The effect of dense circumstellar medium in type IIb supernova and implications for the progenitor of SN 1993J

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Abstract:

Progenitors of type IIb supernovae, which behave like type II supernovae in their early phase and evolve to type Ib-like phase, are believed to be supergiant stars retaining a small amount of the hydrogen envelope (Menv ~0.01–0.5 $M_\odot$). In previous observational and theoretical studies, the progenitor of SN1993J had been suggested as a red supergiant. However, we find that supernova light curve simulations using the most recent red supergiant progenitor models and the multi-group radiation hydrodynamics code STELLA fail to predict early time features of SN 1993J. Instead, supernova models using a compact progenitor, whose stellar radius is less than 20$R_\odot$, with a dense wind-driven ircumstellar matter about 0.1$M_\odot$, can reproduce early time light curve properties like strong U-band magnitude and stiff luminosity drop after post-shock peak. Our result gives new insights into type IIb progenitors and their mass loss history.

Input models:

- Progenitor models were obtained from the public stellar evolution code MESA.[1][2]
- Additional circumstellar matter(CSM) by stellar wind was attached to the progenitor, employing

$$\rho_{csm}(r) = \frac{\dot{M}}{4\pi v_{wind}(r)} r^{-2} \quad , \quad v_{wind}(r) = v_0 + \alpha(v_\infty - v_0)\left(1-\frac{R_0}{r}\right)^{\beta}.$$

Composition of the wind-driven CSM is same as the outermost layer of the progenitor supergiant.[3]

Name	M_f	L_f	R_f	$T_{eff,f}$	He	CO	H_{env}	m_H	m_{He}	$Y_{s,f}$
Sm11p600	3.66	4.70	565.4	3.56	3.459	1.743	0.198	0.082	1.719	0.46
Tm13p50	4.27	4.87	8.6	4.51	4.230	2.192	0.043	0.002	1.888	0.87

Table 1: Properties of the progenitor models. [2]

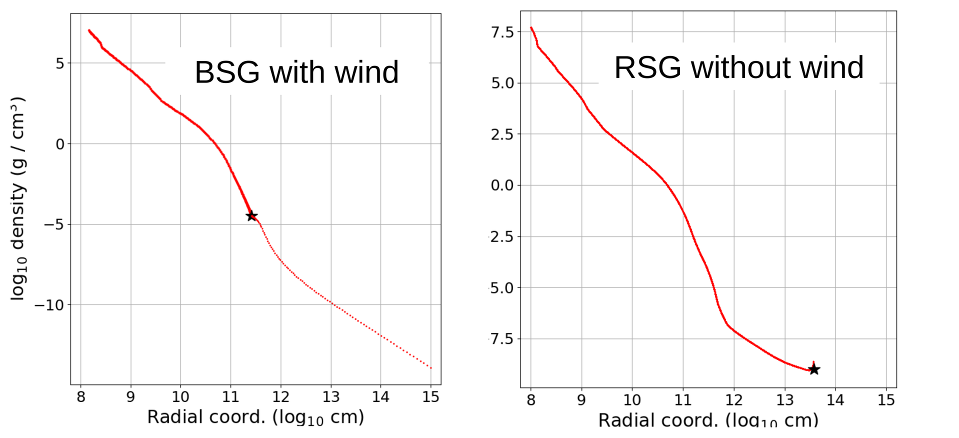

Figure 1: Density profile of each pre-supernova progenitor. The innermost core region (~1.4$M_\odot$) was excluded. The black marker shows stellar surface of the progenitor.

Light curve modeling:

- The multi-group radiation hydrodynamics code STELLA was employed to compute explosion.[4]
- Parameter space for BSG model
  - Explosion energy (E_{exp}): 1.0 B.
  - Maximum CSM extent (R_{max}): 10^{15} cm (14395$R_\odot$)
  - Nickel mass (M_{Ni}): 0.075$M_\odot$
  - CSM mass: 0.08 (BSG progenitor)
  - Mass loss rate($\dot{M}$): 1.55 × $10^{-2}$$M_\odot$/year.
  - Wind profile β: 5

Experimental Results:

