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HYDRODYNAMICAL MODELS OF TYPE II-P SUPERNOVA LIGHT CURVES

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RESUMEN

Presentamos los progresos en el modelado de curvas de luz de supernovas de tipo II plateau (SNe II-P) obtenidos a partir de un código hidrodinámico unidimensional que recientemente hemos desarrollado. Usando modelos iniciales simples (polítropas) reprodujimos el comportamiento global de las curvas de luz observadas y analizamos la sensibilidad de la curva de luz a la variación de los parámetros libres.

ABSTRACT

We present progress in light curve models of type II-P supernovae (SNe II-P) obtained using a newly developed, one-dimensional hydrodynamic code. Using simple initial models (polytropes), we reproduced the global behavior of the observed light curves and we analyzed the sensitivity of the light curves to the variation of free parameters.

Key Words: hydrodynamics — shock waves — stars: interiors — supernovae

1. INTRODUCTION

It is currently thought that SNe II-P are a subclass of core-collapse supernovae with red supergiant progenitors that have retained their H-rich envelopes. Recent studies have suggested their use as reliable distance indicators (Hamuy & Pinto 2002). However, our knowledge of the physical properties of SNe II-P needs to be improved. This need and the availability of a large database of high-quality light curves of SNe II-P motivated us to develop a one-dimensional hydrodynamical code to obtain theoretical light curves (LC) of SNe II-P and study possible correlations among model and observational parameters.

2. SAMPLE OF SUPERNOVAE

We have access to a sample of ~30 nearby SNe II-P with well-covered *BVRI* light curves and spectra. The observations were done between 1986 and 2003, in the course of three programs (Calán/Tololo, Hamuy et al. 1993; SOIRS, Hamuy et al. 2002; and CATS, Hamuy et al., in preparation). Additionally, there are ~15 SNe II-P available from the literature, and the CSP (Hamuy et al. 2006) is currently observing even more objects with unprecedented temporal coverage, both at optical and IR wavelengths.

3. CALCULATION METHOD

Theoretical LC's were obtained by numerical integration of the hydrodynamic equations which express conservation laws, plus radiation transport. To accomplish this, we developed a code that uses an

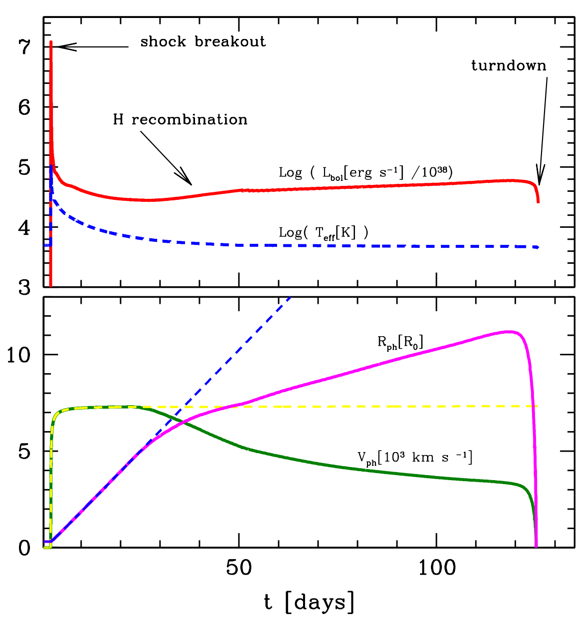

Fig. 1. Time evolution of the bolometric luminosity, effective temperature $T_{\rm eff}$, photospheric radius R_{ph} and velocity of the gas at the photosphere v_{ph}. Matter is quickly accelerated until a homologous regime is established ($v_{ph} \sim$ const. and $R_{ph} \propto t$). As the expansion continues, recombination sets in, and the photosphere starts to recede in mass. At the same time, R_{ph} begins to rise more slowly and v_{ph} sharply decreases. Note that the interval with $v_{ph} \sim$ const. is a measure of the time required for the onset of recombination.

