Early Light Curves of Hydrogen Rich Supernovae

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During the last years, an increasingly number of early observations of hydrogen-rich supernovae (SNe II) become available. These data show that their light curves (LCs) have a substantially slower decline to the plateau phase than had been predicted by models. One possible solution to this discrepancy is considering the existence of some circumstellar material (CSM), probably ejected by the progenitor star several years before the explosion (Moriya+11, Morozova+16, Yaron+17, etc.). In this work we analyzed its effect on the early LCs using a 1D hydro code (Bersten et al. 2011) that simulates stellar explosions and calculates LCs under different physical conditions. We also considered a sample of SNe II possibly affected by CSM and analyzed relations between some observables parameters of their bolometric LCs and properties of their progenitors.

CSM parametrization

Outermost part of the pre-SN density profile was modified to consider the presence of a CSM:

$$\rho_{CSM}(r)=\frac{\dot{M}}{4\pi r^2}\frac{1}{v_{wind}(r)}$$

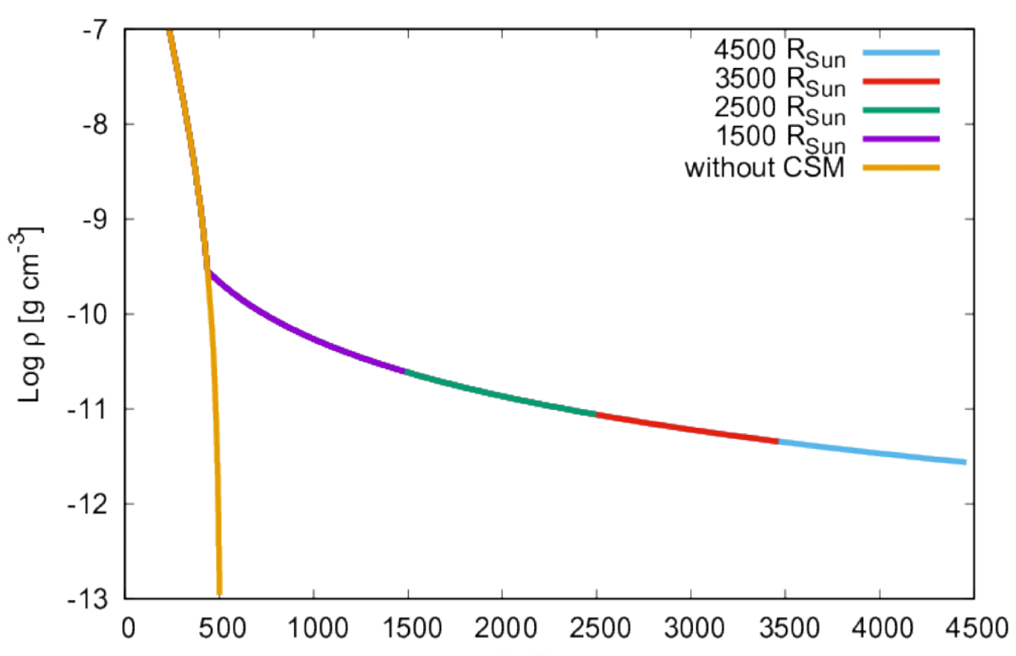
β–law velocity profile for an accelerated wind was assumed, following Moriya et al. 2017:

$$v_{wind}(r)=v_0+(v_\infty-v_0)\left(1-\frac{R}{r}\right)^\beta$$

where v_0, fixed to be 10 m s^{-1}, is the wind velocity at the stellar surface (R), and v_∞, fixed to be 10 km s^{-1}, is the final wind velocity. We assumed RSG stars as the progenitors.

