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## UTR-2 LOW FREQUENCY CONTINUUM SURVEY OF THE NORTHERN SKY. PART II

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**ABSTRACT.** The Ukrainian T-shape radio telescope (UTR-2) has been used to carry out a multifrequency radio survey of a part of the northern sky with coordinates of the declinations  $+10^\circ < Dec. < +29^\circ$ , and right ascensions  $0^h < R.A. < 24^h$ . The observations were performed at very low radio frequencies, 12.6, 14.7, 16.7, 20 and 25 MHz. They were fulfilled by scanning the sky due the Earth's rotation with the five-beam pattern antenna at 11 fixed declinations. The observations for six five-beam strips, that covered the declinations ranges from  $+10^\circ$  to  $+19^\circ$ , the so-called "a fast scanning mode" was used. In this mode, the antenna positions were switched in the cycle between the three selected strips at fixed declinations every 40 seconds in the observational process. For the remaining strips, both the fast scanning mode and the usual observation mode at one fixed declination were used. Each pattern pencil-beams are spaced apart by 23' in the meridian. The angular size of the beam is about  $1^\circ$  at 12.6 MHz and  $0.5^\circ$  at 25 MHz at the zenith. The receivers' bandwidths are 10 kHz at frequencies from 12.6 to 16.7 MHz and 40 kHz at the two highest frequencies. A calibration of the output power was performed with the aid of the etalon noise generator for the each observation. These data surveyed were obtained during the period from 1997 to 2013 only at nighttime. The total number of observation amounted to more than 700 nights. The statistics for each point of the survey varied from 5 to 40 realizations. The results of these observations are the brightness temperature maps presented here at each mentioned above frequencies of the decameter band. However, it should be noted that there are shown "raw" maps without the zero level and striping effect corrections. These maps comprise emission from discrete and extended radio sources, the Galaxy and extragalactic background. The most intense radio emission on the maps is observed from the Galactic Plane and the North Polar Spur (NPS).

**АНОТАЦІЯ.** Проведено багаточастотний радіо огляд частини Північної небесної півкулі з схиленнь:  $+10^\circ < Dec. < +29^\circ$ , і прямих

піднесень:  $0^h < R.A. < 24^h$ , з використанням Українського Т-подібного радіотелескопу (УТР-2). Це друга частина огляду на УТР-2, перша частина стосувалася області північного неба з координатами:  $+29^\circ < Dec. < +55^\circ$ ,  $0^h < R.A. < 21^h$ . Спостереження здійснені на дуже низьких радіочастотах, 12.6, 14.7, 16.7, 20 і 25 МГц. Пропускна здатність приймачів становить 10 кГц на частотах від 12,6 до 16,7 МГц і 40 кГц на двох найвищих частотах. Спостереження були реалізовані шляхом сканування неба за рахунок обертання Землі п'ятипроменевою діаграмою спрямованості (ДС) антени на 11 фіксованих схиленнях. Кожен голкоподібний промінь ДС відстоїть один від другого на 23' в меридіані. Кутовий розмір променя становить приблизно  $1^\circ$  на 12.6 МГц і  $0.5^\circ$  на 25 МГц в зеніті. Для шести смуг, які охоплювали схилення від  $+10^\circ$  до  $+19^\circ$ , спостереження виконувалися, в так званому, „режимі швидкого сканування”. У цьому режимі в процесі спостереження положення антени перемикалося в циклі, кожні 40 секунд між трьома вибраними смугами з фіксованими схиленнями. Для решти смуг використовувались як режим швидкого сканування, так і звичайний режим - спостереження на одному фіксованому схиленні. Калібрування вихідної потужності виконували для кожного спостереження за допомогою еталонного генератора шуму. Дані були отримані за період з 1997 по 2013 рік. Загальна кількість спостережень становила понад 700 ночей. Статистика для кожної точки огляду коливалася від 5 до 40 реалізацій. Результатом цих спостережень є представлені тут карти температур яскравості радіовипромінювання на кожній з вищезгаданих частот декаметрового діапазону. Однак слід зазначити, що це «сирі» карти, без редукції нульового рівня і коригування ефекту смугастості. Дані карти вміщують випромінювання як від точкових, так і протяжних радіоджерел, а також фону Галактики і Метагалактики. Найбільш інтенсивне радіовипромінювання спостерігається

від Галактичного диску і Північної Полярної Шпори.

