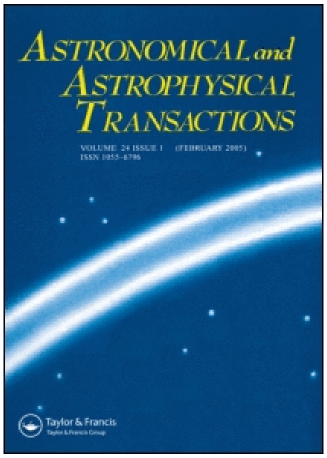

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Spectral index evolution of young shell supernova remnants in the milky way and other galaxies

A. P. Glushak [a]
[a] Radio Observatory of P. N. Lebedev Physical Institute, RUSSIA

To cite this Article: Glushak, A. P. (1996) 'Spectral index evolution of young shell supernova remnants in the milky way and other galaxies', Astronomical & Astrophysical Transactions, 11:3, 317 - 323
To link to this article: DOI: 10.1080/10556799608205480
URL: http://dx.doi.org/10.1080/10556799608205480

Astronomical and Astrophysical Transactions, 1996,
Vol. 11, pp. 317-323
Reprints available directly from the publisher
Photocopying permitted by license only

SPECTRAL INDEX EVOLUTION OF YOUNG SHELL SUPERNOVA REMNANTS IN THE MILKY WAY AND OTHER GALAXIES

A. P. GLUSHAK

Radio Observatory of P. N. Lebedev Physical Institute, Pushchino, Moscow region, 142292, RUSSIA

(Received April 14, 1995)

We show that the radio spectral index of young shell supernova remnants evolvs differently in galaxies with and without a star burst (M82, NGC253 and the Galaxy, M31, M33, LMC, SMC). This is explained by the difference in gas density, which determines the dynamic evolution of shell supernova remnants in these galaxies ($\rho_{M82}/\rho_{Gal} \approx 150$). The spectral index – diameter dependence is suggested to be used for the estimation of a typical initial mass, M_0, of a shell supernova remnant. For shells in M82, it is estimated as $M_0 = 2.3 \pm 1.1 M_{\odot}$. This is the first known estimate of this kind for the remnants in M82, as well as the kinetic energy of the shell 41.9+ 58, 10^{51} ergs. We conclude that the unusually high radio brightness of supernova remnants in M82 is a consequence of only the interaction with ambient medium.

KEY WORDS **Supernova remnants, spectral index evolution, initial shell mass**

1 INTRODUCTION

It was shown by Glushak (1985) and confirmed independently by Allakhverdiev *et al.* (1986) that there exists a correlation between the radio spectral index α and the linear diameter (D) of a young shell supernova remnant (SNR). This variation of α can be a result of the statistical acceleration of the radio emitting electrons (Cowsik and Sarkar, 1984). Many SNRs with well-determined α and D have been revealed observationally in external galaxies. This allows to perform comparative analysis of the α-evolution of SNRs in different galaxies.

2 DATA OF ANALYSIS

The data on D and α are presented in Table 1 and Figure 1, where α is defined through $S_\nu \propto \nu^{-\alpha}$. The notation is as follows: ϕ is the angular size, d is the

Table 1. The Galaxy ($d_{G.C.} = 7.7 \pm 0.7$ kpc) (14)

