8·8 GHz RADIO OBSERVATIONS OF 12 SUGGESTED SUPERNOVA REMNANTS

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[Manuscript received 8 November 1972]

Abstract

Brightness distributions and flux densities at 8·8 GHz are presented for 12 small-diameter radio sources near the galactic plane. Each of these sources has been classified at one time or another as a supernova remnant. For one source, G295·2−0·6, the flux density at 8·8 GHz confirms the thermal spectrum suggested by lower frequency measurements and indicates that it is not a supernova remnant. Another source, G309·6+1·7, is thought to be extragalactic.

I. INTRODUCTION

About 80 known or suspected galactic supernova remnants have now been catalogued (Milne 1970; Downes 1971; Dickel and Milne 1972) and contour maps giving an indication of structure have been published for almost 50 of these sources (see the summary by Milne 1971). Most of the sources mapped are necessarily of relatively large angular extent. Milne's (1970) catalogue shows that they also have relatively large linear dimensions and are presumably the older remnants. In fact, emission distribution is known for only 5 of the 18 supernova remnants in Milne's list which have linear diameters $<$ 10 pc.

In this paper we report the results of observations of 12 sources with a resolution of 2′·8 arc at 8·8 GHz. For 7 of the 12 sources the surface brightness–diameter relation derived by Milne (1970) would indicate a diameter of $<$ 10 pc; of these only Kepler's supernova remnant has been previously observed with higher resolution. The remaining five sources all have small angular diameters and have not been previously observed with this resolution.

II. OBSERVATIONS

The 8·8 GHz receiver was a cooled parametric amplifier with a 3 dB bandwidth of 45 MHz and a total system noise temperature of 180 K, and was Dicke-switched between a cold (30 K) load and a linearly polarized single-hybrid-mode feed on the Parkes 64 m telescope. This resulted in a half-power beamwidth of 2′·64 arc. The *E* vector was vertical.

The observations, in March and June 1971, consisted of declination scans at a drive rate of $1° \min^{-1}$ at right ascensions separated by about 1′·3 arc (half-beamwidth). Tie-in scans in right ascension were also made to establish the baseline

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levels. The scans were integrated over half-beamwidth intervals, making the effective resolution $2'\cdot8$ arc. Two scans were averaged at each right ascension to produce a total integration time of $2\cdot6$ s for each point on the map grid. This produced an r.m.s. noise of $0\cdot025$ K in full-beam brightness temperature.

The flux density and full-beam temperature scales were calibrated from scans through the source Hydra A, for which an integrated flux density of $7\cdot65$ f.u.* was adopted.

TABLE 1

FLUX DENSITIES AND SPECTRAL INDICES

Galactic source No.	Other source name	8·8 GHz flux density (f.u.)	Spectral index α
G4·5+6·8	Kepler's supernova remnant	7·5	−0·57
G31·9+0·0	3C 391	9·6	−0·4
G290·1−0·8	MSH 11−6*1*A	18·4	−0·62
G292·0+1·8	MSH 11−5*4*	6·6	−0·36
G295·2−0·6	Kes 16	22·8	−0·1
G304·6+0·1	Kes 17	6·8	−0·4
G309·6+1·7	13S6A A+C	14·5	−0·65
	13S6A B	6·4	−0·7
G326·2−1·7	MSH 15−5*6*	40*	—
G332·4−0·4	RCW 103	9·1	−0·50
G348·5+0·1	CTB 37A	28·2	−0·5
G348·7+0·3	CTB 37B	19·0	−0·5
G357·7−0·1	MSH 17−3*9*	8·3	−0·6

* Compact component only.