The CSM was characterized by:

- Radial extent
- Mass loss rate
- Density slope (β)



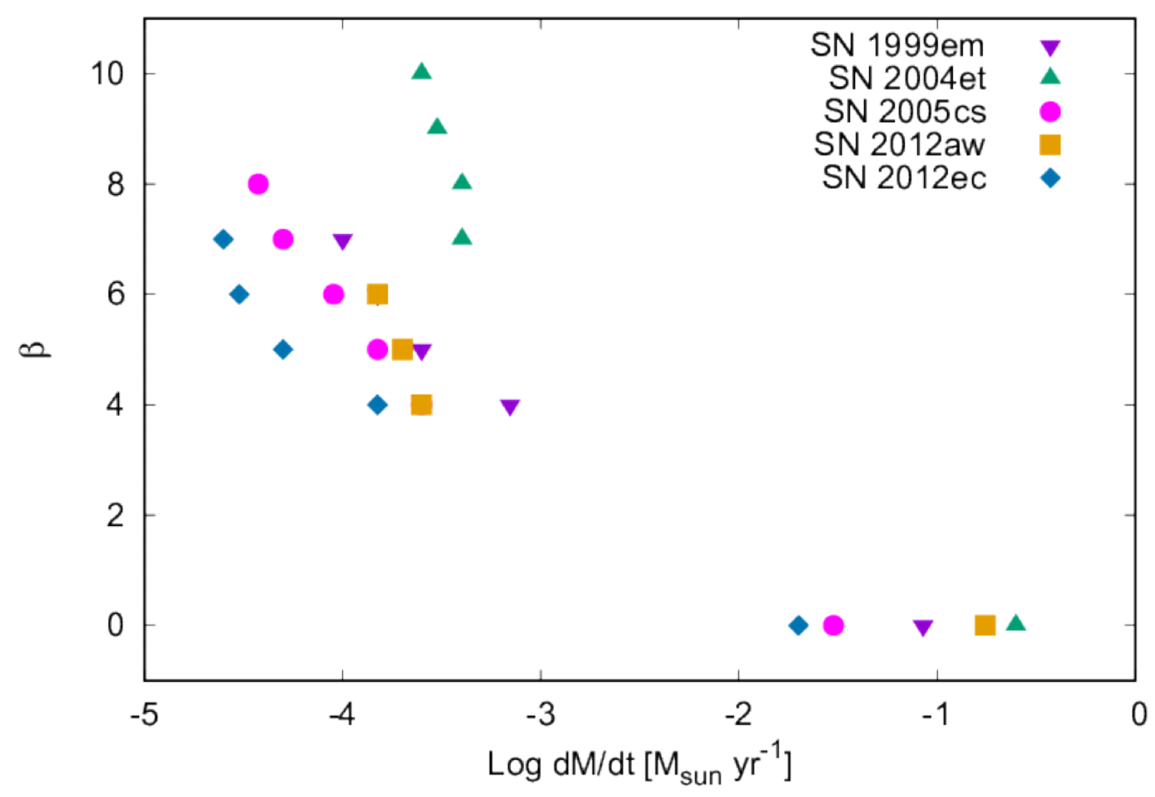
External density profile as a function of the radial coordinate with different CSM extensions. A model without CSM (orange) is also included.

