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ORIGINAL ARTICLE

On the spherical-axial transition in supernova remnants

L. Zaninetti

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Abstract A new law of motion for supernova remnant (SNR) which introduces the quantity of swept matter in the thin layer approximation is introduced. This new law of motion is tested on 10 years observations of SN 1993J. The introduction of an exponential gradient in the surrounding medium allows to model an aspherical expansion. A weakly asymmetric SNR, SN 1006, and a strongly asymmetric SNR, SN 1987A, are modeled. In the case of SN 1987A the three observed rings are simulated.

Keywords Supernovae: general · Supernovae: individual (SN 1993J) · Supernovae: individual (SN 1006) · Supernovae: individual (SN 1987A) · ISM: supernova remnants

1 Introduction

The theoretical study of supernova remnant (SNR) has been focalized on an expression for the law of motion. As an example the Sedov-Taylor expansion predicts $R \propto t^{0.4}$, see Taylor (1950), Sedov (1959), McCray (1987) and the thin layer approximation in the presence of a constant density medium predicts $R \propto t^{0.25}$, see Dyson and Williams (1997), Dyson (1983), Cantó et al. (2006). The very-long-baseline interferometry (VLBI) observations of SN 1993J (wavelengths of 3.6, 6, and 18 cm) show that $R \propto t^{0.82}$ over a 10 year period, see Marcaide et al. (2009). This observational fact does not agree with the current models because the radius of SN 1993J grows slower than the free expansion and faster than the Sedov-Taylor solution, more details for the spherical case can be found in Zaninetti (2011). The SNRs can also be classified at the light of the observed symmetry. A first example is SN 1993J which presented a circular symmetry for 4000 days, see Marcaide et al. (2009). An example of weak departure from the circular symmetry is SN 1006 in which a ratio of 1.2 between maximum and minimum radius has been measured, see Reynolds and Gilmore (1986). An example of axial symmetry is SN 1987A in which three rings are symmetric in respect to a line which connect the centers, see Tziamtzis et al. (2011). The models cited leave some questions unanswered or only partially answered:

- Is it possible to deduce an equation of motion for an expanding shell assuming that only a fraction of the mass enclosed in the advancing sphere is absorbed in the thin layer?
- Is it possible to model the complex three-dimensional (3D) behavior of the velocity field of the expanding nebula introducing an exponential law for the density?
- Is it possible to make an evaluation of the reliability of the numerical results on radius and velocity compared to the observed values?
- Can we reproduce complicate features such as equatorial ring + two outer rings in SN 1987A which are classified as a "mystery"?
- Is it possible to build cuts of the model intensity which can be compared with existing observations?

In order to answer these questions, Sect. 2 describes two observed morphologies of SNRs, Sect. 3.3 reports a new classical law of motion which introduces the concept of non cubic dependence (NCD) for the mass included in the advancing shell, Sect. 4 introduces an exponential behavior in the number of particles which models the aspherical expan-

L. Zaninetti (✉)
Dipartimento di Fisica Generale, Università degli Studi di Torino, Via Pietro Giuria 1, 10125 Torino, Italy
e-mail: zaninetti@ph.unito.it