The SKA Technical R&D program at NFRA
Arnold van Ardenne (NFRA)

From time to time in this Newsletter we have reported on various of our technical activities relevant to the SKA project. Here we present a more or less complete overview of our program in this area as it stands now.

The challenge

In the early nineties a desire to observe the 21 cm line of neutral hydrogen in galaxies like our own out to redshifts of 2-4, led to the plan of building a next generation radio telescope with sub-microjansky sensitivity. Setting up a program to tackle the challenge of creating an instrument that is almost two orders of magnitude larger than any radio telescope today, is by no means easy. After a series of preliminary studies, NFRA started a program in 1995 to seriously address the many questions that need to be answered to demonstrate the technical feasibility of such an ambitious plan.

Right from the start, guidelines regarding the capabilities of what we will refer to as the Square Kilometer Array (SKA for short) were already apparent. Not only should SKA probe the Universe with unprecedented sensitivity, but its use as a cosmological instrument makes continuous frequency coverage of at least a decade from approximately 200 MHz to 2 GHz a necessity. Sub-microjansky sensitivity then determines that the telescope should have a total collecting area of roughly one square kilometer. By balancing the demands of uv-coverage and size of the primary beam, one soon arrives at a configuration as an array of at least 30 interferometer stations. Exact details of the optimum configuration for high quality imaging, with both sufficient resolution and brightness sensitivity for unresolved sources, has not yet been settled but will be decided in due course based upon scientific priorities.

At NFRA, the decision was taken early on to develop the concept of the phased array antenna. A radio telescope built on that principle has no moving parts; tracking and beam forming are done electronically. The development of such a telescope can profit from the extremely fast technological progress in the areas of micro-electronics, signal processing and computing. Electronic beam control would also add enormous flexibility. With a phased array radio telescope it is possible to provide simultaneously multiple beams in different spatial directions as well as much reduced sensitivity to electromagnetic interference. Apart from allowing multiple observations to be carried out in parallel, it has been suggested that simultaneous multibeaming on different pulsars may provide exotic new scientific possibilities – such as using the timing of large numbers of pulsars to detect gravity waves!

The concept of phased array antennas is not new to radio astronomy. Active electronic control of the (synthesized) beam direction is done in all aperture synthesis radio telescopes. In these instruments, the individual telescopes are widely spaced in terms of wavelength and therefore many grating lobes appear in the beam of a single telescope. In the traditional phased array, the aperture consists of closely packed elements at typical distances of between half and a single wavelength, arranged either in one, two or even three dimensions (as in the case of...
The planning and objectives

A timescale for the realization of a project as large as building the Square Kilometer Array is likely to be at least 15 years, i.e. completion around 2010. In 1996, funding was secured for the majority of a four year technical R&D program. Its aim is to perform a feasibility study of the phased array approach, to select the appropriate technologies and address the cost issue as an integral part of the functional design. In addition to a long-term parallel technical research effort, this phase consists of three development programs aimed at guiding the system design and providing a sound understanding of needs and solutions, at least in principle.

If successful, a subsequent period of five years will be devoted to the development and building of one or more prototype array antennas. In terms of the SKA terminology, this is equivalent to a single station. (See Figure 3, for a definition of the terms used to describe the various elements of the telescope.) This station telescope could be a successor, or addition to the Westerbork array and therefore be located at (or near) the present site. Or it could be a collaboration with other interested groups and be located elsewhere. It will in any case be a functioning telescope and will serve to provide real experience observing with the new capabilities. As in the first phase, parallel technical research for the purpose of the construction phase will continue.

The third phase will almost certainly be an international enterprise. At this moment, there is no clear indication of siting possibilities or of the organization that will run and operate the telescope. The emphasis of the technical research program in phase three will lie in the first 3-5 years of the total 5 - 7 year timespan.

In order to allow NFRA to remain involved in the development of instruments in the optical and mm-wave regions, the internal structure of the institute has been adapted to ensure that these efforts can be maintained at the agreed levels. Recruitment of new staff in key areas for the Square Kilometer Array has broadened the technology base, but the team currently working on the various projects will only be at full strength upon completion of the upgrade of the Westerbork array (now expected to be fully operational in 1999). Fortunately, in particular the new low frequency observing capability of the WSRT offers an excellent testbed for Radio Frequency Interference (RFI) research, which is also important for SKA. Experience gained throughout the upgrade of the WSRT provides an excellent point of reference of today’s capabilities.

In this first phase of R&D several interesting perspectives have presented themselves, which are all likely to have a major impact on the system design. From an astronomer’s point of view, the need to remove strong sources in order to see the faint sources creates the demand for an ultra-sensitive telescope with a dynamic range in the synthesized and calibrated map of the order of $10^{-5}$. The translation of this specification imposes important, but as yet not fully known constraints on the design. In order to bring down costs, a high level of integration is likely to feature heavily in the final designs.

The hierarchy of elements that make up a station in the Square Kilometer Array. On the left, the names of various instruments, at the appropriate level.
An antenna and receiver engineer will look at SKA from the point of view of at least a decade of frequency bandwidth, its demands for sky coverage, dual polarization, low noise and RFI-suppression. The demand for a high level of integration soon becomes rather compelling if only for cost reasons. This is easily understood, because in order to achieve a collecting area of a square kilometer at 2 GHz, over $10^7$ receiving elements are required. A high level of integration is likely to have a major impact on the degree to which a completed telescope can later be upgraded. The issue of power consumption also creeps in and leads one to consider low voltage/low power concepts.

From a signal processing point of view, there is the need to translate the (maximum of) $10^7-10^8$ input signals to the number of beams (of order $10^4$) that are subsequently to be correlated. Finding the optimum (hierarchical) architecture is not trivial and detailed simulation of this process will be essential. In fact, for many reasons there is the need for an end-to-end simulator that can be used to model the telescope all the way from an input distribution of sources on the sky to the final reduced data set. The description of a telescope by (an evolution of) the "Measurement Equation", now being implemented in AIPS++, will contribute to this effort.

### The R&D-phase I (1996-2000)

NFRA’s first R&D phase involves the prototyping of a series of three adaptive arrays with increasing size and complexity regarding the level of integration. Each instrument is to be built over a one and a half year period in parallel with a number of research programs with longer time horizons.

The three development programs differ by an order of magnitude in complexity as measured by both the increasing number of elements and by the technology level. The first step is the Adaptive Array Demonstrator (AAD) which consists of 8 active elements. The next step is the One Square Meter Array (OSMA) with about 64 active and 80 passive elements. The third fully planned step is the Thousand Element Array (THEA), which will consist of 1024 elements. The objectives of each phase are summarized in the table.

At this stage funding has not yet been fully secured for the next step, the Proof of Principle Array (POPA) which we see as the first prototype antenna that will be capable of serious astronomical observations. The various phases of the R&D

<table>
<thead>
<tr>
<th>System</th>
<th>Delivery</th>
<th>Concept</th>
<th>Main Aim</th>
<th>Technology</th>
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<tbody>
<tr>
<td>AAD</td>
<td>April 1997</td>
<td>8 element array</td>
<td>Adaptive DBF Infrastructure</td>
<td>Commercial components</td>
</tr>
<tr>
<td>OSMA 1m² model</td>
<td>November 1998</td>
<td>64 element array</td>
<td>Dual Beam</td>
<td>Commercial DBF ASIC</td>
</tr>
<tr>
<td>THEA 4x4 m model</td>
<td>Q1 2000</td>
<td>1024 elements</td>
<td>RFI environment</td>
<td>In-house developed RF PCB's</td>
</tr>
<tr>
<td>POPA 10x10 m array</td>
<td>2001-2002</td>
<td>$10^4$ elements</td>
<td>Station in an aperture</td>
<td>Low cost antenna technology</td>
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<tr>
<td></td>
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<td>synthesis telescope</td>
<td>Integrated LNA's</td>
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<td></td>
<td></td>
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<td>20 MHz video bandwidth</td>
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Table 1: Instruments, concepts, aims and technology currently defined in Phases I-II of NFRA’s SKA R&D program.
AAD – The Adaptive Antenna Demonstrator

The Adaptive Antenna Demonstrator is the first development step in the R&D program. Its main aim is to gain experience in the use of a digital beamformer and to demonstrate the adaptive nulling of an interferer. AAD’s receiving array consists of microstrip antennas with 15% bandwidth arranged in a 2x4 regularly spaced grid. The entire system uses commercial components, although the adaptive digital beamformer (ADBF) (where the received signals are multiplied with complex weights) runs on an application specific integrated circuit (ASIC). The complex weights are computed using an adaptive minimum variance algorithm implemented on a TMS320 C30 digital signal processor. AAD operates at 5.3 GHz, with an instantaneous bandwidth of 4 MHz. The update rate of the beamformer is limited to about 40 msec. AAD is installed in the Antenna Measurement Setup (AMS) which includes an on-axis transmitting source and an off-axis fixed interferer. AMS is set up in our anechoic antenna test chamber and is suitable for antenna measurements between 1.5 and 20 GHz. AAD only has a single ADBF because it is a single beam system. The setup is shown in Figure 4 and an illustrative example of the suppression that was achieved in Figure 5.

Figure 5: Suppression of an interfering source with AAD.

Figure 6: Layout of the OSMA antenna panel. On the right, a schematic diagram of the beamforming options available in OSMA.
Figure 7: The effect on the size of the OSMA beam of the number of antenna elements that are combined.

OSMA – The One Square Meter Array

OSMA is the next step, and is currently being completed. The receive array consist of 64 active elements surrounded by 80 passive elements. Embedded in the panel are four calibrating elements, one on each side. In order to work towards the desired frequency range for the phased array solution for the Square Kilometer Array, while still being able to perform the measurements in the AMS, this array will operate at lower frequencies. OSMA represents a tile in the hierarchy as defined in Figure 3. Broadly speaking the antenna elements can either be configured in a plane (“broadside array”) as shown in Figure 6 using bow-ties as antenna elements or with the elements orthogonal to the receive direction (“endfire array”). Antenna element like the bow-tie have a much wider bandwidth than those used for AAD. It now seems clear that a decade in bandwidth can be covered by three elements, each with 1:2.5 bandwidth but centered at increasing frequencies.

OSMA will not be optimized for low noise and frontend integration but is tunable over a wide range. Optimum performance is possible in the range from 1.5 to 3.5 GHz and with slight pattern degradation of the combined beam, even up to 4 GHz. OSMA has a number of different beamforming capabilities (see Figure 6). In the first radio frequency beamformer (RFBF1) the signals of four neighbouring antenna elements are combined using amplitude and phase control. At this stage the signal is fed to different second stages. A second true-time delay RF beamformer combines the output of four first stage beamformers. As it is the intention to form two independently controlled beams (compared with only a single beam in AAD), there are 8 second stage beamformers. The output of each first stage beamformer is also fed to the two adaptive digital beam formers (ADBF) in parallel to the second stage RF beamformer.