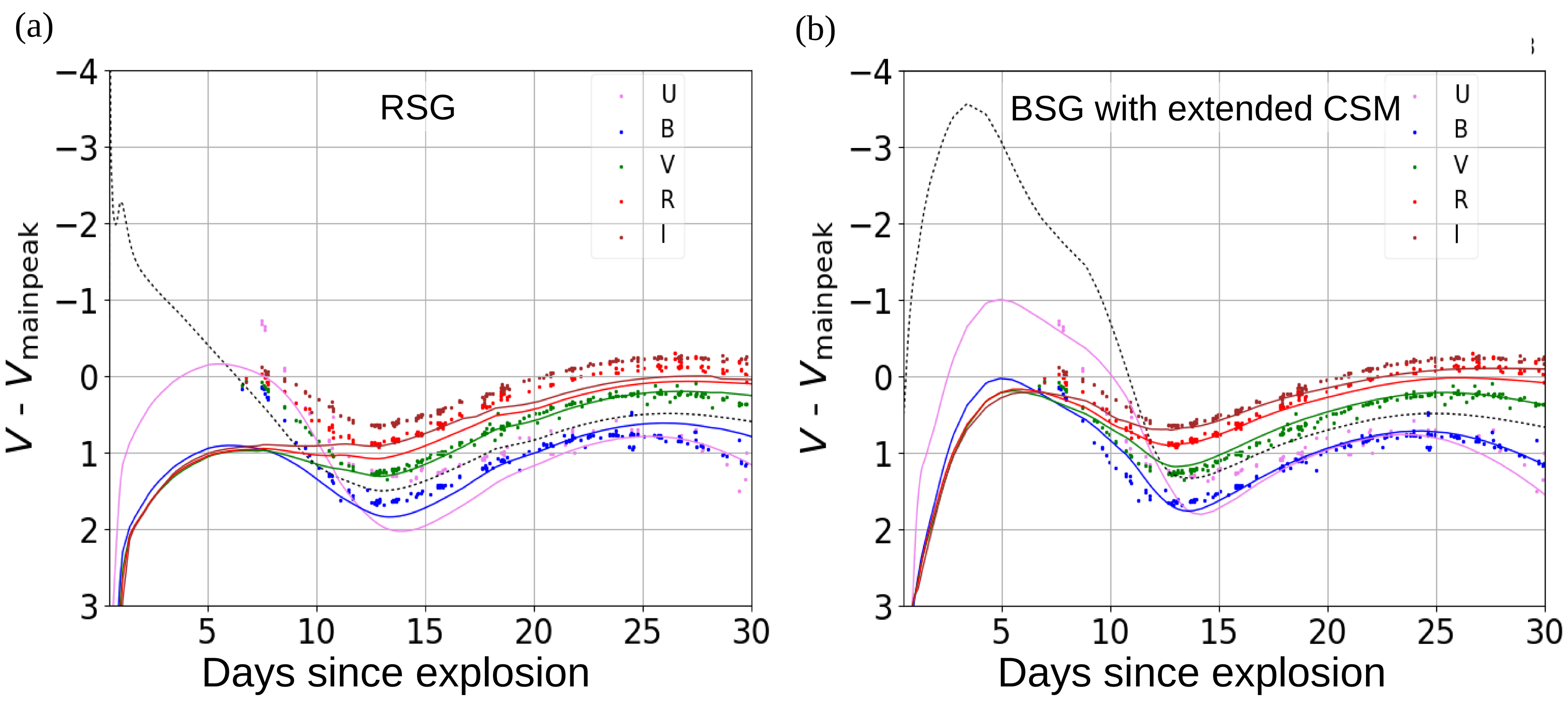

Figure 2: Early time light curves of two supernovae from RSG and BSG progenitors. Both models are shown in comparison with the observed data of SN 1993J (filled circles), synchronized by V-band main peak from the decay of nickel-56. Both have the same explosion energy of 1.0B. (a) Light curves of the BSG model(Tm13p50) with 0.08$M_\odot$ of CSM, R_{max}= 10^{15}cm. (b) Light curve of an RSG model(Sm11p600) [2]. Total hydrogen mass of extended envelope is 0.198$M_\odot$.

