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THERMAL AND NONTHERMAL COMPONENTS OF THE GALACTIC RADIATION AT 38 MHz FOR $4^\circ < l < 65^\circ$, $b = 0^\circ$

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Summary. The separation of components was done by Westerhout's method using surveys of the resolution of 7°.7 at 38 and 408 MHz. The derived distribution shows that the both components lie mainly inside and at the galactocentric distance of the Sagittarius arm. The nonthermal component is much more intense. The thermal component and optical depth have a distinct maximum in the direction of well known HII regions S54, S49 and S45. The derived nonthermal emissivity increases with decreasing longitude. Electron density is 0.4 cm^{-3}.

J. Milogradov-Turin, TOPLOTNA I NETOPLOTNA KOMPONENTA GALAKTIČKOG ZRAČENJA NA 38 MHz ZA $4^\circ < l < 65^\circ$ — Razdvajanje komponenti je izvršeno Vesterhautovim postupkom na pregledima razdvojne moći oko 7°.7 na 38 i 408 MHz. Dobijena raspodela pokazuje da obe komponente leže uglavnom unutar galaktocentričkog rastojanja koje odgovara Strelčevom kraku. Netoplotna komponenta je mnogo jača. Toplotna komponenta ima izrazit maksimum u pravcu HII oblasti S54, S49 i S45. Izračunata netoplotna emisivnost raste sa opadanjem longitude. Elektronska gustina je 0.4 cm^{-3}.

INTRODUCTION

The separation of the thermal and nonthermal components of radiation is a problem which has interested astronomers for more than twenty years. Nevertheless, there is no agreement yet on the contribution of components. A recent review of this field was given by Baldwin (1976).

As pointed out by Baldwin (1976), the extraction of a thermal component from two or more surveys at different frequencies depends very highly on the equality of beam shapes and the accuracy of zero levels.

It therefore seemed appropriate to attempt the separation of components using the survey at 38 MHz of Milogradov-Turin and Smith (1973) and the survey at 408 MHz (Haslam et al. 1974) which was convolved to the resolution of the 38 MHz survey by Haslam (1975). Both surveys have well known zero levels and were made to have the same beam shapes. The half-power beamwidth was $7^1/_4{}^\circ$

(RA) × $8^1/_4$° (Dec). Relatively large beam has not allowed clearing of data from individual sources but it made the major assumption of Westerhout's method concerning uniform mixing of components likely to be fulfilled over most of the investigated region. Exceptions are expected at places of very strong absorption or emission produced by objects of a relatively large angular size.

The use of the surveys at 38 MHz and 408 MHz has been particulary stimulated by the fact that one of the frequencies is amongst the lowest currently available.

ANALYSIS

The basic equations used for separation were:

$$T(38) = \left[T_e + \frac{T_n(38)}{\tau(38)}\right][1 - e^{-\tau(38)}] + T_{ex}(38)\, e^{-\tau(38)}, \tag{1}$$

$$T(408) = T_e \tau(408) + T_n(408) + T_{ex}(408) + T_{re}, \tag{2}$$

where T_e is the electron temperature of the thermal material, τ is its optical depth, T_n is the brightness temperature of the nonthermal emission, T_{re} is the relict temperature and T_{ex} is the brightness temperature originating in integrated emission of extragalactic sources. The brightnes temperatures are denoted by T.

Additionally

$$T_n(408) = T_n(38)\,(408/38)^{-\beta_n}, \tag{3}$$

$$\tau(408) = \tau(38)\,(408/38)^{-2.1}, \tag{4}$$

$$T_{ex}(408) = T_{ex}(38)\,(408/38)^{-\beta_{ex}}, \tag{5}$$

$$T_{re} = 2.7\,\mathrm{K}. \tag{6}$$

It was taken that $T_{ex}(38) = 2000$ K and $T_{ex}(408) = 3.1$ K as would follow from the values derived by Bridle (1967). Values for β_n were taken from the spectral indices map of Milogradov-Turin (1981b) in the high latitude region where the contribution of the thermal component was expected to be insignificant. The lowest values additionally chosen are the values close to the differential spectral index derived by Sironi (1974) between 408 and 17.5 MHz. Electron temperatures were chosen in the range of values which were observed at radio frequencies in HII regions (e.g. Spitzer 1978).

In order to obtain result as close as possible to real values, antenna temperatures were first processed. Details of the procedure are given in Milogradov-Turin (1981b). Essentially, it was attempted to estimate the maximum amplitude of the constant longitude galactic plane profiles by the correction of the observed gaussian distribution for the broadening of the profile due to the 7$^\circ\!\!.$75 beam. This equivalent gaussian profile (EGP) temperature gives a first beam independent approximation to the brightness temperature.

