

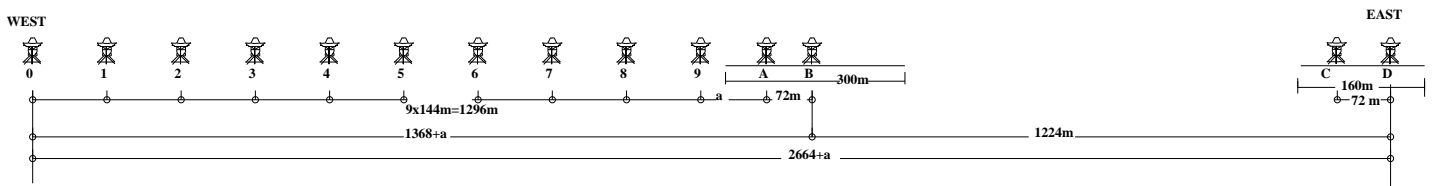
# WRSN USER DOCUMENTATION

## PART I

## PROPOSING FOR WSRT OBSERVING TIME

July 16, 1993

Version: 1.0.0



# WSRT

USER DOCUMENTATION

## CONTENTS OF PART I

*This is part I of the WSRT User Documentation.*

*The WSRT User Documentation consists of 7 Parts; we may refer to other parts of the User Documentation. To get more information about how to obtain a copy and/or updates of parts of the User Documentation please send an e-mail request to [wsrt@nfra.nl](mailto:wsrt@nfra.nl)*

*The roman number in the pagenumber indicates the part.*

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# WSRT PART I

## USER DOCUMENTATION CHAPTER 1

# INTRODUCTION

*This paper is part I of the WSRT user documentation. In this paper all the information necessary to write a proposal for the WSRT has been compiled. More background information can be found in other parts of the user documentation.*

## 1.1 THE WESTERBORK SYNTHESIS RADIO TELESCOPE (WSRT)

The Westerbork Synthesis radio telescope (WSRT) in the Netherlands is an observing facility operated by the Netherlands Foundation for Research in Astronomy (NFRA) with financial support from the Netherlands Organization for Pure Research (NWO). Its headquarters are located at the Radio Observatory (Radiosterrenwacht) in Dwingeloo.

The WSRT is available to observers from all countries, and time is awarded on the basis of merit of the scientific program. We have compiled here the information which we hope will be sufficient so that any astronomer with a basic understanding of radio synthesis techniques (part II of the user documentation) can plan and propose a WSRT observational program.

# WSRT PART I

## USER DOCUMENTATION CHAPTER 2

# SUMMARY OF TECHNICAL CAPABILITIES OF THE WSRT

## 2.1 GEOMETRY

The WSRT consists of an East-West array of fourteen equatorially mounted parabolic 25-m dishes. Ten (labeled 0-9) are on fixed mountings, 144 meters apart; the four ( $2 \times 2$ ) remaining dishes (labeled A, B, C and D) are movable along two rail tracks, one, 300 m long, adjacent to the fixed array and another, 180 m long,  $9 \times 144\text{m}$  towards the East (see figure). The movable dishes can be used at any position on the rail tracks. The pointing accuracy of the dishes is 15 to 20 arcseconds, the surface accuracy is of the order of 1-2 mm. In the focal plane ( $f/D = 0.35$ ) of the dishes, exactly on the 'optical axis', the frontend feeds are mounted. These feeds consist of two perpendicular probes for the detection of linearly polarized radiation (dipole cross) designated X and Y. The dipole crosses can be rotated. In the most common case the X and Y dipoles on all telescopes have the same orientation (indicated by ++) but it is possible to rotate dipoles such that interferometers are formed for which the dipole crosses differ in orientation by  $45^\circ$  (indicated by  $+\times$ ). In the backend correlation system for Westerbork all 4 possible combinations can be produced for each interferometer.— *i.e.* XX,XY,YX and YY.

The geographical coordinates are: altitude 16 m, longitude -6.60417, and latitude 52.91692.

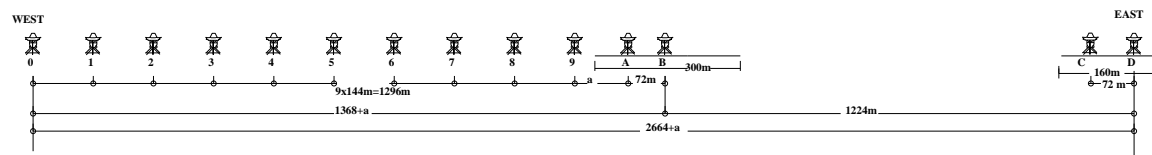


Figure 2.1: Geometry of the Westerbork East West array of 10 fixed 25 meter dishes, spaced by 144m and 4 movable dishes on rail tracks. Standard available baselines are 36 to 2772m in 18m increments ( $4 \times 12^h$ ) but spacing increments of 12m ( $6 \times 12^h$ ) or 9m ( $8 \times 12^h$ ) are also possible

standard mode of operation for line and continuum observations	e.g. PART III Chapter 2 and Chapter 3
standard mode for polarization measurements	Part III Chapter 4
standard mode using redundant baselines	Part III Chapter 5
mosaicing mode	Part III Chapter 6
autocorrelation mode	Part III section 3.4.1
pulsar mode	Part III section 3.4.2

Table 2.1: The various observing modes of the WSRT. For more information read the indicated chapters elsewhere in the user documentation

## 2.2 OBSERVING MODES

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

A new method of using the WSRT in mosaic mode was developed in 1990. This mosaic method allows mapping of large areas of the sky in a relatively short time. During one twelve hour period the telescopes, along with the fringe-stopping and delay centers, cycle through a grid of positions a number of times. The grid may contain as many as 120 positions specified by the user; it can be arranged in a flexible way. If done sensibly no more than 10 seconds are required to change positions within the grid. The method allows large surveys of continuum or line radiation in those cases where sky coverage is more important than sensitivity. Part of the time the WSRT is used for *Very Long Baseline Interferometry (VLBI)* along with other telescopes in Europe and elsewhere (mainly the USA). The fourteen WSRT dishes are then used as a 'tied array', together yielding the equivalent of one 93-meter single dish in the VLBI network. The tied array mode will also be used sometimes for pulsar observations.

The WSRT can also be used as 14 independent 25 m dishes. This mode has been used for a Deuterium search at  $\lambda = 92$  cm.

## 2.3 RECEIVERS AND BACKENDS

Table 1.2 summarizes the characteristics of the WSRT at each of the five wavelengths for which receivers are currently available. At 18 cm there are only five (cryogenically cooled) receivers which can be mounted in telescopes 0, A, B, C, D. In the near future also telescope 9 will be equipped for a cryogenic frontend. At this wavelength the WSRT is generally used in the VLBI tied-array mode. For the other four wavelengths a complete set of 14 receivers can be used. All receivers have two linear polarization channels.

