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THREE FIELDS CONTAINING YOUNG PULSARS: THE OBSERVABLE LIFETIME OF SUPERNOVA REMNANTS

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ABSTRACT

Observations of the fields containing three of the youngest known pulsars show little radiation attributable to any supernova remnants associated with their formation. While it is possible that these pulsars were formed without the production of such remnants, these observations together with an analysis of well studied galactic supernova remnants are strongly suggestive of a mean observable lifetime of less than ~20,000 yr for both pulsar and blast-wave powered remnants. The relatively rapid luminosity decline of both these phenomena can be understood if most massive supernovae occur within regions of low density bounded at radii of 10–30 pc by high-density shells. The requirement for low internal density comes from both our low surface brightness limits obtained for pulsar-powered nebulae and the rapid expansion to large sizes of shell components. The presence of a dense external shell, on the other hand, would account for an apparent secondary peak in both X-ray and radio luminosity observed between 4000 to 8000 yr and the rapid subsequent dissipation of energy via radiative shocks implied by the low luminosity of any shell component that remains after 20,000 yr.

Subject headings: nebulae: supernova remnants — pulsars — stars: evolution

I. INTRODUCTION

Three young pulsars with ages of ~20,000 yr have recently been discovered in a high-frequency survey at Jodrell Bank (Clifton and Lyne 1986). Only three of the 440 known radio pulsars, PSR 0531+21, PSR 1509−58, and PSR 0833−45 have smaller characteristic ages. These are believed to be associated with the Crab, MSH 15-52, and Vela supernova remnants (SNRs) respectively. If the new pulsars, PSR 1737−30, PSR 1800−21, and PSR 1823−13, were born in supernova events, and the remnants have lifetimes of the order of 20,000 yr or greater, they should be visible. The period and period derivative of the Crab pulsars (PSR 0531+21) in 20,000 yr time will be close to those of PSR 1800−21 and PSR 1823−13. Similarly, PSR 1509−58 in 20,000 yr time will be very like PSR 1737−30. Perhaps in these new pulsars we are seeing the Crab pulsar and PSR 1509−58 and their associated nebulae 20,000 yr hence. The standard catalogs of the galactic plane (e.g., Haynes, Caswell, and Simons 1978, 1979) show no sources close to any of the pulsars. We have therefore conducted a search using the VLA of the regions around each of the three new pulsars for nebulosities which might be remnants of a supernova explosion or synchrotron nebulae powered by the pulsars.

II. THE OBSERVATIONS

Observations have been made with the VLA of the fields around PSRs 1737−30, 1800−21, and 1823−13. These were made in the D-configuration or C/D-configuration and provided images at both 1465 and 1665 MHz with resolution of ~45″. A further observation of the field around PSR 1823−13 was obtained with the C/D-configuration at 4835 and 4885 MHz. Parameters of the observations and the resulting images are summarized in Table 1.

The positions of the pulsars provided by Clifton and Lyne (1986) had errors of a few arc minutes in both coordinates. These have since been refined by a combination of the use of the VLA at *L* band together with some pulse timing measurements (Lyne and McKenna 1989) which were required to resolve some positional ambiguities in the maps. These new positions are given in Table 2.

Figure 1 shows the map of a 40′ square region centered on PSR 1737−30 obtained at a frequency of 1465 MHz. The pulsar has a flux density of ~9 mJy. It lies close to the galactic plane ($l = 358^\circ\!.3$, $b = +0^\circ\!.2$) and the extended area of emission to the east of the pulsar is probably due to H II regions in the galactic disk. There is no evidence of compact nebulosity centered on the pulsar to a limiting surface brightness of 5.5 Jy deg^{-2}.

The field of the PSR 1800−21 ($l = 8^\circ\!.4$, $b = +0^\circ\!.1$) shown in Figure 2 is also close to the galactic plane and is confusion limited but shows a weak extended region of emission near the pulsar ~10′ in extent and of rather unclear morphology. This may be (part of) a SNR possibly associated with the pulsar or it may be an H II region. Unfortunately the source is of such low surface brightness that it will be difficult to distinguish between the two possibilities. The integrated flux density of this feature at 1465 MHz is 1.2 ± 0.2 Jy. The pulsar itself was detected at the expected level of ~15 mJy. Again, there is no indication for compact nebulosity centered on the pulsar to a limiting surface brightness of 15 Jy deg^{-2}.

