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The Miyun 232 MHz survey.

II. The main list

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Abstract. A meter-wave survey of the sky region north of declination +30° has been carried out with the Miyun Synthesis Radio Telescope (MSRT), Beijing Astronomical Observatory, at 232 MHz. A catalog of 34426 radio sources is given in Table 2[1]. The instrument and the data reduction procedure are described, and the experimental errors are discussed.

Key words: surveys — catalogs radio continum: general

1. Introduction

Sky surveys are a basic research tool of astronomy. Radio sky surveys have never been stopped since radio astronomy was born. Before 1990's, a sky survey with large area could be done either by a radio Schmidt telescope such as 6C survey (Baldwin et al. 1985), or by a transit instrument such as NCT (Ficara et al. 1985). But recently, large radio telescopes begin to perform large sky area survey, for examples, the WENSS[2] (De Bruyn 1995) and NVSS[3] (Condon et al. 1993) are being carried out by WSRT and VLA respectively.

The Miyun 232 MHz survey is a moderately deep meter-wave survey. Its working frequency is in between that of 6C and that of B3 among the tens radio sky surveys. Its sensitivity, resolution and width of the primary beam are comparable to those of MRAO and DRAO telescopes (Veidt 1985). The Miyun aperture synthesis system (Wang 1984), working at 232 MHz, consists of an E-W array of 28 dishes, each of 9 m in diameter. This array is divided into sub-array A (16 dishes in the center part) and sub-array B (12 dishes, 6 dishes at the east of the sub-array A, and the other 6 dishes at west of the sub-array A). The configuration of the telescope can be found in a paper written by Zhang et al. (1993, hereafter Paper I), and the characteristics of the array are summarized in Table 1. For details about the telescope, refer to Beijing Observatory Meter-Wave Radio Group (1985).

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[1] Tables 2 and 3 are only available in electronic form at the CDS via anonymous ftp 130.79.128.5 or on WWW.

[2] WENSS: Westerbork Northern Sky Survey at http://cdsweb.u-strasbg.fr/abstract.htmlp.

[3] NVSS: NRAO VLA Sky Survey.

Table 1. The characteristics of the MSRT

observing frequency	232 MHz
aerials	9 m parabolic
number of aerials	28
primary beam	$10° \times 12°$
baseline	1164 m East-West
spacing interval	6 m
number of baselines	192
min. and max. baselines	18 m - 1164 m
synthesised beam width(232)	$3.8' \times 3.8' \csc\delta$
trans. frontend noise	100 K
FET frontend noise	50 K
band width	1.5 MHz
sampling interval	10 s.
rms noise/spacing/sampling	10 Jy(232)
path compensation	digital
correlator	96 dig.(1 bit)

2. Observation and data reduction

2.1. Observation

Observations were made with MSRT between January 1985 and December 1993. The sky area north of declination +30° had been divided into 156 fields of view. Basically all adjacent fields were separated by 8° angular distance. Figure 1 shows the layout of the fields in the sky. Only 6 dishes in the sub-array B are used during a single observation to reduce the effect of shadowing between any two adjacent elements. So a complete UV-coverage is obtained by two observations. For each field of view four observations were performed to reduce the effect of interference. The preliminary calibration for the constant parts of the phases and gains of the array were made by observing Cyg A for 10 min. before or after the observation (Nan 1986). MSRT has been suffering from various kinds of interference. Usually about 15 percent of the recorded data were rejected because of the contamination by interference. In some extreme cases, we found it necessary to repeat the observations. Fields #54, #57, #115, and #116 have no data yet.

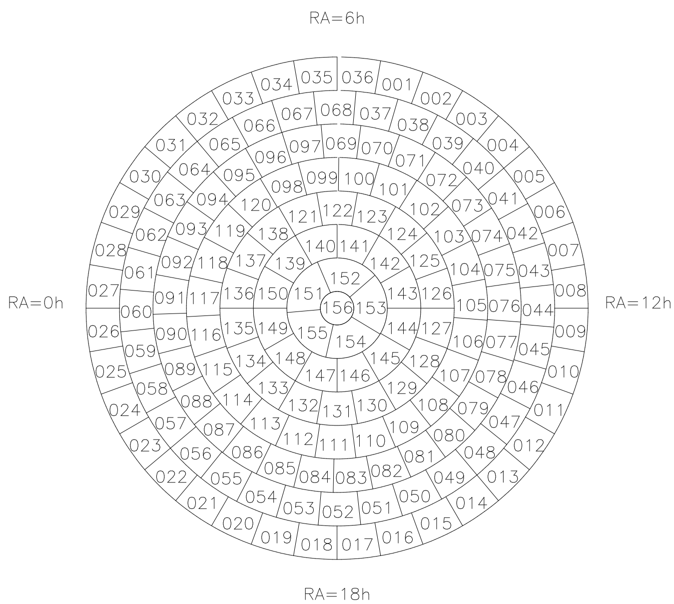

Fig. 1. The arrangement of the fields in the Miyun 232 MHz survey

To check the stability of the receiving system, long duration calibration observations of Cyg A were made about once a month.