The beamforming algorithm is to be implemented in a silicon ASIC, as a Cordic algorithm, developed in collaboration with the Technical University Delft. In principle this implementation should allow update rates of about 10 msec using a different algorithm than was used in AAD. The new ADBF unit gives much more flexibility as it is also equipped with a DSP in which other algorithms can be tested.

The control will be through a user friendly interface as part of the versatile Experimental Chassis for OSMA (ECHO). ECHO allows easy configuration, data collection and control of measurements with the array in its development environment.

The entire system will be ready for commissioning and tests in the final quarter of this year. At the time of writing we can only give the first results of the proper operation of the RF-beamformers. These show a calibrated scan over 10 degrees using four antenna elements and a second beamformer with true time delay beam steering. The agreement with theory is excellent.

THEA – The Thousand Element Array.

Preparations are also well under way for the third step: the thousand element array (THEA). The project will start in September 1998 and is expected to be completed in the first months of 2000. Although still primarily intended as a development project, not optimized for lowest noise, one of its main objectives is to demonstrate outdoor operation, observing the first real astronomical sources in a realistic RFI environment. The array will consist of 16 reconfigurable “tiles” and will measure about 4x4m in total. Although of limited astronomical use, observations will be possible using two independent beams and an on-line calibration system.

With THEA, the emphasis will be on a higher level of integration than was the case for OSMA but for a lower production cost. It is expected that the integrated cost (i.e. including manpower) per element will come to about 3k$ i.e. 10 times lower than for OSMA and about 65 times less than for AAD. Although this figure is still far from being acceptable for a large array, the downward trend is very promising and based on present insight there is no reason why this cannot continue in the future for even larger arrays.

Although no definite plans have yet been made, the present scope of THEA does not exclude the possibility of combining an adapted version of THEA with the Westerbork array. In that case a real synthesis observation can be done thereby achieving an important milestone!
local measurements, a total RFI-dynamic range of some 10
and important implications regarding integratability. Based on
eration is being given to the idea that high impedance match-
• As part of the RF/IF architectural studies for SKA, consid-
erations were intended for the upgrade of the Westerbork IF system.
an active upconverter for a band around 200 MHz up to 2GHz
together with an I-Q downconverter mixer. Both functions were
intended for the upgrade of the Westerbork IF system.
• As part of the RF/IF architectural studies for SKA, consid-
eration is being given to the idea that high impedance match-
ing, e.g. to the antenna, has advantages in power consumption
and important implications regarding integratability. Based on
local measurements, a total RFI-dynamic range of some $10^{13}$.
$10^{15}$ is required for good mapping, but this may conflict with
the desired low voltage implementations. This is an area of
active investigation both at NFRA and at other institutes.
• Some trade-offs as part of the study program need to be
mentioned as well. As today’s lowest noise is achieved using
GaAs or InP technology, frontend integration in those tech-
nologies (Monolithic Microwave Integrated Circuits or
MMIC’s) is worth studying which is being done in Australia
at CSIRO stimulated by ATNF. These technologies offer
the potential of integration with optical functions (see below) but
power consumption and cost may be serious stumbling blocks.
New low noise silicon technologies, now being developed else-
where, may turn out to be serious competitors as electronic
integration of both analog and digital functions are possible
in very low power implementations. NFRA is involved in study
programs together with the Technical University in Delft in the
area of silicon technologies.
• As a step towards a more integrated A/D converter we have
integrated a dual channel 2-bit converter with 40 MHz clock
into a single chip. The equivalence performance is of a dual
channel 12 bit converter. A next step entails studies of other
architectures implying different functional designs as part of
the A/D research work.
• The implementation of suitable algorithms in silicon i.e. IC’s
in a DSP environment are also a topic of study. These so-called
spatio-temporal algorithms should be RFI robust as well as
being able to preserve a well known or calibratable adaptive
beam. No satisfactory solutions have yet been found but this
work could be part of the end-to-end simulation environment
mentioned earlier. NFRA has an active research program with
the Technical University in Delft in the area of RFI suppres-
sion techniques.
• The implementation of optical functions in the signal trans-
port and processing chain needs to be mentioned. So far, we
have only talked about electronic-only implementations, but
after a wide-ranging technology assessment study, it has be-
come clear that so-called RF-photonic and optical processing
functions deserve serious attention. The SKA implementation
have only talked about electronic-only implementations, but
after a wide-ranging technology assessment study, it has be-
come clear that so-called RF-photonic and optical processing
functions deserve serious attention. The SKA implementation
requires coherent systems for example in the distribution of
local oscillator or reference clocks. This last application is
now also part of the study for the MMA/LSA, opening an
excellent opportunity for cross benefit. NFRA is in the proc-
cess of establishing a number of studies with the Technical Uni-
versity in Eindhoven, which is the core competence centre in
this field in the Netherlands.

**Recent developments**

In the course of the meetings held so far by URSI’s Large
Telescope Working Group, a huge number of scientific possi-
bilities have been brought up. As a consequence, the concept
of the Square Kilometer Array has developed from a decade
frequency coverage, that was part of the original NFRA plan
several years ago, to three decades. Technically, it is hard to
imagine a single instrument that can use the same principles
all the way from 20 MHz to 20 GHz. In the end SKA may well
be built as three instruments, possibly co-located and sharing
the same general infrastructure. A possible solution may look
like this:

<table>
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<tr>
<th><strong>Table 2: THEA System Specifications</strong></th>
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<tbody>
<tr>
<td>Number of array elements</td>
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<tr>
<td>Antenna area</td>
</tr>
<tr>
<td>Array grid type within tile</td>
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<tr>
<td>Polarisation</td>
</tr>
<tr>
<td>Number of reconfigurable RF tiles</td>
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<tr>
<td>Number of simultaneous (independent)</td>
</tr>
<tr>
<td>RF beams</td>
</tr>
<tr>
<td>Sensitivity (Ks=2, 10 sec integration,</td>
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<tr>
<td>breadthside )</td>
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<tr>
<td>Design frequency of antenna</td>
</tr>
<tr>
<td>Instantaneous (IF) frequency bandwidth</td>
</tr>
<tr>
<td>Electronic scan volume of main beam</td>
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<tr>
<td>Scan loss (additional to cos theta loss)</td>
</tr>
<tr>
<td>Beam width of RF beam (of single tile)</td>
</tr>
<tr>
<td>Cross polarisation level</td>
</tr>
<tr>
<td>RFI suppression w.r.t. received source</td>
</tr>
<tr>
<td>signal</td>
</tr>
<tr>
<td>* Element pattern at horizon</td>
</tr>
<tr>
<td>* with RF beamformer</td>
</tr>
<tr>
<td>* with digital beamformer</td>
</tr>
<tr>
<td>Max. number of simultaneous RFI</td>
</tr>
<tr>
<td>sources</td>
</tr>
<tr>
<td>Sidelobe level due to system errors</td>
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<tr>
<td>after calibration</td>
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</table>
• L-SKA would cover the “low band” between 20-200 MHz. At these frequencies, galactic noise dominates the receiver noise and hence the active antenna concept will be more cost effective. NFRA is at present conducting a technical pre-study for a low resolution low frequency array “LOFAR” (which will operate up to 350 MHz) in response to requests from the Dutch astronomy community. If this array is built, valuable experience would also be gained for the Mid-range array; for example with respect to calibration in a confusion- and side lobe noise limited environment including the effect of the ionosphere. 
• M-SKA would cover the “mid band” between 200-2000 MHz. This array could well be the array concept now under study by NFRA.
• The high band array H-SKA beyond say 1.8-2 GHz and up to 20 and may be even 40 GHz, can presumably best be covered with reflecting surfaces and fewer receivers. A concept mentioned at last year’s workshop in Sydney is that in part of a tile, say 1/3 of the area, the beam control is still done by array techniques but the surface reflects the waves into a single, possibly cooled, low noise receiver. Other solutions, including the use of paraboloids possibly combined with phased arrays, may be more obvious candidates and are being studied elsewhere, for example in the context of SETI.

Further reading:
Most of these references can be found at NFRA’s SKA web site: http://www.nfra.nl/skai

Message from the Director
Harvey Butcher

The past six months saw important developments on several fronts. Good news from our Minister caused a flurry of new planning activity at both our national graduate research school (NOVA) and at NFRA. Restructuring at our research council (NWO) required rethinking and readjustment of NFRA’s core program. Design was completed and construction begun of a prototype phased array “tile” to demonstrate our concept for the Square Kilometer radio telescope. In August, following many months of difficult negotiation, agreement was reached with IRIDIUM on the levels of interference to be caused by this satellite project’s down-links at European radio astronomy observatories. And in Westerbork, the phased installation and commissioning of the new cooled frequency agile receivers (as this Newsletter goes to press, 7 MFfE’s are operational), of the new back-end correlator system, and of new control and data acquisition software, as well as the program of major maintenance on the telescope, all continued on schedule for completion later this and early next year.

NOVA

At a stroke, the astronomical research landscape for the coming five years in the country has been transformed. On 29 April, the Minister of Education, Culture and Science announced that our graduate research school, NOVA (Nederlandse Onderzoekschool Voor Astronomie), will receive Mf 46 additional funding from university channels. NOVA is a country-wide cooperation that aims to provide top-level graduate education through participation in advanced research projects. With this new injection of funds it will be possible adequately to exploit several important new observing facilities, including the ESO VLT as it comes on-line, and to develop innovative instrumentation in new research areas. NFRA is not formally a part of NOVA, but we expect to play an important role in several of the instrumental projects, and planning activities to this end began just before the summer vacation. Projects under discussion include an upgrade to the PuMa pulsar back-end at the WSRT, a wide-field visible-IR imaging camera for use on La Palma, a multi-object fiber spectrometer for the VLT (Australis), and auxiliary instrumentation for the ESO VLT IIR-interferometry program.

Restructuring

The government reaffirmed its policy intention formally to separate responsibilities for the operation of research facilities from that for making decisions on the funding of science. NFRA operates observatories and supports a technical laboratory for developing new instrumentation, but also has responsibility for the university grants program in astronomy, which frequently does provide financing for the scientific exploitation of the observatories and of our laboratory. We are therefore a prime candidate for surgery in the proposed restructuring. While final decisions have not yet been taken - national elections were held in May, a new coalition government was formed in August, and the full extent of science policy evolution should be evident in the course of the autumn - the general contours of policy are unlikely to change, and NWO notified us in April of its intention to complete at least a first phase of reorganization by the end of the year. The main lines of this operation as it affects NFRA will be as follows.