Two digital correlators and two VLBI recording systems can be used to combine the signals from the array for different types of observations. A summary of their characteristics is given in the table 2.3

wavelength(cm)	6	18	21	49	92
frequency range at RF (MHz)	4770-5020	1590-1730	1365-1425	607-610	305-385
field size HPBW(degr)	0.17	0.5	0.6	1.4	2.6
max. bandwidth at IF (MHz)	80	80	80	2.5	80
T <sub>sys</sub> of frontend (K)					
cooled	55	60	35	–	–
uncooled	150	–	90	110	140 <sup>†</sup>
synthesized beam in RA for 2.8 km maximum baseline (arcsec)	3.7	11	13	30	55
for a standard 12 h measurement with 40 baselines and a standard taper:					
distance to grating ring in RA (arcmin)	2.9	8.5	10	24	44
theoretical continuum sensitivity (r.m.s. in 12 <sup>h</sup> obs) (mJy/beam)	0.07	–	0.05	0.6*	0.5* <sup>‡</sup>

<sup>†</sup>: In the coldest regions of the sky

\*: At these wavelengths a 12<sup>h</sup> observation is confusion limited and will not reach the theoretical sensitivity.

<sup>‡</sup>: This value is based on 5 MHz bandwidth while a wider bandwidth may be unuseable in practice.

Table 2.2: Characteristics of the WSRT and its receivers

<b>DXB spectral line backend</b>								
bandwidth options(MHz):	10	5	2.5	1.25	.625	.313	.156	.078
# of complex channels (2-bit):	1280	2560	5120	10240	20480	40960	40960	40960
# of complex channels (1-bit):	2560	5120	10240	20480	40960	40960	40960	40960
channel separation (kHz):								
91 interferom. 4 polariz.2-bit <sup>†</sup>	-	-	-	-	19.5	9.77	4.88	2.44
10 interferom. 1 polariz.1-bit	39.06	19.53	9.77	4.88	2.44	1.22	0.61	0.31
40 interferom. 2 polariz.1-bit	312.5	78.1	19.53	4.88	2.44	1.22	0.61	0.31
<b>DCB continuum backend</b>								
total bandwidth (MHz):	8 × 10 = 80	40						
bandwidth options (MHz):	10	5						
# of complex channels:	2048	2048						
<b>MK2 VLBI backend</b>								
max. total bandwidth (MHz)	2							
bandwidth options (MHz)	2	1	.5	.25	.125	.0625		
<b>MK3 VLBI backend</b>								
max. total bandwidth (MHz)	14 × 4 = 56							
bandwidth options (MHz)	4	2	1	.25	.125	.0625		

<sup>†</sup>: See part III, table 5.2 for the DXB settings used for this configuration.

Table 2.3: Characteristics of the WSRT backends

### 2.3.1 THE SPECTRAL LINE BACKEND (DXB)

The basic number of independent 1-bit complex correlation products which the DXB<sup>1</sup> can produce simultaneously is 2560. In 2-bit mode the correlator produces half the number of products (1280) with a sensitivity improved by approximately 1.25. When the observed spectrum can be covered adequately with an overall bandwidth ( $B$ ) narrower than its maximum value (10 MHz), the clockrate of the correlator (20 MHz) allows the number of correlation products to be increased by a factor  $10/B$  to a maximum of 40960 ( $10/B$  is a power of 2). The number of complex channels, obtained after Fourier transformation of the correlation functions, may be distributed over interferometers and polarization channels of the array. How one chooses to do this depends not only on the spectral resolution required but also on the sensitivity needed per frequency point (= complex channel) on each interferometer. Sensitivity may be increased by observing in 2-bit mode and with two independent polarization channels.

The number of independent frequency channels  $N_F$  in each observed spectrum depends on the overall bandwidth  $B$  (MHz), the correlator bit-mode  $N_B$  (1 or 2), the number of interferometers  $N_I$  and the number of polarization channels  $N_P$  by the relation:

$$N_F \cdot N_B \cdot N_I \cdot N_P = 2560 \times \frac{10}{B(\text{MHz})} \quad (2.1)$$

The maximum number of frequency channels, set by the capacity of the on-line computer and software, is 256. As an example the channel separation is given in table 2.3 for each of the eight possible overall bandwidths available and for two rather extreme choices: (i) use of 91 interferometers in 4 polarization channels and 2-bit correlation mode for maximum sensitivity (e.g. for HI absorption and polarization studies), and (ii) use of all possible correlation products on, for instance, 10 interferometers in one polarization channel in 1-bit correlation mode for high spectral resolution. We also show a more common case of 40 interferometers in a 1-bit mode observing at 2 polarizations.

### 2.3.2 THE CONTINUUM BACKEND (DCB)

The digital continuum backend, DCB, is a broadband backend with a maximum total bandwidth of 80 MHz. This 80 MHz is divided in 8 bands of 10 MHz maximum width to avoid bandwidth smearing at the edges of the maps.

The 8 frequency bands are independent in the sense that each of them can be set to either 5 or 10 MHz width and that they can be tuned independently over the whole frequency range available (table 2.2) with the restriction that the IF bandwidth is limited to a maximum of about 110 MHz at all frequencies. For 49 cm only 2.5 and for 92 cm only 5 MHz **total** bandwidth are available. In most practical cases there is no need to use the DCB at 49 and 92 cm and so the DXB is used for continuum observations at these wavelengths.<sup>2</sup>

The DCB has a total of 4096 interferometer channels, or 512 channels per band. For each band these 512 channels are divided over the telescopes in the same, fixed, way. This is different from the DXB for which the division of channels over the telescopes can be chosen by the user.

The 512 channels are 256 complex channels (256 pairs of cos and sin correlations). These are divided in 160 standard and 96 non-standard complex channels. The standard channels comprise all the fixed-movable telescope (*i.e.* the standard baselines) and all polarization combinations.

The non-standard channels are used to determine telescope errors using the baseline redundancy in the non-standard baselines. Therefore enough correlated power must be available in the non-standard baselines; for this reason the cross-channels (XY and YX) are not used. The 96 available non-standard channels are divided over 47 XX and 47 YY combinations. For the WSRT there are 51 independent non-standard baseline combinations possible for each polarization. Interferometers 0-5, 0-6, 1-6 and 1-7 are not measured in this case.

<sup>1</sup>The correlator actually consists of a DLB and a DXB unit. For 10 MHz bandwidth the DLB is used. For  $B < 10$  MHz the DXB is used to obtain more channels by recirculation of the interferometer channels over the DLB input channels. For clarity we do not make a distinction between the DLB and DXB in this documentation. And we will refer to the DLB/DXB spectral line backend as DXB.

<sup>2</sup>In the near future a DCB configuration for 92 cm will become available. It is then possible to cover 40 MHz total bandwidth in 8 bands each with a width of 5 MHz



### 2.3.3 VERY LONG BASELINE INTERFEROMETRY (VLBI)

Any combination of the WSRT dishes can be used as a 'tied array' to serve as one station in the VLBI network. Two types of VLBI backends are available: The narrow-band Mark2 system and the wide band Mark3 system. Input to the recording terminals is from one of the normal WSRT backends: the DXB in combination with the MK2 and the DCB in combination with the MK3. It is possible to observe with two polarization channels simultaneously with the MK3 system. With the MK2 system one can switch between polarizations but one cannot observe them simultaneously.

