THE CARINA NEBULA AT 30 MHz

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Abstract

A map of the Carina nebula, with 50′ arc resolution, has been made using the 30 MHz aperture synthesis telescope at Fleurs. At this frequency the nebula appears in absorption. A strong nonthermal source, presumably a supernova remnant, has been found in front of the nebula. Estimates of the emissivity in this region from brightness temperatures are found to vary markedly over the extent of the nebula. The average measured emissivity is lower than that in the local arm, suggesting the presence of an interarm gap between the Sun and the nebula.

I. Introduction

The Carina nebula, NGC 3372, has been studied quite extensively at higher radio frequencies. In particular, high resolution maps of the region have been obtained at 408 MHz with a 3′ beam (Shaver and Goss 1970*a*) and at 5000 MHz with a 4′ beam (Gardner *et al.* 1970), while somewhat lower resolution maps at 1410 and 2650 MHz have been obtained by Beard and Kerr (1966). These results together with the H109α line measurements of Gardner *et al.* have established the thermal nature of the source. Electron temperatures in the vicinity of 7000 K have been deduced both from the continuum data at 5000 and 408 MHz (Shaver and Goss 1970*b*) and from the H109α line and 5000 MHz continuum data (Gardner *et al.* 1970). No evidence of nonthermal components has been reported by any of these workers, although a presumed extragalactic nonthermal source (G287·7−1·3) on the southern edge of the nebula has been noted by Shaver and Goss (1970*b*).

The present 30 MHz observations reveal the presence of a nonthermal source near the position of the peculiar star η Carinae. Rodgers and Searle (1967) have noted that the optical continuum emission from this star is similar to that from the Crab nebula and the Seyfert galaxy NGC 4151 and have suggested that its origin may be synchrotron radiation. However, no radio synchrotron emission has been detected from the region until now.

II. Instrument

The 30 MHz telescope consists of an array of length 1 km in the east–west direction phased so as to produce a fan beam along the meridian. This is used in an interferometer combination with two small movable aerials, each consisting of three half-wave dipoles. The two small aerials are placed symmetrically to the north and south of the east–west array. Correlators form the outputs required for aperture synthesis and, after observations have been made with the north and south aerials in each of 50 positions, maps of sky brightness can be obtained by Fourier transformation. The receiver system has been described in more detail by Finlay and Jones

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(1973). The half-power width of the synthesized beam at declination $-60°$ is $0°\cdot 8$ in right ascension and $0°\cdot 9$ in declination.

Interaction between the east–west array and the north and south aerials made it necessary to remove the central portion of the former array for observations at the closest spacings. This meant that low order Fourier components corresponding to a beamwidth of about 30° were missing from the synthesized maps. These components have been restored by calculating them from the 30 MHz map made with the Parkes antenna (beamwidth 12°) by Mathewson *et al.* (1965). The calibration of the present measurements has been based on a flux density of 1510 f.u. for Hydra A (Finlay and Jones 1973). The brightness temperature scale has been related to the flux density scale using a value of beam solid angle determined from the response to a number of point sources.

III. Observations

The 30 MHz map of the region containing the Carina nebula is shown in Figure 1. The contour interval is 1450 K and the background temperature has been restored as described above. The contour interval corresponds to a peak flux density of $11\cdot 4$ f.u. at this declination. For the region of sky mapped here the background temperature level is considered to be accurate to ± 2000 K.

(*a*) *Thermal Region*

The nebula appears as a depression in the nonthermal galactic radiation which at this longitude has a brightness temperature of about 50 000 K near the galactic plane. The brightness temperature in the direction of the nebula is reduced due to free–free absorption in the ionized gas of the nebula.

The optical depth τ of an ionized region is given by the relation of Mezger and Henderson (1967)

$$\tau = 8\cdot 235\times 10^{-2}\, a(\nu, T_e)\, E\, \nu^{-2\cdot 1}\, T_e^{-1\cdot 35},$$

where $a(\nu, T_e)$ is a slowly varying term which is approximately unity, E (pc cm^{-6}) is the emission measure of the nebula, and T_e (K) is the electron temperature. If an electron temperature of 7000 K is assumed, an optical depth of unity at 30 MHz corresponds to an emission measure of 1200 pc cm^{-6} and the corresponding brightness temperatures at 408 and 5000 MHz ($\approx \tau T_e$) are 29 and $0\cdot 14$ K respectively. These values are well below the minimum contours plotted on the maps of Shaver and Goss (1970*a*) and Gardner *et al.* (1970). Thus the whole of the region surrounded by contours on these high frequency maps is optically deep at 30 MHz and the region of absorption extends considerably beyond the high frequency source.

In Figure 2, the 30 MHz isophotes (contour interval 2900 K) are shown superimposed on an Hα photograph of the region, kindly supplied by D. Mathewson. A region with an emission measure of 1200 pc cm^{-6} shows on the photograph as a faint nebulosity. Apart from some obscuration by dust lanes, the agreement between the regions of nebulosity and 30 MHz absorption is close.

