Aust. J. Phys., 1987, **40**, 767–70

Relationship between Supernova Type and Their Remnants*

T. A. Lozinskaya[A] *and N. N. Chugaj*[B]

[A] Sternberg Astronomical Institute, 119899, Universitetsky Pr., 13, Moscow, USSR.
[B] Astronomical Council of the USSR Academy of Sciences, 109017, Pyatnitskaya, 48, Moscow, USSR.

Abstract

The genetic relationship between supernovae (SNe) and supernova remnants (SNRs) is an important factor in understanding the nature of both phenomena. We present here some new results on SNe and SNRs and discuss their implications in the SN–SNR relationship.

1. Supernovae

Recently a new type of supernova was discovered. It turned out to be of the type formerly known as a peculiar Type I (Bertola 1964) or Type Ib (in contrast with the 'normal' Type I or Type Ia). The most striking property of Type Ib SNe making them quite different from Type Ia SNe is revealed in late epoch ($\sim$300 day) spectra, which are dominated by very strong oxygen emission [O I] λλ6300, 6363 (see e.g. the spectrum of SN 1985f in Filippenko and Sargent 1986), and which is absent in the spectra of SN Ia. Other properties of SN Ib have been summarised by Panagia (1985). It is remarkable that SN Ib strongly correlate with H II regions and/or with the spiral arms of galaxies. Hence, at present we observe in spiral galaxies three different types of SN, namely Ia, Ib and II, with roughly comparable frequencies (see e.g. Panagia 1985).

SN Ia are probably produced by the explosion (with the complete disruption) of a carbon–oxygen white dwarf. The ejected mass of $\approx 1\cdot 4 M_{\odot}$ consists of half of the ^{56}Ni decaying ultimately into ^{56}Fe (Axelrod 1980; Branch *et al.* 1985).

SN II result from the explosion of red supergiants with a hydrogen envelope (Grasberg *et al.* 1971). The ejected mass of SN II vary from $\approx M_{\odot}$ for fast declining SN II-L, to $\lesssim 10 M_{\odot}$ for slow declining SN II-P (Litvinova and Nadezhin 1983). The mechanism for the envelope ejection in SN II is still unknown, but possibly it is connected with a neutron star being created in SN II.

SN Ib are poorly studied so far. The oxygen lines in the spectrum of SN 1985f suggest an oxygen mass $M_{\rm O} \gtrsim 5 M_{\odot}$ (Begelman and Sarazin 1986), whereas the light curve and the expansion velocities rule out an ejected mass $>6 M_{\odot}$ (Chugaj 1986). It seems that an SN Ib ejects several solar masses consisting primarily of oxygen. If so, SN Ib could be the principal producers of oxygen in spiral galaxies, whereas SN Ia are definitely the main producers of iron; the amount of iron per SN Ib is probably several times less than in SN Ia (Shklovskii 1985; Wheeler and Levreault 1985).

* Paper presented at the Joint USSR–Australia Shklovskii Memorial Symposium on Supernova Remnants and Pulsars, held at Pushchino, USSR, 8–11 June 1986.

0004-9506/87/060767$02.00

2. Young Supernova Remnants

Six young galactic SNRs can be divided into three classes: (1) the Balmer-line SNRs Tycho, SN 1006 and (somewhat differently) Kepler; (2) the oxygen-rich SNR Cas A; and (3) SNRs with an active neutron star, i.e. the Crab and 3C 58 (or SN 1181) (see Lozinskaya *et al.* 1986).

The SNRs Tycho, Kepler and SN 1006 are traditionally considered to be SN I according to the light curves of Tycho and Kepler. One now needs to place them into the more specific Type Ia or Ib. The expansion velocity of iron in SN 1006 is $v_{Fe} \approx 6000\ \mathrm{km\,s^{-1}}$ (Wu *et al.* 1983), which is higher than the value in SN 1983n (Ib) of $v_{Fe} \approx 2500 \pm 1000\ \mathrm{km\,s^{-1}}$ (Graham *et al.* 1986), but similar to the value $v_{Fe} \approx 5000$–$8000\ \mathrm{km\,s^{-1}}$ for SN Ia (see e.g. Axelrod 1980). This suggests that SN 1006 and Tycho are of Type Ia rather than Ib. The SN Kepler can be tentatively classified as Ia, although the distinction between Kepler and the other two SN Ia remnants has yet to be understood. Recent analysis of the X-ray properties of Tycho and SN 1006 by Hamilton *et al.* (1985) also favours the parameters of SN Ia.

Cas A shows fast moving knots consisting practically of pure oxygen. This implies that Cas A is the descendant of an SN Ib which is the only known type producing oxygen-rich ejecta. The question, however, arises as to why Cas A was not seen at the maximum (around 1658 AD, see van den Bergh and Kamper 1983). The possible answer is either (1) strong interstellar absorption and unfavourable weather conditions or (2) that Cas A was an unknown type of subliminous SN (Chevalier 1976). We would not like to postulate yet another type of SN and therefore prefer the first answer.