Good maps were obtained of the field around PSR 1823−13 and the one at 1665 MHz is shown in Figure 3 ($l = 18^\circ\!.0$, $b = 0^\circ\!.7$). The pulsar is seen with a mean flux density of ~5 mJy. There are a few discrete sources within the field, but there

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TABLE 1

OBSERVATIONS

SOURCE PSR	FIELD CENTER R.A.(1950.0)	FIELD CENTER Decl.(1950.0)	CONFIGURATION	FREQUENCY (MHz)	INTEGRATION TIME (hr)	BEAM (Major × Minor [P.A.])	IMAGE RMS (mJy/beam^{-1})	(Jy deg^{-2})
1737−30..........	$17^{\mathrm{h}}37^{\mathrm{m}}22^{\mathrm{s}}$	−30°14′12″	C/D	1465	2.7	33.9 × 31.2 (−85)	0.5	5.5
				1665	2.7	34.5 × 30.2 (−58)	0.6	6.6
1800−21..........	18 00 28	−21 34 00	D	1465	1.8	60.7 × 33.4 (−6)	2.6	15
				1665	1.8	54.2 × 30.9 (−14)	2.5	17
1823−13..........	18 23 19	−13 37 00	D	1465	1.8	51.2 × 39.0 (−8)	0.9	5.2
				1665	1.8	48.1 × 35.2 (−15)	0.6	4.0
1823−13..........	18 23 12.2	−13 40 09	C/D	4835/4885	3	10.4 × 5.7 (89)	0.4	77

TABLE 2

PULSAR POSITIONS

PSR	R.A.(1950.0)	Error	Decl.(1950.0)	Error	Source of Measurement
1737−30..........	$17^{\mathrm{h}}37^{\mathrm{m}}21^{\mathrm{s}}.14$	0.10	−30°14′10″.0	1.5	VLA C/D-configuration
1800−21..........	18 00 51.09	0.03	−21 37 17.5	0.5	VLA A-configuration
1823−13..........	18 23 23.36	0.03	−13 36 33.8	0.5	VLA A-configuration

is no indication of extended structure centered on the pulsar with a radius of 10′ down to 4.0 Jy deg^{-2}. The 4835/4885 MHz observation listed in Table 1 was directed at the diffuse nebulosity 4′ to the SW of the pulsar. This source has an integrated flux density of 130 ± 7 mJy at 1665 MHz, a flat spectrum between 1465 and 4885 MHz and less than 5% linear polarization at 4885 MHz. These characteristics are consistent with those of a normal H II region.

III. DISCUSSION

The relative youth of these three pulsars is illustrated in Table 3, in which all the pulsars with characteristic ages of less than ~10^5 yr are shown in order of increasing age. Also shown in the table are the estimated distances to the pulsars (Lyne, Manchester, and Taylor 1985, scaled to a galactocentric radius of 8.5 kpc where appropriate), the pulsar kinetic energy loss

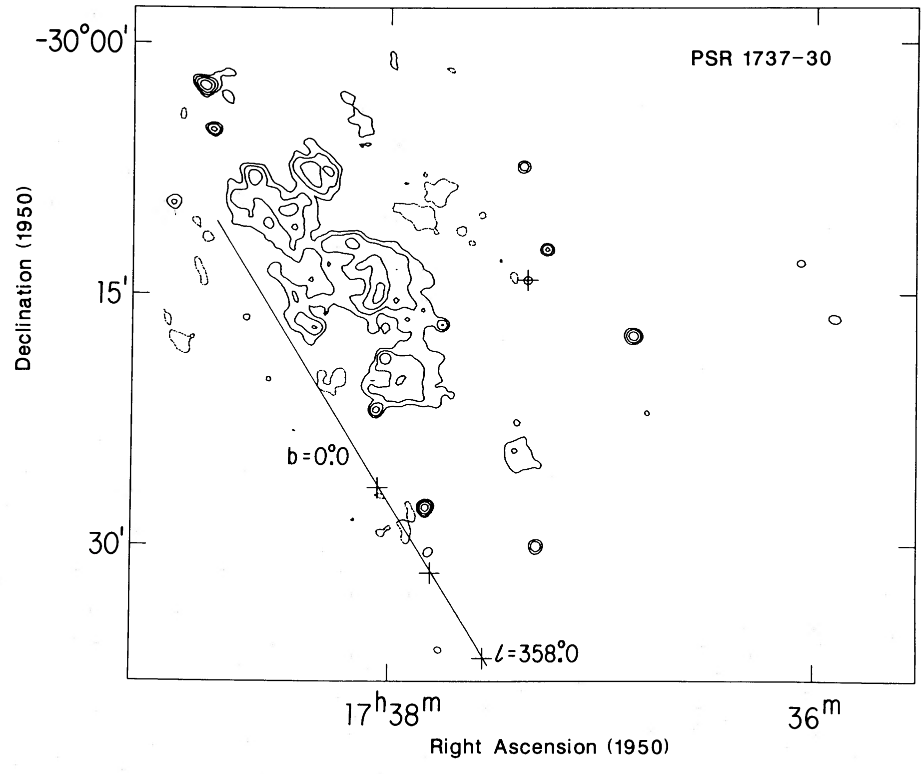

FIG. 1.—PSR 1737−30 field at 1465 MHz. Contours are at −3, 3, 6, 12, 24 mJy beam^{-1}. The negative contour is dashed. The rms noise is 0.5 mJy beam^{-1} (33″.9 by 31″.2 at P.A. −85°). No primary beam correction (~30′ FWHM) has been applied. The pulsar position is indicated by the plus sign (+) and the galactic plane by the diagonal line.