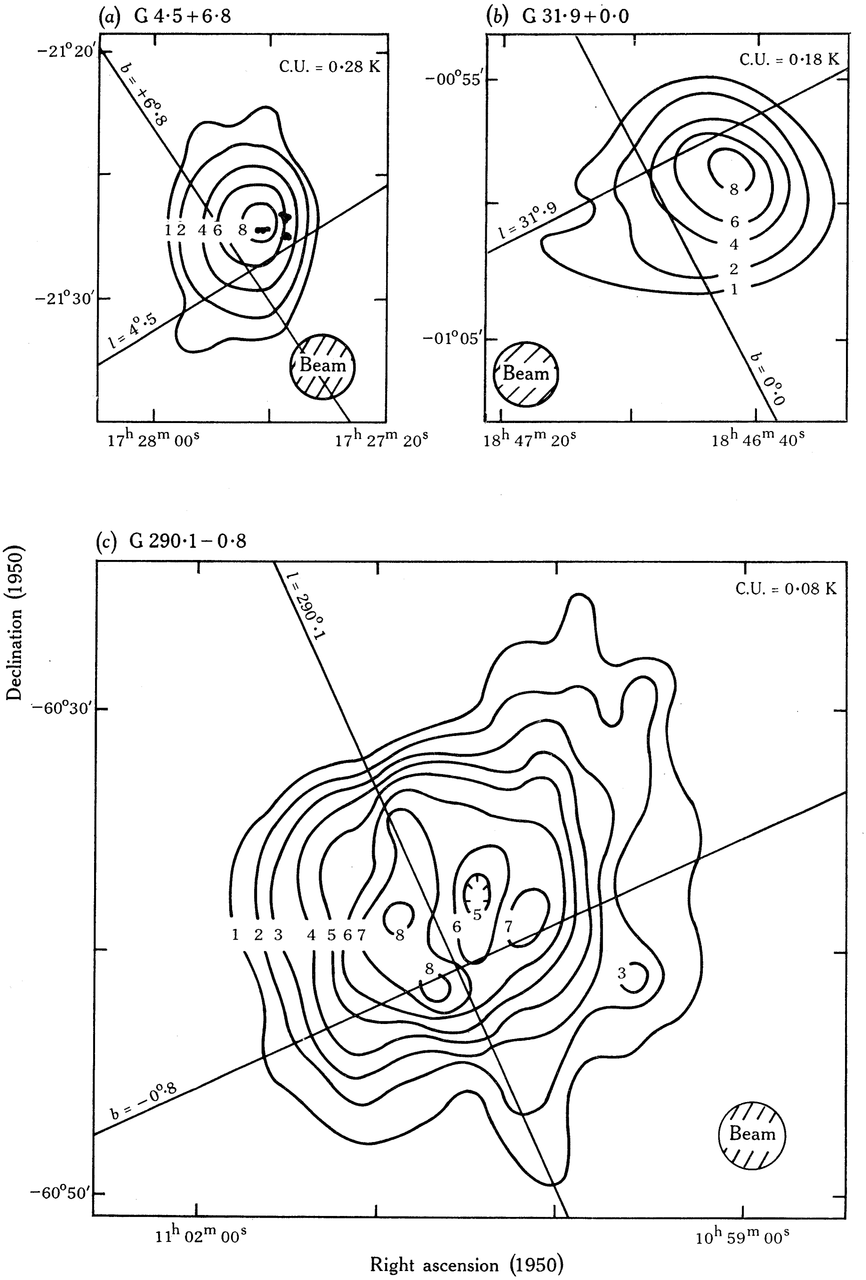
III. RESULTS

The sources which were observed are listed in Table 1, together with the integrated flux density at $8\cdot8$ GHz and the spectral index derived from these and other published flux densities. Contour maps are presented in Figures 1(*a*)–1(*k*). For all but two of the sources, we have not included spectral index diagrams because their spectra are well determined from previous observations (Milne 1969; Lockhart 1971; Dulk and Slee 1972; Dickel 1973) and the new values agree well with those predicted at this frequency. The exceptions are G295·2−0·6 and G357·7−0·1, and the spectra of these two objects are shown in Figure 2. Each source is considered individually, in order of increasing galactic longitude, below.

