting Notch Filters

Experience at the WSRT has repeatedly demonstrated that strong interfering signals from man-made sources (such as TV broadcasting stations) mix with each other in the signal chain electronics, to produce a series of unwanted product signals scattered throughout the radio spectrum. With the advent of the new wide band, tunable UHF receiver systems designed to survey in redshift space, these products are a serious nuisance. One solution is to insert notch filters in the signal chain prior to the first stage of amplification and LO mixing, thereby reducing the strength of the product signals produced to a harmless level. In practice, however, conventional RF filters inserted at the front of the signal chain add unacceptably to the total system noise. Super-conducting filters offer an alternative and high-temperature super-conducting materials promise operationally straightforward solutions to this problem.

Gain and Noise of MFFE LNA's

	92cm	50cm	18-21cm	13cm	6cm	3.6cm	UHF_{high}	UHF_{low}
Gain (dB)	32	32	33	27	36	42	35	33
Noise (K)	27	22	3.5	3.5	10	16	37	30

NFRA has been collaborating with Prof. J.E. Mooij and graduate student S. Wallage at the Delft Technical University in the design of a prototype filter of the required sort.
During 1996, the project produced a functional prototype filter based on a coplanar waveguide transmission line design and using $YBa_2Cu_3O_7$ on a substrate of $LaAlO_3$.
The first test results with this filter installed in the prototype MFFE unit demonstrated very satisfactory interference suppression (40 dB) combined with essentially no increase in system noise (<1.2 dB). At year's end a search was in progress to identify an affordable supplier for these filters, so that all of the new MFFE's can be outfitted with such filters.

High speed digital signal processing

Correlator/spectrometer for WSRT

An essential part of upgrading the Westerbork radio telescope involves a new correlator and spectrometer, that will permit all 91 interferometer pairs to be formed continuously and that will generate a total of 262144 complex spectral channels.

The development of the correlator is being carried out within the framework of the International Advanced Correlator Consortium, under an agreement between NFRA and the U.S. National Aeronautics and Space Administration (NASA). Participants in the project include groups working at NFRA, JIVE, the MIT Haystack Observatory (USA), Nuffield Radio Astronomy Observatory (UK), Institute of Radio Astronomy, Bologna (I), and the University of New Mexico (USA). Plans are to build at least six correlators based on this design, 3 in the USA and 3 in Europe (including the EVN/JIVE correlator and the WSRT correlator).

During 1996, the project finalized the design of the custom chip and ordered a complete set including spares. The design of the main correlator printed circuit boards was completed and an order placed for series production. Various technical problems were encountered during debugging of other system units, resulting in a total delay in the hardware development phase of almost a year. At year's end, the project expected to be able to install a working prototype system in Westerbork for use by astronomers sometime during the summer of 1997.

ADC sub-system

The input data stream to the correlator derives from the so-called ADC sub-system. For the WSRT this unit not only digitizes (2-bit quantization) the 28 signals from the 14 telescopes (dual polarization), but also performs interferometric fringe delay tracking and when desired permits coherent addition of the signals to simulate a single dish telescope with 93-m equivalent diameter.

During 1996, the ADC project moved from the design phase into bread-boarding and debugging. At year's end, various problems discovered relating to the final series production process were being sorted out, in the

expectation that a final prototype system would be ready for installation at the WSRT during the late spring of 1997.

Correlator for mm-array telescopes

NFRA has joined the European Southern Observatory (Garching), Institut de Radio Astronomie Millimetrique (Grenoble) and Onsala Space Observatory (Onsala) to develop the scientific and technical specifications for a future European synthesis array radio telescope operating at millimeter wavelengths. During the year, a study of the requirements for the back-end correlator and spectrograph was carried out by NFRA staff. Areas requiring substantial R&D were identified, in particular to permit the cost to be reduced from the estimated Mf 70,- if implementation were to be carried out using technology available today. The results of this and studies by other consortium members were combined in a final project document to be used for promoting discussion in the wider community and to serve as input to follow-on costing studies.

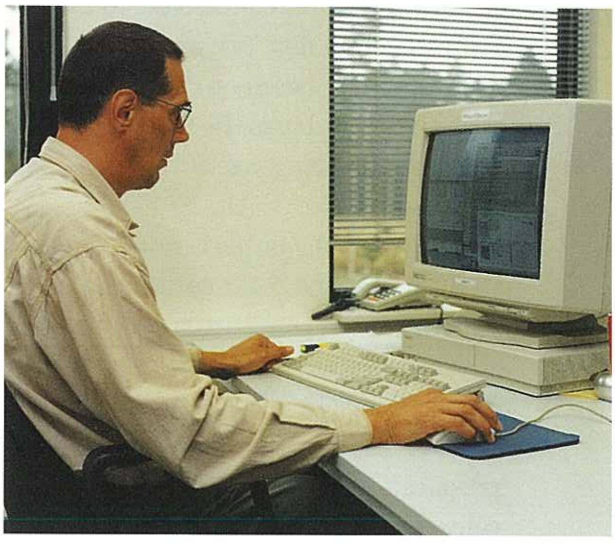
Software engineering

Instrument control: Telescope Management System

To make use of the greatly expanded potential and unsurpassed flexibility provided by the new front-ends and back-end at the WSRT, a new instrument control software system is being developed. Going by the name TMS (for Telescope Management System), the project is making use of modern software engineering tools based on Object Oriented Programming technologies (OOP).

During 1996, NFRA's software engineering group completed the first phase of the project, in which existing functionality was "encapsulated" by combining a TMS shell and user interface with existing software routines. In addition, control of the numerous distributed processors used at the telescope, monitoring of the observing schedule and tasks and interaction with the data-base servers were implemented as background tasks. This package let telescope users and software engineers gain experience with new capabilities and new ways of interacting with the observing hardware.

At year's end, plans were well advanced for the second phase of the project, in which existing software (mostly running on the HP-1000 mini-computers) will be phased out, its functionality is to be extended and will be built into TMS.



Control of the new correlator hardware and of its data handling will be implemented, automatic scheduling of observations will be made possible and an expanded graphical user interface will be installed. Extensive use will be made of AIPS++ libraries and file formats, so that interfacing to that environment in future for near real-time data reduction will be straight-forward. This second phase is scheduled to be completed at the end of 1997.

AIPS++

The AIPS++ project aims to produce an internationally supported data reduction and analysis environment for radio astronomy. It involves programmers and scientists at seven institutes in six countries. NFRA has been heavily and centrally involved since its inception, with a view to making the WSRT more accessible to astronomers from other countries and to making other radio astronomy observatories more accessible to the Dutch community. The project engineering is based on OOP techniques and uses the C++ programming language.

During 1996, the project consolidated its efforts on the basic, common system, on which future specific applications are to be built. Basic tools, data formats, libraries and measurement models were frozen and preparations were made for a "beta" release of the package in early 1997.

Antenna design

NFRA's program to develop the technology of adaptive phased array antennas for application in future large radio telescopes will necessarily involve innovative antenna design. In particular, to be interesting for application to SKAI, a bandwidth of a decade or more is required of the completed phased array. During 1996, a first inventory was made of known antenna types and possible future directions for research.

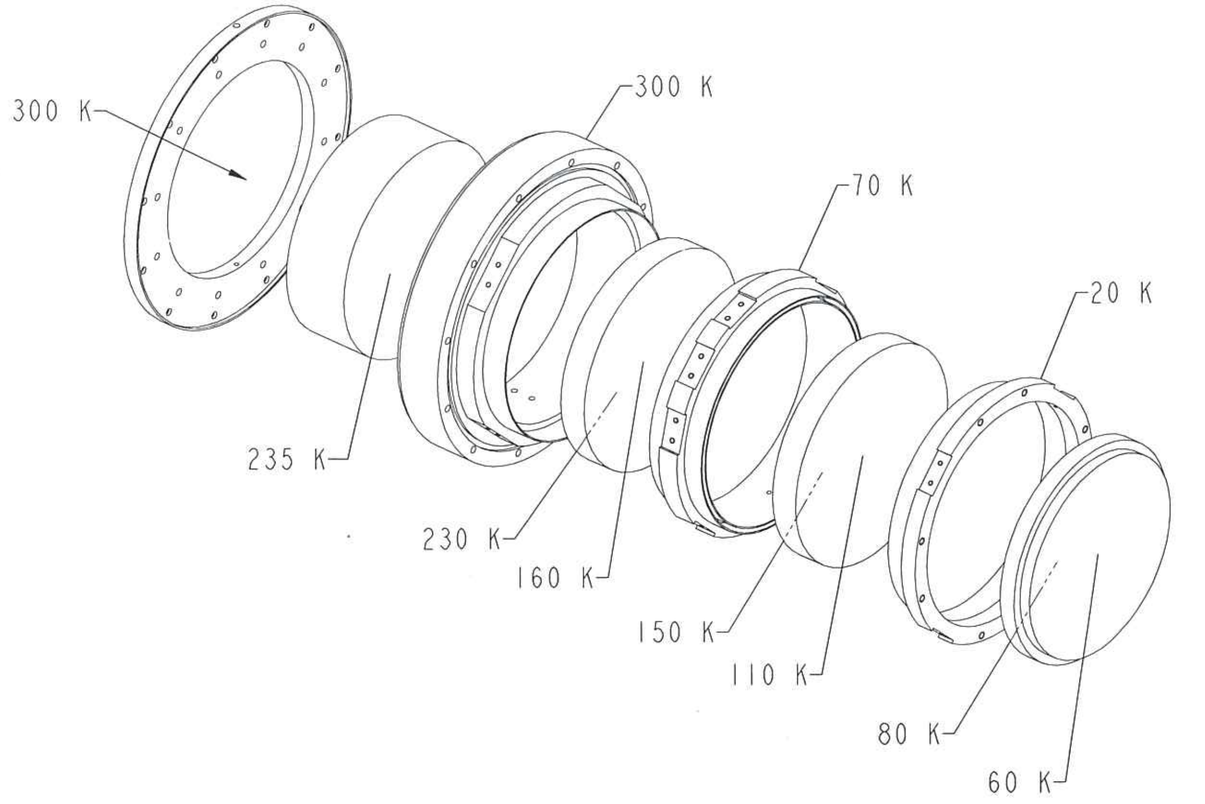
Passive radiators seldom achieve more than an octave of bandwidth, so must be implemented in a fractal-like hierarchy to achieve the desired total bandwidth of a decade or more. Active antennas, in which close coupled, sub-resonant radiators are designed together with the signal processing electronics as a single circuit, should in principle allow good performance over a very broad bandwidth. The latter approach offers new and potentially important possibilities, but design tools and an existing development base do not yet exist. Most of the year was spent studying this problem and making plans for a focussed research program to demonstrate the achievable performance of these two approaches. At year's end, a plan for 1997 was in place, in which R&D on the passive, hierarchical radiators option would be undertaken in-house, and study of the active, sub-resonant radiators option would be made by Ms. A. Cox under the supervision of Prof. Z. Popovich at the University of Colorado, Boulder (USA).

In parallel with research into the optimum antenna design for SKAI, the year saw the installation of an anechoic antenna test chamber in Dwingeloo. Optimized for operation at 5 GHz, this facility permits rapid validation of antenna designs involving both simple radiators and phased arrays.

Systems engineering

NFRA's Multi-Frequency Front End (MFFE) project involves integrating eight receiver and feed systems into a single rotating unit that is mounted at the prime focus of a 25-m antenna. Four of the receiver systems (for the 3.6, 6, 13, and 18-21 cm bands) are cryogenically cooled, and are installed in a single vacuum cryostat. The cryostat has temperature plateaus internally at 20 K and 70 K, and input windows on three sides that are transparent to radio waves. The system uses closed cycle helium refrigeration (cooling engine is a CTI 1020) which must consume a minimum of power so as to operate at an affordable cost. The size (30x32x76cm) of the cryostat and mass of the entire front-end (325kg) are limited by the mechanical construction of the telescope. For ease of maintenance the cryostat should cool down in less than 18 hours and warm up fully in less than 4 hours, without suffering undue mechanical stress at critical points, and it should remain operable following 2 hours of power loss. Major maintenance intervals (usually set by the amount of He and Ne gas permeating in the cryostat) should be at least a year. And of course, the system must operate in all weather conditions and be able to withstand lighting strikes.

The engineering challenge of this



Exploded view of the 18-21cm waveguide window of the cryostat, showing the four foam plugs employed and the temperatures achieved.

system has been considerable and required a structured, multi-disciplinary approach to the design. With completion of the prototype MFFE in 1994, a test bed became available with which both to validate the approach chosen and to improve the final design in its details. Early in 1996, these activities resulted in publication of a step-by-step approach to the design of such cryogenic receiver systems. Particular innovations include the use of foam plugs in the input windows for mechanical support of a vacuum membrane and as radiation shields, a dry nitrogen flush across the windows to reduce He permeation into the cryostat, and careful sorber design to control the combined dynamic effects of gas desorption and gas conductive heat transfer during warm-up.

Infrastructure

NFRA's new headquarters building almost doubles the floor space available to the organization, and its completion during 1996 has permitted the installation of numerous new infrastructural facilities. A brief overview of these facilities is given in this section.

Anechoic antenna measurement chamber

A 4x6.4m shielded chamber has been installed to allow rapid, automated measurement of the performance of test antennas. This facility is outfitted with microwave absorbers to provide a measurement volume of one meter diameter, in which the reflected power (i.e., unwanted signal level due to reflections from walls, floor and ceiling) at 5 GHz is suppressed by 45 dB. Standard gain horn radiators are available, and the antennas to be measured can be mounted on a fully automated, 2 axis positioner. Antenna design software packages include MAFIA (CST, Darmstadt) and WireZeus (Univ. Belgrade), and antenna measurements utilize an HP 8720D model network analyzer.

Optical laboratory

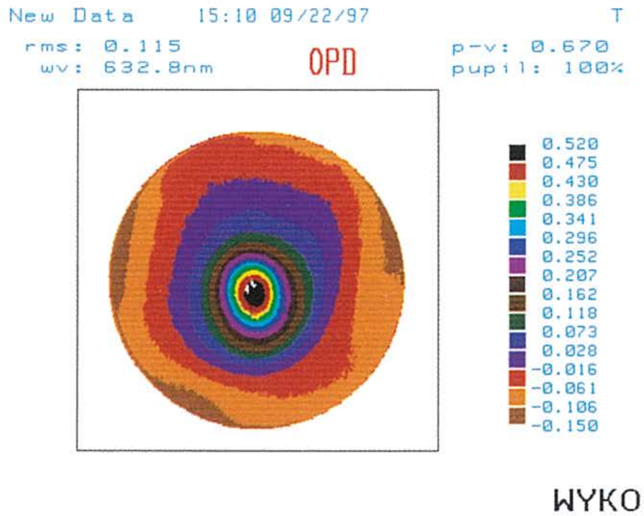
A temperature stabilized, optical fabrication and test facility, including a mechanically isolated floor, has been installed in the new building. At year's end, the fabrication and measurement apparatus previously housed at the Kapteyn Observatory in Roden were moved to Dwingeloo. Of particular interest is the WYKO model 6000 test interferometer, which permits rapid, automated surface shape measurement (flats, spheres, conics etc) of optical components up to 152 mm in diameter, with $\lambda/100$ surface accuracies at 632.8nm. In addition, collimators having 0.2 arcsec and 1.0 arcsec accuracies, a rotating table having

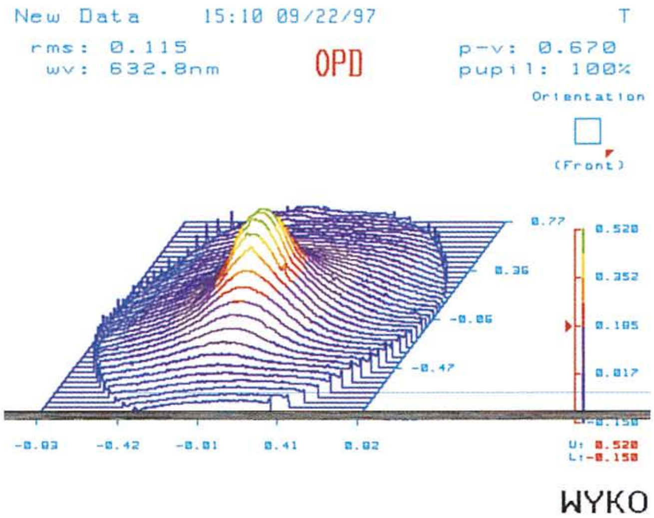
1.0 arcsec accuracy, a spherometer, 0.1 micrometer feelers, and various alignment lasers are now available.