For 408 MHz it is possible to compare large beam profiles with the full resolution observations. The EGP peak values are about 20% below the full resolution values. They are however more below the full resolution values (40%) nearer the centre ($1 < 35°$) and near the full resolution values for $1 \approx 60°$.

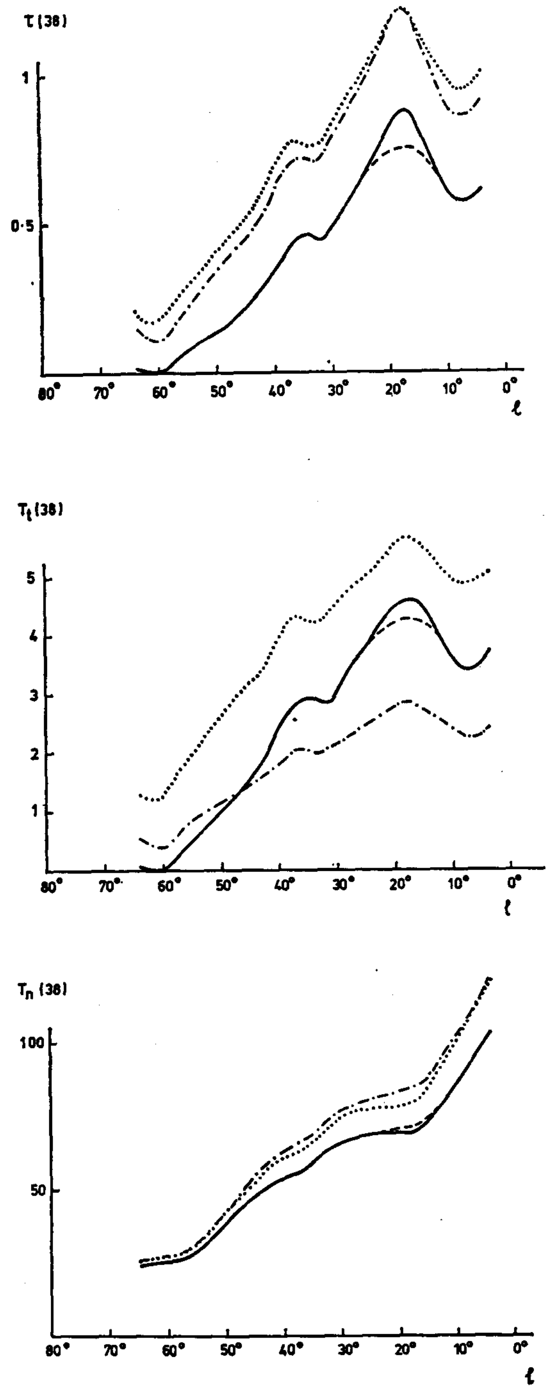

Fig. 1. The distribution of the thermal component T_t, nonthermal component T_n and optical depth τ with galactic longitude at 38 MHz. Both components are given in units of 1000 K. The solid line is the solution obtained for $T_e = 8000$ K, $\beta_n = 2.5$; the dotted line is the solution for $T_e = 8000$ K, $\beta_n = 2.6$ and the broken/dotted line is the solution obtained for $T_e = 4000$ K, $\beta_n = 2.55$. The broken line around $l \approx 20°$ represents the solution obtained after the addition of 3000 K to 38 MHz temperatures.

Comparison with the medium resolution 400 MHz survey of Seeger et al. 1965) shows that the EGP approximation will be very similar to values with a reolution of about 2°.

The values obtained for the peak of the EGP at 38 MHz and 408 MHz were used to separate thermal and nonthermal components. The system of symultaneous equations were solved for each 4° in longitude for $4° \leq l < 65°$, $b = 0°$.

The following three cases were solved initially:

1) $T_e = 8000$ K, $\beta_n = 2.5$,
2) $T_e = 8000$ K, $\beta_n = 2.6$,
3) $T_e = 4000$ K, $\beta_n = 2.55$.

The result is presented in Fig. 1. The thermal component was calculated in the same way as did Westerhout (1958)

$$T_t = T_e(1 - e^{-\tau}).$$

The cases for $\beta_n = 2.4$, $T_e = 6000$ K and $T_e = 8000$ K were additionally solved as well as $\beta_n = 2.35$, $T_e = 8000$ K only in the region $4° \leq l \leq 40°$, $b = 0°$. They give less than half of the value of τ and T_e for $l = 18°$ than those obtained in the previous cases. T_n is about 10^4 K less in the case of $\beta_n = 2.4$ than in the case for $\beta_n = 2.5$. The peak at $l = 18°$ is much more dominant feature on the graphs of τ versus l for lower values of β_n than for higher ones.

