High-resolution radio observations of five supernova remnants

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Summary. Five supernova remnants have been mapped with high resolution using the Fleurs synthesis radio telescope. Four of the sources (G33.6 + 0.1, G309.2 − 0.6, G315.4 − 0.3 and G320.4 − 1.2) possess shell structures, albeit with considerable distortion; the fifth source, G308.7 + 0.0, has a centrally concentrated brightness distribution reminiscent of the Crab nebula but considerably more elongated. In the general direction of G320.4 − 1.2 there is considerable optical emission but only the brightest features seem to be associated with the radio source; currently available sky survey photographs show no associated optical nebulosity in the direction of the other four remnants.

1 Introduction

A description of the Fleurs synthesis telescope (FST) is given by Christiansen (1973). We have already made studies of several galactic supernova remnants (SNRs) with the instrument (Lockhart et al. 1977; Milne et al. 1979; Caswell et al. 1980) and the present paper reports a continuation of this programme. Problems of particular relevance when using the instrument to study sources in the galactic plane were discussed by Caswell et al. (1980).

The present observations were made between 1977 October and 1979 June; the full north–south and east–west baselines currently available (786 m) were used, giving synthesized beam sizes of ∼ 50 arcsec. The system is sensitive to linear polarization with a position angle of the E vector of 90°. The rms noise level on a full-resolution map has a contribution of ∼ 5 mJy from the receivers; fluctuations arising from weak sidelobe responses can also reach ∼ 5 mJy for some galactic plane fields. In order to increase the dynamic range of the maps in the vicinity of strong sources, the ‘clean’ operation (Högboom 1974) was used for all the observations reported here.

2 Results

Table 1 lists the sources observed. The field centre of each observation is given in columns 2 and 3. The sources are generally slightly offset from the field centre (see maps); the map contours have not been corrected for attenuation by the primary beam response (except
<table>
<thead>
<tr>
<th>Galactic source name</th>
<th>Field centre (1950)</th>
<th>Beamsise (E×W×S) (arcsec)</th>
<th>Spectral index</th>
<th>Flux density at 1415 MHz</th>
<th>General remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>G33.6 + 0.1</td>
<td>18 50 00</td>
<td>+00 33 65×48</td>
<td></td>
<td>16.8*</td>
<td>Shell, unusual point source nearby</td>
</tr>
<tr>
<td>G308.7 + 0.0</td>
<td>13 39 00</td>
<td>-62 06 50×49</td>
<td></td>
<td>10.8*</td>
<td>Centrally concentrated, resembles Crab nebula</td>
</tr>
<tr>
<td>G309.2 - 0.6</td>
<td>13 39 00</td>
<td>-62 06 92×89</td>
<td></td>
<td>6.3*</td>
<td>Shell with considerable asymmetry</td>
</tr>
<tr>
<td>G315.4 - 0.3</td>
<td>14 31 00</td>
<td>-60 24 50×48</td>
<td></td>
<td>6.2*</td>
<td>Shell with small H I region superimposed</td>
</tr>
<tr>
<td>G220.4 - 1.2</td>
<td>15 30 05</td>
<td>-59 05 51×47</td>
<td></td>
<td>6.15*</td>
<td>Shell: optical counterpart is RCW 89.</td>
</tr>
</tbody>
</table>

*Data from Clark & Caswell (1976).*
in the case of G309.2 − 0.6), but the attenuation at any point can be calculated given that the primary beam is approximately Gaussian with half-power width ≈ 1°.3. Flux densities labelled on the maps and quoted in the text have been corrected for the primary beam response. The synthesized beam size to half-power (the same before and after cleaning) is given in column 4. The flux density at 1415 MHz ($S_{1415}$) and the spectral index ($\alpha$, defined by $S \propto \nu^{-\alpha}$) given in columns 5 and 6 are estimates made from measurements covering the wide frequency range from 408 to 5000 MHz (flux densities measured from our maps are cited in the discussion of individual SNRs but in several cases are less reliable than the interpolated values of Table 1). Using our new maps, we approximated the outer boundary of each SNR by an ellipse, and the major and minor axes are given in column 7; the method of measurement was consistent with that used by Clark & Caswell (1976) so that the 'equivalent angular size' (appropriate for surface brightness and diameter measurements) is the geometric mean of the major and minor axes.

A discussion of each SNR follows.

