EXPLOSION OF WHITE DWARFS

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ABSTRACT. We present models for Type I supernova light curves based on the explosion of partially solid white dwarfs in close binary systems. Studies of such explosions show that they leave bound remnants of different size. Our results reproduce quite well the maximun luminosities, the expansion velocities and the shape of the light curve. As the two basic parameters that govern the light curve, the ejected mass and the mass of ^{56}Ni produced, are variable our models reproduce the slow and fast subclasses of "classical" Type I supernovae.

1. INTRODUCTION

It is generally thought that "classical" Type I supernovae are the outcome of the explosion of a massive white dwarf in a close binary system. This scenario succesfully predicts the global shape of the light curves and gives a natural explanation for the homogeneity of the spectral and photometric characteristics of individuals. Current models predict the production of about one solar mass of ^{56}Ni as well as the total disruption of the white dwarf (Nomoto 1982, Nomoto et al 1984; Sutherland and Wheeler 1984; Schurmann 1983).

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2. MODELS AND DISCUSSION

Despite their spectrophotometric homogeneity, a more detailed analysis of the observational properties of the Type I supernovae shows a range of variations in the rate of the decline of the light curves. Barbon, Ciatti and Rosino (1973) proposed a clasification in two groups, "slow" and "fast", according to the width and amplitud of their maxima. Later on, Pskovskii (1977, 1984) and Branch (1982) found the following correlations between the peak luminosities, the expansion velocity and the rate of decline of the light curve: the "slow" supernovae are brighter, have higher expansion velocities and their luminosity decays more slowly than the "fast" ones.

This behaviour can be understood on the basis of the dimensional relations obtained by Arnett (1982) from his analytical models, which give the peak luminosity (L_{peak}), the velocity of the ejected material (v_{ej}) and the "effective difussion time" (τ_m)

$$L_{peak} \propto M_{Ni}$$

$$v_{ej} \propto (M^*_{Ni} / M_{ej})^{1/2}$$

$$\tau_m \propto (M^3_{ej} / M^*_{Ni})^{1/4}$$

where

$$M^*_{Ni} = M_{Ni} - \Delta M_{Ni}$$

being M_{ej} the ejected mass, M_{Ni} the total mass of ^{56}Ni synthesized and

$$\Delta M_{Ni} = (BE_i - BE_f)/q$$

where BE_i and BE_f are the binding energies of the initial and final configurations and q the energy released per unit of mass in the incineration to ^{56}Ni.

We see, then, that the two basic parameters governing the shape of the light curve are the amount of ejected matter (M_{ej}) and that of ^{56}Ni synthesized (M_{Ni}). In the models where the total disruption of the star is assumed, one of these parameters, the ejected mass, is fixed and aproximately equal to the Chandrasekhar's mass ($M_{ej} \sim M_{Ch}$). As a consequence of this restriction these models give a correlation between luminosity at maximun, expansion velocity and effective difussion time which is the opposite to the observed one.

In order to verify this aasertion we have calculated a serie of such models whose characteristics are presented in Table 1, where R_p, v_p, L_{43}, M_B, and E_{kin} are respectively, the radius, the velocity, the absolute magnitude in the photometric band B, at maximun brightness, and the kinetic energy of the initial configuration. In Figure 1 we present the corresponding light curves. It becomes clear that the bigger the amount of ^{56}Ni synthesized, the narrow the light curve is.

We can find a way out of this dilemma if we admit the possibility of off-center ignitions, as is the case if we deal with partially solid white dwarfs. Effectively, solidification could produce a chemical

TABLE 1

MODELS THAT SUFFER TOTAL DISRUPTION

Model	M_{ej} (M_O)	M_{Ni} (M_O)	E_{kin} (10^{51} erg)	R_p (10^{15} cm)	v_p (km/s)	L_{43} (erg/s)	M_B
a	1.435	1.2	1.12	1.60	13118	2.26	-20.01
b'	1.435	0.9	0.70	1.69	10247	1.48	-19.44
c'	1.435	0.65	0.36	1.46	7615	0.91	-18.85