Fabrication machines are available for small prisms, lenses, beamsplitters, optical fiber preparation, micro-lenses, and cylindrical and other off-axis optical components. A small optics coating bell permits gold, aluminum and chrome coatings to be made on-site.

CAD/CAM capabilities

Special attention has been paid to developing the capability rapidly to design complex mechanical structures and subsequently to execute them on computer controlled machines. NFRA's computer aided design software is currently Pro-Engineer version 17 (all modules), and our computer aided manufacture software is Pro-Engineer Manufacture plus Rand generic Post generator version 2/3. The latter CAM capability allows transfer from drawing file to machine program in less than an hour for most designs, and permits doubly curved surfaces to be fabricated with full machine accuracy. A Deckel model FP4 CNC milling machine with a Dialog 11 control system and 520x750mm stage is available, as is a





Surface measurement of an optical flat after a human finger was held in contact for 15 seconds. The thermal expansion of the glass around the point of contact is made readily apparent by the WYKO interferometer.

Schaublin model 125 CCN D lathe with a Fanuc 20-T control system and 270mm turning diameter.

Also available in the mechanical workshop are various conventional machines, measuring instruments, welding, anodizing and painting facilities, and cryogenic development and maintenance tools (closed cycle coolers, vacuum pumps and Leybold Ultratest UL100 leak detector).

Clean room

A class 10.000 clean room has been installed, which contains a class 100 laminar flow cabinet with a 120x60x60cm working volume. Temperature and humidity in the room may be regulated as required.

EMC measurement chamber

A 5x3.4x3m Faraday cage from Euroshield has been installed, to allow quantification of radiated signal levels (usually qualifying as interference) from the electronic systems produced by or purchased for use at NFRA. The shielding effectiveness follows MIL-STD-285.

Environmental chambers

To qualify systems for use out of doors, two temperature contolled chambers are available: (i) a Frigotronic ZA type CL-EU-20 unit, with internal dimensions 2.9x5.1x2.4m and programmable temperature control between -20°C and +60°C; and (ii) an Heraeus HT4020 unit having 0.65x0.55x0.55m internal dimensions and programmability between -40°C and +180°C, also including an RS232 interfacing to external computers.

Computing and networking

NFRA's Institute and JIVE together have 55 UNIX and 105 PC workstations. These systems are connected in the new headquarters building to an internal network consisting of five sub-nets and a central 100/10 Mbit/sec switch on a 155 Mbit/sec fiber optic backbone. An integrated email system is used and all systems have access to the Internet.

Workshops and conferences

As NFRA has begun to carry out R&D on phased array antennas it has become clear that many of the problems to be solved are also being confronted by engineers in other application areas. To make contact with these technical groups, NFRA staff regularly attend symposia and workshops around the world. During 1996, two specialist meetings were also organized by NFRA.

On 28-29 February, together with the ESA/ESTEC Technical Directorate and the IEEE AP/MTT Chapter Benelux, a "Workshop on Large Antennas in Radio Astronomy" was held at the ESTEC complex, Noordwijk. The proceedings were published as ESA special publication WPP-110.

On 9-10 September, together with the DIMES research institute of the Delft Technical University, the first "Technical Workshop on SKAI Antennas and Architectures" was held in Delft. Participants from NFRA and DIMES were joined by radio engineers from ESTEC, Holland Signaal Apparaten and CSIRO, Sydney, as well as interested astronomers from the USA, Australia and the Netherlands.

Square Kilometer Array Interferometer

During the last several years discussions have begun in the international radio astronomical community concerning the next generation of telescopes. A consensus has emerged that the next large step in capability at cm to m wavelengths should be a telescope having a million square meters of collecting area. In the Netherlands this project is going under the name Square Kilometer Array Interferometer (SKAI, pronounced "sky").

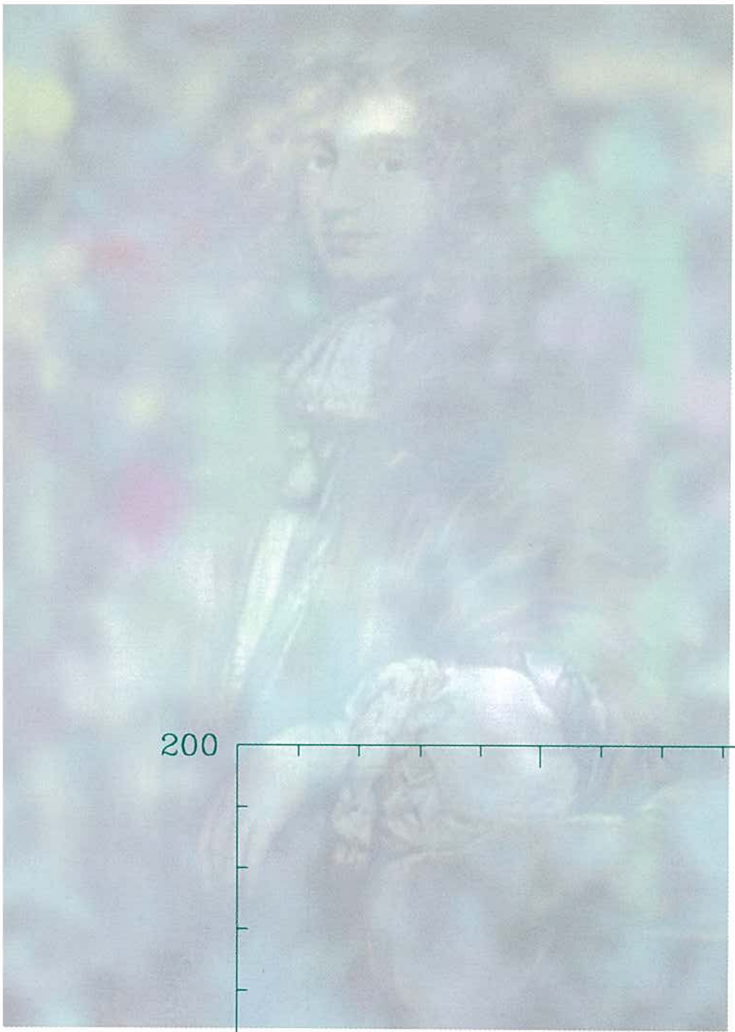
At NFRA, the innovative observing possibilities offered by the adaptive phased array concept for SKAI are being closely examined. These include electronic steering and hence absence of moving parts, the possibility for many simultaneous and independently steerable primary beams on the sky, adaptive suppression of interference, and the flat and unobtrusive profiles of even very large antennas.

During the year, agreement was reached with the Physical Sciences Board of NWO that NFRA should devote the major portion of its R&D effort in the coming years to developing these technologies for application in a future radio telescope. Necessary infrastructure was installed in NFRA's new headquarters building in Dwingeloo, and plans were made for detailed technical investigations. In parallel with the technical studies, various initiatives were taken internationally to promote discussion and refinement of the project.

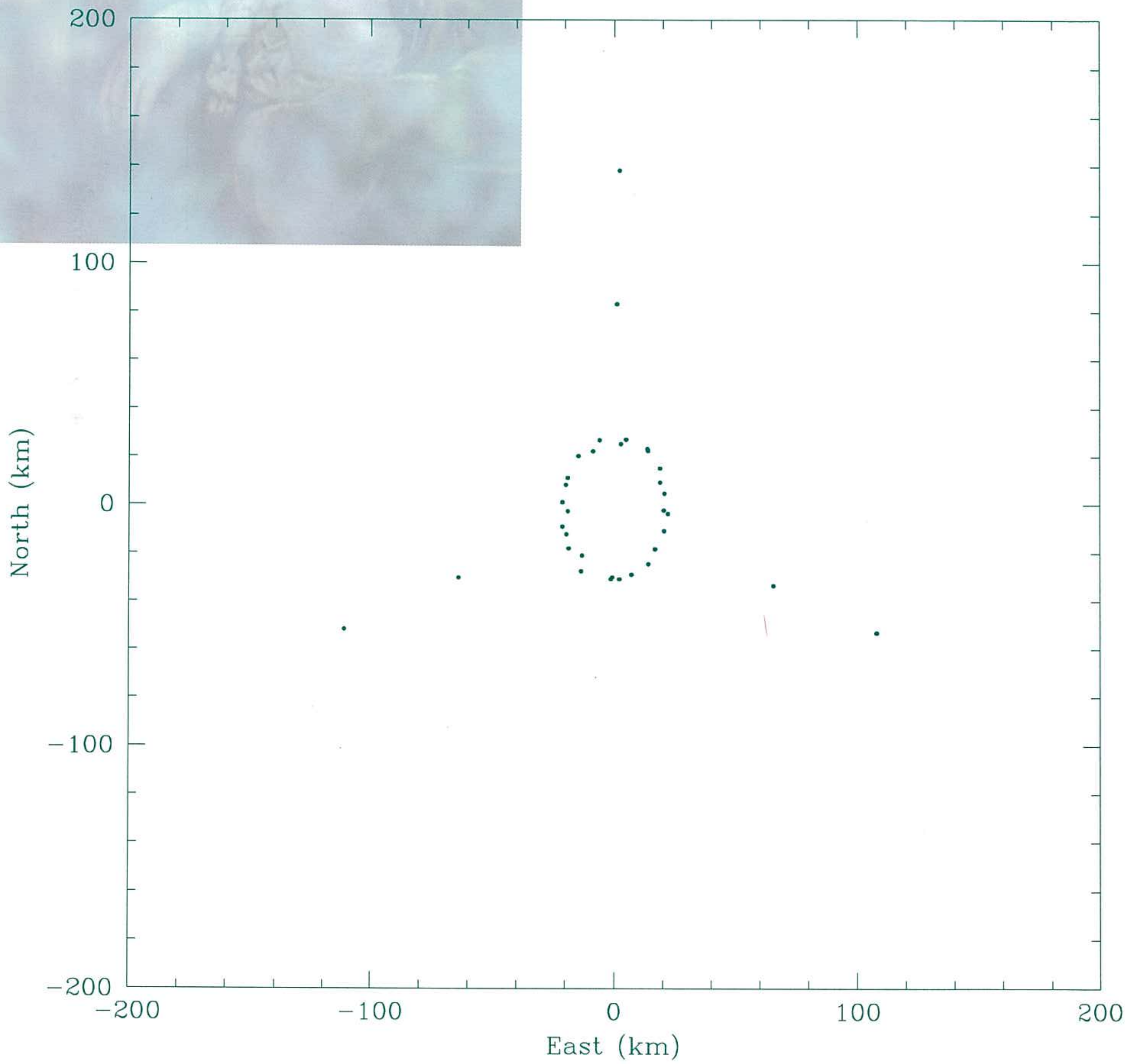
Further in this section are summarized the thoughts, results and plans relating to SKAI as they developed during 1996 at NFRA.

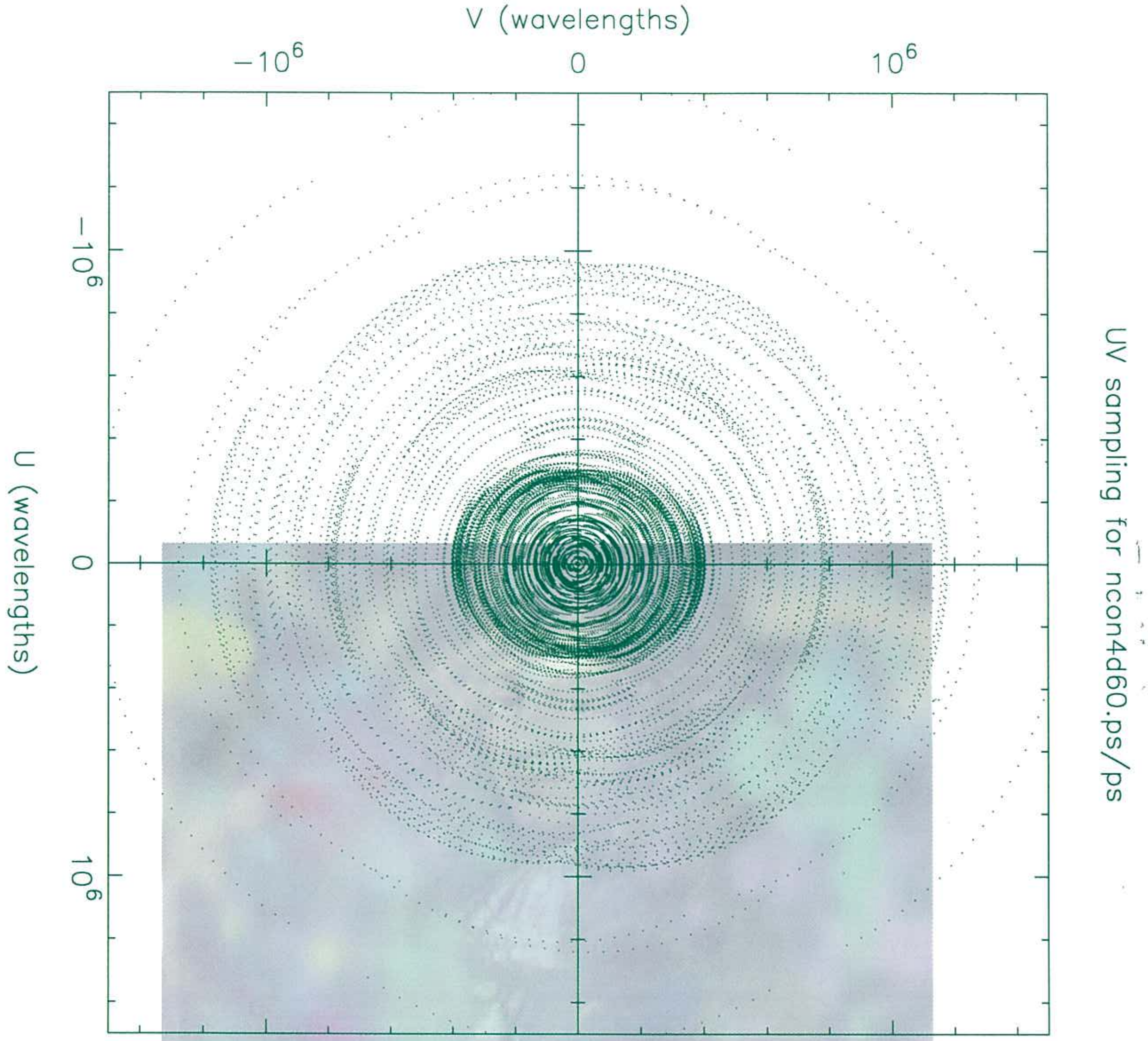
Science drivers

There is strong evidence that the primary epoch of galaxy formation, which is believed to have occurred at look-back times corresponding to redshifts of 2 - 3, can be studied observationally, providing only that telescopes with sufficient sensitivity are built. Because observations of neutral hydrogen (HI) have proven essential in unraveling the masses, dynamics and evolutionary states of galaxies nearby, and because there is no other more effective tracer of these fundamental parameters, a new large facility capable of observing HI in normal galaxies at these redshifts is essential. Typical large spiral galaxies nearby have one to ten billion solar masses of HI. Nearly a hundred times the sensitivity of the largest existing radio telescopes will be required to detect such quantities of gas in the radio line of HI at $z = 3$. This increase in sensitivity can only be achieved by increasing the collecting area to a million square meters – a square kilometer. To be able to resolve galaxies at such large distances the instrument will have to be an array of telescopes connected together to work as an interferometer. Hence the name assigned to the project, SKAI: Square Kilometer Array Interferometer.



