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SN1987A: Supernova Remnant Prospects

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Introduction

A Supernova explosion may produce two remnants namely, a collapsed compact object and an expanding envelope. These may be observable for a very long time (upto hundred thousand years or more) after the explosion as a pulsar and an extended diffused emission around the region where the explosion occurred. The term supernova remnant (SNR) usually refers to the long lived extended emission region. In this paper we discuss the prospects for the formation of such a supernova remnant at some later stage in the region around 1987A. Although in reality a separate physical picture may be required for each supernova and supernova remnant, some general trends are already known from the studies of supernova remnants in our Galaxy and Magellanic clouds and supernovae in external galaxies. A brief description of the features of the supernova remnants is presented, tracing their evolution from supernova stage.

Supernova Remnants

In order to understand the connection beteween a supernova and it later supernova remnant, let us look at some of the SNRs in our Galaxy. In Figure 1 is shown an example of a supernova remnant observed in the region around the supernova a few thousand years after the explosion (Helfand et al. 1988). SNRs may be broadly divided into two classes-shells (like Cas A) and pulsar nebulae(like the Crab Nebula). In principle, a single supernova remnant can have two components, a shell surrounding a pulsar nebula. The SNR shown in Figure 1, consists of a shell of radio emission of diameter ~4' surrounding a bright 1' diameter core near the centre. Multifrequency observations and higher resolution maps of the core show that the shell radio emission has characteristics similar to that of Cas A, while the core near the centre resembles the Crab Nebula. The interaction of the ejecta of the supernova with the surrounding interstellar medium has led to the formation of the shell of radio emission, while the relativistic electrons generated by the pulsar have given rise to a synchrotron nebula around the pulsar near the Centre. In this case(Fig.1), the pulsar has not been observed directly.

In Table 1, we summarise the characteristics of the two classes (or the components) of supernova remnants. The basic difference between the two classes (or components) of SNRs is the sources of energy powering their radiation over the entire electromagnetic spectrum. The shells are powered by the kinetic energy of the supernova explosion itself, that is, energy in the expanding ejecta, while the pulsar nebulae are powered by the loss of rotational energy of the neutron star. As seen from Table 1, 90 percent of the known supernova remnants have only shells and no pulsar nebula, while 4 percent have only pulsar nebulae without any surrounding shells. Only about 6 percent of the known SNRs have both the shell and pulsar nebula. The nature and evolution of the shell are determined by the initial conditions in the envelope ejected in the supernova, and during the initial stages by the pre-supernova environment, i.e. the circumstellar matter around the progenitor, and at later stages by the interstellar matter around the supernova (e.g. Chevalier 1988). Of course, the evolution of the pulsar nebula depends on whether a neutron star was formed in the explosion and its subsequent development into a pulsar (e.g. Bandiera et al. 1984). Since no neutron star is formed in Type I supernovae, they will have only shell SNRs, while type II supernovae may have both shell and pulsar nebula or any one of them. However, as mentioned earlier, the formation and evolution of SNR of any individual supernova will be decided entirely by its initial conditions and environment.

