

# Observations of the giant H II region complex W51 at decameter wavelengths

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**Summary.** Radio continuum absorption observations at 34.5 MHz with a spatial resolution of  $34' \times 48'$  have been obtained for the giant H II region complex W51 with the decameter wave radio telescope at Gauribidanur, India (Lat.  $13^{\circ}36'N$  and long.  $77^{\circ}27'E$ ). A mean electron temperature of  $9500 \pm 600$  K and a background temperature of  $28,000 \pm 2600$  K have been derived. The proportion of non-thermal emission originating on the near side of W51 corresponds to a mean emissivity of  $2 \text{ K pc}^{-1}$ . The present observations also indicate that the ring towards the east of the nebula (W51C) is non-thermal.

**Key words:** radio continuum – interstellar medium: H II regions: W51

## 1. Introduction

The giant H II region complex, W51, was first detected by Westerhout (1958) in his 22 cm survey of the galactic plane. Since that work many studies of the ionised gas in continuum emission at high radio frequencies have been made with resolutions as high as  $3'$  (Shaver, 1969; Macleod and Doherty, 1968; Terzian and Balick, 1969 etc.). The W51 continuum complex has been separated into three main components (see e.g. Mufson and Liszt, 1979): W51A, comprising the sources G49.5–0.4, and G49.4–0.3; W51B consisting of G48.9–0.3, G49.0–0.3, G49.4–0.4 and G49.2–0.3; W51C or the eastern arm. Some of the individual objects have been mapped with arcsecond resolution by Martin (1972) and Scott (1978). These observations have revealed a complicated structure with a mixture of thermal and non-thermal emission.

At a low enough radio frequency where an H II region is optically thick, it may appear as a continuum absorption feature against the combined non-thermal galactic and extragalactic background emission. Such absorption measurements on the W51 complex have not been published so far. We present here observations in radio continuum absorption at 34.5 MHz with high sensitivity. These observations together with the observations by Parrish (1972) in the frequency range 53–89 MHz have been used to derive the mean electron temperature and the proportions of background and foreground emission.

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## 1.1. Equipment and observations

The observations reported here were made with the low frequency radio telescope at Gauribidanur (Longitude  $77^{\circ}27'07''E$ , Latitude  $13^{\circ}36'12''N$ ) at 34.5 MHz. The telescope consists of two broadband arrays arranged in the form of a “T”. The outputs of the two arrays are correlated to produce a beam whose half-power beamwidths are  $34' \times 48'$  ( $\delta - 14^{\circ}.1$ ) in right ascension and declination respectively. The effective area is approximately  $250 \lambda^2$ . It is possible to observe a given region of the sky either using a single beam or in a beam scanning mode wherein the beam is shifted rapidly to various declinations. A brief description of the electronic beam scanning system of this telescope is given by Sastry and Shevgaonkar (1983).

A radio map (34.5 MHz) of the galactic plane in the declination range  $12^{\circ}.8$  to  $15^{\circ}.6$  and from  $19^{\text{h}}00^{\text{m}}$  to  $19^{\text{h}}40^{\text{m}}$  in R.A. is presented in Fig. 1. The continuum absorption due to W51 is very striking around  $= 13^{\circ}.8$  and R.A. of  $19^{\text{h}}20^{\text{m}}$ . The half power width of the absorption in R.A. is about  $30'$ .

These observations were calibrated using the point source 3C33 whose flux density according to Kuhr et al. (1981) at 34.5 MHz is 158 Jy. The decrease in flux density at the position of maximum absorption is  $70 \pm 15$  Jy. This corresponds to a decrease in full beam brightness temperature of  $21,000 \pm 4200$  K.

## 2. Discussion

The observed flux density  $S_{\nu}$  in the direction of an H II region at a frequency  $\nu$  is given by

$$S_{\nu} = \frac{2k\nu^2}{c^2} \iint_{\Omega} (T_e - T_{bg})(1 - e^{-\tau_{\nu}}) d\Omega,$$

where

$T_e$  = electron kinetic temperature

$T_{bg}$  = total background temperature =  $T_{bv} + T_{xv}$

$T_{bv}$  = galactic background temperature on the far side of the H II region

$T_{xv}$  = extragalactic component of the background temperature

$\tau_{\nu}$  = optical depth

$\Omega$  = solid angle.