G33.6 + 0.1

The primary beam contains several strong sources (notably the H II region G34.3 + 0.1), but none of them generate prominent sidelobes in the region of interest near the supernova remnant. Mechanical limitations near declination 0° restrict the hour-angle range to ±3 h and thus the UV-plane coverage has quite large gaps; the resulting near-in sidelobe level prior to cleaning was 34 per cent. Cleaning was continued to a level of 0.13 Jy per beam area, which is sufficient to remove sidelobes of the more intense small-diameter sources. The map shown in Fig. 1 reveals a roughly circular source centred at RA 18h 50m 05s, Dec +00° 37', with two

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{g33_6_01_map.png}
\caption{Map of G33.6 + 0.1 at 1415 MHz. Contour interval is 0.08 Jy per beam (or 15.6 K in main beam brightness). The lowest contour shown is at 0.08 Jy. The source G33.50 + 0.19 at RA 18h 49m 13s 597, Dec +00° 31' 53'' is of very small diameter and at its centre a solid ellipse equal in size to the half-power beamwidth is shown.}
\end{figure}
arcs, at the north-east and south-west, indicating shell structure; the reliability of the low-
level single contour outside the south-west arc is not certain. Comparison with the 408 and
5000 MHz maps of Caswell, Clark & Crawford (1975) shows satisfactory agreement, with
more detail present in the new map. Our measurement of the integrated flux density is
\( \sim 20 \) Jy, compatible with the (preferred) value of 16.8 Jy interpolated from the Caswell et al.
(1975) data. A map of quite high resolution (\( \sim 2 \) arcmin) made at the low frequency of
160 MHz (Slee 1977) shows strong radio emission to the north of the SNR shell; this
emission is not present on any other maps, including the present one. Although it might
represent a steep-spectrum feature, we suggest it is more likely spurious — a result of side-
lobe responses to one of the other sources in the 8° primary beam field of the radio-
heliograph.

A small-diameter source, G33.50 + 0.19 (\( \equiv 1849 + 005 \)), is present in Fig. 1 at
RA 16:49 m 13.597, Dec +00° 31' 53"; the declination is from the present results (rms error
\( \sim 2 \) arcsec) and the right ascension from the Cambridge 5-km telescope measurement at
2.7 GHz (rms error \( \sim 0.2 \) arcsec — Ryle et al. 1978). Spectral information, extending from 408 MHz to 15 GHz, is summarized in Table 2. Ryle et al. (1978) found an indication of

Table 2. The point source G33.50 + 0.19 (\( \equiv 1849 + 005 \)).

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Date</th>
<th>Flux density (Jy)</th>
<th>Telescope</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>408</td>
<td>~ 1971</td>
<td>1.74</td>
<td>Molonglo</td>
<td>Caswell et al. (1975)</td>
</tr>
<tr>
<td>1407</td>
<td>1976 Dec. 13</td>
<td>0.79</td>
<td>Cambridge OMT</td>
<td>Caswell (unpublished data)</td>
</tr>
<tr>
<td>1415</td>
<td>1977 Oct. 12</td>
<td>0.83</td>
<td>FST</td>
<td>Present observations</td>
</tr>
<tr>
<td>2700</td>
<td>1977 May—Sept.</td>
<td>~ 0.60</td>
<td>Cambridge 5-km</td>
<td>Ryle et al. (1978) (see text)</td>
</tr>
<tr>
<td>4875</td>
<td>~ 1974</td>
<td>0.77</td>
<td>Bonn 100-m</td>
<td>Altenhoff et al. (1978)</td>
</tr>
<tr>
<td>5000</td>
<td>1973 April</td>
<td>0.77</td>
<td>Parkes 64-m</td>
<td>Caswell et al. (1975)</td>
</tr>
<tr>
<td>5000</td>
<td>~ 1974</td>
<td>0.76</td>
<td>Parkes 64-m</td>
<td>Haynes, Caswell &amp; Simons   (1979)</td>
</tr>
<tr>
<td>15 000</td>
<td>1977 Aug. 23</td>
<td>0.79</td>
<td>Parkes 64-m</td>
<td>Caswell (unpublished data)</td>
</tr>
<tr>
<td>15 400</td>
<td>1977 Feb—April</td>
<td>0.6—1.0</td>
<td>Cambridge 5-km</td>
<td>Ryle et al. (1978) (see text)</td>
</tr>
</tbody>
</table>

