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WSRT Observations of Radio Sources in the Galactic Plane near *l* = 54°

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Abstract. A radio continuum map of a 1°.5 × 1°.5 region in the galactic plane near $l = 54°$ is presented at 49 cm with a resolution of 100 arcsec × 200 arcsec. The shell source G 54.4 – 0.3 has the characteristics of a supernova remnant while the second large ring structure G 53.9 + 0.3 is a H II ring consisting of W 52 and several small-diameter thermal sources. One of the twelve small-diameter sources (G 54.73 + 0.61) has a spectral index ~ –1.6.

Key words: supernova remnants—H II regions—interstellar medium

1. Introduction

The complex region near l = 54°, b = 0° was first considered to be a supernova remnant (SNR) by Holden & Caswell (1969) and was designated as HC 40. However, further observations of this region at 11 cm with higher resolution (5.5 × 5.5 arcmin) showed several resolved features (Velusamy & Kundu 1974): (1) G 54.4 – 0.3 appears to be a SNR with a nearly symmetric shell structure of size ~ 40 arcmin. A linear polarization of ~ 5 per cent was observed at 11 cm confirming the nonthermal nature. (2) G 53.9 + 0.3 to the southwest also shows a ring structure of size 40 arcmin with a deep minimum near the centre. The source W 52 (Westerhout, 1958) appears to be a part of this shell. Although some polarization was detected in G 53.9 + 0.3, the nature. of this source was not clear. (3) The source of angular size ~ 2 arcmin with a flat radio spectrum near the position of 4C 18.57, is a blending of an H II region and the 4C source (Day, Caswell & Cooke 1972). In the recent Effelsberg maps of this complex region around l = 54° at 6 cm (Altenhoff *et al.* 1979) and 11 cm (Reich *et al.* 1984) with resolutions of 2.6 and 4.3 arcmin, several small-diameter sources are seen in addition to the large-diameter sources G 54.4 – 0.3 and G 53.9 + 0.3. Radio recombination line and continuum data are also available for some of these small diameter sources (Downes *et al.* 1980; Wink, Altenhoff & Mezger 1982). The pulsar 1926 + 18 lies on the boundary of G 53.9 + 0.3. It is possible that some of these features are physically associated and it is important to investigate the nature of the various sources in this region and any physical association between them. Recently, Caswell (1985) has discussed the nature of the sources in this region based on the Penticton Synthesis telescope observations at 21 cm with a resolution of 2.6 × 1.3 arcmin. In this paper we present high resolution observations of this field using the WSRT at 49 cm and discuss our results along with the recently available high-frequency continuum and line observations.

2. Observations and results

The observations at 49 cm were made in 1978 November using the Westerbork Synthesis Radio Telescope (WSRT); the relevant observational parameters are given in Table 1. The observations, data reduction, mapping and cleaning were performed using standard procedure. The full resolution of the original 49 cm map was 50 × 191 arcsec. However, the map shown in Fig. 1 has been smoothed to a resolution of 100 × 200 arcsec in order to improve the signal-to-noise ratio. Due to the shortest spacing of 36 m, structures > 20 arcmin are heavily resolved. The extended emission near the bottom left and top right corners in Fig. 1 are spurious features caused by bad data. The improved position of the pulsar PSR 1926+ 18 (Vivekanand, Mohanty & Salter 1983) is marked in Fig.1. The positions, flux densities and angular sizes of the small diameter sources in this field are listed in Table 2. The flux densities at 49 cm are corrected for the primary beam attenuation. The angular size and flux densities were obtained using the full resolution map and the unresolved sources are indicated as P. The flux densities at 21,11 and 6 cm are from Caswell (1985), Reich *et al.* (1984) and Altenhoff *et al.* (1978) respectively. The recombination line (H 110α) velocities are from Downes *et al.* (1980).

3. Discussion

In order to clarify the nature of the individual sources in this field we have compared the present map at 49 cm with those at 6 cm (Altenhoff *et al.* 1979), at 11 cm (Reich *et al.*

Table 1. Observing parameters.