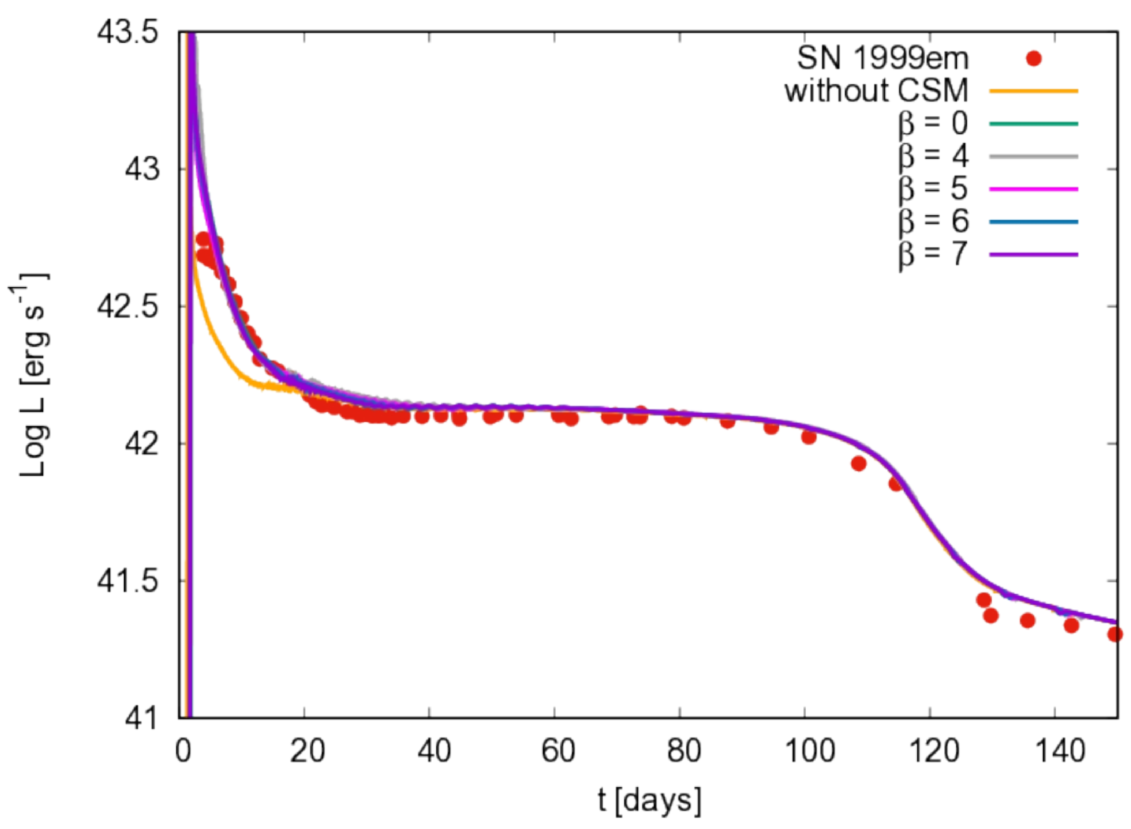
Light curve models

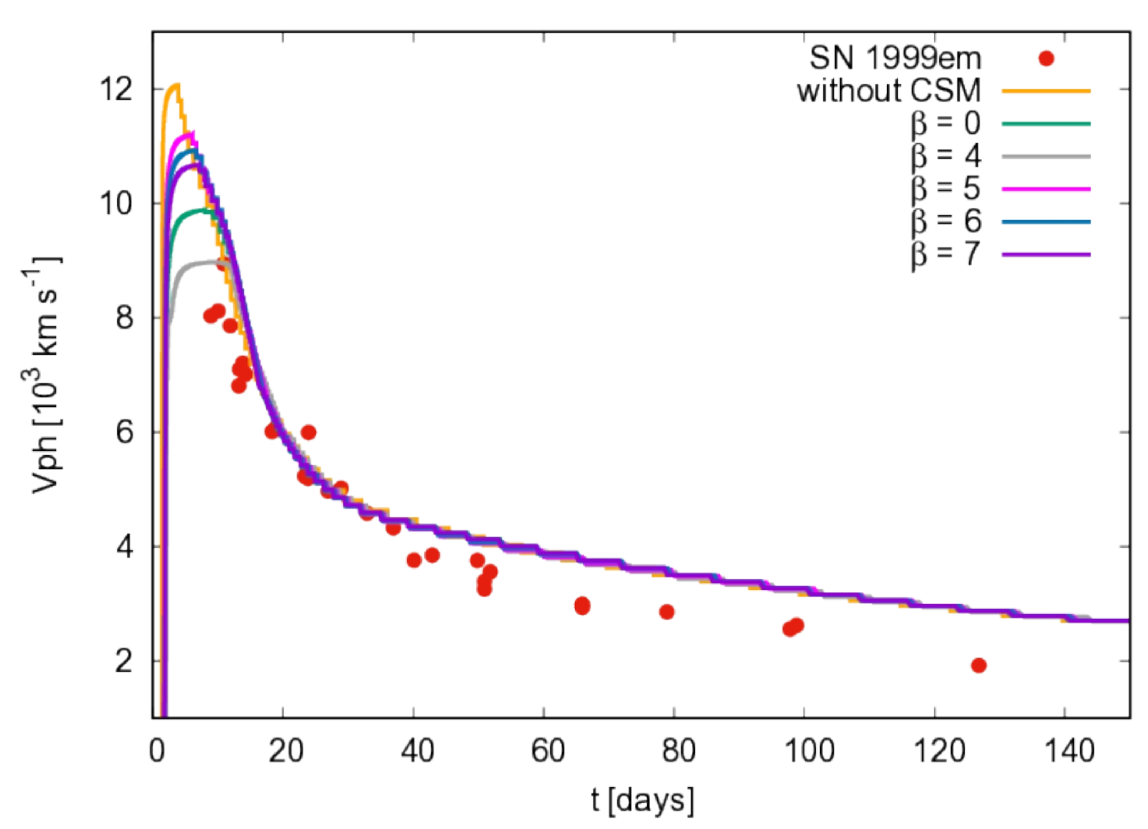
A sample of SNe (1999em, 2004et, 2005cs, 2012aw and 2012ec) possibly affected by CSM was modeled. First, the stationary wind case ($\beta=0$) was considered, but high mass loss rates (~ 10^{-1} M⊙ yr^{-1}) were derived for all the cases (bottom right on the figure).