variability at 15 GHz and measured the angular size to be less than 0.13 arcsec; this led them
to suggest that it is an unusual galactic source (comparable with SS 433 or Circinus X-1) and
possibly associated with the nearby SNR G33.6 + 0.1. H I interferometry has shown the
SNR to be almost certainly beyond 7 kpc (Caswell, Roger et al. 1975), while comparison of
its surface brightness with other SNRs (Clark & Caswell 1976; Caswell & Lerche 1979; Milne
1979) suggests that its distance is \( \leq 10 \) kpc; future H I interferometry will probably allow us
to determine the distance of the point source, and in particular to assess whether it is
galactic or extragalactic. A search for an optical counterpart using the Palomar Sky Survey
plate copies revealed nothing within an error box of 16 arcsec in declination (representing
\( \pm 4 \) times rms uncertainty in the radio position) and 4 arcsec in right ascension (representing
\( \pm 4 \) times the uncertainty in aligning optical and radio positions, since this exceeds the radio
position error). A general comparison of Fig. 1 with the red plate of the Palomar Sky Survey
also shows no diffuse or filamentary optical emission in the direction of any part of the SNR;
in view of the large SNR distance (\( > 7 \) kpc) this can readily be accounted for by obscuration;
a particularly prominent absorbing cloud is evident to the south-east of the shell.

The Ariel X-ray source A1850 + 00 (Seward et al. 1976) has an error box approximately
0°.5 square which encloses both the SNR and G33.50 + 0.19; an improved position for the
X-ray source is needed to ascertain whether it is associated with either radio source.
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Figure 2. G308.7 + 0.0. The contour interval is 0.03 Jy per beam area (≈ 7.5 K in main beam brightness temperature). The lowest contour shown is at 0, and tick marks indicate the side of lower temperature. At the centre of the small-diameter source at RA 13\(^{h}\) 39\(^{m}\) 32\(^{s}\).3, Dec − 61° 53'49" the half-power beamwidth is shown as a solid ellipse.

G308.7 + 0.0

Good UV-plane coverage was achieved at the southerly declination of this source and the sidelobe level before cleaning was 8 per cent. Cleaning was continued to a level of 0.09 Jy; its main effect is simply to 'remove' sidelobes of a quite strong small-diameter source at the north-east of the map, since the remainder of the map shows relatively little small-scale structure. The cleaned and rebuilt map is shown in Fig. 2. Earlier low-resolution maps showed no shell structure and Caswell (1979) interpreted the extended source G308.7 + 0.0 as a centrally concentrated SNR resembling the Crab nebula. The spectrum of G308.7 + 0.0 is fairly flat but definitely non-thermal, and the measured polarization (Milne & Dickel (1975) confirms its non-thermal nature.

The present map with its high resolution is the first to reveal structure in the SNR. Near the centre of the source there is some indication of a small shell, but it is confined to a region much smaller than the total extent of the source; there is a very gradual fall-off in intensity from the centre to the outer edges (which are consequently ill-defined) and thus the source differs markedly from the common variety of shell remnants in which the brightness falls sharply at the outer edge of the shell. Overall, the interpretation of this source as an SNR somewhat similar to the Crab nebula is reinforced by the present observations. As can be seen from the line marking the galactic equator on Fig. 2, the source is strikingly well aligned with the galactic plane — a general feature of this class of remnant noted by Caswell (1979).

The SRC(J) and ESO(B) plates of the southern sky survey show no extended optical emission in the direction of the radio source.

The small-diameter continuum source at RA 13\(^{h}\) 39\(^{m}\) 34\(^{s}\).3, Dec − 61° 53'49" ± 2'" (with \(S_{1415} = 0.40\) Jy) essentially coincides with the OH maser, OH 308.9 + 0.1, at RA 13\(^{h}\) 39\(^{m}\) 37\(^{s}\) 0 ± 2\(^{s}\).4, Dec − 61° 53'55" ± 17'" (Robinson, Caswell & Goss 1974). We suggest that the continuum source is a compact H II region, optically thick at 408 MHz (\(S_{408} ≤ 0.2\) Jy according to Clark et al. 1975). No optical counterpart is detectable, a common situation among the compact H II regions associated with OH masers.
A further continuum source of interest occurs outside the region of Fig. 2, at RA $13^h\ 36^m\ 47.5^s$, Dec $-62^\circ\ 30'\ 24''$ with $S_{1415} = 0.10$ Jy. At 408 MHz, $S = 1.15$ Jy (Clark & Crawford 1974) and thus $\alpha = -2.0$; a spectrum as steep as this is unusual amongst extragalactic sources and the source might be a pulsar (for which such a spectrum is typical), unrecognized as such perhaps on account of a very short period or severe interstellar scattering.