Field centre (1950.0) R.A.	$19^h29^m00\overset{s}{.}0$
Dec.	$+18° 35' 00\overset{''}{.}0$
Period of observation	1 × 12 hours
Frequency	608.5 MHz
Baselines—Shortest	36 m
increment	36 m
largest	1476 m
Primary beam FWHM	$1\overset{\circ}{.}4$
First grating ring (RA × Dec)	47 × 147 arcmin
Largest structure present	20 arcmin
Full resolution (RA × Dec)	50 × 191 arcsec
Map resolution (RA × Dec)	100 × 200 arcsec
Conversion from flux density to brightness temperature	S(mJy/beam) = 6.0 T_b(K)
rms noise	10 mJy/beam

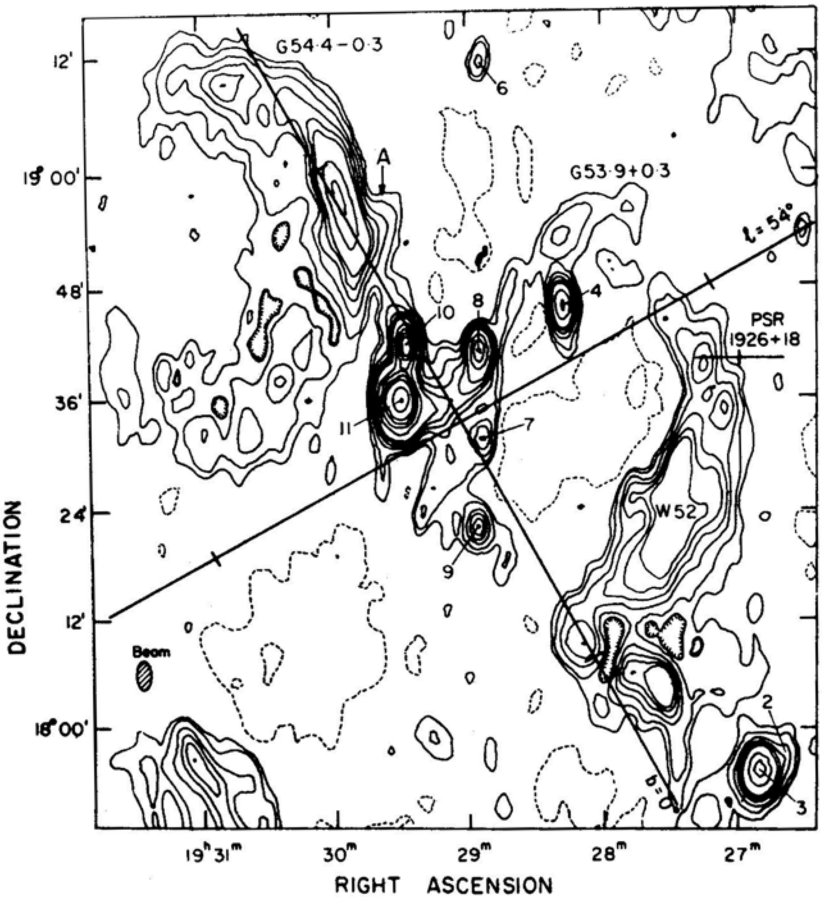

Figure 1. 49 cm continuum map of the field around l = 54°. The resolution is 100 × 200 arcsec (hatched ellipse). The contour levels are –20, 10, 20, 40, 60, 80, 100, 200, 300, 400, 500, 750, 1000 mJy per beam where 10 mJy per beam is 1.7K in full beam brightness. The dashed contours indicate negative values and the hatched contours indicate local minima. The map is not corrected for primary beam attenuation. The rms noise in the map is 10 mJy /beam. Small diameter sources are indicated by the WSRT source number as given in Table 1 (*i.e.* 62W1, 62W2 *etc.*). The position of pulsar 1926 +18 is indicated. Arrow 'A' indicates a distortion in the shell (see text).

1984) and at 21 cm (Caswell 1985). The spectra and nature of the small-diameter sources are summarized in Table 2.