Proposed layout of SKAI element antennas. Each dot here represents one element-antenna, whose dimension is such that the total collecting area of all antennas combined is a million square meters.





The u-v coverage of the proposed configuration The core-halo configuration shown optimizes surface brightness sensitivity for the scales on which one expects interesting sources to occur: mK sensitivity on arcmin scales, K sensitivity on arcsec scales and 100 K sensitivity at HST/MMA resolutions.

While the primary driver for the project is to determine empirically the evolution of galaxies – simply by observing them as a function of look-back time all the way back to the epoch of galaxy formation – the unsurpassed sensitivity of SKAI will permit many other important scientific questions to be addressed as well.

The evolution of large scale structure in the Universe will be laid open, as SKAI provides the positions and velocities of ten thousand high redshift galaxies in a single long integration.

The inter-galactic medium should have become neutral some 300,000 years after the Big Bang, but it is observed to be ionized nearby and also in the lines of sight to the most distant objects known. Did the first galaxies ionize the medium, and if so, when did they turn on? If they began to shine at epochs corresponding to redshifts not above ten, SKAI should be able to observe the ionizing process,

telling us about the state of the inter-galactic medium just prior to the earliest galaxies.

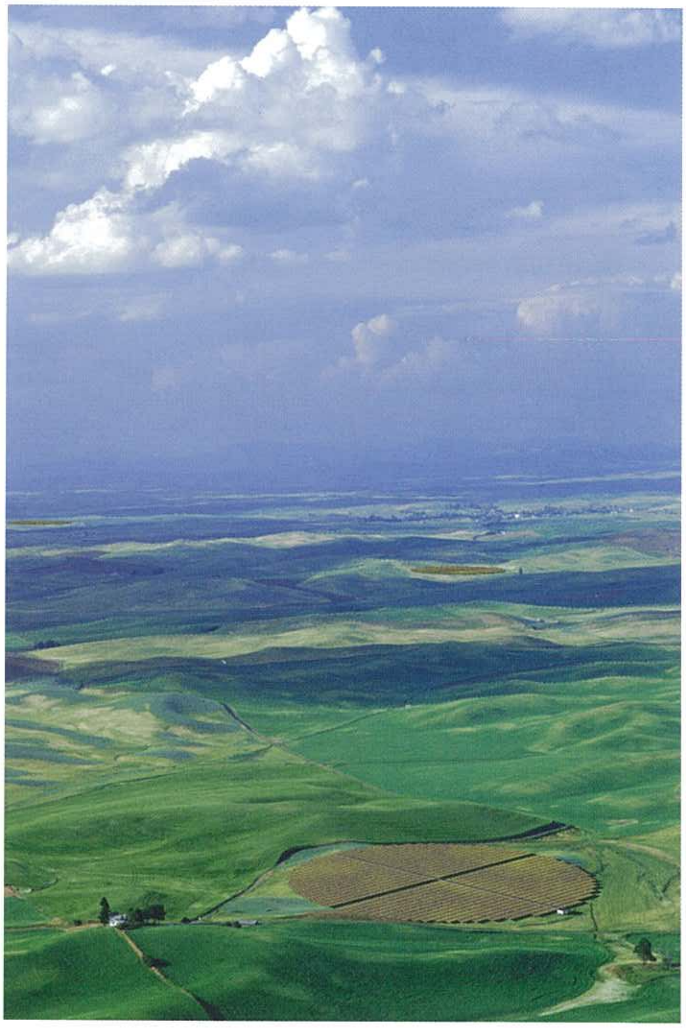
Mapping the systematics and possibly even the evolution of dark matter in galaxies, attacking the question of the origin and evolution of magnetic fields in galaxies, and studying for the first time non-thermal phenomena in ordinary stars like the Sun, are additional areas in which SKAI will dominate future research. And combined with a powerful radar transmitter located elsewhere, SKAI could quickly determine exquisitely precise orbits of Earth-crossing asteroids and could efficiently monitor the evolution of those orbits as well.

These scientific drivers argue for an interferometer of several tens of elements, each on the order of 300m in diameter, spread over an area of at least 300 km diameter. Its sensitivity per 100 kHz of bandwidth will lie in the range of a μJy per minute of integration time. Its instantaneous bandwidth should exceed 200 MHz, and the total accessible bandwidth should cover at least the range 150 - 1500 MHz, with higher frequencies possibly accessible at reduced sensitivity.

Technology research and development

Early in the year a technology plan was developed that has as it goal, within five years, construction of a functional phased array antenna that demonstrates competitive sensitivity, electronic steering, broad bandwidth, multiple primary beams, and adaptive interference suppression. In addition, the plan will lead to the identification of technologies that can be developed further for fabrication at an affordable cost (\$ 200 per m^2).

The principle technology research studies begun in 1996 may be summarized as follows:



Artist 's impression of SKAI antennas installed in a generic agricultural region. The flat, unobtrusive profiles of the antennas will increase the possible choices for siting, both as regards the impact on local environment and by minimizing sensitivity to local interference.

(i) Antenna design

Studies of fractal-like hierarchies of passive radiators are being undertaken to determine the practically achievable bandwidth and radiation patterns. In parallel, in cooperation with researchers at the University of Colorado at Boulder arrays of active, close coupled, sub-resonance radiators are being investigated.

(ii) Photonics for RF signal processing

To attain very broad bandwidths, the phase delays employed in classical phased array antennas must be replaced by time delays. True time delays in, and control and processing of, RF signals may well turn out best implemented using opto-electronic, or photonic, components now being developed for the telecommunications industry. NFRA staff joined with technical researchers at the University of Colorado, George Mason University, Montana State University and Optivision, Inc. in an interdisciplinary working group to study these possibilities.

(iii) Algorithms for adaptive beam formation

Full control of n radiators in a phased array antenna requires computing power proportional to n^3 and for even modest arrays rapidly becomes impractical. Algorithms are known, however, which very generally can reduce the proportionality to n^2; using a priori knowledge it seems likely that one can reduce the computing requirement even further. Together with researchers at the Delft Technical University, these algorithms are being examined for use in adaptive phased arrays.

(iv) Systems on chips

Large numbers of receiver systems will only be affordable if the circuits are highly integrated, even to the point of combining analog and digital functions on a single chip. To gain experience in this field, NFRA is working with researchers at the Technical Universities in Delft and in Twente to study and implement low noise amplifiers and analog-to-digital conversion circuits on chips.

In parallel with these research activities, plans were formulated during the year to design and build a series of demonstrator antennas in Dwingeloo. These phased array systems will successively increase the achieved bandwidth, system complexity and level of component integration, until in 2000 they will culminate in an antenna that will demonstrate the functionality required for SKAI.

At year's end construction of the first antenna had begun. A 2x4 element phased array employing commercially available components, it will demonstrate digital adaptive beam forming and serve as a test-bed for algorithm development.
Also on-going at year's end were discussions with the research council NWO concerning the additional financing required for subsequent antennas in the series.

Institute Science

NFRA's institute in Dwingeloo and Westerbork is dedicated to providing world-class observing facilities and to carrying out innovative technical R&D in support of astronomical research. Essential to the success of this program is a small research staff to provide liaison with the wider community. These staff 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 1996.

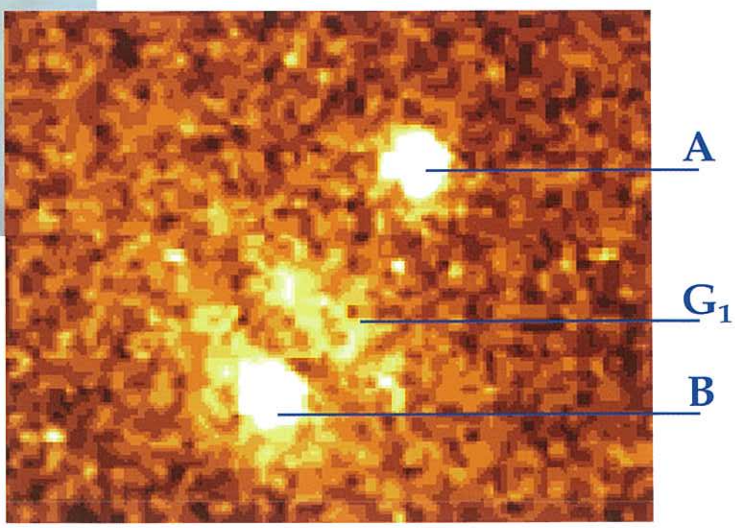
Dark matter lenses

One of the biggest mysteries in astronomy and cosmology concerns the roughly 90% of the mass in the Universe that is inferred by its gravitational effects but that is otherwise invisible. Substantial amounts of this "dark" matter are found in the outer halos of spiral galaxies. Its presence in these halos is inferred by the HI rotation curves observed with the Westerbork array and other radio telescopes. Although these curves can be measured to many times the visible radii of the galaxies and require large amounts of unseen matter to be present, they provide little information on the distribution of that matter. For example, it has generally been assumed that dark halos are essentially spherical, but recently it has been pointed out that significant amounts of matter could be hidden in the form of very dense, very cold molecular hydrogen lying exclusively in the planes of disks.

One way to learn about the distribution of dark matter could be to study cases of gravitational lensing where the lens is a spiral galaxy seen nearly edge-on. In this case, the distribution of the dark matter will have a profound effect on the image formation of the background source.

In an attempt to identify new examples of gravitational lenses NFRA staff have joined colleagues at Leiden University, Jodrell Bank and Caltech. A survey, called the Cosmic Lens All-Sky Survey (CLASS), is examining flat spectrum objects in various radio catalogues, including the Westerbork Northern Sky Survey (WENSS), to discover sources consisting of a small number of point-like components with sub-arcsec separations. Such sources will frequently turn out to be gravitationally lensed quasars and active galactic nuclei. Among the sources should also be some having a spiral galaxy as the lens.

Nearly edge-on spiral galaxy (G_1) is seen to be producing two images (A and B) of a background quasar. The separation and orientation of the quasar images have been modelled to infer the size and shape of the dark matter halo of the galaxy.



One of the early discoveries in CLASS is the double object B1600+434. Subsequently, observations by an international team have provided optical, IR and radio images and spectra with a variety of angular resolutions and timescales. A Hubble Space Telescope image of the system, showing the two point-like components (A and B) and the lensing galaxy (G_1) is shown in the figure.
The lensed images A and B have redshifts of z=1.59, the lens galaxy z=0.415. The image of the lens galaxy with its prominent dust lane indicates that it is indeed the sought after late type spiral seen nearly edge-on, and the system appears to be an excellent case for studying the shape of any dark halo in the lens galaxy.

To try to constrain the flattening of dark halos, Koopmans (Groningen) and de Bruyn have constructed a grid of some ten thousand multi-component mass models to compare with the observations. Their conclusions are that:

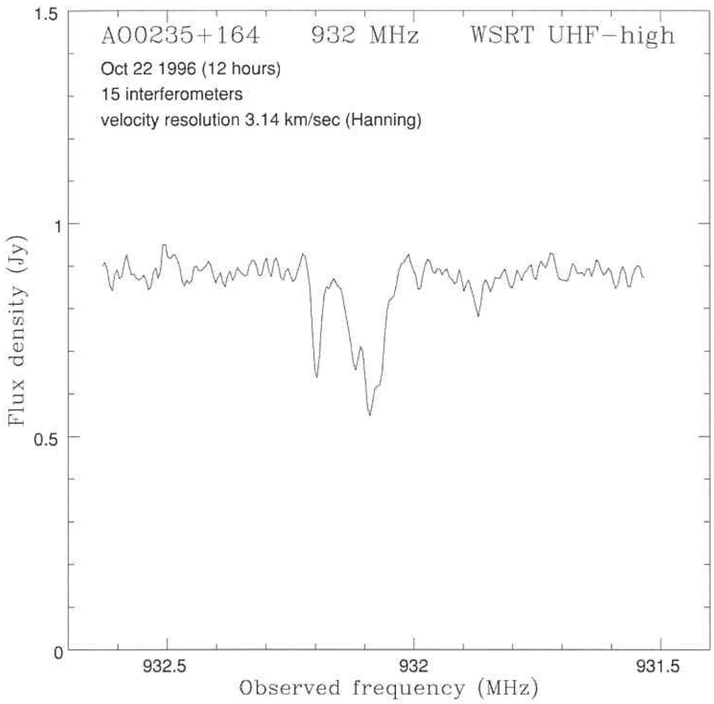
(i) a dark halo is definitely required to fit the observations.
(ii) oblate dark halos fit the data well, but realistic mass models cannot neglect the mass of the luminous disk material.
(iii) the axial ratio of the surface mass density in the halo of G_1 must be less than about 0.4, so while the dark matter is likely not spherically distributed, neither can it be confined to the much flatter luminous disk.
(iv) the required flux magnifications are only about a factor of 2.
(v) variations in the fluxes of the two images of the lensed source due to variability of the source itself are predicted to be delayed one to the other by between 50 and 75 days, depending on the mass model and assuming H_0 = 50 km/sec/Mpc.

Koopmans, Nair (Manchester) and de Bruyn have also begun a study of the distribution of dark matter generally in galaxies using the statistical properties of the CLASS sources. Koopman 's mass models are being used to predict the statistical properties of the gravitational lenses. The number of 3 and 5 image lenses, the fraction of disk galaxies in the sample and the total number and fluxes of the lenses found will be compared with the distribution of galaxies in space and with models of the distribution of dark matter in galaxies in order to constrain the latter.

A first analysis of the available data indicates that the so-called "maximum disk hypothesis"– in which one minimizes the amount of unseen mass when fitting to the observed rotation curve – is incompatible with the statistical properties of the CLASS sample. That is, dark matter appears to dominate the mass density even well inside the luminous disks.
A quantitative study will be carried out in the coming year.

Neutral gas at high redshift

During the year, Norman (Johns Hopkins University) and Braun (NFRA) published their survey of the current state of knowledge regarding cold gas at high redshift, and presented simulations showing how a number of observational issues can be resolved by the next generation of large radio instruments.

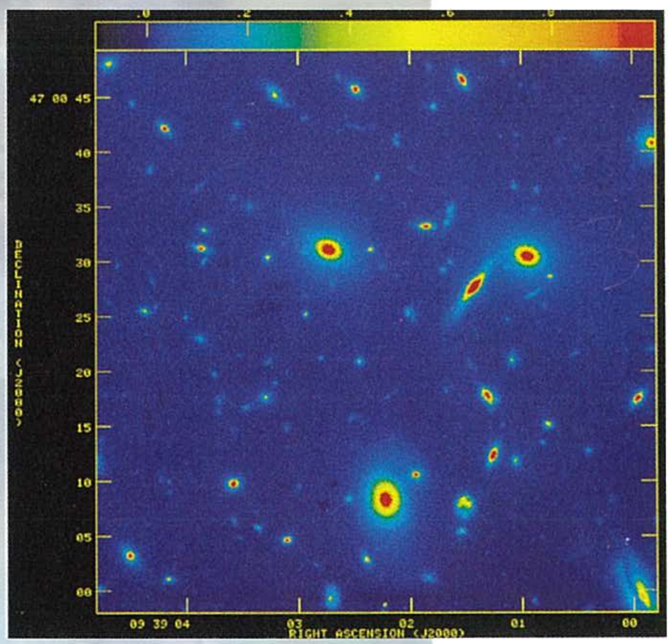


Spectrum of neutral hydrogen seen in absorption at z = 0.52. The image of a faint galaxy is seen in projection some 2 arcsec from the background BL Lac object, so the absorbing gas is probably located in the outer regions of this galaxy. The spectrum is one of the first observations made with the new UHF$_{high}$ receivers on the WSRT.

