HIGH RESOLUTION OBSERVATIONS OF THE RADIO SOURCE W49

C. G. Wynn-Williams

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SUMMARY

Observations of the galactic radio source W 49 (3C 398) have been made with the Cambridge One Mile Radio Telescope, with beamwidths of $23'' \times 148''$ at 1407 MHz and $80'' \times 510''$ at 408 MHz. The thermal component is more compact than was previously thought, having a bright region with a complicated double structure whose main peaks correspond closely with the regions of OH emission, and a feature of lower brightness which extends towards the non-thermal component; the electron temperature of the bright region has the unusually high value of $14,000\pm3000$ K. The structure of the non-thermal component, a supernova remnant, displays a remarkable variation with frequency, which is probably associated with the presence of the nearby H II region and may involve directed emission.

I. INTRODUCTION

W 49 (3C 398) is a radio source on the galactic equator consisting of two components separated by about 12' arc. The region is heavily obscured, yet despite the absence of optical data W 49 is of unusual interest because radio observations have shown that it consists of an H II region [A], associated with which are two centres of intense OH emission (Rogers et al. 1967) and a non-thermal component [B], which may be an old supernova remnant (Mezger & Henderson 1967). From studies of the Doppler shift of the 5 GHz recombination line Mezger & Höglund (1967) deduced that the thermal component is at a distance of 14·1 kpc. This value agrees well with the measurements of Sato, Akabane & Kerr (1967) who, from H I absorption line studies, placed the thermal component at a distance of 15 kpc and the non-thermal component about 1 kpc nearer the Sun. This result suggested that the two components are physically unrelated, a conclusion that is disputed by Mezger et al. (1967a).

Maps of the source have been published by Mezger & Henderson (1967) at 5 GHz, Mezger et al. (1967a) at 0·611, 1·414 and 15·4 GHz, and by Hughes & Butler (1967) at 10·5 GHz. In the maps at the two highest frequencies, which have resolutions of 2' and 2'·8 arc respectively, the thermal component showed signs of having a complex structure, being extended along a line approximately joining the two centres of OH emission. From this evidence, and from a study of the spectrum of the source, Mezger et al. (1967a) concluded that the H II region consists of an extensive fairly low density envelope containing several high density condensations which become optically thick at about 7 GHz and hence contribute little to the total flux below 2 GHz.

Since W 49 is one of the more distant galactic sources, it has a comparatively small angular size which has made it a difficult subject for detailed study at
intermediate frequencies, where both components have large flux densities and the main part of the H II region is becoming optically thick. In this paper results of observations at 408 and 1407 MHz made with the Cambridge One Mile Radio Telescope (Ryle 1962) are presented, which have allowed examination of the structure of the source with far greater resolution than has hitherto been possible.

2. OBSERVATIONS

Observations at the two frequencies were made simultaneously during the autumn of 1967. The operation of the telescope, which consists of one movable and two fixed 18-m paraboloids, has been fully described elsewhere (Elsmore, Kenderdine & Ryle 1966). The aperture which is synthesized by the telescope consists of a series of concentric circular annuli lying in the equatorial plane, producing a response with a half-power beamwidth at 1407 MHz of 23" arc in right ascension and 23° cosec δ in declination. Because of the low declination of W 49 (δ = 9°), the beam is greatly elongated in the north–south direction, having an elliptical section 23" x 148" at 1407 MHz and 80" x 510" at 408 MHz. Since the overall extent of W 49 is about 12' arc, 32 spacings of the aerials were necessary to ensure that at 1407 MHz the innermost grating rings from one component did not confuse the other. Since the data for two spacings are recorded simultaneously, sixteen 12-hour observing periods were required. The reduction of the data closely followed that of Elsmore, Kenderdine & Ryle (1966), the necessary Fourier transforms being performed on the TITAN computer of the University Mathematical Laboratory. The output consists of maps with contours of equal surface brightness (Fig. 1). The most useful method of presentation of these maps is in coordinates with the declination scale multiplied by a factor sin δ. This makes it easier to determine whether or not fine structure has been resolved by the telescope, since the beam then has a circular cross section. However, at this low declination sin δ = 0.156 and this process results in considerable distortion of fully resolved features.

