Interaction with hydrogenless envelopes as the least energetic model for a bulk of Type Ic Superluminous Supernovae

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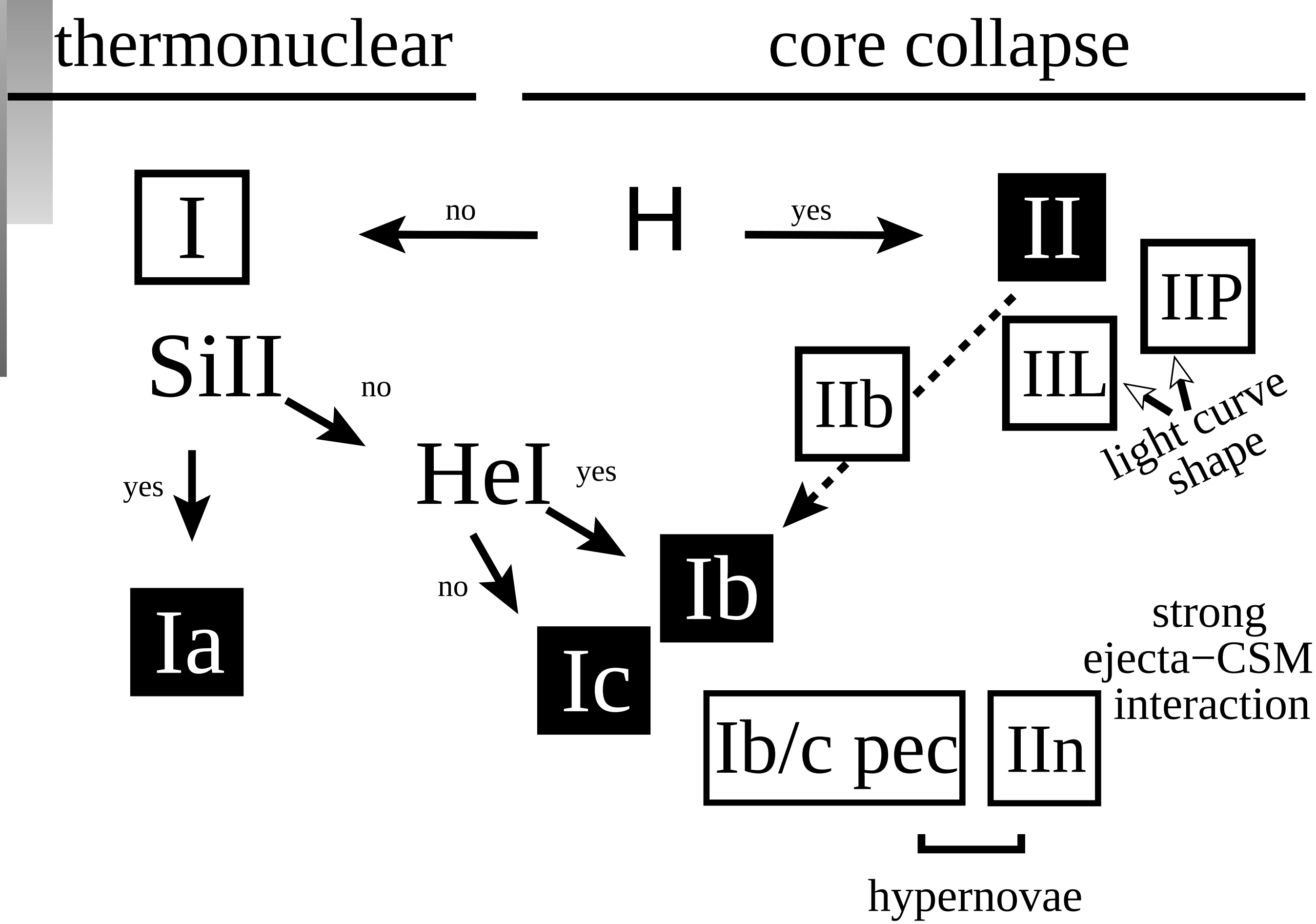
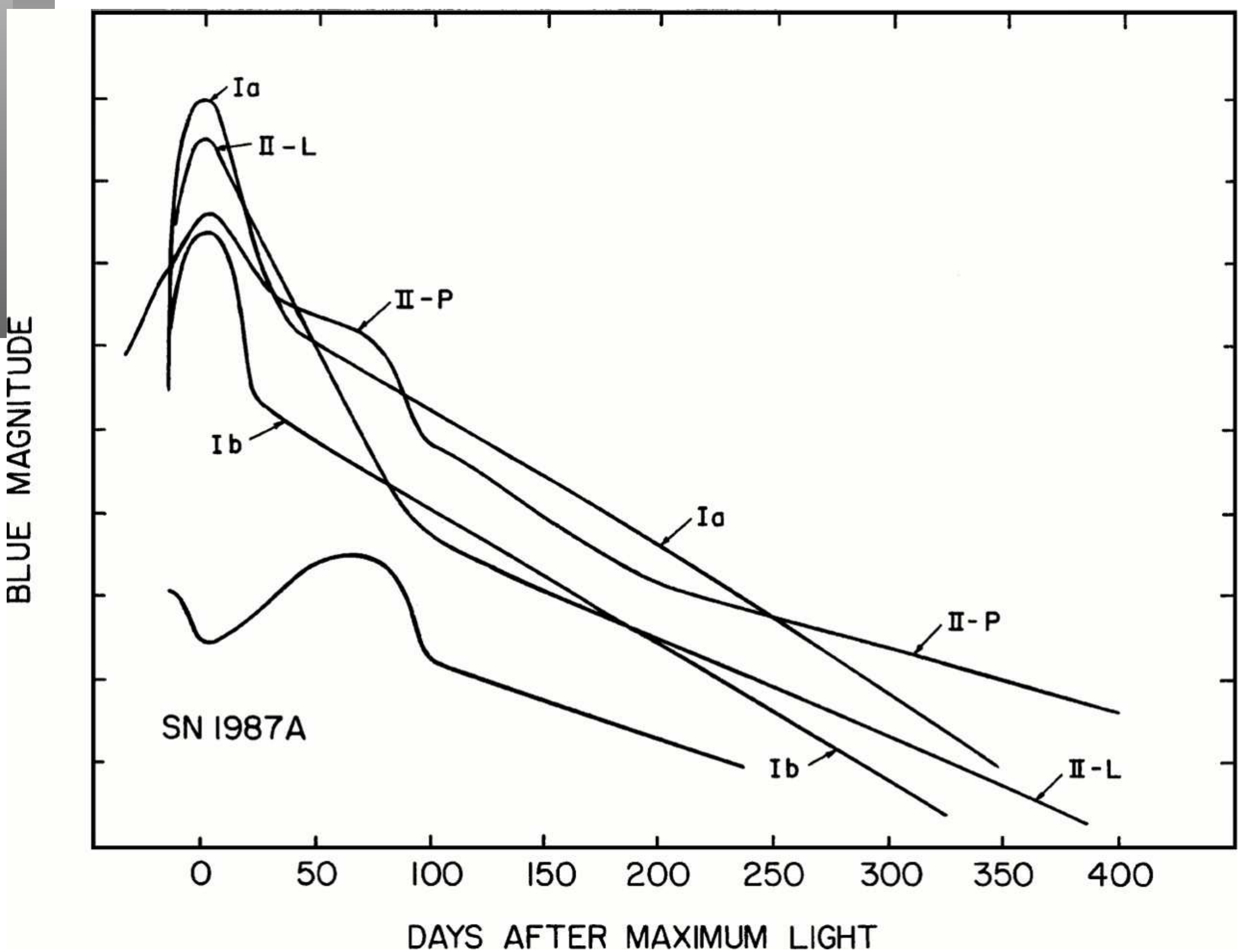
SN classification