Two main conclusions to emerge from new observations made during the last few years. First, initial theoretical models for the formation of large scale structure in the Universe predicted the early formation of very large masses of neutral gas, up to 10^{15} $M_{\odot}$. However, sensitive searches, initially with the Westerbork array and later also with other telescopes, have shown that such structures are not common at high redshifts, and theoretical studies are now focusing on models in which structure first becomes evident at small scales. Most cool gas at high redshift is now presumed to reside in galaxy-sized structures that to date are only visible in absorption and which have column densities of at least 10^{20} cm^{-2}. The figure shows an example of this type of absorption in the 21cm line of neutral hydrogen.

Second, as these structures begin to condense into galaxies, at least some will exhibit rapid, systemic star formation, which can be detected in emission in several possible ways – at mm wavelengths using molecular lines and continuum dust emission, which originate in the most massive star forming complexes; in the strong non-thermal radio continuum that results from the accompanying supernovae; and via (mega)maser emission at radio wavelengths that forms in the interstellar medium of these systems.

In nearby galaxies, neutral hydrogen provides the estimate of total gas mass having the least cosmic scatter. Tracing the evolution of galaxies that is, observing the process of gas turning into stars, whether during quiescent evolution or by star



Simulation of a 24 hour radio continuum synthesis image of a spiral galaxy undergoing rapid star formation during the epoch of maximum galaxy formation (z≈2) such as would be possible with SKAI.

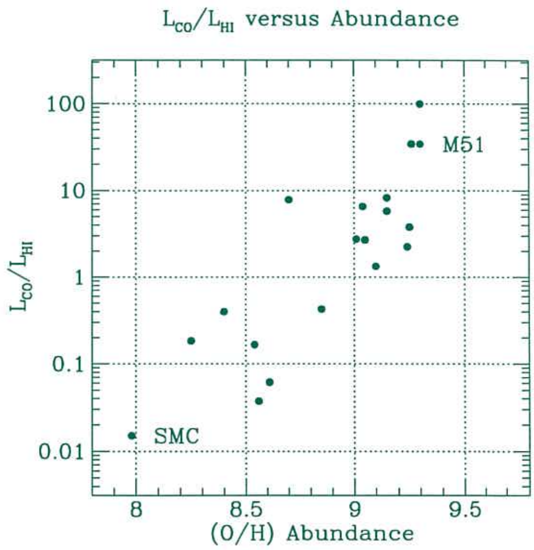
formation stimulated by mergers and collisions – will therefore ultimately rely on studies of neutral hydrogen in galaxies as a function of redshift, back to the suspected epoch of galaxy formation around z = 2 - 3. In absorption, the new instrumentation at the WSRT already provides access to the entire distribution of damped Ly-α absorption systems ($N_{HI} > 10^{20}$ cm^{-2}). Observations at radio wavelengths complement those in the optical and UV by giving insight into the physical conditions (T_{spin}) of the absorbing clouds and by allowing imaging of the clouds with milli-arcsec resolution using the techniques of VLBI. With a new generation of radio instruments such as SKAI it will be possible to extend such observations to include the so-called Lyman limit systems ($N_{HI} > 10^{17}$ cm^{-2}) and explore the role of much lower mass clouds in the galaxy formation process.

Of special interest will be the period of heavy element production. As shown in the figure, observations of molecular gas in galaxies cannot alone yield reliable information on the gaseous content, but the combination of molecular and neutral atomic hydrogen masses will shed light on galaxy chemical evolution.

Warmer galaxies at early epochs

As noted above, absorption measurements of neutral hydrogen provide insight into the physical conditions in galaxies in the early Universe. De Bruyn, O 'Dea (STScI) and Baum (STScI) reported observations with the WSRT during the year of a neutral hydrogen absorption system at z = 3.4, seen against the background quasar PKS 0201+113. This absorption system has the highest redshift studied to date in the radio and is one of the earliest known systems (look-back time 9.3 Gyr) for which such observations are currently possible.

The observations yield a line width of 9±2 km/sec, an equivalent width of 1.5 km/sec, and an optical depth of 0.085±0.02. The derived column density in HI is $N_{HI}=2.7\times10^{18}\,T_{spin}$ cm^{-2}. There is good evidence that both the optical damped Ly-a and radio HI absorption are seen against an essentially unresolved nuclear source. In this case the optically derived column density of $N_{HI} = 3\times10^{21}$ cm^{-2} provides an estimate of the equivalent temperature of the gas of T_{spin} = 1100 K, a value consistent with the kinetic temperature derived from the observed line width. The five other moderate and high redshift absorption systems studied to date also show equivalent temperatures near



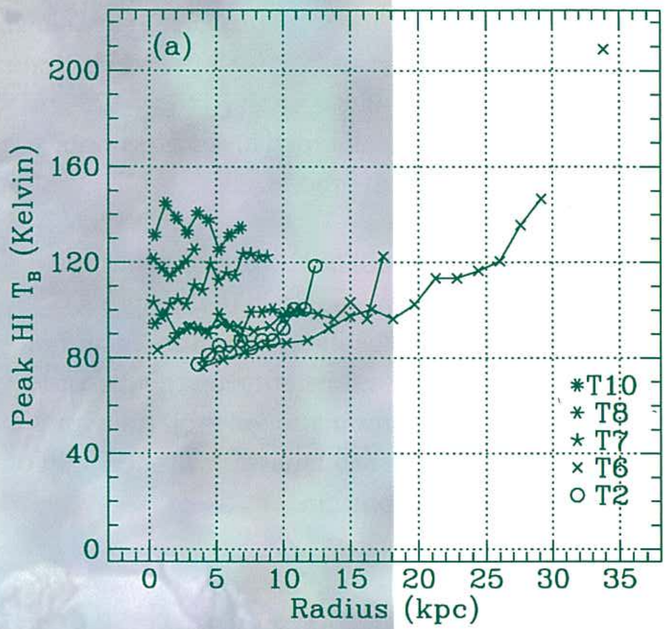
Ratio of the luminosity of galaxies in the molecular lines of CO to the luminosity in neutral hydrogen, as a function of the abundance of the element oxygen (representing the heavy elements synthesized in stars and not in the Big Bang). The plot shows that the combination of observations in mm-wave molecular lines and in dm-wave neutral hydrogen at earlier epochs will shed light on the early chemical evolution of galaxies.

1000K, while in our own Galaxy and in other nearby systems T_{spin} is typically an order of magnitude less. Evidently, the mix of gas temperatures in galaxies at earlier epochs was significantly different than it is in systems today, with more material at higher temperatures.

Complementary studies nearby

In previous years Braun discovered that neutral hydrogen in the disks of Local Group spiral galaxies often occurs in optically thick filamentary structures. Resolved observations of optically thick material provides direct information on the physical temperature of the gas, so if this phenomenon is general in spiral galaxies, it will permit direct determination of the state of the neutral interstellar medium across galactic disks and between the different types of spiral galaxies.

During the report year, Braun analyzed the HI emission properties in the disks of eleven nearby spirals.
The resolutions available in the data are about 100 pc spatially and 6 km/sec in velocity. Two components to the emission are seen, a high brightness temperature filamentary network, and a diffuse inter-arm and outer disk component. The filaments are marginally resolved spatially in their narrow dimensions and are often unresolved in velocity. The brightness temperature approaches the kinetic temperature as inferred from the line widths where the latter are resolved, indicating that much of the filamentary component is optically thick. Globally, each component accounts for about half the total line flux, but within the star-forming disks between 60% and 90% of the total HI line flux is from the filamentary network, which has a face-on covering factor of typically about 15%.



Radial changes in peak brightness temperature in the disks of seven galaxies of differing morphological types.
These temperatures are believed to reflect the gradient in kinetic temperature with radius in galactic disks.

Particularly interesting is the radial brightness temperature gradient found in all galaxies. Galaxies with earlier morphological types also show systematically lower temperatures at all radii. Modeling of the line profiles indicates that these trends are due to gradients in the kinetic temperature radially across the disks, in the sense

that outer disk regions are warmer than the inner regions. The data are consistent with a picture in which regions actively forming stars exhibit the filamentary, optically thick gas with temperatures in the range 80 - 200 K, while non-star forming areas and the outer disks beyond the outer edge of star formation show optically thin gas having temperatures up to 8000 K.
These results may be understood on the basis of gradients in the physical conditions affecting the local temperature, such as gas phase chemical composition, dust content, radiation field and midplane gas pressure.

More clues to the evolution of disk galaxies

For nearly a decade it has been clear that simple, passive evolution cannot explain the observed colors and spectra of galaxies at look-back times of 5 billion years and more. Many objects seen at those epochs are as blue as extreme starburst systems nearby and show spectra indicative of strong current or recent systemic star formation.
This increase in the number of galaxies actively forming stars parallels the increase with look-back time of the numbers of systems exhibiting strong radio emission, although different objects are generally involved in the two effects. Unfortunately, available observations have not been able unambiguously to distinguish between mechanisms that might stimulate the rapid star formation seen (nor the radio emission).

In an effort to improve the observational base for exploring these effects, Butcher has joined Oemler (Yale University) and Dressler (Carnegie Institution) to study high resolution images obtained with the Hubble Space Telescope of galaxies in four rich clusters of galaxies at $z \approx 0.4$.
The clusters all have substantial populations of blue, star forming and starburst galaxies. Morphologically, most of the galaxies can readily be accommodated in the Hubble classification sequence of nearby galaxies, although systems exhibiting the spectra of starbursts usually also show disturbed morphologies.
The radial distributions of galaxy types in the clusters are similar to those in nearby rich clusters, although there are uniformly more late type systems than in parallel environments today.

Curiously, a significant fraction of the apparently normal cluster spirals show abnormal patterns of star formation. Rings of star formation are more common than two-armed spiral patterns, for example, while rings are rare in nearby disk galaxies.
An interesting possibility could be that the rings are a normal phenomenon in disks at an early phase of their evolution, when they perhaps contained much more gas than they do today. A future radio telescope such as SKAI is required to verify this idea, but a natural prediction is that disk systems at even greater look-back times should generally show deviant patterns of star formation.

The simplest explanation of the morphologically disturbed systems, that they are the result of interactions or mergers of cluster galaxies, is confounded by the theoretically expected small numbers of such interactions at any given epoch in the cluster environment. An interesting alternative, at least in the cluster environment, could be disturbance of the dark matter halos of the systems as they orbit in a lumpy intra-cluster potential, followed by slow readjustment of the visible material.

Deuterium abundance in the outer Galaxy

The amount of deuterium produced in theoretical models of the Big Bang is a sensitive function of the assumed physical parameters. The observed deuterium abundance is therefore of considerable importance to cosmology. Unfortunately, the deuterium nucleus is fragile and all known astrophysical processes except the Big Bang itself destroy the element. Observations of the species in nearly primordial gas are clearly necessary to gain reliable information for modeling the physics of the Big Bang.

Gas seen during early epochs in the Universe almost certainly has undergone less processing through stars than has material nearby us today. Observations of deuterium at optical wavelengths in high redshift quasars, however, have yielded abundance results differing by an order of magnitude. Possible compromising effects in such observations include contamination of the suspected absorption line of deuterium by weak lines of atomic hydrogen, chemical differentiation via the formation of the molecule HD in the high density gas being observed, and the unknown history of the material being observed.

The outer parts of most galaxies are believed to have experienced rather limited star formation over the history of the Universe. An alternative approach to obtaining the primordial abundance of deuterium therefore might be to observe gas in the very outer parts of galaxies. The diffuse, low density gas in such regions cannot readily be observed in absorption in optical or ultraviolet but can be seen in the hyperfine transition of neutral atomic deuterium at 327 MHZ.

During the year, Chengalur, Braun and Burton (Leiden) analyzed the most sensitive observations of this deuterium line to date. They observed interstellar gas in the galactic anti-center region in the direction (l,b) = ($183^o.0$, $-0^o.5$). Gas in this part of the Galaxy is believed to have undergone minimal processing through stars and contains little or no molecular component. That is, this specific direction was chosen so that the line is formed by a long pathlength through low density, low metallicity gas rather than by a short pathlength through high density, high metallicity material.

The 14 element telescopes of the WSRT array were used as 14 single dish instruments, whose frequency switched signals were analyzed for external interference and then summed incoherently. A final rms noise level of 0.85 mK (per spectral channel of width 11.2 km/sec) was achieved, which is consistent with the expected

thermal noise of 0.80 mK. The interstellar gas in the observed direction fills the 2.5 degree primary beams of the telescopes, making the observations extremely sensitive to DI. The HI in this area displays an essentially constant brightness temperature of 135±3 K.

A faint emission line at the expected velocity is indeed evident in the data. Assuming the DI emission is either mixed with or lies behind the galactic continuum emission in this region and that the spin temperatures for DI and HI are equal, the inferred abundance of neutral deuterium is $3.9 \pm 1.0 \times 10^{-5}$. This value is comparable to the lowest values derived from high redshift systems, and argues for a significant baryon density in the Universe, possibly even as much as that needed for closure.

Giant radio galaxies

The largest radio galaxies discovered to date have maximum dimensions well over a Mega-parsec. Do these giants owe their extreme sizes to abnormally powerful central engines (extremely massive black holes?), or are the engines normal but the environmental conditions in some way unusual?

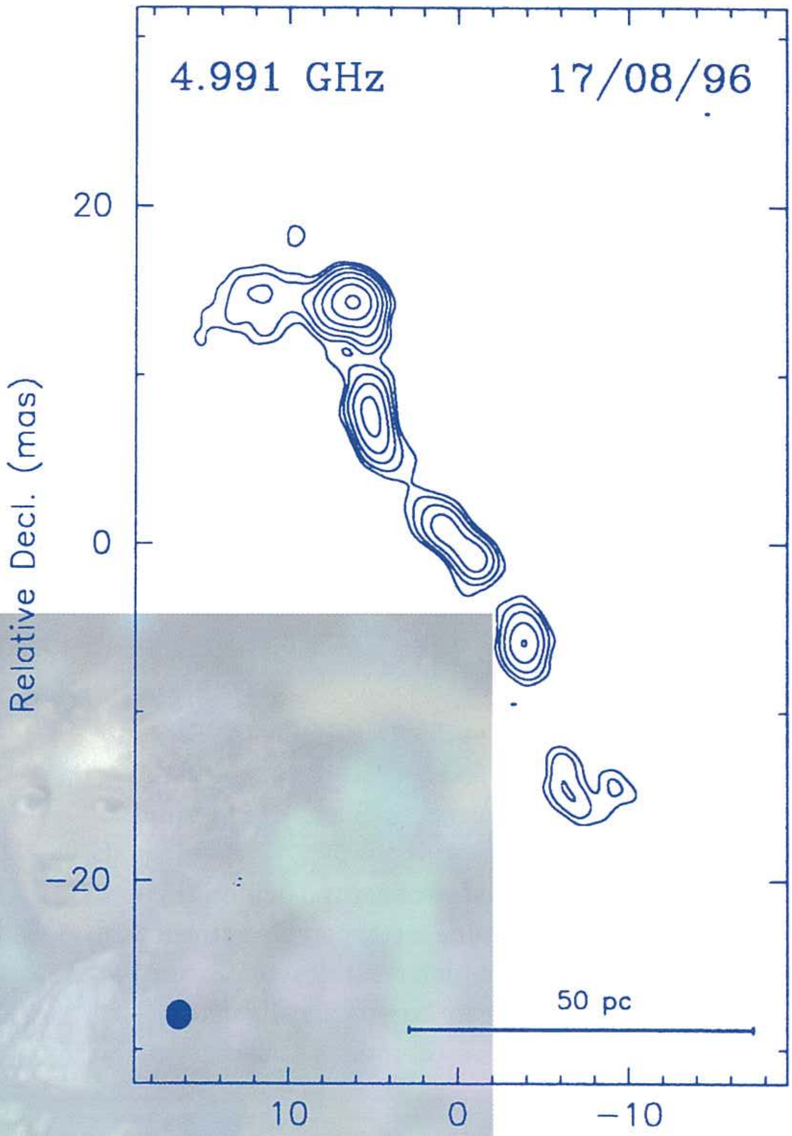
In an effort to constrain the propagation conditions in such sources, Strom has joined with colleagues in Bonn to study eleven of the largest systems known. Low frequency observations with the WSRT and VLA have been combined with 10 GHz maps made with the 100-m Bonn telescope to map the spectral index of the radio emission and provide estimates of the ages of the emitting plasma.

