Non-Hydrogen Supernovae within Extended Envelopes: Light Curve Modeling and Parameter Dependencies

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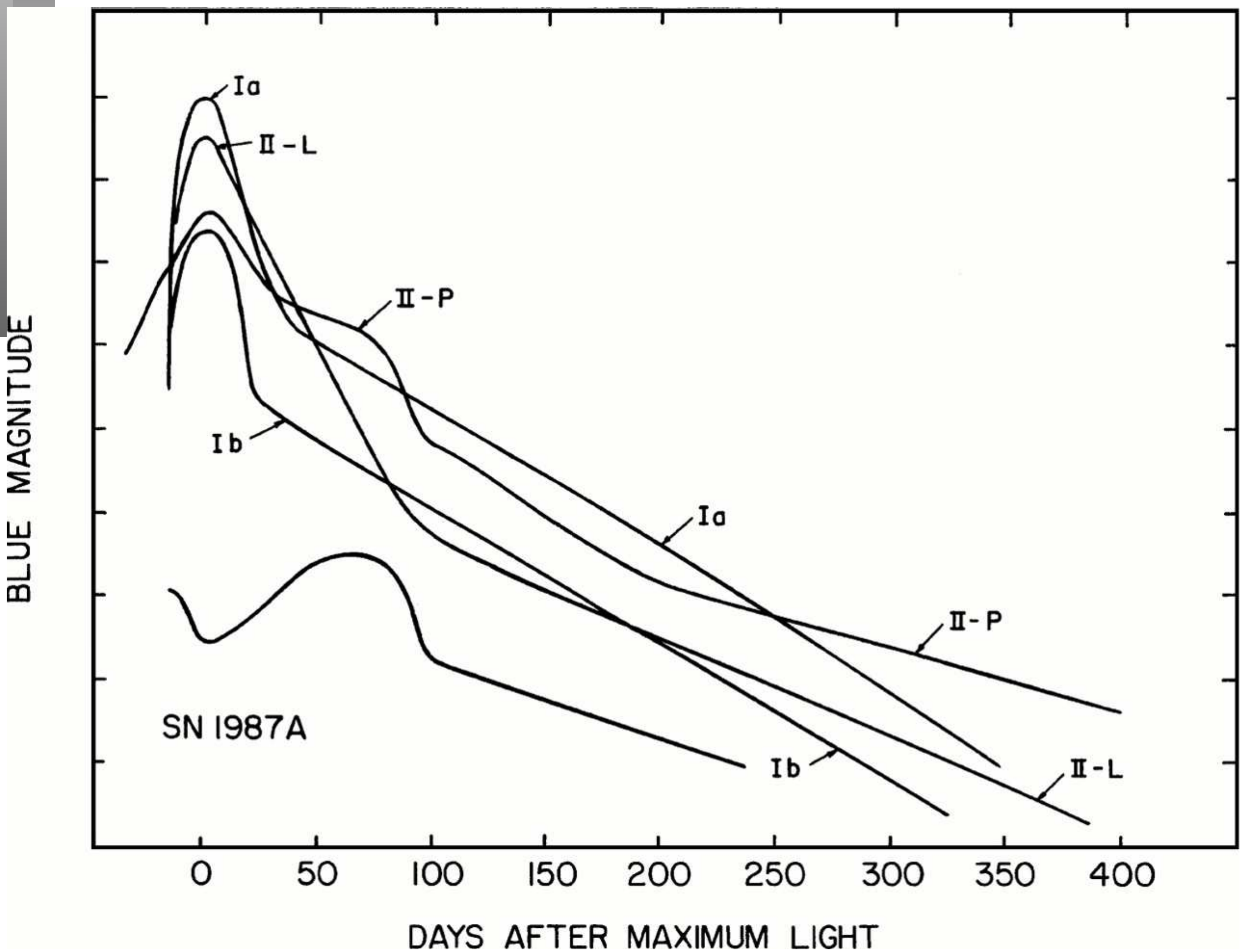
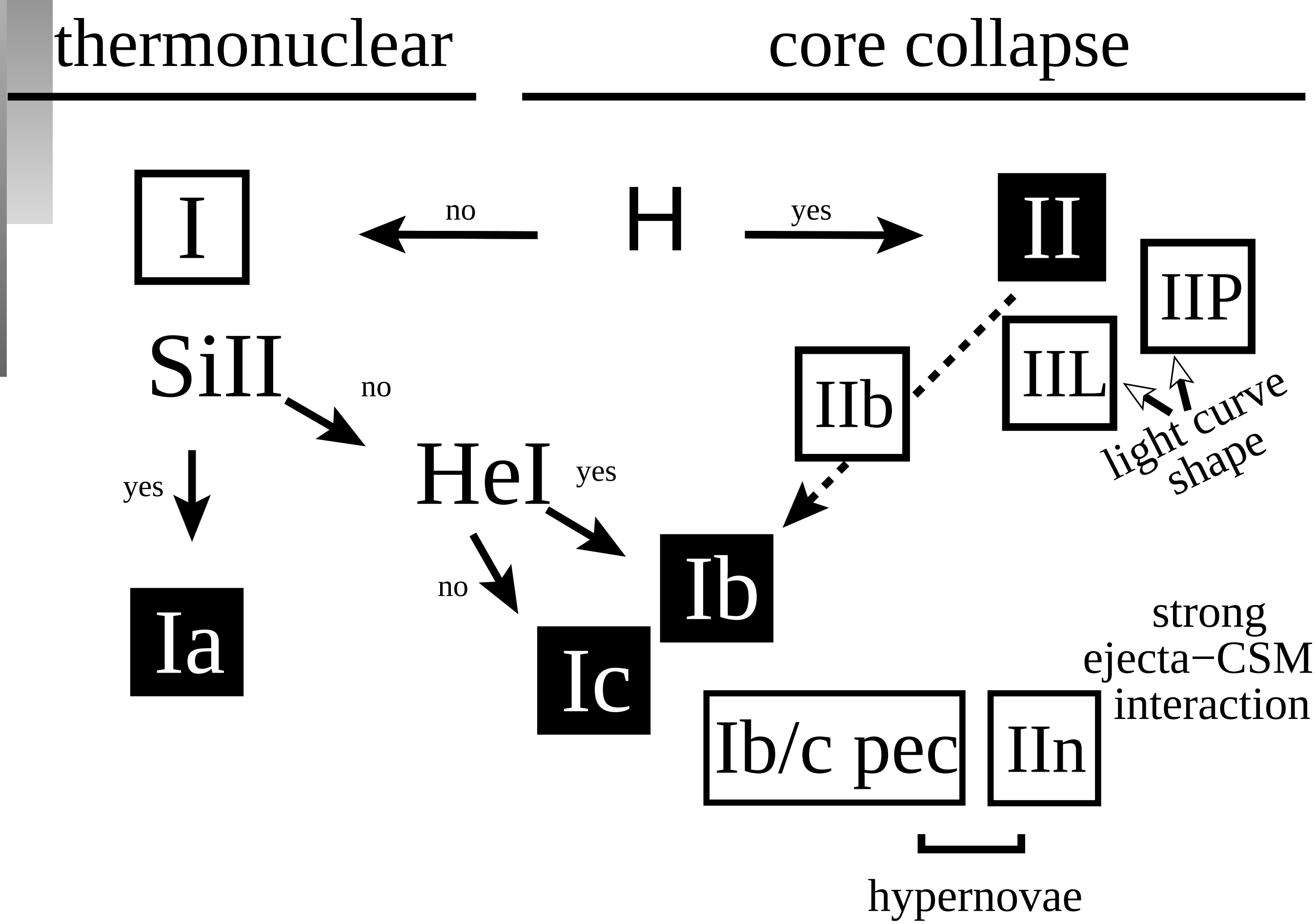
SN Light Curves

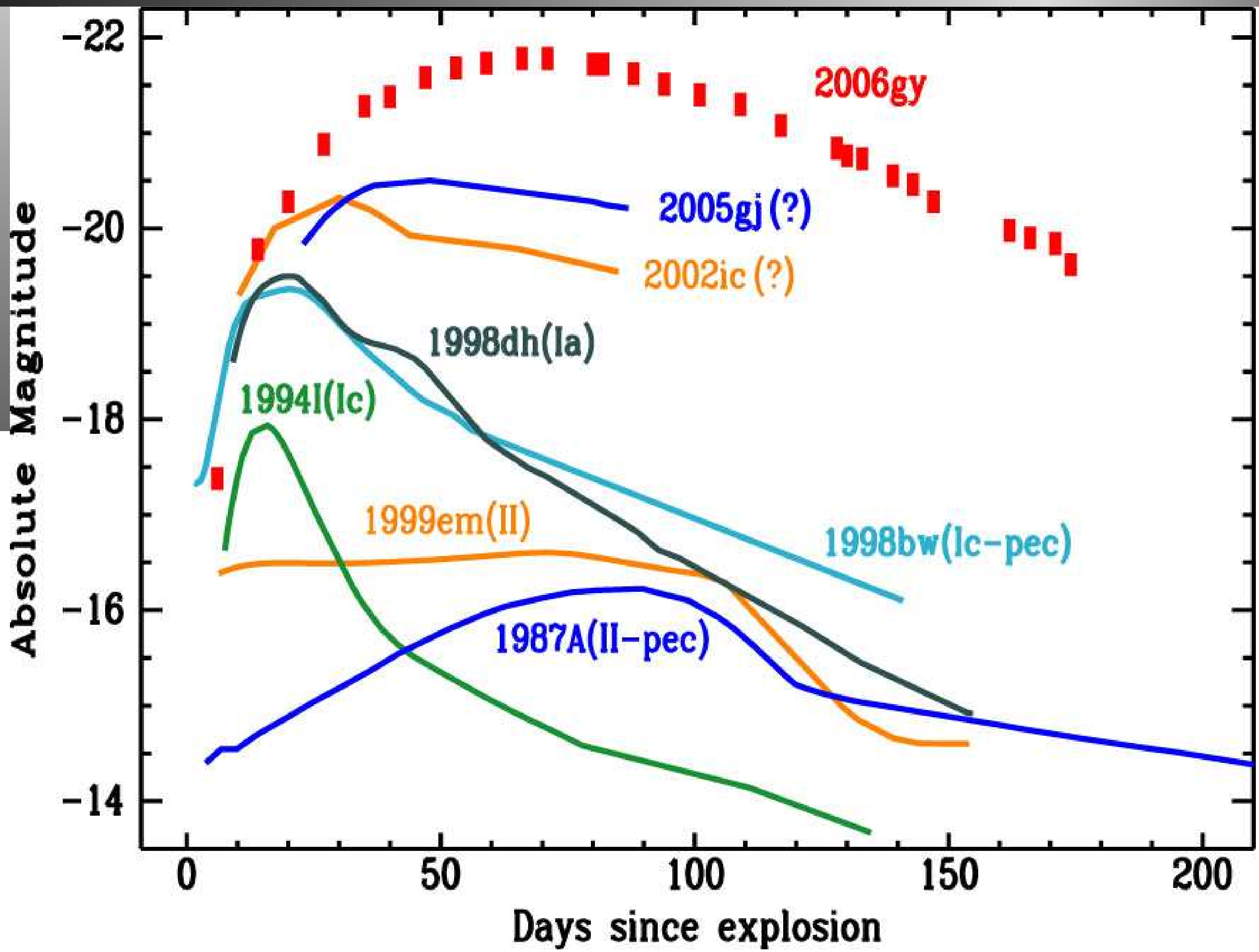


SN classification



Turrato 2003

Extremely bright Type IIn SNe



V-band (Drake et al. 2010)