## 2.4 FUTURE DEVELOPMENTS

### 2.4.1 PULSAR FILTERBANK

In the autumn of 1993 a new backend will become available. This backend is especially designed for work on pulsars. In the near future specifications will be published in this documentation.

### 2.4.2 THE DZB BACKEND

In the future the DZB correlator will replace the DCB and DLB/DXB backend. The most important improvement over the previous backends is that:

- it will provide adequate < 1% spectral resolution for spectral line observations with bandwidths ranging from 160 MHz down to 156 kHz.
- it will measure all redundant baselines to enhance dynamic range and sensitivity.
- it will extend the continuum bandwidth by a factor 2 to 160 MHz.
- it supports a tied array mode for VLBI and pulsar observations.
- it will support gating facilities for pulsar observations and interference suppression.

More details of the DZB can be found in the NFRA internal technical report by Bos (1993).

### 2.4.3 THE MULTIFREQUENCY FRONT ENDS

In 1996 the multi frequency front ends (MFFE's),(ready in 1996/97), will replace the current 6, 21, 49, and 92 cm frontend boxes in all 14 telescopes. The frequencies at which these frontend will be able to operate are shown below. More information about the MFFE's can be found in the note by Tan (1990)

wavelength (cm)	frequency (MHz)	System Temp. (K)	Bandwidth (MHz)
92	305-386	<120	>10
49	608±2	<100	>10
21	1200 - 1450	27	160
18	1590 - 1750	26	160
13	2215 - 2375	52	160
6	4770 - 5020	53	160
3.6	8150 - 8650	84	160
UHF low	250 - 460	<150	>10
UHF high	700 - 1200	<100	>10

## 2.5 THE WSRT VIS-A-VIS THE VLA

Many astronomers have gained experience in synthesis mapping through use of the Very Large Array (VLA), and therefore may be reluctant to use another instrument which is perceived as less powerful or less accessible. We want to stress that, on the contrary, the WSRT is quite accessible, and that certain research programs can be carried out equally well, if not better with the WSRT. Below we will give a brief summary of the kind of programs for which the WSRT is especially well suited. A general description of the VLA can be found in Thompson et al. (1980) or Napier, Thompson and Ekers (1983).

1. Long wavelength observations: With the WSRT observations at both 49 and 92 cm are possible. This is important for spectral index studies (deconvolving thermal and non-thermal components), observations of steep spectral index sources, and very wide field mapping. Especially the broadening of the '92 cm band' will provide opportunities for studies of high redshift HI absorption and emission.
2. Polarization studies: Since the WSRT uses dipole feeds accurate measurements of circular polarization are possible. All dipole feeds are positioned on the optical axis of the telescope; this is not the case for the VLA which introduces severe off-axis instrumental polarization effects. For the WSRT the instrumental polarization across the primary beam, at 6, 21, and 49 cm, is very low; at 92 cm the off-axis polarization are well known and can be calibrated out. In addition the WSRT has the advantage that the feeds do not rotate with respect to the sky during an observation because the dishes have a polar mount. Therefore instrumental off-axis polarization can be corrected much more easily.
3. Line polarization: The line system can record I, Q, U and V simultaneously. (For example 21 cm Zeeman observations at high precision are possible).
4. Wide field mapping at 6 and 21 cm: Since the standard mode for continuum observations divides the total bandwidth into 8 channels, the effect of bandwidth smearing are reduced to levels that permit accurate work down to the 10 percent level of the primary beam.
5. The possibility exists, especially with the DCB and, if one is not limited by the number of channels, also with the DXB, to measure a large number of redundant baselines. In combination with extraordinary small 'closure errors' ( $\sim 0.01^\circ$  in phase and 0.02% in amplitude) this enables the attainment of very high dynamic range (current record is 500,000:1) in a fast and reliable way.

It should be noted here that the WSRT has no capabilities for 1.3 and 2 cm observations, that 'snapshot' type observations are better done at the VLA where instantaneous UV coverage is quite good, and that sources below  $20^\circ$  declination suffer a degradation in resolution of more than a factor of 3, since the declination resolution scales as  $\text{cosec}(\delta)$ , and the observations below the equator suffer from incomplete UV coverage.

## 2.6 REFERENCES

- Bos, A. (1993): *NFRA internal tech. report*, **200** (available at NFRA).
- Napier, P.J., Thompson, A.R. and Ekers, R.D. (1983): 'The Very Large Array; Design and Performance of a Modern Synthesis Radio Telescope', *Proc IEEE*, **71**, pp. 1295-1320.
- Tan, G.H. (1990): *NFRA NOTE*, **555** (available at NFRA).
- Thompson, A.R., Clark, B.G. and Napier, P.J. (1980): *Astrophys. J. Suppl.*, **44**, pp. 151-167.

Some of the first articles about the WSRT are:

'*The Synthesis Radio Telescope at Westerbork. Principles of Operation, Performance and Data Reduction.*

Högbom, J.A. and Brouw, W.N. (1974): *Astron. & Astrophys.*, **33**, p. 289.

'*The Synthesis Radio Telescope at Westerbork.*'

Baars, J.W.M., Brugge, J.F. van der, Casse, J.L., Hamaker, J.P., Sondaar, L.H., Visser, J.J. and Wellington, K.J. (1973): *Proc IEEE* **61**, p. 158.

*'The Synthesis Radio Telescope at Westerbork. General Lay-Out and Mechanical Aspects.'*

Baars, J.W.M. and Hooghoudt, B.G. (1974): *Astron. & Astrophys.* **31**, p. 323.

The calibration procedures were originally discussed by:

Bos, A., Raimond, E., and Someren Greve, H.W. van (1981): *Astron. & Astrophys.* **98**, p. 251.

Someren Greve, H.W. van (1974): *Astron. & Astrophys. Suppl.* , **15**, p. 343.

# WSRT PART I

## USER DOCUMENTATION CHAPTER 3

# WSRT PROPOSALS

## 3.1 THE PROPOSAL PROCEDURE

### 3.1.1 INTRODUCTION

In this chapter we give guidelines to the preparation and submission of proposals. A proposal cover sheet (page 3-8) should accompany each proposal. All proposals should be sent to the PC chairman (see chapter 5). We emphasize that the WSRT is available to observers from all countries, and time is awarded on basis of merit of the scientific program.

### 3.1.2 THE PROGRAM COMMITTEE

The program committee (PC) currently meets twice a year. About one month after the proposal deadline the PC determines the allocation of telescope time based on referee reports. Minutes of the PC are kept and distributed after each meeting. After the PC has met, all proposals, material and referee's comments become public. Copies of the PC minutes can be requested from the PC secretary (see section 5). Interim allocations for urgent and/or highly rated proposals are also possible.