If the energy densities of the magnetic fields in these objects and of the relativistic electrons that give rise to the radio emission are roughly equal, one expects magnetic field strengths of about a micro-Gauss. In this case, the electrons radiating at 10 GHz will lose more energy to inverse Compton scattering from microwave background photons than to direct synchrotron radiation, and electron lifetimes are estimated to be typically on the order of 3×10^7 years. No steepening of the radio spectra generally is observed across the sources, indicating that the sources themselves are probably no older than this age, and also that they are nearly as large as they possibly can be in the time available to them. Evidently one is witnessing essentially unconfined expansion in these objects.

Jets and counterjets constrain Hubble constant

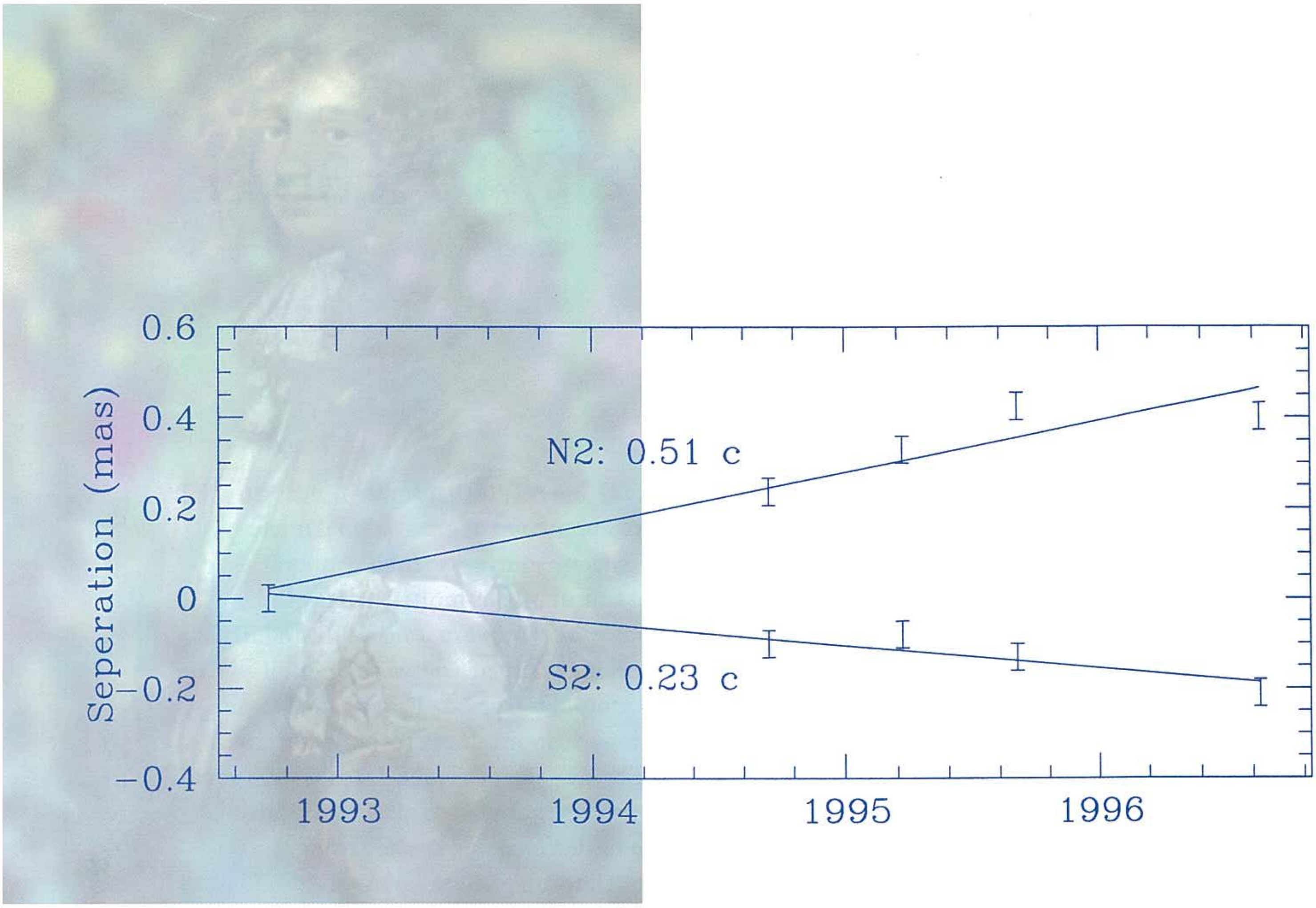
If one can measure the apparent motion of an object across the sky, and can also determine independently its likely intrinsic velocity – say by means of the Doppler effect – then one can estimate directly the distance to the object. And that distance together with a measured systemic redshift yields an estimate for the expansion rate of the Universe, the Hubble constant.

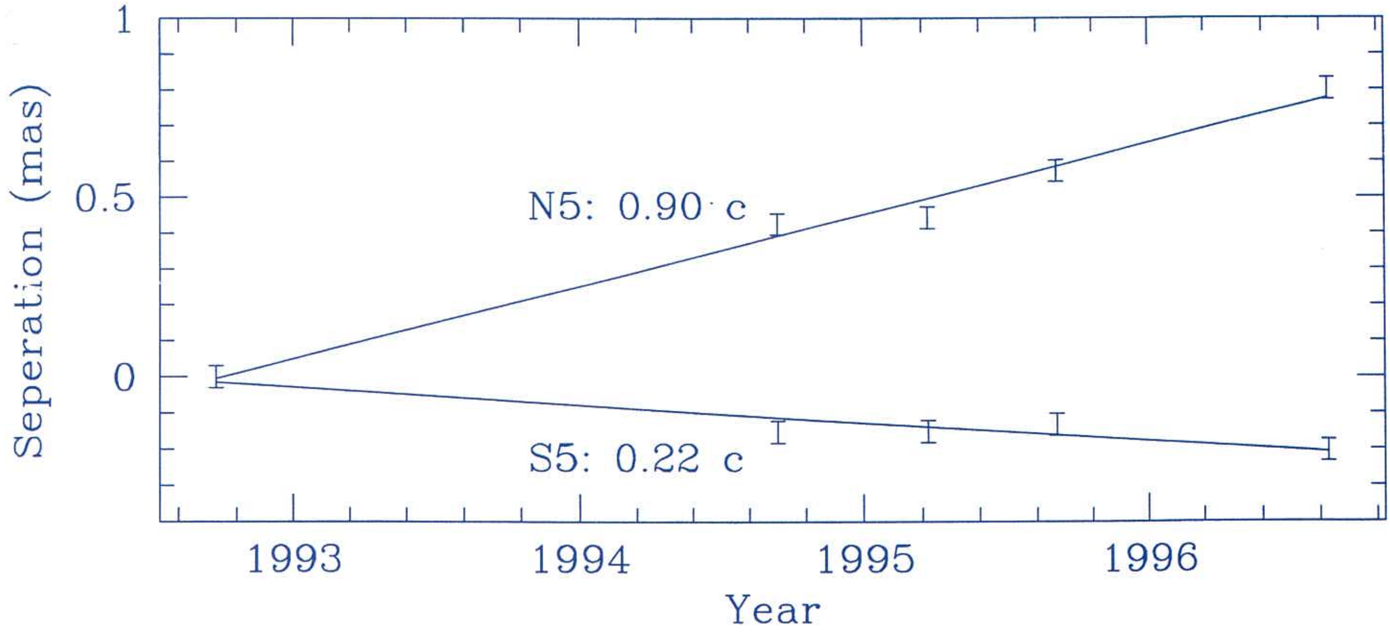
One way to effect such measurements could be to measure the apparent motion of the relativistic plasma in the



jets of extragalactic radio sources.
To avoid propagation effects one would like to make use of the parsec scale inner jets found in many powerful radio sources. These jets are generally one sided, that is, although they are expected to be ejected in opposite directions from their active galactic nucleus, they are mostly seen only on one side of the nucleus.
The interpretation of this observation is that such jets are propagating relativistically (at very nearly the speed of light), such that the component approaching the observer is boosted in intensity while that receding is dimmed and hence not visible. Only pairs of jets essentially propagating in the plane of the sky will reveal both jet and counter-jet to the observer.
Five such parsec scale pairs of jets have been discovered to date, but in none has detectable motion been observed.

Now, however, Vermeulen and Taylor (NRAO) have combined European and North American VLBI network observations at five epochs spread over 4 years to show that the 18th magnitude radio galaxy 1946+708 ($z = 0.101$) not only displays twin, parsec scale jets, but also that its jets show measurable expansion with no evidence of acceleration. Assuming the expansion velocity is intrinsically near the speed of light and that the expansion is occurring essentially in the plane of the sky, they derive a Hubble constant of 36 ± 3 km/sec/Mpc. Other methods of determining the Hubble constant generally find values between 50 and 100 km/sec/Mpc. The greatest systematic uncertainty in the present measurements is thought to lie in the difficulty of modeling the knots such that their apparent motion is reliably determined. But the reliability of the determination is expected to improve linearly with time as the expansion of the jets is tracked by new observations.





Twin, parsec scale jets in the radio galaxy 1946+708 that are being used to estimate the expansion rate of the Universe. Left page: map of the jets. This page: expansion velocities of the features in the jets.

Support for University research

NFRA not only provides observing facilities and other infrastructure in support of astronomical research at Dutch universities, but also finances specific research projects and makes available administrative and technical support for instrumental projects. This section gives brief summaries of these activities in 1996.

Grants program

NFRA's grants program provides financing for graduate students and postdoctoral fellows to work in the university research groups. Each year applications are accepted for specific projects involving either a single graduate student or postdoc, and for larger scale programs of research to include several temporary research positions and non-salary funding to continue for up to typically five years. In addition, the contributions from the university groups to the VISIR project for the ESO VLT are managed through NFRA's budget line for this grants program.

The application round for 1996 saw twelve applications for projects, and two for new programs. The external peer review (3 foreign referees) and selection committee (Achterberg, UU; Butcher, RuG; Franx, RuG; Katgert, RuL; and Waters, UvA) awarded funding to three project applications and to both programs.

P. Sackett and J.W. Pel (RuG) received funding to study the phenomenon of gravitational micro-lensing of galactic sources via high temporal resolution, simultaneous multi-wavelength observations in the visible and near-infrared. This research will make use of a network of small telescopes around the globe – the so-called PLANET collaboration – to monitor micro-lensing events seen towards the galactic center. The ultimate goal is to demonstrate that planets around the lens objects can be detected and studied using the gravitational lensing phenomenon.

G. de Bruyn (RuG), R. Schilizzi (RuL) and F. Verbunt (UU) received funding to carry out and analyze VLBI astrometry of selected pulsars, in order to study their motions and locate their birthplaces in the Galaxy, to yield information on their origins and on the masses of the progenitor stars.

K. Kuijken (RuG), R. Sancisi (RuG) and van Albada (RuG) were awarded funding to study the phenomenon of galactic warps. Current theoretical explanations of the outer warps of galactic disks are unable satisfactorily to account for the ubiquity of the effect. This research will compare high quality neutral hydrogen and velocity field maps of spiral galaxies taken with the WSRT (as part of the WHISP survey – see next section), with the predictions of the various theoretical scenarios.

T. de Zeeuw (RuL) received funding for two postdocs and a research assistant to continue his research on the formation, structure and evolution of elliptical galaxies. In addition, financing was granted to permit an international collaboration (the SAURON collaboration), involving researchers at the universities of Leiden, Lyon (F) and Durham (UK), to design and construct a special purpose spectrograph for the 4,2-m William Herschel telescope on La Palma. This instrument will be able to record velocity fields and velocity dispersions to large radii in elliptical galaxies.

And M. van der Klis (UvA) and F. Verbunt (UU) were granted funding to continue their research on neutron stars and black holes in X-ray binary systems and in radio pulsars. Observations with the XTE and SAX satellites and with the WSRT are to be combined with theoretical modelling to pin down the fundamental properties of these objects.

A summary of all research projects and programs financed during 1996 by NFRA is given in the following table.

Projectsubsidies

Stellar systems

Number	Proposer(s)	Title	Inst.	Researcher
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

Project subsidies

Interstellar mater

Number	Proposer(s)	Title	Inst.	Researcher
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

Project subsidies

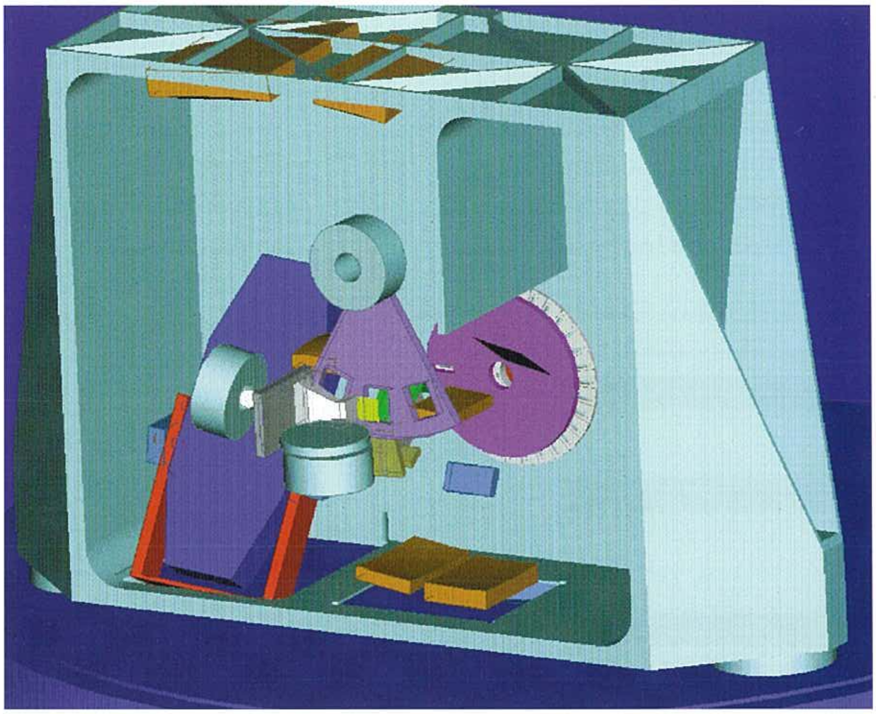
Galaxies

Number	Proposer(s)	Title	Inst.	Researcher
781-73-055	Dr. W. Jaffe	The dynamics of the 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: super-starbursts 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 compesition 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
781-73-060	Dr. P.D. Sackett Dr. J.W. Pel	A study of Galactic gravitational micro-lenses	RUG	Dr. J.P.L. Beaulieu Drs. R.M. Naber
781-73-060	Dr. K. Kuijken	"Warps" in galaxies	RUG	Drs. I. Garcia

Programme subsidies

Number	Proposer(s)	Title	Inst.	Researcher
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 RUG	Dr. H.J.A. Röttgering Dr. M. Bremer 50% ASTRON Drs. L. Pentericci Drs. L. Koopmans
781-76-011	Prof.dr. J.A. van Paradijs, Prof.dr. E.P.J. van den Heuvel Prof.dr. M. van der Klis	Structure and evolution of close binary sytems with a compact component	UvA	Dr. E.A. Magnier (Postdoc) Drs. F. van der Hooft Drs. T.J. Galama
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
781-76-017	Prof.dr. M. van der Klis Prof. F. Verbunt	Fundamental properties of neutron stars and black holes	UvA UU	Drs. M.C. van den Berg

Instrumental and observing projects



Three dimensional display of the VISIR optical layout. The main dimension of the instrument is 60 cm.
(Drawing by G. van der Heide, NIKHEF)

In addition to administering the university grants program, NFRA provides administrative, technical and financial assistance to a variety of ad hoc instrumental and observing projects that are initiated and led by university based astronomers in the country. During 1996, these projects included especially the following.