3.1 *Small-Diameter Sources*

Twelve small-diameter sources were detected at 49 cm with flux densities greater than 50 mJy. All these sources are also present in the 21 cm map (Caswell 1985), and only one source 62W2 (Fig. 1) is not listed by Caswell probably because it is confused by 62W3. The observed parameters of these sources at 49 cm and the flux densities at 21,11 and 6 cm are listed in Table 2.

Table 2. Small-diameter sources near $l = 54°$.

WSRT No.	RA (1950) h	m	s	s	Dec (1950) °	′	″	″	Galactic coordinates	Angular size (arcsec)	Flux density (mJy) 49 cm		21 cm	11 cm	6 cm	Spectral index between 49–21 cm	Remarks
62W1	19	26	30.1	±0.5	18	53	04	±25	54.00+0.69	P	70	±15	49			−0.42	
62W2		26	39.2	0.3	17	56	10	15	53.18+0.21	P	115	18					Confused by 62 W3
62W3		26	50.5	0.2	17	54	53	10	53.18+0.16	110	1500	100	2285	2260	2680	+0.50	HII. $V_{HII} \sim 8.3\,km\,s^{-1}$
62W4		28	17.3	0.2	18	45	53	10	54.09+0.26	40	430	30	364	580	400	−0.20	HII?
62W5		28	18.8	0.5	19	28	40	15	54.73+0.61	< 40	380	80	70			−2.00	Steep-spectrum source
62W6		28	53.7	0.5	19	11	38	14	54.54+0.35	P	95	15	150	290	100	+0.53	HII ? 21 and 11 cm fluxes include extended emission
62W7		28	52.3	0.5	18	31	50	15	53.97+0.02	P	45	15	105			+0.10	HII ?
62W8		28	54.7	0.2	18	41	10	10	54.07+0.10	P	390	30	170			−1.00	Extragalactic?
62W9		28	55.1	0.3	18	22	14	15	53.82−0.06	P	85	15	103			+0.23	HII ?
62W10		29	27.3	0.2	18	41	50	10	54.17−0.01	P	615	40	321			−0.76	4C 18.57—Extragalactic?
62W11		29	30.0	0.6	18	36	07	17	54.09−0.07	105	1300	200	2500	2650	2470	+0.77	HII. $V_{HII} \sim 43\,km\,s^{-1}$
62W12		32	13.4	0.2	18	13	28	10	54.07−0.81	P	380	20	215	200	100	−0.67	Extragalactic?

(i) 62W8 and 10 are the most prominent nonthermal sources close to the galactic plane within $|b| < 0^{\circ}.1$ in the field shown in Fig. 1. 62W10 can be associated with the source 4C 18.57. Caswell (1985) noted this association but incorrectly listed the 4C source as 4C 18.42 due to copying error. The position at 178 MH*z* (Gower, Scott & Wills 1967) is within 70 arcsec of 608.5 MH*z* position. In the earlier low-resolution maps at centimetre wavelengths it was confused by 62W11, an HII region to the south. Both 62W8 and 10 have steep radio spectra (with $\alpha_{49-21\mathrm{cm}} \sim -1.0$ and -0.8 respectively) and are likely to be extragalactic.

(ii) 62W3 and 11 are clearly HII regions (G53.18 + 0.16, G 54.09 – 0.07)as indicated by the radio spectrum as well as the detection of radio recombination lines (Wink, Attenhoff & Mezger 1982; Downes *et al.* 1980). Both these sources seem to have a turnover frequency around 1 GHz. 62W3 is at the far side of the galaxy at distance of ~ 11.4 kpc while 62W11 is at distance of 3.9 or 7.9 kpc from the Sun (Wink, Altenhoff & Mezger 1982).

(iii) 62W4, 7 and 9 seem to be thermal radio sources as indicated by the flat radio spectrum between 49 and 6 cm. It is interesting that 62W4, 7 and 9 and W52 lie along the ring structure centred on G 53.9 + 0.3.

(iv) 62W6 is located in the direction of the extension which appears to rise from the shell of SNR G 54.4 – 0.3(feature A in Fig. 1). This is discussed in detail in Section 3.2.