SNR name	*Cas A*	*Kepler*	*Tycho*	*G349.7+ 0.2*	*W49B*	*G15.9+ 0.2*	*IC443*	*W44*	*CTB 37B*	*G316.3− 0.0*	*G18.8+ 0.3*
ϕ (arc min)	4.4 (3)	3.3 (3)	7.9 (2,3)	2.0 x 2.5 (2,3)	4.0 (2,3)	4.7 x 6.5 (2,3)	35 x 50 (2,3)	25 x 35 (2,3)	9.3 (2,3)	12 x 16 (3)	13 x 18 (2,3)
$\frac{d}{0.77}$ (kpc)	3.3 (1)	5.7 (2,3)	3.0 (2)	18.3 (1,3)	12.0 (1,3)	6.6 (3)	1.9 (2)	3.0 (1,3)	10.2 (1,3)	$\gtrsim 7.2$ (1)	9.5 (1)
D (pc)	3.2	4.2	5.3	9.2	10.7	8.1	18.2	19.9	21	$\gtrsim 22.3$	32.5
α	0.77± 0.01 (2,3)	0.64± 0.02 (2,3)	0.61± 0.03 (2,3)	0.49± 0.05 (2,3)	0.48± 0.03 (2,3)	0.57± 0.04 (3)	0.36± 0.02 (2,3)	0.30± 0.05 (2,3)	0.3± 0.1 (4)	0.35± 0.07 (3)	0.36± 0.07 (3)

M31 (d = 710 ± 30 kpc) (14)

SNR name	*M31-7 (5)*	*M31-19 (5)*
ϕ (arc sec)	5 (5)	9 (5)
D (pc)	17	31
α	0.36(±0.1) (5)	0.31(±0.1) (5)

LMC (d = 49 ± 2 kpc)

SNR name	*N103B*	*0519− 690*	*N11L*	*0509− 675*	*0453− 685*	*N49*
ϕ (arc sec)	23 x 27 (6)	28 (7)	60 (7)	26 (8)	131 x 140 (8)	66 (8)
D (pc)	5.9	6.6	14.2	6.2	32.2	15.7
α	0.67 (6)	0.65 (7)	0.42 (7)	0.48 (7)	0.38 (7)	0.45 (7)

Table 1. (Continued)

M82 (d = 3.25 ± 0.2 Mpc) (15,16)									
SNR name	41.9+ 58	44.0+ 59.6	43.3 +59.2	45.2 +61.3	40.7 +55.1	43.2 +58.4	44.3 +59.3	44.5 +58.2	45.4 +67.4
$\phi_{1992.6}$ *(mas)*	28	47 (10)	44	85	240 (10)	75 (10)	140 (10)	240 (10)	145 (10)
$D_{1981.1}$ (pc)	0.31	0.61	0.56	1.26	3.76	1.14	2.16	3.76	2.23
$\alpha_{1981.1}$	0.93± 0.02 (11)	> 0.46 ±0.03 (9,11)	0.73 ±0.05 (11)	0.52 ±0.06 (11)	0.45 ±0.07 (11)	0.71 ±0.09 (9,11)	0.26 ±0.39 (11)	0.25 ±0.49 (11)	0.36 ±0.66 (11)

NGC253, d = 2.5 Mpc (12)			
SNR name	5.48 −43.3	5.62 −41.3	5.72 −40.1
ϕ_{1983} *(mas)* (12)	70 x 50	100 x 90	240 x 80
D_{1983} (pc)	0.7	1.1	1.7
α_{1990} (13)	0.56 (±0.05)	0.58 (±0.07)	0.60 (±0.10)

References: (1) Clark and Caswell, 1976; (2) Green, 1988; (3) Glushak, 1991b; (4) Kassim *et al.*, 1991; (5) Dickel and D'Odorico, 1984; (6) Dickel and Milne, 1995; (7) Mills *et al.*, 1984; (8) Mathewson *et al.*, 1983; (9) Huang *et al.*, (1994); (10) Maxlow *et al.*, 1994; (11) Bartel *et al.*, 1987; (12) Turner and Ho, 1985; (13) Ulvestad and Antonucci, 1994; (14) Pottasch, 1990; (15) Fabbiano, 1988; (16) Heckman *et al.*, 1990.

