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"Hypernova" Radio Remnants

Abdul I. Asvarov

Institute of Physics, 33 H. Javid Ave, 370143 BAKU, Azerbaijan

Abstract. If recently discovered hypernova events are intrinsically energetic explosions of stars with a kinetic energy output of $E_K \gtrsim 10^{52}$ ergs than they can produce very large diameter (up to 500 pc) nonthermal radio shells. The properties of such shells are modelled and compared with the observational data on the large diameter supernova remnants (SNRs). One real candidate for the hypernova remnant is found. This is the supernova remnant N7793-S26 in the galaxy NGC 7793 (Pannuti et al. 2002).

1. Introduction

Until recently the energy of Supernova (SN) explosions was considered to be restricted within rather narrow range of energies of $10^{50} - 10^{51}$ ergs. Such belief was based on a vast observational data on the SNe spectra and the estimations of the energy content of the supernova remnants (SNRs) (Lozinskaya 1992).

Recently several SNe have been identified as Hypernovae? since they show excessive velocities and luminosities. The most famous examples, SN Ic 1998bw (Iwamoto et al. 1998) and SN Ic 1997ef (Iwamoto 2000; Mazzali 2000), have been found to have such a large kinetic explosion energy as $E_K \gtrsim 10^{52}$ ergs. This is more than one order of magnitude larger than typical SNe energy. More interesting was the strong evidence for the connection of SN 1998bw with an another phenomenon, much more powerful than SN, the gamma ray burst (GRB). The evidence for connection between SNe and GRBs include apart from the coincidence between SN 1998bw and GRB 980425 also bumps in the afterglow of some GRBs which are compatible with an underlying SN explosion, possible identifications of the Fe K line in the X-rays, and some evidence that GRBs are related to star forming regions (e.g. Höflich et al. 2001)

The models for super energetic SN events presented to date tend to fall into two classes - an intrinsically energetic explosion of a massive progenitor star (Hypernova) and more normal SNe artificially brightened by beaming. At least the spectra of several events (SNe 1998bw and 1997ef) are much better reproduced with the hypernova models than with the ordinary SN Ic model (Nomoto et al. 2000). The second type of models have much more strong observational support. Firstly, there is mounting evidence for an asphericity in SNe. This evidence includes the observed high polarization of light from SNe (e.g. Wang et al. 2001), pulsar kicks (Lai, 2000) and direct observations of SN1987A (Wang et al. 2001) and young SNRs (e.g. Cas A, Willingale et al. 2002). Secondly, though GRBs, which are considered to be connected with SN events, show much higher (up to 10^{54} erg) isotropic energies but Frail et al.(2001) have recently claimed that considering correction for possible beaming effects the range of real energy release is restricted to a narrower band around 10^{51} erg as for classical SNe. So, direct observations do not answer the question of the physical existence of Hypernovae. The term "Hypernovae" was first proposed by Paczyński (1998) to explain the gamma-ray bursts. Here, any explosive liberation of $\gtrsim 10^{52}$ kinetic energy without specification of the mechanism of explosion we call a Hypernovae and the remnant which will be produced by such explosion – Hypernova remnant (HNR). Note, it is not also required the explosion to be strongly spherical because as was shown recently by Piran & Ayal (2002) the remnant of even initially strongly beamed explosion lately will become spherical.

If Hypernova events indeed are realized in the Universe than they should produce expending remnants, HNRs, similar to usual SNRs but with higher energy content. More detail study of such expanding shells can help to answer this problem. Observationally HNRs in high density environments can show themselves in different appearances (superluminous X-ray or/and radio sources, very energetic H I shells, ets.) depending on age of the remnant and the physical conditions in the ambient medium. Indeed, such shell-like structures are observed and among them there are real candidates for HNRs (e.g. Chen et al. 2002; Uyaniker & Kothes 2002). However, the interpretation of such energetic shells is ambiguous. Usually, such structures are interpreted as a result of the joint action of strong stellar winds from early type stars and multiple supernova explosions.

In low density environments HNR may evolve adiabatically up to a few hundred pc in diameter without beginning of the radiative cooling. From the study of SNRs we know that the non-thermal radio emission is the main characteristic of such shells. So, the investigation of very large diameter non-thermal radio sources can help to answer the question of an existence of Hypernovae.

