Astron. Astrophys. 160, 129–131 (1986)

ASTRONOMY AND ASTROPHYSICS

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

A.A. Deshpande[1] **and C.V. Sastry**[1,2]

[1] Raman Research Institute, Bangalore 560080, India
[2] Indian Institute of Astrophysics, Bangalore 560034, India

Received October 22, accepted November 25, 1985

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 W 51 with the decameter wave radio telescope at Gauribidanur, India (Lat. 13°36′N and long. 77°27′E). A mean electron temperature of 9500 ± 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 W 51 corresponds to a mean emissivity of 2 K pc^{-1}. The present observations also indicate that the ring towards the east of the nebula (W 51 C) is non-thermal.

Key words: radio continuum – interstellar medium: H II regions: W 51

1. Introduction

The giant H II region complex, W 51, 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 W 51 continuum complex has been separated into three main components (see e.g. Mufson and Liszt, 1979): W 51 A, comprising the sources G49.5 – 0.4, and G49.4 – 0.3: W 51 B consisting of G48.9 – 0.3, G49.0 – 0.3, G49.4 – 0.4 and G49.2 – 0.3: W 51 C 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 W 51 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.

Send offprint requests to: C.V. Sastry

1.1. Equipment and observations

The observations reported here were made with the low frequency radio telescope at Gauribidanur (Longitude 77°27′07″E, Latitude 13°36′12″N) at 34.5 MHz. The telescope consists of two broad-band 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°.8 to 15°.6 and from 19^h00^m to 19^h40^m in R.A. is presented in Fig. 1. The continuum absorption due to W 51 is very striking around = 13°.8 and R.A. of 19^h20^m. The half power width of the absorption in R.A. is about 30′.

These observations were calibrated using the point source 3C 33 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 ± 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_ν in the direction of an H II region at a frequency ν 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 = $T_{b\nu} + T_{x\nu}$
$T_{b\nu}$ = galactic background temperature on the far side of the H II region
$T_{x\nu}$ = extragalactic component of the background temperature
τ_ν = optical depth
Ω = solid angle.

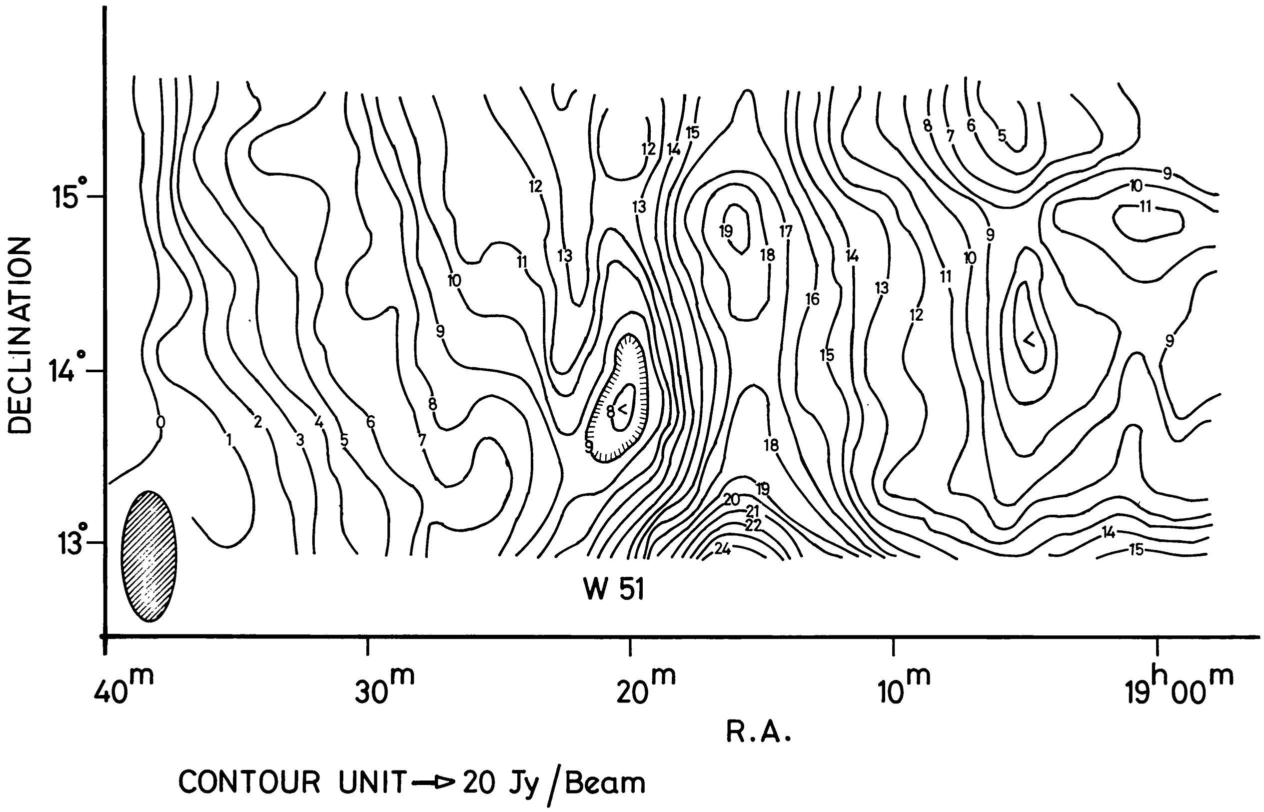

Fig. 1. Radio (34.5 MHz) map of part of the galactic plane made with the decameter wave radio telescope, Gauribidanur. The beam widths are 34′ × 48′. W 51 is shown as a hatched region