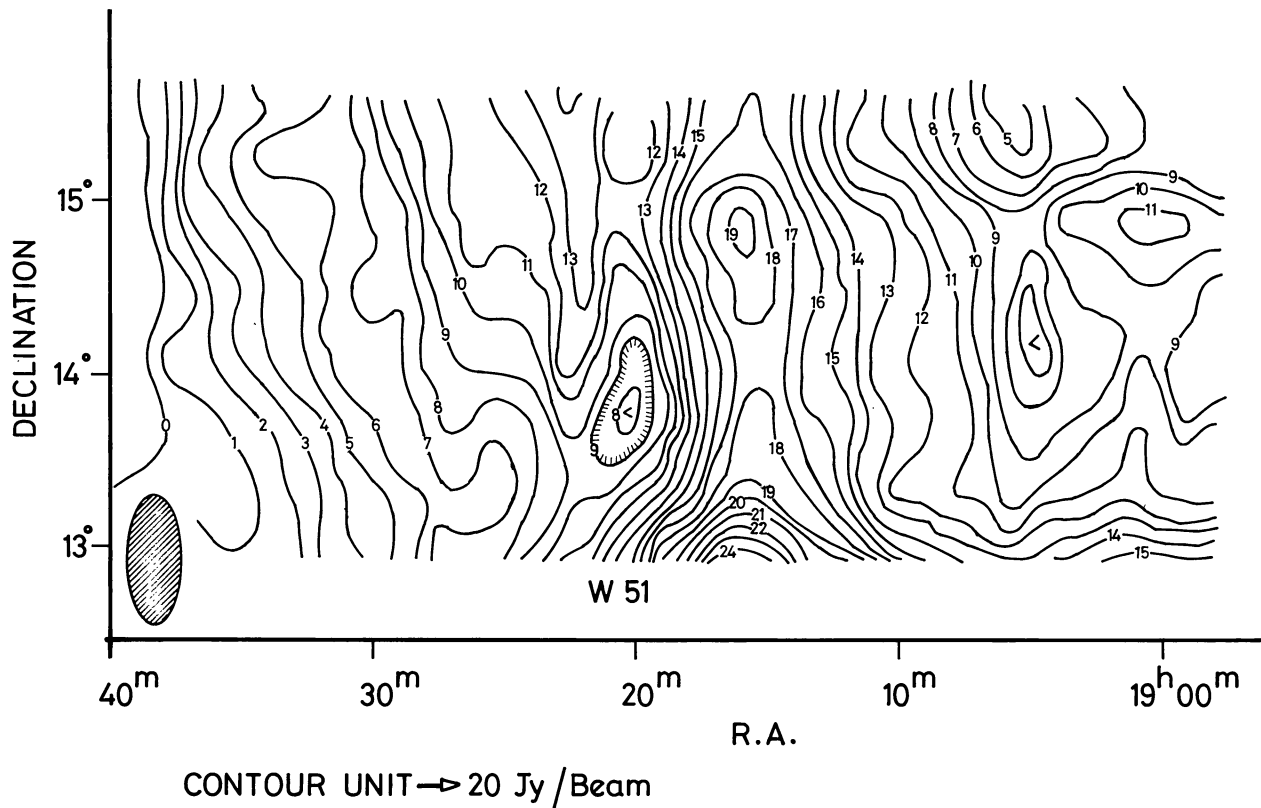


Fig. 1. Radio (34.5 MHz) map of part of the galactic plane made with the decameter wave radio telescope, Gauribidanur. The beam widths are  $34' \times 48'$ . W 51 is shown as a hatched region

Table 1. Flux densities for the H II region complex W 51 and brightness temperatures on the near and far sides of W 51

