THE DISTRIBUTION OF THE GALAXY NONTHERMAL RADIO EMISSION SPECTRAL INDEX AT DECAMETER WAVELENGTHS

N.M. Vasilenko

Institute of Radio Astronomy of National Academy of Sciences of Ukraine
4,Chervonopraporna St., Kharkov 61002 Ukraine, *vasnat@ira.kharkov.ua*

ABSTRACT. A spatial distribution map for the background spectral index of the decameter radio-wave emission from the Northern sky is presented. The spectral index was determined by using radio surveys obtained with the UTR-2 radio telescope for 14.7, 16.7, 20, and 25 MHz. The temperature spectral index $\beta \left(T_\nu \sim \nu^{-\beta}\right)$ was calculated for all pairs of the above frequencies and then averaged. The contributions from the point and extended Galactic sources were removed from β with the a low-pass FIR filter. The spectral index distribution includes the continuous galactic and the isotropic extragalactic components. The spectral index averaged over the entire investigated part of the sky is $\sim$ 2.43. For a rather large region with high galactic latitudes ($b > 30°$), the spectral index flattens to become $\sim$ 2.24. The map clearly reveals regions with increased values of the spectral index ($\beta \sim 2,6 - 2.8$); they correspond to parts of Loop I and Loop III.

Key words: Galaxy: structure - Galactic radio spectral index - radio continuous: general; ISM.

1. Introduction

Obtaining maps of the Galactic radio emission at different frequencies is one of the major tasks of radioastronomy. Such maps allow us to determine the structure of the Galaxy and that of its individual emission sources in different wavebands. By comparing radio surveys for several frequencies, we can establish significant properties of the Galaxy emission. It is this way that enables us to separate the thermal and the nonthermal Galaxy emissions, find the spectral index distribution for the radio emission, and obtain direct information of the electron energy spectrum and the magnetic field in the Galaxy.

The temperature spectral index β_{i-j} is calculated between two frequencies ν_i and ν_j as

$$\beta_{i-j} = log(T_i/T_j)/log(\nu_j/\nu_i),$$

where T_i and T_j are the Galactic brightness temperatures corresponding to ν_i, ν_j. The distribution of the spectral index of the Galactic radio emission over the sky depends on the frequency and direction of observations. The spectral index varies over the entire sky. The variations of the spectral index for continuous emission of low frequency may be indicative of peculiarities of the interstellar magnetic field, or a mechanism of propagation of cosmic rays in the Galaxy. Those for high radio frequencies may suggest a non-uniformity of the density distribution of sources of cosmic rays.

Early investigations of the distribution of β were carried out with a low angular resolution ($> 10°$). Detailed maps of the temperature spectral index for radio emission from of the northern sky $\beta_{408-1420MHz}$ (Reich and Reich 1988) and the map $\beta_{22-408MHz}$ (Roger et al. 1999) for a greater part of the sky were obtained with an angular resolution of $\sim 2°$. Recently published 5°-angular-resolution maps of the spectral index for the entire sky were calculated between the pairs of frequencies 408 MHz –1420 MHz and 1420 MHz –22.8 GHz (Reich et al. 2003).

It follows from the above papers that the spectral index variations for radio emission are in the range from 2.3 to 3.0. It was noticed that the low-frequency part of the spectrum is rather flat: $\beta = 2.3 - 2.6$. At frequencies $\nu > 100$ MHz, the spectral index increases to 2.8–3.0. The structure of the spectral index maps changes according to the ratio of the thermal and the nonthermal contributions to the total Galaxy emission. For example, the spectral index maps for low frequencies, where nonthermal emission is dominant, reveal high-latitude regions with steep spectra, called Loop I and Loop II. The high-frequency maps demonstrate rather flat spectra of the Galaxy plane, where the thermal emission is prevailing. The separation of these components introduces some uncertainty. After the separation of the thermal component with spectral index $\beta_{th} = 2.1$ from the galactic emission, a mean nonthermal spectral index β_{non} for different frequencies was determined to range from 2.6 to 3.1 (see Reich and Reich 1988b). It should be noted that the spectral index for very low radio frequencies (decameter wavelengths), the spectral index the Galaxy radio emission characterizes basically the nonthermal radiation.