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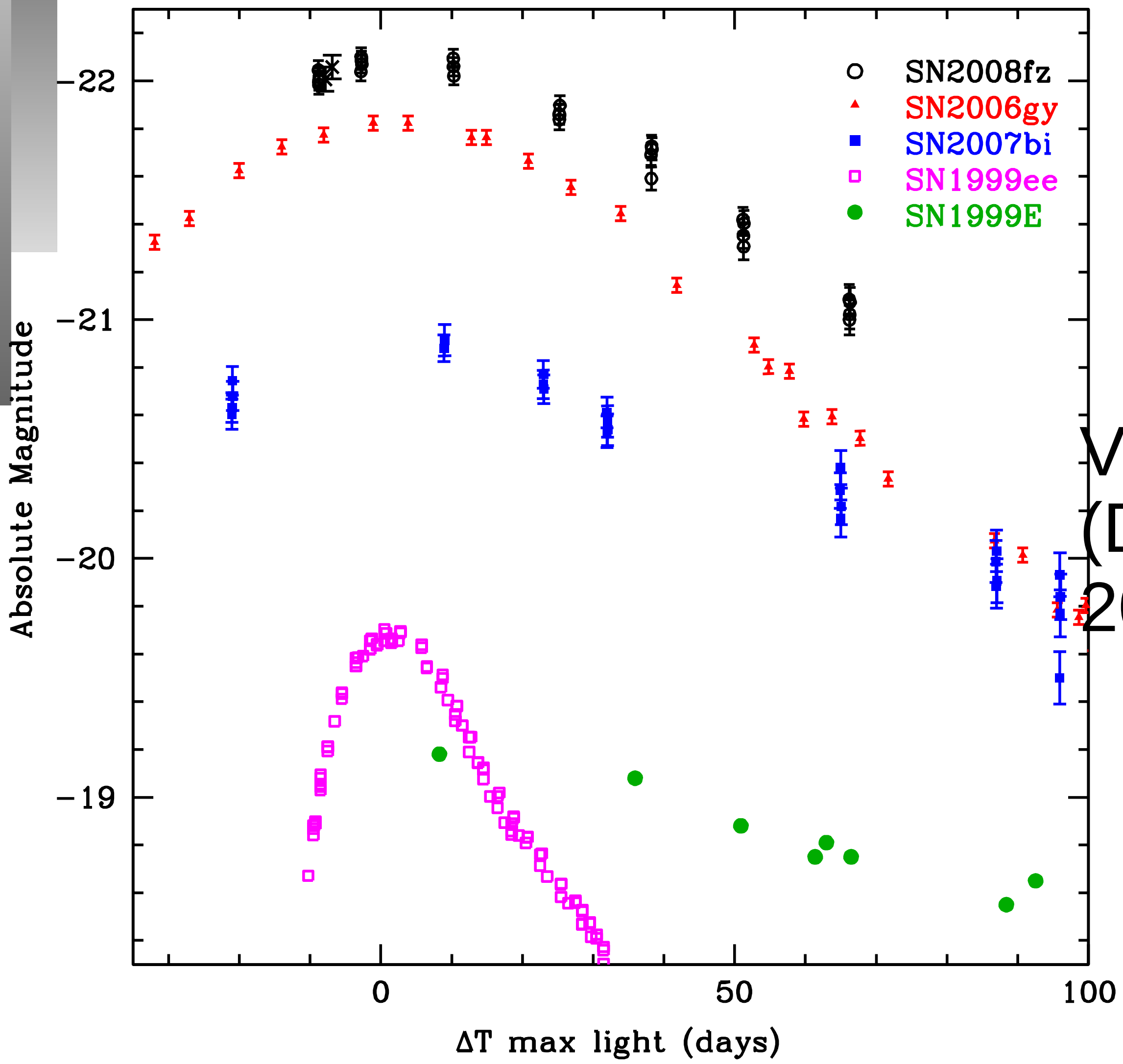
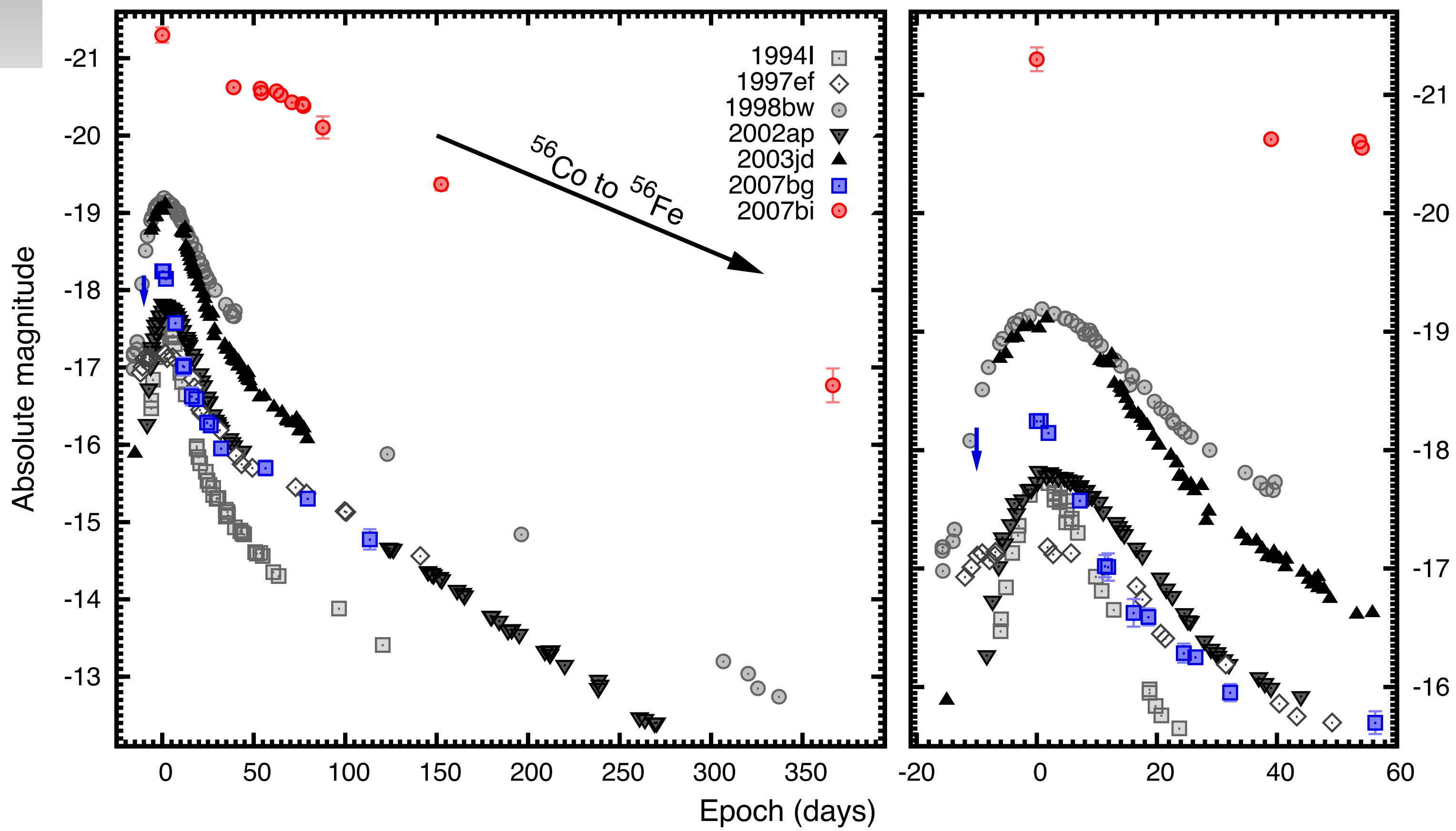


V-band (Drake et al. 2010)

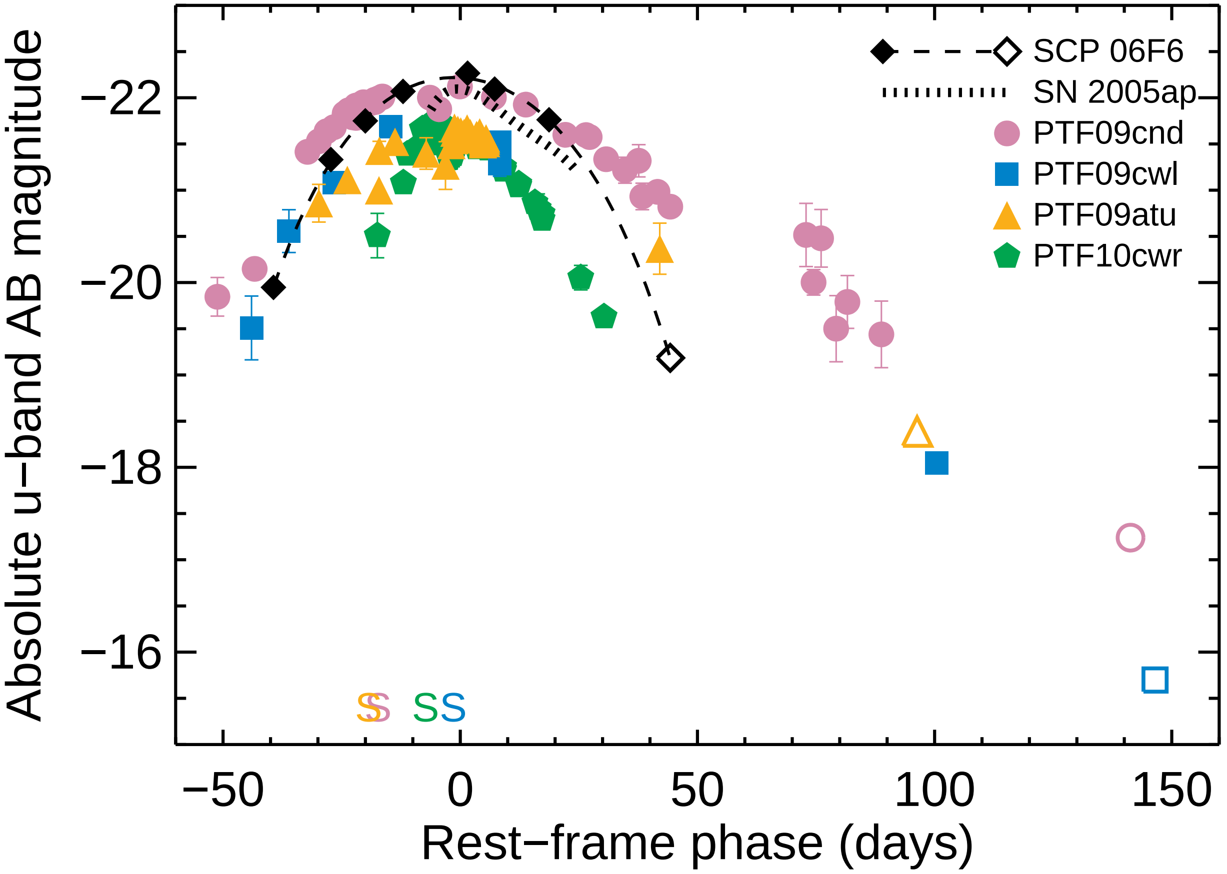
Extremely bright Type Ic SNe

R-band light curves (Young et al. 2010)