The university grants program will become part of a much broader competition involving both university groups and national laboratories such as NFRA, that will also cut across the disciplines of physics, mathematics, computer science and...
astronomy. Evidently our basic budget will be reduced such that structural financing will be the minimum necessary to operate our observing facilities and maintain the core of our technical laboratory. Financing for instrumental and scientific projects will have to be won in the competitive arena or found outside the normal funding channels of the research council. Coordination and administration of the competitions will move to a central office at NWO in the Hague. The next deadline for submission of grant applications is projected to be in February 1999.

In recent years we have had considerable difficulty handling exchange rate variations in the financing of the island observatories (on La Palma and Hawaii). In the proposed future funding model, island operations will be decoupled from the rest of NFRA’s program and administered as a separate activity through NWO’s central programs office in the Hague. NFRA’s future involvement with the Isaac Newton Group and with the JCMT will focus principally on instrumental projects proposed by Dutch university researchers and funded externally to NFRA’s basic budget.

The net result of these changes is that NFRA’s core program in future will involve operating the Radio Observatory and running our Technical Laboratory. The former is expected to be financed largely from our base budget and will include support for the European VLBI Network, Joint Institute for VLBI in Europe, and the European Science Foundation’s radio spectrum management secretariat. Our Technical Laboratory will have to rely on an increasing extent on incidental financing, with the level of external funding increasing to some 30% of the budget. Its program will remain (i) development of the technologies needed for the Square Kilometer Array radio telescope, and (ii) carrying out ad hoc instrumental projects in support of Dutch university research needs. Our base budget will be reviewed by NWO in the course of next year with a view to possible revision from fiscal year 2000.

**Status of instrumental projects**

In addition to the new funding for instrumental development through NOVA, several other instrumental projects have been funded recently. On 11 May, NWO approved a request for Mf 3.5 to develop a new IF-to-Video Conversion unit for the WSRT (the IVC project). This project will increase the instantaneous system bandwidth to the full 160 MHz available with the new front-end receivers. It will make spectral line surveys in redshift space as wide as and multi-band continuum surveys possible (rotation measure mapping, searches for rapid variables, etc). Plans are to have much of the construction work carried out in industry.

During the spring, NWO’s Area Council for the Physical Sciences approved a special grant to start development of auxiliary instrumentation for Utrecht University’s Dutch Open Telescope on La Palma. The DOT now regularly achieves diffraction limited (~0.2 arcsec) imagery of the solar surface at visible wavelengths. Plans are now to study possible instrumentation optimized for investigating the physics of convection in the solar photosphere.

The VISIR (Visible Imager and Spectrometer for the mid-IR) project for the ESO VLT is in the phase in which critical areas are modeled and critical components prototyped. During the spring, the mass and thermal model for the spectrometer (for which we are primarily responsible) was completed. A test setup was produced to permit laser interferometer surface quality measurements during component cool-down (from room temperature to 60 K), thereby locating regions of high temporary stress, demonstrating acceptable optical performance at operating temperature, and permitting the development of alignment procedures at room temperature. Upgrades to optical lab facilities were also completed to permit polishing and testing not only of metallic aluminum but also cadmium-telluride and germanium optics. The project is on course for a Final Design Review in February 1999.

PuMa (Pulsar Machine) is the new 20 GFLOP pulsar backend for the WSRT, based on arrays of ADSP 21062 SHARC DSP’s. It has been designed and built during the past two years under the leadership of Dr. Paul van Haren at the Instrumentatie Groep Fysica of the Utrecht University. Delivery and installation of the first half unit in Westerbork took place just before the summer, and high quality performance was demonstrated almost immediately. Early results are presented elsewhere in this Newsletter. The rest of the back-end is expected during the fall and regular observations with the complete system should be possible by the year’s end. On behalf of all of us at NFRA, as well as the pulsar groups in Amsterdam and Utrecht, congratulations to Paul and his IGF team for a job well done!

Because the step to a Square Kilometer radio telescope is large, it clearly will be advisable to build and gain experience with an interim telescope based on the new technologies being developed. George Miley of the Leiden University has proposed that such an instrument could be a low frequency array, which he calls LOFAR (an imaginative contraction of “Low Frequency Array”). In this case, low frequency refers to the 20 - 350 MHz region, in which the sky has been explored only at very low angular resolution. LOFAR science would focus on achieving confusion limited, wide field imaging and multiple beam operation with angular resolutions of several arcsec. This would for the first time permit complementary and reliable follow-up observations with other ground- and space-based facilities. Locating objects in the early Universe is George’s primary interest, but new science could be expected in a variety of other fields as well. At NFRA a pre-feasibility study was carried out during the spring and summer, which showed that the desired performance might be achieved with some 10,000 dipoles clustered in antenna stations spread over an area that is about 2,000 km in diameter. Excellent use of the new technologies is possible, especially as regards adaptive, broad-band, integrated antenna architectures. In the preliminary design active antenna elements are sparsely spaced to compensate for the strong wavelength dependence of the foreground galactic emission that determines the noise performance in these bands. The advanced capabilities of the aips++ environment permit calibration of the system in the presence of strong ionospheric “seeing” as well as provide a platform taking account of beam shape variations inherent in adaptive arrays. Signal transport over long distances remains as an important area of further investigation. As this Newsletter
Square Kilometer Array: SKA1 loses its I

Each year the URSI Large Telescope Working Group and the international consortium of institutes cooperating on R&D hold a meeting to discuss the science that might be accomplished with a Square Kilometer radio telescope. This year’s meeting was held on 20 - 22 July in Calgary, Canada. Highlights included new simulations of observations at two meter wavelengths of the process of re-ionization in the early Universe. Arguments were also presented that understanding the process of star formation will require observations at centimeter wavelengths with 100 times the sensitivity of current telescopes, so that the effects of magnetic fields can be determined empirically and velocity fields can be observed in cold collapsing clouds that are optically thick at shorter wavelengths due to dust. It was agreed to extend and edit the available draft Science Case document and to widely distribute it early in the new year.

To date each country investing significant resources in R&D has employed its own name for the project - 1kT in Australia, SKA in Canada, KARST in China, SKAI in the Netherlands, and so on. This seemed appropriate because the R&D generally involves different technical concepts. But in Calgary it was argued that the project will soon move into the broader arena of astronomical decision making, especially in the USA, to be considered together with proposals for many other future facilities. To avoid any possibility of confusion it was agreed that a single name should be used in all discussions of the project, regardless of the technical concept being studied. Those assembled in Calgary favored the use of the name “Square Kilometer Array” radio telescope, SKA for short. A final decision will be taken soon, but we anticipate that the Calgary decision will stick.

NFRA’s own R&D is focussing on the development of broadband, highly integrated (phased array) antenna’s. The basic construction unit in this concept is a “tile”, an integrated phased array panel that can readily be coupled to other tiles to form larger antennas. The design of a prototype tile, an 8x8 element array that we are calling OSMA (One Square Meter Array) was completed during the spring and construction begun. As described elsewhere in this Newsletter, we expect to complete construction by year’s end and carry out the test program during the first quarter of next year. The new year will also see development of a multi-tile prototype, the Thousand Element Array, THEA, now scheduled for completion early in 2000.

Global telecommunications and Radio astronomy

Regular readers will be aware that NFRA currently hosts the secretariat of the European Science Foundation’s Committee on Radio Astronomy Frequencies (CRAF). This office serves as the center for radio spectrum management for astronomy in Europe; Titus Spoelstra is CRAF secretary and spectrum manager. Over the past year most of the office’s effort has been expended on negotiations with national administrations and with Motorola’s IRIDIUM project, often supported by other CRAF members and recently by Willem Baan, the WSRT’s new director and chairman of the Commission on Frequency Allocation for Radio Astronomy and Space Science (IUCAF). The IRIDIUM project involves a constellation of 66 telecommunications satellites in low Earth orbit, that from September will provide mobile telephone service with nearly global coverage.

The issue at hand concerns the choice by IRIDIUM not to observe the internationally agreed regulations concerning interference to other users of the radio spectrum. As explained elsewhere in this issue, from this month the down-link signals from IRIDIUM will seriously compromise observations in the 1612 MHz band (OH at zero redshift). These very difficult negotiations have finally led to an agreement, signed in mid-August by the ESF and by IRIDIUM, that should help make radio astronomy in the 1612 MHz band possible at least some of the time.

On behalf of radio astronomers all across Europe, I would like to express heartfelt thanks to Titus and his CRAF and IUCAF colleagues for their heroic efforts in achieving an agreement that will be an important precedent in licensing procedures for other planned satellite systems.

Personnel

I cannot conclude this Message without a few words concerning three important personnel changes at NFRA.

This spring Hans Kahlmann handed over the reins in Westerbork to Willem Baan. Hans will not be leaving us right away, but will continue to contribute to our studies of how to minimize man-made interference. Hans joined NFR in January 1976 as Head of the Telescope Group. He came from Royal Dutch/Shell with a strong background in geophysics and instrumentation for seismological measurement. His first year saw installation of telescopes C and D in Westerbork, as well as the first VLBI observations. The first digital line back-end correlator was installed and commissioned the following year, and a major maintenance operation was planned and carried out. Hans saw as few others the importance of becoming involved in the international decision making about allocating frequencies in the radio spectrum. He played a central role in having our currently reserved bands agreed at the World Radio Conference in 1979. During the 1980’s, most of our investment resources were spent on the island observatories and it became especially peaceful in Westerbork. Hans not only kept the facility running but developed a close and efficient team that could get the most from the telescope. As the 1990’s dawned, he joined with astronomers and engineers to plan and carry out the extensive modernization and upgrade now approaching completion. On behalf of WSRT users and colleagues, wherever they may now be, many thanks Hans for 22 years of service to our science.
From early in the fall, Wilfried Boland (currently NFRA's Adjunct Director) will be transferring to a new position at the research council, NWO. Wilfried came to NFRA in 1988 as Head of Administration, at the same time as the R in NFRA changed its meaning from Radio to Research and the organization expanded its activities far beyond radio astronomy. He has been responsible for a broad range of activities but in particular for our university grants program and in recent years for our participation in the island observatories. He has seen the organization through three restructurings and has overseen implementation of modern management practice in both personnel and finance sections. His departure will leave a gaping hole in Dwingeloo, but we are reassured to note that he will remain involved in promoting the interests of astronomy at NWO, in particular by continued involvement in the grants program and in helping organize the new activities at NOVA from the NWO side. We wish you all the best in your new situation, Wilfried.