2. Results of measurements and discussion.

In the present work, the calculations of the spatial distribution of the spectral index are based upon radio survey maps of part of the Northern sky (Vasilenko et al. 2006), which were obtained with the world-biggest low-frequency radio telescope UTR-2 (Vasilenko et al. 2006). The brightness temperature maps were obtained for frequencies of 12.6, 14.7, 16.7, 20 and 25 MHz with an angular resolution of 65° to 28° near the zenith direction. The survey covers the Northern sky region with $0^h < R.A. < 20^h, +29° < Dec. < +55°$. The fluctuation sensitivities of the survey on the Galaxy plane and away from the Galaxy plane are given in Table 1. To analyze the spectral parameters of the continuum nonthermal emission, we used a low-pass FIR filter to remove the contributions from both point sources and extended Galactic sources.

Table 1: Survey fluctuation sensitivity.

Frequency	FLUCTUATION On the Galaxy plane	SENSITIVITY Away from Galaxy plane
12.6MHz	5.58 kK	7.27 kK
14.7MHz	3.38 kK	3.83kK
16.7 MHz	2.45 kK	3.11 kK
20 MHz	1.250 kK	1.77 kK
25 MHz	0.94 kK	1.36 kK

The background emission temperature T_b includes the isotropic extragalactic component, which is the contribution from unresolved extragalactic sources. The estimate of this contribution for the decameter waveband reveals some peculiarity and requires special consideration. A frequency of 12.6 MHz was excluded from the analysis due to a poor statistic and a large number of missing figures in the data arrays, as compared to our other frequencies. For the same reason, we restricted our consideration to $0^h30^m < R.A. < 19^h00^m$. The temperature spectral index $\beta_{14.7-25MHz}$ was calculated for all pairs of the above frequencies and then averaged.

The resulting map shows small-scale and large-scale variations of the spectral index over the sky. The variations of the temperature spectral index lie in the range from 2 to 2.8, the root-mean-square error being 0.2. With the survey fluctuation sensitivity being good, this error, rather large, is a result of the closeness of the frequencies used in the study. The spectral index averaged over the entire investigated part of the sky is ~ 2.43. A rather large region of the sky ($8^h < R.A. > 12^h$), corresponding to high galactic latitudes ($b > 30°$), shows a flatter spectral index, with its average value being 2.24. The maps of the spectral index for the galactic radio emission clearly reveal regions of increased values of the spectral index ($\beta \sim 2,6 - 2.8$). These regions extend to high galactic longitudes and correspond to parts of North Polar Spur (LoopI) and Loop III, the southern and northern edges of these loops respectively.

Fig.1 represents the map of the spectral index $\beta_{14.7-25MHz}$ in the equatorial coordinates in shade of gray. The grid of the galactic coordinates is superposed in steps of 30° in l and b. The spectral index values change within the range from 2 up to 2.8.

The spectral index map obtained in the present work was compared with the $\beta_{22-408MHz}$ map presented by Roger et al (1999). It should be noted that in determining the spectral index, the surveys (Roger et al. 1999)were used, which were carried out for a frequency of 22 MHz, belonging to our frequency range, and a frequency of 408 MHz (Haslam et al. 1982). In addition, the contribution from the isotropic extragalactic components was not removed from the total emission. We observe a good visual agreement between our map (see fig. 1) and the map (fig. 5 in work Roger et al. 1999). A numerical comparison for three regions of the sky is given in Tab. 2. The greatest difference between the spectral index values for these regions corresponds to the region of lowest radio emission ($10^h, 40°$). This fact may be related to a large root-mean-square error in determining the spectral index for our frequencies, as compared to that of Roger et al.(1999), where the frequency spacing in determining the spectral index was considerably greater. Besides, some discrepancy are due to the following factors. First, the continuous radiation of the Galaxy at 408 MHz includes 11-16% of the thermal radiation (Reich and Reich 1988b). Second, the spectral index of the nonthermal emission becomes steeper at frequencies > 100 MHz. Finally, a small scale of the presented map hinders a detailed comparison of the results.

Table 2: Spectral index for three regions of sky such as the outside of Galactic plane, the minimum radio emission and Loop I, Loop III.

spectral index	$b > 10°$	min fon	Loop I, III
$\beta_{22-408MHz}$	2.47	2.41	2.51-2.54
$\beta_{14.7-25MHz}$	2.4	2.2	2.6-2.8