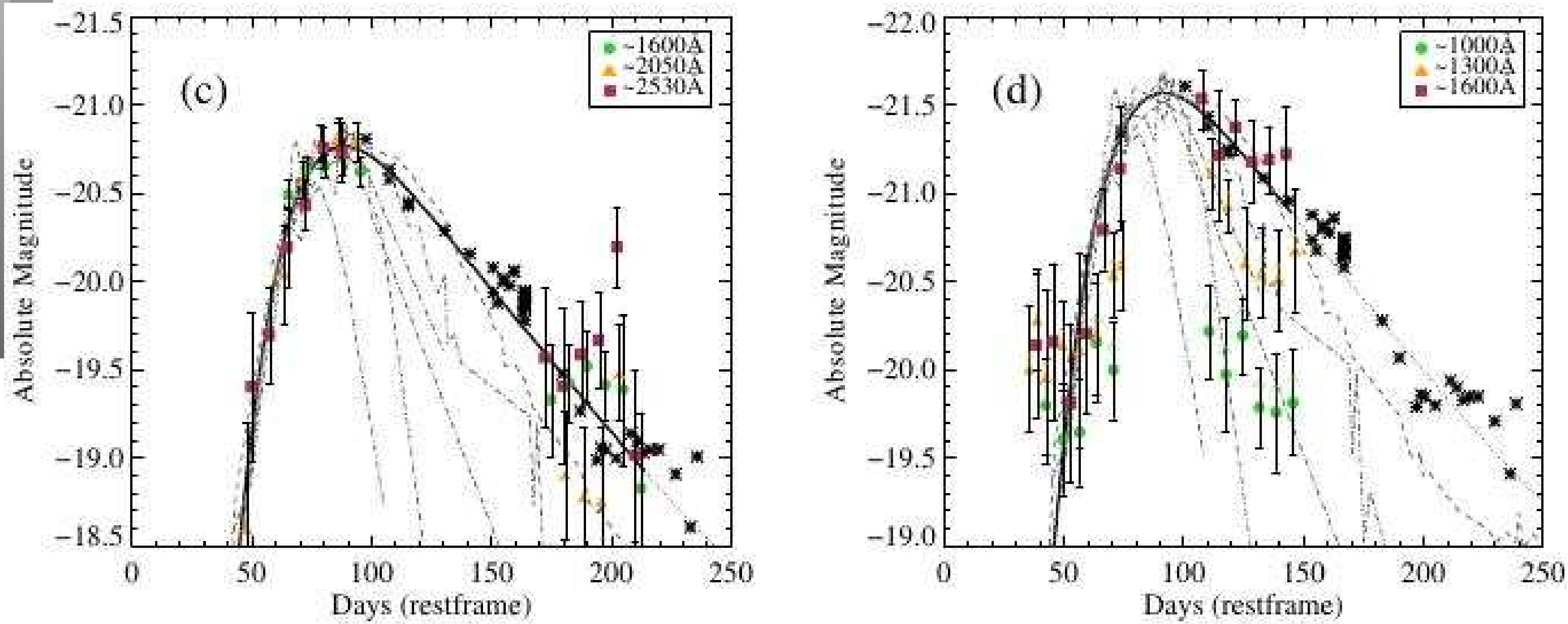


Observations of the superluminous SNe

Quimby et al. 2011



More exotic case – High-z SNe



$z = 2.05$ $z = 3.9$

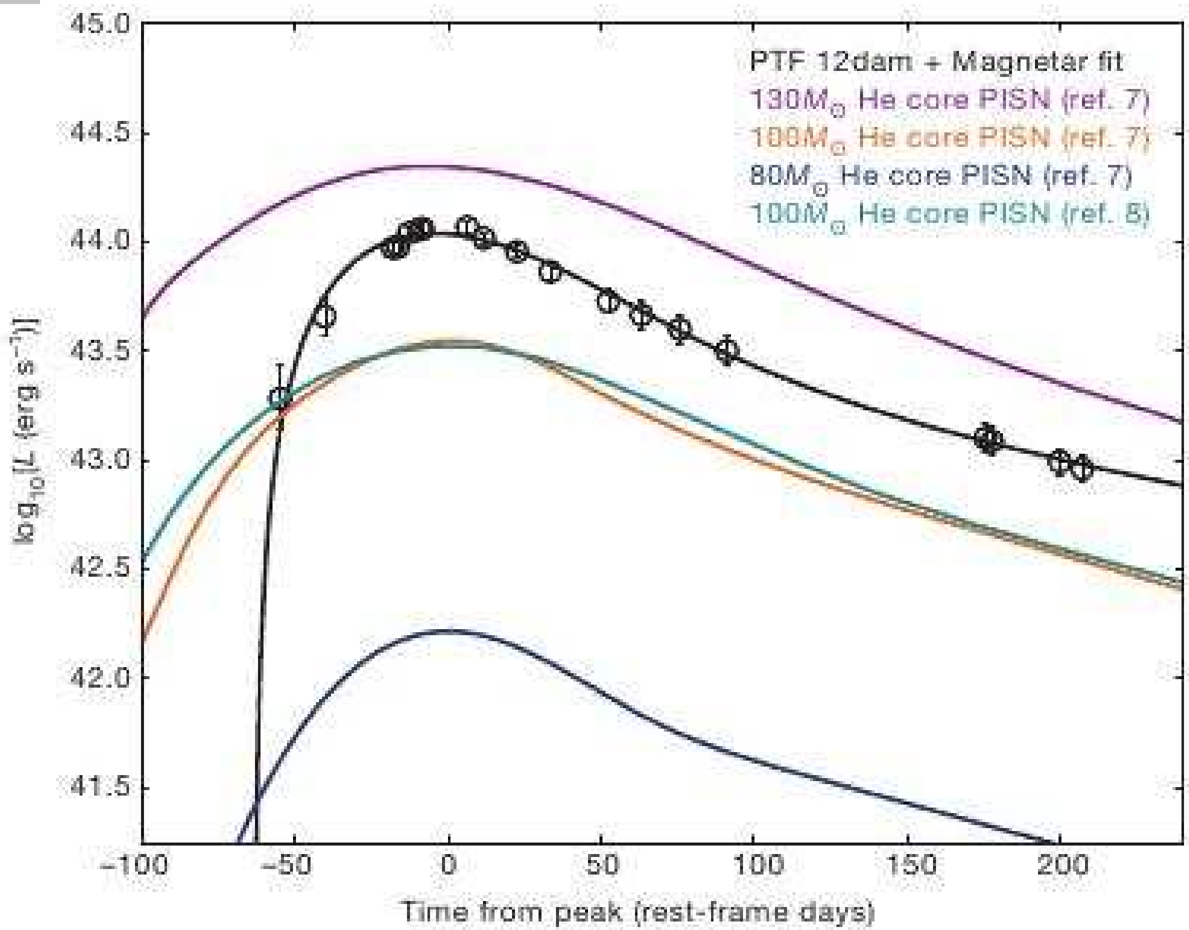
Cooke+ 2012

Possible models for SLSNe

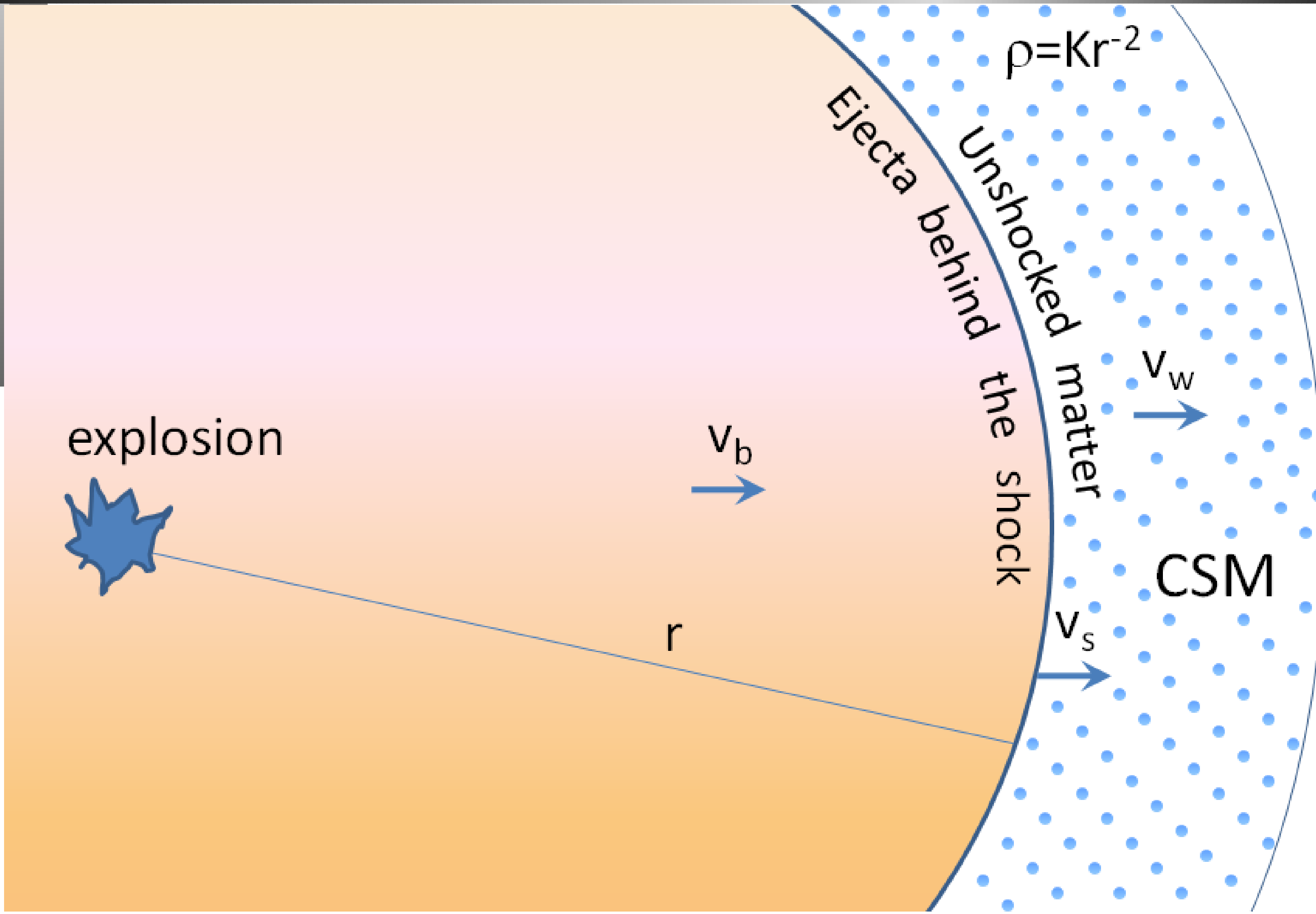
- Pair instability SNe
- Magnetar energy pumping
- Interaction with CSM

PISN vs. magnetar model

One of the latest and the brightest SLSN PTF 12dam (Nicholl+, Nature, 2013)



Windy model for core collapse SNe



Ofek et al. 2010

Windy models for type Ib/c SNe

Ejecta: polytropic mass distribution
Parameters: $M_{\rm ej}$, $R_{\rm ej}$, $E_{\rm explosion}$

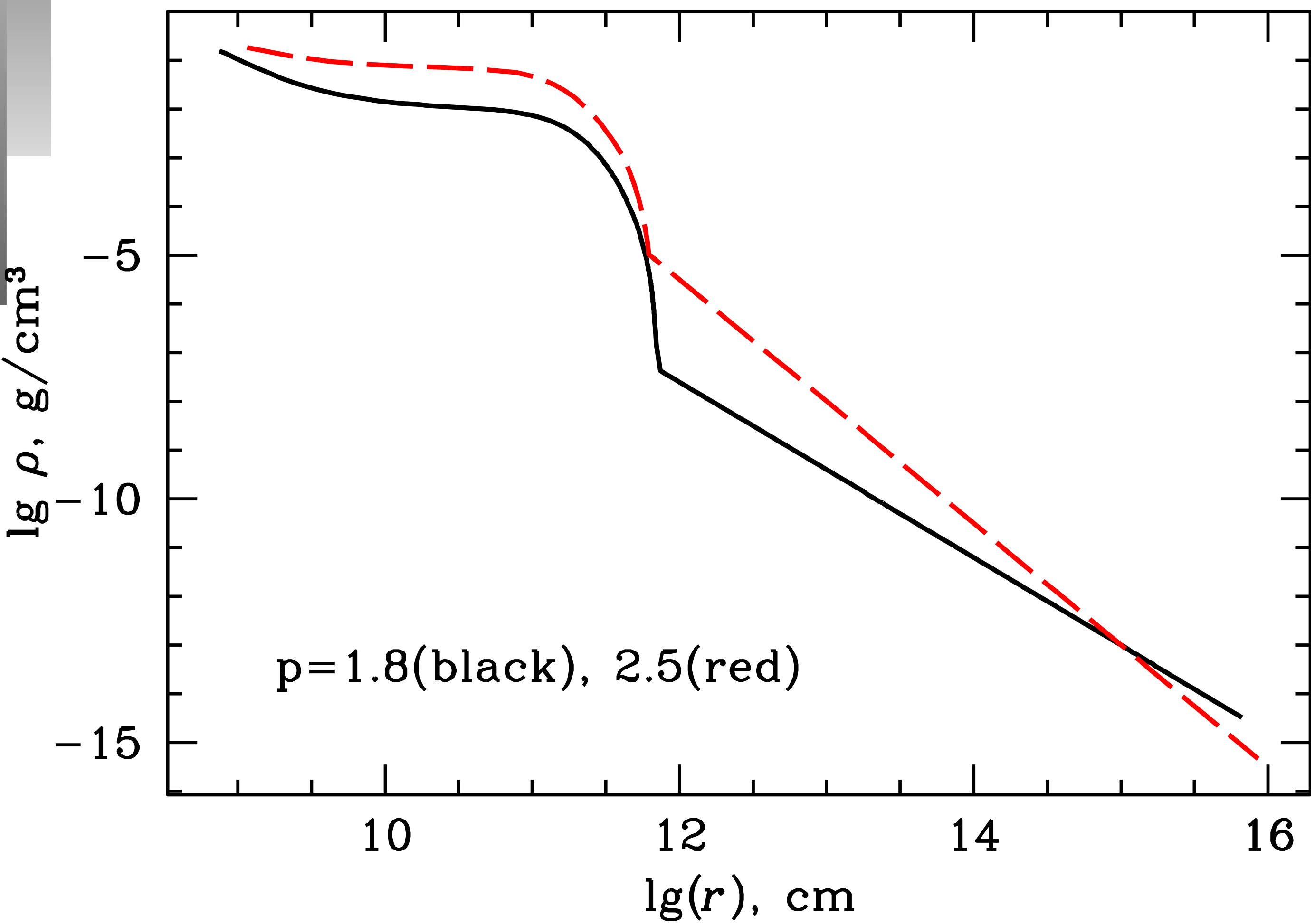
Wind: power-law mass distribution $\rho \sim r^{-p}$
Parameters: $M_{\rm w}$, $R_{\rm w}$, p, $E_{\rm kin}$

Recently done: detached envelope
Parameters: $M_{\rm w}$, $R_{\rm w}$, ρ

Composition: uniform for most of models;
mostly CO in different ratio + 2% of metals;
a few He models;
no ^{56}Ni in most of models;

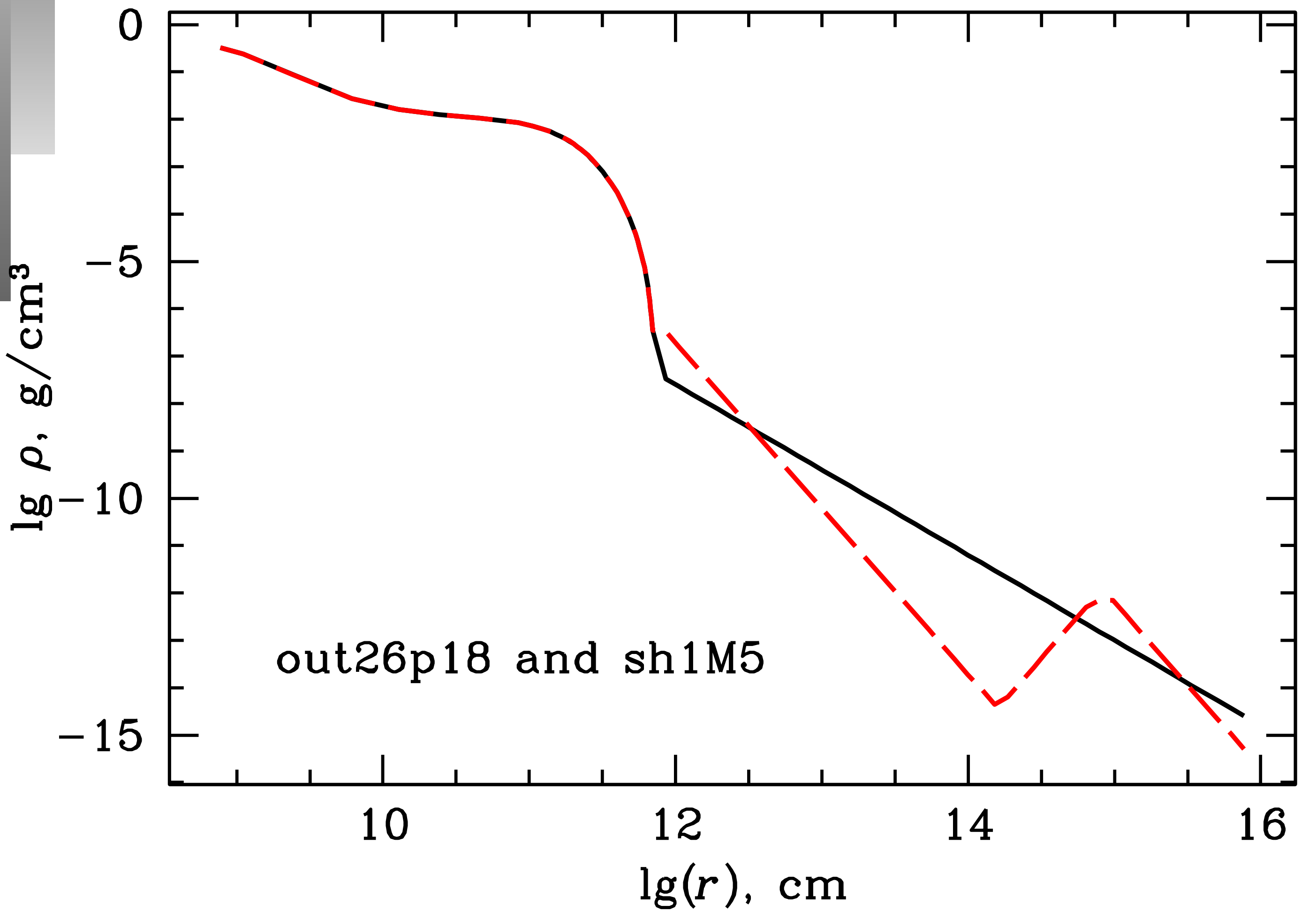
Initial models

Samples of the density distribution



Initial models

Detached envelope



The radiative hydro code ***STELLA***

- time-dependent equations for the angular moments of intensity (coupled to hydro equations) in fixed frequency bins are solved implicitly

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- time-dependent equations for the angular moments of intensity (coupled to hydro equations) in fixed frequency bins are solved implicitly
- no need to ascribe any temperature to the radiation: the photon energy distribution may be quite arbitrary
- up to ~ 500 zones for the Lagrangean coordinate and up to 200 frequency bins are used (usually 100)

Code ***STELLA***

- heating by decays of ^{56}Ni $\rightarrow$ ^{56}Co $\rightarrow$ ^{56}Fe with the γ-ray transfer in a one-group approximation following Swartz et al. 1995 (with purely absorptive opacity in the gamma-ray range)

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- the effect of line opacity is treated as an expansion opacity according to Eastman & Pinto 1993 (and our new recipes).

How to estimate luminosity

Simplificated picture:

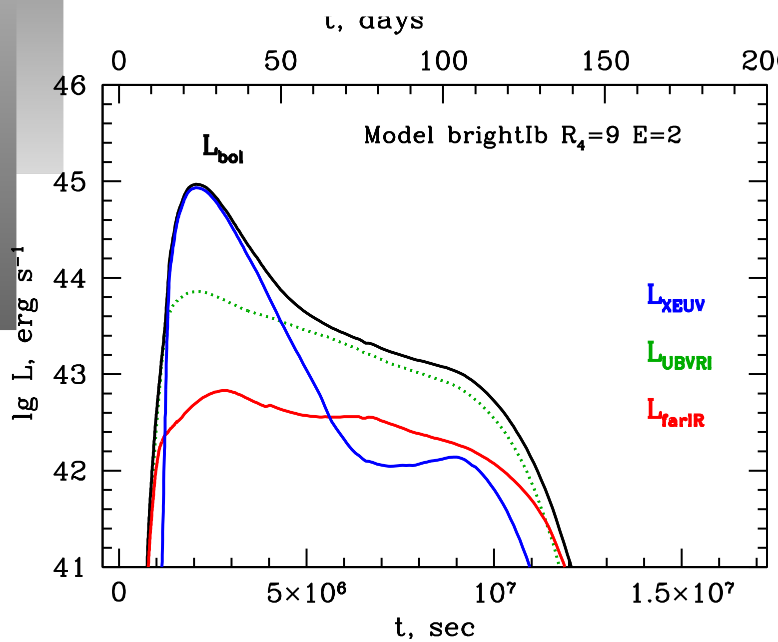
Source of luminosity: SHOCK WAVE with the velocity v which originates from the ejecta.