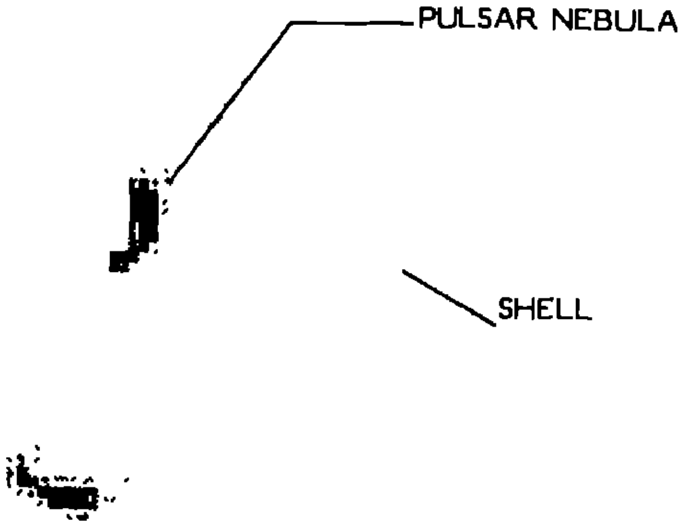

Fig.1 VLA map of SNR G16.73+0.08 at 1.4 GHz

Table 1
CHARACTERISTICS OF SUPERNOVA REMNANTS

	Shells	**Crab-like Pulsar Nebulae**
I. Radio		
a) Emission	Non thermal	Non-thermal
b) Morphology	Limb brightened-Partial or complete shell	Filled centre - Centrally peaked
c) Spectrum($S_\nu \sim \nu^\alpha$)	$\alpha \sim -0.5$	$\alpha > -0.3$ typically ~ 0.0
d) Polarization	~ 5% indicating circumferencial or radial magnetic field geometry	~10% indicating well aligned field geometry
e) Emission process	Synchrotron radiation from compression of ambient interstellar magnetic fields and electrons accelerated at supernova shock	Synchrotron emission from electrons generated by the the pulsar
II. Infrared	Emission from the heated dust shell around the supernova shock	Filled Centre- continuum nonthermal synchrotron radiation from electrons generated by pulsar
III. Optical	Thermal line emitting filaments fill a complete or partial shell	Thermal line emitting filaments embedded in a filled centre-nonthermal continuum synchrotron radiation from electrons generated by the pulsar.
IV. X-ray		
a) Morphology	Limb brightened shell partial or complete Filled centre morphology is also seen in some cases.	Filled centre with centrally peaked/compact source present
b) Emission Process	Thermal X-ray emission from plasma heated by the supernova shock	Nonthermal synchrotron radiation from electrons generted by the pulsar.
V. γ-ray	None	Probable
VI. Source of Energy	Kinetic energy in the Supernova Ejecta	Rotational energy of the neutron star
VII. Number of SNRs		
a) The Galaxy	140	15(9 with shells & 6 without shells)
b) LMC & SMC	38	1

Prospects for SNR in SN 1987A

a) **Shell**: It has been generally accepted that SN 1987A in the Magellanic clouds was of Type II and a neutron star was formed. The progenitor is a blue super giant of ~ $20M_\odot$ unlike the progenitors of other Type II supernovae, which are all believed to be red super giant. It could not have gone through substantial mass loss to form an extensive circumstellar envelope. Since the stellar atmosphere and circumstellar environment have very significant effects on the early evolution of the supernova remnant, it is an important question whether the progenitor was a red giant before it became a blue one. It is possible that it was a red supergiant in the past about 20,000 years ago, as inferred from the IUE spectra indicating existence of circumstellar matter at a distance of about 1 light year (e.g. Kirshner et al. 1987). The light echoes (reflection of supernova radiation) by interstellar clouds and circumstellar material in the foreground have been observed by direct photograph (e.g. Rosa et al. 1988) providing evidence for existence of clouds up to distance 30" and 50" (7 and 12 pc) from the supernova. Thus the circumstellar and interstellar matter environment of SN198A are favourable for evolution of SNR shell at a later stage.

The prompt radio emission from SN1987A within 2 days of opticl increase and its decay within a week (Turtle et al.1987) was rather unexpected but is consistent with the environment of the progenitor. Now, the ejecta is expanding freely into a low density wind bubble created in the past during the red giant phase of the progenitor. Radio and X-ray emission from a minishell will be turned on within a few years as it starts interaction with the circumstellar material inferred from IUE data. This phase of the shell emission will decay gradually over few years as it expands beyond the circumstellar region into the low density interstellar medium. The next significant phase in the shell emission appears only after a few hundred years, that is, when the swept up interstellar matter in the shell is of the same order as of the mass of the ejecta (Gull 1973). Obviously the fate of the shell emission depends very much on the surrounding interstellar density distribution. The presence of clouds at distances of ~ 7 pc from the supernova seem favourable for the shell emission after a few hundred years.

b) **Pulsar in SN 1987A**: The neutron star in SN 1987 indicates prospects for the development of a supernova remnant with a pulsar nebula. However, the neutron star should be first turned on as pulsar in order to transfer the energy. A spinning neutron star with magnetic field similar to the Crab pulsar would be directly observable only after the supernova envelope becomes optically thin, which may be after several years. But, one can infer its presence through the energy transferred to the SN envelope (e.g. Michel et al. 1987). The steady decline of supernova light curve will be levelled out by the additional energy supplied by the pulsar. This has not been observed so far, indicating a pulsar period >20ms. Further, if any ejecta matter should fall back on to the neutron star, it will evolve as accreting X-ray object rather than becoming pulsar. Obviously one has to wait for a more positive signature of the pulsar in SN 1987A.