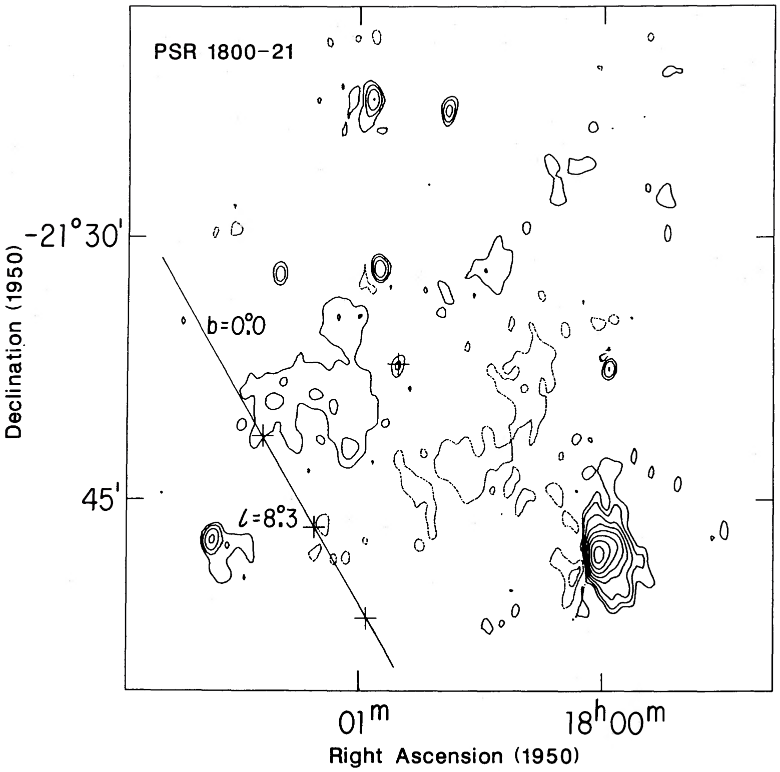

FIG. 2.—PSR 1800−21 field at 1465 MHz. Contours are at −6, 6, 12, 24, 48, 96, 192, 384, 768 mJy beam^{-1}. The negative contour is dashed. The rms noise is 2.6 mJy beam^{-1} (60″.7 by 33″.4 at P.A. −6°). No primary beam correction (~30′ FWHM) has been applied. The pulsar position is indicated by the plus sign and the galactic plane by the diagonal line.