The Crab Nebula (SN 1054) is the best candidate for an SN II. In fact, SN II is the only known type having hydrogen in the ejecta. 3C 58 is similar to the Crab in many respects and should also be of Type II. If we identify the Crab as SN II we face the well-known problem of where are the missing fast moving ejecta. The outer layers of SN II expand with a velocity of the order of $10\,000\ \mathrm{km\,s^{-1}}$ and with an r.m.s. velocity $\sim 5000\ \mathrm{km\,s^{-1}}$, yet the Crab ejecta expand slower than $2000\ \mathrm{km\,s^{-1}}$. There are two possible ways out of this contradiction: (1) the Crab has no fast moving ($>2000\ \mathrm{km\,s^{-1}}$) gas at all or (2) fast moving gas is present but unobserved because of the very low density of circumstellar gas. The first assumption suggests that the Crab was a very unusual Type II SN, while the second requires some adequate mechanism (e.g. fast pre SN wind or expansion into hot rarefied gas). The existence of the broad family of Crab-like and combination SNRs (Weiler 1983) makes the first assumption unnatural and the second preferable.

The SNRs with active neutron stars raise several questions:

(1) Do these SNRs represent a single evolutionary sequence of similar objects?

(2) Which parameter is the best age indicator?

(3) Are plerions and combination SNRs short lived, or rarely born?

(4) Are combination SNRs simply an intermediate stage between plerions and shell SNRs?

These questions can be answered briefly the following way (Lozinskaya 1986): (1) Four known SNRs with pulsars (the Crab, 0540−693, Vela and MSH 15–52) are probably at different evolutionary stages of similar objects (Weiler 1983; and references therein). However, 3C 58 probably has a less powerful pulsar than the Crab. (2) The

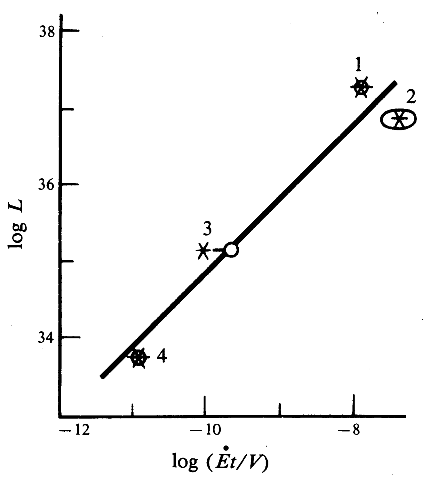

Fig. 1. Dependence of synchrotron X-ray luminosity L (erg s^{-1}) of SNRs with pulsars (over the energy range 0·2–4 keV) on the parameter $\dot{E}t/V$ (erg cm^{-3}): (1) Crab; (2) 0540–693; (3) MSH 15–52; (4) Vela X (see Lozinskaya 1986).

best evolutionary age indicator is found to be $\dot{E}t/V$ (see Fig. 1), where $\dot{E}$ is the pulsar energy loss rate, t is the age and V is the radio emitting volume. (3) Plerions and combination SNRs are short lived ($\lesssim 10^4$ yr) and their number is in rough agreement with the frequency of SN II ($\sim$0·02 per yr). (4) Combination SNRs emerge at the intermediate stage between plerions and pure shell SNRs (Lozinskaya 1980, 1986).

3. Conclusions

In summary, at present the best correspondence between the three classes of young galactic SNRs and the three types of SN observed in spiral galaxies is: SN 1006, Tycho and, probably, Kepler are SN Ia; Cas A is SN Ib; and the Crab and 3C 58 are SN II.

References

Axelrod, T. S. (1980). Ph.D. thesis, Univ. of California, Santa Cruz.
Begelman, M. C., and Sarazin, C. L. (1986). *Astrophys. Lett.* **302**, 59.
Bertola, F. (1964). *Ann. Astrophys.* **27**, 319.
Branch, D., Doggett, J. B., Nomoto, K., and Thielemann, F. K. (1985). *Astrophys. J.* **294**, 619.
Chevalier, R. (1976). *Astrophys. J.* **208**, 826.
Chugaj, N. M. (1986). *Pisma Astron. Zh.* **12**, 461.
Filippenko, A. V., and Sargent, W. L. W. (1986). *Astron. J.* **91**, 691.
Graham, J. R., Meikle, W. P. S., Allen, D. A., Longmore, A. J., and Williams, P. M. (1986). *Mon. Not. R. Astron. Soc.* **218**, 93.
Grasberg, E. K., Imshennik, V. S., and Nadezhin, D. K. (1971). *Astrophys. Space Sci.* **10**, 3.
Hamilton, A. J. S., Sarazin, C. L., and Szymkowiak, A. E. (1985). *Astrophys. J. Lett.* **297**, 5.
Litvinova, I. Y., and Nadezhin, D. K. (1983). *Astrophys. Space Sci.* **89**, 89.
Lozinskaya, T. A. (1980). *Astron. Zh.* **57**, 707.
Lozinskaya, T. A. (1986). *Astron. Zh.* **63**, No. 5.
Lozinskaya, T. A., Blinnikov, S. I., and Chugaj, N. N. (1986). Preprint ITEP No. 46.
Panagia, N. (1985). Space Telescope Science Institute Preprint No. 83.
Shklovskii, I. S. (1985). *Pisma Astron. Zh.* **11**, 261.

van den Berg, S., and Kamper, K. W. (1983). *Astrophys. J.* **268**, 129.
Weiler, K. W. (1983). *Observatory* **103**, 85.
Wheeler, J. C., and Levreault, R. (1985). *Astrophys. J.* **294**, 17.
Wu, C. C., Leventhal, M., Sarazin, C. L., and Gull, T. R. (1983). *Astrophys. J. Lett.* **269**, 5.

Manuscript received 19 March, accepted 8 July 1987