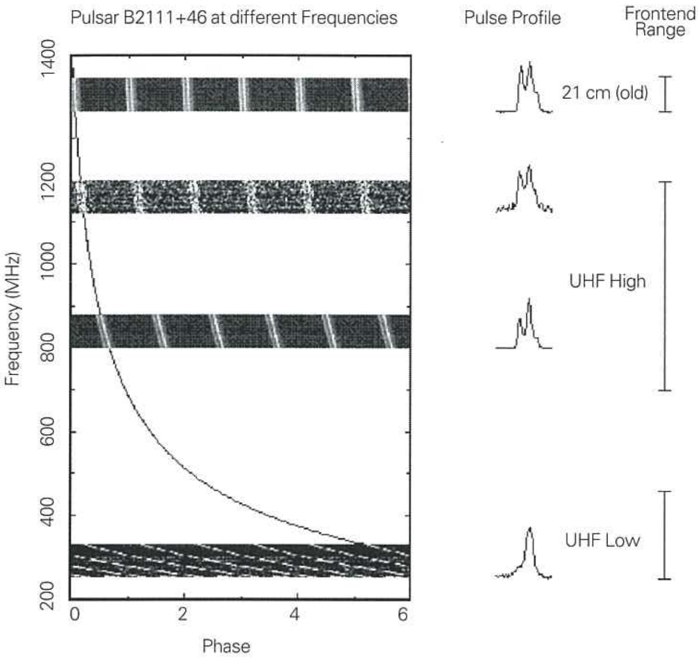
VISIR

NFRA has joined with the Service d'Astrophysique of CEA/DAPNIA at Saclay to design, construct and commission VISIR, a mid -infrared imager and spectrometer for the ESO Very Large Telescope (VLT). This instrument will provide diffraction limited imaging and long - slit (40 arcsec) spectroscopy in the N (λ= 7.7 - 13.5 micron) and Q (λ = 16 - 28 micron) bands, with low (R = 150 - 400), medium (R = 1500 - 4000), and high resolutions (R = 10000 - 30000). NFRA will carry primary responsibility for the spectrometer sub-section of the instrument. Dr. J.W. Pel (Groningen) is P.I. The project involves collabaration with researchers of NIKHEF in Amsterdam and SRON in Groningen to design and manufacture specific modules.
The figure shows the proposed optical layout. Two large echelle gratings are ruled back-to-back on one 350x140 mm blank, and light-weighte, diamond milled reflectors help minimize total mass. The entire spectrometer is cooled to 35 K, while the detector and its immediate surroundings will operate at 5 - 10 K.

The year was primarily one of preparation for the formal "kick-off "meeting held at ESO, Garching in December. The optical design was optimized and strategies were developed for the design and testing of the cryogenically cooled components. The optical laboratory to be used in the project, including an isolated floor, was installed in NFRA's new headquarter building in Dwingeloo in November. The project has its preliminary design review planned for the autumn of 1997, a final design review a year later and delivery and installation on the third VLT 8-m telescope in mid-2001.

PuMa

As interest in searching for new pulsars with the WSRT has grown, it has become clear that an optimized back-end for this purpose should be developed. Given typical values of pulse dispersion in the interstellar



Dispersion and pulse profiles of the pulsar B2111+46, as observed with the new wide band, tunable receiver systems and existing pulsar filter bank at the WSRT.

medium at frequencies near 300 MHz, one requires measurement channels no broader than about 10 kHz, but to maximize sensitivity one wishes to make full use of the 80 MHz band provided by the IF system of the telescope. During the year, the technical specifications for this new pulsar back-end, termed PuMa (for Pulsar Machine), were finalized and a feasibility study was carried out by the Instrumentation Group of the Physics Faculty of Utrecht University.

The proposed design involves 8 processing clusters, each managing the data from a 10 MHz wide band of spectrum. Each cluster performs the functions of a 1024 channel spectrum analyzer followed by calculation and averaging of the Stokes parameters. The hardware consists of 32 computer boards, each equipped with 6 high-performance DSPs to realize a total computing power in excess of 20 Gigaflops. Implementation in a VME environment allows ready interfacing to the local computing network and to the hydrogen maser clock at the WSRT.

At year's end detailed design had begun, with projected project completion and delivery to Westerbork during the summer of 1997.

Dutch Open Telescope

For some years the Astronomical Institute in Utrecht has been developing an optical telescope for high resolution imaging of the Sun. The instrument, currently referred to as the Dutch Open Telescope, or DOT, is mounted on a 15-m high tower and is specially designed to work in the open air. The project aims to achieve diffraction limited imaging from apertures up to about 70 cm diameter. Dr. R. Rutten (Utrecht) is project P.I. and Dr. R. Hammerschlag (Utrecht) is project engineer. In the early phases of the project, the tower was installed and tested in Westerbork next to the radio telescope. Recently NFRA concluded an MoU with the Instituto de Astrofysica de Canarias to allow the telescope to be sited at the Roque de los Muchachos on the island of La Palma.

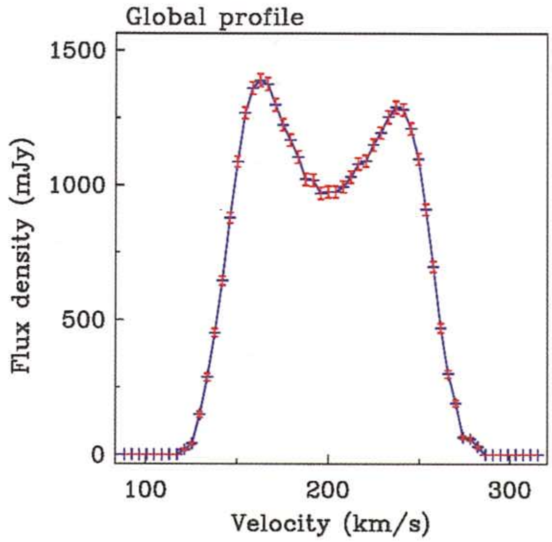
During 1996, the telescope and tower were shipped to the island and installed. A ceremony was held in June, at which the Netherlands ambassador to Spain formally inaugurated the facility as the first all Dutch instrument on the island. At year's end, the optics were being prepared for installation and first light was being planned for the spring of 1997.

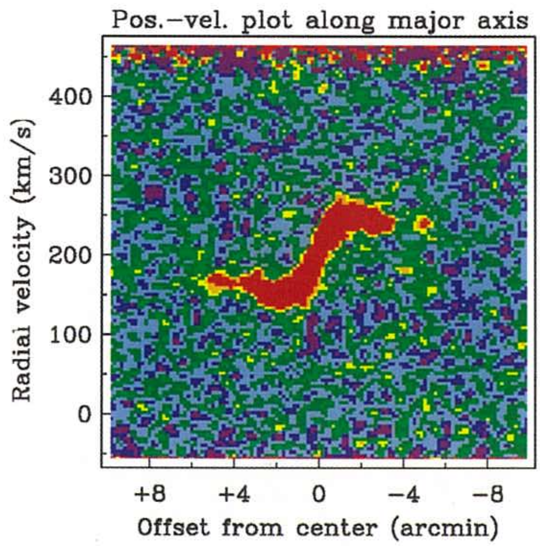
The Dutch Open Telescope installed at the Roque de los Muchachos Observatory on La Palma. The tower and telescope are designed thermally to avoid locally generated image degradation, and mechanically so they are extremely stiff and can withstand substantial winds without shaking.

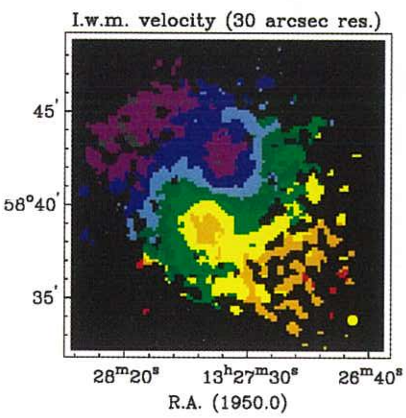
SCUBA

A major new instrument planned for use on the JCMT is the Submillimeter Common User Bolometer Array, SCUBA. It provides two arrays of bolometers that can observe simultaneously continuum radiation in bands around 450 and 850 microns. The long wavelength array 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 millimeter wavelengths.

The detectors sample the sky sparsely, however, so that at least 16 new 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 at the JCMT has implemented the former mode, NFRA will implement the latter in a project having Mr. Rudolf Le Poole (Leiden) as P.I. A design study to this end was carried out in 1995 with a view toward implementing the scheme at the telescope in 1996, but various technical problems found during commissioning of the instrument have caused the project to be rescheduled for sometime in 1997.







Examples of the data being obtained in the WHISP. Similar data for other galaxies can be found on the WWW pages of the Kapteyn Institute, Groningen.

WHISP

The Westerbork survey of HI in Spiral galaxies (WHISP) is a survey of the neutral hydrogen content and velocity fields of a large sample of nearby galaxies, currently in progress using the WSRT. The scientific goals of the project include studies of the systematics of dark matter halos, the effects of environment on the structure and growth of galaxy disks, and the determination of galaxy distances. Van Albada (Groningen) is P.I. for the project. A sample of 500 - 1000 galaxies from the Uppsala General Catalogue of Galaxies is being observed, with as criteria that objects be larger than 1.5 arcmin diameter in blue light and situated north of $+20^0$ declination. Short observations are first made. At year's end, 265 twelve hour synthesis observations and 94 short cuts (to demonstrate mapping feasibility) had been made.

Over a hundred of the twelve hour observations had been fully reduced, and R-band photometry had been obtained and reduced for over 300 galaxies with the telescopes of the Isaac Newton Group on La Palma.

WENSS

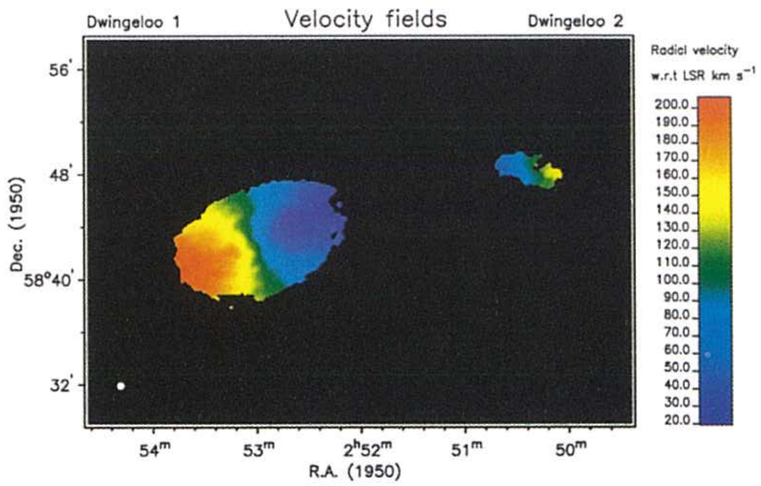
The Westerbork Northern Sky Survey (WENSS) is a survey of the sky above declination +30° at 92cm wavelength, to a limiting flux density of about 18 mJy (5σ). About a quarter of the region is also being observed at 49cm wavelength. The project is being carried out in a collaboration between NFRA staff and researchers at the Leiden Observatory, with de Bruyn (NFRA) and Miley (Leiden) jointly acting as P.I. Several months of observing time at the WSRT have been devoted to WENSS over the past several years. During 1996, the observational phase of the project was completed, and the analysis of a 570 square degree sub-region around the north ecliptic pole was published. Preparation of the full survey and source catalog for publication is scheduled to take place in Leiden during 1997. NFRA is also financing three of the seven PhD projects currently making use of WENSS data.

DOGS

Nearly 20% of the sky in the plane of the Milky Way is obscured to visible light by absorption and scattering by interstellar material. This so-called Zone of Avoidance, however, is transparent to radio waves. To see whether there are interesting objects in the Zone that have not yet been discovered, a survey has begun of the northern part of the Zone by Burton (Leiden), Henning (New Mexico), Kraan-Korteweg (Paris) and collaborators elsewhere. Going by the name, Dwingeloo Obscured Galaxy Survey (DOGS), it is being carried out using the Dwingeloo 25-m radio telescope and is being supported operationally by NFRA staff.

Among the first objects found in the survey was the previously unknown galaxy and named Dwingeloo 1. New WSRT data obtained during the report year show this object to be the nearest grand design barred spiral system, and also probably among the 10 largest galaxies within about 5 Mpc. The new observations yield a total mass for Dwingeloo 1 of about 3.1 x 10^{10} $M_\odot$, about that of the Local Group spiral M3.

They also reveal the presence of yet another system, duly dubbed Dwingeloo 2, a small galaxy (2.3 x 10^9 $M_\odot$) that is probably a physical companion to Dwingeloo 1. The estimated distance to the systems of 3.8 Mpc and their angular proximity to the galaxies Maffei 1, Maffei 2 and IC 342, make it plausible that they together form a bound group located just outside our own Local Group.



Radio synthesis image of the galaxy pair Dwingeloo 1 and 2 obtained with the WSRT.