2.2. *Data reduction*

The description in general about data editing, mapping, CLEAN and self-calibration for each individual field of view was made in Paper I. Here we just summarize as following and add some description in detail.

(1) A procedure was employed to remove the effect of interference and compensate the zero-offset errors. Two methods had been developed by Yang et al. (1985) for this purpose.

(2) Calibrations for the constant parts of phases and gains of the whole receiving system were made daily by means of the modeling software which was written by Zheng.

(3) Mapping, CLEAN and self-calibration were performed with the support of the AIPS package. Software had been developed by ourselves for interfacing Miyun data to the AIPS and modifying the CLEAN components list to ensure most sources within the wide primary beam of the MSRT are included (Zhang 1992).

(4) We leave the correction for the instabilities of the instrument and ionosphere to the self-calibration stage. Research on such instabilities have been done for the calibration of MSRT data (Zheng 1988; Zhang et al. 1989). The accuracy of the calibration at this stage is better than 5° for the phases and 10% for the gains.

Data of most fields of view were reduced according to the procedure mentioned above. The weighting function was changed from 'NA' (natural, the visibilities of short spacings are given much more weight) to 'UN' (uniform). With the 'UN' weighting function, the background fluctuation of maps become much flatter than that of 'NA' weighting maps. Despite of some loss of the ratio of signal to noise (Condon et al. 1995), especially for a field of view with some strong sources far from the center of the field, source searching could go much deeper without increasing the number of spurious sources.

In Paper I, we described the method of removing interference and compensating for the zero-offset. This method could be used up to the north pole area of sky. In the data reduction of the whole sky survey, we subtracted model-source first for all sky areas of declination larger than 75°. Though the effects of zero-offset were more serious at areas around the north pole, with this method the background fluctuation was found to be no worse than that of the areas at smaller declination.

Design of the pixel grid allows a synthesized beam to contain at least 3 to 4 pixels, to ensure that the CLEAN and self-calibration processes as well as the fitting program work properly. Usually the cell size is $85'' \times 85''$. Some times it is changed to ensure that strong sources far from the edges of the map can be included.

After several cycles of CLEAN, data editing, and self-calibration, maps usually became stable and converge. At this stage, low level features of a set of straight lines can been seen sometimes in the background. This could be caused by the holes in the visibilities when the self-calibration is not perfect. A way to reduce the level of this kind of background is to add some extrapolated visibilities to fill the hole in the visibilities. We calculated the visibilities of these holes by modeling with the CLEAN components.

3. Compilation of the list

3.1. *Source searching*

On average the $\sigma_{\rm N}$ (the rms of background fluctuation of a map) is about 50 mJy, but for fields near Cyg A and Cas A the $\sigma_{\rm N}$ may be as large as 200 mJy, while the lowest σ_N is about 30 mJy. Information of all 152 fields of view including field-centers and RMSs of background fluctuation are shown in Table 3[4]. In each field of view sources with $S \geq 3\sigma_N$ are searched and only those with $S \geq 4\sigma_N$ are presented in this catalog. Sources with $4\sigma_N \geq S \geq 3\sigma_N$ are presented only when they have counterparts in other catalogs. As the source searching procedure is carried out in a CLEAN map, the distorted area at the foot of the strong sources is rather limited.

A source searching program was developed by Zhang (1995) and Cao (1995). The program checks the surroundings of a maximum first. If a feature like a straight line or an arc of a circle is found, the program will mark the small area as not a real source and then search for the next maximum. Only for fields of view around Cyg A and Cas A, this situation was encountered rather often. If none of such features is found, the program will go on to analyze the surroundings further. Next, the program will measure the position and the intensity by fitting a small area, usually 3×3 pixels, with a Gaussian function which has the same width as the synthesis beam. Sometimes the program also measures positions and intensities of subpeaks within the small area.

At this stage the source searching program is also used to integrate the flux densities of the sources contained in the area. The integral flux is not given for sources whose integral fluxes are less or equal to their peak fluxes. The boundary is determined automatically by the program. The limitation of boundary is reached that when the intensity is either smaller than $3.5 \times \sigma_N$ (for sources with $S/N \geq 10$) or down to $2\times\sigma_N$ (for sources with $S/N < 10$). Because the integration is carried out for values on the pixels, for sources with small S/N the integral flux may less than the peak flux.