Freq. (MHz)	Half power beamwidth (degrees)	Observed flux density (Jy)	$S_{E\nu}^a$ (Jy)	Corrected flux density (Jy)	Foreground temperature (K)	Background temperature (K)	Ref.
34.5	$0.57 \times 0.80$	$70 \pm 14$	0	$70 \pm 14$	$12,500 \pm 4,300$	$28,000 \pm 2,600$	Present work
53.0	$1.78 \times 1.78$	$72 \pm 30$	$90 \pm 15$	$18 \pm 30$	$4,400 \pm 1,514$	$9,860 \pm 915$	Parrish (1972)
65.0	$1.58 \times 1.58$	$150 \pm 20$	$86 \pm 15$	$64 \pm 20$	$2,680 \pm 920$	$6,010 \pm 560$	Parrish (1972)
73.8	$1.35 \times 1.35$	$170 \pm 25$	$83 \pm 15$	$87 \pm 25$	$1,970 \pm 680$	$4,410 \pm 410$	Parrish (1972)
89.1	$1.10 \times 1.10$	$288 \pm 30$	$80 \pm 15$	$208 \pm 30$	$1,250 \pm 430$	$2,790 \pm 260$	Parrish (1972)

<sup>a</sup> See text for explanation

At a frequency  $\nu_{\text{HF}}$ , sufficiently high that the H II region becomes optically thin, the brightness temperature  $T_{b\text{HF}}$  will be equal to the product of the optical depth and the electron temperature. The optical depth at a low frequency,  $\tau_{\text{vLF}}$  can be derived from the observed brightness temperature  $T_{b\text{HF}}$  for any assumed electron temperature. One can then estimate the fractional absorption expected at a low frequency. If observations at several low frequencies are available, then it is possible to determine the mean electron temperature, and also the background temperature on the far side of the nebula. Note that the background temperature is the sum of the galactic non-thermal emission originating on the far side of the H II region and an isotropic extragalactic component which is also non-thermal. The extragalactic component can be taken from the measurements of Bridle (1967). The method of

determining the electron temperature etc is described in detail by Roger (1969). We have taken the high frequency brightness temperature values from the 10.6 GHz map of Macleod and Doherty (1968) where the nebula is heavily resolved and optically thin. The low frequency (53–89 MHz) observations of Parrish (1972) have also been used. The measured flux densities at various low frequencies are listed in Table 1.

We found that it is not possible to obtain any meaningful values for  $T_e$  and  $T_{bg}$  by iteratively solving a set of equations using the measured flux densities given in Table 1. It should be noted that Parrish (1972) derived a background temperature on the far side of W 51 of 4500 K at 50 MHz using only his observations. According to Milogradov-Turin (1974) the spectral index  $\beta$ , defined as in the expression  $T \propto \nu^\beta$  of the brightness temperature variations in the

direction of W 51 is  $-2.43$ . Using this value of spectral index the background temperature at 34.5 MHz is found to be 11,000 K, which obviously is not sufficient for producing the observed depth of absorption of 21,000 K. Also the total temperature (Sum of the background and foreground temperatures) in the direction of W 51 measured by Parrish (1972) at 50 MHz is 39,000 K, which corresponds 76,000 K at 38 MHz. But the temperature at 38 MHz in the same direction measured by Milogradov-Turin and Smith (1974) is only 34,000 K.

It can be seen from Fig. 1 and also from the 408 MHz galactic survey maps of Haslam et al. (1982) that there are pronounced variations of the galactic background radiation in the region around W 51. It is therefore possible that the measurements of Parrish (1972) are affected by galactic background fluctuations due to the large beamwidths used. As shown in Table 1, the beamwidths used by Parrish (1972) are two to three times the size of the nebula. Therefore the measured flux densities of Parrish (1972) would be equal to the sum of the flux densities of the nebula itself and that due to the small scale variation of the galactic brightness. In order to take this possibility into account, we have added another term,  $S_{Ev}$ , to the equation relating the observed flux density to the electron temperature and optical depth etc, stated above. The modified equation applicable to the measurements of Parrish (1972) is

$$S_v = \frac{2kv^2}{c^2} \iint_{\Omega} (T_e - T_{bg})(1 - e^{-\tau}) d\Omega + S_{Ev}.$$