**Key words:** Key words. Radio continuum: ISM, surveys, Galaxy: Structure, decameter range.

## 1. Introduction

Surveys of the sky radio emission at different frequencies have been carried out for more than 70 years, the first map of the Galactic radio emission at 160 MHz was made by G.Reber (1944). There are well-known maps of the all sky at frequencies 408 MHz (Haslam et al., 1982), 1420 MHz (Reich and Reich, 1982). Also a number of low-frequency surveys have been carried out, including those at 10 MHz (Antonov, 1973; Caswell, 1976), at 22 MHz (Roger et al., 1999), at 34.5 MHz (Dwarakanath and Udayashankar, 1990), at 38 MHz (Milogradov-Turin and Smith, 1973), at 45 MHz (Alvarez et al., 1997; Maeda et al., 1999). In the last years the LWA1 survey at nine frequencies from 35 to 80 MHz was presented by Dowell et al. (2017). Despite this, obtaining maps in a wide frequency range with high resolution and sensitivity, especially at low frequencies, remains an important task in modern radio astronomy. The such maps are necessary to study spectral properties of the thermal and non-thermal components of the continuous radio emission of the Galaxy, to build a global model of sky radiation at the entire radio frequency range, for example as in (De Oliveira-Costa et al., 2008; Dowell et al., 2017). In the work, we represent the maps of the decameter waveband survey of the part of the Northern sky with declinations  $+10^\circ < Dec. < +29^\circ$ , and right ascensions  $0^h < R.A. < 24^h$ , which were carried out with the UTR-2 radio telescope. Earlier we introduced the maps of the sky in the declination range from  $+29^\circ$  to  $+55^\circ$  and right ascensions  $0^h < R.A. < 20^h$  (Vasilenko et al., 2006).

## 2. Observations and data processing

The UTR-2 radio telescope has been used to carry out a multifrequency radio survey of the northern sky. This is T-shaped telescope, it consists of two NS and EW antenna arms, one of which, with dimensions  $1880 \times 54 \text{ m}^2$ , is located along the meridian and the other, with dimensions  $900 \times 54 \text{ m}^2$ , along the parallel. The effective area is approximately equal to  $150\,000 \text{ m}^2$  at 25 MHz at the zenith. The directional pattern represents a fan of five pencil beams at each frequency. The beams separation ( $\Delta Dec.$ ) is about  $23'$  at the zenith. The first side-lobe level in the meridian plane is 13 dB. A detailed description of the UTR-2 can be found in Braude et al. (1978).

Under the program of the survey, the observations

were carried out at frequencies of 12.6, 14.7, 16.7 and 25 MHz. These observations were performed with a five-beam directional pattern, scanning the sky due the Earth's rotation, at 11 fixed declinations in the ranges from  $+10^\circ$  to  $+29^\circ$ . Each sky strips, covered with five beams, was observed at four different hour angles ( $\pm 1^h, \pm 2^h$ ). Since the sidelobes differ at different hour angles, this helps us to reduce the confusion errors. For six five-beam strips, in the declination ranges from  $+10^\circ$  to  $+19^\circ$ , the so-called "fast scanning mode" was used. In this mode, the antenna positions were switched in the cycle between the three selected strips at fixed declinations every 40 seconds in the observational process. This switching speed allows, due to the Earth rotation, to move to the starting point of the cycle spaced to half of the beam-width at 25 MHz. For the remaining strips, both the fast scanning mode and the usual observation mode at one fixed declination were used. The angular resolution, receivers' bandwidths of the corresponding frequency channels are shown in Table 1.

Table 1: UTR-2 observational parameters for the Northern sky survey

Frequency (MHz)	Bandwidth (kHz)	HPBW (arcmin)
12.6	10	$55 \times 67$
14.7	10	$47 \times 53$
16.7	10	$41 \times 46$
20.0	40	$34 \times 39$
25.0	40	$27 \times 31$

At the beginning and end of each observation day, a calibration of the output power was performed with the aid of the etalon noise generator connected with distributed amplifiers placed in the field of the telescope array. The method of observations and calibrations of the continuum radio emission using the UTR-2 is described in detail by Krymkin (1978).

The presented data were obtained with observations at the UTR-2 during from 1997 to 2013 only at night time. The total number of observation amounted to more than 700 nights. The statistics for each point of the survey varied from 5 to 40 realizations.

For each frequency, the survey data processing consisted of several stages.

1) Initial analysis of records and calibrations, where data subject to the influence of narrow-band interference were excluded, and if the calibrations before and after the observation session differed by more than 15%, then such a session was completely excluded from processing.

2) Statistical processing of the data was carried out separately to each observational strip, each hour angle, and each series of observations; and included the determination of the rms brightness temperatures and