Since the total angular extent of W 49 is an appreciable fraction of the response of a single 18-m paraboloid (54' arc at 1407 MHz), a correction for the appropriate reduction in gain was made to each point on the map before the contours were drawn. In addition, the use of 32 spacings for the synthesis resulted in the first grating ring having a radius of 16' arc in right ascension at 1407 MHz and 54' arc at 408 MHz. In the former case traces of these rings were visible on the original map near the outer edges of the two components. However, since most of the structure lies along an east–west line, the rings were of constant cross-section over the declination range of interest. Thus the profile of the rings could be calculated at declinations north and south of the source and a small correction applied to the maps. The modified contours were then redrawn manually.

The flux densities of the various components were obtained by numerical integration of the brightness distribution, corrected for the response of the paraboloids. A further correction was necessary because of the automatic gain control used in the phase-switched receivers, which is arranged so that the sum of the aerial noise and receiver noise is kept constant at the output of the IF amplifiers. The receiver noise temperature at 408 MHz is about 130°K and at 1407 MHz is about 200°K, so that during observations at low galactic latitudes, the output sensitivity is reduced compared with that when observing the calibration source 3C 295, since
Fig. 1. W 49 at 1407 MHz and 408 MHz. The thermal component [A] is on the right, with the positions of regions of OH emission marked on the 1407 MHz map. The shaded circles represent the half power beamwidths. The vertical scale is compressed by a factor 0.156 as explained in Section 2. The contour intervals are 49°K at 1407 MHz, and 126°K at 408 MHz.
W 49 is in a region of the Galaxy which has a brightness temperature of about 130°K at 408 MHz (Pauliny-Toth & Shakeshaft 1962). To evaluate this correction, a separate measurement was made in which the automatic gain control of one receiver was switched off and the relative total noise temperature for the area of sky around W 49 and for a nearby region of sky outside the galactic plane was recorded, by pointing the dish at the two regions alternately and monitoring the detector current in the receiver. This experiment showed that the measured brightness had to be increased by factors of $1.43 \pm 0.04$ at 408 MHz and of $1.14 \pm 0.03$ at 1407 MHz.

The final values for the flux densities of the main components are shown in Table I. These values are considered accurate to about \pm 15\% per cent and have been used to calculate the mean spectral index over the range, using the convention:

$$S_\nu \propto \nu^{-\alpha}.$$

The values for the thermal component are given separately for the two principal components and for the long easterly extension towards R.A. 19h 08m 16\'. The two bright components are referred to as $A_{51}$ and $A_{59}$ according to their R.A. position in seconds. This is to avoid confusion with the differing uses of the designations $A_1$ and $A_2$ by Mezger et al. (1967a, 1967b) and by Hughes & Butler (1967).

<table>
<thead>
<tr>
<th>Table I</th>
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<tr>
<td>Flux densities of W 49</td>
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<tr>
<td>Flux density ($10^{-26}$ W m$^{-2}$ Hz$^{-1}$)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Thermal source A</td>
</tr>
<tr>
<td>$A_{51}$</td>
</tr>
<tr>
<td>$A_{59}$</td>
</tr>
<tr>
<td>Easterly extension</td>
</tr>
<tr>
<td>Non-thermal source B</td>
</tr>
<tr>
<td>31 $\pm$ 5</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Agreement between these results and those of previous workers is quite good, except that Pauliny-Toth et al. (1966) and Mezger et al. (1967a) obtained values of 47.2 $\pm$ 1.8 and 44 $\pm$ 4 $\times$ $10^{-26}$ W m$^{-2}$ Hz$^{-1}$ for the flux density of component A near 1400 MHz as opposed to the value of 36 $\pm$ 5 found in these observations. Since, however, the integrated flux densities from both components together agree within the experimental errors, the discrepancy may be due to inaccurate estimation of the relative contributions of the two components at the lower resolving powers previously obtainable. This is not unlikely in view of the fact that both components are now seen to have a very complicated structure and that there are steep gradients in the sky brightness temperature in this region. In these new observations, however, the resolution is sufficient to distinguish the components completely, whilst errors caused by variations in background temperature are very small.

The components are discussed in detail in the following sections.

3. The thermal component W49A

The radiation from the thermal component [A] has two main peaks of emission, whose positions are very close to those of the two intense regions of OH emission (Rogers et al. 1967), as may be seen from Table II.
Table II

Positions of peaks of H II continuum (1950.0) compared with positions of OH emission given by Rogers et al.

