THE WESTERBORK NORTHERN SKY SURVEY

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1. Introduction

The WEsterbork Northern Sky Survey (WENSS) is a large–sky survey being carried out at 92 and 49 cm with the Westerbork Synthesis Radio Telescope (WSRT). At 92 cm WENSS will cover the sky north of declination +30° (an area of 10,000 square degrees) to a limiting (5σ) flux density of about 15-20 mJy. Both linear and circular polarization data is obtained. The polarization images have a noise level of about 2 mJy (1σ). The spatial resolution at 92 cm is about $1'$. At 49 cm about one fifth of this area will be covered to somewhat lower flux density and with twice the resolution. The resulting catalogue will contain about 250,000 sources at 92 cm and 30,000 sources at 49 cm.

We expect to finish the observations for the WENSS project in early 1996. The final reductions should be completed at the end of 1996. We expect that the first results of the survey will become available to the astronomical community sometime in 1996. The WENSS product will consist of a catalogue of radio sources extracted from the survey and a set of FITS images (each 1024x1024 pixels covering 6°x6° at 92cm). We plan to make them available in both digital (DAT/CD-ROM) and graphical form (atlas). Images will be centered at the locations for the new Palomar Observatory Sky Survey plates. A variety of low resolution images will be made as well to facilitate comparison with other surveys.

2. WENSS data processing

To image large areas of the sky with the WSRT (an east-west synthesis array) within a reasonable amount of time we have to make use of the mosaicing technique whereby the array is repeatedly stepping through a

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fixed pattern (a mosaic) on the sky in a relatively short time. At 92 cm the pointing grid has a stepsize of about 1.3°, half the primary beam width, resulting in very uniform sensitivity. In 40 minutes the 14-element array is steered through a mosaic with 80 pointing centres covering a region of about $10° \times 13°$ in size. At each pointing we integrate for 20 seconds followed by 10 seconds to move the array to the next field. In 12 hours we thus accumulate 18 observations at each pointing. In order to bring down the sidelobe confusion to acceptable levels each mosaic is observed for 6 periods of 12 hours, with different array configurations, to provide radial sampling in steps of 12 meters. This typically takes six weeks. The starting field during each 12 hour observation is chosen such that we get uniform coverage of the UV-plane leading to very low (1%) sidelobe levels in the dirty images. The net observing time spent on each field is 36 minutes. The sky has been divided into four declination zones. The lower two zones ($+30° < \delta < +43°$, and $+43° < \delta < +56°$) each have mosaics containing 8×10 fields. The high declination zones ($+56° < \delta < +75°$, and $\delta > +75°$) have more complicated pointing patterns resulting in a slight non-uniformity in the sensitivity across the mosaics. The lowest three zones were observed with a bandwidth of 5 MHz split into 7 channels of 0.625 MHz each. The polar cap zone, about 10% of the survey, will be observed in the winter of 1995/96 with a recently commissioned broadband 92cm system which has 8 bands of 5 MHz spanning the range from 307 to 385 MHz. The noise in this part of the survey is expected to be lower by about a factor of 2 (depending on the highly variable RFI interference levels). Due to the large spectral baseline this part of the survey may also be expected to yield useful spectral information for the brighter sources.

The reduction of the data is done in Dwingeloo on a dedicated HP730 workstation with about 3 Gbyte of disk space. Early 1995 a second HP715 workstation with 6 Gbytes of diskspace was added to speed up processing. All data are phase-selfcalibrated to remove ionospheric and instrumental phase errors which dominate the raw images at low frequencies. Fields with strong sources are also selfcalibrated in gain. The positions are calibrated using point sources from the Jodrell-VLA-Astrometric Survey (JVAS) augmented with WSRT 21 cm positions of a few hundred pointlike WENSS-sources. This has enabled us to reduce the systematic position errors to about 1″ across the sky. Subsequent analysis is done at Leiden Observatory. In addition to the large mosaic images we also construct 'frames' of 1024x1024 pixels, separated by 21.1″, yielding images of $6° \times 6°$. After converting them to FITS-format they are sent to Leiden where they are searched for discrete sources. Both the peak flux and integrated flux densities are determined.