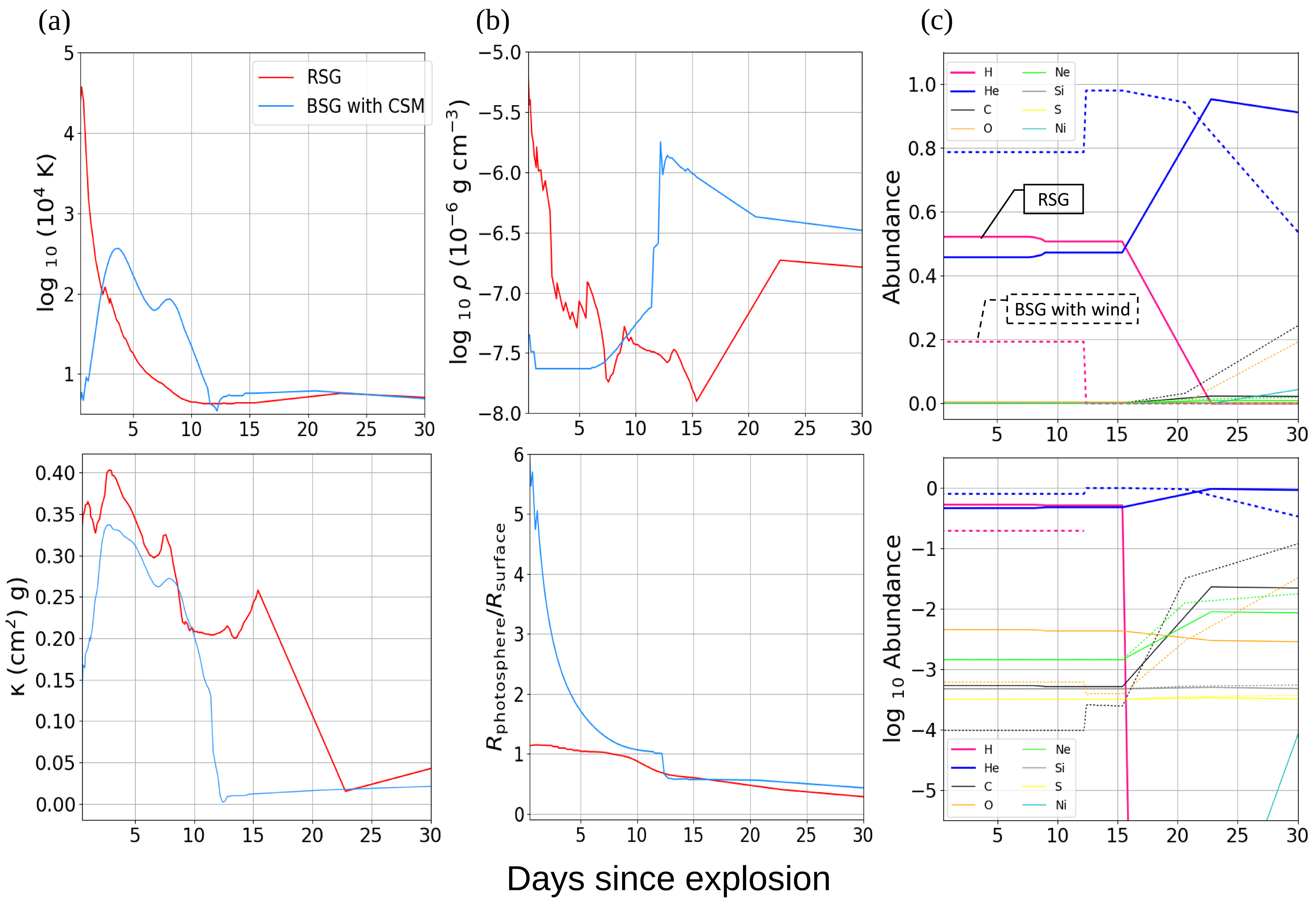

Figure 3: Photospheric parameters with respect to the days since explosion. (a) Temperature profile (upper panel) and corresponding Rosseland mean opacity(lower panel). (b) Density profile(upper panel) and relative position of photosphere in terms of stellar surface(lower panel). (c) Chemical composition of photosphere in linear(upper) and logarithmic(lower) scales The solid lines show photospheric chemical composition of the RSG progenitor based model, whereas the dashed lines show the model with BSG progenitor.

Discussions:

- Burst energy injected has an intense effect on the height, FWHM and duration of the post-shock breakout peak. Nickel decay emerges earlier with rapidly receding photosphere.
- Early features of SN 1993J, especially the properties like U-band magnitude and stiff luminosity drop after the post-shock breakout peak, cannot be well-explained by the RSG model with M_{Henv} ~ 0.2⊙.
- Early time photospheric properties evolve in very dissimilar ways in different models. Key features which make this difference(e.g. He recombination) is to be analysed.
- Since the observer progenitor of SN 1993J was a red - yellow supergiant, this 'BSG' model should possess its photosphere in the midst of its CSM. This scenario should be tested [5].

References:

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