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*Letter to the Editor*

# UV light curves of thermonuclear supernovae

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**Abstract.** Ultraviolet light curves are calculated for several thermonuclear supernova models using a multifrequency radiation hydrodynamic code. It is found that Chandrasekhar-mass models produce very similar light curves both for detonation and deflagration. Sub-Chandrasekhar-mass models essentially differ from "normal" Chandrasekhar ones regarding behaviour of their UV fluxes. Differences in absolute brightness and in shape of light curves of thermonuclear supernovae could be detectable up to 300 Mpc with modern UV space telescopes.

**Key words:** hydrodynamics – methods: numerical – stars: supernovae: general – ultraviolet: stars

## 1. Introduction

Early ultraviolet (UV) emission from Type Ia supernovae (SNe Ia) is poorly known by now. Only a very few brightest events have been observed a decade ago with the International Ultraviolet Explorer (IUE). Although observational data were sometimes quite fascinating, as in the case of SN 1990N (Leibundgut et al. 1991, Jeffery et al. 1992), an amount of observed UV light curves and spectra remained too small to reveal what is typical for the UV emission from SNe Ia and how individual features of the explosion can be displayed.

The Hubble Space Telescope (HST) has slightly improved the situation. More data of better quality were obtained. This allowed theorists to make a comparison between the predictions of explosion models and the observational results. Reproduction of supernova UV emission is a good test for an explosion model because this spectral region reflects more directly the distribution of $^{56}$Ni synthesized during the explosion and the conditions in the exploding star. Several models were already used to fit the observed spectra. Analyses of early and late emission from SNe Ia by Kirshner et al. 1993, Ruiz-Lapuente et al. 1995, Nugent et al. 1997 show that Chandrasekhar-mass models DD4 (Woosley & Weaver 1994b) and W7 (Nomoto et al. 1984) and sub-Chandrasekhar-mass helium detonation models (see Livne 1990; Livne & Glasner 1991; Woosley & Weaver 1994a; Höflich & Khokhlov 1996) can reproduce some features of UV spectra of SNe Ia quite well.

In this Letter we calculate the light curves of the similar models and discuss how they differ from each other in several UV wavelength ranges. It is quite probable that more observational data will soon be available with the HST, and that the Far-Ultraviolet Spectroscopic Explorer (FUSE), operating at shorter wavelengths (Sembach 1999), will be able to obtain light curves and spectra of SNe Ia in the range where they were not observed so far. The analysis proposed here can help to distinguish which mode of explosion is actually realized in the SNe Ia.

## 2. Models and method of calculations

In our analysis we have studied two Chandrasekhar-mass models: the classical deflagration model W7 (Nomoto et al. 1984) and the delayed detonation model DD4 (Woosley & Weaver 1994b), as well as two sub-Chandrasekhar-mass models: helium detonation model 4 of Livne & Arnett (1995) (hereafter, LA4) and low-mass detonation model with low $^{56}$Ni production (hereafter, WD065; Ruiz-Lapuente et al. 1993). Main parameters of these models are gathered in the Table 1, as well as the values of rise time and maximum UV fluxes in the standard IUE range (just as it is the most typical form of representation; e.g., Pun et al. 1995) and in the FUSE range. For definiteness the distance to a supernova is supposed to be 10 Mpc.

The method used here for light curve modeling is multi-energy group radiation hydrodynamics. Our code STELLA (Blinnikov & Bartunov 1993; Blinnikov et al. 1998) solves simultaneously hydrodynamic equations and time-dependent equations for the angular moments of intensity averaged over fixed frequency bands, using up to $\sim 200$ zones for the Lagrangean coordinate and up to 100 frequency bins (i.e., energy groups). This allows us to have a reasonably accurate representation of non-equilibrium continuum radiation in a self-consistent calculation when no additional estimates of thermalization depth are needed. Local Thermodynamic Equilibrium (LTE) for ionization and atomic level populations is assumed in our modeling. In the equation of state, LTE ionization and