And on 1 July, René Rutten formally assumed the position of Director, Isaac Newton Group, on La Palma. He has been acting in the position for about a year and will be guiding the observatory through major changes brought about by reorganization of the British research council’s (PPARC) operations in the UK. On behalf of the Dutch community, congratulations on your appointment and our best wishes as you take up the challenge ahead!

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RFI Policy, Monitoring and Treatment

Willem Baan (NFRA)

Spurious signals in radio astronomy observations have become a fact of life. Anyone who has followed developments in the telecommunications world will realize that the situation is quickly set to become worse. A significant amount of effort at NFRA is going into trying to monitor matters and to develop strategies for anticipating and for dealing with the new threats. This article gives a brief overview of these activities, and summarizes in particular the state of play relating to the first of the coming constellations of telecom satellites in low Earth orbits, the IRIDIUM project.

Background

Decisions regarding the allocation of the radio spectrum are taken at World Radio Conferences (WRC’s), held about every 2-3 years. These conferences are organized by the International Telecommunications Union (ITU), a specialized agency of the United Nations. Agreements reached at the WRC’s have the status of International Treaty, and are ratified by the governments of the countries participating in the ITU. In Europe, spectrum management issues are coordinated by the CEPT (Conférence Européenne des Postes et Télécommunications). Astronomical spectrum management interests are represented by a number of organizations: IUCAF (the Commission on Frequency Allocation for Radio Astronomy and Space Science), is a global organization sponsored by the IAU (International Astronomical Union), URSI (International Union of Radio Science) and COSPAR (Committee on Space Research). Regional committees, such as the European Science Foundation’s CRAF (Committee on Radio Astronomical Frequencies), and the USA/North American CORF (Commission on Radio Frequencies) are also actively involved in protection of radio spectrum bands used by Radio Astronomy and other passive users (defined as those who receive signals that can not be manipulated by man).

Developments and Trends in Spectrum Management

The regulations themselves consist of a list of frequencies and primary allocations to a particular service. Secondary allocations and notifications of use are also included, but these do not provide for protection from harmful interference caused by primary users in the same band. Infringements of the regulations are generally resolved in the country where the victim resides. The ITU Radio Regulations, which in most countries have the status of international treaty, binds the signatories to take action when asked to do so. Radio astronomy has less than a percent of the spectrum below 30 GHz as primary and exclusive allocation for passive use. Another two percent are shared primary and secondary allocations.

Certain parts of the spectrum (below 10 GHz) are beginning to get full with users, while the spectrum between 1 and 3 GHz is already seriously congested. Much of the congestion and many of the unfulfilled spectrum demands are caused by old inefficient systems that take many years to be replaced. Re-farming (re-using) of the spectrum is a slow process and faces many interest groups.
The demand for high bandwidth and high data rate systems has generated much interest in higher frequencies (up to 50 GHz). High-Density Fixed Service applications are being designed to provide internet access to each home and even to children playing games in the back of the car. Balloon platforms above major cities (Sky Station), various satellite systems (SkyBridge and Teledesic-Celestri), and wireless local loop systems will provide a great variety of such services. The word “interference” is being used more frequently in spectrum management circles. Radio astronomers and the remote sensing community are no longer the only victims. Major coordination efforts are needed to phase-in applications that prevent interference to neighboring systems. Although the radio astronomy and remote sensing stations are still the most vulnerable, concerns among the passive science community are now shared by the emergency services and even medical applications.

Preparations for the Year 2000 World Radio Conference

Preparations for the WRC in the year 2000 are already in full swing and various members of the passive user community are actively involved in preparing positions for this meeting. The relatively short period between these conferences causes a large workload for the administrations and ITU Radiocommunication sector (ITU-R) members. IUCAF, together with CRAF and CORF, will produce position documents on the 12 or so Agenda Items that are of interest for the passive user community. Some of the agenda items relevant for the passive science user community include:

• The spectrum for remote sensing and radio astronomy above 71 GHz. For radio astronomy the IUCAF MilliMeter Working Group chaired by Phil Jewell (JCMT) and Masatoshi Ohishi (Nobeyama) has been active for more than a year to prepare documentation and recommendations for the astronomy use of the mm-wave spectrum. CEPT Project Team 33 has produced a draft allocation table based on the work of IUCAF MMWG and the ITU-R Working Party on Radio Astronomy.

• ITU-R Task Group 1-5 on Unwanted Emissions is working on an update of the standards for spurious and out-of-band emissions. Some of these standards did not exist until the last WRC, held in 1997, and even the new ones are based on technology from the seventies for use mainly below 1000 MHz. These “new” standards are known not to be adequate for the broadband and higher frequency applications that are currently being designed. The CEPT countries have taken the lead in designing much tighter standards and are strongly supported by terrestrial and space services industries in this effort, while other countries like the USA, strongly supported by their space industry, seem to oppose all progress.

On the preliminary agenda for the next WRC, to be held in 2002-2003, are discussions regarding the regions close to the protected neutral hydrogen 21cm line. Pressure is mounting from satellite services on this, for radio astronomy, so vitally important spectral feature.

The IRIDIUM Story…

It has been known for several years now that the planned Mobile Satellite Service (MSS) system IRIDIUM is likely to cause interference in the 1612 MHz band used for OH spectral line observations. Both IRIDIUM and its mother company, Motorola, have been aware of this since 1991. As a result of these concerns, the status of the radio astronomy band was upgraded at the WRC in 1992 to primary (in combination with a very strong footnote). The specific goal of this action was to protect the band from Mobile Satellite Service downlink emissions in the upper part of the 1610-1626.5 MHz band.

It took some time for IRIDIUM to recognize that they would have to protect radio astronomy. However, instead of preventing out-of-band transmissions, they proposed that astronomers run their system in the periods that IRIDIUM was relatively lightly loaded. Agreements along these lines have been made between the National Radio Astronomy Observatory (NRAO) and the National Astronomy and Ionosphere Center (NAIC).

Technical RFI Research and Development at Dwingeloo and Westerbork

In addition to the Spectrum Management activities, NFRA’s technical laboratory is involved in a number of different activities aimed at combating the effects of interfering signals. These include the following:

• Research on RFI-robust receivers is coordinated by NFRA as part of a Project on “Interference Suppression in Radio Astronomy Receivers” awarded to JIVE by the European Commission. This project comprises monitoring studies at Jodrell Bank, Noto, Effelsberg and Westerbork in the 50 MHz to 2 GHz range and developing new techniques to build receivers that operate in this same frequency range.

• NFRA has collaborated with scientists at the Technical University in Delft to develop and test High Temperature Super- Conducting Notch Filters, which provide the high-Q and low insertion loss systems. These filters will ultimately allow observations adjacent to strong signals as those from IRIDIUM.

• Plans are being implemented to improve the spectrum Monitoring Station at the WSRT. Enhancements will include making the system computer driven and remotely controllable.

• Various studies are under way to develop algorithms for digital processing of telescope data and to remove interfering signals. Plans are under way to try a digital signal processing solution on one of the WSRT antennas, similar to the method tested earlier in Russia at the Ratan 600 telescope.

• TV stations from the nearby Smilde transmitting tower have caused some inter-modulation problems for the new UHF-high and UHF-low receivers at the WSRT. Filters have been produced for the new Multi-Frequency Front End phase 2 systems that are currently being installed. Successful operation at UHF frequencies is possible and many new redshifted HI and OH lines have already been found during recent months.
in the USA and the main question for debate was how many hours would there be for science. Another proposal by IRIDIUM that astronomers use half the time of IRIDIUM’s 90 msec uplink-downlink cycle, was rejected by all radio astronomy negotiating teams. Similar negotiations have also taken place in Australia, Canada, Japan and India, but only in Australia has the administration issued a provisional license for IRIDIUM with a review in five years to evaluate the damage done to the radio astronomy operations in Australia.

During the first six months of 1998, a CRAFT team has negotiated with IRIDIUM representatives about an agreement that would open the door to obtaining a license to operate in Europe. The CEPT set up a special Milestone Review Committee (MRC) to discuss such issues and the IRIDIUM – Radio Astronomy debate was its first big case. After long and very difficult negotiations, a preliminary agreement between the ESF (on behalf of CRAFT and the radio astronomy observatories in Europe) and IRIDIUM was reached on July 7 and signed on August 11. Many administrations had been waiting for this agreement, as a precondition for issuing a license for IRIDIUM in Europe.

The ESF-IRIDIUM agreement makes three major statements on interference.
• IRIDIUM shall not interfere with Radio Astronomy operations from its start of operation on 23 September, 1998 until March 1, 1999 to the level of –238 dB(W/m²/Hz), which is taken from the harmful interference document ITU-R RA.769.
• IRIDIUM and CRAFT will have until 1 March, 1999 to reach a second agreement describing time sharing in the period 1 March, 1999 until 1 January, 2006.
• From 1 January, 2006 onwards IRIDIUM must again be below the –238 dB(W/m²/Hz) level.

The agreement contains some far-reaching stipulations for IRIDIUM and there is hope that the situation will improve after the current generation of satellites. Nevertheless, even with the level specified in ITU-R RA.769, there will still be considerable interference when a satellite passes through the main beam of the telescope. With a total number of 66 IRIDIUM satellites, it still means that about 8 percent of the time there will be interference to radio astronomy operations. This is more than any telecommunications company would accept as a drop-out rate for its system. Negotiations about the time-sharing conditions up until 2006 will start this fall and look set to be quite difficult.

The OECD

A recent phenomenon among governments is networking at the level of policy makers. Senior civil servants increasingly maintain formal and informal contacts with their counterparts in other countries, both to learn from each other and, when appropriate, to co-ordinate activities and policies to mutual benefit. The phenomenon is general, from economic affairs to the judiciary, and as one might expect also includes science policy makers. Some years ago the latter formalised their activities relating to very large investments within the framework of the Organisation for Economic Co-operation and Development (OECD), the forum of the industrialised democracies for promoting world-wide economic progress. Civil servants at or near the top of science ministries in 27 countries come to Paris twice a year to exchange information on priorities, on planning activities and on problems, especially as they relate to science projects costing more than roughly one hundred million dollars. This activity has taken the name “OECD Megascience Forum”.

As its name suggests, the Megascience Forum is a venue for discussion. It disperses no funds nor makes any binding decisions. Its purpose is to promote the orderly development of big science, first by keeping those most directly responsible for safeguarding investments informed of what is happening elsewhere, and second by identifying ways in which international co-operation and co-ordination might be beneficial to the goals of the scientific communities involved. It intends to promote collaboration where appropriate without compromising the final decision-making authority of the separate countries.