**G309.2 − 0.6**

This SNR lies $0^\circ.7$ from the field centre of our observation made principally to study G308.7 + 0.0; the map of G309.2 − 0.6 is shown in Fig. 3. In order to facilitate ‘cleaning’ in the region of G309.2 − 0.6 and to reduce the noise level, the beamsize was degraded to 90 arcsec (approximately twice its usual value). To the north-west of the cleaned map (Fig. 3), there may be residual effects of grating sidelobes from an H II region (G308.6 + 0.6) located north of the field centre (not shown). The quoted contour interval of the map includes a correction factor of 2.3 to compensate for the reduced gain of the primary beam at the centre of the region shown; however, the gain varies by $\pm 30$ per cent from the north-west to the south-east of the map and this has not been corrected for; furthermore the background level slopes from a low value at the north-west to a higher value in the south-east.

G309.2 − 0.6 was first detected with the Molonglo Cross (Green 1974; Clark, Caswell & Green 1975). Its uncanny resemblance to the strong source G309.7 + 1.7 (13S6A) was a cause of some concern, since both sources lie at the same right ascension with a separation of only $2^\circ.5$ in declination and G309.2 − 0.6 is only $\sim 5$ per cent of the intensity of G309.7 + 1.7; since the sidelobe structure of the Molonglo Cross is predominantly north-south and can approach values of 5 per cent, it seemed possible that G309.2 − 0.6 might be affected by a sidetube response to G309.7 + 1.7. However, 5000-MHz maps (Clark et al.

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**Figure 3.** G309.2 − 0.6. The contour interval is $\sim 0.046$ Jy per beam area ($= 3.55$ K main beam brightness temperature) – see text for variation across map. The zero contour is thickened and a negative contour is shown as a broken line. The half-power beamwidth is shown as an ellipse in the top right-hand corner (there is no source at this position).
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1975; Haynes, Caswell & Simons 1978) obtained with the Parkes 64-m paraboloid (whose sidelobe responses are quite dissimilar to those of the Molonglo Cross) gave some reassurance, since the overall appearance at 5000 MHz was similar to that at 408 MHz. The present map (Fig. 3) confirms the gross features of the earlier low-resolution maps, while the improvement in resolution reveals a well-defined 'horseshoe-shape', in the southern section of the source, which is characteristic of many SNR shells. To the north, somewhat beyond the break in the horseshoe, is the brightest feature, whose position and appearance suggest that it is a portion of the shell which has expanded at a different rate from the remainder. While the northern emission could conceivably be an unrelated source, its position, in line with the break in the horseshoe, and the spectral index similarity of both features (Clark et al. 1975) favour the interpretation as a single shell.

In view of the uncertainties in intensity scaling so far from the field centre, the surface brightness is in satisfactory agreement with the 'expected' value interpolated from earlier observations (but does not provide an improved estimate). The structure (from the present map) can be approximated by an ellipse with major and minor axes of 15 and 8.5 arcmin, with geometric mean diameter of 11.3 arcmin.

Adopting this size, and using the $\Sigma - D$ relationship of Caswell & Lerche (1979), we derived a distance of 10.6 kpc, diameter of 35 pc, and $z$ of $-130$ pc; values 20 per cent less than these are obtained if the relationship of Milne (1979) is used.

The SRC(J) film copy of the Southern Sky Survey shows no extended (non-stellar) optical emission in the region of the radio source. The star cluster NGC 5281 covers approximately a 4 arcmin region near the centre of the shell. Its distance is $\sim 1.6$ kpc (Hogg 1959) and the coincidence in position with the SNR is likely to be one of projection only.

$G315.4 - 0.3$

Good UV-plane coverage was obtained for this source, and the sidelobe level before cleaning was 9 per cent. Within the field of view there are very few radio sources compared with most galactic plane fields. In the vicinity of the SNR, cleaning was continued to a level of 0.04 Jy and the cleaned and rebuilt map is shown in Fig. 4.

Earlier observations left a number of puzzles concerning this SNR: the 5000- and 408-MHz maps (Clark et al. 1975) differed quite markedly, and although a non-thermal shell was discernible on the 408-MHz map, this was very weak at 5000 MHz and largely masked by a compact ($\sim 2$ arcmin) feature with a very flat spectrum ($G315.31 - 0.27$ in Fig. 4). Of additional interest is the existence of an historical record in AD 185 of a possible supernova in this region of sky (Clark & Stephenson 1977) — it is still not known which of several nearby radio supernova remnants (including $G315.4 - 0.3$) might be related to this event. A planetary nebula in this vicinity also appears to have suffered an explosive outburst at about AD 185 (Webster 1978) and this too is in the field which we observed.