(v) 62W5 appears to be a steep spectrum source with $\alpha_{49-21\ \mathrm{cm}} \sim -2.0$. This source is located outside the map shown in Fig. 1. It has a flux density of 380 ± 80 mJy at 49 cm and may be resolved with size $\lesssim 40$ arcsec. It may be noted that the uncertainties in the size and flux density are due to the large primary-beam correction (a factor of 3.7) as this source is about 55 arcmin away from the map centre. In Fig. 2 is shown the flux-density

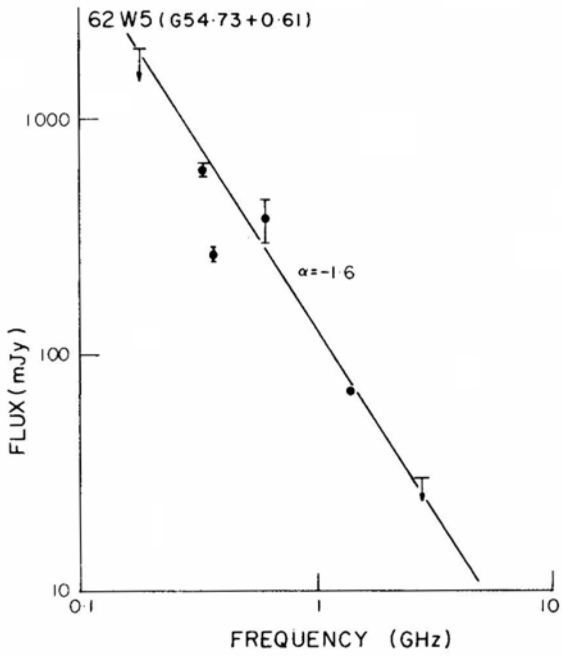

Figure 2. Flux-density spectrum of the source 62W5 (G 54.73 4 + 0.61).

Spectrum of this source. The upper limits to the flux densities at 178 MHz and 2.7 GHz are 2 Jy and 30 mJy respectively as this source was not detected in the 4C survey (Gower, Scott & Wills 1967) and in the Effelsberg map of this region (Reich *et al.* 1984). A flux density of 614 ± 30 mJy at 92 cm was obtained from the WSRT observation made in January 1984 with a resolution of 56 × 163 arcsec (Goss *et al.* in preparation). It is not clear why the flux density of 263 mJy at 365 MHz in the Texas Survey (Douglas *et al.* 1980) is not consistent with the spectrum shown in Fig. 2. In view of its close proximity to the galactic plane ($b \sim 0\overset{\circ}{.}6$) and rather steep spectrum, this source would be extremely interesting for further high-resolution observations.

3.2 *SNR G* 54.4 – 0.3

In the 49 cm WSRT map (Fig. 1) the shell structure of this source is obvious supporting its identification as a SNR. In the earlier low-resolution maps the shell structure became clear only after the substraction of a source near the 4C 18.57 position (Velusamy & Kundu 1984), and its identification as a SNR is now confirmed. In Fig. 1 this shell is nearly circular and about 60 per cent complete. However, when smoothed to lower resolution (~ 300 arcsec), we see some evidence for weaker emission extended over a nearly complete shell. The maps at 11 and 21 cm (Reich *et al.* 1984; Caswell 1985) also show a complete ring except for a small gap near the north-east boundary. The shell thickness appears to be nearly constant along the shell, with mean thickness of ~ 10 arcmin and a shell radius of ~ 20 arcmin. However, the brightness along the shell is quite irregular. The brightest emission is seen along the western part of the shell and the brightness decreases monotonically towards the east (Fig. 1). Further, the brightness along the shell is peaked near $b = 0°$ and decreases steadily away from the galactic equator. Such a brightness variation may be expected from an SNR expanding into the interstellar medium with large gradient in the density of relativistic particles and magnetic field (Caswell 1977). A detailed study of the spectral-index distribution would be very useful.