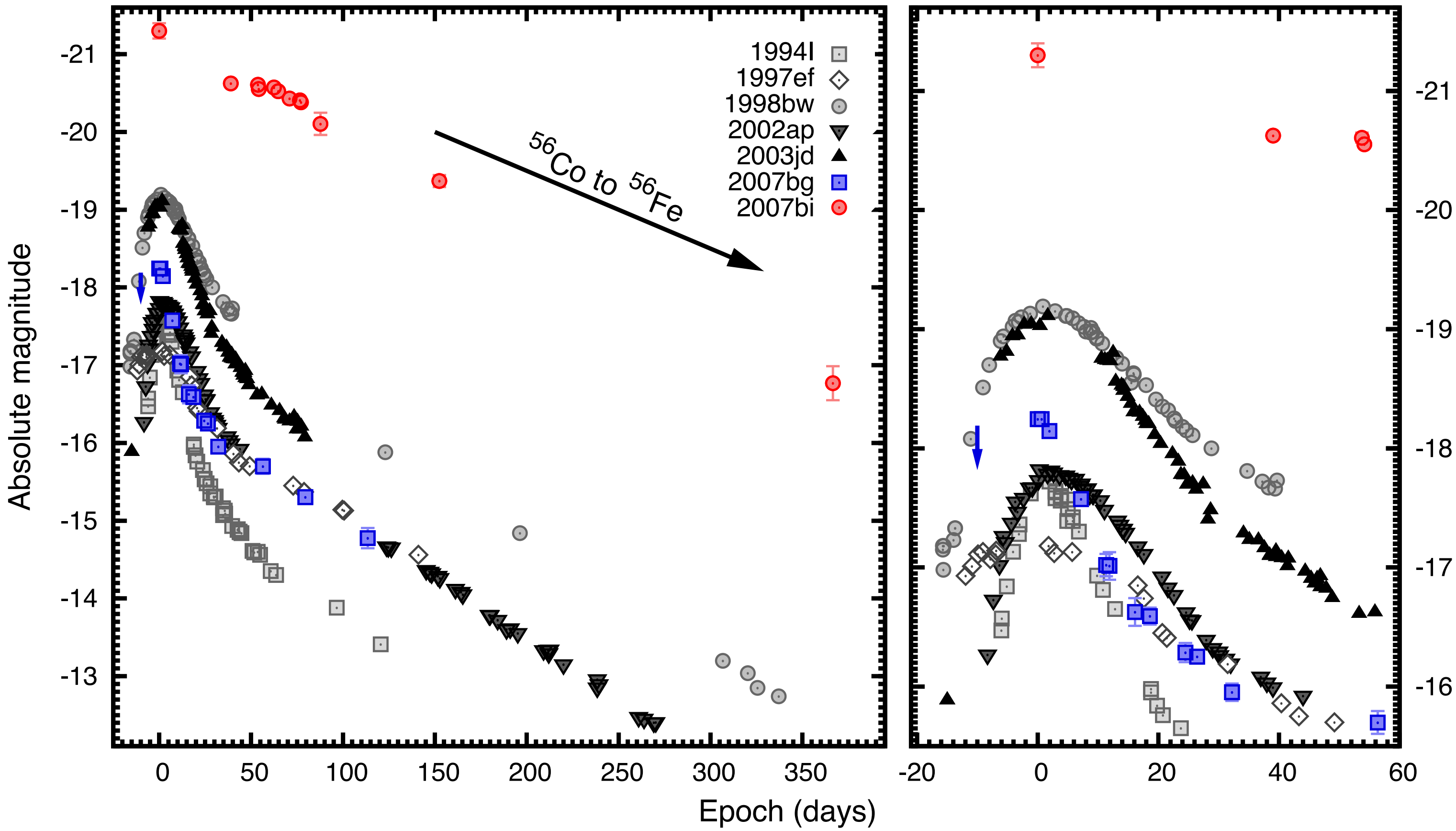
Turrato 2003

SN Light Curves



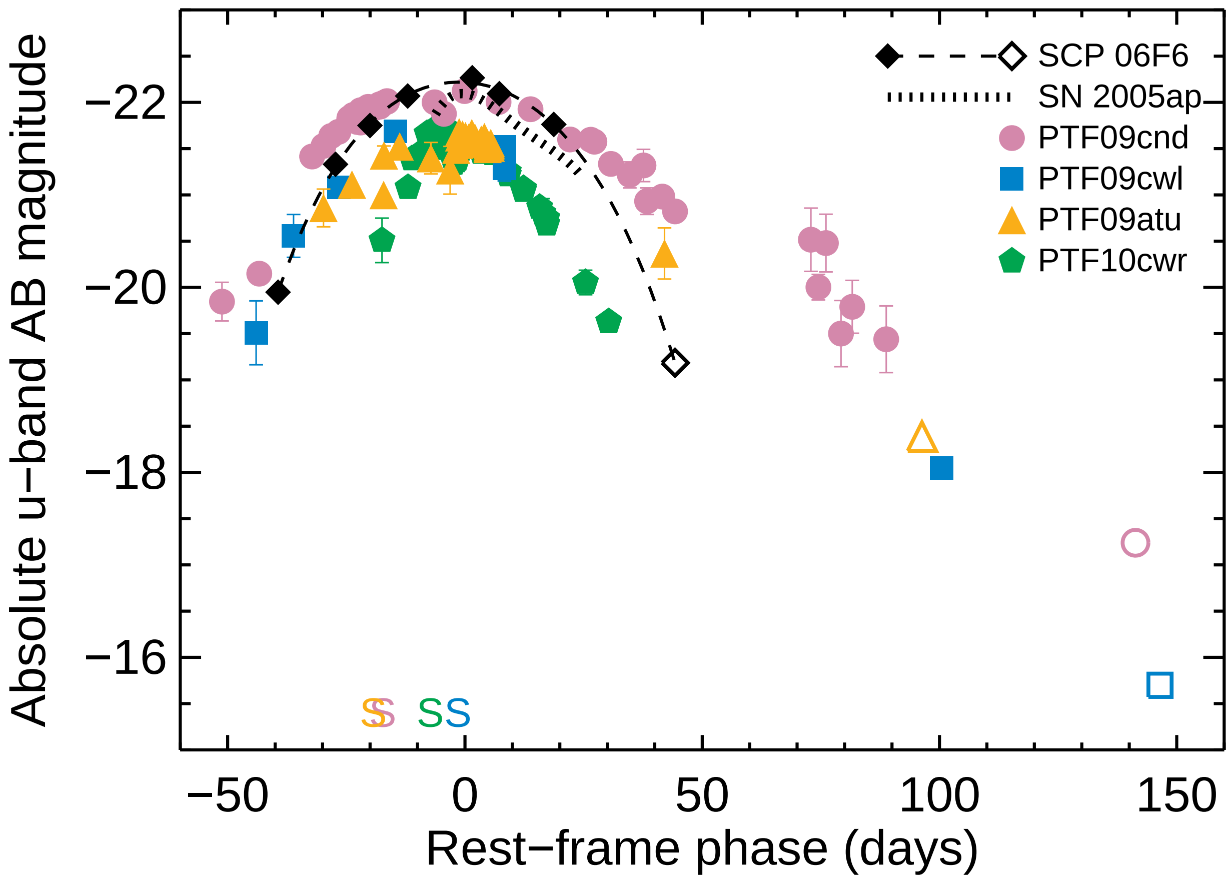
Extremely bright Type Ic SNe

R-band light curves for different SNe Ic
(Young et al. 2010)