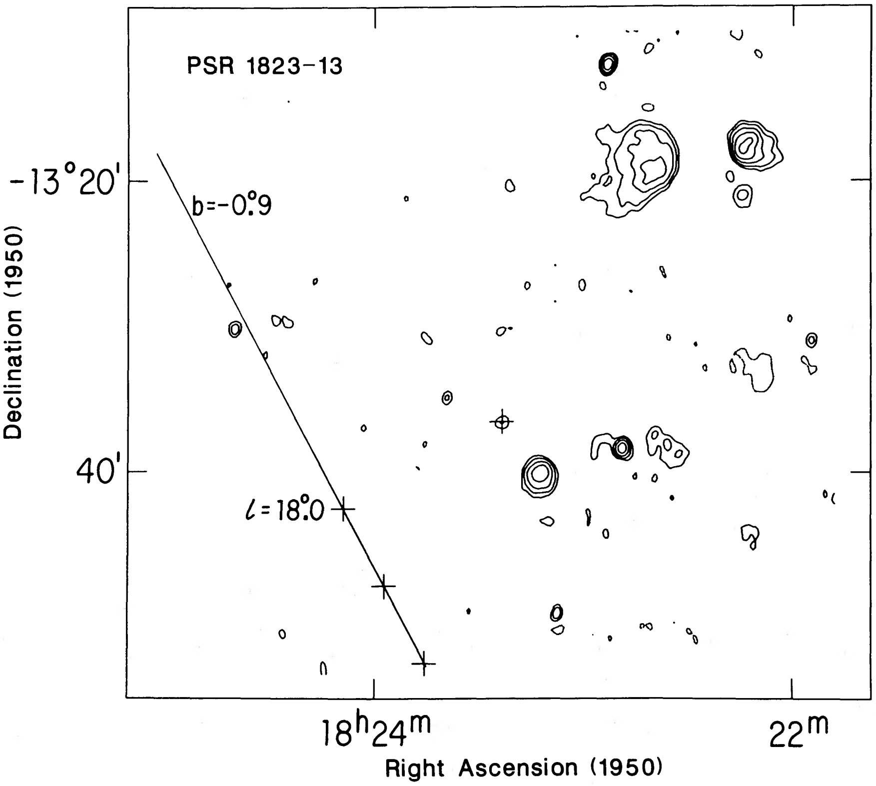

FIG. 3.—PSR 1823−13 field at 1665 MHz. Contours are at −2.5, 2.5, 5, 10, 20, 40 mJy beam^{-1}. The negative contour is dashed. The rms noise is 0.5 mJy beam^{-1} (48″.1 by 35″.2 at P.A. −15°). No primary beam correction (~26′ FWHM) has been applied. The pulsar position is indicated by the plus sign and a line of constant galactic latitude at −0°.9 by the diagonal line.

TABLE 3

YOUNG PULSARS

PSR	P (s)	$\dot{P}$ (10^{-15})	Distance (kpc)	Age (10^3 yr)	$\dot{E}$ (10^{36} erg s^{-1})	B (10^{12} G)	Extended Emission
0531+21	0.033	420	2.0	1.2	500	4	Synchrotron nebula. No shell
1509−58	0.150	1540	3.6	1.5	6	15	Synchrotron nebula. Shell?
0833−45	0.089	120	0.5	11	7	3	Synchrotron nebula. Shell
1800−21	0.133	134	4.4	16	1	4	None detected
1737−30	0.607	466	3.0	20	0.07	17	None detected
1823−13	0.101	72	4.7	22	2	3	None detected
1930+22	0.144	58	5.9	40	0.5	3	None detected
2334+61	0.495	192	1.3	40	0.04	10	None detected
1727−47	0.830	164	3.5	80	0.007	12	None detected
0611+22	0.335	60	2.8	89	0.04	5	None detected
1916+14	1.181	211	0.7	89	0.004	10	None detected
1951+32	0.039	6	1.3	104	4	0.5	Synchrotron nebula. Shell
0656+14	0.385	54	0.4	112	0.04	5	None detected
0531+21[a]	0.133	105	...	20	2	4	None detected
1509−58[a]	0.552	424	...	20	0.1	15	None detected

[a] These are the predicted parameters at an age of 20,000 yr using a simple model of the period evolution (braking index of −3.0).

rates and the surface magnetic field calculated from the period and period derivative (Manchester and Taylor 1977). The last column contains an indication of any nebular emission associated with each pulsar.

It is notable that the four pulsars which display a synchrotron nebula powered by the pulsar have the four largest values of $\dot{E}$, the smallest being 4×10^{36} ergs s^{-1}. The three most energetic (and youngest) correspond to the "classical" synchrotron nebulae mentioned above, while the CTB 80 nebula, although pulsar-powered, appears to have been recently revitalized by interaction with a high density environment (Kulkarni *et al.* 1988). PSRs 1823−13 and 1800−21, with similar $\dot{E}$ values of 2 and 1×10^{36} ergs s^{-1}, respectively, as we report here, show no detectable nebulae. This absence may allow significant constraints to be placed on the ambient density in the pulsar environment. Indeed, the evolutionary models of Bhattacharya (1988) which assume expansion within a low-density cavity ($n_{\rm H} = 0.01$ cm^{-3}) are consistent with our upper limits to the nebular radio surface brightness, while similar models with a higher ambient density ($n_{\rm H} = 1$ cm^{-3}) predict detectable radio emission.

The nondetection of shell emission such as that found associated with most historical supernovae is possibly more surprising, since the lifetimes of shell supernova remnants are usually thought to be greater than 20,000 yr, the greatest possible age of the new pulsars. This point is illustrated in Table 4, where the predicted surface brightness, angular size, and primary beam attenuation (as seen with a single VLA pointing at 1500 MHz) of a hypothetical SNR with the luminosity of S147 are listed, assuming a distance of 5 kpc, a shell thickness of 20% of the radius and physical sizes ranging from 20 to 60 pc. As will be shown below, S147 has one of the lowest radio luminosities of known galactic SNRs and as such is useful for comparison. Careful examination of the images illustrated in Figures 1–3 reveals faint, patchy emission at a surface brightness and radius consistent with such a low-luminosity SNR with radius greater than ~30 pc. At such low surface brightnesses it will likely remain impossible to make firm identifications of SNR shell emission due to confusion along the galactic plane, although more luminous SNRs can clearly be ruled out on the basis of our observations.