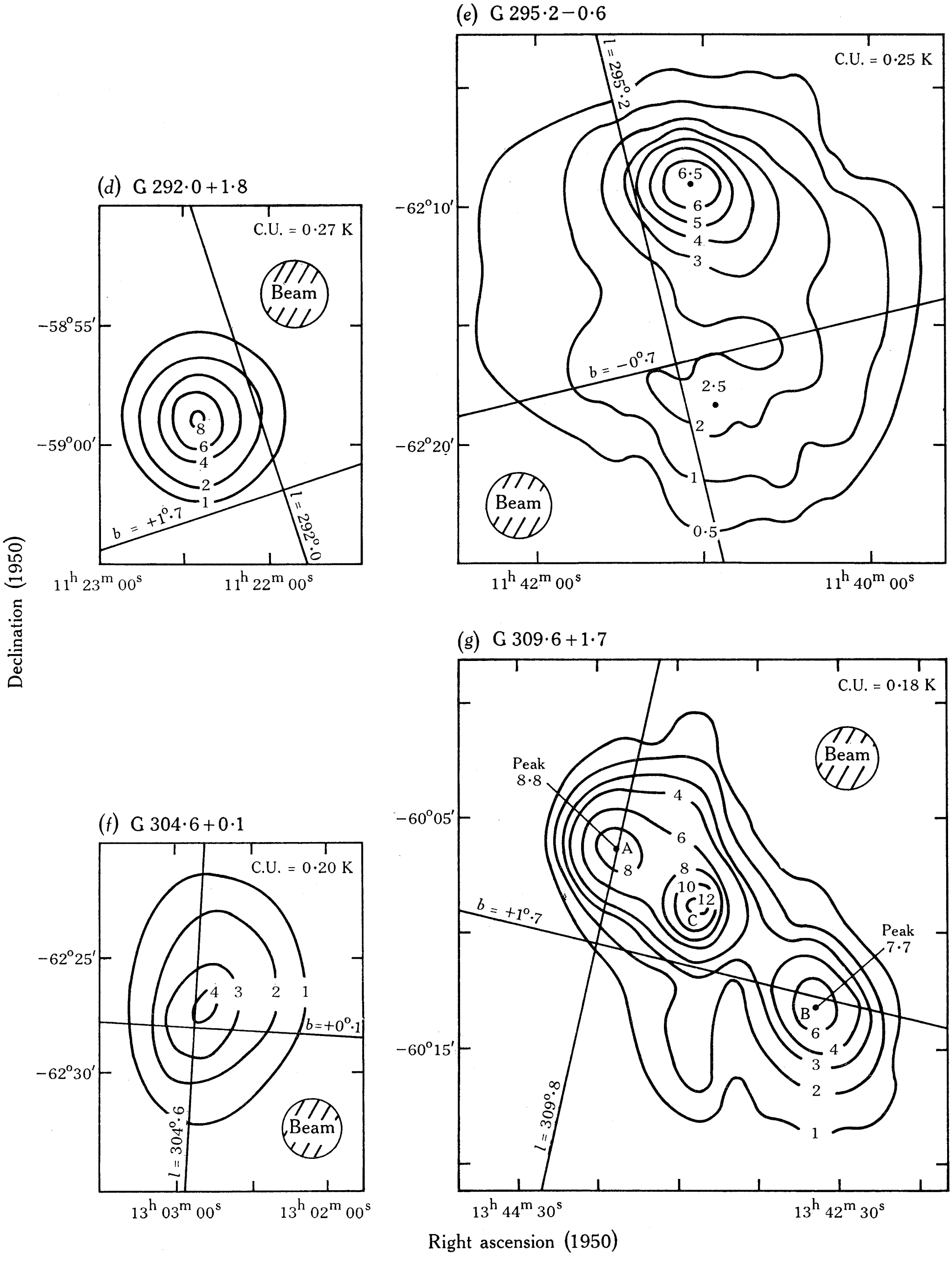
G4·5+6·8 (Kepler's Supernova Remnant)

Interferometric observations of this source by Milne (1969) and Hermann (1972) indicate an irregular shell brightness distribution with an outer diameter of about $2'\cdot3$ arc and a thickness of about $1'$ arc. With the $2'\cdot7$ arc beam, Kepler's supernova remnant (Fig. 1(*a*)) appears approximately Gaussian with deconvolved half-widths of $2'\cdot1$ and $2'\cdot5$ arc in right ascension and declination respectively, which are consistent with the interferometric brightness distributions.

* 1 flux unit (f.u.) = $10^{-26}\,\mathrm{W\,m^{-2}\,Hz^{-1}}$.