Early in 1997 Megascience Forum delegates agreed to sponsor a Working Group on Radio Astronomy under the chairmanship of NFRA’s Harvey Butcher. Its main purpose was to identify issues that might require the attention of governments at a high level. Clearly one such issue is that of increasing congestion in the radio spectrum, with telecom satellites in low Earth orbits the greatest immediate threat. That is, the down-links from systems such as IRIDIUM not only generate very strong, rapidly moving sources in the sky, but because the basic goal is globally complete coverage, nowhere on Earth will be safe from their effects. Looking to the longer term, when a new generation of radio telescopes will go into operation, radio astronomy will also inevitably require very deep observations as a function of redshift, so the currently protected bands are themselves insufficient for future needs. These are areas in which initiatives should be taken now to safeguard the future of the field.

Managing the use of a limited common resource such as the radio spectrum is of course a natural role of governments, and at their meeting in Paris on 25-26 June this year, the Forum
delegations agreed to support “a constructive dialogue involving the scientific community, the telecommunications industry, science funding agencies, national regulatory bodies, and the International Telecommunication Union. The goal of this activity should be to develop technological and regulatory solutions to ensure access to the radio spectrum at selected observatory sites for significant periods of time, while causing minimal interference to the operations of the telecommunications industry.”

The specific effects these words may ultimately have will in the end depend on what we astronomers make of them in the coming few years. It is in any case a signal that initiatives relating to spectrum management, especially as they concern safeguarding the next generation of large observing facilities, will in principle be entertained favorably at science ministries around the world.

Acknowledgements:

Many administrations have been very supportive of the radio astronomy cause during the Radio Astronomy-Iridium negotiations, in particular those in France, Germany, the Netherlands, Norway and the United Kingdom, as well as the European Commission. The CRAF team consisted of Eric Gérard (Meudon), Klaus Ruf (MPIfR), Jean-Claude Semiond (INSU), Titus Spoelstra (NFRA, head of delegation), Goliardo Tomassetti (Bologna), Bernard Darchy (Nancay) and Willem Baan (NFRA, IUCAF) as a guest expert. Our ministry of Education, Culture and Science, as well as our research council, NWO, have been very supportive of the discussions at the OECD and at the ESF.

DREAM: First Results

R. S. Le Poole (Leiden) and H.W. van Someren Greve

The DREAM (Dutch REal time Acquisition Mode) is a new observing mode for the recently commissioned SCUBA instrument on the JCMT.

SCUBA consists of two Front-End arrays operating at wavelengths of 450 and 850 micron. The (circular) apertures are placed in the focal plane in a hexagonal layout of \((1+6+12+18)=37\) bolometers for the long-wave array, and by two more rings of bolometers in the short-wave array, bringing the number there to 91.

The stepping along these 16 different pointing positions is nicknamed “jiggling”. It is achieved in the standard mode by spending 1 second on each of the 16 positions. Apart from jiggling, regular sky suppression takes place during that single second by chopping, generally to a position (more than 2 arcminutes) outside the target field onto notional empty sky.

The size of the horns of the bolometers causes the elementary pixel separation to be 4 times larger than required by Nyquist sampling, so that 16 different directions need to be observed in order to obtain a fully sampled image. Only then can a resampling algorithm perform a practical image restoration onto an (oversampled) rectangular array, and provide for de-rotation and co-addition (integration).

Figure 1: Sample of raw data, 2 cycles of 256 samples, taken at 125 Hz, so the total length is 4.096 seconds. Shown is the output of the central bolometer (H7). The samples on each sub-pixel are clearly visible, because of the presence of a strong source (Uranus) at the edge of the central “tile”. The left frame shows the unfiltered data, the central frame the same data but now filtered for microphonics. The filtering is done by a forward time FFT of the data over 8 cycles (2048 points), then performing a Hanning taper up to 25 Hz, and then a reverse FFT to the time domain. The frame on the right shows a model for the same “observation” assuming a 7.2 millisecond thermal time constant for the bolometer, 530 millisecond time constant for the AC output, and an estimate of the true sub-pixel intensities.
In the DREAM the Secondary Mirror Unit (SMU) jiggles to all 16 positions in a single second without chopping. The AC outputs then reflect only the differences in pictorial contents. Restoration of the relative picture intensities without the sky contribution depends on the degree to which the assumption holds that the telluric sky does not change during that second. In order to address the sub-pixels as effectively as possible, one must measure the sequence of sub-pixels in as short a time as possible. This means not dwelling more than a few thermal bolometer time constants per sub-pixel and eliminates the need to spend more than half the time observing "non-target" sky, or being in transit.

Description of the Mode

Addressing the sub-pixels is achieved by operating the SMU in a mode that does not involve chopping to sky outside the target area, thereby doubling the time available for observation of the actual source. In this arrangement each bolometer samples only a small area of sky, 4x4 Nyquist samples in size, or equivalently 2x2 HPBW. These small "tiles" form the "elementary" image parts to be integrated into a full image.

The present system allows a sub-pixel period of 64 milliseconds, providing for a basic "cycle" of about 1 second, after which one starts anew. As the thermal time constants are just a bit larger than 5 milliseconds, sub-pixel periods which are half that time are to be preferred in future.

The cycle is the basic period, sufficient for making full images. All sky variations slower than this period would be suppressed. At present the power spectrum of the telluric sky at these frequencies is not very well known for the JCMT, but there are hints that there may be a significant level of fluctuations on time scales as short as a second.

The present implementation of the data acquisition in SCUBA is by means of transputers. These obtain the 125 Hz samples of all 128 bolometers, and operate as phase locked amplifiers to extract the intensity per addressed sub-pixel per bolometer once a second. For the DREAM it is required that each sample of each bolometer is transported to the data-reduction software. This is done by buffering the samples, and sending the buffer once per second to the VAX system. Due to current speed limitations in the link it is however only possible to transfer the data of the 37 bolometers of the long wave array. As data reading is continuous, it means that we have 8 samples (including transit) per sub-pixel.

For solving the sub-pixel intensities, the basic algorithm is a least-squares estimator of the 16 sub-pixels out of all bolometer readings collected during one cycle. That this is correct may be argued on the basis that all the bolometer samples can be considered to read a linear combination of the intensities of all the 16 sub-pixels in the jiggle pattern. This is particularly true as the instantaneous pointing never goes outside the elementary "tile". The basic problem is thus the construction of the coefficients for this least-squares estimator. It is here that the relative timings of the SMU actions and the samples of the bolometers are important. This is more the case the faster the SMU is moved, as the actual transients, both from SMU pointing and from the thermal time constants of the bolometers, become more and more part of the "driving" signal for the bolometer readings.

The electronics supplies only AC outputs; this means that for each bolometer the mean intensity of the 16 sub-pixels is lost, and that a separate estimator for the relative zero points on the different "tiles" is required. Obviously the input for such an estimator is the requirement that the astronomical sky is continuous at the boundaries between tiles.

In the end, the target result for DREAM will be a full image every cycle, at present about one per second. Each image will consist of 16x37 sub-pixel intensities in a hexagonal layout. These images need to be regridded to rectangular grid, and de-rotated to allow co-addition for integration and display with an increasing S/N ratio. It is an attractive possibility for the future also to display the "live" 1 Hz data in order to "observe" seeing, spikes and/or other mishaps, and to allow the observer to suppress co-addition of suspect data as well as the option to decide, in real time, to complete the exposure and to go on to the next target. Data can be "exported" at the level of the individual images, to interface with the present software for other present-day facilities.

Data Processing

A number of software programs have been written in "Engineering mode", to perform the reduction of the data observed in the DREAM mode, described above. These programs run off-line, i.e. the observation has to be done first, and the JCMT software produces a file on the VAX system, containing some administrative information together with all the raw data from the transputers.

• First the data in the VAX observation file is read, checked, converted and sorted to a file suitable for the DREAM reduction process.
• Software has been developed to filter raw data for spikes and suppression of microphonics. Spikes seem to be present in the raw data with a frequency of about 1 to 3 per minute, randomly distributed over all bolometers. A spike is caused, rather like in CCD's, by a high energy particle which triggers a sudden very strong signal (sometimes above the saturation limit) followed by a long (0.5 second time constant) exponential tail back to its standard intensity. The tail is due to the electronics causing the AC coupling. The software is able to detect spikes above a specified level, zero the first few samples, and correct the exponential tail, thereby decreasing its disturbing effects after reduction by more than a factor of 100. The basic technique for reducing the effects of microphonics is by retaining only the lower 18 Hz in an FFT of the data, which contains the frequencies onto which the actual data are modulated (see Figure 1).
• The basic reduction program performs the least-squares estimation of the elementary sub-pixel intensities within each "tile".
• The result of the estimation of the "tile" images delivers sub-images with mean zero. The relative offsets must be found from the continuity requirement in the final image. This is possible because the Point Spread Function (beam) of the tel-
 escape is properly Nyquist sampled, which allows the offset difference between any two adjacent bolometers to be determined.

- Calibration consists of transforming the pixel values into meaningful units, for which a relation between total system temperature and the amplitude of the internal calibrator signal can be determined. For the moment it is taken for granted that one can rely on “standard” JCMT values for extinction and gain (flat fielding etc.), to be derived as usual through skydips. As an option it is possible to remove a linear slope over the whole image.
- The calibrated output of DREAM data can be converted to an input file for the standard SURF data processing software.
- The present system includes co-addition, regridding and statistical examination tools as well as display (false colour, grey scale, contour, line plot) facilities.

Commissioning

In May 1998 DREAM was tested and installed on the JCMT. In about 8 sessions at the telescope, of which 6 were in daytime, and 2 at night (including 1 good night), many sources were observed. Most were strong sources like Uranus, W3OH, IC342, NGC253, 16893-2422, and 3C279, but some weaker sources like NGC7552, NGC3690, M83 were also included. Sag A was observed to demonstrate DREAM in the case of a fully filled image, with no “empty sky”. In general the strong sources (> 2 Jy) gave good images (see Figure 2) however for sources below 1 Jy, the disturbing effects of microphonics, compounded by the variations of the sensitivity between individual bolometers were very. By observing and subtracting the sky next to the source it was possible to improve the image considerably (see Figure 3), although this necessarily leads to a loss of efficiency because chopping to an “empty” sky patch was once again required.