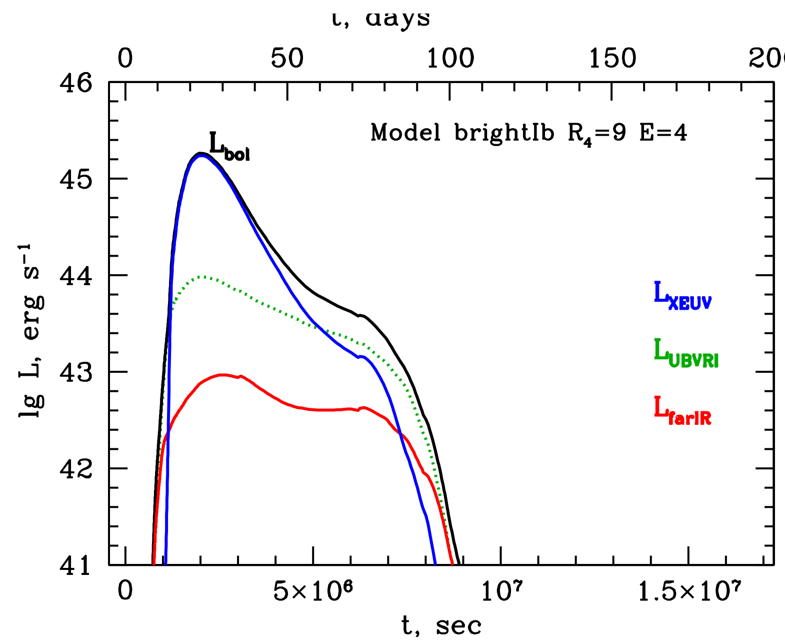
Emitter: CSM with the density ρ which passes through the shock

If all kinetic energy of the shock would transform to the luminosity we would have:

$$L = 4\pi R^2 \cdot v \cdot \rho v^2/2$$

Light curves for different $E_{\text{explosion}}$

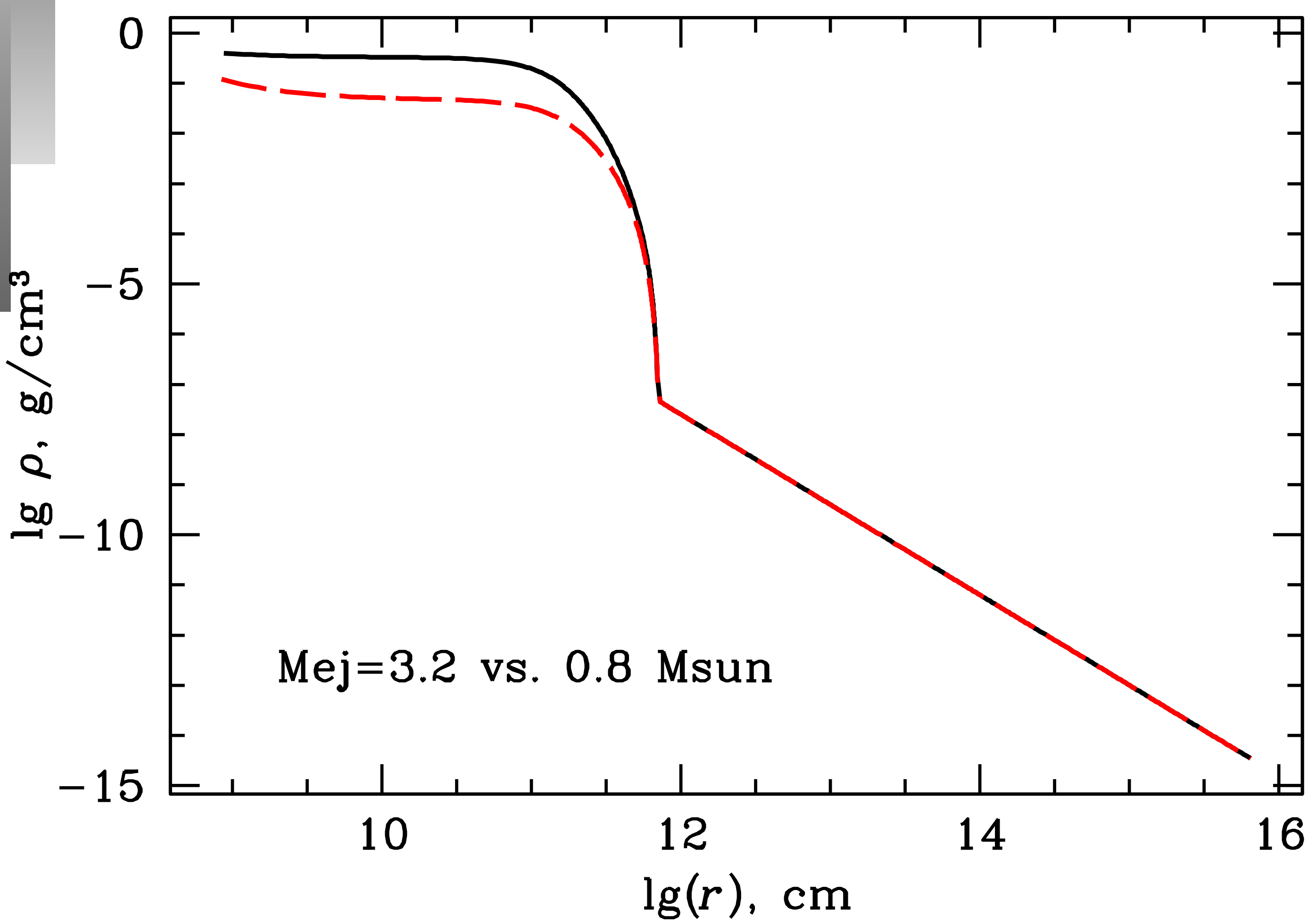




$E_{\text{exp}} = 2B$ $\qquad$ $p = 1.8, M_w = 4.8 M_\odot$ $\qquad$ $E_{\text{exp}} = 4B$

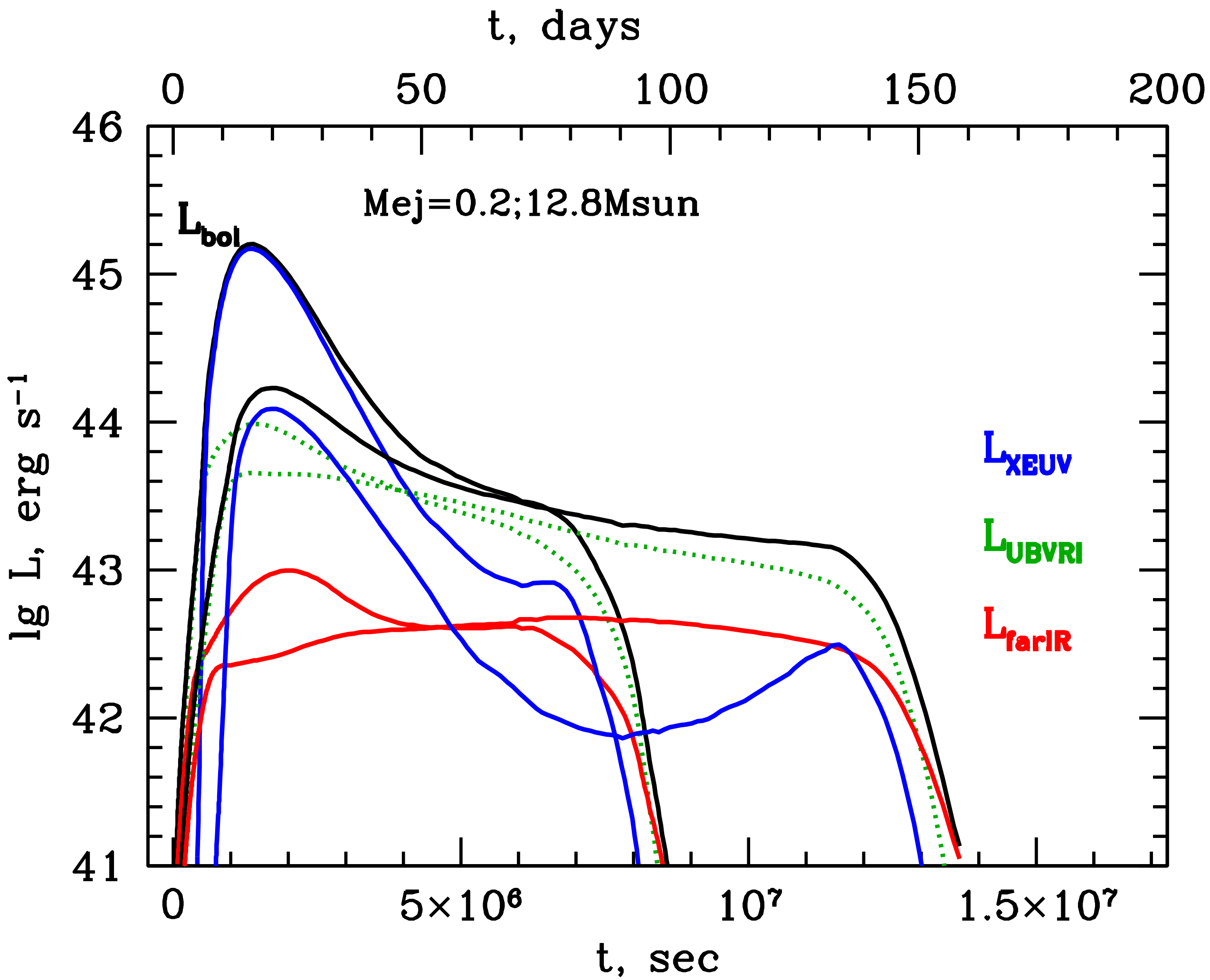
Higher $E_{\text{exp}} \rightarrow$ higher $v \rightarrow$ higher L