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 × 0.80	− 70 ± 14	0	− 70 ± 14	12,500 ± 4,300	28,000 ± 2,600	Present work
53.0	1.78 × 1.78	72 ± 30	90 ± 15	− 18 ± 30	4,400 ± 1,514	9,860 ± 915	Parrish (1972)
65.0	1.58 × 1.58	150 ± 20	86 ± 15	64 ± 20	2,680 ± 920	6,010 ± 560	Parrish (1972)
73.8	1.35 × 1.35	170 ± 25	83 ± 15	87 ± 25	1,970 ± 680	4,410 ± 410	Parrish (1972)
89.1	1.10 × 1.10	288 ± 30	80 ± 15	208 ± 30	1,250 ± 430	2,790 ± 260	Parrish (1972)

[a] See text for explanation

At a frequency ν_{HF}, sufficiently high that the H II region becomes optically thin, the brightness temperature T_{bHF} will be equal to the product of the optical depth and the electron temperature. The optical depth at a low frequency, $\tau_{\nu LF}$ can be derived from the observed brightness temperature T_{bHF} 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 β, defined as in the expression $T \propto \nu^{\beta}$ of the brightness temperature variations in the direction of W51 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 W51 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 W51. 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 beam-widths 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, $S_{E\nu}$, 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

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

$S_{E\nu}$ is the error in the measured flux densities of Parrish (1972) with a spectral index "α" defined as in the expression $S_{E\nu} \alpha \nu^\alpha$. 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}, $S_{E\nu}$ and α. The best fit value of "α" is -0.25 ± 0.21 which corresponds to a brightness temperature spectral index of -2.25 ± 0.21. This value is in reasonable agreement with the measured brightness temperature spectral index close to the direction of W51. 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 W51 complex is 9600 ± 600 K. The derived brightness temperature of the galactic radiation on the far side of W51 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 W51 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 W51. The derived temperatures on the near and far sides of W51 at other frequencies are listed in Table 1. The usually accepted value for the distance of W51 is 6.5 pc, (Bieging, 1975). On this basis, the volume emissivity of the galaxy in the direction of W51 at 34.5 MHz turns out to be 2 pc^{-1}. This value is in reasonable agreement with that derived by Milogradov-Turin (1982) of 2–3 pc^{-1}, at 38 MHz in the direction of CygX.

An interesting aspect of the study of W51 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. W51C 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 W51C, 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 W51 which includes the eastern arm (W51C), 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 $19^h20^m20^s \pm 10$. The width of the high frequency maps including the eastern arm (W51C) is more than 45′ in R.A. It would therefore appear that the region W51C 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. $19^h21^m00^s$. 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 W51 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 W51C are $\gtrsim 2.4$, whereas in the regions of W51A and W51B they are $\simeq 2.0$. It would appear therefore that the extended background component of W51 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).

Acknowledgements. We would like to thank V. Radhakrishnan for his keen interest and kind support of the low frequency radio astronomy project at Gauribidanur and for critically reading the manuscript. Our thanks are also due to R.K. Shevgaonkar for many useful discussions. G.N. Rajasekhara, Nanje Gowda and Aswathappa are thanked for their help in collecting the data. We would like to thank the referee for his very useful comments which enabled us to present our results in a very lucid way.

References

Bieging, J.: 1975 in H II *Regions and Related Topics* eds. T.L. Wilson, D. Downs, Springer, Berlin, p. 443
Bridle, A.: 1967, *Monthly Notices Roy. Astron. Soc.* **136**, 219
Haslam, C.G.T., Salter, C.J., Stoffel, H., Wilson, W.E.: 1982, *Astron. Astrophys. Suppl.* **47,** 1
Kuhr, H., Witzel, A., Pauliny-Toth, I.I.K., Nauber, U.: 1981, *Astron. Astrophys. Suppl.* **45**, 361
Macleod, J.M., Doherty, L.H.: 1968, *Astrophys. J.* **154**, 883
Martin, A.H.M.: 1972, *Monthly Notices Roy. Astron. Soc.* **157**, 31
Milogradov-Turin, J.: 1974, *Mem. Soc. Astron. Ital.* **45**, 85
Milogradov-Turin, J.: 1982, *Hvar Obs. Bull. Suppl.* **1**, 23
Milogradov-Turin, J.: Smith. F.G.: 1973, *Monthly Notices Roy. Astron. Soc.* **161**, 269
Mufson, S.L., Liszt; H.S.: 1979, *Astrophys. J.* **232**, 451
Parrish, A.: 1972, *Astrophys. J.* **174**, 33
Roger, R.S.: 1969, *Astrophys. J.* **155**, 831
Sastry, Ch.V. Shevgaonkar, R.K.: 1983, *J. Astrophys. Astron.* **4**, 47
Scott, P.F.: 1978, *Monthly Notices Roy. Astron. Soc.* **183**, 435
Shaver, P.A.: 1969, *Monthly Notices Roy. Astron. Soc.* **142**, 273
Westerhout, G.: 1958, *Bull. Astron. Neth.* **14**, 215
Wilson, T.L., Mezger, P.G., Gardner, F.F., Milne, D.K.: 1970, *Astrophys. Letters* **5**, 99