### 3.1.3 WSRT SCHEDULING

Since the WSRT (still) has single frequency frontends, quick changes of observing frequencies are impossible. The duration of a particular observing period at a given frequency is therefore determined by proposal pressure at each wavelength. Typical lengths of such periods are 1-2 months at 6 cm (often spring or fall) and at 49 cm, 2-3 months at 92 cm and 3-4 months at 21 cm (often late spring to fall). The telescope calendar is published in the PC minutes.

**INTERIM PROPOSALS** Proposals of urgent nature ( or in cases when PC deadlines cannot be met) can be sent to the PC chairman at all times for consideration of interim allocation. Interim proposals will pass through the standard refereeing system, but do not require passing the PC meeting before time is allocated.

**SERVICE OBSERVING** The WSRT is operated by on-site staff and in general there is no need for the astronomer to be present during the observations. Proposers who plan to reduce their data with their own software package (e.g AIPS) can receive their calibrated data on tape from the Telescope Operation Group upon request. For more information on the reduction of WSRT data we refer to part IV.

## 3.2 ACKNOWLEDGMENT

If a publication is based on observations with the Westerbork Synthesis Radio Telescope the following line should be included as a footnote or in the acknowledgments:

*“The Westerbork Synthesis Radio Telescope is operated by the Netherlands Foundation for Research in Astronomy with financial support from the Netherlands Organization for Scientific Research (NWO)”*

## 3.3 GUIDELINES FOR SUBMISSION OF PROPOSALS FOR USE OF THE WESTERBORK SYNTHESIS RADIO TELESCOPE

### 3.3.1 CONTENTS OF THE PROPOSAL

A proposal must contain all information needed for a proper evaluation of its scientific merit, time lines and technical feasibility. The program committee has to analyze and discuss some 30 or 40 proposals each meeting. To make this reasonably possible, proposals must be concise but complete. Within 1-4 typewritten pages, a proposal should contain the following items in the order indicated.

1. A highly informative title (maximum 42 letters and spaces), to be called ‘**Subject of study**’; this title will be used in summary listings and for reference.
2. A brief **summary** (1-5 lines) of the project.
3. A **statement and discussion of the scientific purpose** of the project. It should include a summary of the present status of the subject, with reference to recent literature; discuss the problems to be attacked, methods to be followed, and importance of the results to be obtained. It should mention earlier, related proposals (with their Westerbork code numbers), summarize their results and/or refer to publications based on them. If the proposal is a sequel to earlier proposals on the same subject, a progress report should be given summarizing the dates of earlier proposals, times allocated, status of the reduction and analysis, and results achieved. For the discussion of scientific purposes a reference to an earlier proposal may then suffice.
4. **Required instrumentation** For standard arrangements this item can be quite brief. If any non-standard arrangement is required, the proposal must be submitted several months in advance, so that the PC has time for consulting specialists within the NFRA. Standard arrangements are available for line and continuum observations. Non-standard arrangements include special modes of operation like e.g. the pulsar- or mosaicing mode and special backend configurations (e.g. the use of special redundant baselines). For more information about special modes of operation see part III section 3.4.2, section 3.4.1, Chapter 5 and Chapter 6.
5. **Proposed observations**, with amount of time required and detailed arguments for these, including considerations of angular size, confusion, required resolution (in angle and velocity), signal-to-noise ratio, etc. The proposed observations must be individually listed (one line per observation) on the cover sheet as found on page 3-8.  
  
Short observations (duration  $\leq 1$  hour), however, may be arranged in blocks and listed one block per line. (Such blocks will normally be scheduled in detail, with the proper calibrations included, by the proposer in consultation with the Westerbork Telescope group.)
6. **Total amount of time** required, with specification (if necessary) of time of year and (for visitors, PhD. theses, etc) deadlines.
7. **Names of proposers**, including those responsible for handling of observations and reduction, and for analysis and interpretation.
8. **Date of the submission.**

9. **Address and telephone, fax number and computer mail address of the project leader.** The project leader is the person responsible for the project; he will be consulted by the PC for further information if required.

### 3.3.2 PROCEDURE FOR SUBMISSION AND EVALUATION

Proposals must reach the PC Chairman before the deadline. There are two deadlines each year, **March 15 and September 15** (at 12.00h), before which proposals for observations, regardless the wavelength range of the observation, can be submitted. These deadlines are chosen not to conflict with deadlines for PATT and ESO. One (original) copy only will suffice. The Chairman will circulate the proposals to the PC members, after assigning a code number and referees; therefore do *not* send proposals directly to individual PC members. Extensive progress reports, preprints and reprints (if required) should be sent in triplicate, for Chairman and referees.

Acknowledgment of receipt will in general be sent only for foreign proposals, or if the proposal is held to a later meeting.

Proposals are critically evaluated by (normally) two referees, who may request further information from the project leader. Decisions about time allocation are (normally) taken by the PC at its meeting. Project leaders are notified of time allocations, with appropriate comment as the case may be. Proposers have the right of appeal.

Allocations are given priority 1 or 2. Short observations can sometimes be allocated as 'Filler'. Observations with priority 1 will normally be carried out during the current or imminent observing period, if at all possible. If an observation has priority 1 NFRA guarantees data of satisfactory quality (e.g. no important baselines missing. etc)

Priority 2 observations can only be carried out if they do not delay the telescope calendar.

Allocations are valid for a particular observing period. If they can not be carried out in that period, the proposal will only be considered after receipt of a written note from the project leader.

Once a partial allocation has been made, the proposal will *not* automatically be considered for further allocations. These require a new, written request, with a project information sheet; and in general such a request should be accompanied by a progress report.

**RUSH TREATMENT** In some cases, proposals for observations at very short notice can be given rush treatment. In such cases it is best to consult the PC Chairman by telephone, fax or e-mail. Where necessary, decisions can be taken within a few hours; in general such interim allocations will be done as fillers.

### 3.3.3 THE PROJECT INFORMATION SHEET

The purpose of the information sheet <sup>1</sup> is to provide the PC with a rapid overview of the main astronomical and technical data for a proposal, the observing time required, and its effect on WSRT schedules. It is important that the cover sheet be fully completed. Observations at different frequencies (*i.e.* with different receiver frontends) require separate sheets.

The separate items on the project information sheet are summarized below. We refer to the relevant sections in this documentation for more information. Please fill in the information sheet with utmost care, it provides the PC and the Telescope operation group with important information. <sup>2</sup>

**Project leader:** Person responsible for the project: to be consulted by the PC for further information.

**Project Members:** All those collaborating in the project.

**Subject of Study:** A brief yet highly informative title of the project, to be used in summary listings and for reference. Maximum: 42 letters and spaces.

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<sup>1</sup>the project information sheet (page 3-8) can be also be copied from the anonymous FTP-node `rzwmw10.nfra.nl (192.87.1.160)` or ordered at NFRA.