Along the way, a number of problems were encountered and overcome. First there was a drift of 1 part in 3000 between the sampling clock and the SMU clock, causing a degradation of the least square estimator of the sub-pixel intensities. By synchronising the two clocks to the nearest millisecond and calibrating the phase between sampling moments and SMU pointing this problem was solved. Microphonics, caused by vibrations of all telescope elements to which the SCUBA electronics are very sensitive, was (and still is) by far the largest problem that was encountered. As an illustration of the level of the problem: the characteristic instantaneous signal level is a vibration around 30 Hz with an amplitude like a signal of some 30 to 60 Jy. Yet the bolometer performance to be extracted is at the level of 1000 times fainter per second of integration. Apart from filtering frequencies above 18 Hz, two things were done to reduce further the effect as much as possible. Firstly, the waveform of the SMU (the largest contributor to the vibrations after demodulation) was smoothed as much as possible at the expense of increasing the transit times. Secondly, by permutating the jiggle sequence it was hoped that the effects would at least partially cancel each other. It seems that both additions have reduced the effects of microphonics on the data by a factor of 10 or so.
Discussion and Future Improvements

The present software works well. Reduction of the data is a factor of three faster than data acquisition. However the software is at an engineering level. A major effort is required to make it into a real-time common-user facility. Many features, some of them already mentioned, should then also be implemented. To this can be added: an extension towards simultaneous operation of the full short-wave array and the DC pixels, and extending the size of the image by “mosaicking” observations of adjacent elementary images, in rather the same way as tiles are integrated into the full image.

The current instrument description in the DREAM reduction software is not very sophisticated; only a single (thermal) time constant for each bolometer, and one time constant for the AC output electronics are implemented into the model. However, with the present, relatively slow, jiggling of only 16 Hz pixel rate, these effects do not impede demonstration of the algorithms. In fact other disturbances have made these “defects” irrelevant for the moment.

The microphonics still create the most severe limitation for the mode. It appears that filtering out all frequencies above 18 Hz is not sufficient for suppressing this effect. Moreover there seems to be a factor of 20 or so difference between bolometers that suffer most and that suffer least from this effect. Furthermore, the response is variable on timescales of less than days. Its effect on data at frequencies below 16 Hz, the frequencies at which the actual data is modulated, is so unpredictable in time, that it severely limits this mode in reaching the shotnoise limit of the bolometers.

The present power of the mode lies in its ability to map strong sources in a very short time, making the mode ideal for tasks such as Pointing correction and flat field calibration. Also high dynamic range on bright sources is more readily achieved by this new mode. It is expected that elimination of the microphonics, by improving the SCUBA electronics, will ensure that DREAM can fully exploit its advantage of being twice as fast as the normal SCUBA observing mode.

Our efforts at the telescope were very helpfully supported by the whole JCMT team, in particular R. Prestage’s continuous support should be mentioned.

Redshifted 21cm Line Absorption by Intervening Galaxies

F.H. Briggs, W. Lane, A.G. de Bruyn (Kapteyn Astronomical Institute)

The 21 cm line of neutral hydrogen has proved to be an excellent source of information about the kinematical behavior of nearby spiral galaxies, yielding the first and strongest evidence for the existence of dark matter, as well as providing a fundamental indicator of where star formation will occur and the behavior of gas in the vicinity of star forming regions. Neutral gas at present constitutes only a fraction of the total number of baryons, since the bulk of the baryons have been ionized since very early epochs. Neutral gas must be confined in a gravitational potential of a galaxy in order to have sufficiently high density that its recombination rate exceeds the rate of ionization by ionizing background radiation.

Since the 21 cm line from the neutral gas apparently traces galactic potentials, it will be valuable to apply the kinematical studies that are now familiar to extragalactic astronomers to galaxies at high redshift, in order to trace the development of the potentials over cosmic time and to relate the enhanced density regions to regions of star formation at epochs at redshifts greater than about z ~ 3 when the mass in neutral gas exceeded the luminous stellar mass. Alas, the current generation of radio telescope is not sufficiently sensitive to observe emission in the 21 cm line from galaxies at these high redshifts. On the other hand, galaxies are sufficiently common in the Universe that it is probable for them to lie occasionally in front of a bright, high redshift quasar or radio galaxy. In these case the intervening galaxy can be seen in absorption against the background object, enabling many of the same kinds of studies to be performed, albeit on a limited sample of galaxies.

Progress in observing redshifted 21 cm lines has been limited in the past by the frequency coverage available at the large fully-steerable telescopes and by radio interference. Recent installation of wide-band receiving systems at the Westerbork Synthesis Radio Telescope (WSRT) has led to a surge in the discovery of redshifted 21 cm and OH lines, as well as providing a fresh look at some old favorites. Interferometers are relatively invulnerable to moderate levels of interference, and the new observations are showing that the new absorption systems are there, awaiting discovery. As one example, W. Lane, A. Smette and F. Briggs have been using known MgII ultraviolet absorption to select redshifts for observation with the UHF receivers and current narrow band spectrometer. In the future, the full DZB will make possible unbiased, radio selection through broad band surveys.

PKS 1229-021 revisited

The quasar PKS 1229-02 presents an interesting case study of the intervening galaxy class of 21 cm line absorber, since it illustrates how absorption against complex background sources can be used. As one of the earliest identified absorption systems through its strong MgII doublet at z_{abs}=0.395, it has al-
already received much attention, becoming a prototype of the quasar absorption-line class known as “DLa systems with asymmetric metal lines” and the focus of detailed VLA polarization studies, since the radio continuum extent of ~15'' in the background quasar permits mapping the Faraday rotation along a cut through the disk of the intervening absorber.

The radio source is marginally resolved by the Westerbork synthesized beam at 1018 MHz, allowing the data to be decomposed to obtain spectra against the two main components as shown in Figure 1. The absorption appears to be concentrated on the SW structure, and no absorption is detected against the NE extended lobe. In addition to the narrow 21cm absorption that has been known for some time, the new WSRT data show broad, low level absorption in the 21cm profile at frequencies both above and below the narrow line.

Ground-based and HST imaging have identified the absorber with a galaxy of optical luminosity L=0.25 L* . HST spectroscopy has measured the HI column density in the DLa line, which permits estimation of the spin temperature. Comparison of the angular size of the radio structure with the angular size subtended by a moderately bright disk galaxy at this redshift (see Figures 1 and 2) shows that the quasar nucleus must be close to the disk center and that the radio jet extends on galactic scales behind the intervening disk galaxy.

Tests of a range of differentially rotating disk models describing gas-rich disk galaxies show that an inclined disk with a flat rotation curve and a gradually declining optical depth with radius mimics very well both the narrow feature and broad wings in the absorption profile. The optical depth against the quasar core is τ~0.25, and parameters for inclination and position angle of the major axis are surprisingly (see Figure 2) well constrained for such a model. The natural next step is to map the absorption with a moderate resolution interferometer system operating at 1018 MHz.

**Figure 1:** Background continuum structure of the z_em = 1.045 quasar PKS 1229-21 (Kronberg et al 1992) and the intervening z_abs=0.395 21cm line absorption spectrum (Briggs, Lane and de Bruyn 1998). Top map: 1630 MHz. Lower map: 4980 MHz. Spectra against the two components can be isolated as indicated in the lower panels. An oval is drawn over the SW component to represent the kinematic model described in the text and Figure 2. The simple model produces the smooth curve for the narrow and broad absorption components in the right panel.

**Figure 2:** Left: HST image (Le Brun et al 1997). Contours with shading represent the optical emission after subtraction of the QSO point-spread function, which is centered under the cross. Overlaid gray contours show the 8.2 GHz radio continuum of the background QSO from P. Kronberg. The oval indicates the size of a large disk galaxy as drawn in Figure 1. Right: Differentially rotating disk model for the distributed absorption, drawn on a larger scale than in the left panel. Velocity contours are drawn in 30 km/s intervals, with shading used to highlight the ±200 km/s ranges.
Future

The broadband spectrometers coming on line over the next year will enable radio spectral surveys for absorption against large samples of high-\(z\) sources. The low redshift regime \(0<z<1.6\) will benefit from radio surveys to find DLa systems, free from bias by dust and Lyman limits, and without need to resort to HST to cover the range of redshifts where Lyman-\(\alpha\) cannot be observed by ground based telescopes. Furthermore, selection on 21cm absorption permits use of optically dim, high-\(z\) radio galaxies as the background sources, with the advantage that optical follow up to identify the intervening DLa absorber and study its environment will be simpler, since there are less stringent requirements on precise subtraction of the quasar point-spread function. Selection on 21cm can detect heavy absorption against extended radio components in quasars for which the optical nucleus is uncovered and shows no DLa line; in this sense, the largest high-\(z\) radio sources provide multiple lines of sight, increasing the efficiency of observing the high \(N_{\text{HI}}\) end of the absorption-line distribution.

High spatial resolution observations will define the extent and fine-scale kinematics in intervening absorbers as well as measuring the local 21cm optical depth against the background nucleus for comparison with DLa lines and refinement of spin temperatures. To this end, a number of EVN telescopes are being equipped with UHF receivers, and test observations are showing that this kind of work can be done despite levels of rfi that would be intolerable in single-dish spectroscopy.

As an example of how very, limited uv coverage can provide kinematic information, Figure 3 shows a simple model for PKS1229-021, made by adjusting the flux densities of the knots seen in Figure 2 to 1018 MHz, while keeping the positions and shapes fixed. Figure 4 illustrates the response of a single Westerbork-Bonn baseline to the continuum model, along with models where selected components attenuated, to simulate localized, frequency dependent absorption.

A variety of follow-up observations are possible for the growing sample of 21cm lines. Faraday rotation and Zeeman splitting in very narrow and deep lines will soon be specifying magnetic fields in the absorbers. The time has come to re-examine the idea of Davis & May (1978) that precise measurements of narrow radio absorption lines (in HI or molecules) could determine fundamental constants (\(\Omega_0\) and \(\Lambda\)) by observing the deceleration of the Universe as a function of \(z\) in observations spaced over a few decades.

References


Figure 3: PKS 1229-02 model for VLBI observations at 1018 MHz. The map was constructed with 0.1” resolution and contour levels at 0.5, 2, 10, 40, 200, 600 mJy per beam. Integral fluxes of each of the model components along the jet are 600, 250, 110, 115, 125, 300, 430 mJy from left to right.