Different $M_{\rm ej}$



Different $M_{\rm ej}$

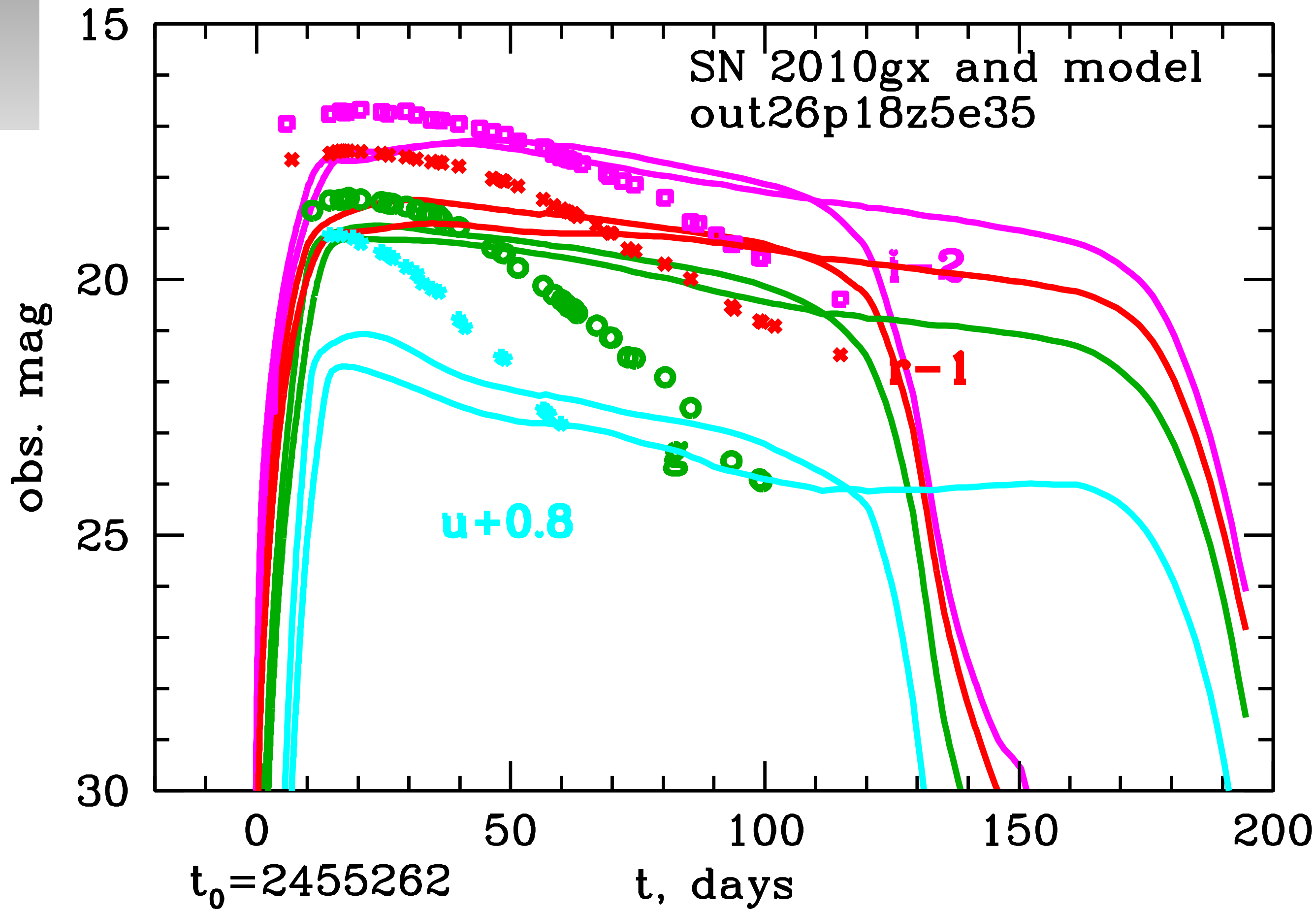
0.2 Msun and 12.8 Msun



Higher $M_{\rm ej} \rightarrow$ lower $v \rightarrow$ lower L

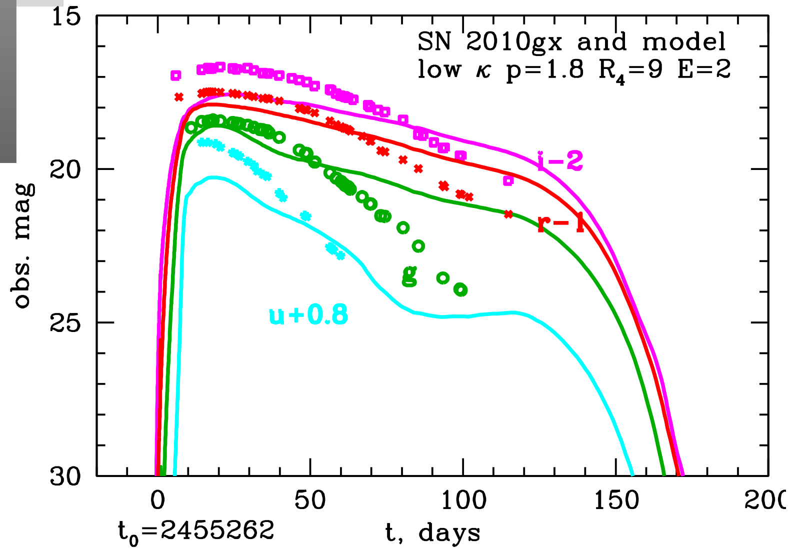
Different $M_{\rm ej}$

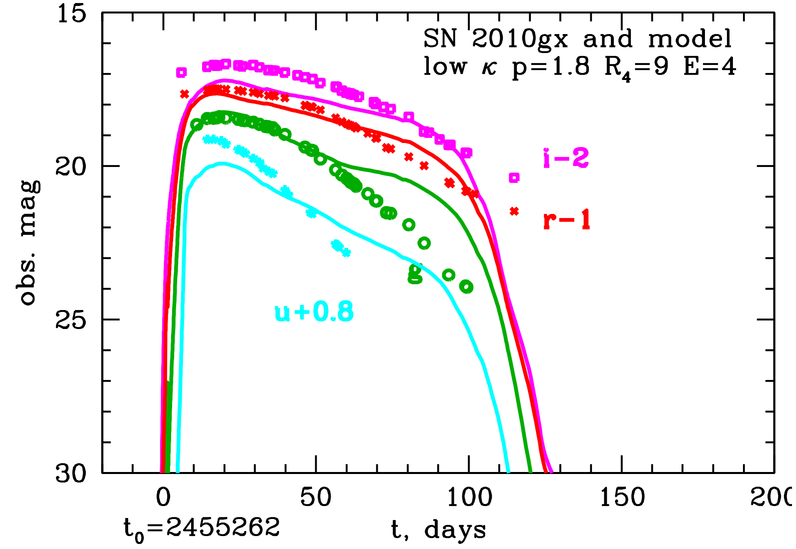
3.2 Msun and 12.8 Msun



More massive - dimmer and wider

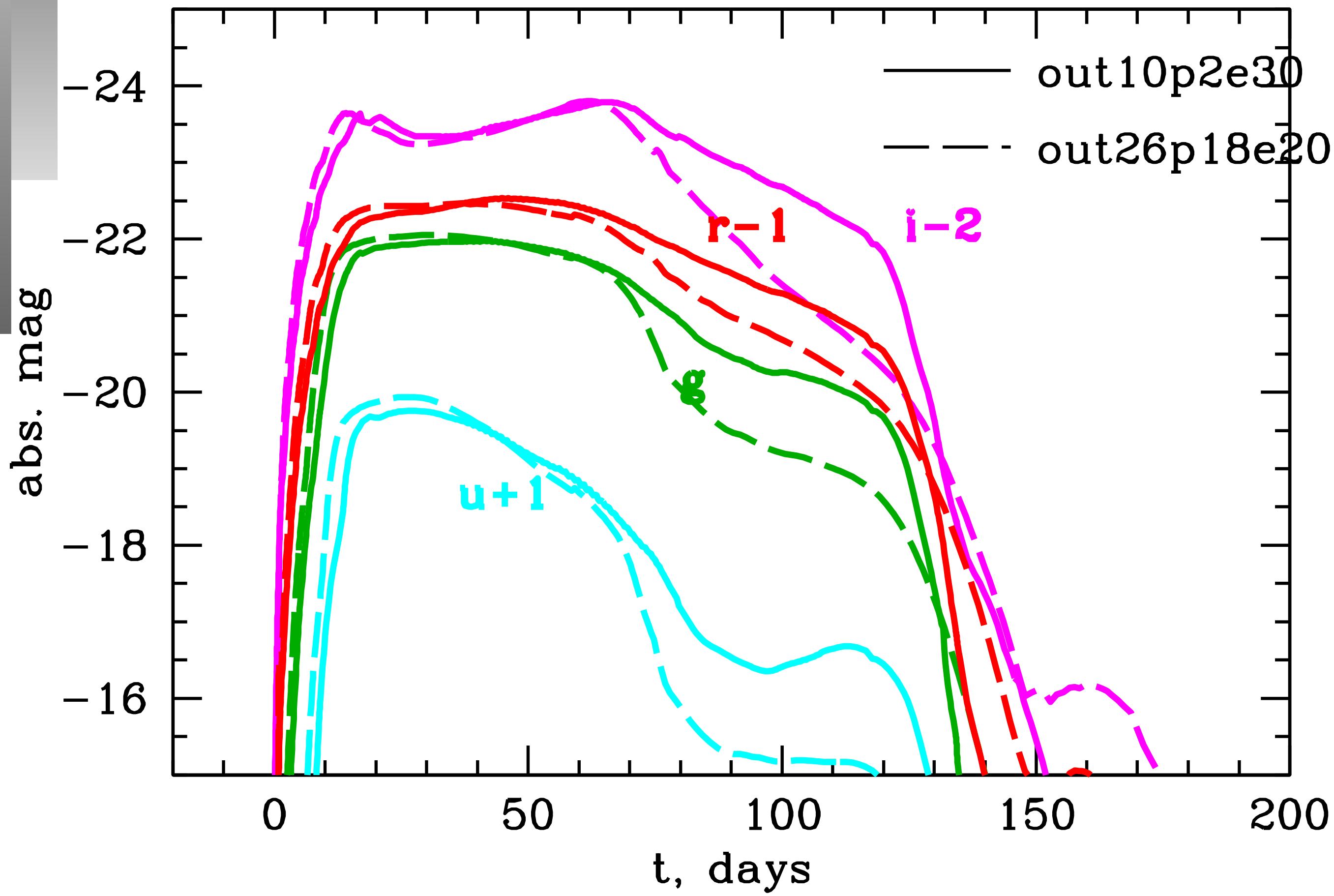
Best models for SN 2010gx





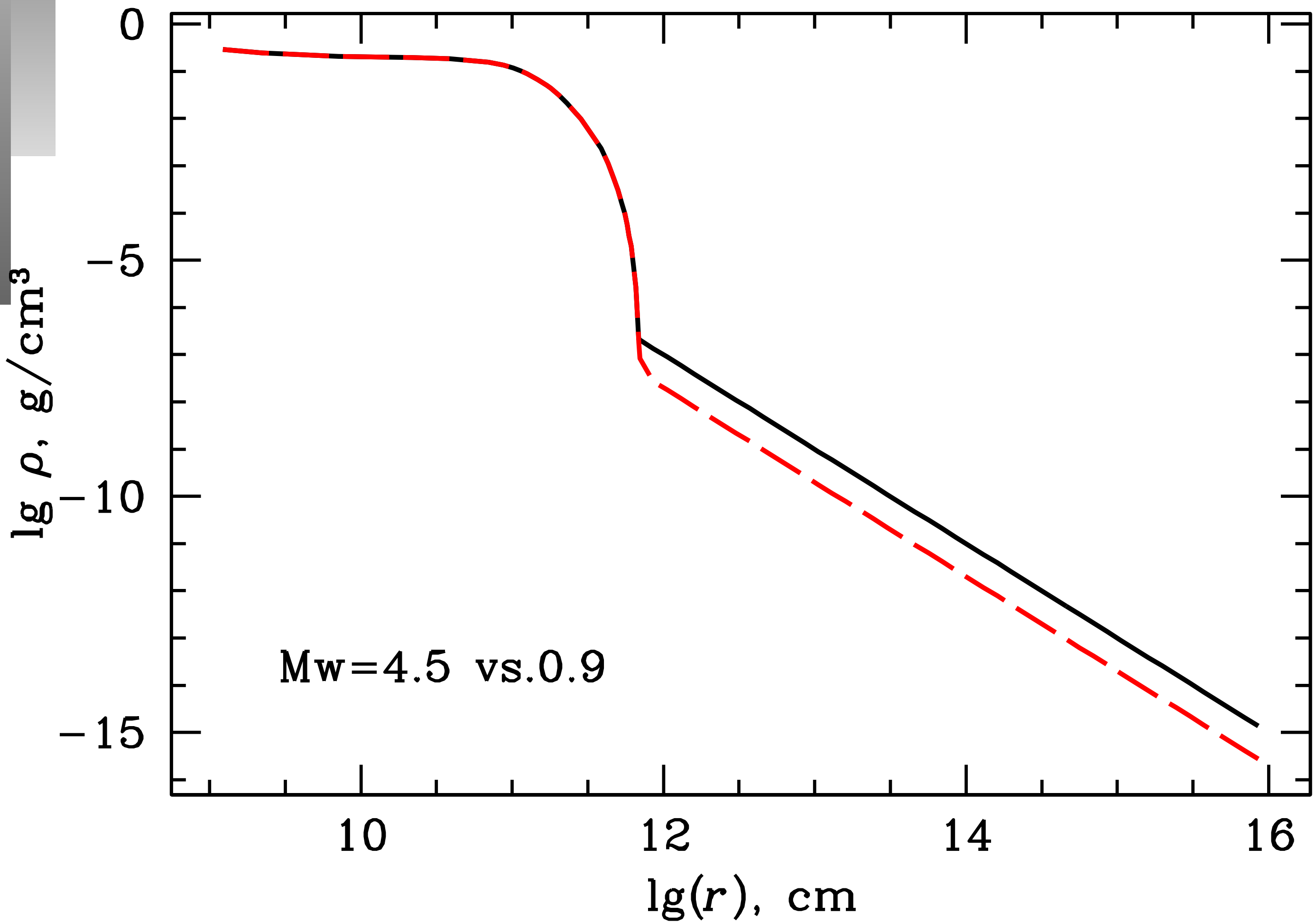
$E_{\mathrm{exp}} = 2B$ $\quad M_{\mathrm{ej}} = 0.2 M_{\odot}$ $\quad E_{\mathrm{exp}} = 4B$

Light curves for different E and $M_{\rm ej}$



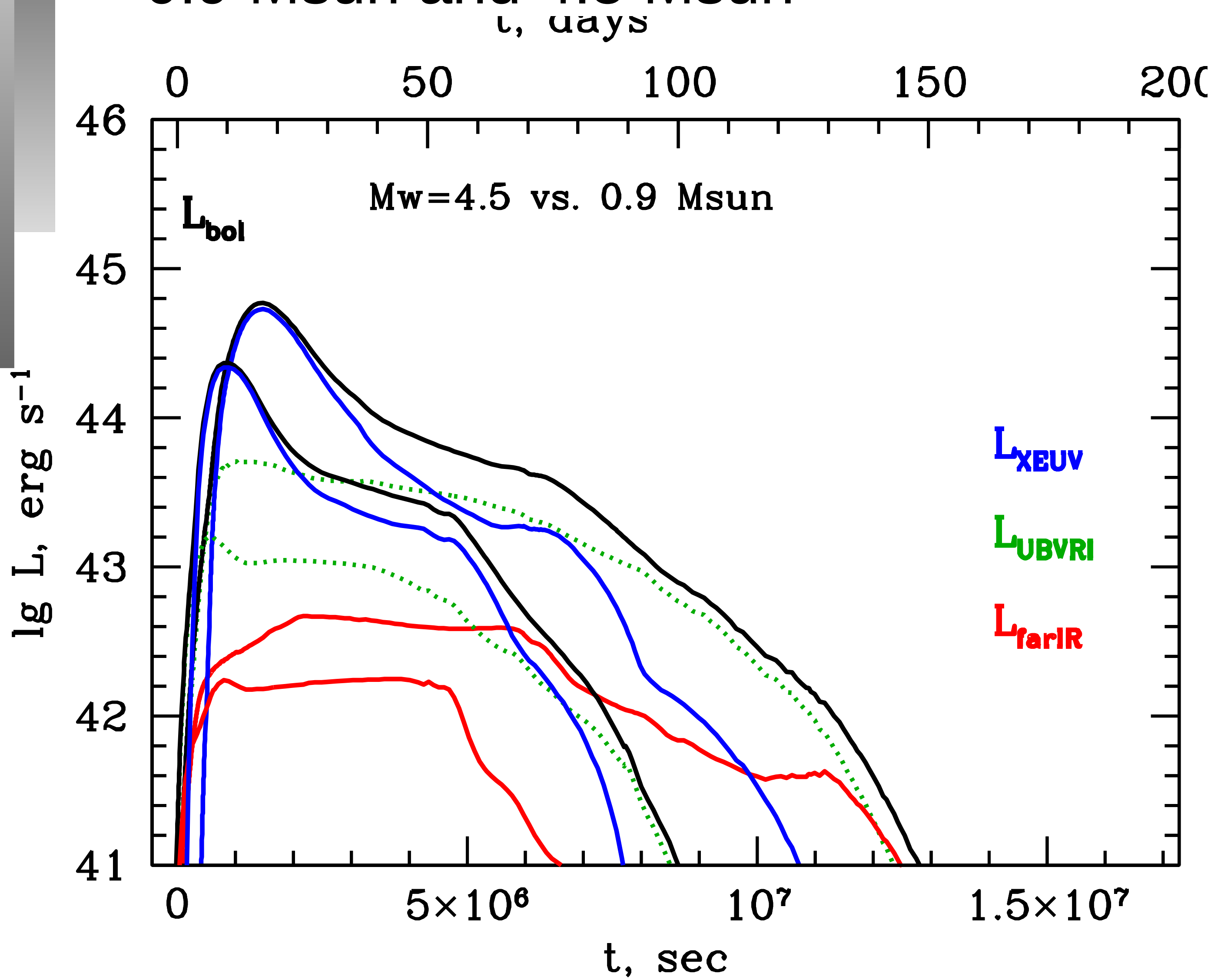
out10: $M_{ej} = 2M_\odot, p_w = 2, E = 3$ Bethe
out26: $M_{ej} = 0.2M_\odot, p_w = 1.8, E = 2$ Bethe