The three major features visible on our high-resolution radio map (Fig. 4) consist of a weak shell with diameter $\sim 10$ arcmin, a strong feature in the shell ($G315.31 - 0.27$), and a small-diameter source at RA $14^h 33^m 14^s.58$, Dec $-60^\circ 14' 34''$ with $S = 0.40$ Jy. This latter source has $S_{408} = 1.2$ Jy and its quite steep spectral index, $\alpha = -0.88$, suggests that it is an unrelated background extragalactic source. Superimposed on the shell, the dominant feature $G315.31 - 0.27$ at RA $14^h 31^m 20^s$, Dec $-60^\circ 24' 30''$, has a peak intensity on our map of 0.155 Jy; however, it is clearly extended, with measured half-power widths of $\sim 135$ and 110 arcsec (no allowance made for our finite beamsize of $\sim 50$ arcsec) and an integrated flux density of 1.08 Jy. It shows hydrogen recombination lines at $\nu = +16$ km s$^{-1}$ (Caswell & Haynes, unpublished data) and at both 408 and 5000 MHz the flux density is roughly 1 Jy,

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consistent with an H\,II region still optically thin at 408 MHz. The remaining shell structure is approximately elliptical and brightest near the rim, and thus typical of shell supernova remnants. Comparison of the maps at 408 and 5000 MHz with the 1415-MHz map of Fig. 4 suggests that a weak northerly extension seen only at 408 MHz is not part of the shell. For the shell as defined by the 1415-MHz map and excluding the superimposed H\,II region, our best estimate parameters are: equivalent shell diameter 11.9 arcmin (elliptical major and minor axes of 14.6 and 9.7 arcmin), $S_{408} = 11\ Jy$, $S_{1415} = 6.25\ Jy$, $S_{5000} = 3.8\ Jy$, $\alpha = -0.4$ and $\Sigma_{408} = 0.117 \times 10^{-19}\ W\ m^{-2}\ Hz^{-1}\ sr^{-1}$. Application of the $\Sigma-D$ relationship of either Caswell & Lerche (1979) or Milne (1979) yields a linear diameter of 39.4 pc, distance of 11.3 kpc, galactic height $z$ of $-54$ pc and age of $10\ 000$ yr. Inspection of the Sky Survey atlas shows no extended (non-stellar) optical emission on either the SRC(J) or ESO(B) plates at the position of the SNR shell. However, the sensitivity to faint emission is poor on account of the very bright image of one of our closest stellar neighbours, $\alpha$ Cen at RA $14^h 36^m 11^s$, Dec $-60^\circ 37' 49''$. The absence of any optical counterpart to the H\,II region may well be due to obscuration (in view of its large kinematic distance of $\sim 15$ kpc); the same is true of the SNR shell (in view of its similarly large distance estimate).

Clark & Stephenson (1977) suggest that the optical outburst of AD 185, if due to a supernova, occurred at a distance of less than 2 kpc; G315.4 $-$ 0.3 with distance and age estimates of 11.3 kpc and 10 000 yr (see earlier) thus appears to be excluded as being the remnant of such a supernova. Hill (1967), followed by Clark & Stephenson (1977), favoured G315.4 $-$ 2.3 ($\equiv$ RCW 86) as the shell remnant of AD 185, but the probable distance and age of G315.4 $-$ 2.3 (at 3.4 kpc with age 7500 yr as estimated by Caswell & Lerche 1979) are also discrepant with the optical estimates.

Webster (1978) tentatively associates the outburst of AD 185 with the planetary nebula He-2-111. This object is at RA $14^h 29^m 30^s.94$, Dec $-60^\circ 36' 28''.5$ and has a peak flux density of 0.066 Jy (position and flux density measured from our observations, but outside the map area shown). The optical image has a size of $\sim 20$ arcsec and, if the radio and optical
sources are roughly coextensive (as expected for thermal emission), the integrated radio flux density is $5/4 \times 0.066 \, \text{Jy} = 0.082 \, \text{Jy}$ (compatible with Milne & Aller's (1975) flux density measurement of 0.073 Jy at 5 GHz). Our 1415-MHz map shows no source extended on a scale of ~ 5 arcmin, the size of the optical halo noted by Webster (1978) – our upper limit for the surface brightness of such extended emission is ~ 0.01 Jy per beam area ($\Sigma_{1415} < 0.2 \times 10^{-20} \, \text{W m}^{-2} \text{Hz}^{-1} \text{sr}^{-1}$). In our opinion, Webster's tentative interpretation, that activity in the planetary nebula He-2-111 accounts for the 'supernova' of AD 185, is an attractive one; however, apart from the thermal emission expected from the planetary nebula, we find no additional (non-thermal) radio emission associated with it and it is therefore unlikely to have been a normal supernova.