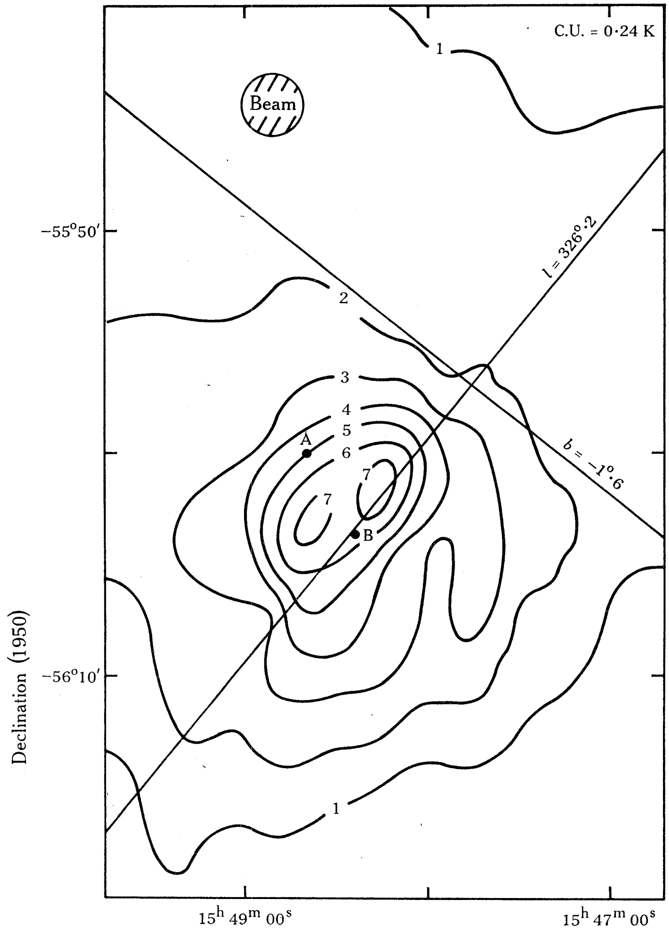
Figs. 1(*a*)–1(*k*).—Isotherms at 8·8 GHz for the 12 observed sources. The contour unit (C.U.) in full-beam temperature is indicated in each figure. The optical filaments associated with G4·5+6·8 are shown in (*a*).



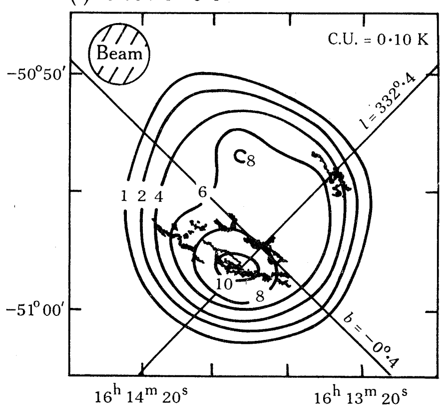
Figs. 1(*d*)–1(*g*)

Figs. 1(*h*) and 1(*i*) (*opposite*).—In (*h*), point B is the centre of the compact source shown here while A is the centre of the extended source as determined from Milne's (1969) map at 6 cm. The optical filaments associated with G332·4–0·4 are shown in (*i*).

