Effects of the envelope structure of cool supergiant progenitors on the early-time light curves of Type IIb supernovae

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Abstract

Progenitors of some Type IIb supernovae (SNe IIb) like SN 1993J and SN 2013df have been identified as cool supergiants in the pre-SN images. Their light curves and spectra bear evidence that their progenitors have a relatively low-mass hydrogen-rich envelope. This implies that the progenitors undergo strong mass-loss via stellar winds and/or binary interactions during their pre-supernova evolution. There exist many theoretical studies on the SNe IIb light curves and spectra, but the effect of the hydrogen-rich envelope structure on SNe IIb has not been fully explored yet. We systematically investigate how the early-time light curves of SNe IIb are affected by the density profiles of the hydrogen-rich envelope of cool supergiant progenitors, using the radiation-hydrodynamics code STELLA. We find that with a steeper density profile of the hydrogen-rich envelope, the post-breakout emission in the optical reaches its peak earlier, and thereafter its luminosity declines more rapidly. However, with a flat density profile, which is predicted by recent SN IIb progenitor models where the effect of envelope inflation due to the iron opacity bump is taken into account, the post-breakout emission declines too slowly after its peak, compared to observations. This indicates that the early-time light curves of SNe IIb of SN1993J and SN 2013df are not compatible with the most recent predictions of stellar evolution models.

Introduction

- Type IIb Supernovae are characterized by the disappearance of hydrogen lines in late-time, indicating a significant stripping of the hydrogen envelope from the progenitors. Stellar wind and binary interactions can create such mass loss.
- In pre-SN images, the progenitors of SN1993J and SN2013df have been identified as cool supergiants(RSG, YSG) of which the radii exceed $200R_{\odot}$. (Aldering et al. 1994; Van Dyk et al. 2014)
- The effect of the density profile of the hydrogen-rich envelope of cool supergiant progenitors on the early-time light curves has not been studied in detail. We numerically simulate various models with different density structures of the hydrogen-rich envelope and compare their early-time light curves with SN1993J, a typical SN IIb.