Different M_w



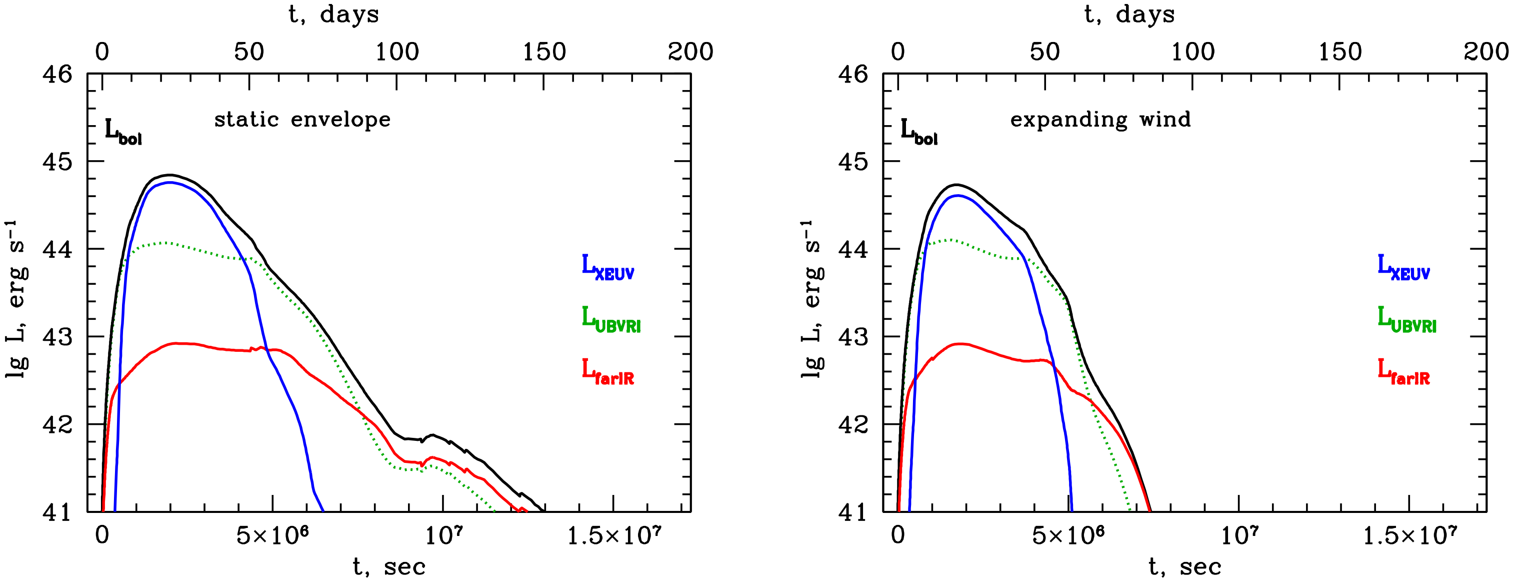
Different M_w

0.9 Msun and 4.5 Msun



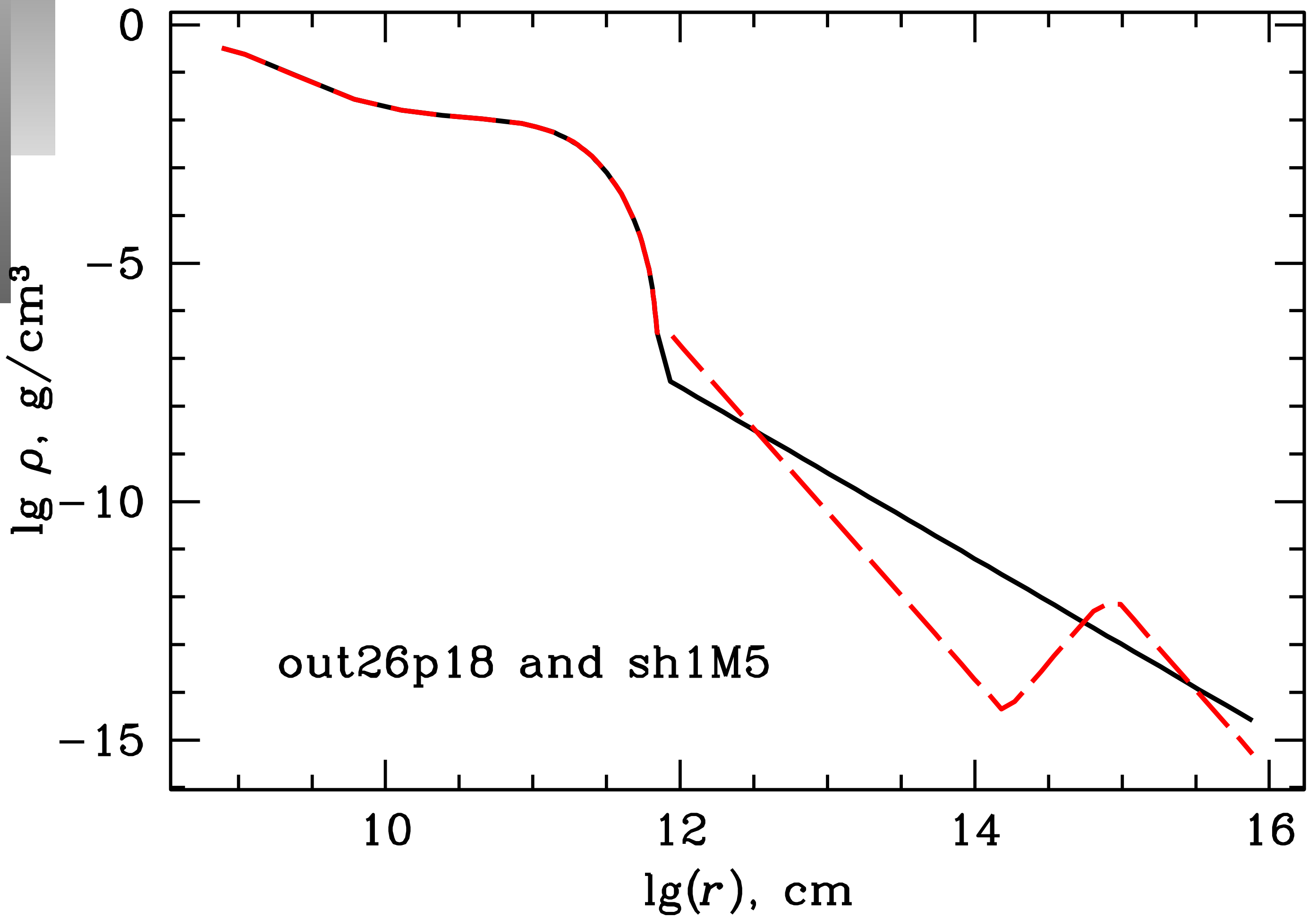
Higher $M_w \rightarrow$ higher $\rho \rightarrow$ higher L

Expanding vs. static envelope



More complicated structure

Detached envelope



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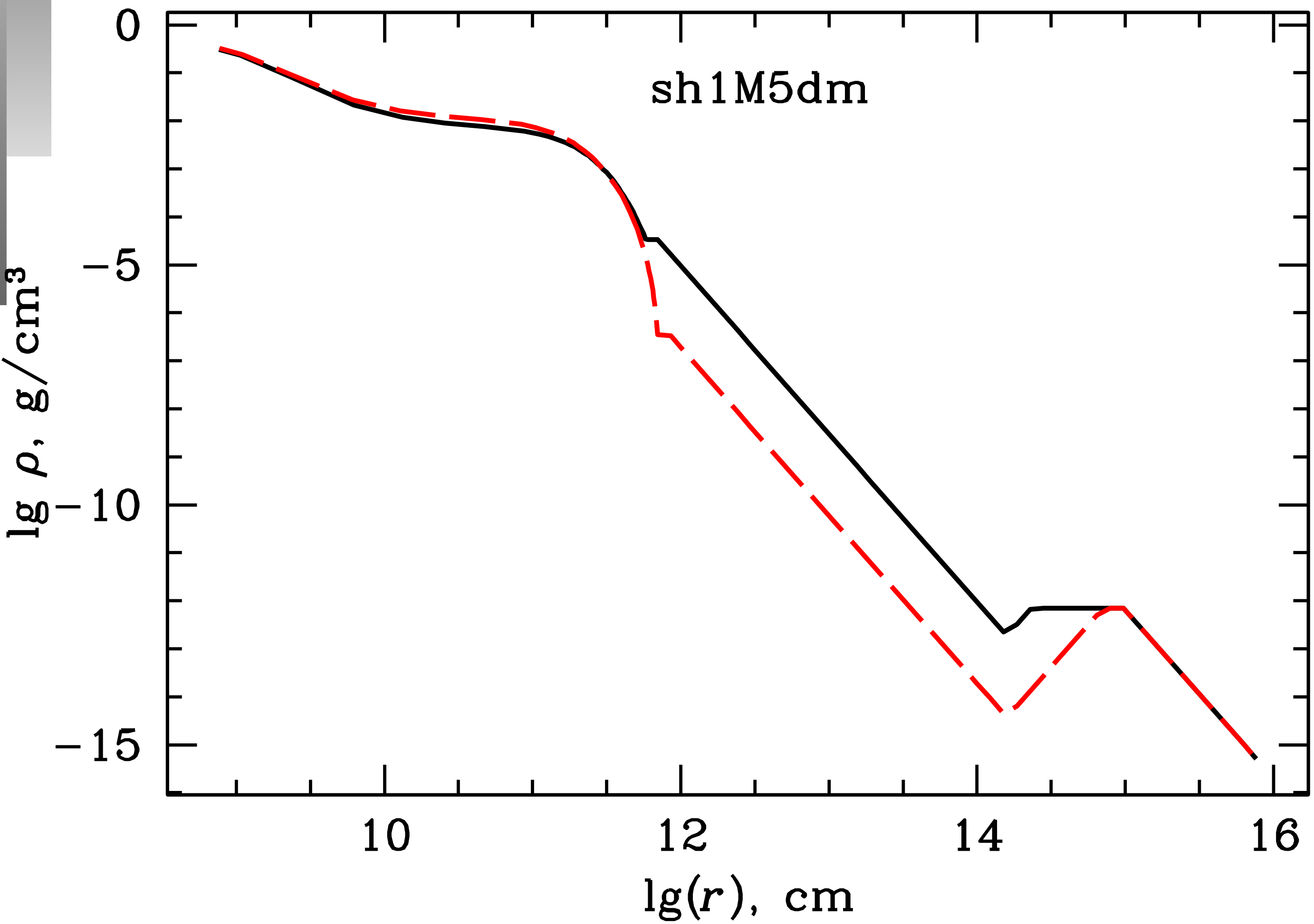
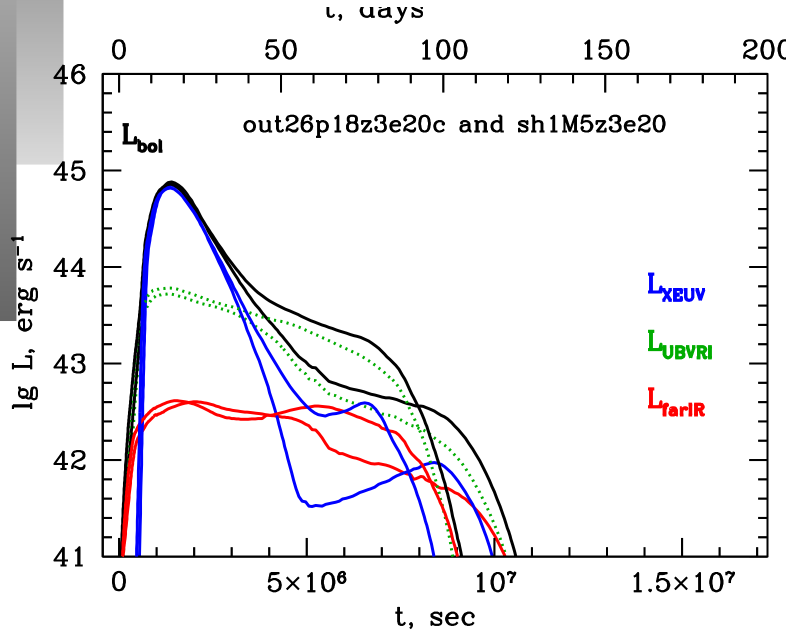
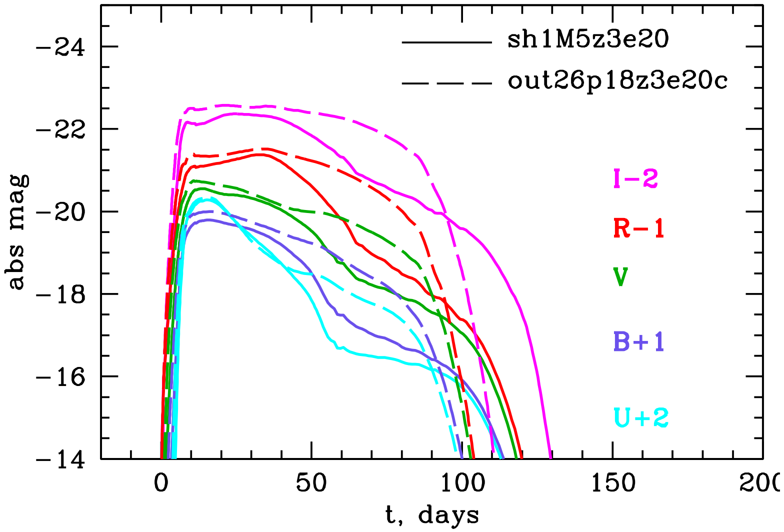


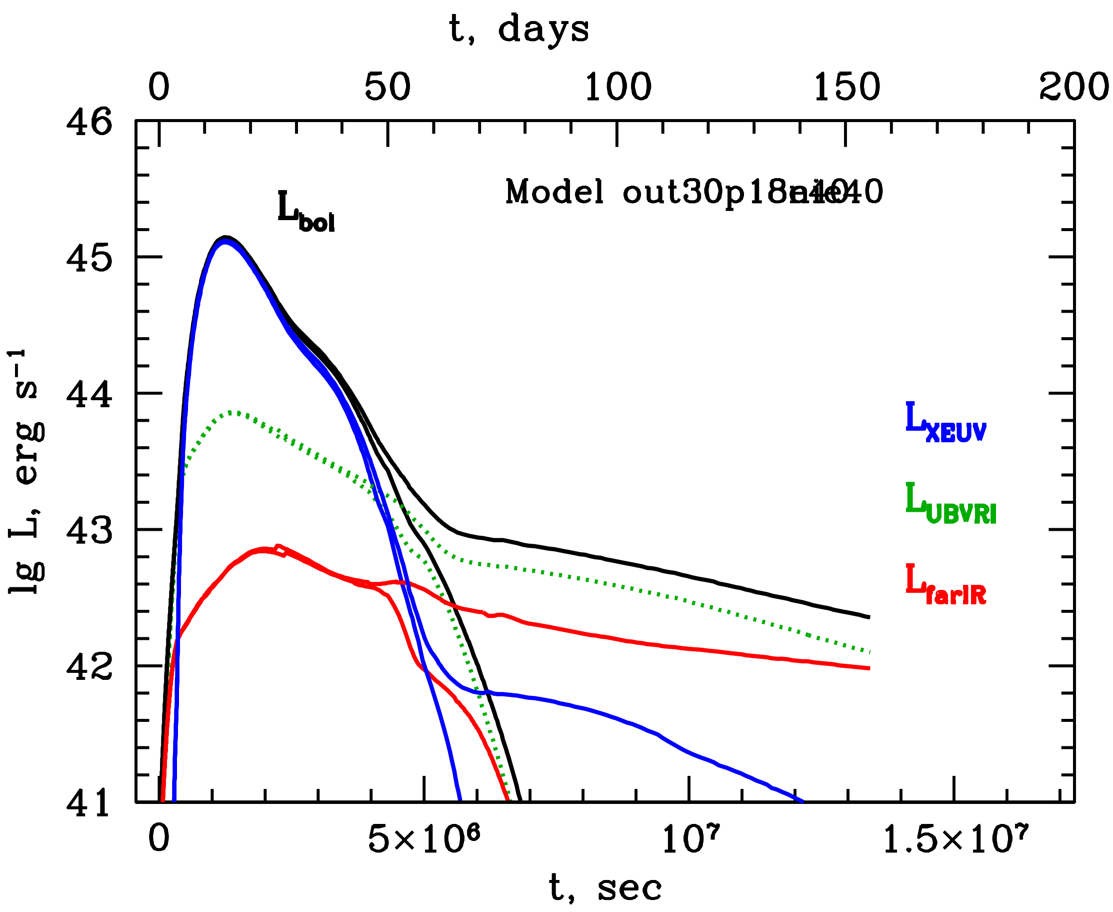
Detached envelope





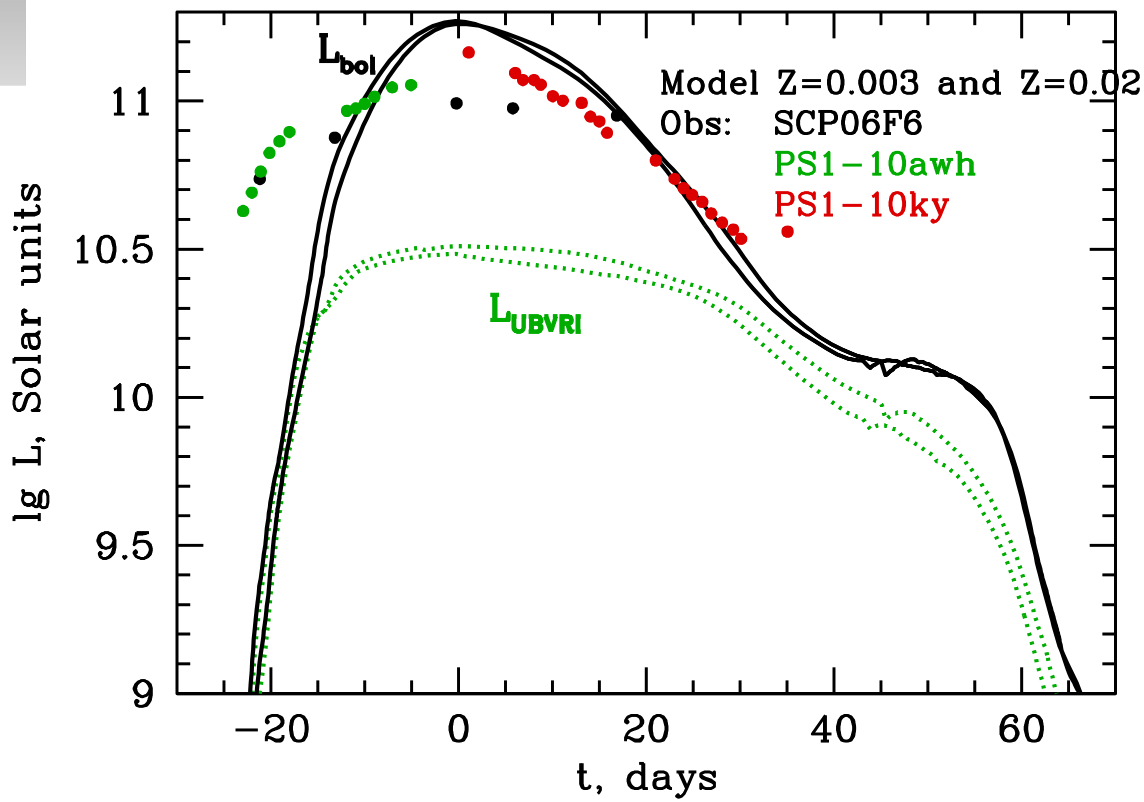
Detached shell parameters are not yet explored.
We plan this for the nearest future.