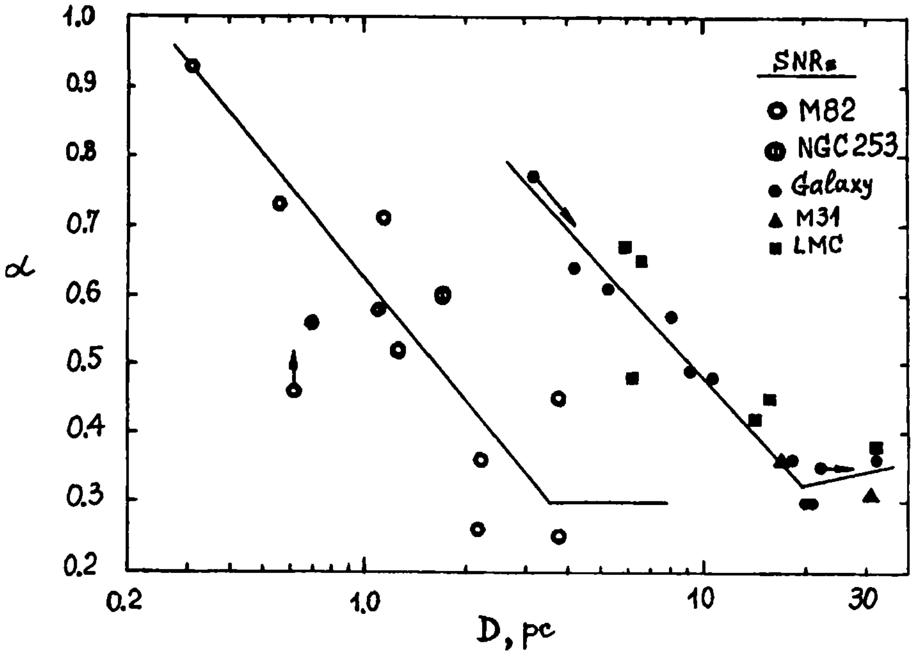

Figure 1 The $\alpha - D$ relations for all young shell SNRs listed in Table 1. Solid lines are least - squares fits to all data points presented, except 44.0+59.6 and LMC's SNRs. The errors of α were taken into account. The longer arrow shows the observed direction of α-evolution in Cas A. The horizontal line corresponds to radio nonthermal background in M82 with $\alpha = 0.30 \pm 0.05$.

distance, D is the angular size, $d_{\mathrm{G.C.}}$ is the solar galactocentric distance adopted and α is the spectral index. Numbers in parenthesis indicate the relevant references. For 9 most luminous SNRs in M82, the average angular diameters were taken and measured by the author from the data and maps of Maxlow *et al.* (1994) and Bartel *et al.* (1987). The average values of α and their errors were taken from the data of Bartel *et al.* (1987) and Huang *et al.* (1994). The diameters were reduced to the epoch 1981.1 in which α were measured. For this reduction, a simple analytical equation for the shell velocity in a uniform medium was used (equation (B8) of Braun, 1987) and the initial expansion velocity of the typical shell in M82 was taken as $V_{41.9+58} \approx 5500$ km s^{-1} (Bartel *et al.*, 1987); the ratio of the swept-up mass to the initial one was adopted as $M_{\mathrm{swept}}(D = 3.5\ \mathrm{pc})/M_0 = 17$ (see Section 4). Our angular sizes (ϕ) of 43.3+59.2 and 45.2+61.3 are in a good agreement with $\phi = 1.20\phi_{0.5}$ of Huang *et al.* (1994). This confirms the correctness of our size estimates. The average size of 41.9+58 was measured on Bartel's *et al.* (1987) contour map by approximating the SNR edge with an ellipse.

The average values of α and D for NGC253's brightest SNRs, which exhibit a decreasing flux, were taken from Turner and Ho (1985) and Ulvestad and Antonucci (1994). For these values of α approximate errors are given.

The values of distance d, angular size ϕ and α for the 19 SNRs belonging to the Galaxy, M31 and LMC were collected from original papers referred to in notes to Table 1. The values of ϕ were taken from observational data of the highest angular resolution available. The value of ϕ - for Cas A is given for the epoch 1975 and without taking into account the low-brightness outer emission. The errors for α were taken from original papers indicated in Table 1, except the values enclosed in brackets.