<sup>2</sup>For users of a MS-DOS Personal computer there is a program available to fill in the project information sheets. People interested in a copy should send a request to J.Sluman, NFRA. The MS-DOS executable can also be found on the anonymous ftp node (`rzwmw10.nfra.nl(192.87.1.160)`)

**Category:** Under which category we can put the subject of study.

For each object to be observed in this telescope configuration fill in the items below. Remember that for a different telescope setting, or different observing wavelength you have to fill in a separate project information sheet.

**Source Name:** Use current name helping to identify the astronomical object.

**Ra, Dec:** The right ascension, declination and epoch. No precise coordinates are required. An accuracy of 1/10 the primary beam suffices; hence, rounding to 0.1 minute of time and 1 arcmin is adequate. The purpose of coordinates on the information sheet is twofold:

1. Checking for overlap with observations already made. <sup>3</sup>
2. Assessment of the effects of the observations on WSRT schedules.

**9A spacing** (Shortest spacing): This will normally be 36, 54, 72 or 90 meters.

Also see the discussion in chapter 8, "WSRT Beams", of part III.

**Sidereal time:** Sidereal time of the begin and end of the measurement. Check when the object is visible in the azimuth elevation diagram (part V, figure 1.1, page 1-3) and if shadowing occurs (part III section 9.3, page 9-1).

**Velocity:** The systemic velocity of the object if applicable.

**Comments:** Comments on the items listed above.

You are now at the point where you have to specify the frontend, backend, and telescope settings.

There are two modes of operation in which the WSRT is often used: continuum and line observation mode. These modes of operation can be specified by using this form. Other modes of operation like mosaicing, observing in pulsar mode and observations using other than the default DXB redundant setting need to be specified by writing the full specification on the backside of this form. In that case a motivation for the chosen specification must be included in the proposal.

If the standard continuum mode or standard line mode is chosen (in the specification block of the form) there is a number of obligatory items to specify. The other parameters have sensible default values which will be taken if the observer did not specify otherwise. However, not specifying items is at the observers own risk.

**Setting specification of the standard continuum mode:** If you want to use the standard correlator mode for continuum measurements answer 'yes' here. This means you have to specify the following items:

1. Frontend item 1; the wavelength of your observation. (6, 18, 21, 49 or 92 cm)
2. The reduction you want to be applied to the data.

Once you have chosen the wavelength the frontend and backend specification and all the telescope specifications are fixed and do not need to be specified anyfurther. These are summarized, together with default settings, in the table 3.1.

**Note 1.** The digital continuum backend (DCB) consists of 8 independent IF systems with 5 or 10 MHz wide bands. Each IF can be tuned independently so one can cover up to 80 MHz total bandwidth. Each band provides the standard spacings for all 4 polarizations, and most redundant baselines for the XX and YY correlations.

The common situation at 6 cm wavelength is that the 8 bands are set to a width of 10 MHz and tuned such that they are placed side by side in frequency to cover 80 MHz total bandwidth.

The common setting for 21 cm observations is:

band no.	1	2	3	4	5	6	7	8
bandwidth	5	10	10	5	10	10	10	5
central freq.	1423.5	1415.0	1405.0	1397.5	1395.0	1385.0	1375.0	1367.5

<sup>3</sup>You can do this yourself using ARCQUERY, see chapter 4

Frontend			Backend							velocity	
$\lambda$	Tel	dp	BE	$B$	$N_I$	$N_P$	$N_F$	$N_B$	TPR	ref	def
6	ALL	++	DCB	80	†	*	$\bar{h}$	$\flat$	xxx	xxx	xxx
18	0 ABCD	++	DXB	10	10	2	0	1	HN	LSR	RADIO
21	ALL	++	DCB	60	†	*	$\bar{h}$	$\flat$	xxx	xxx	xxx
49	ALL	++	DXB	2.5	RC	*	$\bar{h}$	$\flat$	HN	xxx	xxx
92	ALL	++	DXB	5	RC	*	$\bar{h}$	$\flat$	HN	xxx	xxx

abbreviations:

$\lambda$  =wavelength

Tel=Telescopes

dp=dipoles

BE=Used Backend

$B$  =Maximum Bandwidth (MHz)

$N_I$  =number of interferometers

$N_P$  =number of polarizations

$N_B$  =number of bits

RC =redundant configuration ( $N_I > 40$ )

$N_F$  =number of freq. channels

$\nu$  =frequency (MHz)

ref =velocity reference

def=velocity definition

Used signs:

† =40 standard 48 non standard

\* = 4 standard 2 non standard

$\bar{h}$  = 8 standard 8 non standard

$\flat$  = 2 standard 2 non standard

xxx= No answer possible

Here standard refers all the fixed-movable telescope pairs and non-standard refers to the other redundant telescope pairs. Dipole setting ++ means that the dipoles of fixed and movable telescopes are parallel, +x means that the dipoles of the movable telescopes are rotated with respect to the dipoles of the fixed telescopes by 45°.

Table 3.1: The default setting for the standard mode of continuum observations. Not that  $B$  is the maximum bandwidth available; you must always specify the bandwidth of the observation.

The observer may want a different setting of these bands. Please answer ‘no’ to “standard continuum? (yes/no)” and specify the bands on the backside of the Project information sheet.

**Note 2.** The bandwidths available at 49 and 92 cm are 2.5 and 5 MHz respectively. Therefore there is no reason to use the DCB and in practice the DXB is used<sup>4</sup>. Default settings provide all 4 polarizations, the standard and redundant baselines for the XX and YY correlations, and the standard baselines for the XY and YX correlations. The number of frequency channels is 8, giving some possibilities for editing narrow band interference if present.

If the DXB is used for continuum observations, the distribution of correlator channels over telescopes and polarization does not need to be the same as specified above. If you want, you may specify another set-up. If you do so, please indicate you do not want to use the default correlator setup and answer ‘no’ to “standard continuum? (yes/no)” to indicate that you want to measure in a special redundant mode also specify your setting (with motivation please) on the backside of the Project information sheet.

**Setting-Specification of the standard line mode:** If you want to use the standard correlator mode for line measurements answer ‘yes’ here. This means you have to specify the following frontend items:

- Frontend item 1; the wavelength of your observation. (6, 18, 21, 49 or 92 cm)
- Frontend item 2; the velocity definition, radio or optical. If a velocity,  $v$ , is specified (in the object information block of the project information sheet), the frequency,  $\nu$ , is calculated from the rest frequency  $\nu_0$  following either the radio of the optical definition.

$$\text{optical } \nu = \nu_0(1 + v/c)^{-1}$$

$$\text{radio } \nu = \nu_0(1 - v/c)$$

- Frontend item 3; the velocity reference (local standard of rest or heliocentric) of the velocity specified in the object information block of the project information sheet.
- Frontend item 4; the line transition you are interested in. (see e.g. table 1.1 in part V)

<sup>4</sup>Possibilities for the placement of 8 DCB bands of 5 MHz width in the 92 cm band will be investigated in the fall of 1993



Also specify the following backend items (for some hints also see III, section 3.1):

- Backend item 1;  $N_F$  (# channels) the number of frequency channels. ( $N_F \leq 256$ )
- Backend item 2;  $B$  (Bandwidth) the bandwidth of the observation. This can be 10, 5, 2.5, 1.25, ..., 0.0078 MHz.