Lower mass loss rates (~ 10^{-3} – 10^{-5} M⊙ yr^{-1}) with $\beta \geqslant 4$ were obtained by analyzing the accelerated wind case (top left on the figure).

For each SN more than one solution was obtained, as can be seen below (figures and table) for the case of SN 1999em. This imply that the properties of the CSM are not univocally determined.



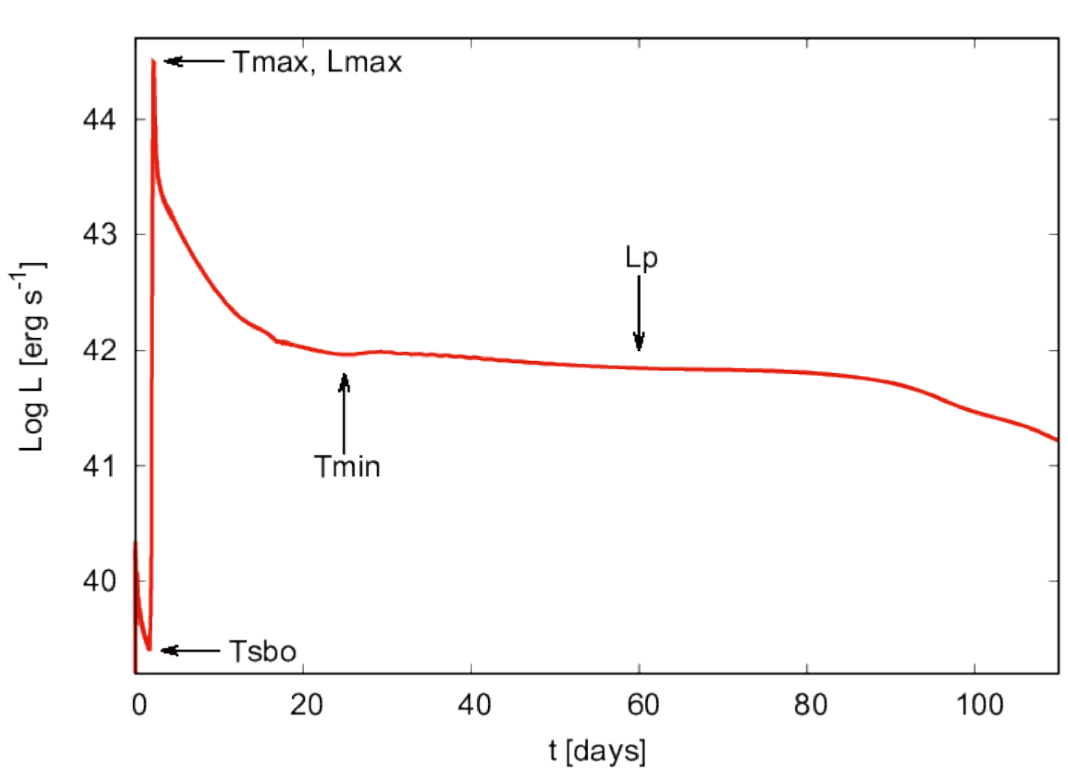


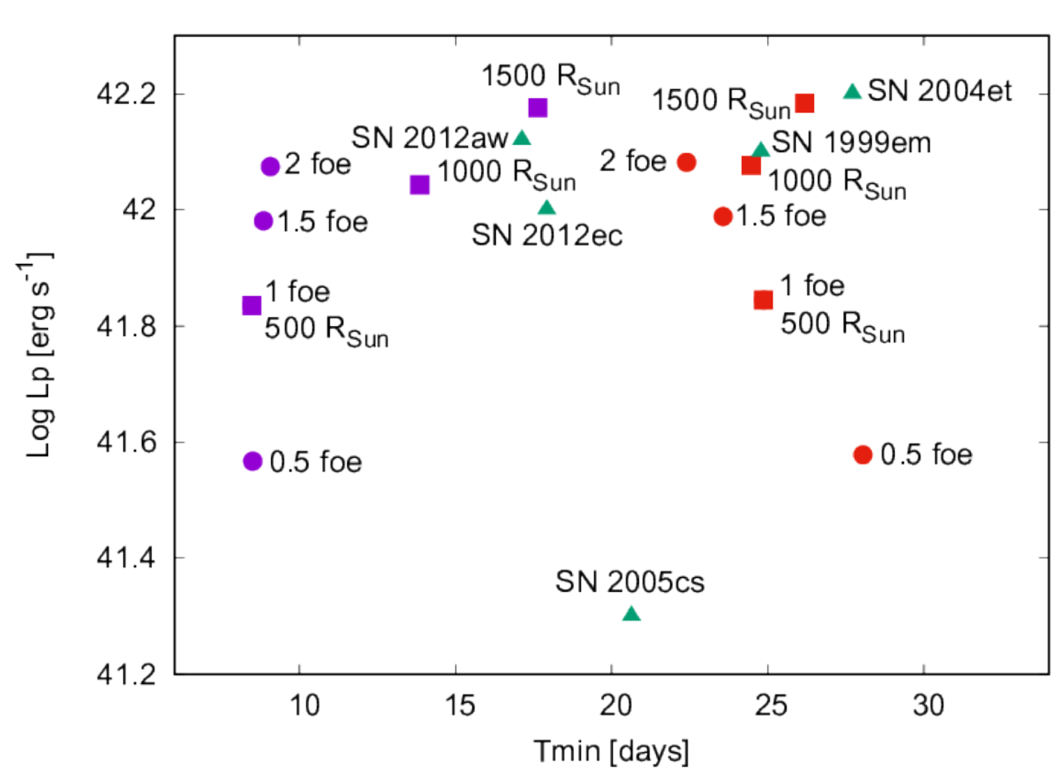


SN 1999em: 19 M⊙, 800 R⊙, 1.25 foe			
R_{CSM} [R⊙]	dM/dt [M⊙ yr^{-1}]	β	M_{CSM} [M⊙]
1100	8.5x10^{-2}	0	0.081
2000	7x10^{-4}	4	0.227
1100	2.5x10^{-4}	5	0.125
1100	1.5x10^{-4}	6	0.101
1100	1x10^{-4}	7	0.081

- Type II SN 1999em (red points), shows discrepancies between early observations and the LC model without CSM (orange).
- Models with CSM (β = 0, 4, 5, 6 and 7) substantially improves the match.
- Early spectra can help to distinguish between CSM models (see velocity evolution).

Observable and progenitor parameters





Left: Bolometric LC of a typical SN II Plateau affected by CSM. Some LC observables are defined.

Right: Plateau luminosity at 60 days (*Lp*) as a function of the beginning of the plateau phase (*Tmin*) for models with (red) and without (violet) CSM. Different progenitor radii (squares) and explosion energies (circles) were considered. Our SNe sample is also included.

- Increasing the energy of the explosion increases *Lp* (independently of the CSM), while *Tmin* is almost not affected for models without CSM but decreases for models with it.
- Increasing the progenitor radius increases *Tmin* and *Lp* but not enough to reproduce the observed mean of *Tmin* (Anderson et al. in prep.).
- *Tmin* of the SNe can be better explain by models with CSM.

Conclusions

- Models with CSM are needed to match the LCs with early observations.
- Considering an accelerated wind, mass loss rate of ~ 10^{-3} – 10^{-5} M⊙ yr^{-1} are derived.
- A family of possible CSM solutions for each SN was obtained, implying that the properties of the CSM are not univocally determined.