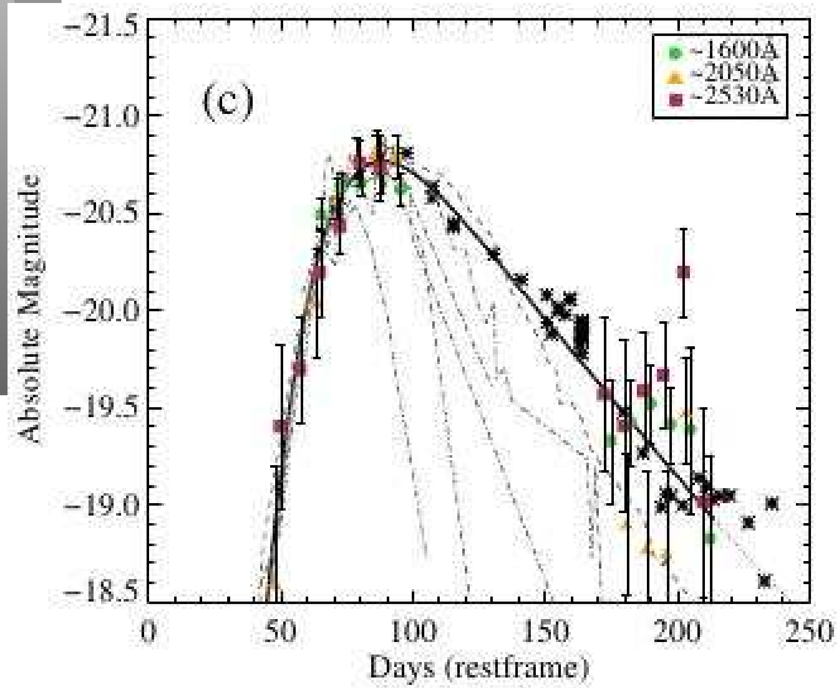


Observations of superluminous SNe

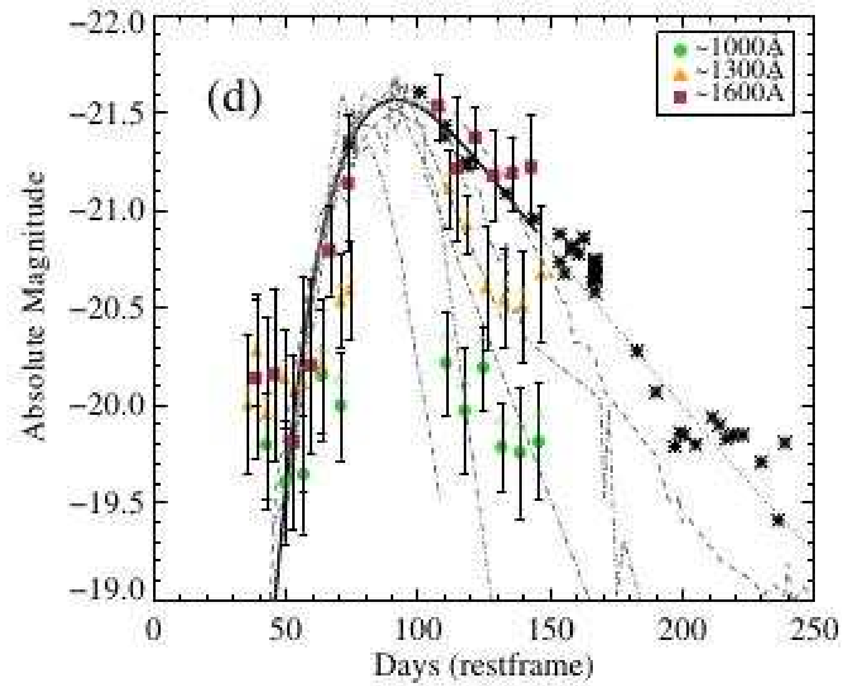
Quimby et al. 2011



More exotic case – High-z SNe



$z = 2.05$



$z = 3.9$

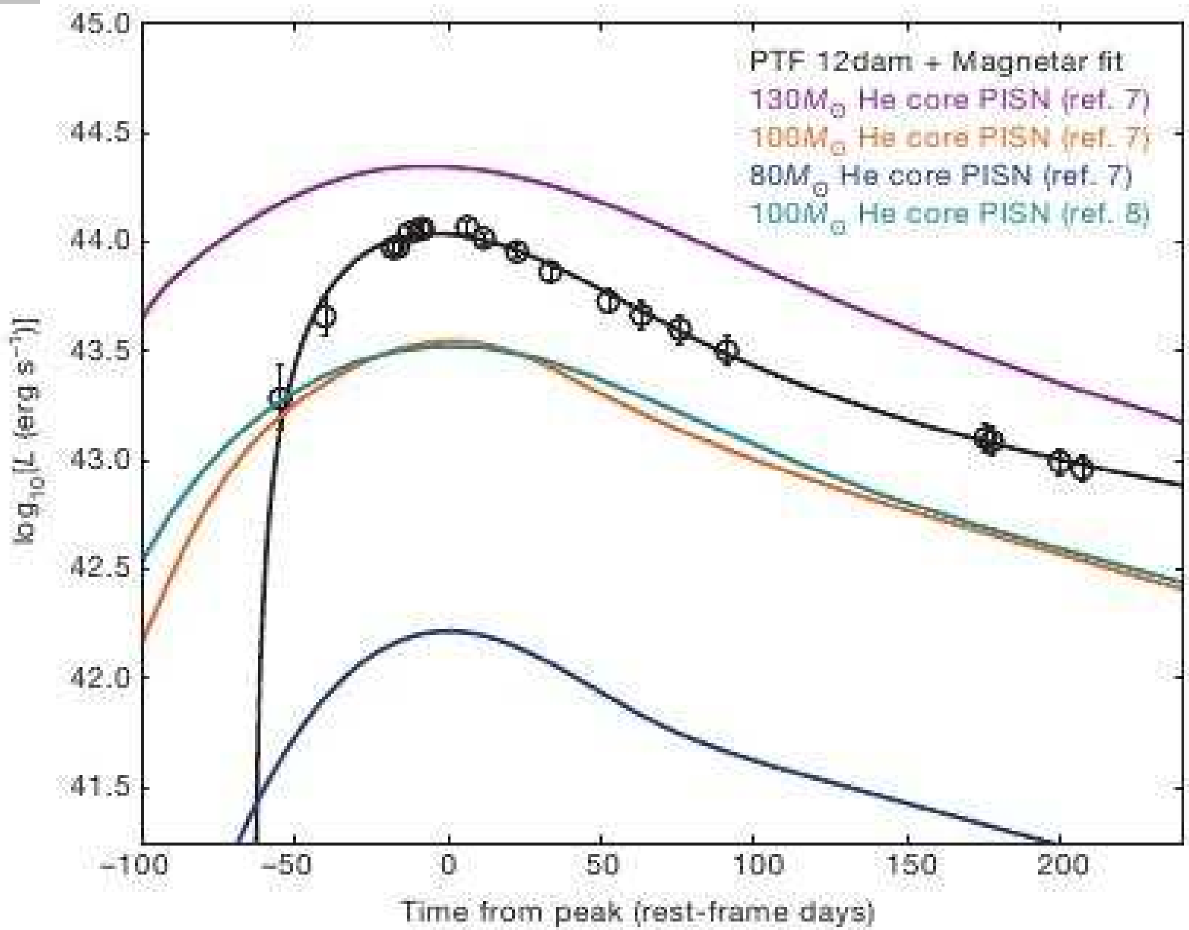