TABLE 4

EXPECTED RADIO Σ OF A LOW-LUMINOSITY SNR AT 5 KPC

Diameter (pc)	Σ (in annulus) (Jy deg^{-2})	Radius (of annulus)	Primary Beam Attenuation (30′ FWHM)
20..........	97	7′	0.90
30..........	43	10	0.75
40..........	24	13	0.60
50..........	16	17	0.45
60..........	11	20	0.30

To put this result into perspective it is worthwhile to review the attributes of both blast-wave and pulsar-driven components of the galactic SNRs with reasonably well-determined distances. (All distances based on kinematic models of the Galaxy have been scaled to a solar galactocentric radius of 8.5 kpc.) In Table 5 are summarized the parameters of three SNRs thought to be due to Type I supernova events (although some doubt exists in the classification of Kepler's SNR) 19 SNRs that are likely due to Type II (or Ib) events (based on the observed ejecta content or possible association with regions of massive star formation, or both) and six which are pulsar driven nebulae. Ages of historically observed and kinematically studied objects have been noted, while lower limits to the ages of the shell components of the Type II SNRs have been derived on the assumption that the blast wave has evolved to the current radius within a stellar-wind or previous SNR–blown bubble with interior density $n_{\rm H} = 0.01$ cm^{-3} (see Weaver *et al.* 1977). The expression describing the pre-Sedov time evolution of radius, r_s,

$$r_s = v_0(0.75 - 0.127 \log^2 \chi)\chi^{-0.195} t \ \text{(cgs)}$$

for $0.05 < \chi < 17$ with the mass ratio $\chi = 4\pi r_s^3 \mu n_{\rm H} m_{\rm H}/3M_0$ was taken from Braun (1987). The blast wave was assumed to be powered by $M_0 = 0.4\ M_\odot$ of $v_0 = 12{,}000$ km s^{-1} ejecta, corresponding to an initial kinetic energy in diffuse ejecta of $E_k^0 = 2.4 \times 10^{50}$ ergs, yielding

$$t = 860\left(\frac{D}{20\ \text{pc}}\right)^{1.585}\left[0.75 - 0.127 \log^2 \left(\frac{D}{20\ \text{pc}}\right)^3\right]^{-1} \text{yr}$$

for diameter, $D \leq 48$ pc. These parameters are in keeping with recent estimates based on the dynamics and shocked ISM mass observed in Cas A and G292.0+1.8 (Braun 1987; Braun *et al.*

TABLE 5

SUPERNOVA REMNANT PARAMETERS

Name (1)	Other Name (2)	Age (yr) (3)	Distance (kpc) (4)	Diameter (pc) (5)	n_H (cm^{-3}) (6)	L_X (10^{35} erg s^{-1}) (7)	T_X (10^7K) (8)	L_R (10^{33}erg s^{-1}) (9)	α_R (10)	References (11)
					SNR I					
G4.5+6.8	Kepler	380	4.1	4.2	4	6.9	2	6.2	0.6	1,2,3
G120.1+1.4	Tycho	410	2.3	5.4	0.4	3.4	0.6,6	5.1	0.6	1,2,4,5
G327.6+14.6	SN1006	980	1.7	15	0.02	1.0	0.1,1	0.85	0.6	2,3,6
					SNR II					
G111.7-2.1	Cas A	300	2.9	3.6	1	18	1,6	330	0.8	1,2,7
G43.3-0.2	W49B	>360	8.5	8.5	...	7.9	5	66	0.5	2,8,9
G292.0+1.8	MSH 11-54	900	3	10	0.4	8.6	0.4	8.0	0.2	2,10,11
G320.4-1.2	RCW 89	>270	3.6	6.2	100	2.3	1.3	9.0	0.5	2,12,13,14
G315.4-2.3	RCW 86	1800(?)	2.5	29	100	1.4	1.4	6.3	0.6	2,3,15,16,17
G109.1-1.0	CTB 109	>3700	3.6	38	100	3.8	...	7.8	0.5	2,18,19,20
G332.4-0.4	RCW 103	>480	3.9	11	100	88	0.5	10.	0.5	2,3,17,21
G260.4-3.4	Puppis A	3700	1.5	24	100	100	0.3	7.0	0.5	2,3,13,22
G74.0-8.5	Cygnus Loop	>3700	0.7	39	10	8.3	0.3	2.4	0.5	2,3,23,24
G34.7-0.4	W44	>1300	2.6	22	...	3.0	1	68	0.3	2,12,25
G263.9-3.3	Vela XYZ	$\lesssim$11,000	0.5	50	10–100	3.0	...	19	0.3	2,26
G78.2+2.1	...	>1300	1.2	22	100	1	1.5	7.3	0.7	2,19,27,28
G189.1+3.0	IC 443	$\lesssim$7000	1.5	22	100	2.1	1.2	11	0.4	2,3,27,29
G132.7+1.3	HB 3	>10000	2.7	55	10	1.3	0.3,1	9.6	0.5	2,30,31,32
G160.9+2.6	HB 9	>14000	1.7	60	10–100	0.2	0.3	12	0.4	2,31,33,34
G116.9+0.2	CTB 1	>1300	2.3	23	10	...	...	1.2	0.5	2,33,35
G166.0+4.3	VRO 42.05.01	>2700	3	32	100	...	...	2.0	0.4	2,19,35,36
G180.0-1.7	S 147	>4600	0.8	42	10	...	...	1.0	0.5	2,35,37
G166.2+2.5	OA 184	>6000	2	47	100	...	...	1.2	0.4	2,35,38
					Crab-like SNR					
G130.7+3.1	3C 58	800	2.2	4.5	...	0.1	...	13	0.1	2,39,40
G184.6-5.8	Crab	930	2.0	2.9	...	370	...	170	0.3	2,41,42
G21.5-0.9	...	...	4.7	1.6	...	0.34	...	13	0.1	2,43,44
G320.4-1.2	MSH 15-52	1500	3.6	8.4	...	1.2	...	[a]	[a]	2,12,14
G263.9-3.3	Vela	$\lesssim$11,000	0.5	0.3	...	0.07	...	[a]	[a]	26
G69.0+2.7	CTB 80C	$\lesssim 10^5$	1.3	3.1	...	0.04	...	0.2	0.3	45,46,47