(*b*) *Nonthermal Source*

The strong source at $l^{\rm II} = 287°\cdot 8$, $b^{\rm II} = -0°\cdot 5$ is seen in the direction of a part of the nebula which shows strong thermal emission at 5000 MHz and which must be optically dense at 30 MHz. The source is therefore in front of the nebula. The

30 MHz properties of the source are:

Position (1950·0) of G287·8−0·5	$10^h 45^m$, $-59° 23'$ ($\pm 10°$)
Peak flux density	81 ± 8 f.u.
Angular diameter	$< 25'$
Full beam brightness temperature	55 000 K

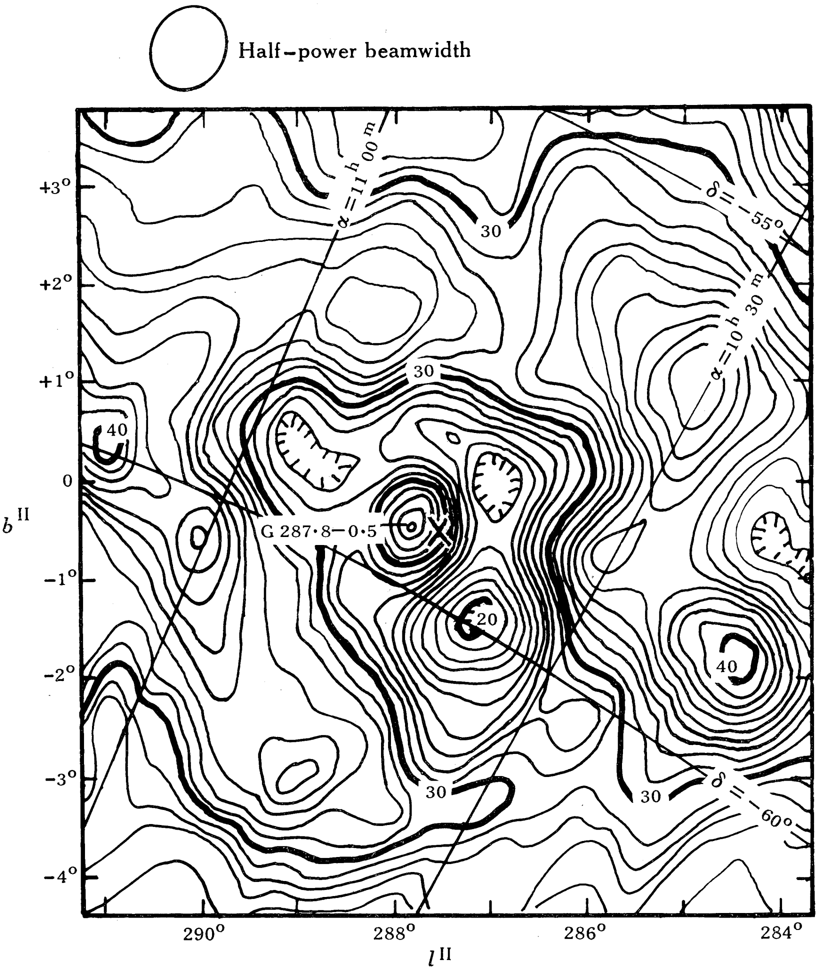

Fig. 1.—Isophotes at 30 MHz of the region including the Carina nebula. The contour interval is 1450 K. The position of η Carinae, which is indicated by a cross, is about 14′ west of the nonthermal source G287·8−0·5. The supernova remnant MSH 11–6*1* (G290·0−0·7) can also be seen.

The high full beam brightness temperature precluded the possibility that the source is thermal and so it is probably a supernova remnant. The 30 MHz position is 14′ to the west of η Carinae. A check on the accuracy of the measured positions of 30 MHz sources away from the galactic plane showed that about 8% of sources had position errors greater than 14′. Positions of sources superimposed on varying baselevels may be less accurate.

This source has not been detected on higher frequency surveys, probably because of a low surface brightness and confusion with the thermal emission from the HII complex. The empirical relation of Milne (1970) between the surface brightnesses and diameters of supernova remnants can be used to estimate the approximate angular diameter of the source. The relation predicts a value of 40′ if a spectral index of $-0 \cdot 5$ and a distance to the Carina nebula of $2 \cdot 5$ kpc (Thé and Vleeming 1971) are assumed. This angular diameter is too large for consistency with the 30 MHz observation but a value of 25′ is possible. The surface brightness temperature at 408 MHz would then be about 100 K, which is less than the contour interval (200 K) on the 408 MHz map of Shaver and Goss (1970*a*).