2. The Model

The physics of the hypernova remnants is expected to be the same as in the case of typical SNR and can be described by self similar Sedov solution until radiative cooling becomes important. In this paper we applied to HNRs our model (Asvarov 1992) with several modifications which describes the evolution of the radio emission of adiabatic SNRs in low density environments when the effect of radiative cooling can be ignored. The model is based on the following assumptions: a) electrons are accelerated diffusively at the main shock front from thermal energies; test particle approximation is used; b) magnetic field in the shell is the typical interstellar field compressed at the shock front; c)the effect of external pressure on the final stages of the SNR evolution is included by using the approximation of Cox & Anderson (1982) for the structure and kinematics of the remnant. There are three sets of input parameters of the model. The kinetic energy E_{SN} and the mass m_{ej} of the envelope ejected at the explosion are the characteristics of SN event. The thermal electron density n_e and the total pressure P_{tot} (the sum of the thermal gas P_{th} and the magnetic field P_m) in the ISM are input parameters characterizing the ambient ISM. The effect of the magnetic field is parameterized by $\beta = P_{th}/P_m$. P_{tot} and E_{SN} determine very important quantity in our model the maximum size of the SNR. The input parameter which characterizes the mechanism of acceleration is the injection parameter ϕ (Bell, 1978). In all models we use $\beta = 1$ and $\phi = 4 \times 10^{-3}$.

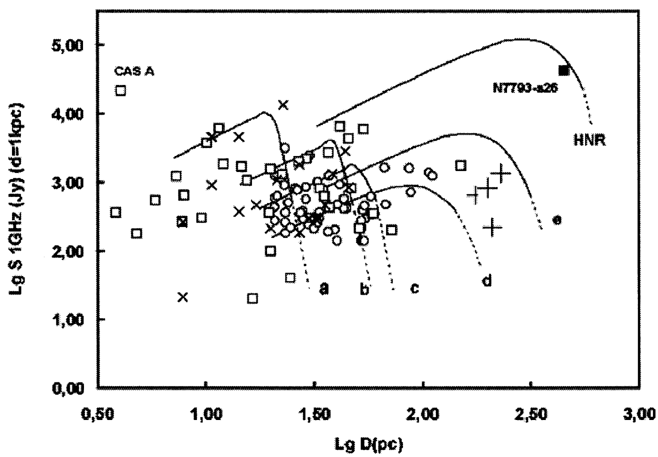

Figure 1. Luminosity - Diameter diagram for shell-like SNRs. Observational SNRs are labeled as: open squares –SNRs in our Galaxy, crosses – SNRs in LMCs, open circles – SNRs in the galaxy M33, pluses - Loops in our Galaxy, filled square - SNR N 7793 - S26 in the galaxy NGC 7793. Tracks are drawn for: (a) $n_e = 5$ cm^{-3}, $E_{SN} = 10^{51} erg$; (b) $n_e = 1$ cm^{-3}, $E_{SN} = 10^{51} erg$; (c) $n_e = 0.1$ cm^{-3}, $E_{SN} = 10^{51}$ erg; (d) $n_e = 0.05$ cm^{-3}, $E_{SN} = 10^{51}$ erg; (e) $n_e = 5$ cm^{-3}, $E_{SN} = 5 \times 10^{51}$ erg; HNR) $n_e = 0.05$ cm^{-3}, $E_{SN} = 10^{53}$ erg.

3. Results

In Fig 1 the results of model calculations are represented in the empirical Luminosity – Diameter diagram. Our sample of SNRs consists of Galactic shell and composite type SNRs from the catalogue of Green (2000) and 4 Galactic Loops from Berkhuisen (1986), SNRs in M33 from (Duric et al. 1995), and SNRs in LMC (Mathewson et al. 1985).With the help of our model it is possible to explain many features of the distribution of SNRs on the Luminosity-Diameter diagram. Note that the largest catalogued SNRs can be explained with $E_{SN} \lesssim 5 \times 10^{51}$ erg. The detection of the radio HNRs in our Galaxy is problematical because of their low surface brightness but they can be detected in nearby galaxies: at 10 Mpc above modelled HNR can be detected as nonthermal source with mean characteristics:$\alpha \simeq 0.7$, $S_{1GHz} \simeq 1$ mJy and $\theta \simeq 6''$. Real candidate for the

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HNR was found in the Nearby Sculptor Group Galaxy NGC 7793 (Punniti et al, 2002). SNR N7793-S26 is the only SNR in this galaxy that is detected at all three wavelengths (X-ray, optical and radio). This is extremely luminous radio source with a diameter of about 450 pc. Using only two measurements of flux densities 1.24 ± 0.19 Jy at 6 cm and 3.75 ± 0.30 Jy at 20 cm it was estimated the value of the spectral index of $\alpha = 0.9$, which is somewhat larger than predicted by our model value $\alpha \leq 0.70$. It is important to note that there is no evidence for any interior star cluster (Blair and Long, 1997), the presence of such a cluster would argue in favor of the collective supernova remnant hypothesis. Thus, N7793-S26 is the most real candidate for Hypernova remnant.

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