Figure 4: PKS 1229-02 visibility as a function of time for a Westerbork-Effelsberg baseline at 1018 MHz. Visibility in the continuum is indicated by the solid line. The lower dotted line shows the effect of halving the flux density of component 1 in Figure 3. The upper dotted line shows the effect of halving the flux density of component 2.
Strategic Thoughts on our Radio Observatory

Willem Baan, Director of WSRT

As the end of the upgrade program at the WSRT comes into view, it is time to revisit the role the instrument can play in the future, both for our national research efforts and internationally. In my first half year as Director I have talked extensively to staff and users, trying to synthesize their thoughts and to formulate my own ideas of how best to confront the future. I am not yet finished with this process, but I would like to share here some of my conclusions to date.

The New WSRT

Three comments can readily be made about the telescope.

The Upgraded WSRT – The Upgrade will result in a fundamental change in the operation and the scientific capabilities of the telescope. The expanded observing capacity allows new and innovative science over a wide range of frequencies. Current optical research with the Hubble Space Telescope, the Keck telescopes, as well as the new ESO Very Large Telescope (VLT) has opened up a new Universe of large redshifts. Complementary studies across the vast frequency range now accessible to the WSRT allows spectral line observations of HI, OH, formaldehyde, and even H$_2$O in large portions of the early Universe. The new PuMa pulsar backend and the increased sensitivity of the system helps the WSRT to measure up to other successful “pulsar telescopes”. The increased instantaneous bandwidth and the reduction in system temperatures will allow significantly deeper continuum studies. We will have a very competitive telescope.

Staying in the forefront with limited means – The Upgrade will ensure that the WSRT remains a unique instrument for some years to come. But its capabilities will need to be maintained and enhanced from time to time if it is to play an important role in Dutch and in European radio astronomy. In the current budgetary situation this will be a challenge. My view is that the instrument should not attempt to duplicate capability elsewhere in Europe, but we should strive to complement instruments at other frequencies both in Europe and in other parts of the world. We expect to build the necessary bridges to our colleagues at other facilities to avoid duplication, while ensuring access to the capabilities for our research needs.

Testbed for SKA – The WSRT will be able to contribute significantly to the realization and the success of the Square Kilometer Array and can serve as a testbed for SKA technologies and algorithms, for trying out RFI rejection techniques, and for integration of prototype SKA elements within the existing interferometer. I have started the internal discussions about what this might mean in practice.

In the following I summarize the present status of the Upgrade and consider what further improvements should be implemented in the coming years in order to fulfil our hopes for the facility.

System Enhancements

DZB, TMS, aips++ – The first half of the new (half million channel) DZB correlator is being tested furiously right now at the WSRT. Around the time of writing a preliminary production system was set to be frozen that supports operations of the DZB with 10 MHz bandwidth in a number of operational modes and with the new Telescope Management System (TMS) software environment. Also the Compound Interferometer (CI) observing mode is in its final testing phases and will soon become operational. Work will continue on the DZB system and on TMS for some months, and the 20 MHz option will also be implemented. At the same time, the aips++ data reduction and analysis environment is being installed and tested. It will include the new format WSRT Measurement Sets (MS) which should allow us readily to develop innovative data taking schemes limited mostly by our imaginations. This fall we will witness great changes at the WSRT and the reader is invited to look for us on the Web to stay up to date on developments. It is my intention to begin a discussion in the coming half year on the priorities for new capabilities that make use of the new software and hardware platforms.

Time keeping – Designs have been developed to improve the time transfer and LO (local oscillator) distribution system. Such changes are needed for an optimal use of the MFFE front-end systems, the complete DZB correlator, and the PuMa pulsar backend. Such a system is also needed for improved timekeeping between the internal WSRT atomic clock systems and external systems like those of GPS (Global Positioning Satellites). In March 1998 the Hydrogen maser clock stopped working, seriously affecting both VLBI and pulsar observing. It was only brought back into operation after weeks of time and intense efforts of the WSRT staff. In the short term this 30 year old maser will be refurbished. In the longer term, plans are being made to replace the system in order to accommodate the future requirements of the VLBI, pulsar and geodetic (see item below) communities. We must strive to ensure that we have a time-keeping system second to none.

Broadband IF System IVC – A recent grant from NWO will ensure that a broadband IF system can be constructed for the WSRT. The new IVC system with a maximum bandwidth of 160 MHz, compared with the current 20 MHz, will make the WSRT truly unique among the large telescopes of the world. Broadband searches for HI and OH emission at high redshifts, the flexibility of choosing continuum bands without RFI, the
inventory of HI in the local universe, and innovative pulsar studies are a few of the many possibilities for the IVC system. While this funding has not become available as soon as one would have liked, it has materialized and the final result will be wonderful.

PuMa-II – After taming the first generation Pulsar Machine, a second generation is already being planned, to be funded through NOVA. It currently looks as though PuMa-II will be able to do timing to a few nanoseconds resolution and will have an improved capability for pulsar searching.

MFFE phase 3? – The current phase 2 Multi Frequency Front Ends (MFFE-2) are (steadily) being delivered and installed on the telescopes. It is expected that the 15th and last unit will be in operation early next year. Although a few problems still need to be ironed out for the MFFE-2 installation, the new systems already show the dramatic changes for the operation of the WSRT. How will these changes affect satisfaction with the system? One thing is clear. When use of the new capabilities has been explored, the results will point the way to additional observing modes and the need for even better performance. Better UHF systems? Wider bands for the cooled systems? Interference rejection loops before the LNA? Simultaneous measurement with other frequencies than is now possible? The choice of priorities and of specific frequency bands will have to be based on experience with the current MFFE systems and the directions of astronomical research. I will be working to ensure that a budget is available to make such enhancements possible.

Cryogenic and High Temperature Super-Conducting Filters

– New filter technology is needed to protect the high sensitivity receivers from signals of other legitimate spectrum users such as TV stations and various satellite systems. Low insertion losses and minimal increase in system temperature are a requirement for filters placed at the entry of the receiver system. Great progress is expected in the coming years in the field of HTSC filter technology for application at the WSRT, more so because satellite and terrestrial telecommunication systems will require similar filter systems. These developments are a priority.

Recirculation in the correlator – The spectral capacity of the new DZB correlator system is at present sufficient to cover all proposal requirements. In future, there may be a need for much higher spectral resolution. Such resolution can only be reached with “re-circulation” in the FFT process in which bandwidth is traded for computing capacity. Appropriate measures are being taken to make implementation of this re-circulation at some later time at least a possibility.

New Roles for the Observatory

Netherlands Astrometric-Geodetic Observatory – The Netherlands Commission for Geodesics has set up a task group to establish an Observatory at Westerbork. A geodetics research group from the Technical University in Delft already maintains a reference station on the WSRT site. This station could be expanded in order to integrate global positioning, time housekeeping, and the transfer of global satellite time, while serving as a reference point for geodetic studies in Northern Europe. WSRT and JIVE staff members actively participate in this task group in order to represent the interests of the VLBI and pulsar communities. I view these developments favorably and will do my best to make possible what is needed within the constraints of our budget.

Expanded Antenna Configuration of WSRT – Plans exist to develop telescope prototypes as part of the Square Kilometer Array R&D program. The integration of these test elements would require an operational expansion of WSRT. The use of the Dwingeloo telescope for UHF-VLBI could also give interesting astronomical possibilities. Other suggestions have been made to combine new technology antennas with the WSRT for the search for extra-terrestrial intelligence (SETI). I will remain open to such possibilities and will try to ensure that the Observatory is capable of implementing them if and when they are agreed and funded.

Dwingeloo Telescope

Single Dish Operations with Dwingeloo – The Dwingeloo Telescope (DWT) as a stand-alone instrument is no longer at the cutting edge scientifically. Unless a substantial upgrade program is undertaken, essentially all observations can in future be done better and quicker with a single WSRT telescope. I have therefore decided to accept no further single-dish DWT proposals. Unless additional support can be found for projects like UHF-VLBI, one must consider closing the DWT in the near future.

Spectrum Environment

Like it or not, radio telescopes in future will have to work in a hostile interference environment. This will be the case regardless of the fate of the spectrum bands currently reserved for radio astronomy, because we will increasingly want to observe lines at non-zero redshifts. With the ESF/CRAF and ICSU/IUCAF radio spectrum management secretariats in Dwingeloo, we are in an excellent position to play an effective role in working with other spectrum users to minimize the impact of their systems on astronomy. I believe we really have no choice but to do our utmost in this area and I intend to devote what resources I can to carry out this work.

On-Line RFI rejection – Plans have been made earlier this year to experiment with on-line RFI rejection on one of the WSRT telescopes. This project will serve as a “feasibility study” and the results could be used for the whole WSRT in the coming years.

EMI Monitor Station – A big problem in confronting RFI in practice is knowing what is happening in the various parts of the radio spectrum. I feel it is necessary to equip an RFI monitoring station for automatic as well as manual operation. Besides a fixed station on top of the maintenance hall at the WSRT (currently in operation), a mobile monitoring unit is needed in order to find interfering trans-
ments. A similar system is needed for the evaluation and planning of the location of SKA elements. We have built up valuable experience in monitoring during the past several years, so I am confident that we will be able to develop effective strategies for observing in the presence of RFI.

National and International Spectrum Management—It is essential that the relations with government agencies and other spectrum users in the country are strengthened in the coming years. Positive and constructive contributions from Dwingeloo and Westerberk in the national and European dialogues on frequency use and frequency protection are important for a “protected future for the WSRT”. I have taken the initiative to start discussions at local, provincial and national levels to implement a “national coordination zone” for the protection of the WSRT. I have found a general willingness to cooperate, although it is also clear that we will have to do essentially all the organizational work ourselves to make this happen.

Support for Users

Budgetary pressures in recent years have made effective user support at the WSRT difficult to provide. On the other hand, our current policy of scheduling, data taking and data processing for our users is very expensive. Furthermore, when users do not actively participate in the observing process they tend to decouple from the facility and lose sight of the possibilities it offers for advancing their research. This is especially unhealthy as regards training young scientists to do radio astronomy and to make the best use of this extraordinarily powerful and interesting instrument. I therefore will be examining the possibilities for involving observers directly in the observing process. The pulser and WHISP teams of course already do this to some extent, and it is my intention to evolve our procedures to make it both possible and desirable for observers to participate in taking their observations.

On the data reduction side, it is clear both that aips++ will provide us with a powerful new platform for innovative projects, and that it is way behind schedule and limping only slowly into operation. This is unfortunate, but I believe the wrong decision would be to halt its further implementation. I have decided to delay filling certain staff positions to allow us to hire at least one and probably two new programmers to ensure that aips++ as well as TMS do fulfil their promise.

It has been some time since we have held formal User Committee meetings. I will be consulting with users about re-instuting these meetings, probably beginning early in 1999.