c) Influence of Pulsar on shell: There is a possibility that if the neutron star in SN 1987A exerts appreciable dynamical effects on the shell, the shell would be fragmented (Bandiera et al. 1983). This could result due to Rayleigh Taylor instability in the shell caused by pulsar wind (a lighter fluid) pushing the expanding shell. In such cases the long lived SNR will have only the pulsar nebula without the shell around it. However, for this mechanism to be effective, the energy supply from the pulsar should be comparable to the kinetic energy in the shell, and requires very low initial rotation period (P_0). The fact that the pulsar has not revealed its presence so far, puts a limit $P_0 > 20$ ms. In that case, its influence on the shell will be negligible and the SNR shell will continue to evolve into a SNR shell.

d) Pulsar Nebula: The evolution of SNR powered by a central pulsar has been discussed in detail by Bandiera et al. (1984). In Figure 2 are shown the time evolution of the luminosity of the pulsar nebula, for initial rotation periods of 1 ms and 16 ms. For a comparison the luminosities of three supernovae SN1979C, SN1970 and SN 1987A and three pulsar nebulae, the Crab, CTB80, 0540-693 with initial rotation periods 16, 20 and 25 ms respectively are also indicated. The radio emission from the supernova 1987A was detected within 2 days of increase in optical brightness(Turtle et al.1987) and it is very unusual. Radio emission in other supernovae has been observed hundreds of days after the optical increase. Obviously, radio luminosity of 1987A does not fit into the evolution of pulsar nebulae shown in Fig.2. The prompt radio emission is perhaps due to synchrotron radiation originating from the thin shell near the outer edge of the ejecta and is not powered by the pulsar. The limit on the initial rotation period - 20 ms for the neutron star suggests that, if at all the pulsar emerges, the evolution of the pulsar nebulae will be similar to that of the Crab in the Galaxy or 0540-693 in LMC, as shown in Fig.2.

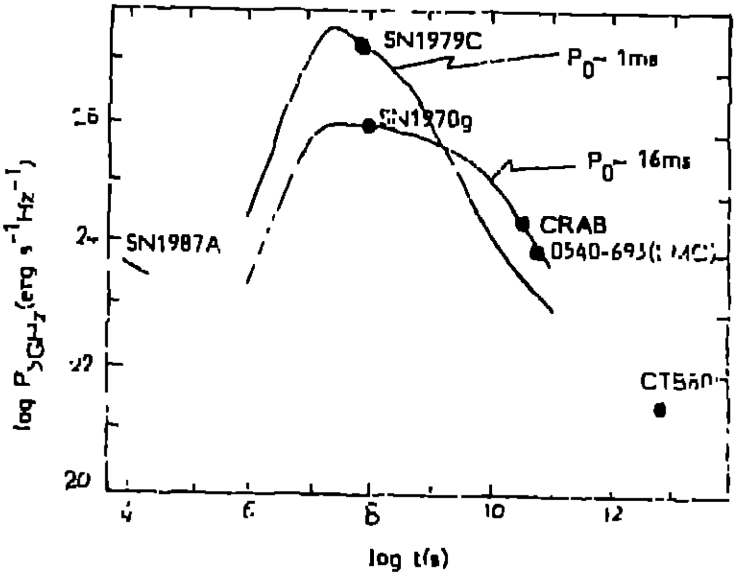

Fig.2 Time evolution of radio luminosity of pulsar nebula for initial pulsar periods 1 and 16 ms, and observed luminosities of supernovae and remnants.

SNR Statistics in LMC:

The 38 SNRs in the Magellanic clouds is a reasonably complete sample for diameter less than 40 pc (Mills et al. 1984). The supernova rate estimated from the number-diameter relation is ~ 1 per every 120 years. This rate derived purely from SNR statistics is quite consistent with the frequency of supernovae expected from SN statistics in other galaxies. Therefore, one may conclude that for every supernova occurred in the Magellanic clouds there has been a long lived SNR and there is a high probability that SN1987 also will have its long lived SNR in course of time.

Conclusion

The pulsar nebula may become visible within a few decades as the expanding ejecta becomes optically thin. The shell will become visible within a decade for a few years interacting with the circumstellar matter. It will become observable again interacting with the interstellar matter a few hundred years later. Thus SN1987A may develop into a long lived supernova remnant exhibiting an expanding shell surrounding a central pulsar nebula.

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