All remaining well-known SNRs in the Galaxy, M31, M33, LMC and SMC, having known α and D values, are not presented in Figure 1 because most of them are located considerably higher and to the right ($D > 12$ pc) of the points shown.

3 ANALYSIS OF DEPENDENCES

The dependences in Figure 1 were well approximated by least squares with the following form (with errors in α taken into account):

$$\alpha = P \log\left(\frac{D}{pc}\right) + \alpha_0,$$

where $P = -0.58 \pm 0.07$, $\alpha_0 = 0.62 \pm 0.03$ for M82 and NGC253 ($0.3 < D < 4$ pc), and $P = -0.54 \pm 0.03$, $\alpha_0 = 1.03 \pm 0.02$ for the Galaxy and M31 ($3 < D \leq 21$ pc).

The following three facts definitely indicate that both dependences reflect an average evolution of α:

(1) the objects closely follow the $\Sigma - D$ and $L - D$ relations (Glushak, 1991a; Glushak, 1993; Huang *et al.*, 1994), as a rule, in the same order, with respect to one another, as in the $\alpha - D$ plot;

(2) the slope P is the same within errors for M82 and the Galaxy;

(3) The slope for Cas A, well-known from the measurements, to be $P = -0.58$ (Glushak, 1991b; this point is marked by a longer arrow in Figure 1), is about the same as the average value.

Then a shift along the D-axis in the $\alpha - D$ dependences for SNRs in starburst galaxies (SBG) and those with normal star formation (NSG) is explained by the beginning of an α-decreasing evolution stage in SBGs when $D_{\mathrm{M82}} \cong D_{\mathrm{Gal}}/5.4$, with $\alpha_{\mathrm{M82}} = \alpha_{\mathrm{Gal}}$.

It is known that the results of the statistical analysis of SNR data can be influenced by different errors, because of the measurement values inaccuracies, heterogeneity of the sample and observational selection effects. Neither of these cause can explain the dependences in Figure 1. Thus, in Table 1, SBG objects are a homogeneous group of SNRs originating from SNII, and selection effects are still less important for them (Huang *et al.*, 1994). The NSG objects (Table 1) form a heterogeneous group originating from SNII and SNIa (Mathewson *et al.*, 1983; Glushak, 1991b; Glushak, 1993); however, this does not influence the behaviour of the dependence. Moreover, their sizes and the surface brightnesses are in agreement with criteria from Green (1988), under which the selection effects are not important.

4 ESTIMATION OF THE SNR INITIAL MASS IN M82

As follows from the $N(< D) - D$ relations of Maxlow *et al.* (1994) and Huang *et al.* (1994), for SNRs in M82 a substantial deceleration of the expansion by a swept-up mass occurs when $3 < D < 4$ pc. According to observations and modelling of the nonthermal radio emission spectrum of the M82's plane, which is due to a combined emission of a large number of relatively old and observationally indistinguishable SNRs, the background spectral index is $\alpha = 0.3$–0.4 (Seaquist *et al.*, 1985). As the result, in the Figure 1, α should not vary for a typical SNR with $D > 3$ pc, i. e. the $\alpha - D$ dependence has a break at $D = 3$–4 pc. A similar break is well seen in Figure 1 for NSG's SNRs at $D = D_b^{\rm Gal} = 19$ pc. It can be shown that the break at $D_b^{\rm Gal}$ corresponds to the beginning of the adiabatic evolution stage, when the condition

$$M_{\rm SW}(D_b) = 17M_0 \tag{1}$$

is met, which results from Braun's (1987) equation (B9), with $E_k^{\rm SW} = 0.283\,E_0$, where $M_{\rm SW}$ and $E_k^{\rm SW}$ are the mass and kinetic energy of the swept-up ambient medium, and E_0 is the initial kinetic energy of the supernova explosion. Here

$$M_{\rm SW} = 12.95 \times 10^{-3}\mu \left(\frac{n_0}{\rm cm^{-3}}\right) \left(\frac{D/0.75}{nc}\right)^3 \; [M_\odot], \tag{2}$$

where n_0 is the average density of ambient gas, μ is the average gas particle mass in units of the hydrogen atom mass.