Cooke+ 2012

Possible models for SLSNe

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

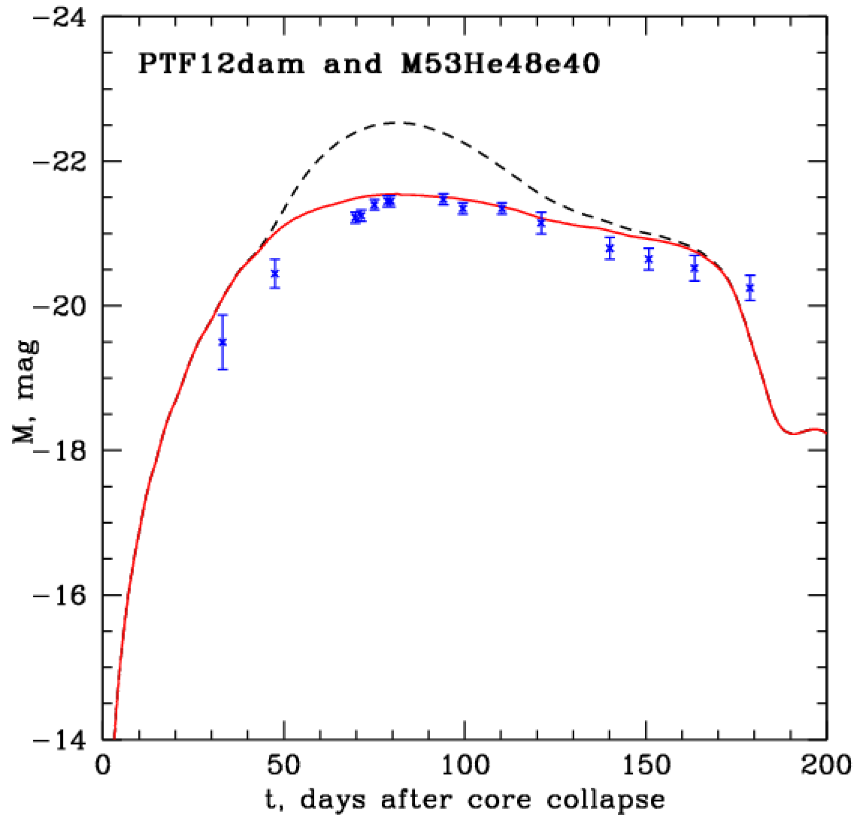
PISN vs. magnetar model

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