At $l = 16°$ and $l = 20°$ the system of equations was also solved for case 1. after addition of 3000 K to the 38 MHz peak temperatures. The new values of T_n, T_t and τ are shown as a broken line on the appropriate curves.

As an extreme normalization to main beam temperatures sample values for all the three cases were reevaluated multiplying the EGP peak antenna temperatures by 1/0.85. The forms of the resultant curves were unchanged, but systematic scaling up of T_n by 20% and τ by 6% was derived.

DISCUSSION

Separation of components shows that the nonthermal component at 38 MHz is much stronger than the thermal component. Their ratio is at its lowest near $l = 18°$ where it is 15. The ratio of the nonthermal to thermal component is particularly high near $l = 60°$ where the thermal component is negligible.

The general form of the curves on Fig. 1 is very similar in all three cases. The distribution is rather smooth except the regions near $l = 18°$ and $l = 37°$. The nonthermal component exhibits a smooth step near the position of the tangential point of the Sagittarius arm and a less clear step near the tangential point of the Scutum arm. The direction $l = 60°$ corresponds to the interarm region between the Sagittarius arm and the Cygnus feature. The weak thermal component in the direction $l \approx 60°$ indicates that the corresponding part of the Perseus arm contains only a small amount of ionized hydrogen. This result is in agreement with the work of Georgelin and Georgelin (1976) who found no high-excitation-parameter HII regions in the directions close to $l = 60°$. The 38 MHz nonthermal component in this direction is about 2.5×10^4 K. It should originate either in the Perseus arm or in this arm and a hypotetical general base disc. A bulk of both components lies within the boundary formed by the Sagittarius arm as seen from Fig. 1.

Comparison of curves on Fig. 1. with appropriate distributions obtained from data free of bright sources by Westerhout (1958) at 1390 MHz and by Large et al. (1961) at 408 MHz shows that only the thermal component derived here has maxima at $l \approx 18°$ and $l \approx 37°$. The nonthermal component at 38 MHz changes gradient at these longitudes. Thus the conclusion is that these maxima are due to sources which were not cleared from the low resolution 38 and 408 MHz data.

Comparison with the longitudinal distribution of galactic tracers presented by Burton and Gordon (1978) also suggests that the features near $l \approx 18°$ and $l \approx 37°$ are not produced by large scale galactic structure.

These maxima arise by application of the Westerhout's method to the 38 MHz data which show a minimum at $l \approx 18°$ and a change of gradient at $l \approx 37°$ while the same resolution 408 MHz data do not show such features. Knowing the spatial distribution in depth to be important at low frequencies and unimportant at high frequencies one can conclude that these features are due to the presence of relatively large angular size nearby HII regions acting as foreground screens for the nonthermal radiation and as sources of the thermal radiation.

As it was shown by Milogradov-Turin (1981a) S54, S49 and S45 which are only about 2 kpc away could cause large reduction of the 38 MHz radiation at $l \approx 18°$. The fact that addition of 3000 K does not cancel the maximum at $l \approx 18°$ should be attributed to large uncertainities in the value of reduction and in the method.

As it can be seen on the high resolution 38 MHz unpublished map (Baldwin 1979) the area near $l \approx 37°$ contains the bright nonthermal source 3C 392 and several absorption regions less deep than S54 complex. This combination could produce a maximum less high than that at $l \approx 18°$.

NONTHERMAL EMISSIVITY

The nonthermal emissivity was computed using the nonthermal component derived for the case $\beta_n = 2.5$, $T_e = 8000$ K. It was assumed as a first order approximation that the sources of emission are uniformly distributed within the radius of 15 kpc from the galactic center. The nonthermal component was increased by 20% according to normalization to brightness temperatures.

The resulting distribution of the nonthermal emissivity versus galactic longitude is given in Fig. 2 as a curve. Dots and straight lines represent values obtained by other authors when scaled to 38 MHz. Dots are plotted for emissivities determined for particular galactic longitudes and latitudes as did Purton (1966), Baldwin (1967), Holden (1968), Graham et al. (1981) and those included in the paper of Krymkin (1978). Emissivities obtained as a general value (Mills 1959, Shain 1959, Alexander et al. 1970), or for the solar neighbourhood (Wilson 1963) or in the direction of galactic poles (Cane 1979) are represented by lines covering the whole range of longitudes. The scaling to 38 MHz was done with two values of spectral indices $\beta_n = 2.4$ and $\beta_n = 2.7$ as extremes of the expected values. Both values of emissivities were plotted. Only the value communicated by Graham et al. (1981)

is included as scaled by the authors. Values obtained by Bridle (1968) were taken in all suggested modifications.