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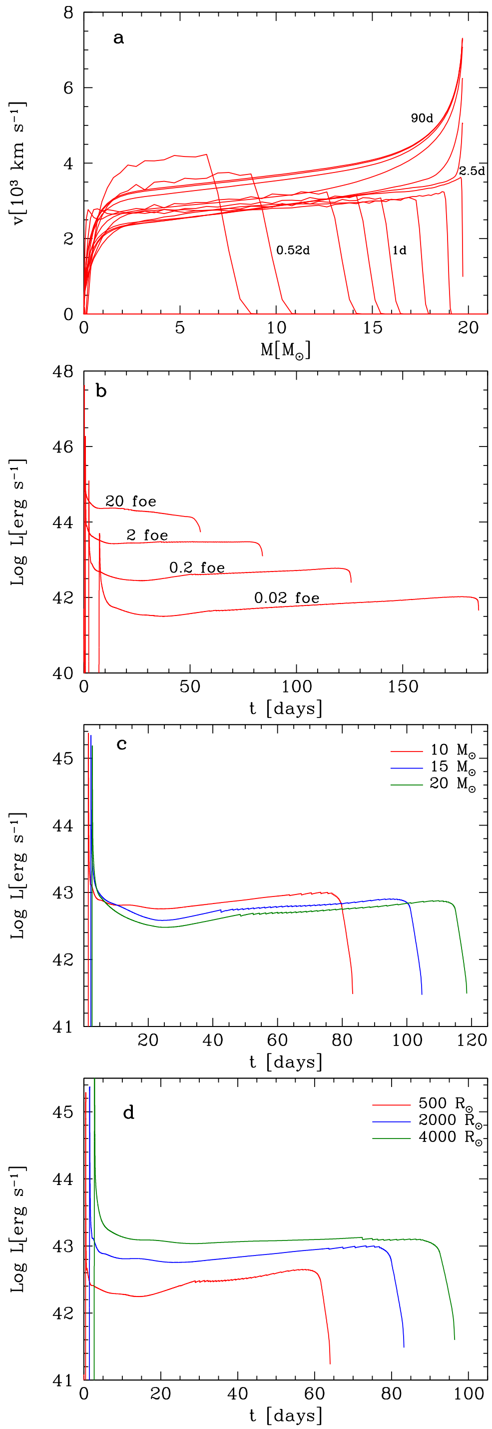

Fig. 2. (a) Profiles of velocity with respect to interior mass. The time elapsed since the energy is injected is shown as reference for some of the curves. The following panels show changes in bolometric luminosity for different injected energies (b), initial masses (c) and radii (d).

explicit scheme for the velocity and density and an implicit scheme for the temperature (T). The equations were linearized in δT and solved iteratively for each time step using the tridiagonal method. Our calculations considered the following: (a) spherical symmetry (supported by recent spectropolarimetric studies), (b) diffusion approximation, (c) inclusion of an artificial viscosity term in the equations, and (d) a sudden release of energy near the core to simulate the onset of the explosion.

4. RESULTS

We tested our code using simple initial models, such as polytropes. Here, we present the case of a polytrope of index 3, a mass of 20 $M_\odot$ and a radius of 2000 $R_\odot$. A powerful shock wave (SW) is propagated outward when we artificially inject an energy of 2×10^{50} erg (0.2 foe) near the star center. The SW changes dramatically the velocity (see Figure 2a), density and temperature profiles (see figures in Bersten et al. 2007). By day 2.5, the SW reaches the surface of the object causing the luminosity and the effective temperature to sharply rise (breakout). This phase is followed by a violent expansion and cooling of the outermost layers. The effective temperature decreases until it reaches the hydrogen recombination temperature at day ~32 (recombination phase). As the hydrogen is recombined the luminosity and effective temperature remain nearly constant. Finally, the LC sharply turns down at day 123 as recombination is essentially complete in the whole envelope. The phases we described above are shown in Figure 1 along with the behavior of the photospheric temperature, radius and velocity. Note that while the hydrogen is recombining the photosphere moves inward in mass (but not in radius) and samples matter with lower speed.

We also analyzed the sensitivity of the resulting LC to the amount of injected energy (E_0; Figure 2b), initial mass (M_0; Figure 2c) and initial radius (R_0;Figure 2d). The behavior of the plateau luminosity (L_p) and duration (t_p) with respect to those quantities is in agreement with the analytic expressions $L_p \propto R_0^{2/3} E_0^{5/6} M_0^{-1/2}$ and $t_p \propto R_0^{1/6} E_0^{-1/6} M_0^{1/2}$ obtained by Popov (1993).

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