The zero level and noise at the position of each source is estimated by taking the average of its surroundings (A belt with 7 pixels in R.A. direction and 15 pixels in DEC. direction around the beam). In fact, zero levels of different sources are almost equal to zero (only a few mJy from zero), and the noise of different sources are found to be nearly the same within each field of view before the primary beam correction. But there are somewhat bigger differences of noise between some different fields of view, for example, some fields near very strong sources have larger noise. It may be caused by the imperfect phase and gain calibration, and the primary beam correction will cause an increase of the noise at the edge of the field.

No attempt was made to measure source-angular-size, because most of them are unresolved by our telescope and some may not be a single source.

[4] Table 3 is only available in electronic form at the CDS via anonymous ftp 130.79.128.5.

3.2. Calibration of flux density and position

Research aimed at establishing flux density standards covering a wide range of wavelengths have been done by many authors. The absolute flux density systems of Baars et al. (1977 =BGPW) and RBC (Roger et al. 1973) are among the most widely used. Laing et al. (1980) gave the calibrated flux density spectra of 165 3CR sources at frequency ranges 10 − 178 MHz and 750 MHz−15 GHz. Riley (1988) presented the flux densities at 408 MHz of a number of sources. Flux density spectra of sources at different frequencies and in different sky regions have been collected by Kühr et al. (1981), Veron et al. (1974), Gregorini et al. (1984), Long et al. (1966), Williams et al. (1967), and Kellermann et al. (1969).

We rely on the reference sources to determine the flux density scale in terms of the recorded values on map-plane. The BGPW absolute flux scale is used as the flux scale of the Miyun Survey. The catalogs of 6C (6C1−6C6) and the 87GB (Condon et al. 1991) are used to make a reference source list. Spectra of selected sources from 6C and 87GB catalogs were assumed to be a straight power law spectra. As the frequency ratio of the two catalogs is about 32, the spectral index error would not be too large. For some sources, when other frequency data are available, quadratic curve fitting was adopted.

About 7200 sources were detected in two or more fields of view. If a source appeared in more than one field of view the flux density is taken from the field in which the source has the largest ratio of signal to noise.

The primary antenna pattern is corrected before proceeding to the flux density calibration. The width of primary beam used for the demodulation is $10^\circ \times 12^\circ$ measured by Kang et al. (1985). As the calibration of the flux density is done in the map-plane, the AGC system has no effect on the calibration.

After primary beam correction and flux scaling of the 152 maps, 70 sources which have straight-line spectra were selected from the preprint of MPI (Kühr et al. 1981) to check our flux scale. The factor between the Miyun survey and BGPW system is 1.01 ± 0.15. Figure 2 shows the result.

Coordinates conversion from map-plane grid to celestial equator system α, δ on epoch 1950.0 were done by using synthesis formulae of NCP coordinates system. The formulae we used are:

$$X = -\cos(\delta)\sin(\alpha - \alpha_0) \quad (1)$$

$$Y = [s(\delta_0) - \cos(\delta)\cos(\alpha - \alpha_0)]/\sin(\delta_0) \quad (2)$$

(α_0, δ_0) is the phase tracking point which is taken as the field centre, i.e. $X = 0, Y = 0$. Systematic shifts in the apparent positions of sources can be caused by large scale gradients in the ionosphere. Self-calibration can also cause a constant position shift. On the average shifts of tens of

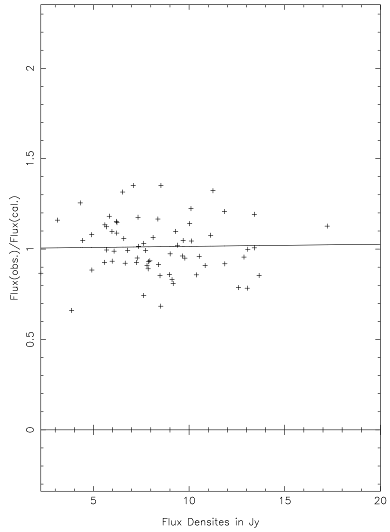

Fig. 2. The comparisons of flux densities of 70 straight-line spectra sources selected from the preprint of Kühr et al. (1981). Ordinate: values of observed fluxes devided by calculated fluxes. Abscissa: the observed fluxes in Jy/Beam

arcsec for most fields in this survey were found. To correct the systematic errors, some sources taken from 6C and Texas catalogs (Douglas et al. 1973) are used as position references.