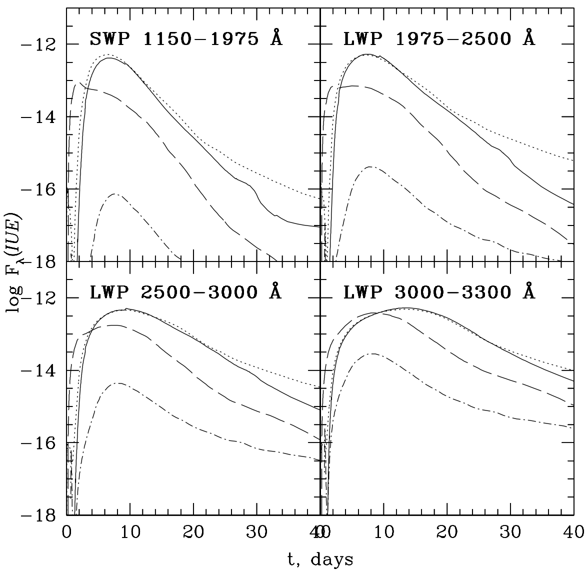


**Fig. 1.** Near-UV light curves of the models DD4 (solid), W7 (dots), LA4 (long dash), and WD065 (dash-dot). Fluxes $F_\lambda$ in units ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$ averaged in the four IUE spectral bands are reduced to distance of 10 Mpc.

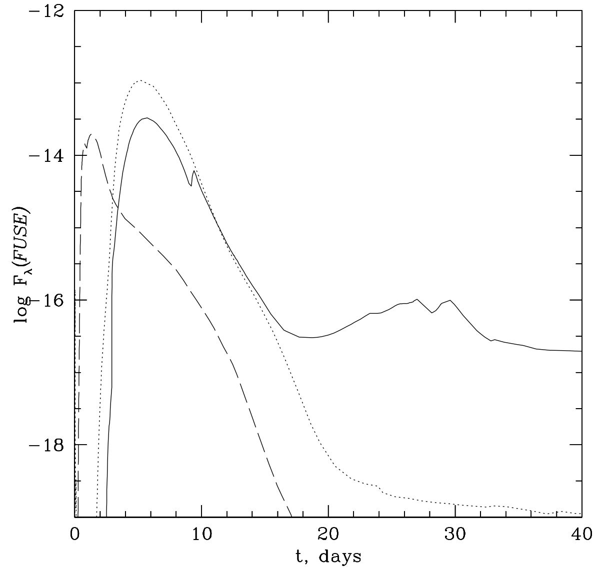


**Fig. 2.** Far-UV light curves for the same models as in Fig. 1, but in the FUSE working wavelength range (905–1187Å)

recombination are taken into account. The effect of line opacity is treated as an expansion opacity according to the prescription of Eastman & Pinto (1993) and Blinnikov (1996, 1997).

## 3. Results and discussion

The main results of our calculations are presented in Figs. 1, 2. The light curves of our models are shown in near and far UV ranges. The fluxes are plotted as they would be seen for supernovae at distance of 10 Mpc. Declared sensitivity of FUSE is $\sim 3 \cdot 10^{-15}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$, and sensitivity of HST (at working range of wavelengths almost equal to that of IUE) is roughly $10^{-16}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$. This allows us to estimate that SNe Ia could be observed up to 300 Mpc in the near UV and up to 30 Mpc in the far UV (with HST and FUSE, respectively). Yet it should be noticed that in the far UV SNe Ia are bright enough only during several days, and their flux declines very quickly after the maximum light, so the probability of discovering for them is quite low, unless they are very close to us (a few Mpc or even less).

Differences in the shapes and absolute brightness of SNe Ia light curves become more pronounced in this spectral range, especially in far UV, for different modes of explosion. As we have found in our paper (Sorokina et al. 2000), the light curves of W7 and DD4 are very similar in *B* band close to the maximum light and differ drastically several days after it. We can see likely behaviour in near-UV wavelengths (Fig. 1). In far UV, differences grow up, so that even at maximum light one can distinguish between two Chandrasekhar-mass models. Such a behaviour can most probably be explained by different distribution of $^{56}$Ni inside debris of exploded star. In our case, the fraction of $^{56}$Ni

**Table 1.** Parameters of SN Ia models, rise time to the maximum of the UV light curves and UV fluxes at maximum light in FUSE and IUE ranges. Fluxes are calculated under the assumption that a supernova is at distance of 10 Mpc from the observer.