G320.4 – 1.2

The UV-plane coverage in this observation was good and the sidelobe level before cleaning was 9 per cent. Cleaning was continued to a level of 0.15 Jy – not very low, since the large

![Figure 5. G320.4 – 1.2. Contours are shown at 0, 0.015, 0.03, 0.06, 0.09, 0.12, 0.15, 0.18, 0.27, 0.36, 0.45, 0.54 Jy per beam area (1 Jy = 250 K in main beam brightness temperature). The zero contour is thickened and local minima are indicated by inward-pointing tick marks. Fluctuations of a single contour level outside the source are omitted for clarity. The region above 0.03 Jy is hatched and the region above 0.18 Jy is cross-hatched. At the position of a small-diameter source at RA 15$^h$ 11$^m$ 04$^s$.6, Dec $-58^\circ$ 35' 39" (with $S = 0.14$ Jy), the half-power beamwidth is shown as a solid ellipse.](https://academic.oup.com/mnras/article-abstract/195/1/89/991415)
area needing to be cleaned (on account of the large angular extent of the source) made the cleaning process a slow one. The cleaned and rebuilt map is shown in Fig. 5. The outer boundary of the source is roughly circular and there are bright regions near the periphery in both the north-west and south-east. The equivalent angular diameter of the source measured from Fig. 5 is 29 arcmin. Note that the FST suffers a slight loss of sensitivity to structure on this scale owing to the absence of interferometer spacings shorter than 18 m. Earlier data at 408 MHz (Shaver & Goss 1970) showed a similar gross structure, and comparison of the 408-MHz map with the 5000-MHz map of Haynes et al. (1978) confirms that all features have a similar spectrum, being non-thermal with $\alpha = -0.34$. The present map clearly shows weak radio emission which links the north-west and south-east portions of the source.

The strong north-west radio feature (G320.4 – 1.0, centred at RA $15^h 09^m 43^s$, Dec $-58^\circ 50'$) coincides with the filamentary H$\alpha$ nebula RCW 89 — see the H$\alpha$ print of van den Bergh, Marscher & Terzian (1973) (which unfortunately does not extend to the southern radio arc). The southern sky survey SRC(J) and ESO(B) plates do not detect the nebula RCW 89, nor any optical emission at the position of the southern radio arc. However, a deep H$\alpha$ plate by Georganis & Georgelin (1970) reveals an extremely complicated situation. Weak H$\alpha$ emission is present over the whole radio source and extends more than a degree to the south of the radio source. The further study of these optical features by Lortet, Tarsia & Georgelin (1981) tends to add mystery rather than clarification to the radio picture: the optical (H$\alpha$) emission south of the radio source is interpreted by these authors as a photo-ionized H$\text{II}$ region, in which case it must have a separate origin from the radio non-thermal emission. It seems that the strong northern H$\alpha$ feature, RCW 89, is indeed associated with the SNR, while the remaining, weaker, H$\alpha$ emission is unrelated to the radio SNR, despite some overlap with the southern radio arc.

In conclusion, we interpret the radio source as a single SNR (as Shaver & Goss (1970) did, in contrast with the suggestion by Milne (1970) and Downes (1971) that there were two unrelated sources); one important implication of this interpretation is that the H$\text{I}$ absorption distance (Caswell, Roger et al. 1975) of 4.2 kpc, which was determined for the strong northern component only, then applies to the whole source. It is noteworthy that the considerably brighter northern arc is on the side of the remnant closest to the galactic plane — a common tendency amongst shell SNRs (Caswell 1977; Caswell & Lerche 1979).

The X-ray source 4U1510 – 59 may correspond to all or part of the remnant; it might even be a point source in this direction, but there are no radio point sources with $S \gtrsim 30$ mJy within the SNR which could correspond to it. Future X-ray satellite results from the Einstein Observatory should resolve this question and provide valuable comparisons with the detailed radio structure.

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