The limitation is that  $N_F \cdot B \leq 320$  (because  $N_P = 2$ ,  $N_B = 1$ ,  $N_I = 40$  and  $N_F \cdot N_P \cdot N_B \cdot N_I \leq 25600/B$ )

- Backend item 3; Frequency taper, Uniform or Hanning or Hamming.

For a channel separation  $b = \frac{B}{N_F}$  the effective frequency resolution (FWHM) and sidelobe strength is given for the uniform, Hanning and Hamming taper as follows

	Beamwidth FWHM	highest side lobe in Db	in %
Uniform (US)	$1.21 B/N_F$	-6.5	22.4
Hanning (HN)	$2.0B/N_F$	-16.0	2.5
Hamming (HM)	$1.81B/N_F$	-21.5	0.7

where:

$N_F$  is the number of frequency channels

$B$  is the bandwidth

In the standard line setup a number of items is fixed. The values of these items are summarized in table 3.2 (together with some default values for frontend item 1 to 4 and backend item 1 to 3).

The default setting for line observations at 6 and 21 cm is  $N_P = 2$ ,  $N_B = 1$  and  $N_I = 40$  these values can be changed however as long as  $N_F \cdot N_P \cdot N_B \cdot N_I \leq 25600/B$ . For instance: for strong sources there is a possibility to increase the frequency resolution but then one needs to specify  $N_P = 1$  and increase  $N_F$  by a factor of two. (Remember  $N_F \cdot N_P \cdot N_B \cdot N_I = 25600/B$  is the limit). By default all the telescopes are used, it is possible to use a thinned array, specify which telescopes to use in the telescope setting box and remember to change the number of interferometers accordingly (e.g. Telescopes 0-9,A,B implies  $N_I = 20$  if redundancy is not needed.)

For 49 and 92 cm the redundant ( $N_I > 40$ ) configuration is used. The standard setup is shown in the table. Here also the bandwidth and number of frequency channels are set to a default value.

If you want a different bandwidth or a different number of frequency points the specification of a redundant configuration gets more complicated. Here also the limitation  $N_F \cdot N_P \cdot N_B \cdot N_I \leq 25600/B$  applies. Remember that for each bandwidth there is a large range in the  $N_F, N_P, N_B, N_I$ - space that can be used. See table 7.2, 5.2 and 5.3 of part III for some possible redundant DXB settings.

**If you do not use Standard line or Continuum mode** You have to specify all the items on the project information sheet and add other specifications with motivation on the backside of the project information sheet. We refer to part III of the documentation for more information.

**The telescope** For a standard setup there is no need to specify the telescope setup. The defaults can be found in the tables. For non-standard setups you need to specify the number of polarizations,  $N_P$ , the number of interferometers,  $N_I$  and which telescopes to use.

**Reduction** You can indicate here what corrections you want to be applied to your data. Default is that when the observation is finished, your data is archived without additional corrections. The project leader is informed after the data has been archived and the corrections (if requested) have been made. If special corrections are required, one is requested to get in touch with dr. Tony Foley of the Telescope Operation Group.

Which corrections are (can be) applied can be found in part IV, chapter 1.

Frontend			Backend							velocity	
$\lambda$	Tel	dp	BE	$B$	$N_I$	$N_P$	$N_F$	$N_B$	TPR	ref	def
6	ALL	++	DXB	10	40	2	64	1	HN	LSR	RADIO
18	0 ABCD	++	DXB	10	40	2	64	1	HN	LSR	RADIO
21	ALL	++	DXB	10	40	2	64	1	HN	HEL	OPTICAL
49	ALL	++	DXB	2.5	RC	4	16	1	HN	-	-
92	ALL	++	DXB	5	RC	4	16	1	HN	-	-

abbreviations:

- $\lambda$  =wavelength
- Tel=Telescopes
- dp =dipoles
- BE=Used Backend
- $B$  =Bandwidth (MHz)
- $N_I$  =number of interferometers
- $N_P$  =number of polarizations
- $N_B$  =number of bits
- RC =redundant configuration ( $N_I > 40$ )
- $N_F$  =number of freq. channels
- $\nu$  =frequency (MHz)
- ref=velocity reference
- def=velocity definition

Dipole setting ++ means that the dipoles of fixed and movable telescopes are parallel, +x means that the dipoles of the movable telescopes are rotated with respect to the dipoles of the fixed telescopes by 45°.

Table 3.2: The default settings for the mode of line observations

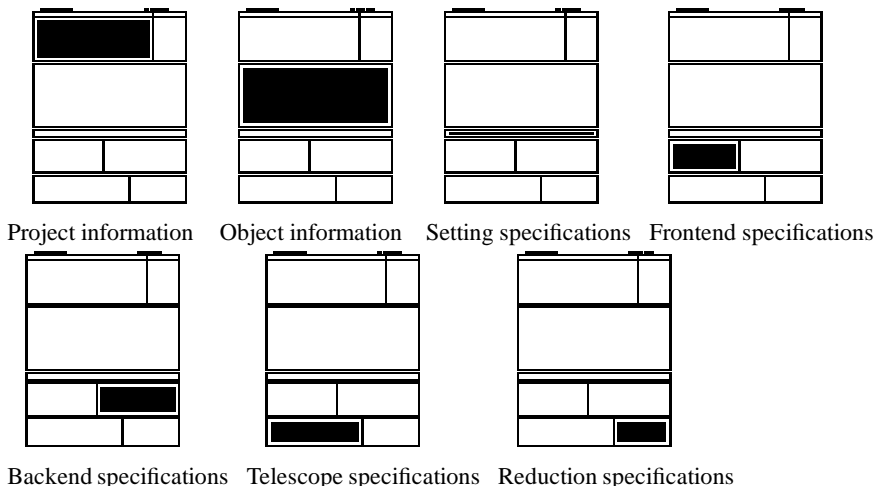


Figure 3.1: Indication of the information blocks on the proposal information sheet

# WSRT Project Information Sheet

Version 1.1 April 1992

		P.C. use only
Proposal date:		Prop.no.:
Project Leader:	E-mail:	Referees:
	Telephone:	
Address:	Fax:	Time Allocated:
Project members:		
Subject of Study:		PC Meeting #:
Last Proposal on this subject:		
Category:* Extragalactic / Nearby Galaxies / Galactic / Stars		

Source Name (in order of priority)	R.A. 1950* 2000* h:m:s (ddd.ddddd)	Dec d:m:s (ddd.ddddd)	9A spacing meters	Sidereal time begin end hh.mm hh.mm (dd.d) (dd.d)	Velocity km/sec or Frequency MHz
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
Comments:					

Standard Continuum*	yes / no ( if yes: fill out at least frontend item no. 1 )
Standard Line *	yes / no ( if yes: only fill out at least frontend items no. 1 - 4 and backend items 1 - 3 )

Frontend	Backend
1 Wavelength:* 6 18 21 49 92 cm.	1 NF (# channels):* 8 16 32 64 128 256
2 Vel. Definition:* Optical / Radio	2 BW (Bandwidth): MHz.
3 Vel. Reference:* LSR / HEL	3 Frequency Taper:* US / HN / HM
4 Line Transition:	4 NB (# bits):* 1 / 2
5 Rest Frequency: MHz	5 Integration time: standard / sec
6 Dipoles:* ++ / +x / xx	6 Backend to use:* DXB / DCB
	7 DCB settings:* standard / MHz.

