NEW SUPERNOVA REMNANTS FROM DEEP RADIO CONTINUUM SURVEYS

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Abstract: Based on radio continuum surveys of the Galactic plane at wavelengths of 21 cm and 11 cm we have so far identified about 32 new supernova remnants in the area $357^\circ.4 \leq \ell \leq 76^\circ$, $|b| \leq 5^\circ$. This increases the number of known objects in this field by about 68%. Most of them are in the Galactic latitude range $|b| > 0^\circ.5$. Some implications are discussed.

Search for new Supernova Remnants

Deep radio continuum surveys with the Effelsberg 100-m telescope at 21 cm and 11 cm wavelength have been used to search for previously undetected supernova remnants (SNRs). The first part of the 11 cm (2.695 GHz) survey covers the area $357^\circ.4 \leq \ell \leq 76^\circ$, $|b| \leq 1^\circ.5$ (Reich et al., 1984b). This survey has an angular resolution of $4'.27$ (HPBW) and a sensitivity of 50 mK T_B (20 mJy/beam area) and has been extended for the area $|b| \leq 5^\circ$. Linear polarization is recorded along with total power (Junkes, 1985; Junkes et al., 1987). The 21 cm survey (HPBW $9'.4$, sensitivity $\approx$100 mK T_B or 50 mJy/beam area) covers at least Galactic latitudes $|b| \leq 4^\circ$ (Reich et al., in prep.). The section $92^\circ \leq \ell \leq 162^\circ$ has been already published (Kallas and Reich, 1980). Both surveys will finally cover the entire Galactic plane visible from Effelsberg.

We have used three different methods to identify SNRs. For several objects we have carried out additional observations at 6 cm wavelength with the 100-m telescope (including linear polarization) and at 3 cm wavelength with the Nobeyama 45-m telescope (Reich et al., 1986; Fürst et al., 1987a). The identification is mainly based on the radio spectral index α.

Particularly in case of plerionic-type SNRs (radio spectrum similar to that of optically thin HII-regions) this identification relies also on the analysis of the linear polarization data. Analysing the polarization data of the 11 cm survey we have found several previously unknown SNRs (Junkes, 1985; Junkes et al., in prep.). This method is limited to regions with a small amount of thermal gas along the line of sight, i.e. to regions of low depolarization.

As a third method we have compared radio and infrared data. Fürst et al. (1987b) have used the 11 cm survey and the IRAS 60 μm survey (IRAS, Beichmann et al., 1985). They have found a ratio R of the infrared to radio emission of typically $R \lesssim 10$ for SNRs and of $R \simeq 1000$ for HII-regions. This contrast in R is used to identify sources even in regions of high confusion. A systematic search for SNRs is in progress.

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Table 1: Preliminary list of newly identified Supernova Remnants based on the Effelsberg 11 cm survey

Source	S(1 GHz) (Jy)	Size (arcmin)	$\Sigma_{1GHz} \cdot 10^{-21}$ (Watt/m^2 Hz sr)	α $S \sim \nu^{\alpha}$	Type	Ref.
G357.7+0.3	10.5	24	2.7	0.4	S	1
G358.4-1.9	12.5	40x36	1.3	0.5?	S	*
G359.0-0.9	23.0	23	6.5	0.5	S	2
G359.1-0.5	15.0	24	3.9	0.4	S	1
G 4.2-3.5	3.2	28	0.6	0.6?	S	*
G 5.2-2.6	2.6	18	1.2	0.6?	S	*
G 5.9+3.1	3.3	20	1.2	0.4	S	*
G 6.1+1.2	4.0	30x26	0.8	0.3?	P	3,4
G 6.4+4.0	1.3	31	0.2	0.4?	S	*
G 8.7-5.0	4.4	26	1.0	0.3	S	*
G 15.1-1.6	5.5	30x24	1.2	0.8?	S	*
G 16.8-1.1	4.9	30x24	1.0	0.2	U	5
G 17.4-2.3	4.8	24	1.3	0.8?	S	*
G 17.8-2.6	4.0	24	1.1	0.3?	S	*
G 18.9-1.1	37.0	33	5.1	0.3	C	6,7
G 24.7+0.6	20.0	30x15	6.7	0.2	P	8
G 27.8+0.6	30.0	50x30	3.0	0.3	P	8
G 30.7+1.0	5.0	24x18	1.7	0.4	S	5
G 30.7-2.0	0.5	16	0.3	0.7?	U	*
G 31.5-0.6	1.5	18	0.7	0.4	S	9
G 33.2-0.6	4.5	18	2.1	0.7	S	10
G 36.6-0.7	---	>25	---	0.9	U	9
G 36.6+2.6	0.7	17x13	0.5	0.5?	S	*
G 42.8+0.6	2.0	24	0.5	0.5	S	9
G 43.9+1.6	8.6	~60	0.4	0.0?	P	*
G 45.7-0.4	3.8	22	1.2	0.4	S	9
G 54.1+0.3	0.5	1.5	33.4	0.1	P	11
G 59.8+1.2	1.6	20x16	0.8	0.5	U	3,4
G 68.6-1.2	0.7	28x25	0.2	0.0?	U	3,4
G 69.7+1.0	1.6	16	0.9	0.8	S	3,4
G 70.7+1-2	1.1	0.3	1840.	0.6	S	11,12
G 73.9+0.9	9.0	22	2.8	0.3	S	5
G179.0+2.6	7.0	70	0.2	0.4	S	13