Let us estimate the $M_0^{\rm M82}$. From Figure 1 and the $N(< D) - D$ relations mentioned above, we have $D_b^{\rm M82} = 3.5 \pm 0.5$ pc; $\mu = 0.60$ and $n_0^{\rm M82} = 50 \pm 20$ cm^{-3} (Seaquist *et al.*, 1985; Petuchowski *et al.*, 1994). Then equations (1) and (2) imply

$$M_0^{\rm M82} = 2.3 \pm 1.1 M_\odot.$$

For the 41.9+58 shell we have also the initial kinetic enegy $E_0 = (9 \pm 7)10^{50}$ ergs, as the expansion velocity is equal to 6000 ± 3000 km s^{-1} (Bartel *et al.*, 1987). Such a normal value of E_0 deduced for a M82's SNR allows us to conclude that unusually high radio brightness of SNRs in M82 is a consequence of only interaction with ambient medium, which is very different from that in NSGs.

Acknowledgements

This work was supported in part by a Grant of the American Astronomical Society in 1994.

References

Allakhverdiev, A. O., Asvarov, A. I., Guseinov, O. H., Kasumov, F. K. (1986) *Ap. Sp. Sci.* **123**, 237.

Bartel, N., Ratner, M. I., Rogers, A. E. E. *et al.* (1987) *Ap. J.* **323**, 505.

Braun, R. (1987) *A&A* **171**, 233.
Clark, D. H., Caswell, J. L. (1976) *MNRAS* **174**, 267.
Cowsik, R., Sarkar, S. (1984) *MNRAS* **207**, 745.
Dickel, J. R., D'Odorico, S. (1984) *MNRAS* **206**, 351.
Dickel, J. R., Milne, D. K. (1995) *A. J.* **109**, 200.
Fabbiano, G. (1988) *Ap. J* **330**, 672.
Glushak, A. P. (1985) *Sov. Astron. Lett.* **11**, 350.
Glushak, A. P. (1991a) In *Theses of the reports at the 23-th All-Union radio astronomical conference*, Ashkhabad, p. 71 (in Russian).
Glushak, A. P. (1991b) *Preprint 53*, Moscow, FIAN (in Russian).
Glushak, A. P. (1993) In *Theses of the Reports at the 25-th All-Union Radio Astronomical Conference*, Pushchino, p. 77 (in Russian).
Green, D. A. (1988) *Ap. Sp. Sci.* **148**, 3.
Heckman, T. M., Armus, L., Miley, G. K. (1990) *Ap. J. S.* **74**, 833.
Huang, Z. P., Thuan, T. X., Chevalier, R. A. *et al.* (1994) *Ap. J.* **424**, 114.
Kassim, N. E., Baum, S. A., Weiler, K. W. (1991) *Ap. J.* **374**, 212.
Mathewson, D. S., Ford, V. L., Dopita, M. A. *et al.* (1983) *Ap. J. S.* **51**, 345.
Maxlow, T. W. B., Pedlar, A., Wilkinson, P. N. *et al.* (1994) *MNRAS* **266**, 457.
Mills, B. Y., Turtle, A. J., Little, A. G. *et al.* (1984) *Aust. J. Phys.* **37**, 321.
Petuchowski, S. J., Bennet, C. L., Haas, M. R. *et al.* (1994) *Ap. J.* **427**, L17.
Pottasch, S. R. (1990) *A&A* **236**, 231.
Seaquist, E. R., Bell, M. B., Bignell, R. C. (1985) *Ap. J.* **294**, 546.
Turner, J. L., Ho, T. P. (1985) *Ap. J.* **299**, L77.
Ulvestad, J. S., Antonucci, R. R. J. (1994) Ap. J. **424**, L29.