Progenitor Model & SN Simulation

1) Progenitor Model

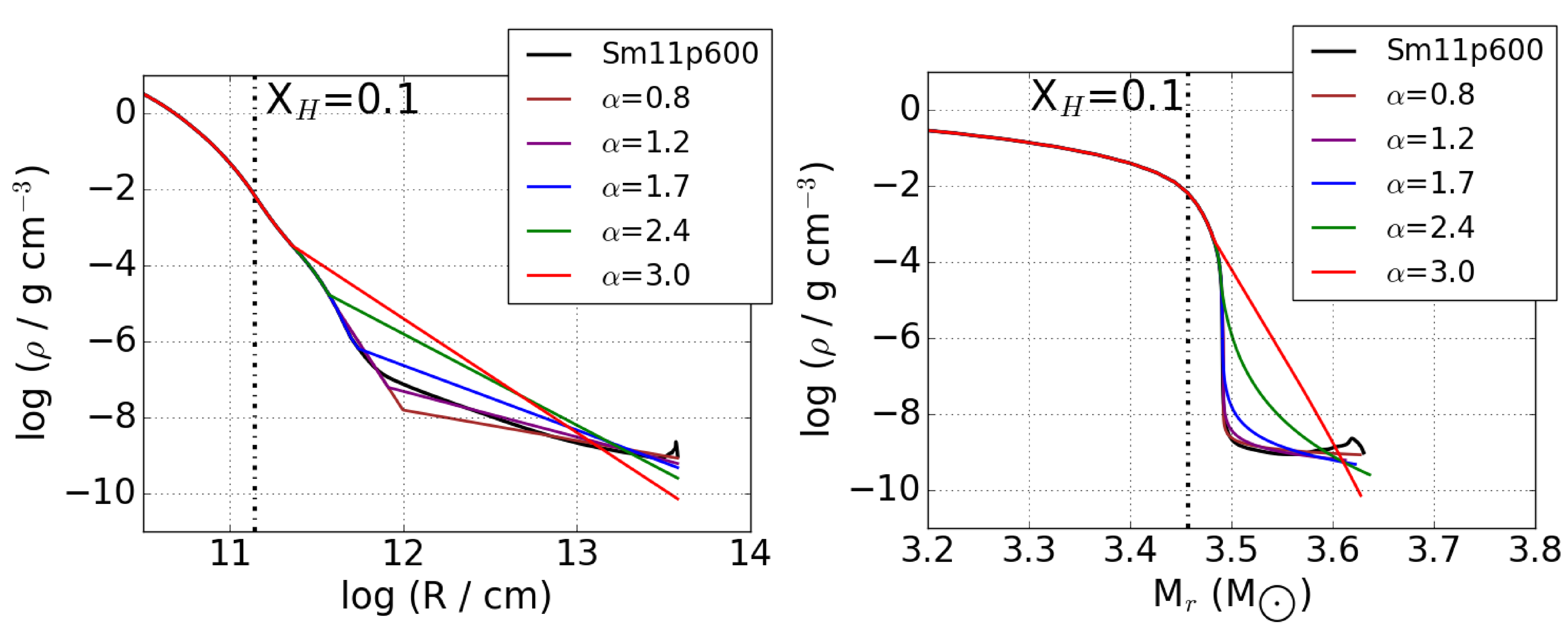
- Sm11p600 : A RSG progenitor from binary system, calculated with the stellar evolution code MESA. (Yoon et al. 2017)
- Binary System Properties
  - Initial binary period : 600 days
  - Binary mass ratio: 0.9
  - Initial primary star mass: $11M_{\odot}$
  - Metallicity: Solar metallicity
- ^{56}Ni mass & distribution
  - Mass: $0.073M_{\odot}$ (adopted by Blinnikov et al. (1998))
  - Distribution: $X_{\mathrm{Ni}}(M_r) = A\exp\left(-\left[\frac{M_r - M_{Fe}}{f_m(M_{tot}-M_{Fe})}\right]^2\right)$, f_m = 0.3

2) Density Profile Modification

- Modified the envelope density structure while not altering the original progenitor model's total mass, radius, and chemical composition.
- In modified models, the density profile of the outmost H envelope follows a power-law. ($\rho \propto R^{-\alpha}$, envelope index $\alpha = 0.8, 1.2, 1.7, 2.4, 3.0$)

3) Numerical Simulation

- We used the radiation-hydrodynamics code STELLA for this work. (Blinnikov&Bartunov 2011)
- All models were exploded with an explosion energy $E = 1.0 \times 10^{51}$ erg.



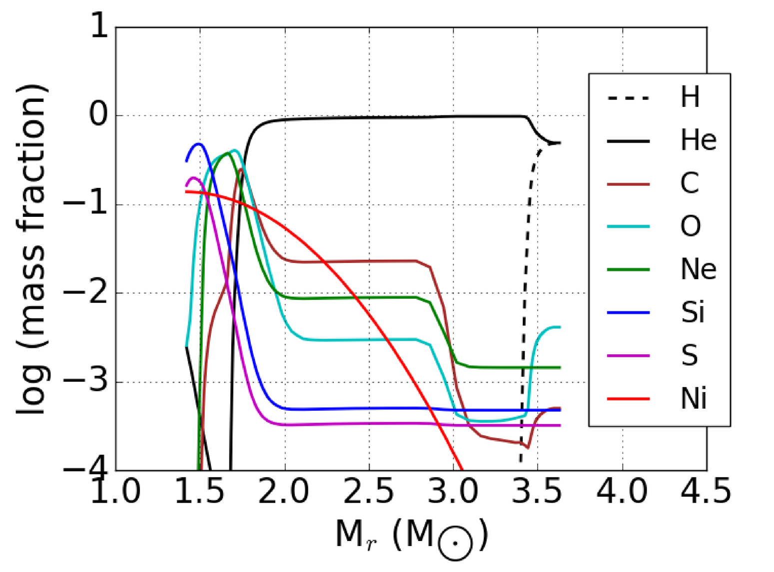


Fig 1. Density profile of the input models as a function of radius (upper left) and mass-coordinate (upper right), and the corresponding chemical composition (lower left)

Results

- The results show that the progenitor models with a steeper density profile in their hydrogen-rich envelopes result in a more rapid decline of the post-breakout emission, while the first peak happens earlier and becomes less luminous.