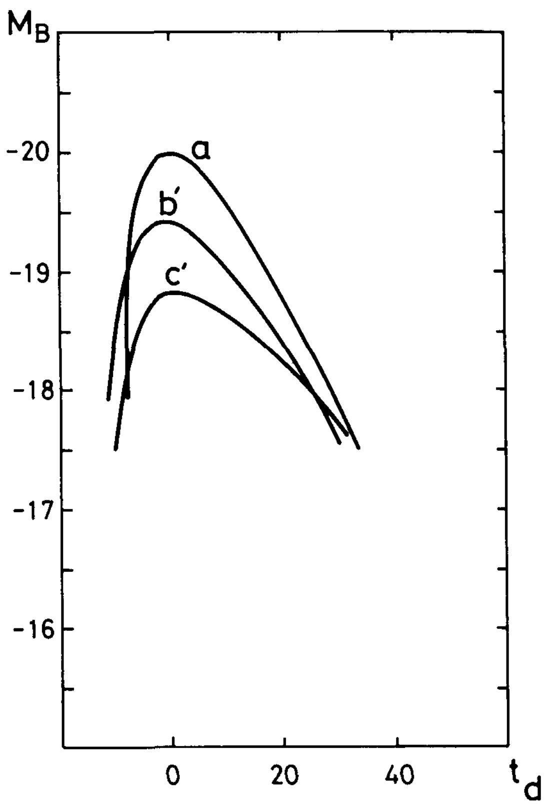

FIGURE 1

Light curves for models of Table 1

TABLE 2

MODELS THAT LEAVE A BOUND REMNANT

Model	M_{ej} (M_O)	M_{Ni} (M_O)	E_{kin} (10^{51} erg)	R_p (10^{15} cm)	v_p (km/s)	L_{43} (erg/s)	M_B
a	1.435	1.2	1.12	1.60	13118	2.26	-20.01
b	1.2	1.0	0.81	1.52	12075	1.83	-19.76
c	0.9	0.7	0.50	1.30	10975	1.49	-19.55
d	0.8	0.6	0.34	1.18	9645	1.22	-19.34

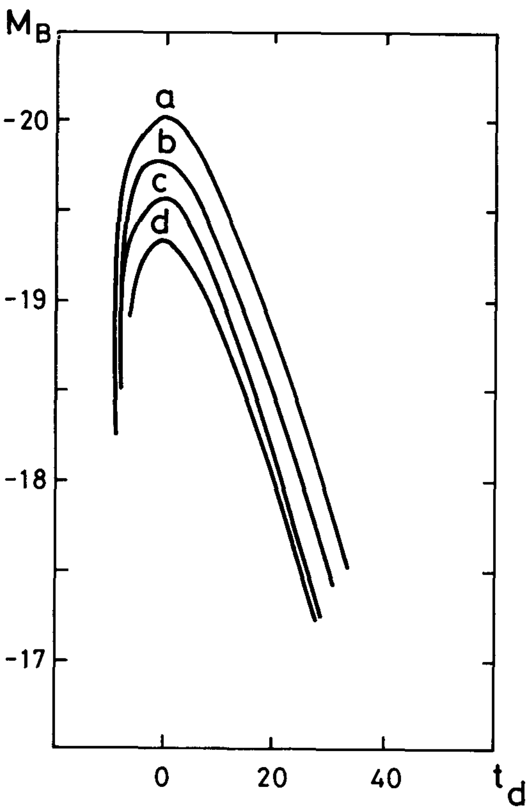

FIGURE 2

Light curves for models of Table 2.

differentiation of the interior of the white dwarf, leading to the formation of a solid pure oxygen core whose size depends on the duration of the detached phase (Isern et al. 1983; Hernanz et al., in preparation).

The crucial consequence of the partially solid models is that not only the mass of ^{56}Ni synthesized changes from one explosion to another but so also does the amount of ejected material, since the solid core will be left as a bound remnant (Isern et al. 1984). Therefore the two main parameters, M_{ej} and M_{Ni}, are both variable, allowing the agreement between the aforementioned dimensional relations and the observational correlations.

Models of this class are presented in Table 2, and their corresponding light curves are plot in Figure 2. We have adopted for the exploding white dwarf a total mass of 1.435 $M_\odot$. It can be seen that these models not only agree with the observational data as to expansion velocities, maximun luminosities and light curve shape, but they also reproduce the correct correlation between these quantities.

It must be stressed that, in the framework of this kind of models it is not necessary to assume the star to be solid in every case. Only a fraction of the explosions leave bound remnants.

3. CONCLUSIONS

From our study we can extract the following conclusions:
- The observational correlation found by Pskovskii and Branch in the Type I supernova light curves can only be account for in those models which assume that Type I supernova explosions might leave, in some cases a bound remnant.
- In order to reproduce the observational data the mass of these remnants must lie in the range between 0 and 0.4 solar masses.
- The total quantity of ^{56}Ni synthesized can vary between 0.6 and 1 $M_\odot$.

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