$S_{Ev}$  is the error in the measured flux densities of Parrish (1972) with a spectral index " $\alpha$ " defined as in the expression  $S_{Ev} \propto \nu^\alpha$ . The measurements at five frequencies yielded five equations and these were iteratively solved using the chisquare method for the four unknowns  $T_e$ ,  $T_{bg}$ ,  $S_{Ev}$  and  $\alpha$ . The best fit value of " $\alpha$ " is  $-0.25 \pm 0.21$  which corresponds to a brightness temperature spectral index of  $-2.25 \pm 0.21$ . This value is in reasonable agreement with the measured brightness temperature spectral index close to the direction of W 51. Therefore our assumption that the measurements of Parrish (1972) are affected by fluctuations in the galactic background radiation appears justified. The derived best fit value for the mean electron temperature of the whole W 51 complex is  $9600 \pm 600$  K. The derived brightness temperature of the galactic radiation on the far side of W 51 is  $28,000 \pm 2600$  K at 34.5 MHz. The total brightness temperature (Sum of background and foreground temperatures) of 34,000 K in direction close to W 51 at 38 MHz measured by Milogradov-Turin and Smith (1974) is corrected for contribution due to extragalactic emission using the measurements of Bridle (1967). The resulting temperature is 31,900 K at 38 MHz which corresponds to 40,300 K at 34.5 MHz. This yielded a temperature of 12,300 K at 34.5 MHz on the nearside of W 51. The derived temperatures on the near and far sides of W 51 at other frequencies are listed in Table 1. The usually accepted value for the distance of W 51 is 6.5 pc, (Bieging, 1975). On this basis, the volume emissivity of the galaxy in the direction of W 51 at 34.5 MHz turns out to be  $2 \text{ pc}^{-1}$ . This value is in reasonable agreement with that derived by Milogradov-Turin (1982) of  $2-3 \text{ pc}^{-1}$ , at 38 MHz in the direction of Cyg X.

An interesting aspect of the study of W 51 is to determine whether the H II region complex is associated with a supernova remnant. Shaver (1969) found that the H II region complex is surrounded by a non-thermal ring, which he suggested to be a supernova remnant. W 51 C or the eastern arm of the nebula is a part of the non-thermal ring found by Shaver (1969). Since no

recombination lines have been observed in W 51 C, Wilson et al. (1970) concluded that its emission is non-thermal. But according to Terzian and Balick (1969) and Bieging (1975), the dominant low frequency component of W 51 which includes the eastern arm (W 51 C), is an extended distribution of ionised hydrogen. As already noted above, the half power width of the observed continuum absorption profile is  $30'$ , in R.A. centered at  $19^{\text{h}}20^{\text{m}}20^{\text{s}} \pm 10$ . The width of the high frequency maps including the eastern arm (W 51 C) is more than  $45'$  in R.A. It would therefore appear that the region W 51 C is not contributing to the low frequency absorption. We have also convolved the fractional absorption map obtained from the 10.6 GHz map of Macleod and Doherty (1968) with our beam and find that the position of the peak absorption should occur at a R.A.  $19^{\text{h}}21^{\text{m}}00^{\text{s}}$ . This is  $10'$  east in R.A. of the observed position of the peak absorption. We also find that if one omits the emission due to the eastern arm then the expected position of the peak absorption moves closer to the observed position. We conclude therefore, that the emission from the eastern arm of W 51 is not thermal. Additional justification for this conclusion comes from the spectral index map we have made from the 10.6 GHz and 408 MHz maps. The values of temperature spectral indices in the region of W 51 C are  $\geq 2.4$ , whereas in the regions of W 51 A and W 51 B they are  $\approx 2.0$ . It would appear therefore that the extended background component of W 51 is not a superposition of evolved H II regions as argued by Bieging (1975), but more likely a non-thermal ring as suggested by Shaver (1969).

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