Interaction model for PTF12dam

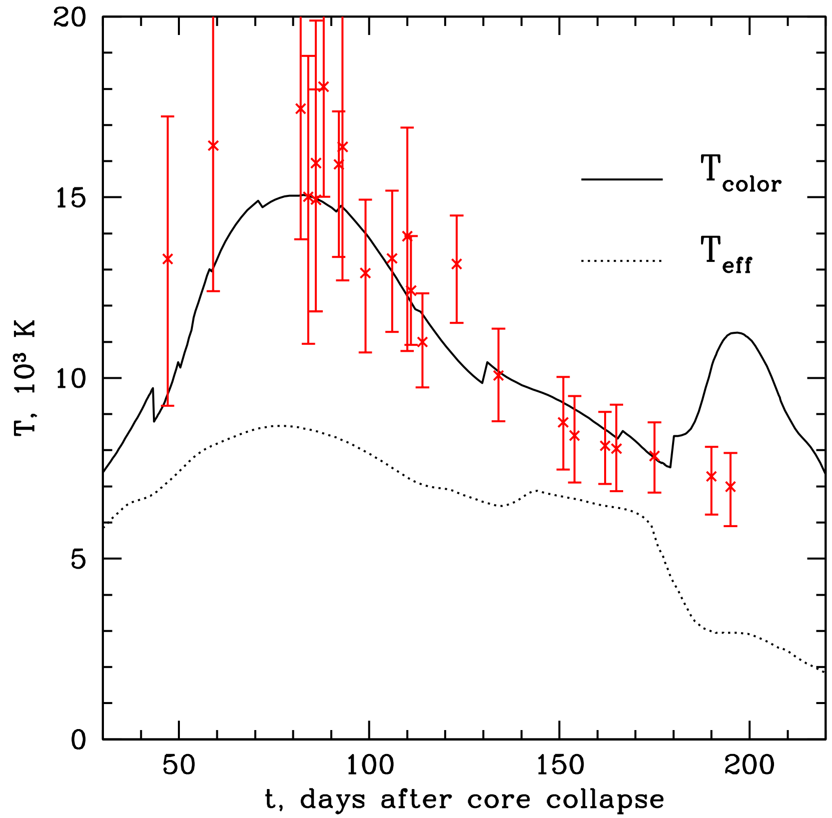
Baklanov, Sorokina, Blinnikov, 2015



Rise time for interacting model of $\sim 50 M_\odot$ He, $E = 4\mathrm{B}$ corresponds to observations !