[a] Too much confusion from shell to identify associated component.

REFERENCES.—(1) Braun 1987. (2) Green 1984. (3) Dwek *et al.* 1987. (4) Chevalier, Kirshner, and Raymond 1980. (5) Seward, Gorenstein, and Tucker 1983. (6) Kirshner, Winkler, and Chevalier 1987. (7) Davison, Culhane, and Mitchell 1976. (8) Radhakrishnan *et al.* 1972. (9) Pye *et al.* 1984. (10) Braun *et al.* 1986. (11) Agrawal and Riegler 1980. (12) Caswell *et al.* 1975. (13) Dopita, Mathewson, and Ford 1977. (14) Seward *et al.* 1984. (15) Clark and Stephenson 1977. (16) Westerlund (1969*a*). (17) Leibowitz and Danziger 1983. (18) Crampton, Georgelin, and Georgelin 1978. (19) Braun and Strom 1986). (20) Gregory and Fahlman 1980. (21) Westerlund 1969*b*. (22) Winkler *et al.* 1988. (23) Raymond *et al.* 1988. (24) Braun 1988. (25) Smith *et al.* 1985. (26) Harnden *et al.* 1985. (27) Humphreys 1978. (28) Higgs, Landecker, and Seward 1983. (29) Braun and Strom 1987. (30) Goudis 1979. (31) D'Odorico and Sabbadin 1977. (32) Leahy *et al.* 1985. (33) Lozinskaya 1981. (34) Touhy, Clark, and Garmire 1979. (35) Fesen, Blair, and Kirshner 1985. (36) Neckel and Klare 1980. (37) Assousa and Erkes 1974. (38) Routledge, Landecker, and Vaneldik 1986. (39) Green and Gull 1982. (40) Becker, Helfand, and Szymkowiak 1982. (41) Trimble and Woltjer 1971. (42) Harnden and Seward 1984. (43) Davelaar, Smith, and Becker 1986. (44) Becker and Szymkowiak 1981. (45) Kulkarni *et al.* 1988. (46) Wang and Seward 1984. (47) Angerhofer *et al.* 1981.

1986). A more "conventional" initial kinetic energy, $E_k^0 \sim 10^{51}$ ergs, results in age estimates which are between 20% and 35% lower (for D between 20 and 40 pc). Data from the literature were used to derive the other quantities listed in Table 5. X-ray luminosities are integrated over the 0.2–4.0 keV band and radio luminosities are integrated between 0.01–100 GHz assuming a constant spectral index, α, defined by $S = S_0 \nu^{-\alpha}$ and noted in column (10).

The SNRs of type I events are seen to occur in a variety of environments, as one might expect given the distribution of low-mass stars in the Galaxy. The young Type II objects which have been identified to date appear to be interacting with the massive wind enriched core of their progenitor's bubble, although this may well reflect an observational bias due to the higher luminosity that results from enhanced early ejecta interception. These objects appear to be dominated by the reverse shock interception of slow ($\sim 10^3$ km s^{-1}) ejecta, which has the characteristic signature of a thick inner shell superposed on a fainter outer-shock plateau/shell. Cas A is a young example of this phenomenon, while G292.0+1.8 is a more evolved and asymmetric case. Although observations of higher sensitivity are necessary to confirm its nature, W49B also appears to belong to this class. We further suggest that the source RCW 89, the 7′ diameter optical forbidden line shell at $\alpha = 15^h09^m30^s$, $\delta = -58°53'$ in the complex region at $l = 320°$, is in fact a distinct SNR (based on its distinct optical properties and radio morphology) rather than the sometimes supposed conglomerate, undergoing the transition from the reverse shock to the bubble shock-dominated phase (see the radio image of Manchester and Durdin 1983), although Caswell, Milne, and Wellington (1981) point out that the spectral index in a larger region is reasonably constant.