The distribution of the nonthermal emissivity given in Fig. 2. is a fairly smooth function. The changes of gradient near $l \approx 18°$ and $l \approx 37°$ are caused by already discussed local features. The nonthermal emissivity at 38 MHz is the greatest in the directions close to the galactic centre and decreases with increasing longitude.

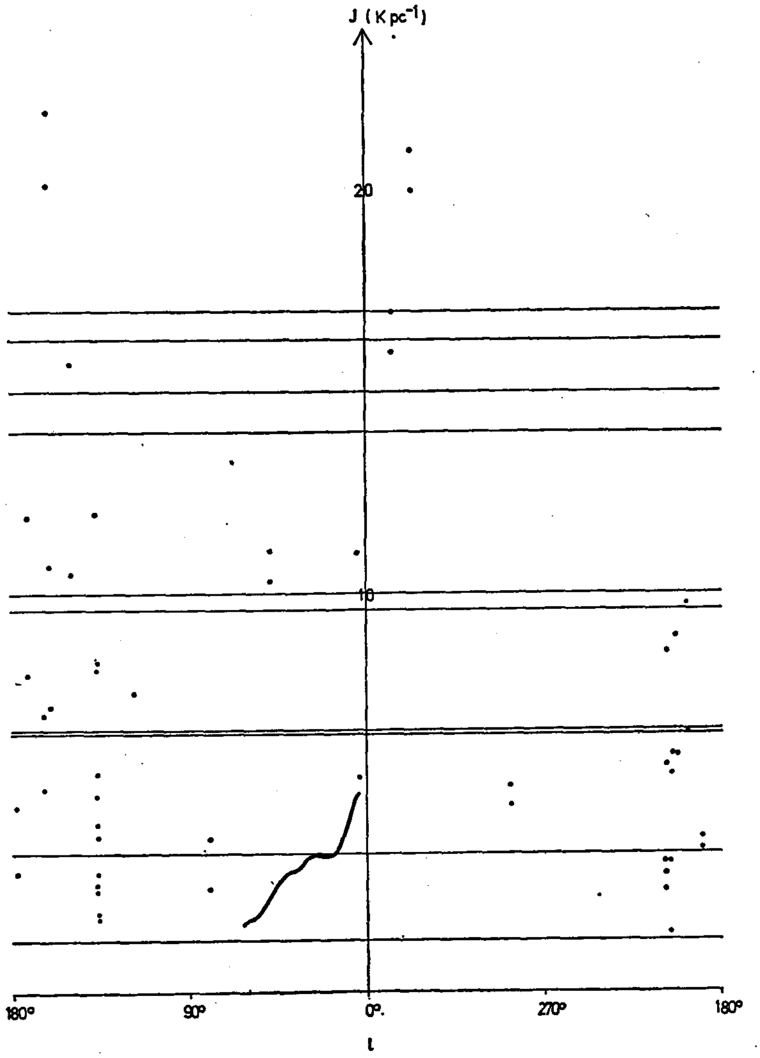

Fig. 2. The distribution of emissivity with galactic longitude. The solid curve gives the emissivity obtained from the nonthermal component at 38 MHz for $4° \leq l \leq 64°$, b = 0. Dots represent emissivities obtained by other authors and scaled to 38 MHz.

Such behaviour could be deduced from the results of other authors but it was not so distinctly seen before due to nonhomogenity of data and uncertainity in determined values. Previously known values could be misinterpreted partly because of the expected differences on the small angular scale which were shown to exist by Jones and Finlay (1974).

The values of emissivity computed here are close to the lower range of emissivities derived by other authors. This is not surprising since the EGP temperatures are below full resolution values.

EMISSION MEASURE AND ELECTRON DENSITY

The curve representing optical depth as a function of longitude has the same shape as the curve of emission measure distribution. In order to get emission measure expressed in cm^{-6} pc, a factor 0.013 $T_e^{1.35}$ should be applied to the optical depths in Fig. 1.

Assuming that all ionized hydrogen is concentrated within spiral arms 0.5 kpc thick, distributed as indicated by the work of Georgelin and Georgelin (1976), an estimate of average electron density was obtained for $40° \leq l \leq 55°$, $b = 0°$. This area was chosen because of the simplicity of the spiral structure in this direction and lack of strong local absorption effects. For the first case, average $n_e = 0.4$ cm^{-3}. This value is consistent with values one can expect from the work of other authors as reviewed by Spitzer (1978).

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