<table>
<thead>
<tr>
<th></th>
<th>H II position</th>
<th>OH position</th>
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<tbody>
<tr>
<td>A51</td>
<td>19° 07' 51.3 ± 0.2''</td>
<td>19° 07' 49.7 ± 1.8''</td>
</tr>
<tr>
<td></td>
<td>09° 01' 20'' ± 20''</td>
<td>09° 01' 12'' ± 5''</td>
</tr>
<tr>
<td>A59</td>
<td>19° 07' 58.8 ± 0.2''</td>
<td>19° 07' 58.2 ± 1.8''</td>
</tr>
<tr>
<td></td>
<td>09° 00' 10'' ± 20''</td>
<td>09° 00' 04'' ± 5''</td>
</tr>
</tbody>
</table>

Both these H II regions are partially resolved at 1407 MHz in right ascension, but only the areas to the west of A51 and the east of A59 are significantly broadened in declination. The large source, A51, clearly has a still more complex structure, which might possibly consist of three components of unequal intensity, or a bright region surrounded by an uneven halo. There is, in addition, a considerable extension towards W 49B, about 4' arc in length. Since the surface brightness of this region is much lower, the width of the extension is difficult to determine, owing to fluctuations in the background level of the map, but is probably of the same order as the rest of the source. The widths $\theta_a$, assuming a Gaussian distribution, are calculated from the formula:

$$\theta_\text{obs}^2 = \theta_\text{obs}^2 - \theta_a^2$$

where $\theta_\text{obs}$ is the observed width and $\theta_a$ is the width of the aerial beam. In declination, a source width of 70'' represents a broadening of 10 per cent, which is about the variation expected from noise and other errors. The dimensions of the components are summarized in Table III.

Table III

Dimensions of the components of W 49A

<table>
<thead>
<tr>
<th></th>
<th>$\Delta \alpha$</th>
<th>$\Delta \delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A51 (total)</td>
<td>130''</td>
<td>$\leq 70''$</td>
</tr>
<tr>
<td>A51 (central component)</td>
<td>55''</td>
<td>$&lt; 70''$</td>
</tr>
<tr>
<td>A59</td>
<td>40''</td>
<td>$&lt; 70''$</td>
</tr>
<tr>
<td>Easterly extension</td>
<td>$\sim 240''$</td>
<td>$\sim 70''$</td>
</tr>
</tbody>
</table>

In order to determine the optical depths, and hence the physical conditions, in different parts of the source, the 1407 MHz map was convolved with a smoothing function so as to give it the same resolution as at 408 MHz. The brightness distribution, integrated over the declination range of the source, is plotted as a function of right ascension in Fig. 2. The areas under the curves are proportional to the integrated flux densities at the appropriate frequencies and the positions of the peaks A51 and A59 are marked. In view of the fact that the separation of these peaks is little more than one beamwidth, and that the components themselves are dissimilar in both shape and brightness, it is impractical to make a quantitative estimate of their optical depths separately. Fig. 2 does suggest, however, that component A59 has a rather smaller optical depth than A51; if both components have similar temperatures and densities this result is consistent with its smaller size. The easterly extension is clearly of small optical depth.

A comparison of the curves in Fig. 2 suggests that A51 contributes about $16 \times 10^{-26}$ W m$^{-2}$ Hz$^{-1}$ at 408 MHz. Its dimensions, recorded in Table III, although determined at 1407 MHz, indicate that this radiation is emitted from a
region no more than 3 square minutes of arc in area. Since the thermal emission \( S \) is given by the formula:

\[
S \lesssim \frac{2kT_e\nu^2}{c^2} \Omega
\]

the 408 MHz results indicate an electron temperature \( T_e \) greater than or equal to 12 000°K. The ratio of flux densities, however, indicates that the source is not completely optically thick at 408 MHz. Mezger et al. (1967a) have tabulated a function derived by Osterbrock (1965) giving the spectrum of a spherical H II region near the turnover frequency. Although not entirely applicable because of the non-spherical shape of \( A_{51} \), the results suggest an optical depth of 2.0 at 408 MHz and a turnover frequency, at which \( \tau = 1 \), of 570 MHz. This corresponds to an electron temperature of 17 000°K. This temperature is higher than is usual for H II regions and is in the range normally associated with planetary nebulae.