Financial Report 1996

Received funds	*(kf)*	*total*
Operations		13,974
NWO	11,968	
NWO beleidsruimte GB-E	900	
Credit balance 1995	724	
Credit balance projects	109	
Business activities	83	
Interest	159	
Contributions from others	31	
Capital Outlay subsidies		4,116
NWO middelgroot	2,516	
NWO groot	1,600	
Total NFRA Institute		**18,090**
Grants program		2,246
NWO grants	2,020	
Contributions from others	98	
Credit balance 1995	128	

Expenditures	*(kf)*	*total*
Operations institute + WSRT		12,320
Staff	9,211	
Exploitation	3,052	
Credit balance 1996	57	
WSRT development projects		2,175
Multi Frequency Front Ends	100	
New digital backend	1,675	
Telescope Management System	280	
AIPS++, Newstar	120	
VLBI projects	pm	
R & D projects		723
Phased Array Study	638	
Others	85	
International Cooperation		2,797
UK/NL	2,797	
ESO-VISIR	pm	
Total NFRA Institute		**18,015**
Grants program		2,321
Projects	1,601	
Programs	510	
Credit balance 1996	210	

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Personnel (31 December 1996)

E-mail: <user> @nfra.nl

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Beheer, Organisatie en Astronomie		
Adjunct Directeur	Dr. W.H.W.M. Boland	boland
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Medewerkster Kantine- en Huishoudelijke Dienst	Mw. G. Hofman-Sterk	
	Mw. I. Lenten	
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	Mw. I. Lefferts-Grit	
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Personeelsfunctionaris	Mw.F.H.Wekking	wekking
Medewerkster Personeelszaken	Mw. A. Bennen	bennen
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Medewerker Financiële Zaken	P. Hellinga	hellinga
Adm. Medewerker FZ/Inkoop Adm.	A. Koster	koster
	Mw. J.B. Mulder (until 22 June)	
Astronomie		
Astronoom	Dr. R. Braun	rbraun
	Prof. dr. A.G. de Bruyn	ger
	Dr. E. Raimond	exr
	Prof.dr. R.G. Strom	strom
Senior Research Fellow	Dr. R.C. Vermeulen (from 15 Sept.)	rcv
Postdoctoral Medewerker	Dr. J. Chengalur (until 1 August)	
	Dr. W. Deich (until 1 June)	
	Dr. M.P. van Haarlem (from 1 Sept.)	haarlem
Research Assistent	Y. Tang	tang
Voorlichting & Communicatie	Drs. R.O. Genee	genee
UK/NL samenwerking Hawaii		
Support-astronoom	Dr. R. Tilanus	rpt@jach.hawaii.edu
Support-fysicus	Dr. F. Baas	baas@jach.hawaii.edu

La Palma		
Support-astronoom	Dr. R.G.M. Rutten	rgmr@ing.iac.es
Support Astronoom	Drs. J.H. Telting (from 1 Sept.)	
Projectmedewerker	Mw. M.J.W. Broxterman	mbrox@ing.iac.es
	B.W.H. van Venrooy	venrooy@ing.iac.es
Ontwikkelings electronicus	R.J. Pit	rjp@ing.iac.es
Programmeur	P.H. van der Velde	pvdv@ing.iac.es
Computertechnicus	G.P.J. Benneker	benneker@ing.iac.es
Onderzoek en Ontwikkeling		
Hoofd Onderzoek en Ontwikkeling	Ir. A. Van Ardenne	ardenne
Secretaresse	Mw. C.B.M.B Bartelds-Jager	bartelds
Software		
Wetenschappelijk projectleider	Drs. J.P. Hamaker	jhamaker
	Ir. J.E. Noordam	jnoordam
	Dr. F.M. Olnon	folnon
	Drs. H.W. van Someren-Gréve	greve
	Dr. C.M. de Vos	devoscm
Onderzoeksmedewerker	H.J. van Amerongen	amerongen
Systeemontwerper	G.N.J. van Diepen	gvandiep
Senior Programmeur	H.J. Vosmeijer	vosmeijer
	A.H.W.M. Coolen	coolen
Hardware		
Wetenschappelijk projectleider	Ir. J.D. Bregman	jbregman
	Ir. A.B.J. Kokkeler	kokkeler
	Dr. ir. F.M.A. Smits	smits
	Ir. G.H. Tan	tan
	Dr. ir. H.P.T. Tolsma (from 1 Feb.)	
	Ir. E.E.M. Woestenburg	woestenburg
Wetenschappelijk hoofdonderzoeker	Dr. ir. A. Bos	bos
Wetenschappelijk onderzoeker	Ir. M.J. Arts	arts
	Ir. J.L.M. Buijnsters (from 1 Sept. until 1 Dec.)	
	Ir. P.G.M.M. van Cleef (until 1 Sept.)	
Post Doctoral medewerker	Dr. M.J. Goris (from 23 Sept.)	mgoris
Project Developer	A. Joseph (from 1 March)	joseph
Electronisch Projectontwerper	A. Doorduin	doorduin
	Ing. A. Henzen	henzen
	Ing. H. Heutink	heutink
	Ing. J. Hofman	hofman
	Ing. P. de Jong	jong
	Ing. R.P. Millenaar	millenaar
	L.J. van der Ree	ree
Project Electronicus	K. Brouwer	kbrouwer
	Y.J. Koopman	koopman
	L. Nieuwenhuis	nieuwenhuis
	P.H. Riemers	riemers
	N. Schonewille	schonewille

Ontwikkelings Electronicus	S. Damstra (from 1 June)	damstra
	R. Kiers	kiers
	M. Leeuwinga	leeuwinga
	E. Mulder	mulder
	S.Th. Zwier	zwier
Waarneembedrijf		
Hoofd Waarneembedrijf	Ir. H.C. Kahlmann	hakah
Waarneemgroep		
Hoofd Waarneemgroep	Dr. T.A.Th. Spoelstra	spoelstra
Radioastronomisch Waarnemer	P. van der Akker	
	L.H.R de Haan	dhaan
	G. Kuper	kuper
	J.J. Sluman	jsluman
	J. Tenkink	tenkink
Reductieleider/VLBI Coördinator	Dr. A.R. Foley	foley
Astronomisch Gegevensverwerker	D.J.J. Moorrees	moorrees
	K. Weerstra (Leiden)	
	Mw. H.H.J. Lem	hlem
Systeemgroep		
Hoofd Systeemgroep	Ir. A.J. Boonstra	boonstra
Werktuigkundig ingenieur	Ing. J.P.R. de Reijer	
Systeemtechn. digitale technieken	J. Weggemans	weggemans
Systeemtechn. analoge technieken	H.J. Stiepel	stiepel
Mechanisch technicus	J. Stolt	
	P.G.J. Gruppen	
Systeemingenieur	Dr.ir. M.J. Bentum (from 1 July)	bentum
Electro-mechanisch technicus	P. Donker	
Senior Programmeur	T. Grit	grit
	B. Kramer	kramer
Terrein en Gebouwen		
Bewakings- en Onderhoudsdienst	H. Bokhorst	
	D.J. Haanstra	
	A. Wieringh	
Adm. Medewerkster/Telefoniste	Mw. A.C.H. Heijne (until 1 May)	
Medew. Huishoudelijke Dienst	Mw. H. Braam	
Instrumentatie en Constructie		
Hoofd Instrumentatie en Constructie	B.A.P. Schipper	schipper
Technisch Ondersteunende Dienst		
Techn. Ondersteunende Dienst	H. Snijder	snijder
Inkoop Documentalist	S. Sijtsma	
Technisch Magazijnmeester	P.C. Jager	jager
Instrumentatie Technicus	H.J. Borkhuis	borkhuis
Electronisch Monteur	A.M. Koster	
Technisch Documentalist	R. van Dalen	dalen
	J. Slagter	slagter
Planning-coördinator	Ing. J.W. Beuving	beuving
Software programmeur	A. van Schie (until 1 May)	

Computer Systeem Beheer

PC-systemen en Netwerken	R. Boesenkool	boesenkool
UNIX-werkstations en Hardware	K.J.C. Stuurwold	stuurwold

Instrument Makerij

Hoofd Instrumentmakerij	Ing. W. van Emden	emden
Werkcoörd. Instrumentmakerij	J. Idserda	idserda
Mech. Ontwikkelings Technicus	J. Bakker	jbakker
	M. Bakker	mbakker
	J.S. Dekker	dekker
	G. Hagenauw (from 1 June)	hagenauw
	T.J. de Jong	tjong
	G.J.M. Koenderink	
	J.H. Nijboer (from 1 August)	nijboer
	M. Schuil	schuil

Stagiaires		**Mentor**
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P.F.P. Casimiri	Techn. College Drenthe	Harm-Jan Stiepel
E.R. van Dijken	MBO Coll. Oost Groningen	Jan Idserda
M. Wassens	HTO Windesheim	Bert Woestenburg
J.R. Timmerman	Morgenland College	Peter Hellinga
J.A.E. Rosenberg	HTO Windesheim	Bert Woestenburg
R. Lowijs	Morgenland College	Peter Hellinga
C.N. Lukassen	Hogeschool Drenthe	Felix Smits
A.F. Mulder	HanzeHogeschool Groningen	Sip Sijtsma
G.Braam	MBO Coll. Oost-Groningen	Jan Idserda
F. Bonte	Hogeschool Enschede	Marco de Vos
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J.F. Dijkhuis	Universiteit Twente	Felix Smits
T. Uildriks	T.U. Eindhoven	Gie Han Tan
C.A. van der Heide	Hogeschool Enschede	Wim van Emden
R.G. Glas	Hogeschool Leeuwarden	Felix Smits
M.G.M. Stegers	Universiteit Twente	André Kokkeler
H.G. Heuving	Hogeschool Drenthe	Felix Smits
C. Bruinewoud	MBO Coll. Oost-Groningen	Jan Idserda
I.J.H. Formanoy	Hogeschool Enschede	Felix Smits
R.F. Beiboer	Hogeschool Leeuwarden	Ger van Diepen
H.J.H. Tigelaar	Hogeschool Enschede	Felix Smits

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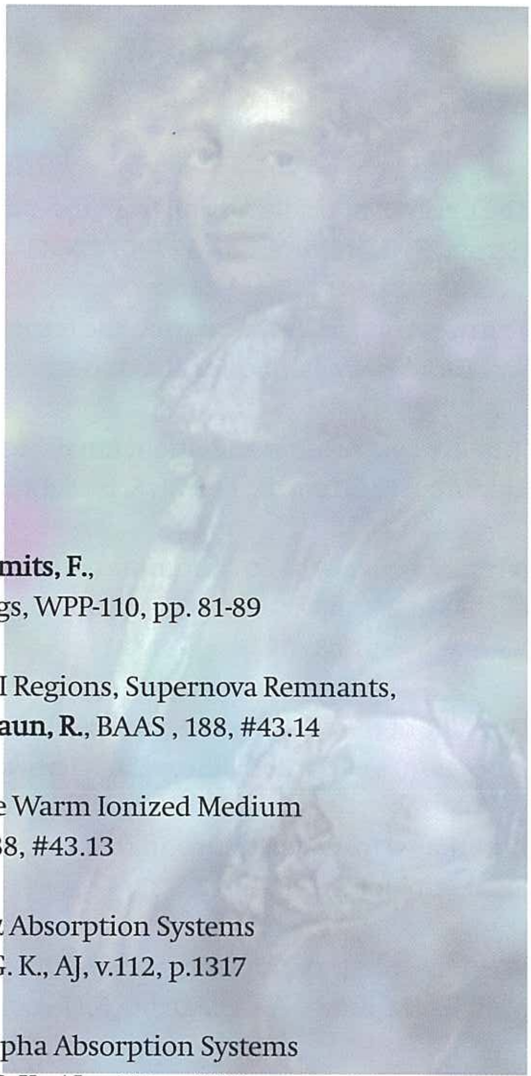

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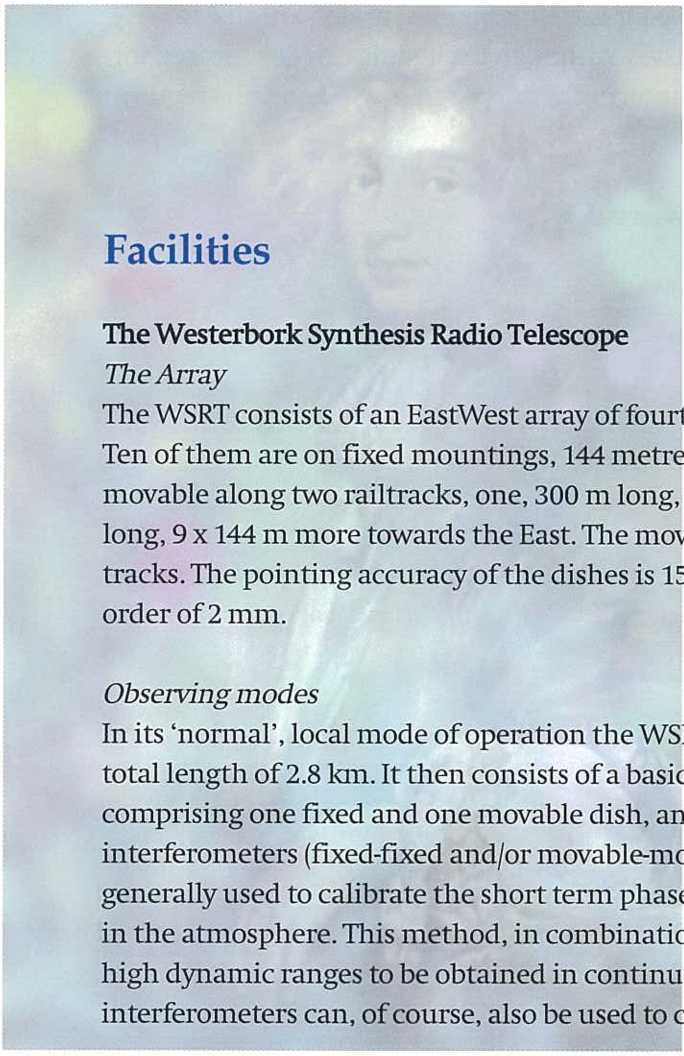
Radio Observatory



Facilities

The Westerbork Synthesis Radio Telescope

The Array

The WSRT consists of an EastWest array of fourteen equatorially mounted 25m 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 on 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 aperturesynthesis 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 radio telescopes 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.

For information and the latest news on the receivers and backends, we refer to our homepage: **www.nfra.nl.**

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)

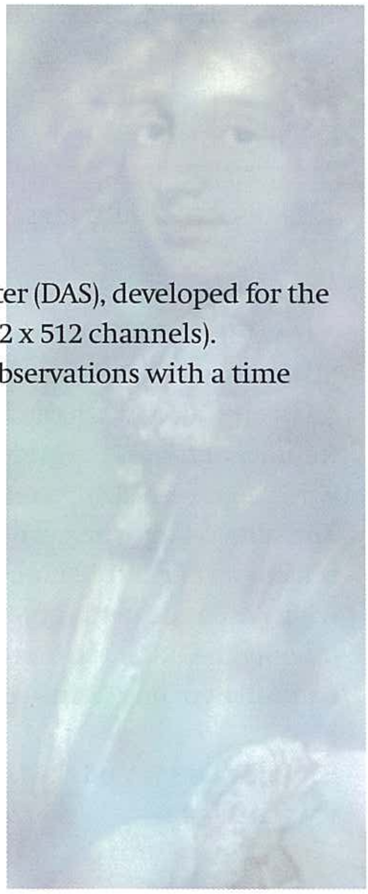
Frontend receivers are available for 21 cm and for 18 cm wavelengths (and, upon request for 6 cm). Their parameters are:

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

Sensitivities (5 x 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 x 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.