? = very uncertain

Type: S = shell, P = plerion, C = combined (plerion+shell), U = unclear morphology

References: * = this paper; 1 = Reich and Fürst, 1984; 2 = Reich et al. 1987b; 3 = Junkes, 1985; 4 = Junkes et al., in prep.; 5 = Reich et al. 1986; 6 = Fürst et al., 1985; 7 = Fürst et al., this volume; 8 = Reich et al., 1984a; 9 = Fürst et al., 1987a; 10 = Reich, 1982; 11 = Reich et al., 1985; 12 = Reich et al., 1987a; 13 = Fürst and Reich, 1986

List of new SNRs

The actual list with some data of SNRs based on the application of the identification methods described above is given in Table 1. The systematic search for SNRs was limited to $\ell < 76°$, because of still incomplete observations outside this longitude range. At present one object, G179.0+2.6, was found at $\ell > 76°$. An example of two new shell-type SNRs at high Galactic latitudes is shown in Figure 1. Some spectral index data of the very weak high latitude objects listed in Table 1 are uncertain, because they are based on 21 cm and 11 cm data only. Consequently the derived flux and surface brightness at 1 GHz are also uncertain.

It is apparent from Table 1 that all except two objects have diameters $\geq$15'. For objects of smaller diameter the distinction between SNRs and extragalactic sources requires observations with high angular resolution to obtain their morphological structure. These observations are available only for a very limited number of sources. The two entries in Table 1, G54.1+0.3 and G70.68+1.2, have been observed by Green (1985) and proved to be Galactic.

G70.68+1.20 is of particular interest. This shell-type object (size $\approx$20") is seen towards a high density molecular cloud of a diameter of $\approx$2' (Reich et al., 1987a). All available data indicate that the SNR exploded inside the molecular cloud, which has a kinematic distance of 5.5 kpc.

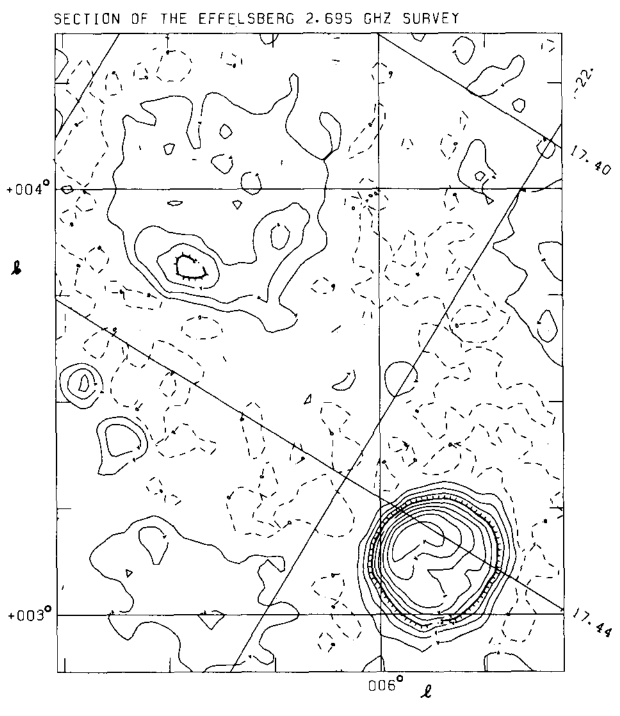

Figure Caption: *Contour map at 11 cm wavelength of the two shell-type SNRs G5.9+3.1 and G6.4+4.0. The contours are 50 mk T_B or 20 mJy/beam area apart. The angular resolution is 4.'27.*

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The size of the SNR is ~0.5 pc and it is still in free expansion. For an average expansion velocity of 2000 km s^{-1} its age is about 135 years. This means it is the youngest Galactic SNR known at present.

Some implications

In the area $357^\circ.4 \leq \ell \leq 76^\circ$, $|b| \leq 5^\circ$ the total number of SNRs reported in the literature and/or listed in Table 1 is 79. At $|b| \leq 0^\circ.5$ the number of SNRs is 33 including 4 objects from Table 1, while for $0^\circ.5 \leq |b| \leq 5^\circ$ the total number is 46 including 28 new sources. The detection limit of the 11 cm survey corresponds to $\Sigma_{1GHz} = 2 \cdot 10^{-22}$ (Watt/m^2 Hz sr) ($\alpha = -0.5$, $S_\nu \sim \nu^\alpha$). While at $|b| \leq 0^\circ.5$ numerous objects may be still undetected due to the high confusion with sources and background emission, the list of objects at $|b| > 0^\circ.5$ seems fairly complete close to the detection limit except for small diameter sources (<12').

No distances are available for most of the objects, so statistical results fully depend on the validity of the application of Σ–D relations. We have applied the Σ–D relation given by Milne (1979): $\Sigma_{1GHz} = 2.88 \cdot 10^{-14}$ D^{-4} $\exp(-|z|/54)$, to derive diameters and we calculated the cumulative count N(D). For SNRs in the adiabatic phase a dependence of $N(<D) \sim D^{5/2}$ is expected. For objects of $|b| \leq 0^\circ.5$ this dependence is found for diameters up to ~30 pc, and for objects at $|b| \geq 0^\circ.5$ up to ~40 pc. This difference is probably due to the higher resolution at lower Galactic latitudes, which hampers the detection of large SNRs with low surface brightness. The diameter of ≈40 pc may, therefore, be taken as a lower limit, up to which the adiabatic phase controls the expansion.

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