Prospects for SNIa Explosion Mechanism Identification Through SNRs

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\textbf{Abstract.} We present the first results from an ongoing work aimed to use supernovae remnants to discriminate among different type Ia supernovae explosion models. We have computed the hydrodynamic interaction of supernova ejecta with the interstellar medium, obtaining the evolution of the density, temperature and ionization structure of the remnant. We have used ejecta profiles obtained from 1D hydrodynamic calculations of the different explosion mechanisms that are currently under debate. We have analyzed the best indicators that allow to discriminate among the different explosion mechanisms, taking into account the diversity of scenarios proposed for the presupernova evolution of the binary system, and the uncertain amount of electron heating in collisionless shocks.

\section{Thermonuclear supernovae remnants}

Modern X-ray observatories, like Chandra and XMM-Newton give the opportunity to collect a huge amount of high quality, high resolution, data about supernova remnants (SNRs). Whereas the atomic codes that allow to compute and fit the X-ray spectra have experienced a considerable improvement in the last years, this is not the case of our knowledge of the evolution of SNRs. One step towards a more complete understanding of these objects is to couple one-dimensional hydrodynamical calculations to an accurate ionization code.

The explosion mechanism(s) responsible for thermonuclear supernovae (SNIa) is still a matter of strong debate. In spite of the advances made in recent years in the understanding of the physics of the flame, there is still no definitive answer to the question of what is the mode of propagation of a thermonuclear flame through a massive C+O white dwarf. To answer this, we need to exploit every piece of evidence that can hold a signature of the flame propagation history. Here, we present the first results from an ongoing work aimed to use SNRs to discriminate among different SNIa explosion models. We have made a systematic exploration of the parameter space of explosion mechanisms including pure detonations, pure deflagrations, delayed detonations, pulsating delayed detonations, and sub-Chandrasekhar models, and we have obtained a set of explosion ejecta profiles with the aid of a 1D SN hydrodynamics code. Then, for each one of the profiles, we have computed the hydrodynamic interaction of the supernova ejecta with a uniform interstellar medium (ISM), obtaining the evolution of the density, temperature and ionization structure of the remnant. In order to
be sure that SNR properties allow to discriminate between explosion models it is necessary to look for the effects of other unknowns of the problem, mainly the presupernova evolution, which determines the ambient medium structure at the time of SN explosion, and the physics of collisionless shocks.

1.1 Presupernova Evolution

We have tested four simple models of presupernova mass loss due to binary wind (for details see [1] and [2]), with parameters chosen in order to reproduce the gross features of different evolutionary scenarios (references can be found in [1]). The structure of the ambient medium at the time of SN explosion has been computed with a SNR hydrocode which included radiative losses. Presupernova winds interact with the ISM producing the typical forward–shock/contact–discontinuity/reverse–shock structure, and providing:

- A cold dense shell appropriated for the formation of dust. This shell could also play a role in the formation of a light echo.
- A close circumstellar shell which could interact early with the SN ejecta (but only in our wind model D: low velocity wind active till the SN explodes).

We have computed the interaction of SN ejecta with the ambient medium sculpted by the four wind models, together with the interaction of the same ejecta profile with a constant density ISM. In Fig. 1 we show the expansion parameter of the forward shock (defined as $\eta = \frac{d(\ln R_{\text{shock}})}{d(\ln t)}$). As can be seen, the dynamical properties of SNR are mostly sensitive to the presupernova history at ages larger than that of Tycho’s SNR ($1.357 \times 10^{10}$ s).

![Fig. 1. Expansion parameter of the forward shock as a function of time. (a) Wind models: A (solid line), B (dotted line), C (dashed line), and D (dash-dotted line), and uniform ISM (triple-dot-dashed line). (b) Explosion models: Delayed detonation (solid line), deflagration (dotted line), pulsating delayed detonation (dashed line), and sub-Chandrasekhar (dash-dotted line)](image-url)
1.2 Explosion Mechanism

We have explored different explosion mechanisms, whose ejecta are characterized by their density and chemical profiles, obtained with a SNIa 1D hydro code (see [2] for details). We have computed the interaction of each SN ejecta profile with a uniform density ISM ($\rho_{\text{ISM}} = 10^{-24} \text{ g cm}^{-3}$) with the same SNR hydrocode previously described, and we have obtained the ionization structure of the SNR as a function of time. In principle, there are two ways to discriminate between the different ejecta profiles: one is the dynamic evolution of the SNR, the other is its X-ray emission.

**Dynamical evolution of the supernova remnant** The dynamics of young SNRs is sensitive to the explosion mechanism up to a few hundred years after the explosion. As can be seen in Fig. 1, our main result is that the expansion parameter of the deflagration model is the largest at early times due to the sharp density contrast at the point of flame quenching.

**Collisionless Shocks Physics** The physical processes that are at work in collisionless shocks physics are not well understood, the main uncertainty being the amount of electron heating in the shocks. The heavy plasma ejected by SNIa poses additional problems, because the electron number density depends on the local chemical composition and the degree of ionization of each element (which is out of ionization equilibrium, [3]).

We have computed carefully the ionization evolution of the plasma, and have checked the sensitivity of the results to the amount of electron heating at the shock. In Fig. 2 we show the results from two calculations in which we have assumed either no electron heating at the shock front or a moderate electron heating (1% of the ion temperature). Coulomb interactions between electrons and ions

![Fig. 2.](image-url)
Fig. 3. Normalized density ($\rho/10^{-24}$ g·cm$^{-3}$, solid line), electron temperature ($T_e/10^6$ K, dotted line), and ionization timescale ($n_e t/10^9$ s·cm$^{-3}$, dashed line), in the region between the reverse shock (left) and the contact discontinuity (right). Note the different r scales. (a) Delayed detonation model. (b) Deflagration model. (c) Pulsating delayed detonation model

were included in both calculations. Our main results concerning the influence of electron heating at the shock are:

- The ionization timescale does not depend on it at all.
- The electron temperature near the reverse shock (and, thus, the high energy X-ray continuum) depends strongly on it.

**X-ray emissivity** Finally, we address the problem of the X-ray emissivity associated to each explosion model. Up to now, we have not concluded this part of the project, but some preliminary results are already available. In Fig. 3 we show the density, temperature and ionization timescale profiles of the deflagration, pulsating delayed detonation and delayed detonation models at the age of Tycho’s SNR. Our results show that the most model sensitive characteristics are:

- The ionization timescale close to the contact discontinuity and, thus, the centroid of the Fe/S He$\alpha$ complex of X-ray lines.
- The density profile and, thus, the emission measure and the X-ray luminosity.
- The high energy continuum is mainly dependent on the assumed physics of the collisionless shocks.

This work has been supported by the MCYT grants EPS98–1348 and AYA2000–1785 and by the DGES grant PB98-1183-C03-02. C. B. is very indebted to CIRIT for a grant.

**References**

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