^{56}*Ni vs. Shock wave heating*

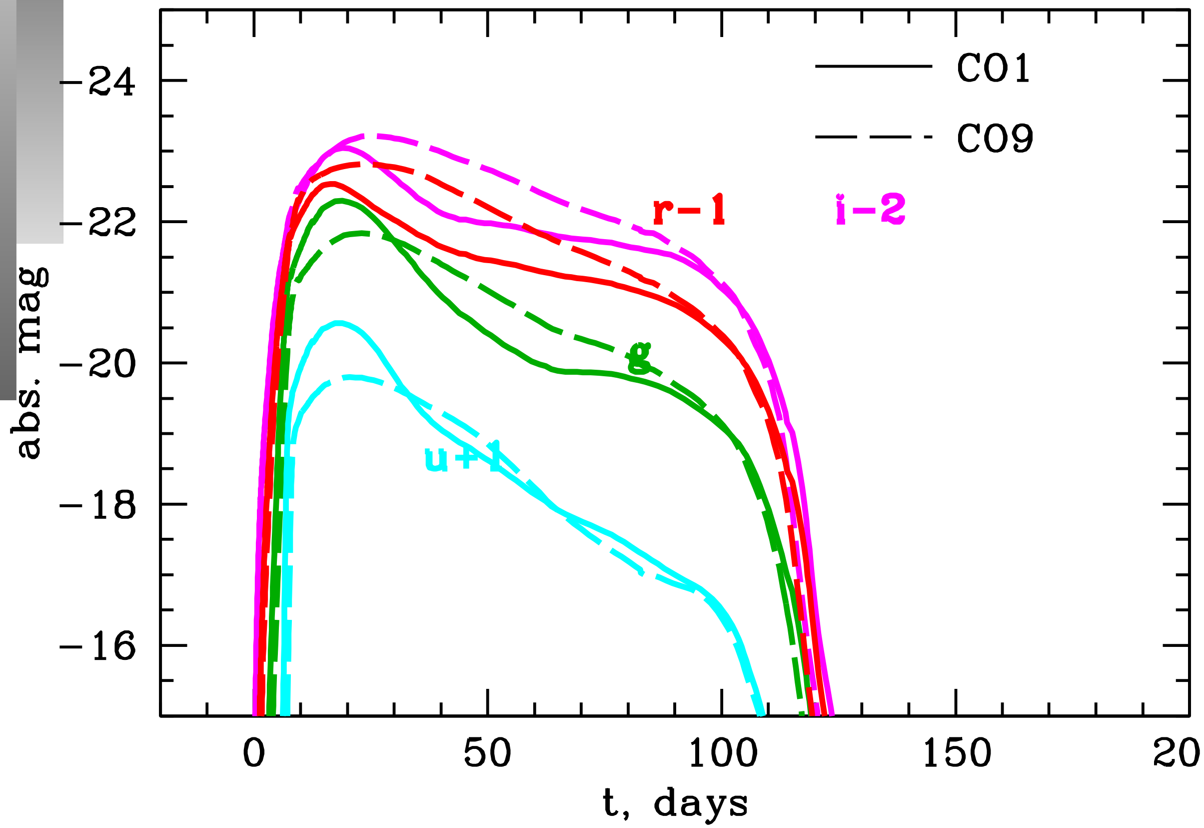


$M(^{56}\mathrm{Ni}) = 1M_\odot$ added to the ejecta

Metallicity

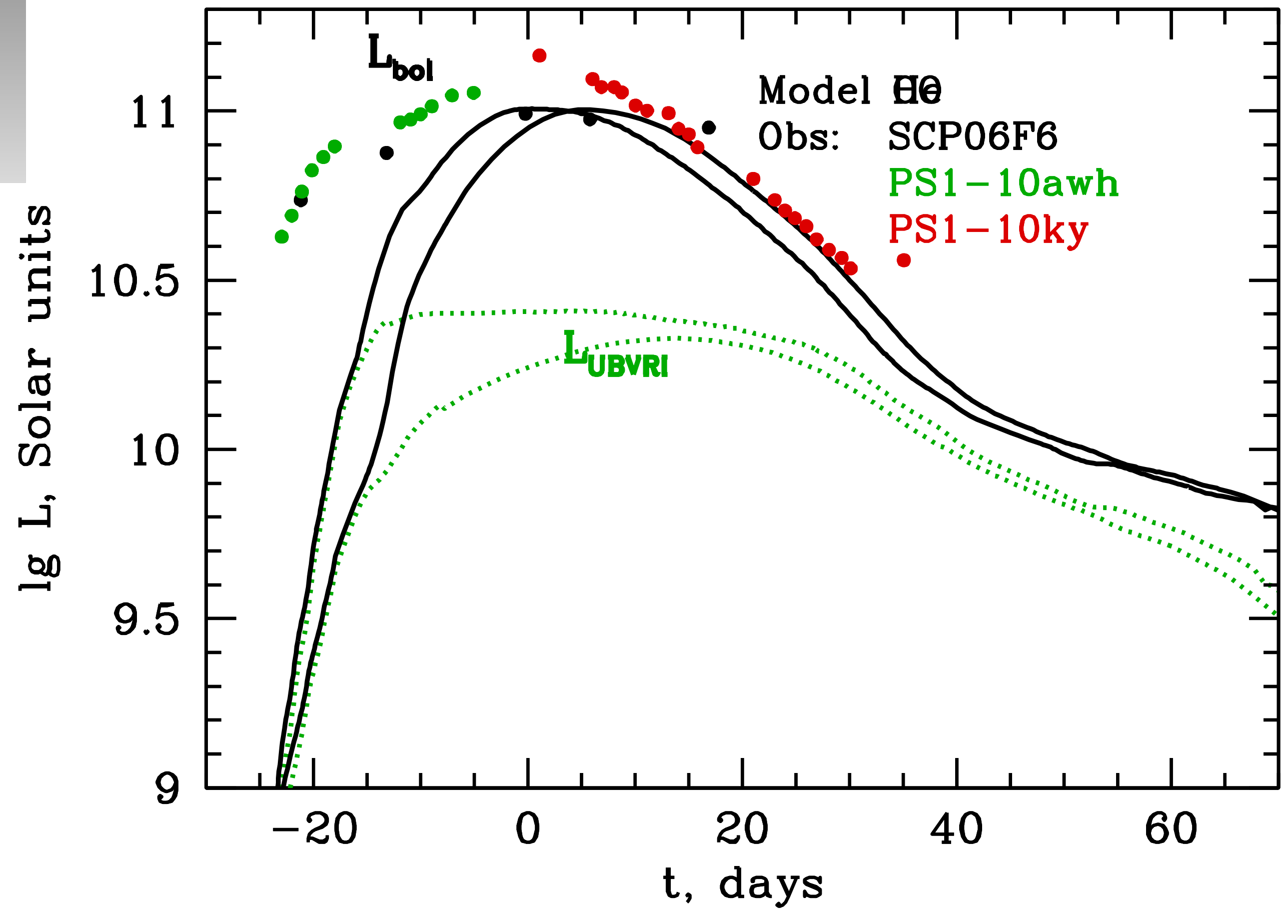


Different C/O ratio



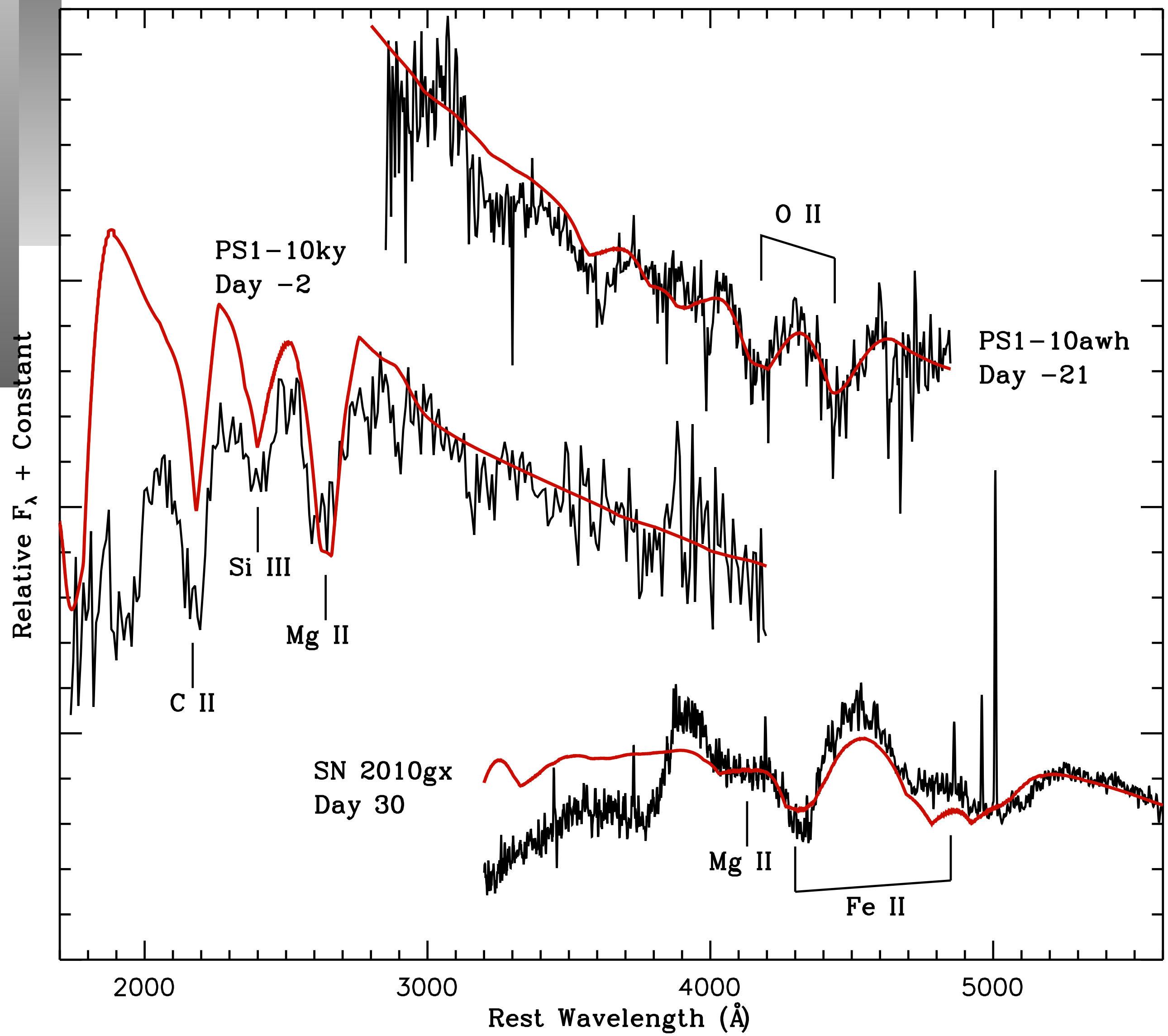
“CO1” means 10% C and 90% O;
“CO9” – 90% C and 10% O.
Oxygen makes SN bluer.

CO vs. He wind



Model with He-wind is more symmetric around maximum light

What is bolometric?



Chomiuk et al. 2009

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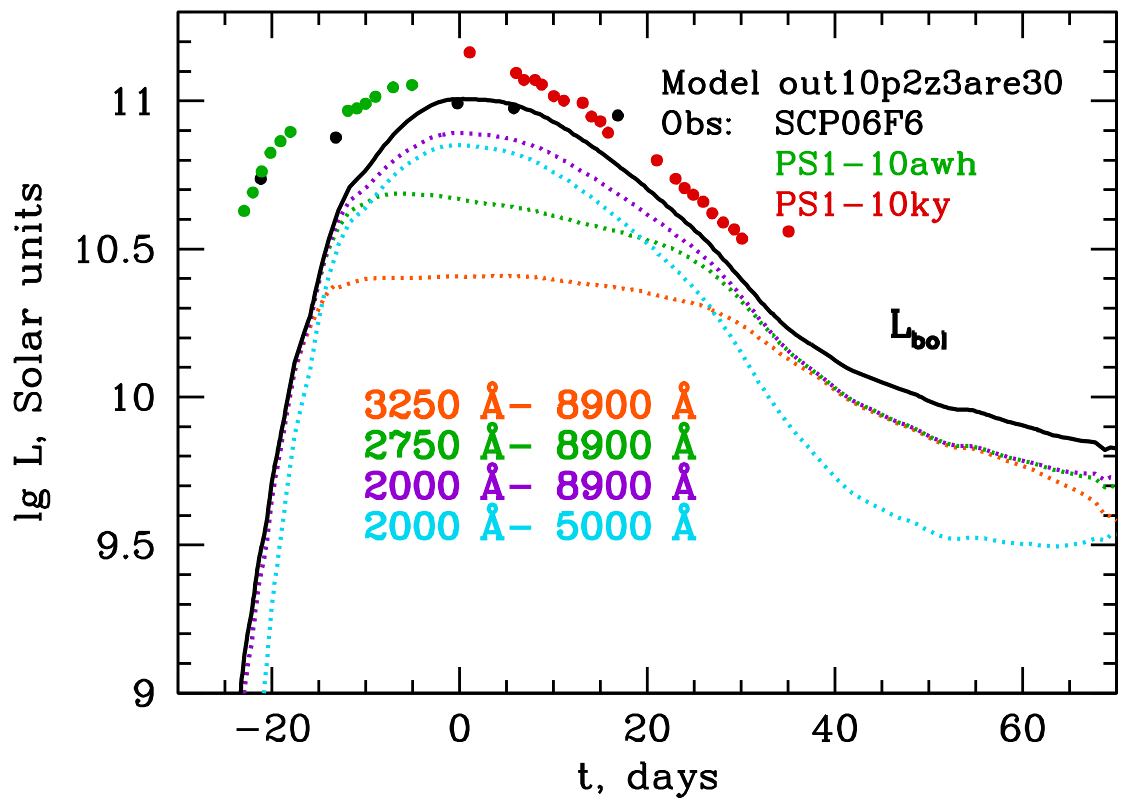