A lower value of \( T_e \) can only be accepted if part of the radiation at 408 MHz is being emitted from an area larger than 3 square minutes of arc. This would be possible if the bright peaks \( A_{51} \) and \( A_{59} \) were surrounded by an envelope of low brightness with a spectral index close to zero which would be contributing proportionally more of the radiation at 408 MHz; such a component might represent a continuation of the optically thin easterly extension. A comparison of the outlines of

\[\text{Fig. 2. Integrated profiles of } W 49A \text{ at } 408 \text{ MHz (continuous line) and at } 1407 \text{ MHz after numerical smoothing (dashed line). The positions of the centres of components } A_{51} \text{ and } A_{59} \text{ are shown.}\]

components [A] and [B] at 1407 MHz (Fig. 1) shows that the thermal component has a rather less well defined edge, which, though not conclusive in view of the effect of noise on the lowest contour, suggests that such an envelope could possibly exist. In view of the surface brightness of the easterly extension, the total contribution of this envelope to the flux density of \( W 49A \) cannot be more than about \( 10 \times 10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1} \) at 1407 MHz. Assuming the spectrum to be flat over the relevant frequency range, this means that \( A_{51} \) and \( A_{59} \) together now contribute only \( 16 \times 10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1} \) at 408 MHz. The flux density of \( A_{51} \) is therefore about \( 11 \times 10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1} \) at this frequency, which leads to a temperature of 11 000°K.
If the envelope had a non-thermal spectrum ($\alpha > 0$), a lower value of $T_e$ would be permissible, but observations at 178 MHz by Gower, Scott & Wills (1967) and by Holden & Caswell (1969) show no increase in the flux density of W 49A at low frequencies. Since the existence of this envelope is not at all well established it can be concluded only that $T_e$ lies in the range 14 000° ± 3000°K.

This temperature leads to the value of $1.35 \times 10^6$ pc cm$^{-6}$ for the emission measure of the bright component $A_{51}$. If it is assumed that the source has an elongated shape and that its average depth is the same as its north–south diameter, namely 4.5 pc, the density and total mass of hydrogen are 550 cm$^{-3}$ and 1200 $M_\odot$ in $A_{51}$. If its shape is more of a flattened disc viewed edge on, as the increase in brightness towards the centre might suggest, the density would be 390 cm$^{-3}$ and the source would contain some 1700 $M_\odot$ of hydrogen. If it is assumed that $A_{59}$ has the same density as $A_{51}$, it would contain about 450 $M_\odot$ of hydrogen.

A comparison of its flux density with its angular size indicates that the easterly extension towards W 49B has an optical depth of $0.10$ at 408 MHz, assuming that it also has a temperature of 14 000°K. Using a cylinder as a model, with the length and diameter noted in Table III, an emission measure of $7 \times 10^4$ pc cm$^{-6}$ and a hydrogen content of 600 $M_\odot$ are obtained. The whole region therefore contains between 1800 and 2300 solar masses of hydrogen. The emission measure of the brightest component is very large and is comparable with the value of $2.3 \times 10^6$ pc cm$^{-6}$ for the Orion Nebula, and $1.5 \times 10^6$ pc cm$^{-6}$ for M17 (Mezger & Henderson 1967). Only in DR21 (Ryle & Downes 1967) and the high density condensations described by Mezger et al. (1967b) are higher emission measures found.

These conclusions differ markedly from those of Mezger et al. (1967a) who, from a study of the 109α emission line, deduced an electron temperature of 6300°K, and used this to construct a model with a spherical distribution of gas $4\arcmin$ arc in diameter with a density of 234 cm$^{-3}$, and a total mass of 9300 $M_\odot$. The high density condensations also mentioned in that paper and predicted independently by Hughes & Butler (1967) have too great an optical depth to be visible at the frequencies used in the present work, although preliminary observations with the One Mile Telescope at 5 GHz have confirmed the presence of fine structure in W 49A, with a scale of 5″–20″ arc.

The cause of the discrepancy in electron temperature is not clear, although there are several possible explanations. One is that the results of this paper have shown that most of the H II continuum emission, as well as the OH emission, comes from two fairly distinct regions. If these have different radial velocities, as is reasonable in view of the complexity encountered in the OH spectrum of W 49 (Rogers et al. 1967) the 109α line will be broadened and too low an electron temperature will result. Although, with perfect resolution, the effective product of the line width and the excess line temperature $T_L\Delta v_L$ would be unaltered by the line being a doublet, visual examination of Fig. 1 (10) in the paper by Mezger & Högland (1967) suggests that an attempt to fit a pair of Gaussian curves to the points available would result in a considerably higher estimate of electron temperature. This difficulty was pointed out by Mezger & Högland in connection with the very low values of electron temperature they derived for W 43 and W 51, sources which have fine structure similar to that in W 49 (Mezger et al. 1967a).