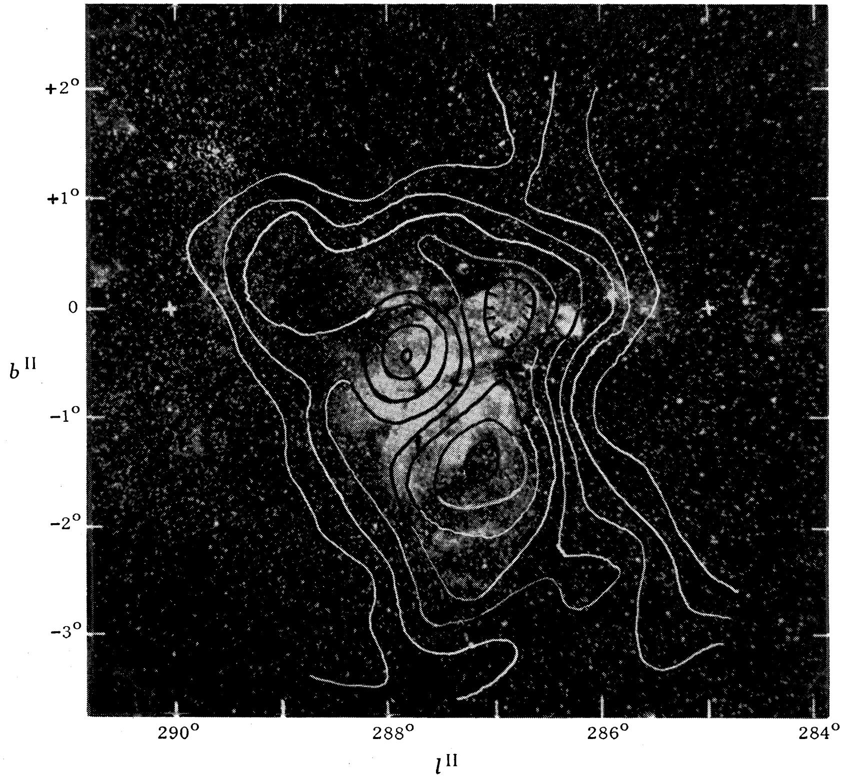

Fig. 2.—Isophotes at 30 MHz (contour interval 2900 K) superimposed on an Hα photograph of the region including the Carina nebula.

The source is not separately distinguishable in the $85 \cdot 5$ MHz survey of Hill *et al.* (1958) but the expected excess beam temperature is only about 400 K, whereas the thermal source gives about 10 times this amount.

(*c*) *Emissivity of Region in Front of Nebula*

Near the centre of the high frequency emission nebula ($l^{II} = 287^\circ \cdot 4$, $b^{II} = -0^\circ \cdot 6$) the 30 MHz brightness temperature is 35 000 K while further to the south ($287^\circ \cdot 0$, $-1^\circ \cdot 5$) it drops to 27 000 K. These temperatures are substantially in excess of the electron temperature of the cloud and since the cloud is optically dense in these directions the excess must result from the nonthermal emission in front of the nebula. Using a distance of $2\cdot5$ kpc for the nebula and an electron temperature of 7000 K the two temperatures correspond to emissivities η_{30} of $11\cdot3$ and $8\cdot0$ K pc^{-1}, or $10\cdot0$ and $7\cdot1\times10^{-41}$ W m^{-3} Hz^{-1} sr^{-1}, with probable errors of 20% (the same for both) resulting from uncertainties in the restoration of the background temperature and in the distance ($\pm0\cdot2$ kpc). The difference between these values may be partly the result of variation of electron temperature over the source, although the temperatures derived from the H109α measurements were as high as 10000 K only in isolated cases and the free–free absorption is weighted towards regions of low temperature. It seems more likely therefore that the variation is detail in the nonthermal emission.

IV. Discussion

The detection at 30 MHz of a supernova which has escaped detection at higher frequencies is due to the increased contrast at low frequencies between the nonthermal source and the thermal emission of the nebula. Higher resolution observations of the object are required in order to examine its extent and possible connection with the star η Carinae. Because of its position in front of the nebula and probable size, it is most unlikely to be obscured optically.

The values of average emissivity measured for the path to the Carina nebula agree well with those obtained by other workers (Bridle 1968; Andrew 1969; Roger 1969) using HII regions in the Perseus arm. Roger (1969), for example, obtained a value at 22 MHz using the HII region IC1805 which corresponds to $\eta_{30} = 8\cdot0\times 10^{-41}$ W m^{-3} Hz^{-1} sr^{-1}, assuming a spectral index of $-0\cdot4$. It appears, however, that the emissivity in the local spiral arm is about three times greater than this. Parrish (1972) has obtained a value equivalent to $\eta_{30} = 30\times10^{-41}$ W m^{-3} Hz^{-1} sr^{-1} using NGC1499 in the local arm, while Alexander *et al.* (1970) have deduced a value equivalent to $\eta_{30} = 39\times10^{-41}$ W m^{-3} Hz^{-1} sr^{-1} from satellite observations at frequencies between $0\cdot4$ and 3 MHz. At $0\cdot4$ MHz thermal absorption limits the received radiation to that originating within a radius of several hundred parsecs of the Sun. A similar value is obtained at $29\cdot9$ MHz using the nebula RCW115, but the optical depth of this nebula is rather uncertain and the value may be high.

The fact that the average emissivity over the path to the Carina nebula is similar to that over paths to nebulae in the Perseus arm and that this is lower than the emissivity in the local arm suggests that there is an interarm gap of low synchrotron emission between the Sun and the Carina nebula.

V. References

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