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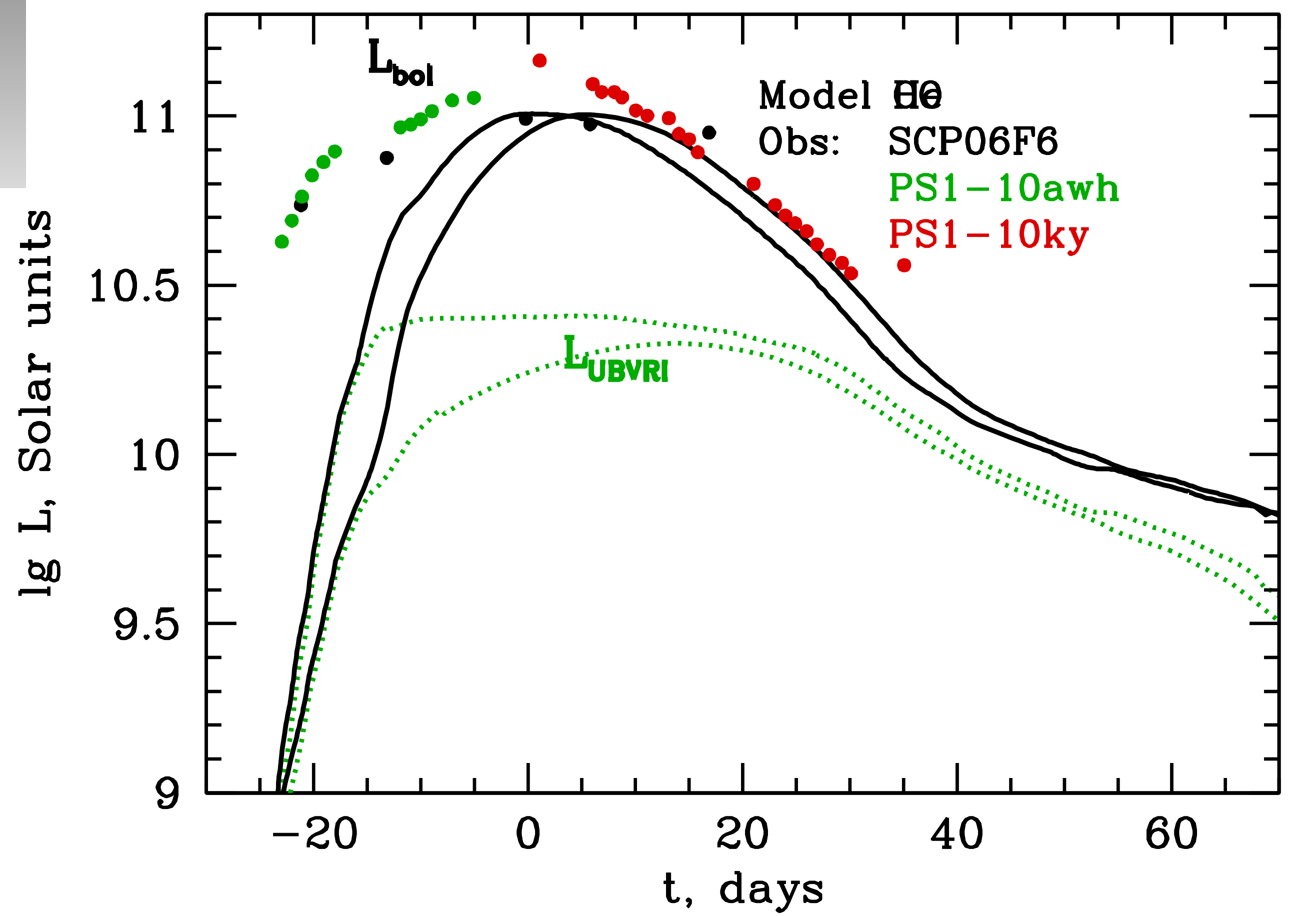

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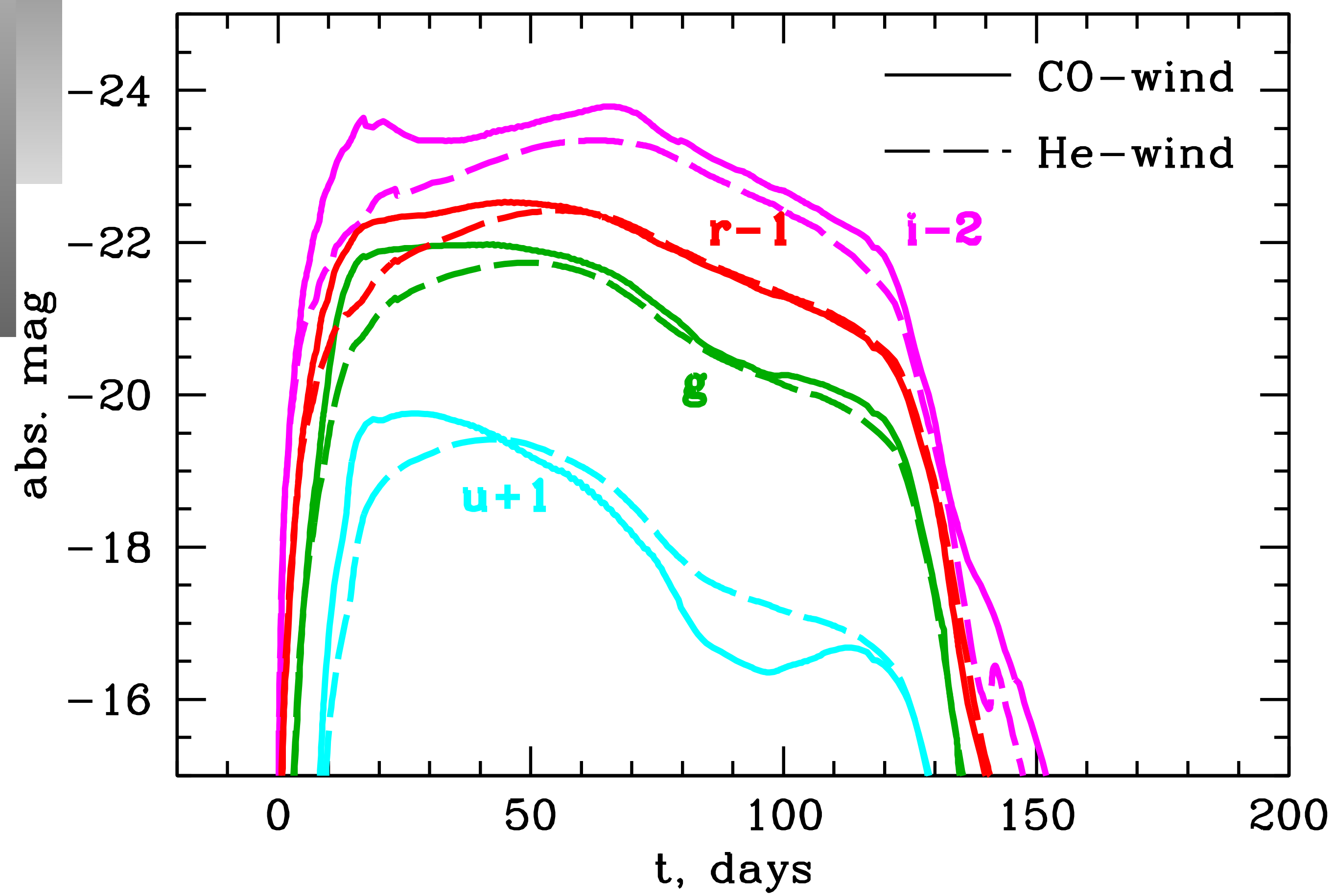
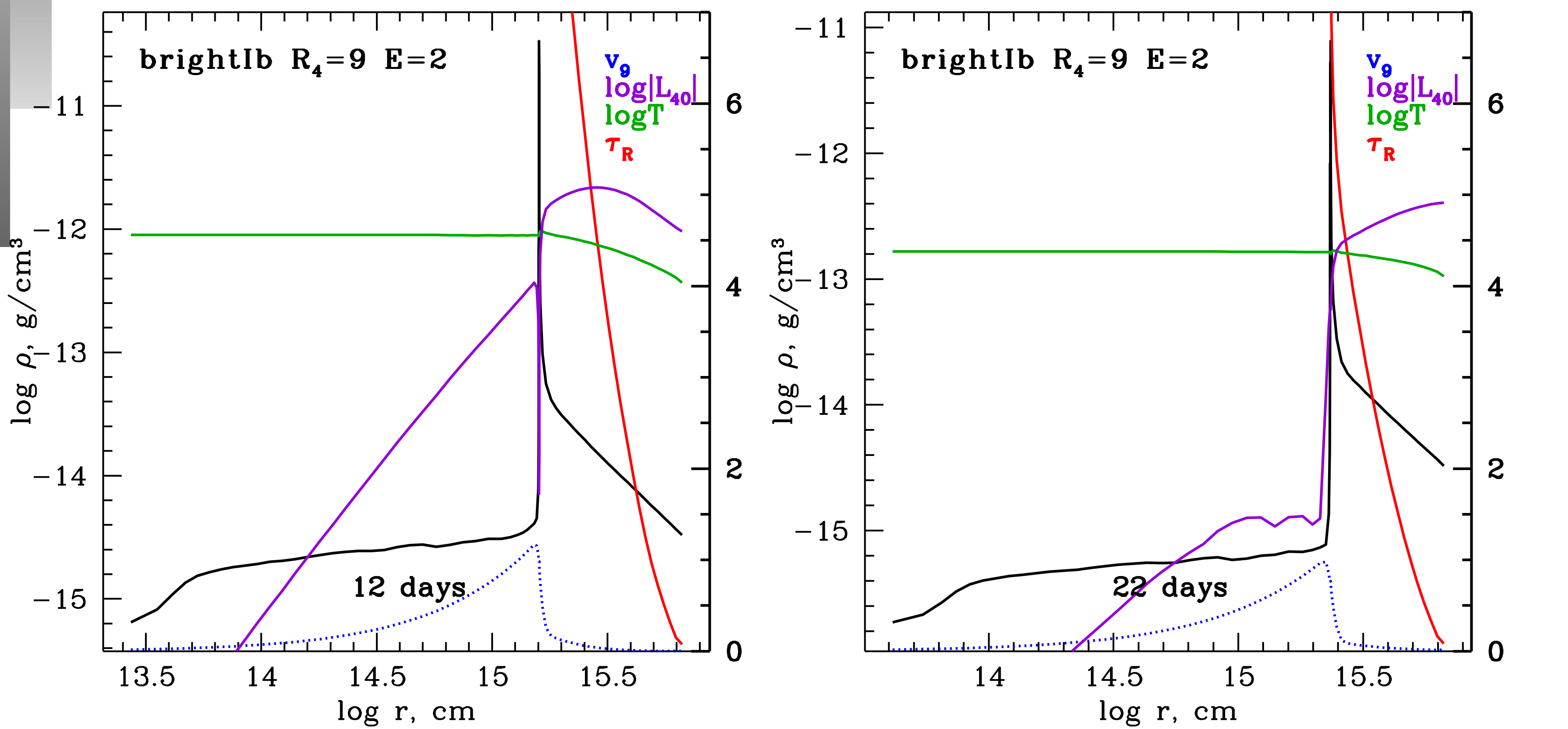
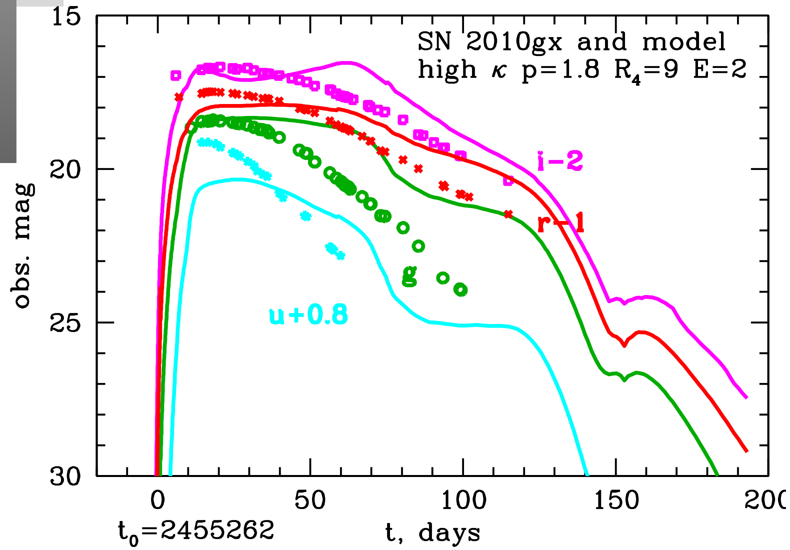

CO−wind
He−wind
r−1
i−2
g
u+1
−24
−22
−20
−18
−16
abs. mag
0
50
100
150
200
t, days

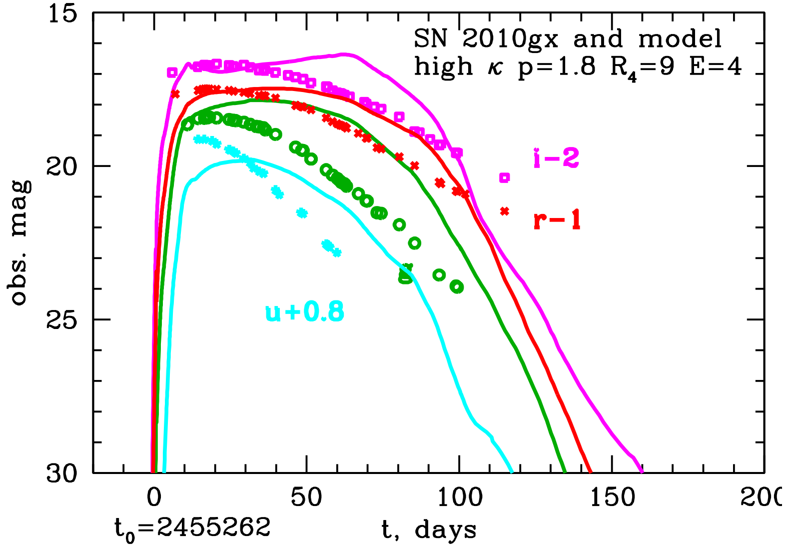
Difficulties in the windy models

Very thin layer contains almost all mass



Uncertainty in expansion opacity





Opacity is taken as for $dv/dr = 1/t = 1/1$day

Summary

- The shock wave which runs through rather dense matter surrounding an exploding star can produce enough light to explain very luminous SN events. No ^{56}Ni is needed in this case to explain the light curve near maximum light (some amount is of course needed to explain light curve tails).
  We need the explosion energy of only 2-3 Bethe for the shell with $M = 3 - 9M_{\odot}$ and $R \sim 10^{16}$cm.
- X-Ray flash might happen when the shock reaches the photosphere (like in Ib shock breakouts, but weaker).

Summary

The brightness and the duration of the light curve strongly depends on the parameters of the model:

- Increase of E_{exp} makes LC higher and shorter;
- Increase of M_{ej} lower and longer;
- Increase of M_{w} higher and longer;
- Increase of v_{w} lower and shorter;
- Oxigen bluer;
- Helium increases rise time (more symmetric LC);
- Detached shell changes the shape of LC - still needed to be explored.

Technical things to be improved

- use correct velocity gradient in the opacity calculation;
- dimensionality: 3D is preferable, since the envelope can most probably be clumpy;
- NLTE spectra

Thank you!