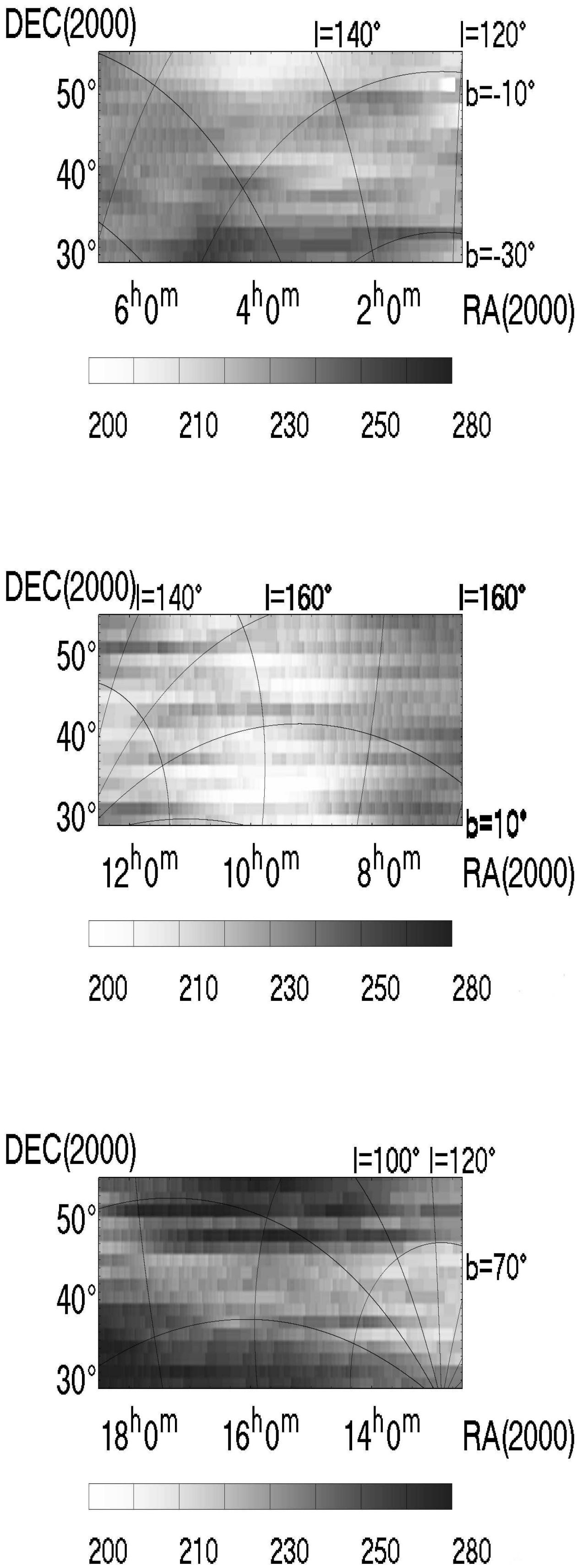

Figure 1: A map of the spectral index sky region with $+29° < Dec. < +55°$ and R.A.: $0^h30^m - 6^h30^m$; $6^h30{-}12^h30^m$; $12^h30^m - 18^30^m$ at decameter in shaded grey levels as indicated by the bar scale.Index values are $\times 10^{-2}$

3. Conclusion.

For the first time, a Galaxy radio emission map with high resolution and fluctuation sensitivity at ultralow frequency has been obtained for five frequencies together. These data made it possible to calculate the spectral index for frequencies where the radiation is practically completely nonthermal. Even though the close spacing of the frequencies used leads to a larger mean-square-root error, there is no difference in the radiation mechanism for such a a not large frequency spacing. Some uncertainty is introduced by the contribution from the isotropic extragalactic component, whose spectrum is steeper, ~ 2.75 (Bridle 1967), ~ 2.9 (in Reich et al 2003), than that of the galactic component. The correct account of this component will allow one to speak of a purely spectral index of the Galaxy radiation.

Acknowledgements. My thanks to my colleagues, Sidorchuk M.A.for the proofreading and discussion, Mukha D.V. for assistance with the computer and also Sushko M.S for proofreading.

References

Bridle A.H.: 1967, *M.N.R.A.S.,* **136**, 219.

Haslam C.G.T., Salter C.J., Stoffel H., Wilson W.E.: 1982, *A.A.S.S.,* **47**, 1.

Reich P., Reich W.: 1988 *A.A.S.S.,* **74**, 7.

Reich P., Reich W.: 1988b *A.A.,* **196**, 211.

Reich P., Reich W. and Testori J.C.: 2004, *in Magnetized Interstellar Medium, Turkey,* 63.

Roger R.S., Costain C.H., Landecker T.L., Swerdlyk C.M.: 1999, *A.A.S.S.* **137**, 7.

Vasilenko N.M., Sidorchuk M.A., Mukha D.V., Zakharenko S.M.: 2006, *XXVI General Assembly, Prague, Abstract,* **JD12-45**, 370.