(h) G 326·2 −1·7

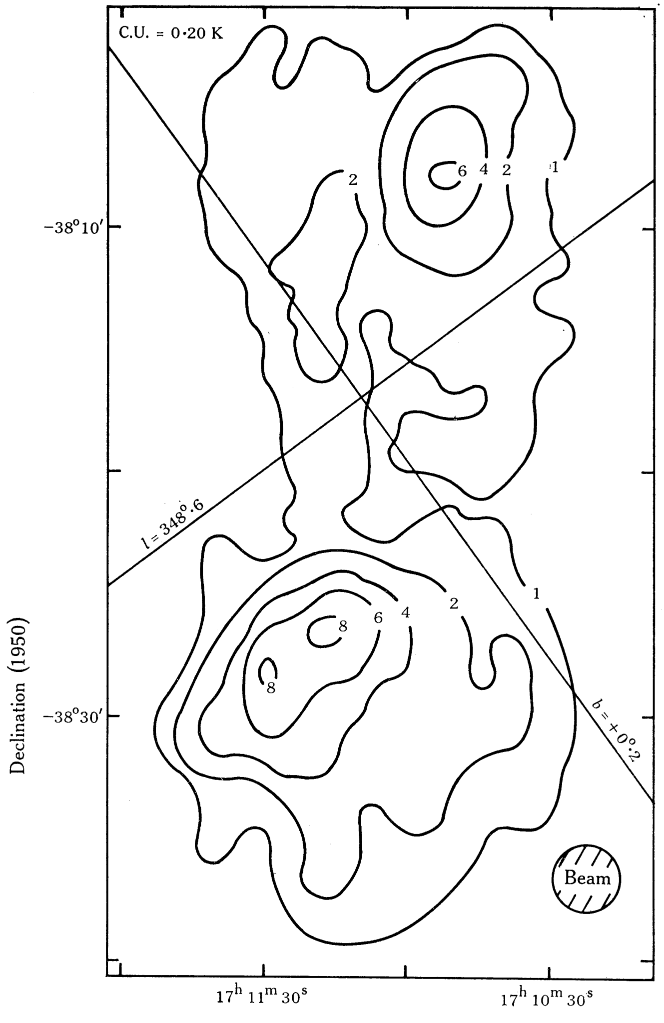


(i) G 332·4 − 0·4

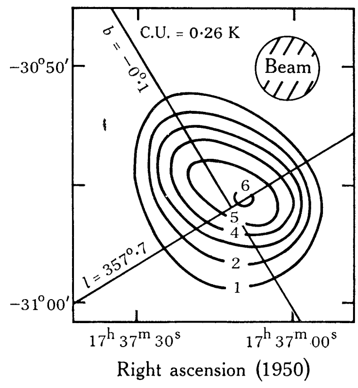


Right ascension (1950)

(*j*) G 348·5+0·1 and G 348·7+0·3



(*k*) G 357·7−0·1



Figs. 1(*j*) and 1(*k*)

G31·9+0·0 (3C391)

Some asymmetry is present in the isophotes for this source (Fig. 1(*b*)), with a steepening on the north-western side and a low-level extension to the east. The deconvolved sizes, 4′·1 and 3′·1 arc in right ascension and declination respectively, agree fairly well with the sizes quoted by Caswell *et al.* (1971). The extension towards the south-east is discernible in the 408 MHz map of Caswell *et al.* and in the 10·63 GHz map of Bridle and Kesteven (1971) and possibly corresponds to the weak secondary source 7′·3 arc from the main peak suggested by Milne's (1969) east–west interferometer measurements.

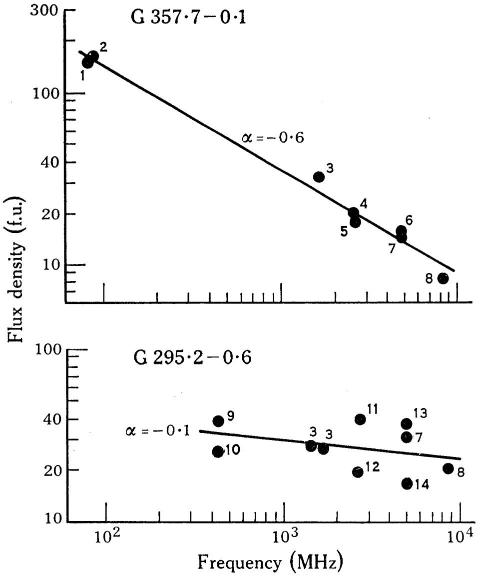


Fig. 2.—Spectra of G357·7–0·1 (MSH 17–39) and G295·2−0·6 (Kes 16). References to data are:

1, Dulk and Slee (1972);
2, Mills *et al.* (1960);
3, Milne *et al.* (1969);
4, Altenhoff *et al.* (1970);
5, Beard *et al.* (1969);
6, Reifenstein *et al.* (1970);
7, Milne and Dickel (unpublished data);
8, Present paper;
9, Kesteven (1968);
10, Shaver and Goss (1970*a*);
11, Milne (unpublished data);
12, Thomas and Day (1969);
13, Milne (1969);
14, Goss and Shaver (1970).