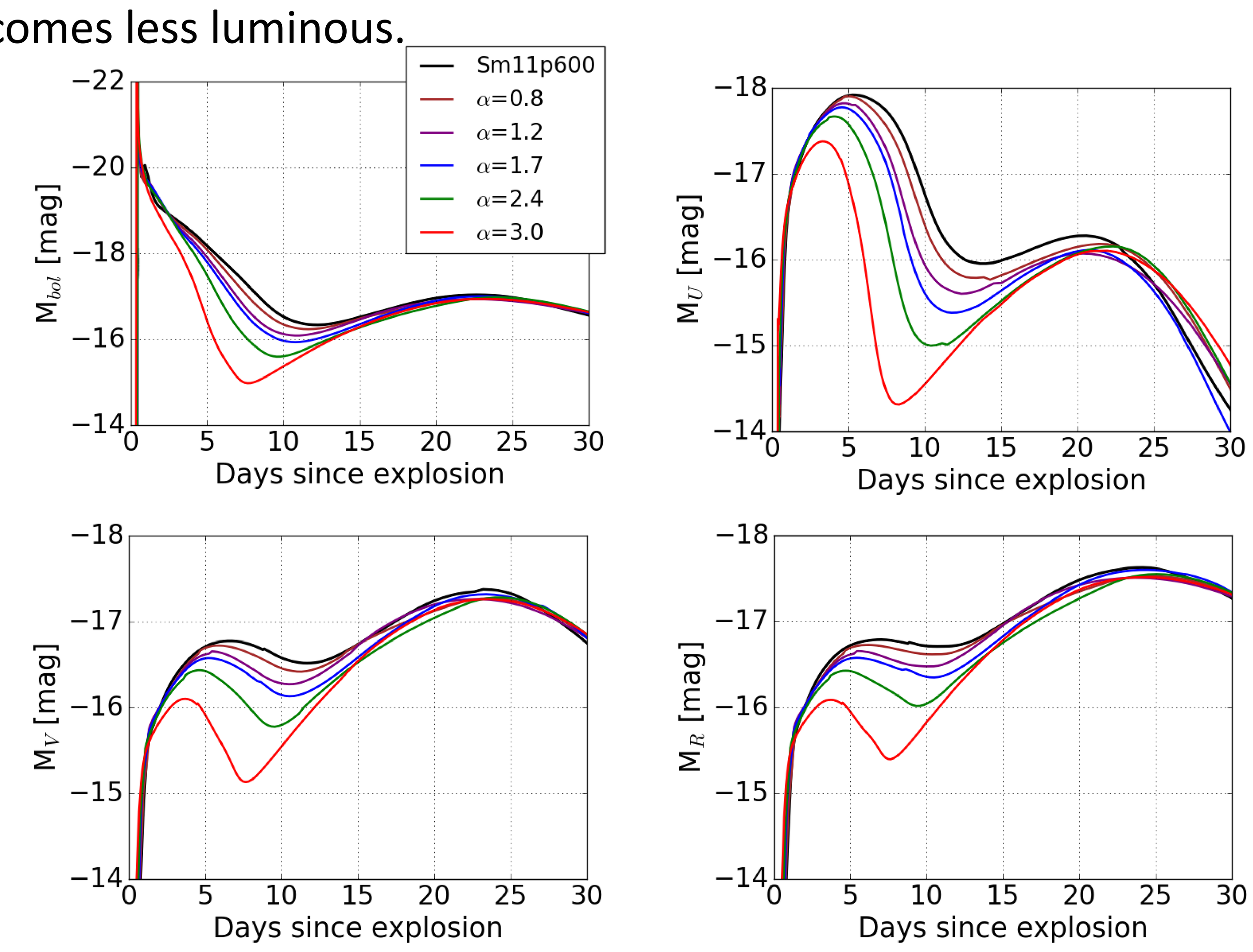


Fig 2. Light curves from SN simulations in absolute magnitude scale
(Upper left) Bolometric (Upper right) U-band (Lower left) V-band (Lower right) R-band

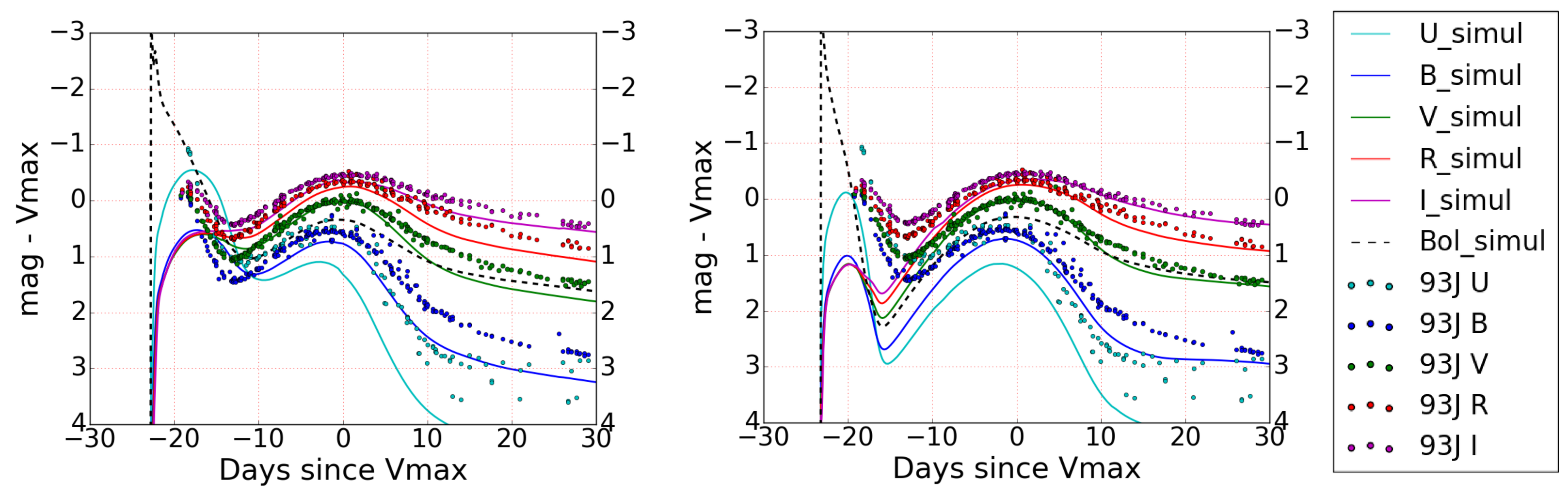


Fig 3. Simulated light curves from selected models compared with SN1993J observation data. Magnitude scaled to the V maximum and time scaled to the V maximum date. (Data retrieved from Open Supernova Catalog; Guillochon et al. 2017)
Left panel: Result from the original Sm11p600 progenitor model
Right panel: Result with the envelope index α=3.0

Conclusion

- Our results show that a flatter density profile of the hydrogen-rich envelope in a SN IIb progenitor results in a too slow decline of the post-breakout emission in the optical compared to the observation.
- SN light curves from the most recent cool supergiant SNe IIb progenitor models show disagreement with the early-time observation, implying SN IIb progenitors could undergo a more complicated evolutionary process than the prediction of the recent stellar evolution theory. (e.g., a stronger mass loss during the pre-SN stages)

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