The epoch of shock and/or slow ejecta impingement on the high-density bubble wall is apparently accompanied by a high X-ray and radio luminosity, most notably seen in RCW 103 and Puppis A. Other objects which appear to be early in the bubble interception phase are RCW 86, CTB 109, the Cygnus Loop, W44, and Vela. Indeed, in the case of the Cygnus Loop, the shock is currently propagating into regions of density ~ 10 cm^{-3} while the harder cavity wall (density ~ 100 cm^{-3}) has not yet been shocked (see Braun 1988). The evidence for the Vela SNR is even more striking, since the lower limit to its age derived under the assumption of early evolution in low density gas ($n_H \sim 0.01$ cm^{-3}), 6500 yr, is only slightly less than the upper limit of 11,000 yr implied by the pulsar spindown time, while current ambient densities are in the range $n_H \sim 10$–100 cm^{-3}. It is worth noting that the conclusion reached by many previous authors that these and other SNRs have recently encountered dense clouds is completely consistent with this interpretation. The distinction arises only in the assertion that virtually the entire shock front encounters a significant preexisting density discontinuity, while the magnitude of this discontinuity will still reflect the original density structure of the environment. After a few thousand years of cavity wall penetration, observable quantities of shock-accelerated neutral hydrogen become visible in objects like G78.2+2.1 and IC 443 (Landecker, Roger, and Higgs 1980; Braun and Strom 1986). Associated external and internal H I structures have also been reported in the apparently more evolved sources HB 3, CTB 1, VRO 42.05.01 and OA 184 (Read 1981; Landecker, Roger, and Dewdney 1982; Braun and Strom 1986; Routledge, Landecker, and Vaneldik 1986).

During this sequence of events, the radio and X-ray luminosities of SNR shell components seem to evolve in a fairly systematic and distinct manner for the two supernova types. The luminosities of those SNRs with a well constrainted age are plotted in Figure 4. Assuming that the three young pulsars studied here originated in SNR events we obtain the very stringent upper limits to radio shell emission reported here, which correspond by analogy to S147 to a radio luminosity of less than $\sim 10^{33}$ ergs s^{-1} at the pulsar ages of 16,000–22,000 yr. Although the sample is regrettably small, a number of trends are apparent. The SNRs due to massive progenitors appear to have higher luminosities in both the radio and X-ray bands at the early times for which both types have been observed. The distribution of luminosity with age for SNR I would be consistent with a roughly power-law decrease with an index of −1.8 in both the radio and X-ray, although such an evolutionary track interpretation is almost certainly too simplistic given the very different ambient densities appropriate to these sources. After an initial decline, both the SNR II distributions seem to show a second luminosity peak, which occurs between ~4000 and 8000 yr. It should be noted that while RCW 86, Puppis A, and IC 443 all have comparable diameters, the Vela SNR has twice this diameter and may therefore be entering a similar evolutionary phase at a significantly later time. As outlined above, we interpret this secondary luminosity peak as arising during the epoch of cavity wall impact when a temporary internal overpressure (and possibly an increased mass flux of intercepted slow ejecta) gives rise to enhanced X-ray emission, while