(As the flux density for G295·2−0·6 from (13) Milne (1969) was obviously in error, the 5000 MHz isotherms were integrated again to give the value S_{5000} = 34 f.u.)

G290·1−0·8 (MSH11−61A)

The general source structure shown in Figure 1(*c*) agrees well with the lower resolution maps of Kesteven (1968), Milne (1969), and Shaver and Goss (1970*a*). The peripheral brightness distribution obtained here is fairly consistent with a shell-source model with an outer diameter of 9′ arc and a thickness to radius ratio of 0·3, well within the range 0·15–0·6 for shell-like supernova remnants (Willis 1972). However, like several other supernova remnants (see e.g. Milne 1971), the central part of this source is not as bright as would be expected from a uniform shell model fitted to the outer rim emission.

G292·0+1·8 (MSH11−54)

The contours in Figure 1(*d*) show that the present resolution is insufficient to resolve this source. The source appears slightly elliptical with deconvolved half-power widths of 3′·1 and 3′·5 arc in right ascension and declination respectively. This extent, together with a relatively flat spectrum ($\alpha = -0·36$, with the flux density proportional to ν^{α} where ν is the frequency), compared with extragalactic sources of these dimensions, clearly suggests that despite its relatively large distance above the galactic plane ($\sim$ 400 pc) G292·0+1·8 is indeed a supernova remnant.

G295·2−0·6 (*Kes 16*)

This source (Fig. 1(*e*)) was considered to be nonthermal by Kesteven (1968). However, Shaver and Goss (1970*b*) obtained a thermal spectrum between 408 and 5000 MHz, and an H109α recombination line has been observed in this direction (Dickel and Milne 1972). The spectrum in Figure 2, drawn from all the available data, shows a satisfactory fit to the optically thin thermal spectrum indicated ($\alpha = -0\cdot 1$). The structure shown in Figure 1(*e*) is very similar to that at 408 MHz (Kesteven 1968; Shaver and Goss 1970*a*) which suggests that the spectral index is uniform over the source.

G304·6+0·1 (*Kes 17*)

The low brightness temperature of G304·6+0·1 at this high frequency makes it difficult to observe. The weak extended emission to the east shown by the observations of both Kesteven (1968) and Milne (1969) is not detectable in Figure 1(*f*).

G309·6+1·7 (*13S6A*)

It has been previously suggested that this bright source may well be an extragalactic object similar to the radio galaxy Fornax A (Milne 1969, 1970; Shaver and Goss 1970*b*). Although the present observations do not conclusively prove this hypothesis they do support it. The map in Figure 1(*g*) shows that the source consists of at least three small-diameter components stretched along a line with a low-level extension to the north and south. This picture is very similar to that of many radio galaxies and unlike that of any other supernova remnant, except perhaps 3C 58 (see below). The peak labelled A in Figure 1(*g*) is by far the most prominent at 408 MHz (Shaver and Goss 1970*a*) whereas at 5 GHz the intensity peak is closer to C (Milne 1969; Whiteoak and Gardner 1971) and at 8·8 GHz point C is considerably brighter. The spectral indices of the three components A, B, and C obtained from a comparison of these maps are −0·7, −0·7, and −0·6 respectively. The mean integrated spectral index of about −0·65 (Milne 1969), −0·69 (Shaver and Goss 1970*b*), or −0·7 (present work) is somewhat steeper than that of a typical supernova remnant and is more comparable with the spectrum of a typical galaxy.

Whiteoak and Gardner (1971) found very little Faraday rotation of the polarization between the frequencies 1410 and 2650 MHz and suggested that 13S6A is therefore a close galactic object. However, the only supernova remnant which even remotely resembles this source is 3C 58, which is composed of a series of small components within a roughly elliptical outline (Weiler and Seielstad 1971) and which has extremely large amounts of differential Faraday rotation across its extent. Thus the lack of significant Faraday rotation is also inconsistent with the source being a supernova remnant with a turbulent irregular structure.

