X-RAY EMISSION FROM RADIATIVE SHOCKS IN TYPE II SUPERNOVAE

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ABSTRACT

A numerical model is presented which calculates the X-ray emission from radiative shocks in supernovae. Type IIL and Type IIn supernovae generally have a sufficiently dense circumstellar medium for the interaction between the supernova ejecta and circumstellar medium to be strong, leading to substantial X-ray emission already a few days after the explosion. Assuming the flow is stationary, our model combines hydrodynamic calculations with time dependent ionization balance and multi-level calculations. We find large differences between the self-consistent, hydrodynamic model and simple one- or two-temperature fits. The dependence of the resulting spectrum on shock velocity and chemical composition are discussed, as well as the difference between spectra produced by this model and single-temperature spectra. The applicability of our model for various types of supernovae is discussed, and examples of applications to observations are given.

Key words: supernovae: general – stars: circumstellar matter – X-rays: supernovae – hydrodynamics .

1. INTRODUCTION

The X-ray emission from most Type IIL and Type IIn supernovae is dominated by the interaction between the ejected material and the circumstellar gas. During a supernova explosion the ejected material collides with and sweeps up the circumstellar gas. This creates two shocks; one moving into the circumstellar medium and one reverse shock, moving backward into the ejecta. The latter is often radiative, creating strong line emission, mostly in X-rays due to the high temperatures involved.

Our goal has been to develop a model which can reproduce the X-ray emission from the reverse shock by taking into account the contributions from all cooling zones. We have applied the model for the radiative shocks of SN 1987A (Gröningsson et al), as well as to Type IIP SNe (Chevalier et al). In the future we hope to model the spectra of especially SN 1993J and SN 1998S.

2. METHOD

Our model combines hydrodynamic calculations for a stationary flow with time-dependent ionization balance and multi-level calculations. The main input parameters to the hydrodynamic code are the reverse shock temperature and the chemical composition, and for the normalization of the spectrum, the mass loss rate of the progenitor and the ejecta and wind density gradients. The output is the density and temperature structure in the cooling region.

For the spectral code we take as input the density and temperature from the hydro-code and use this for computing the time-dependent ionization structure in the cooling region. Multi-level calculations are done which then yield the line emission. The cooling is the sum of line emission and continuum emission, and couples back to the hydrodynamic equations to give the size of each cooling zone. The model is described in detail in Nymark, Fransson & Kozma (2005).

3. ONE TEMPERATURE VERSUS MANY

The reverse shock is often modeled with a single temperature. While this is a good approximation for an adiabatic shock, it is not sufficient to reproduce the emission from a radiative shock. The total emission will be overestimated, and many lines from low-temperature regions will not be present in the synthetic spectrum. In combining hydrodynamic calculations with an emission code, our model traces the cooling region better (Fig. 1).

4. EFFECTS OF COMPOSITION

As the reverse shock travels backwards into the ejecta, it passes through regions of different composition reflecting the different burning zones in the progenitor. This affects the emitted spectrum, as elements normally rare come to dominate both line and continuum emission. We have

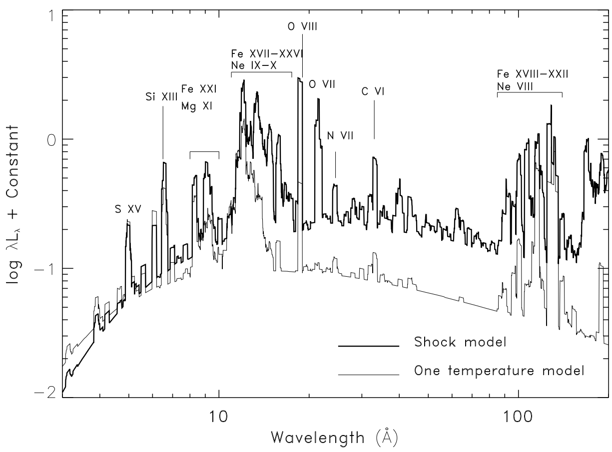

Figure 1. Comparison between a single temperature spectrum with T=1.0 keV (thin line) and a cooling shock spectrum created by our model, with initial temperature T=1.0 keV (thick line), both with solar composition. The spectra are normalized to have the same total flux in the range 1-10 keV.

computed three models to correspond to the most important burning zones, as well as a solar composition model (Fig. 2). We see that both line and continuum emission are strongly affected by the composition.

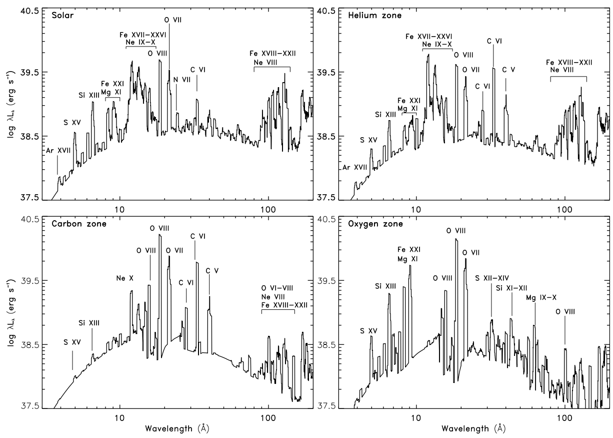

Figure 2. X-ray spectra produced by four models with different composition. All models have V=10,000 km/s and T=1.0 keV.

5. TOTAL SPECTRUM

At early times most of the energy emitted by the cooling gas is absorbed in the cool shell close to the contact discontinuity. At first only the most energetic emission passes through, while lower energies are completely absorbed. As the emitting region expands, the optical depth in the cool shell drops. The absorption decreases, first at high energies, later at lower energies. As time passes, more of the low-energy emission emerges, so that even though the total emission decreases, the emerging emission from the reverse shock increases. The observed spectrum is the sum of the absorbed spectrum from the reverse shock and the contribution from the circumstellar shock.

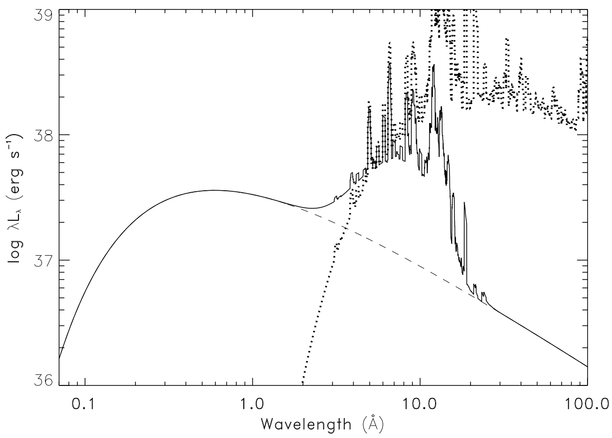

Figure 3. Total spectrum (solid line) for V=10,000 km/s, T=1 keV, t=100 days and solar composition, created by adding the emission from the circumstellar (dashed line) and reverse (dotted line) shocks, assuming an absorbing column density of 10^{22} cm^{-2} in the cool shell.

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