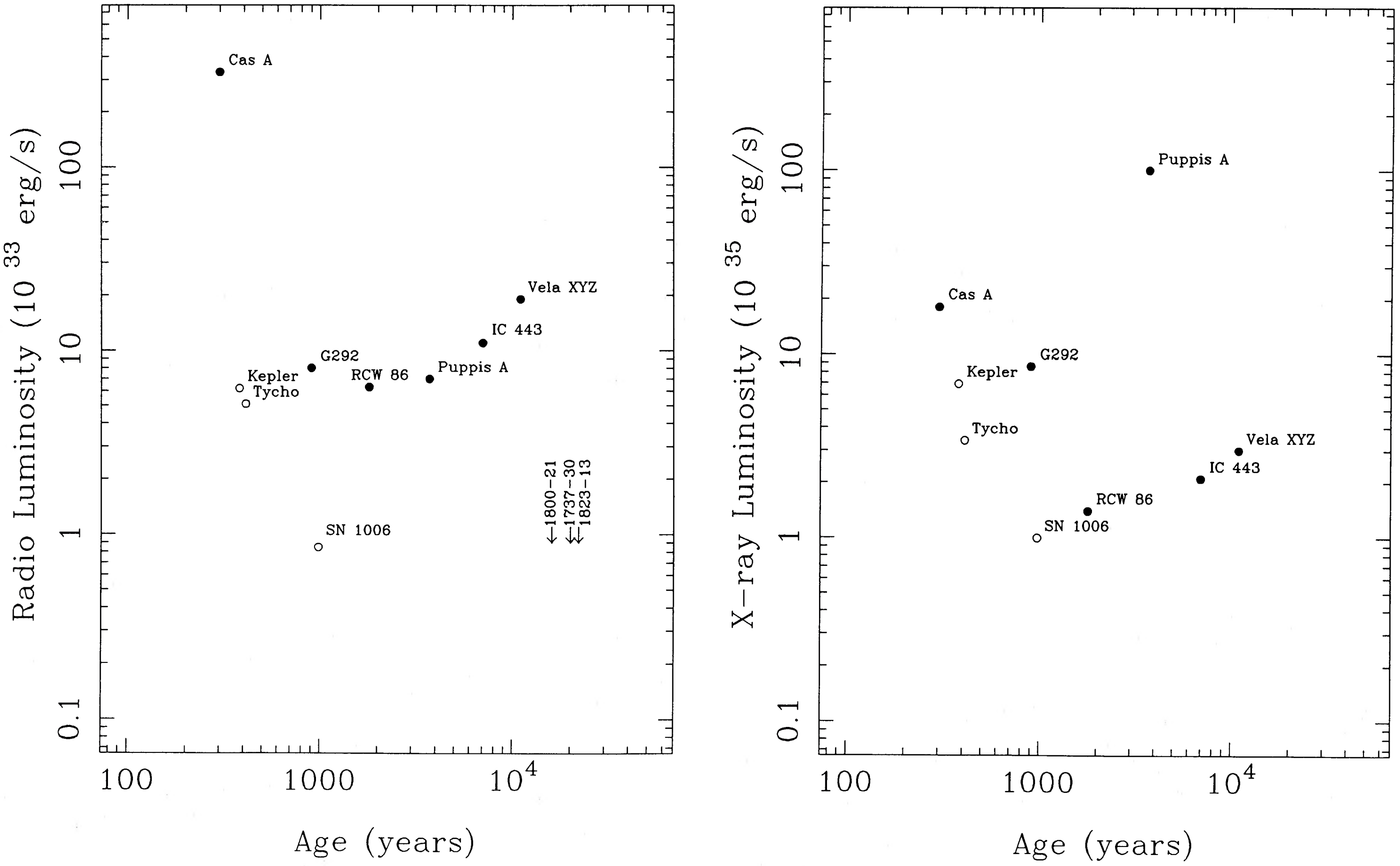

FIG. 4.—Luminosity of SNR of known age. (*a*) Radio luminosity (integrated between 10 MHz and 100 GHz assuming a fixed power-law spectrum) of shell SNRs of known age. Open circles indicate SNRs thought to be due to SNs of type I, while filled circles indicate SNRs thought to be due to the SNs of massive stars; type II (and Ib). The three upper limits correspond to possible shell components at the galactic confusion level for the pulsar fields studied here. (*b*) Same for the X-ray luminosity (integrated between 0.2 and 4 keV) of shell SNRs of known age. The identification of RCW 86 with SN 185 is less certain than the other age estimates.

the sudden onset of highly compressive radiative shocks leads to enhanced radio emission. The relatively low luminosity radio SNRs listed in Table 5 are more evolved objects, as indicated by their nondetection in X-rays and their associated H I systems, and appear to fill the gap between 8000 and 20,000 yr in Figure 4*a* with luminosities between 1 and 10×10^{33} ergs s^{-1}.

The pulsar-powered nebulae listed in Table 5 represent a wide range of luminosities which are more closely related to the properties of the embedded pulsar than indicative of an evolutionary sequence. However, the similar extrapolated properties of the Crab and MSH 15-52 pulsars at an age of 20,000 yr to those of PSRs 1800−21 and 1737−30, respectively, as shown at the bottom of Table 2, suggest that the radio luminosity of young synchrotron nebulae must evolve with (for example) a power-law index steeper than about −2 in order to be consistent with the faint upper limits we observe. In fact, if this type of luminosity evolution applies to the more numerous nebulae having a lower early luminosity, they may become undetectable within a few thousand years and thus only be seen in 10%–20% of SNR II shells (assuming a one to one correspondence between pulsar and blast-wave generation in the supernovae of massive stars).

IV. CONCLUSION

The current observations, together with an analysis of galactic SNR are consistent with, and strongly suggestive of, a mean observable lifetime of less than ~20,000 yr for both pulsar and blast-wave powered remnants. The relatively rapid luminosity decline of both these phenomena can be understood if most massive supernovae occur within regions of low density bounded at radii of 10–30 pc by high-density shells. The requirement for low internal density comes from both the low surface brightness limits we have obtained for pulsar-powered nebulae and the rapid expansion to large sizes of shell components. The presence of a dense external shell, on the other hand, would account for an apparent secondary peak in both X-ray and radio luminosity observed between 4000 to 8000 yr and the rapid subsequent dissipation of energy via radiative shocks implied by the low luminosity of any residual shell component after 20,000 yr.

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