WSRT Projects

Number	P.I Name	Subject
1027	Strom, R.G.	X-1
1030	Wakker, B.P.	HVC-distance
1043	Hucht, K.A. van de	Variable non-thermal wolf-rayet binaries
1103	Albada, T.S. van	WHISP
1140	Hanlon, L.	Rapid radio obs. of gamma-ray burst error boxes
1161	Johnston, H.	Search fot pulsars in WENNS candidates
1172	Chengalur, J.N.	Unbiassed search for high-z HI absorption
1174	Hucht, K.A. van de	2x2 degr 21 cm mosaic of CYG OB2
1175	Paradijs, J. van	Lobes around soft X-ray transients
1177	Breuck, C. de	Synchrotron halo of spiral galaxies
1182	Albada, T.S. van	HI in highly inclinated galaxies
1185	Progrebenko, S.	QSO 2022+171 Radio spectrum variability
1190	Klis, M. van der	Pulsars
1191	Vasisht, V.	Young pulsars in Perseus
1197	Schoenmakers, A.P.	21 cm observations of nearby giant radio galaxies
1208	Deich, W.	Polarisation & scintillation of pulsars
1209	Bruyn, G. de	Hooks & filaments in the galactic lin. polarisation
1210	Spoelstra, T.A.Th.	Galactic contiuum polarisation
1211	Verheijen, M.	The HI polar ring S0 galaxy N3998
1212	Koopmans, L.	Gravitationally lensed high-Z radio sources
1213	Voute, L.	Giant pulses from PSR 1937+21
1214	Paradijs, J. van	Search of phase reference sources near SX0X1
1215	Paradijs, J. van	Study of rapid periodic variations of GRS1915+105
1220	Schoenmakers, A.P.	High redshift giant radio galaxies
1222	Carilli, C.	HI 21 cm absorption by the WNM
1229	Bruyn, G. de	ISM in a galaxy
1231	Strom, R.G.	Pulsar observations
1235	Röttgering, H.	A rearch for neutral gas in the most distant galaxies
1238	Briggs, F.	Redshift 21cm absorption in 3C286/PKS1229-021
1240	Vermeulen, R.C.	The environment of powerful young radio sources
1242	Chengalur, J.	HI & OH towards 1830-211
1245	Smette, A.	HI ass. with the lens of the dbl Quasar Q0957+561
W2000	Bruyn, G. de	WENSS
R/97A/2	Galama, T.	Gamma Ray Burst error box observations
R/97A/7	Hucht, K.A. van de	Radio emission from the Wolf-Rayet binaries
R/97A/11	Snellen, I.A.G.	Role of dense interst. environment of GPS rad. Galax.
R/97A/13	Bruyn, A.G. de	Struct. & kinematics of HI absorber in front of 3C196
R/97A/17	Schoenmakers, A.P.	Mapping large scale structure of nearby radio galaxies
R/97A/18	Moore, C.B.	Gravitational lens redshifts by HI absorption
R/97A/21	Lane, W.M.	Low redshift HI absorption in MgII selected systems
R/97A/24	Carilli, C.L.	Redshifted HI 21 cm line observations of red quasars

WSRT Time Awards

Project	92cm	50cm	21cm	UHFlow	UHFhigh	Total(hours)
1027			25.6			25.6
1030			10.3			10.3
1043	5.8		88.4			94.2
1103			523.5			523.5
1140	34.5		72.1			106.6
1161	8.1					8.1
1172	125.5					125.5
1174			24.0			24.0
1175			24.0			24.0
1177	2.3					2.3
1182			52.0			52.0
1185	15.2		24.8			4
1190			46.5			46.5
1191	38.9					38.9
1197			27.1			27.1
1208	30.4					30.4
1209	49.0					49.0
1210	24.0					24.0
1211			47.9			47.9
1212			121.5			121.5
1213			22.4			22.4
1214			5.8			5.8
1215			191.2			191.2
1220			119.0			119.0
1222			93.6			93.6
1229			9.7			9.7
1231			22.6			22.6
1235				57.3		57.3
1238					19.8	19.8
1240					34.1	34.1
1242					17.5	17.5
1245					12.0	12.0
2000	508.7					508.7
R/97A/2					12.0	12.0
R/97A/7				3.2	6.0	9.2
R/97A/11					9.2	9.2
R/97A/13					5.8	5.8
R/97A/17					45.6	45.6
R/97A/18				12.0		12.0
R/97A/21					34.7	34.7
R/97A/24					23.0	23.0

Addresses

National Institutes

Amsterdam

Sterrenkundig Instituut "Anton Pannekoek", Universiteit van Amsterdam
Kruislaan 403, 1098 SJ Amsterdam, tel. 020-525 7491/7492, fax 020-525 7484

Vakgroep Sterrenkunde en Atoomfysica, Vrije Universiteit Amsterdam
De Boelelaan 1081, 1081 HV Amsterdam, tel. 020-444 7888, fax 020-444 7899

Centrum HogeEnergie Astrofysica (CHEAF)
Postbus 41882, 1009 DB Amsterdam, tel. 020-525 7491, fax 020- 592 5155

Den Haag

Nederlandse organisatie voor wetenschappelijk onderzoek (NWO)
Laan van Nieuw Oost Indië 131, Postbus 93138, 2509 AC Den Haag
tel. 070-344 0640, fax 070-385 0971

Dwingeloo

Stichting ASTRON
Oude Hoogeveensedijk 4, Postbus 2, 7990 AA Dwingeloo
tel. 0521-595 100, fax 0521-597 332

Joint Institute for VLBI in Europe (JIVE)
Oude Hoogeveensedijk 4, Postbus 2, 7990 AA Dwingeloo
tel. 0521-595 100, fax 0521-597 332

Groningen

Kapteyn Laboratorium
Zernike Gebouw, Postbus 800, 9700 AV Groningen
tel. 050-363 4073, fax 050-363 6100

Ruimteonderzoek Groningen
Zernike Gebouw, Postbus 800, 9700 AV Groningen
tel. 050-363 4073, fax 050-363 4033

Leiden

Sterrewacht Leiden
Huygens Laboratorium, Niels Bohrweg 2, Postbus 9513, 2300 RA Leiden
tel. 071-527 5835, fax 071-527 5819

Nijmegen

Sterrekundig Instituut
Katholieke Universiteit Nijmegen, Toernooiveld, 6525 ED Nijmegen,
tel. 024-365 3095, fax 024-365 2440

Noordwijk	Estec Keplerweg 1, Postbus 299, 2200 AG Noordwijk, tel. 071-368 6555, fax 071-361 7400
Utrecht	Sterrenkundig Instituut Princetonplein 5, Postbus 80000, 3508 TA Utrecht, tel. 030-253 5200, fax 030-253 5201
	Ruimteonderzoek Utrecht Sorbonnelaan 2, 3584 CA Utrecht, tel. 030253 5600, fax 030-254 0860
Westerbork	Radiosterrenwacht Westerbork Schattenberg 1, 9433 TA Zwiggelte, tel. 0593592 421, fax 0593-592 486

International Institutes

Beijing	Beijing Astronomical Observatory, Chinese Academy of Sciences, Zhongguancun, Beijing 100080, China tel. +86 10 12551968/12551261, fax +86 10 12561085
Bologna	Istituto di Radioastronomia, CNR, Via P. Gobetti 101, I-40129 Bologna, Italy tel. +39 51 6399385, fax +39 51 6399431
Bonn	Max Planck Institut für Radioastronomie, Auf dem Hügel 69, D 53121 Bonn, Germany tel. +49 228 525244, fax +49 228 525229
Bordeaux	Observatoire de l'Université de Bordeaux, Ave. Pierre Sémirot, BP 89, 33270 Floirac, France tel. +33 56 864330, fax +33 56 404251
Cambridge (UK)	Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge, CB3 0HA, England, tel. +44 1 223 337548, fax +44 1 223 337523
	Mullard Radio Astronomy Observatory (MRAO), University of Cambridge, Department of Physics, Cavendish Laboratory, Madingley Road, Cambridge CB3 0HA, England tel. +44 1 223 337200, fax +44 1223 63263.
	Royal Greenwich Observatory (RGO), Madingley Road, Cambridge CB3 0EZ, England tel. +44 1 223 374000, fax +44 1 223 374700
Charlottesville	NRAO, Edgemont Road, Charlottesville, VA 22903, USA, tel. +1 804 2960211, fax +1 804 2960278
Edinburgh	Royal Observatory Edinburgh (ROE), Blackford Hill, Edinburgh EH9 3HJ, Scotland tel. +44 31 6688100, fax +44 31 6688264

Effelsberg	Radio Observatorium Effelsberg, D 53902 Bad Munstereifel, Effelsberg, Germany tel.+49 2257 3010, fax +49 228525229
Epping	Australia Telescope National Facility (ATNF), P.O. Box 76, Epping NSW 2121, Australia, tel. +61 23724100, fax +61 23724400
	CSIRO, Division of Radiophysics, P.O. Box 76, Epping NSW 2121, Australia tel. +61 23724222, fax +61 23724310
Granada	IRAM, c/o Nucleo Central, Bloque 6/2B, Av. Divina Pastora 7, 18012 Granada, Spain tel. +34 58 279508, fax +34 58 207662
Green Bank	NRAO, P.O. Box 2, Green Bank, WV 24944, USA, tel. +1 304 4562011 fax +1 304 4562271
Grenoble	IRAM, Voie 10 Domaine Universitaire de Grenoble, 38406 St. Martin d'Heres Cedex, France, tel. +33 76 824900, fax +33 76 515938
Guadalajara	Centro Astronomico de Yebes, Apartado 148, 19080 Guadalajara, Spain tel. +34 11 290311, fax +34 44290063
Hawaii	Joint Astronomy Centre (JAC), 660 N. A'ohoku Place, University Park, Hilo Hawaii 96720, USA, office: tel. +1 808 9613756, fax +1 808 9616516
	JCMT, (See Joint Astronomy Centre) Telescope: tel. +1 808 9350852, fax +1 808 9355493
	UKIRT, (See Joint Astronomy Centre) Telescope: tel. +1 808 9616091/9354690
Haystack	Haystack Observatory, NEROC, Route 40, Westford, MA 01886, USA tel. +1 617 692 4765, fax: +1 617 981 0590
Helsinki	Helsinki University of Technology, Metsahovi Radio Research Station, Metsahovintie 114, SF-02540 Kylmala, Finland, tel. +358 0 264831, fax +358 0 264531
Jodrell Bank	University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire SK11 9DL, England, tel +44 477 571321, fax +44 477 571618
Kashima	Kashima Space Research Center, 893-1, Hirai, Kashima-machi, Ibaraki 314, Japan tel. +81 299 821211, fax +81 299 844128
La Laguna	Instituto de Astrofysica de Canarias (IAC), Camino de la Hornera s/n, E38071 La Laguna, Tenerife, Canarias, Spain, tel. +34 22 262211, fax +34 22 605210

La Palma	Observatorio del Roque de los Muchachos, Isaac Newton Group of Telescopes, office: RGO, Apartado de Correos 321, 38780 Santa Cruz de La Palma, Prov. de Tenerife, Canarias, Spain, tel. +34 22 411005/411048/411049, fax +34 22 414203 INT tel. +34 22 405655, fax: +34 22 405646 WHT tel. +34 22 405560, fax +34 22 405566 Residencia tel. +34 22 405500, fax +34 22 4055501
Meudon	Observatoire de Paris, Section de Meudon, Place Jules Janssen, 92195 Meudon Cedex, France, tel. +33 1 45077934, fax +33 1 45077469
Moscow	Astro Space Center (ASC), Profsojuznaja 84/32, Moscow 117810, Russia tel. +7 095 333 2189, fax +7 095 333 2378
Mountain View	SETI Institute, 2035 Landings Drive, Mountain View, CA 94035 USA Tel: 00 1 415 961 6633 Fax: 00 1 415 961 7099
München	ESO, Karl Schwarzschildstrasse 2, 85748 Garching (bei M¸nchen), Germany, tel. +49 89 320060, fax: +49 89 3202362
Nançay	Station de Radioastronomie de Nançay, 18330 Neuvy sur Barangeon, France tel. +33 48 518241, fax +33 48 518318
Onsala	Onsala Space Observatory, S-43992 Onsala, Sweden, tel. +46 317 725500 fax +46 317725590
Pasadena	California Institute of Technology (Caltech), Astronomy Dept. 10524, 1201 E. Calif. Blvd., Pasadena, CA 91125, USA, tel. +1 818 356 4009 fax +1 818 795 1547
Penticton	Dominion Radio Astrophysical Observatory, P.O. Box 248, Penticton, British Columbia, V2A 6K3, Canada, tel. +1 250 493 2277, fax + 1 205 493 7767
Shanghai	Shanghai Observatory, Chinese Academy of Science, 80 Nandan Road, Shanghai, China, tel. +86 21 4386191, fax +86 21 4384618
Socorro	Array Operations Center, P.O. Box 0, Socorro, NM 87801, USA, tel. +1 505 835 7000, fax +1 505 835 7027 VLA-Site, P.O. Box 0, Socorro, NM 87801, USA, tel. +1 505 772 4011 fax +1 505 772 4243
Swindon	Particle Physics and Astronomy Research Council (PPARC), Polaris House, North Star Avenue, Swindon Wiltshire SN2 1ET, United Kingdom tel. +44 793 442089, fax +44 793 442106

Torun	Torun Radio Astronomy Observatory, Uniwersytet Mikolaja Kopernika, ul. Chopina 12/18, PL 87-100 Torun, tel. Inst. +48 5626018/10, Obs. +48 5611655, fax +48 56 11651
Wettzell	Satellitenbeobachtenstation Wettzel, D 93444 Koetzting, Germany, tel. +49 9941 6031, fax +49 9941 603222

Abbreviations

AAT	Anglo Australian Telescope
AIPS	Astronomical Image Processing System
ASTRON	Stichting Astronomisch Onderzoek in Nederland
ATNF	Australia Telescope National Facility
BAO	Beijing Astronomical Observatory
Caltech	California Institute of Technology
CRAF	Commission on Radio Astronomical Frequencies
CSIRO	Commonwealth Scientific & Industrial Research Organization
DAS	Dwingeloo Autocorrelation Spectrometer
DCB	Digital Continuum Backend
DIMES	Delft Institute for Micro electronics and Submicron Technology
DLB	Digital Line Backend
DOT	Dutch Open Telescope
DRAO	Dominion Radio Astronomy Observatory
DSP	Digital Signal Processing
DXB	Extended Digital Line Backend
ESA	European Space Agency
ESF	European Science Foundation
ESO	European Southern Observatory
ESTEC	European Space Research and Technology Centre
EVN	European VLBI Network
FITS	Flexible Image Transport System
IAC	Instituto de Astrofysica de Canarias
IAU	International Astronomical Union
ING	Isaac Newton Group of telescopes
INT	Isaac Newton Telescope
IUCAF	Inter Union Commission for the Allocation of Frequencies
JCMT	James Clerk Maxwell Telescope
JIVE	Joint Institute for VLBI in Europe

JKT	Jacobus Kapteyn Telescope
JPL	Jet Propulsion Laboratory
Jy	Jansky
MFFE	Multi Frequency Front Ends
MIT	Massachusetts Institute of Technology
MOST	Molonglo Synthesis Telescope
MPIfR	Max Planck Institut für Radioastronomie
NAIC	National Astronomy and Ionosphere Center
NASA	National Aeronautics and Space Administration
NCA	Nederlands Comité Astronomie
NCRA	National Centre for Radio Astrophysics
NFRA	Netherlands Foundation for Research in Astronomy
NIKHEF	National Institute for Nuclear Physics and High Energy Physics
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
OSURO	Ohio State University Radio Observatory
OVRO	Owens Valley Radio Observatory
PATT	Panel for Allocation of Telescope Time (UK/NL)
RUG	Rijks Universiteit Groningen
RUL	Rijks Universiteit Leiden
SEST	Swedish ESO Submillimetre Telescope
SETI	Search for Extraterrestrial Intelligence
SKAI	Square Kilometer Array Interferometer
SRON	Space Research Organization of the Netherlands
STScI	Space Telescope Science Institute
TNO	Toegepast Natuurwetenschappelijk Onderzoek
UGC	Uppsala General Catalog
UKIRT	United Kingdom Infrared Telescope
URSI	Union Radio Scientifique International
UU	Universiteit Utrecht
UvA	Universiteit van Amsterdam
VISIR	VLT Imaging and Spectroscopy in the Infra-Red
VLBI	Very Long Baseline Interferometry
VLT	Very Large Telescope
VU	Vrije Universiteit Amsterdam
WENSS	WEsterbork Northern Sky Survey
WHT	William Herschell Telescope
WSRT	Westerbork Synthesis Radio Telescope

Netherlands Foundation for Research in Astronomy

Radiosterrenwacht Dwingeloo
P.O. Box 2
7990 AA Dwingeloo
Tel: +31 (0)521 595100
Fax: +31 (0)521 597332
E-mail: SECRETARY@NFRA.NL
Internet: www.nfra.nl

Radiosterrenwacht Westerbork
Schattenberg 1
9433 TA Zwiggelte
Tel: +31 (0)593 592421
Fax: +31 (0)593 592486

NFRA