Double-Double Morphology in Radio Galaxies

A.G. de Bruyn, A.P. Schoenmakers, H. Röttgering and H. van der Laan

Introduction

One of the outstanding issues concerning extragalactic radio sources is the total duration of their active phase. This physical age is not to be confused with the radiative loss age which can be estimated from radio spectral ageing arguments. Most extended extragalactic radio sources probably have a physical age well surpassing the radiative loss age (e.g. van der Laan and Perola, 1969, A&A 3, 468). The issue of the activity lifetime is complicated by the possible presence of duty cycles in the nuclear activity. If nuclear activity is not continuous, how often do interruptions occur and how long do they last? This question of AGN activity can best be addressed by the study of extended radio sources because they present us with a record of their past activity.

A small number of radio sources show characteristics that can not be fully explained by a continuous jet model. One example is the Fanaroff & Riley (1974, MNRAS 292, 723) class II (FR-II) source 3C219 in which the radio jets abruptly become undetectable at some point between the core and the hotspots. (FR-II sources are double radio sources with edge brightened structures.) They are only found among sources above a certain radio luminosity. Clarke et al. (1992, ApJ 385, 173) propose that the jets in this source could be restarting, although numerical simulations (e.g. Clarke & Burns 1991, ApJ 369, 308) of this effect fail to reproduce the observed structures.

During a search for Mpc-sized radio sources in the Westerbork Northern Sky Survey (WENSS) we have discovered several large radio galaxies which are strongly suggestive of recurrent radio-activity. These giant radio sources have a radio morphology resembling that of two unequally sized FR-II type radio sources aligned along the same axis and with a coinciding radio core. The first source that put us on the trail of this very rare class of sources was WNB1834+62.

The source WNB1834+620

WNB1834+620 stands out as a peculiar source in the 49-cm radio maps of WENSS because of its almost perfect “four beads on a string” radio morphology (see left panel in figure). Higher resolution observations of this source were then made in 1995 with the WSRT at 1.4 GHz. From these it still could not be decided whether WNB1834+620 was a single source or a closely aligned twin. We therefore observed it in 1996 with the VLA at 8.4 GHz in its D-array configuration, to search for a core and determine the spectral index of the various components. A second observation took place in 1997 at 1.4 GHz in the A-array configuration. The radio maps from the VLA observations are presented in the middle and right panels. The 8.4 GHz map unambiguously shows the FR-II type morphology of the outermost components. Of the two bright inner knots, only the southern one is slightly resolved. The high resolution 1.4 GHz map shows this inner structure in more detail and shows that the two bright inner sources are clearly not knots in a jet or unrelated background sources, but form a...
distinct radio source. Because the morphology of the source as a whole is that of a small double-lobed radio galaxy within a large double-lobed radio galaxy, we have adopted the name “double-double radio galaxies” (DDRGs) for this type of source. The 8.4 GHz data also revealed a flat spectrum core in the middle of the source clinching the case for a single source. The radio core coincides with a faint optical galaxy \( (R_s \sim 19.0) \), which is the brightest member of a compact group of three galaxies visible on the POSS-II plates. A spectrum taken with the 2.5m INT telescope on La Palma revealed a rich emission line spectrum, from which we determine a redshift \( z = 0.519 \pm 0.001 \). The projected linear size is 1660 kpc for the outer source and 428 kpc for the inner source, which makes it the second largest radio source at redshifts above 0.5. (we use \( H_0 = 50 \text{ km/s/Mpc} \) and \( q_0=0.5 \).) A detailed multi-frequency, polarimetric, study of WNB1834+62 will be presented in another paper (Schoenmakers et al, in preparation).

Discussion

Triggered by the properties of WNB1834+62, we have found three more sources, all with “giant” dimensions, in the WENSS, NVSS and FIRST surveys. A subsequent literature search revealed several more sources that may belong to the class of DDRG’s. The properties of this class of source are described in the paper by Schoenmakers et al. (1998) which has been submitted to MNRAS. The two-sidedness, and the relatively high symmetry of the inner sources, strongly suggest that the DDRG phenomenon is related to the activity of the nucleus, and almost eliminates any model which puts the primary cause well outside the nucleus. In the case of the DDRGs, we favour a model in which the nuclear jet thrust is temporarily strongly reduced, or even halted. Short term variations in the energy output are known to occur in almost all AGN and it is plausible that they occur on a variety of timescales, from years to millions of years. Small changes in jet power will most likely not disrupt the jet flow, but lead to shocks which are visible as discrete “blobs” in the jet or become manifest only once they reach the hotspot. A large change in jet power, and especially a large decrease, might have fatal consequences for the stability of the jet; the channel to the outer lobes - the jet - may not be able to maintain itself and will, eventually, collapse due to the pressure of the surrounding cocoon. As a consequence, a restarted particle outflow from the nucleus will have to clear a new channel and in doing so, may well form new inner hotspots and a new radio source. In due time, the outer radio lobes will have completely faded and a new, smaller, double-lobed radio source has emerged; we have named this scenario the “metamorphosis model” of double-lobed radio sources. However, we do not suggest that all double radio sources will go through this process.

An important question (and clue!) is why all DDRGs found so far (Schoenmakers et al, 1998) are (nearly) Mpc-sized. We propose that this is due to a combination of two effects. First, as said, once the jet flow to the outer lobes has ceased, they should start to fade quickly. The magnetic field in the lobes of giant sources, which generally have modest radio power, is much weaker than that in powerful FR-II radio sources.
PUMA is ready to pulse!

Richard Strom

The new WSRT Pulsar Machine, PuMa, arrived in Westerbork last May. Actually, this was only the first part of the instrument, with the remainder expected in the autumn. A first observation was performed on 28 May with nine elements of the WSRT in tied array mode at 840 MHz using a 10 MHz bandwidth (one-eighth of what the full PuMa will be capable of). This measurement of PSR B0329+54 is shown in various forms in the figure above. The upper-left panel shows a 60s time series: the envelope of noise, with the pulses sticking out above. The lower left panel shows the resulting power spectrum, with the fundamental and higher harmonics of the pulsar (its period is 0.7s). The PuMa team (P. van Haren, L. Voute, M. Kouwenhoven and B. Stappers) was especially pleased to see that no 50 or 100 Hz “pulsars” appeared. The two remaining panels show (upper right) the average pulse profile which results from folding the data, and (lower right) the average dynamic spectrum of 256 channels over the total 10 MHz band. The variations in the frequency direction (vertical) are caused by scintillations in the interstellar medium.

PuMa can be configured in various ways, with up to 8192 frequency channels, a total bandwidth of 80 MHz, and time resolution of 1.6 microseconds. It can be used in search mode, recording just two polarization channels, or for observations of known pulsars, determining all four Stokes parameters and correcting for dispersion and Faraday rotation on line. The time since the first observations has been used to overcome a number of teething problems before reliable (test) observing was possible. We are now able to output all Stokes parameters, and we have carried out a number of successful observations.

It is hoped that PuMa commissioning will be completed this fall. There will then be a period of astronomical observing and if all goes well, new proposals can be submitted starting next year. There is also a new project, PuMa II, which will greatly expand the instrument’s capability (see also the item by Willem Baan elsewhere in this newsletter). It will be able to handle twice the bandwidth, with real-time dedispersion. It should be particularly suitable for high-precision (nanosecond) timing, searches for binaries in tight orbits, and nanosecond polarimetry. PuMa II is being financed through NOVA.
Next year in April NFRA will be 50 years old. To celebrate this anniversary we are planning to organize two symposia directly relating to our future plans:

**Perspectives on Radio Astronomy**

**Scientific Imperatives at cm and m Wavelengths**

7 - 9 April, 1999

**Perspectives on Radio Astronomy Technologies for Large Antenna Arrays**

12 - 14 April, 1999

Details can be found on the NFRA Web Site http://www.nfra.nl

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**The ING Visiting Panel Report**

**René Rutten (ING)**

A visiting panel of internationally distinguished astronomers was set up in December 1997 by PPARC and NWO to review the Isaac Newton Group of Telescopes (ING) on La Palma, in order to provide an international and independent perspective on its operation and its needs. The executive summary of the report from the ING visiting panel can be found at the ING web site (see below). The panel was chaired by Dr. Russell Cannon. The report reviews the current status of the UK/NL telescopes on La Palma, their operation, and future developments in an international competitive environment. The ever tighter budgetary constraints under which the observatory has to operate, the advent of large 8-meter class telescopes, and the restructuring within PPARC made such a review timely. The Visiting Panel’s report gives an overall favorable impression of the ING and notes some areas where the ING can further improve. It also recommends that the ING prepares itself better for the future, where it has to remain competitive next to the large telescopes, by having a coherent instrument development program, and by providing a lean and effective operation of the telescopes.

The recommendations from the Visiting Panel provide support for the direction into which ING has been moving for some time. The report, and the response from the UK/NL Joint Steering Committee can be found on the ING’s web pages at http://www.ing.iac.es/ and follow the link to “strategic issues”.

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This means the radiative lifetime in small sources is much smaller causing the outer lobes of small DDRGs to fade much more rapidly than those of Mpc-sized DDRGs.

Second, smaller radio sources will probably lose their double-double morphology more rapidly. After the jet stops flowing into the outer lobes, they lose their source of momentum and slow down their forward motion. This allows the inner source to overtake the outer source. If the inner source continues to grow we will probably interpret the old lobes as the manifestation of a backflow within the new lobes and we will no longer recognize such a source as a DDRG. It is quite likely, that it will take less time for the inner lobes to overtake the outer lobes in a small source, and therefore the probability of recognizing a DDRG increases with increasing size of the outer source.

The class of DDRG’s, and their association with sources of giant dimensions, has raised a number of interesting and important questions which may shed light on a range of long-standing questions such as the existence and cause of nuclear activity timescales, their duty cycles, the density of the intergalactic medium, the structure and stability of cocoons and the fading of energy-starved radio sources.

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**NFRA PC News**

The latest news from the NFRA Programme Committee about the available instruments and instructions on the submission of proposals for Semester 99A (which runs from February to July 1999) can be found at the NFRA PC web site: http://www.astro.rug.nl/~nfra_pc. The deadline for proposals for the ING-telescopes on La Palma, the JCMT on Hawaii and the WSRT is midnight 30 September 1998. Note that LATE proposals will NOT be accepted.

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**NFRA Newsletter**

This newsletter is published twice a year in March and September. Electronic versions are available in html, pdf and postscript format at: http://www.nfra.nl/nfra/newsletter. The Netherlands Foundation for Research in Astronomy is an organization dedicated to providing the (Dutch) astronomy community with front-line observing capabilities. Please visit our web site http://www.nfra.nl/ for further information.

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