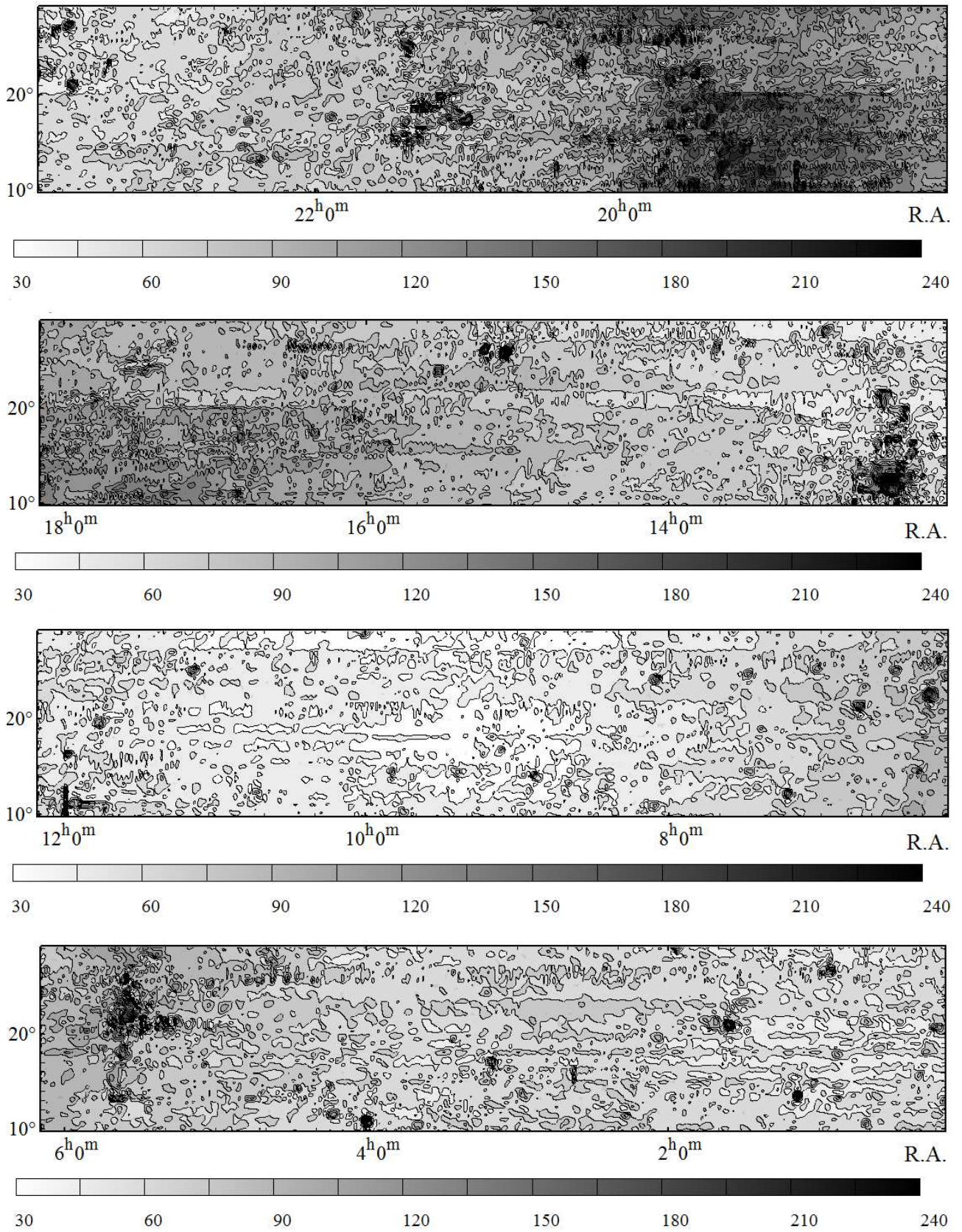


Figure 1: UTR-2 total brightness temperature map of the part of the Northern sky survey at 20 MHz. The region covered:  $+10^\circ < Dec. < +29^\circ$ , and  $0^h < R.A. < 24^h$ . The map is divided into pats at a six hours at R.A..

the filtration of the temperature values by dispersions.

3) Separation of the background component from total the radio emission using an FIR filter and its subsequent analysis.

4) Correlation analysis of the brightness temperature data arrays obtained for different hour angles and series of observations for every declination.

5) Comparison of the data for adjacent strips and obtaining the final brightness temperature scans for the observed region of the sky.

6) Mapping of the observed sky at the corresponding frequencies using the software package Sky Continuum Survey (Vasilenko et al., 2005).

### 3. Results

In this study, the maps of the radio emission of the part northern sky survey at the decameter wavelength are obtained. The region covered  $+10^\circ < Dec. < +29^\circ$  and  $0^h < R.A. < 24^h$ . The survey was carried out at very low radio frequencies, 12.6, 14.7, 16.7 20 and 25 MHz, with the best angular resolution and sensitivity ever achieved at these frequencies. Note for comparison that the angular resolution in the nearest low-frequency survey carried out at 22 MHz with the DRAO radio telescope  $1.1^\circ \times 1.7^\circ$  at the zenith (Roger et al., 1999). However, it should be noted that shown here is the "raw" maps without reducing of the zero level and striping effect corrections. To compare in detail ours' maps with another we need to do it. But this is the task for the next paper. The maps of brightness temperatures comprise the Galactic and extragalactic background, a part of the Galactic plane and the North Polar Spur, discrete and extended sources. Figures 1 represent the map of the total emission at 20 MHz in the equatorial coordinates for the 2000 epoch. The superim brightness temperatures are gray shaded and include isophotes. Contours of brightness temperature are indicated with a bar scale. The brightness temperatures are given in thousands of Kelvins.

### 4. Conclusions

The maps of the Northern sky surveys at the decameter wavelengths carried out in the lowest frequency part of the spectrum open to the ground-based observations are presented. They have the best angular resolution ever achieved for these frequencies. The presented maps are also of great importance for the analysis of the distribution of galactic synchrotron emission and morphology of the magnetic field in our Galaxy. They can be combined with high frequency data to study morphological changes of the background structures. In addition, these maps are

useful for the estimation of the required effective areas of radio telescopes to perform the various research programs for very low frequencies in the north celestial hemisphere.

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