Telescope	Reduction
NP (# Polarizations):* 1 / 2 / 4	Standard Calibration:* yes / no
NI (# Interferometers):* 5 / 10 / 20 / 40 / > 40	Shadowing Correction:* yes / no
Telescopes to use:* 0 1 2 3 4 5 6 7 8 9 A B C D	Ionospheric Corrections:* yes / no
	Format:* EBCDIC / ASCII / FITS

# WSRT PART I

USER DOCUMENTATION CHAPTER 4

## THE ARCHIVE OF WSRT OBSERVATIONS

*by Ernst Raimond and Ger de Bruyn  
from NFRA/ASTRON Newsletter No.1 1990*

### 4.1 INTRODUCTION

All the observations and calibrations ever done with the Westerbork Synthesis Radio Telescope have been archived. Not only were the data, collected between 1970 and today, stored but also was the standard data processing carried out in a controlled environment. Therefore, the processing is reasonably well documented. In the early years (1970–1979) the data reduction was carried out in Leiden and the archived, calibrated data of that period still reside at the Leiden Observatory. Since 1979 the data processing was done in Dwingeloo and the archived observations and calibrations are stored there. The storage medium for all data from 1985 is optical disk. In fact almost all data since 1979, and the ‘Leiden tapes’ are being stored on optical disk.

In this section we wish to restate that data in this archive are available for interested astronomers. Below we will describe which data are available, their sensitivity and other parameters as well as how to explore the archive and request specific data sets.

### 4.2 ARCHIVE RESEARCH POSSIBILITIES

Twenty years of observing have created an enormous data reservoir. An obvious use of this data bank is in the study of variable phenomena (radio stars, active nuclei, supernova remnants etc.). A further use of the archive is in the study of objects that just happened to lie within the synthesized fields. The excellent wide field imaging capabilities of the WSRT are a great asset in this regard. Many fields were observed with the WSRT with the aim to study a single object near the center of the field. In the analysis process the other sources in the field were often ignored. Many serendipitous discoveries have been made this way and no doubt many more are still waiting to be made. Especially at the longer wavelengths (49 cm and 92 cm) but also at 21 cm the number of background sources are very large. Each 92 cm synthesis produces an image with information over an area almost as large as a 48-inch Schmidt plate! Obviously these fields lend themselves perfectly to statistical research on large numbers of sources. A further use of the archive data is the re analysis of old data with the new (self-)calibration tools developed the last years. There are also projects from which results, for one reason or another, even after many years have not reached the press. And some of the data may never be published because their owners left astronomy or got sidetracked. If they were done more than 2 years ago the data are freely available!

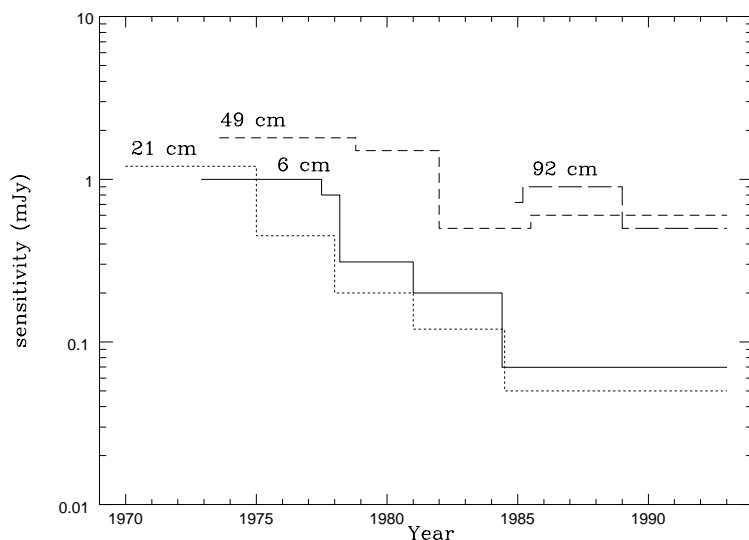


Figure 4.1: WSRT sensitivity ( $1\sigma$  thermal noise during a 12h observation) improvements in the past 20 years

### 4.3 AVAILABILITY OF THE ARCHIVED DATA

NFRA's official policy is that after two years after the date of the observation WSRT data are available to anybody interested. Before that time the original proposers of the observations have exclusive access. The relatively long proprietary period (it is one year for some other observatory archives) was chosen because it often takes several months before all data for an astronomical project have actually been observed by the WSRT. As a result a good portion of a year may elapse before proper analysis of the data can commence in earnest.

### 4.4 SKY COVERAGE AND SENSITIVITY

About three quarters of the sky is accessible from the location of Westerbork. However, the WSRT being an east-west synthesis array, the resolution gets worse at low declination (by a factor  $1/\sin\delta$ ) and for declinations below the equator the obtainable UV-coverage is limited for obvious reasons. To give a potential user of the WSRT archive some idea of the usefulness of a particular data set for the application in mind we give a graphical summary of the nominal sensitivity of the data as a function of time. This graph is shown in figure 4.1. For the four main wavelengths of the WSRT the formal thermal noise level ( $1\sigma$ ) for a  $1 \times 12^h$  continuum observation is plotted as a function of time. The graph also shows since when a given wavelength has been available. A brief explanatory guide to the improvements indicated in the graph follows:

- In 1974 the 21 cm system temperatures were improved from about 250 to 90 K.
- From 1977.5 on the 6 cm data were taken with a hybrid array with system temperatures of 150 and 220 K for 10 and 2(4) telescopes.
- In late 1977 two more movable telescopes were added to the array and the Digital Line Backend became operational. This improved the bandwidth from 4 MHz to 10 MHz at 6 and 21 cm, and decreased

the 49 cm bandwidth from 4 to 2.5 MHz. N.B. the new dishes were moved to a new location in 1980 doubling the resolution of the array.