However, this effect is unlikely to account for the whole of the discrepancy and it seems likely either that the 109α line is being enhanced by stimulated emission or that the line radiation is originating in a region with abnormally low electron
The role of the high density condensations (Mezger et al. 1967b) is almost certainly relevant to this problem.

The positions of the sources of intense OH emission are shown in Fig. 1, using the data of Rogers et al. (1967). The correspondence between the angular positions of the OH sources and the peaks of the H II regions is very close, but it is not possible to deduce whether the OH emission in W 49 comes from the peak or from one side of the main regions of the continuum, as it tends to do in other OH sources such as W 3, NGC 6334 and DR21 (Rogers et al. 1967; Mezger et al. 1967b). The fact that the displacement of the OH sources from the H II peaks is nearly the same in both magnitude and direction for each component of W 49A, however, suggests that there could be a small consistent error in one of the right ascension determinations and that there may be a closer connection between the positions of OH emission sources and of the centres of H II radiation than is indicated by Fig. 1.

4. THE NON-THERMAL COMPONENT W 49B

This component is irregular in shape, but, within experimental error, the centroid lies symmetrically between the main components at both frequencies. Its position [1950.0] is:

<table>
<thead>
<tr>
<th>Right ascension</th>
<th>19h 08m 43.3 ± 0.4&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declination</td>
<td>09° 00' 50&quot; ± 20&quot;</td>
</tr>
</tbody>
</table>

Practically all the emission is confined to an area 4' arc in diameter, and any faint features visible outside this are likely to be spurious. In particular the easterly spur on the 1407 MHz map is probably due to incomplete removal of the grating ring from component A.

From the spectral index in Table I and from the spectrum published by Mezger et al. (1967a) it is evident that the radiation from W 49B is of non-thermal origin. Although obscuration prevents optical confirmation, the spectrum and size (approximately 16 pc at a distance of 14 kpc) of the source are consistent with its being a supernova remnant.

The source at first sight appears to have a double structure at both frequencies, whereas most supernova remnants are observed to have an approximately circular profile. The use of an elongated beam, however, greatly increases the difficulty of interpreting such maps and so the effect of observing radially symmetric sources with an elliptical beam was investigated with the aid of the TITAN computer.

![Fig. 3. A thin spherical shell diameter 4' arc as it would appear at 1407 MHz and 9° declination.](image-url)

A range of different brightness distributions $T(r)$ was convolved with a function representing the known response pattern of the telescope at the appropriate declination in an attempt to reproduce the features of the 1407 MHz map (Fig. 1). Fig. 3 shows one of the most successful attempts, which comprises an isotropically...
radiating thin shell of Gaussian profile. The brightness temperature \( T(r) \) is given by:

\[
T(r) \propto \int \exp \left[ -\frac{(r - \sigma)^2}{2\rho^2} \right] \, dz
\]

where \( \sigma \) is the radius and \( 2\rho \) the thickness of the shell. The integration is along the line of sight and assumes that there is no absorption at this frequency. Fig. 3 shows the map that would be produced by the One Mile Telescope at 1407 MHz of such a source at declination 9° with \( \sigma = 120'' \) and \( \rho = 10'' \).

Although drawn for a specific value of \( \rho \), the map changes very little for \( \rho \) over the range 5°–20°, but above 20°, where the shell thickness is no longer small compared to the source diameter and the telescope beamwidth, the height of the saddle is raised and the double character becomes much less pronounced than it is in the real source. Fig. 4 shows the profile along the centre line of the actual source

![Profiles through the centres of W 49B (continuous line) and of the spherical shell model (dashed line) at 1407 MHz.](image)

and of the shell model. Apart from the inequality of sizes of the two peaks in the real source, the general agreement between it and the model is good, confirming that W 49B is a supernova remnant. The high resolution maps of other such sources published, such as Cassiopeia A (Ryle, Elsmore & Neville 1965) and Tycho’s supernova (Baldwin 1967) show that the shells are fairly irregular, with several emission peaks, so that the asymmetry of W 49B is not unexpected.

This asymmetry, however, is not reflected in the 408 MHz map of W 49B. Fig. 5 shows the profile of the source at 408 MHz compared with that at 1407 MHz after numerical smoothing to the same beamwidth. It is evident that the spectral index on the western side is significantly flatter than on the eastern. Quantitative estimates must be treated with caution, since the resolution is low, but by splitting the source into two halves, values of 0.6 and 0.45 can be obtained for the eastern and western sides of the source.