3.3. Estimation of errors

Monte Carlo method is not employed as it is sensitive only to the background fluctuation and not to systematic errors. Factors which cause position uncertainties mainly come from background fluctuation and wide synthesis beam. The relation between the rms uncertainties σ_α (or σ_δ) of a source and the peak flux density Sp can be expressed by a quadratic sums of two terms (Ball 1975). The first terms are intensity-independent errors ϵ_α, ϵ_δ and the second terms are inversely proportional to Sp. The equations used to analyze the errors σ_α and σ_δ were taken from the preprint of the NVSS (Condon et al. 1995). We have:

$$\sigma_\alpha = \{\epsilon_\alpha^2 + [\sigma_{\rm N}\theta_\alpha/(2{\rm Sp})]^2\}^{1/2} \quad (3)$$
$$\sigma_\delta = \{\epsilon_\delta^2 + [\sigma_{\rm N}\theta_\delta/(2{\rm Sp})]^2\}^{1/2} \quad (4)$$

where θ_α and θ_δ are FWHP of restoring beam in α and δ diretions respectively. To determine the ϵ_α, ϵ_δ, a test area of $\alpha: 6^{\rm h}$ to $16^{\rm h}$, $\delta: 30°$ to $40°$ was selected. By comparing positions of strong point sources in this area with that in 6C catalog, the rms offsets of ϵ_α, ϵ_δ were obtained. They are $2.8''$ in right ascension and $3.7''$ in declination. In this survey $\sigma_{\rm N}\theta_\alpha$ and $\sigma_{\rm N}\theta_\delta$ vary with different field of view. On the average $\sigma_{\rm N}$ is 50 mJy except for that in fields near the Galactic plane, and the synthesis beam is about $200'' \times 200''{\rm csc}(\delta)$.

Figures 3 and 4 show the results of the comparisons between this survey and 6C survey.

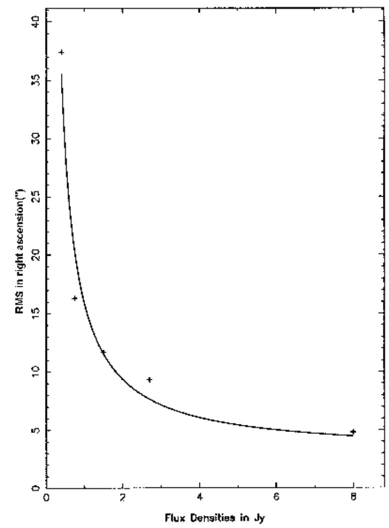

Fig. 3. The RMSs in right ascension direction between the Miyun and the 6C catalog. Sources used in this measurement are within the range: α: $6^{\rm h}$ to $16^{\rm h}$, δ: $30°$ to $40°$. Abscissa: flux density in Jy/Beam

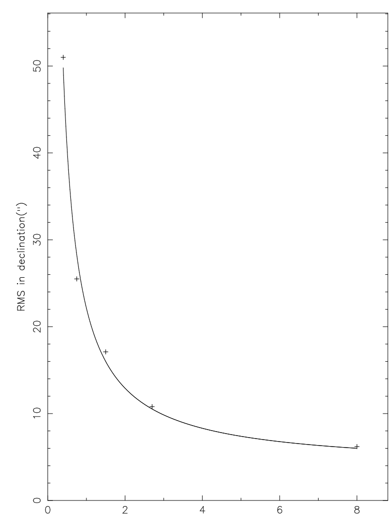

Fig. 4. The RMSs in declination direction between the Miyun and 6C catalogs measured with sources in the range of α: $6^{\rm h}$ to $16^{\rm h}$, δ: $30°$ to $40°$. Abscissa: flux density in Jy/Beam

The random uncertainties of a source, $\sigma_{\rm flux}$ depend on background fluctuations, $\sigma_{\rm N}$, in each field. On the average, about 60% of the sources have apparent flux densities within ± 50 mJy of their "true" flux density. A possible systematic effect on flux densities is that the self-calibration may intensify the flux densities as it may enhance the weighting toward strong sources after several runs of the self-calibrating procedure. The flux scale is slightly going up from low flux density to high flux density.

4. Source list

Table 2 presents the source list of Miyun survey. 34462 sources in total are listed and sources in the fields #54, #57, #115, and #116 are not included.

Items(1) to (8) in the Table 2 are

1) source names
2) right ascension at epoch 1950.0
3) declination at epoch 1950.0
4) peak flux density (Jy, after primary beam correction)
5) integrated flux density (Jy, after primary beam correction)
6) the factor used for correcting the primary beam pattern.
7) local S/N calculated in the way of maximum(peak flux, integral flux)/ (local noise)
8) the number of the field of view

Maps in FITS format are available and are attached to the main list.

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