3. Scientific drivers and first results

The low frequency, positional accuracy, polarization information, angular resolution and sensitivity to large scale structure make WENSS an important and fundamental database for tackling a wide range of astronomical problems. Below we will describe the science drivers and the projects that we have already started. For many of them first results are becoming available and have led to publications now in press. For lack of space we can not show them here (for a colour display of some of the results we refer to the 1994 Annual Report of the NFRA). Although the dataprocessing for the project is still in full swing, and will remain so for one more year, the scientific exploitation has taken off in a very significant way. Several Ph.D. projects have started in 1995 making use of the mosaiced images and the preliminary catalog.

Below we will describe some of projects for which WENSS can be (and is being) used and which have already led to some exciting discoveries.

radio spectra: WENSS will provide spectral information both internally (325-610 MHz for about 2000 square degrees, 307-385 MHz for the polar cap) and by comparison with radio surveys at other frequencies. In combination with available (6C/7C at 151 MHz, GB6 at 5 GHz) and ongoing (VLA-B/D at 1.4 GHz) surveys this will permit the study of very large numbers of (ultra-)steep, flat and inverted spectrum radio sources:

- Ultra-steep spectra sources with indices between -1.3 and -3. Such spectra are often seen in the most distant radio galaxies, in radio sources which populate rich clusters and in pulsars.
- Flat spectrum sources at low flux levels (25-100 mJy). One of the many uses of such a sample (and one already started in 1994) is the search for radio-loud gravitationally lensed objects (the CLASS project, in collaboration with Jodrell and Caltech astronomers). The flat spectrum sources will also be used to define samples of high-redshift quasars selected in an obscuration free manner.
- Peaked-spectrum sources with maxima in their spectra at a few 100 MHz (CSS peaker) and a few GHz (GPS peaker). This is a little-studied but important class of extragalactic radio source which have typical sizes of ten to a few hundred parsecs.

positions: Apart from reaching fainter sources the WENSS will also yield excellent positional information (from 5-10$''$ for the faintest sources to better than 2$''$ for the brighter ones). In a large fraction of the sources this will be sufficient for obtaining optical identifications.

polarization: The sensitive polarization information coupled with the large number of sources give WENSS unique capabilities in searching for radio sources having (anomalously) high linear polarizations at low frequencies. These include pulsars as well as interesting variable extragalactic radio sources. The sensitivity to extended structure (up to one degree, shortest spacing 36 meters) has made it possible to study the large scale distribution of diffuse polarized galactic foreground emission (cf. Wieringa et al. A&A 268, 215, 1993), and will lead to a panoramic view of the Faraday rotation in the magneto-ionic medium within about 1-2 kpc from the sun.

variability: Although not primarily intended to search for variability, the mosaicing technique on which WENSS is based means that information on source variability is available on a variety of timescales ranging from hours to several months. The edges of adjacent mosaics, observed in different years of the survey, will also contain information about very long term source variability. The famous low-frequency variable 4C38.41, recently discovered to be a GRO γ-ray source, decreased its flux density by 20% in just 6 weeks (Peng and de Bruyn, A&A, 301, 25). The bright pulsar B0329+54 revealed itself in the WENSS data through non-cancelling grating rings, caused by 40% variations in its flux density on time scales of weeks.

statistical studies: A combination of WENSS with existing large-sky radio catalogues will produce radio colour-colour diagrams which will enable large numbers of all these sources to be selected to flux-levels fainter by at least an order of magnitude than was previously possible. Using the radio spectral information these various types of sources can be separated. This should provide valuable new data about the evolution of the space density of distant galaxies. In addition, WENSS will allow for the first time studies of large-scale clustering of radio sources to be made which take into account the radio colour discriminant and optical identification information.

giant radio galaxies: The WENSS survey has already detected many tens of radio sources with angular sizes of 10′ or more. Most of these will probably turn out to be giant radio galaxies with linear size in excess of 1 Mpc. One of the first giants followed up was identified with a broad-lined Markarian galaxy with a linear size of about 2 Mpc (Röttgering et al, MNRAS, in press).

4. The survey project team

The WENSS project is an NFRA effort requiring the help from a large group of people. In addition to the author the WENSS team consists of George Miley, Yuan Tang, Roeland Rengelink, Martin Bremer, Malcolm Bremer, Huub Röttgering, Klaas Weerstra and Hedy Versteeghe. The calibration and reduction of WENSS data motivated the development of a sophisticated novel software package (NEWSTAR) as well as automated batch-processing procedures. These are constantly being refined with the expert help of the NEWSTAR project team.