The integrated flux density of G 54.4 – 0.3 at 49 cm is only 6.6 Jy compared to the flux density of 34 Jy at 11 cm (Velusamy & Kundu 1974). However, the 11 cm flux density includes considerable background emission. The flux density at 21 cm is 18 Jy (Caswell 1985). Obviously, the flux density at 49 cm is underestimated because of missing short spacings and has severe limitations for deriving the spectral index and the physical parameters of the SNR. From the 21 cm data, Caswell (1985) has derived a distance of 5 kpc and an age of 33000 years for the SNR.

A jet-like emission (feature A in Fig. 1) emerging to the northwest is seen at $\alpha = 19^h29^m37^s$ $\delta = +18°55'$ along the brightest part of SNR. This feature is seen prominently also in the 21 and 11 cm maps (Caswell 1985; Reich *et al.* 1984). It is interesting to note that the source 62W6 lies 27 arcmin away from the SNR in the direction of this feature. Caswell suggests that this source and the jet-like feature are components of an extragalactic double radio source seen in projection against the SNR. Although in the 49 cm map this source is unresolved, in the 20 and 11 cm maps there are indications of extended emission around it. Further, as seen from the flux densities given in Table 2, its spectrum is rather uncertain and it is not clear whether it forms part of a double radio source. However, it would be interesting if this jet-like feature is not part of a double radio source and is associated with the SNR, particularly since such radio jet features are not uncommon in the SNRs, for example, in the Crab Nebula (Velusamy 1984) and in G 332.4 + 0.1 (Roger *et al.* 1985). Obviously, high-resolution observations are required to investigate the nature of this interesting feature.

3.3 *HII Ring G* 53.9 + 0.3

A distinct minimum is seen near $\alpha = 19^h28^m$, $\delta = +18°35'$ in Fig. 1. This minimum is seen more prominently at high frequencies (*cf.* Velusamy & Kundu 1974; Altenhoff *et al.* 1979; Reich *et al.* 1984), indicating the presence of a ring structure with diameter about 40 arcmin. Although Velusamy & Kundu (1974) had suggested that it may be a supernova remnant, the true nature of its radio spectrum was uncertain. In Fig. 1 the radio emission in the ring is more prominent over the western part coincident with W 52. Over the eastern half, several small-diameter sources are seen superimposed on a rather faint extended emission along the ring. All the other four sources except 62W8 and 10 (Table 2) have thermal radio spectrum. Also recombination lines ($V_{\rm HII}$ ~ 38 km s^{-1} have been detected from the W52 region (Silverglate & Terzian 1979). Further, as shown by Caswell (1985) from a comparison of the radio brightness at 21 and 6 cm, the emission along the ring is predominantly thermal. We therefore conclude that the structure around G 53.9 + 0.3 is an HII shell at a distance of about 3.2 kpc. It is interesting to note that the close proximity of the pulsar PSR 1926 +18 to the ring structure in G 53.9 + 0.3 (Fig. 1). The distance to the pulsar derived from the dispersion measure is ~ 2.8 kpc (Manchester & Taylor 1981). A pulsar–SNR association is ruled out since G 53.9 + 0.3 appears to be an HII ring.

Recently, Sofue *et al.* (1984) have also observed HII rings with diameters ~ 50 arcmin at G 23.2 + 0.2 and G 24.6 + 0.0 in the galactic plane. These are very similar to the HII ring G 53.9 + 0.3 discussed above. The origin of such rings is not clearly understood. These HII rings or shells are perhaps the result of enhanced star formation and may be common throughout the Galaxy.

4. Conclusion

The 49 cm map confirms that G 54.4 – 0.3 is a supernova remnant with structure typical of shell-type SNRs; it has a nearly complete shell. The brightness in the shell is not uniform, with the maximum over the shell closest to the galactic plane, and decreasing steadily away from the plane. The ring-like structure centred on G 53.9 + 0.3 seems to bean HII ring consisting of several small-diameter thermal source sand W52. Of the ten small-diameter sources for which radio spectra are available, four are clearly nonthermal and probably extragalactic and the rest are compact HII regions. The source G 54.73 + 0.61 seems to be a steep spectrum source.

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