Furthermore, Goss *et al.* (1972) have found 21 cm line absorption features in the direction of this source at radial velocities of −30 and −50 km s^{-1}, which indicates that the source is at or beyond the tangential point at 6·5 kpc. If 13S6A is a galactic source at a distance > 6·5 kpc then its surface brightness is 20 times greater than that predicted by the surface brightness versus diameter relations of Milne (1970). In summary, we feel that the evidence favours the identification of 13S6A as an extragalactic radio source.

G326·2−1·7 (MSH 15−56)

The map in Figure 1(*h*) covers only the small bright part of this source and does not extend to completely include a broad faint plateau to the north-east (see e.g. Milne 1969).

G332·4−0·4 (RCW 103)

The contours in Figure 1(*i*) are fairly similar to Milne's (1969) 6 cm map of this object, and it does not seem that the prominent shell structure at 408 MHz found by both Kesteven (1968) and Shaver and Goss (1970*a*) with poorer resolution is as conspicuous at the higher frequencies. The position of the source relative to the optical features is of interest. Figure 1(*i*) shows that at 8·8 GHz the source peak is coincident with the southernmost optical features. After correcting for positional errors in the isotherms of both Kesteven (1968) and Milne (1969)* it seems that at 408 MHz (Kesteven 1968; Shaver and Goss 1970*a*) and at 5 GHz (Milne 1969; Whiteoak and Gardner 1971) the radio peak is placed $\sim 1'$ arc further north, an amount too large to be due to resolution effects alone and outside the errors found in positional checks on other sources.

G348·5+0·1 and G348·7+0·3 (CTB 37A and 37B)

These two sources, shown together in Figure 1(*j*), have the appearance of a Fornax A type galaxy if considered together, whilst separately each is a typical supernova remnant. It may be that they are related only by angular coincidence.

The southern source G348·5+0·1 (CTB 37A) looks like a typical supernova remnant with a partial, relatively thick, shell concentrated towards the north-east side. The spectrum of this source ($\alpha = -0\cdot5$) has a significant turnover at low frequencies (Lockhart 1971; Dulk and Slee 1972) which can probably be accounted for by free–free absorption in ionized hydrogen in front of the source.

The northern source G348·7+0·3 (CTB 37B) has a straight spectrum ($\alpha = -0\cdot5$) and its brightness distribution is peripheral, although not as obviously of the supernova remnant type as CTB 37A. The "bridge" linking the two sources (thought to be evidence of association; Milne 1969) is seen in Figure 1(*j*) to exist mainly as an extension of CTB 37B linking with the southern source at a most unexpected quarter where the shell is strongest, and hence presumably at a region of highest compression. If CTB 37B is a galactic supernova remnant, its measured surface brightness and angular diameter place it $\sim 6\cdot1$ kpc distant from the Sun and well behind CTB 37A ($\sim 4\cdot5$ kpc). The absorbing ionized hydrogen in front of CTB 37A must therefore be very localized, and it may have been ionized by the supernova of which we are now observing the remnant.

G357·7−0·1 (MSH 17−39)

This source (Fig. 1(*k*)) has an elliptical shape with (deconvolved) axes of $6'\cdot1 \times 3'\cdot3$ arc, and higher resolution will be necessary to determine its structure. The flux density of the source is difficult to measure because of the strong background emission close to the galactic centre, but sufficient data now exist to give a reasonable picture of its spectrum, as plotted in Figure 2. A line with a slope of $-0\cdot6$ is shown on this graph.

* The former isotherms should be shifted 2′ arc south-west and the latter 1′·3 arc south (but not 5′ arc as suggested by Whiteoak and Gardner 1971).

IV. Conclusions

In summary, of the 12 sources near the galactic plane investigated in this study, 1 may possibly be extragalactic, 5 show a characteristic peripheral structure, and our resolution of $2'{\cdot}8$ arc is insufficient to determine the structure of 5 of the remaining sources. The observations for G295·2−0·6 (Kes 16) confirm its thermal nature.

V. Acknowledgments

We wish to thank Dr. B. MacA. Thomas, Mr. D. E. Yabsley, Dr. D. N. Cooper, and Mr. A. C. Monticone for constructing the feed system and for measuring its performance on the Parkes radio telescope. We also thank Mr. D. C. Dunn and Mr. R. P. J. Whittle for their considerable assistance in the construction of the receiver.

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