Although such a variation of structure with frequency is rare in supernova remnants, a somewhat similar behaviour has been noted in IC443 by Kundu & Velusamy (1968) in which the spectrum of the north-east rim was found to be flatter than that of the rest of the source at low frequencies. In both cases the region of low spectral index coincides with the brightest part of the shell at 1400 MHz (Hogg 1964).
Fig. 5. Profiles through the centres of W 49B at 408 MHz (continuous line) and at 1407 MHz after numerical smoothing (dashed line).

In his study of HB3, another supernova remnant near an H II region (W 3), Caswell (1967) notes that the strongest emission comes from the region of the shell nearest the H II region. He also points out that the results of Locke, Galt & Costain (1964) show that the density of both neutral and ionized hydrogen around IC443 is also higher near the bright north-east rim than elsewhere.

It is therefore probable that the enhanced emission on the western side of W 49B is associated with its close proximity to W 49A, especially in view of the existence of the easterly extension from the H II region, which stretches at least half way along the projected separation of the components. If such a physical relationship exists, the difference in optical depths of the 21-cm H I absorption profiles (Sato et al. 1967) may be explained by the presence of a diffuse shell of neutral hydrogen surrounding W 49A, having a density of about 25 cm⁻³ and a radius of 40 pc (Mezger et al. 1967a).

Van der Laan (1962) has proposed that in some supernova remnants radiation resulting from the compression of the interstellar medium can coexist with that from the original relativistic electrons. A possible explanation, therefore, of the spectral index variation is that, while on the eastern side the emission is still from the original particles, the increased compression of the interstellar medium on the western side is causing emission with a spectral index appropriate to the flatter energy spectrum of the interstellar medium. It is difficult to estimate the age of the supernova remnant because of the great uncertainty about the interstellar particle density around W 49B but, on the basis of its volume emissivity, Aizu & Tabara (1967) suggest that its age is of the order of 3000 years. This makes it intermediate in age between young sources such as Cassiopeia A and Tycho's supernova, and old remnants such as IC443 and the Cygnus Loop, so that in W 49B one might well expect emission from both the original particles and the compressed interstellar medium.

A second interesting feature of the 408 MHz profile of W 49B is that the depression in the middle is much greater than would be expected for a uniformly radiating spherical shell source, as can be seen in Fig. 6. For comparison, the third, dotted, line in Fig. 6 is the profile that would result at 408 MHz from a source consisting of a thin circular ring of emission, its axis parallel to the line of sight,
with no radiation from the central region. It can be seen that W 49B appears to be intermediate between the two models. There are several factors which might contribute to this effect.

(a) *Absorption inside the supernova shell*

This effect would be stronger at low frequencies, as observed, but for the emission measure to be large enough to cause significant absorption at 408 MHz, the thermal emission from the absorbing medium would have to be greater than the non-thermal emission from the shell above about 10 GHz. The results of Mezger et al. (1967a), however, show that at 15.4 GHz the flux density of W49 B is still compatible with a non-thermal spectrum. In addition, Mezger & Höglund (1967) reported the absence of the 109α recombination line in W 49B, which indicates that any thermal emission must be very weak.

![Fig. 6. Profiles through the centres of W 49B (continuous line), of the thin spherical shell model (dashed line) and of the circular ring model (dotted line) at 408 MHz.](image)

(b) *Irregularities in the shell*

To obtain the profile observed at 408 MHz one would have to postulate that the shell had two strong peaks of emission, one on each side of the source. This is reasonable on the western side, since Fig. 4, the 1407 MHz profile, also shows some signs of such a peak, but the peak on the eastern side would have to have a very steep spectral index indeed to disappear so completely from the 1407 MHz map.

(c) *Directed emission in the shell*

A profile such as that seen in Fig. 6 might arise if the synchrotron radiation were enhanced in directions tangential to the shell’s surface. The existence of such directed emission has been postulated by Baldwin (1967) to occur in Tycho’s supernova, but the absence of evidence for the effect at 1407 MHz in W 49B makes the explanation less attractive. Observations at different polarisations would be useful here.

It is not clear whether the reduced emission from the centre of the shell is associated with the variation of spectral index, or should be regarded as a separate phenomenon. High resolution studies of other such sources of different ages are
very important in ascertaining to what extent these effects are common to all supernova remnants.

ACKNOWLEDGMENTS

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