- In 1981 the four movable telescopes were equipped with a cryogenically cooled frontend creating a hybrid array with at 92 cm a 35/90 K system and at 6 cm a 65/150 K system.
- In 1982 the system temperature of the 49 cm frontends was lowered from 350 to 110 K.
- In 1984 observations at 6 and 212 cm with a considerably wider backend became possible. Normally the 6 cm bandwidth is  $8 \times 10$  MHz and the 21 cm bandwidth  $8 \times 5$  MHz, although the standard has recently become  $5 \times 10 + 3 \times 5$  MHz.
- In early 1985 the recirculating buffer for the Digital Line Backend extended the number of obtainable correlations by a factor of four for the 2.5 MHz bandwidth observations at 49 and 92 cm. This increase has in general been used to yield full polarization data, a large number of redundant baselines and a large number of frequency channels to be less vulnerable to narrow band interference. At the same time the normal mode of correlation changed from 2-bit to 1-bit, leading to a small decrease in the normal sensitivity.
- in January 1989 the RF bandwidth for the 92 cm system was widened to 5 MHz and the 92 cm system temperature lowered from 170 to 130 K.

## 4.5 EXPLORING THE ARCHIVE

The WSRT archive spans twenty years of observing. Obviously, the techniques of cataloging observations have evolved over that period. During the entire period lists of the observations and the calibrations have been maintained by the NFRA WSRT reduction group. The most basic method of finding out what is observed is to consult this lists. Since 1979 those lists are available in computer readable form. Recently they were converted into an Observation Catalogue in which the potential archive user can browse and from which he/she can log into the captive account ARCQUERY on the NFRA VAX. As this is a captive account no password is required; on the other hand the account is arranged in such a way that querying the archives is the only possible activity. The interactive query program (ARCQUERY) was designed by the NFRA for the archive of observations of the La Palma ING optical telescopes. Once you are logged in, you can obtain help on what to do next and you can review what catalogues are available. The current WSRT catalogue is called WSRTOLD. The keywords available to query this catalogue are the ones that were available, rather than a carefully selected set optimal for astronomical use. A new better designed observations catalogue will gradually replace the old one in the process of copying tapes to optical disks. Despite the drawbacks mentioned above, one can search for observations by the project number, object name, coordinates, type of observation, duration of the observation, observing frequency etc. A short manual for ARCQUERY can be found in chapter 3 of part V, ARCQUERY is also described in NFRA Note 474 and the La Palma User Documentation. The Program ARCQUERY has a context sensitive on-line help facility which should enable even the uninitiated user to find his/her way around.

## 4.6 REQUESTING DATA

A request to receive data out of the WSRT archive will always pass over the desk of the Head of the NFRA–WSRT reduction group (Dr. Tony Foley). How the request reaches him depends on what data you would like to receive and on the mechanism by which you made the selection out of the Observation Catalogue.

If you made your selection using ARCQUERY you can issue a request for the observations in your final selection. You can accompany this request with comments. For old observations, which are not in ARCQUERY, you may have to make your selection using a paper copy of a list of archived observations. In that case your request will probably be made by correspondence, by e-mail or by phone to the NFRA reduction group.

# WSRT PART I

## USER DOCUMENTATION CHAPTER 5

# ADDRESSES AND CONTACT PERSONS

## 5.1 ADDRESSES

The address of the Netherlands Foundation for Research in Astronomy is:

NFRA/ASTRON

Postbus 2

NL-7990 AA Dwingeloo

The Netherlands.

tel:+31-(0)5219-7244; telex: 42043 0 srzm nl; telefax+31-(0)5219-7332

e-mail:PSI%(204)1521004::secretary, or secretary@nfra.nl

Address for proposals and information concerning proposals:

Dr. F.P Israel

Sterrewacht Leiden

Postbus 9513

2300 RA Leiden

The Netherlands.

tel:+31-(0)71-275700; telefax:+31-(0)71-275819

e-mail: ISRAEL@strw.Leiden.Univ.nl

For information concerning the instrument:

Dr. R. Braun

NFRA/ASTRON

Postbus 2

NL-7990 AA Dwingeloo

The Netherlands.

tel:+31-(0)5219-7244; telex: 42043 0 srzm nl; telefax+31-(0)5219-7332

e-mail:PSI%(204)1521004::rbraun, or rbraun@nfra.nl

For the preparation of an observation: Dr. T.A.Th. Spoelstra

NFRA/ASTRON

Postbus 2

NL-7990 AA Dwingeloo

The Netherlands.

tel:+31-(0)5219-7244; telex: 42043 0 srzm nl; telefax:+31-(0)5219-7332

e-mail:PSI%(204)1521004::spoelstra, or spoeltra@nfra.nl

The members of the program committee (May 1993) are:

Prof.Dr. A.G. de Bruyn	Dr. P. Katgert
Prof.Dr. H.R. Butcher (99)	Prof.Dr. P.C. van der Kruit (99)
Dr. E. van Dishoek	Prof.Dr. G.K. Miley
Dr. G. Gilmore	Prof.Dr. R.H. Sanders
Dr. J.M. van der Hulst	Dr. T.A.Th. Spoelstra ( <i>secretary</i> )
Dr. F.P. Israel ( <i>chairman</i> )	

## 5.2 CONTACT PERSONS

If you have any questions regarding the WSRT you can always contact NFRA for questions. For specific questions you can contact the persons listed below:

R. Braun : Line Observations.  
J.D. Bregman : Beam properties, instrumental polarization.  
A.G. de Bruyn : (Self-) Calibration.  
A.R. Foley : Archive and standard reduction.  
R.T. Schilizzi : VLBI.  
H.W. van Someren Gréve: Possibilities of the on-line system.  
T.A.Th. Spoelstra: Program committee and the observation schedule.  
R.G. Strom : Polarization measurements.



## USEFUL TABLES

In this chapter we present a few tables where experienced users can find instrument information more quickly. More information can in most cases be found in part III of this documentation

The thermal noise in a 12 h observation can be estimated by:

$$\Delta S_{rms} = \frac{K_\lambda}{\sqrt{\Delta\nu_{\text{kHz}} N_p}} \text{mJy} \quad (6.1)$$

$\Delta\nu$  is the noise equivalent bandwidth,  $N_p$  is the number of polarizations. The factor  $K_\lambda$  is tabulated below.

$\lambda$	6	21	49	90
$K_\lambda$	28	17	42	50

Table 6.1: Thermal noise during a 12h synthesis observation,  $K(\lambda)$  is valid if for 49 and 92 cm the correlation is done in 1-bit mode, and if, for 6 and 21 cm correlation is done in 2-bit mode.

Wavelength (cm)	6	18	21	49	92
Frequency range (MHz)	4770-5020	1590-1730	1365-1425	607-610	305-385
System Temperature (K)					
cooled frontend	55	60	35	-	-
uncooled frontend	150	-	90	110 <sup>†</sup>	140 <sup>†</sup>
interferometer	91	60	56	-	-
$\eta_a$	0.48	0.53	0.53	0.59	0.59

<sup>†</sup>: only on the coolest regions of the sky.

Table 6.2: System temperature and antenna efficiency,  $\eta_a$ , for the different WSRT observing wavelengths.