| Model | DD4 | W7 | LA4 | WD065 |
|---|---|---|---|---|
| $M_{\rm WD}$[a] | 1.3861 | 1.3775 | 0.8678 | 0.6500 |
| $M_{^{56}\rm Ni}$[a] | 0.63 | 0.60 | 0.47 | 0.05 |
| $E_{51}$[b] | 1.23 | 1.20 | 1.15 | 0.56 |
| FUSE 905–1187Å | | | | |
| $t_{\rm max}$[c] | 5.7 | 5.3 | 1.4 | 7.7 |
| $F_\lambda$[d] | 3.28 | 11.0 | 1.97 | $4.83 \cdot 10^{-9}$ |
| SWP 1150–1975Å | | | | |
| $t_{\rm max}$[c] | 6.7 | 6.4 | 1.8 | 7.7 |
| $F_\lambda$[d] | 41.7 | 51.8 | 9.21 | $7.45 \cdot 10^{-3}$ |
| LWPshort 1975–2500Å | | | | |
| $t_{\rm max}$[c] | 7.5 | 7.4 | 2.0 | 8.0 |
| $F_\lambda$[d] | 53.2 | 50.4 | 6.90 | $4.22 \cdot 10^{-2}$ |
| LWPmiddle 2500–3000Å | | | | |
| $t_{\rm max}$[c] | 8.7 | 9.1 | 7.5 | 8.1 |
| $F_\lambda$[d] | 46.0 | 45.8 | 17.7 | 0.447 |
| LWPlong 3000–3500Å | | | | |
| $t_{\rm max}$[c] | 13.5 | 13.4 | 8.5 | 8.2 |
| $F_\lambda$[d] | 52.7 | 48.9 | 38.3 | 2.87 |
| Total IUE luminosity 1150–3300Å | | | | |
| $t_{\rm max}$[c] | 7.9 | 7.4 | 7.6 | 8.2 |
| $L$[e] | 11.0 | 11.4 | 3.72 | 0.161 |

[a]in $M_\odot$
[b]in $10^{51}$ ergs s$^{-1}$
[c]in days
[d]in $10^{-14}$ ergs s$^{-1}$ cm$^{-2}$ Å$^{-1}$
[e]in $10^{42}$ ergs s$^{-1}$

decreases more sharply in the model W7, and this perhaps leads to the faster decline of its light curve.

The shape of the UV light curve of WD065 is conformal to those of Chandrasekhar-mass models, though it shows much lower absolute flux (due to an order-of-magnitude lower $^{56}$Ni mass). The light curve maxima of the Chandrasekhar-mass models are shifted progressively towards later epochs for longer wavelengths remaining almost equal in brightness, while the WD065 maxima occur at nearly the same epoch for all of the IUE and FUSE ranges, and the emission virtually disappears at the shorter edge of the spectrum (see Table 1 and Fig. 1), since such a small amount of $^{56}$Ni as present in this model is not able to maintain high temperature inside the ejecta. The emission of WD065 in far UV becomes so weak that it could be detected only if supernova exploded in our neighbourhood (not farther than a few hundreds of parsecs from us).

The model LA4 (helium detonation in outer layers) is apparently distinguished by its rise time in the shortest spectral bands. The most interesting feature of this light curve is its clear two-maxima structure in the short LWP range. The earliest spike of the far-UV radiation is due to the outer $^{56}$Ni layer specific for this model. It is well known that those helium detonation models are too blue near visual maximum (Höflich & Khokhlov 1996; Ruiz-Lapuente et al. 1999). This is also confirmed by our *UBVRI* computations (Sorokina et al. 2000). In far UV, LA4 looks out not so hot, yet it can be detected in far UV earlier than in visual light.

One should be cautious applying our results directly to observations in UV range. A large fraction of SNe Ia shows a significant correlation with star-forming regions (Bartunov et al. 1994; McMillan & Ciardullo 1996; Bartunov & Tsvetkov 1997). The circumstellar medium in those regions can absorb radiation, especially in UV band. In this case our predictions should be used as an input for calculations of reprocessing of UV photons to redder wavelengths.

Certainly, more thorough investigation of the UV emission from SNe Ia has to be done. It is still necessary to calculate UV light curves of wider range of SNe Ia models and to predict their UV spectra. This work is worth doing because, as it is seen from this Letter, near-UV and far-UV observations with modern UV space telescopes, when combined with standard *UBVRI* study, could be used as an efficient means to distinguish modes of explosion of thermonuclear supernovae leading us to better understanding of these phenomena.

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