Interaction model for PTF12dam

Baklanov, Sorokina, Blinnikov, 2015



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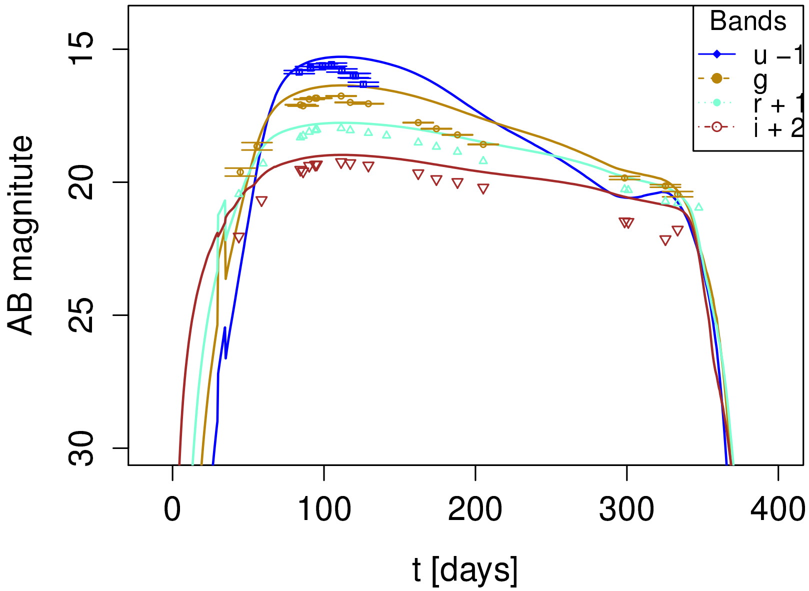
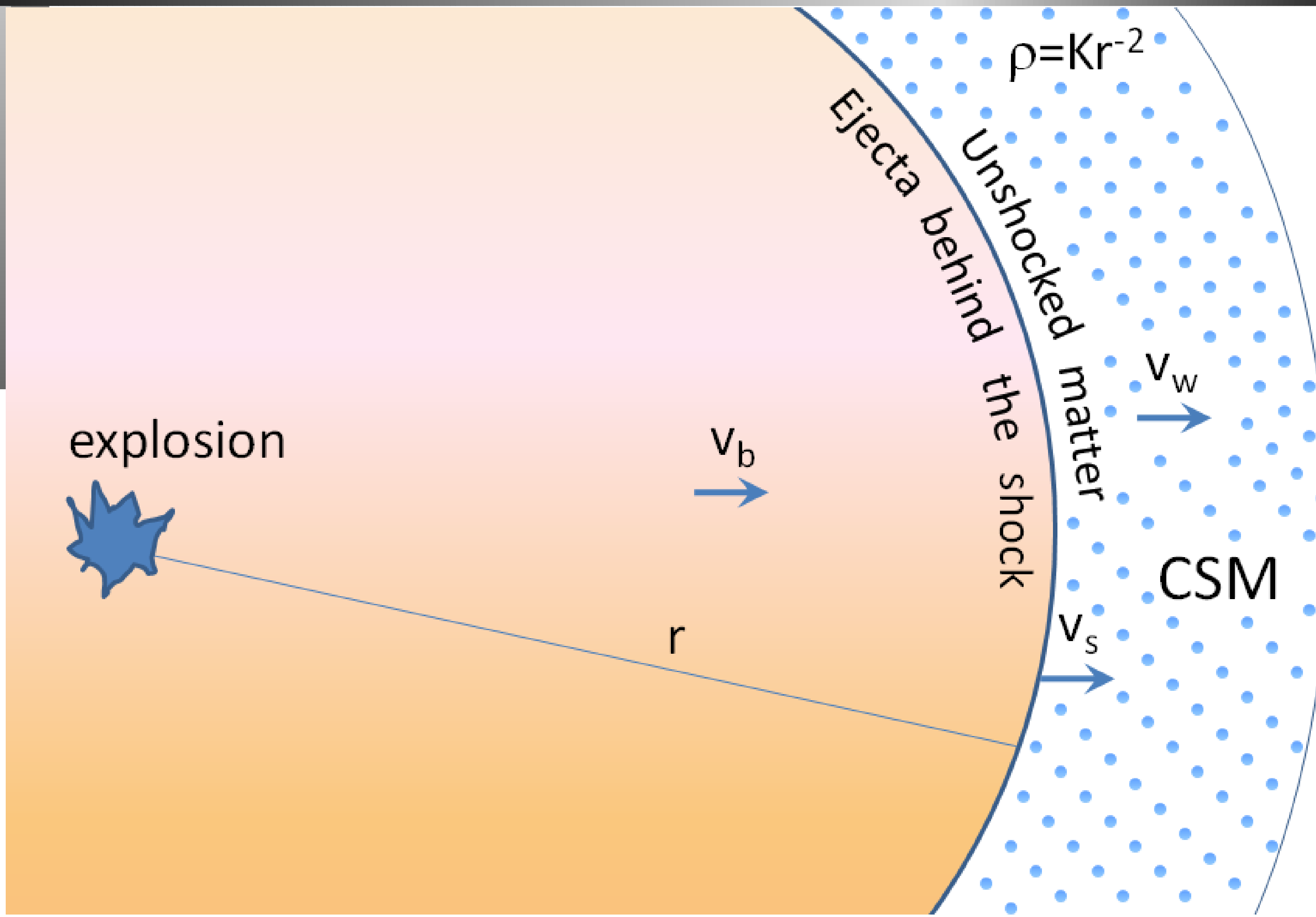
Baklanov, Sorokina, Blinnikov, 2015



Broad band light curves for 100 $M_{\odot}$ of C and O

Windy model for core collapse SNe



Ofek et al. 2010

Windy models for type Ib/c SNe

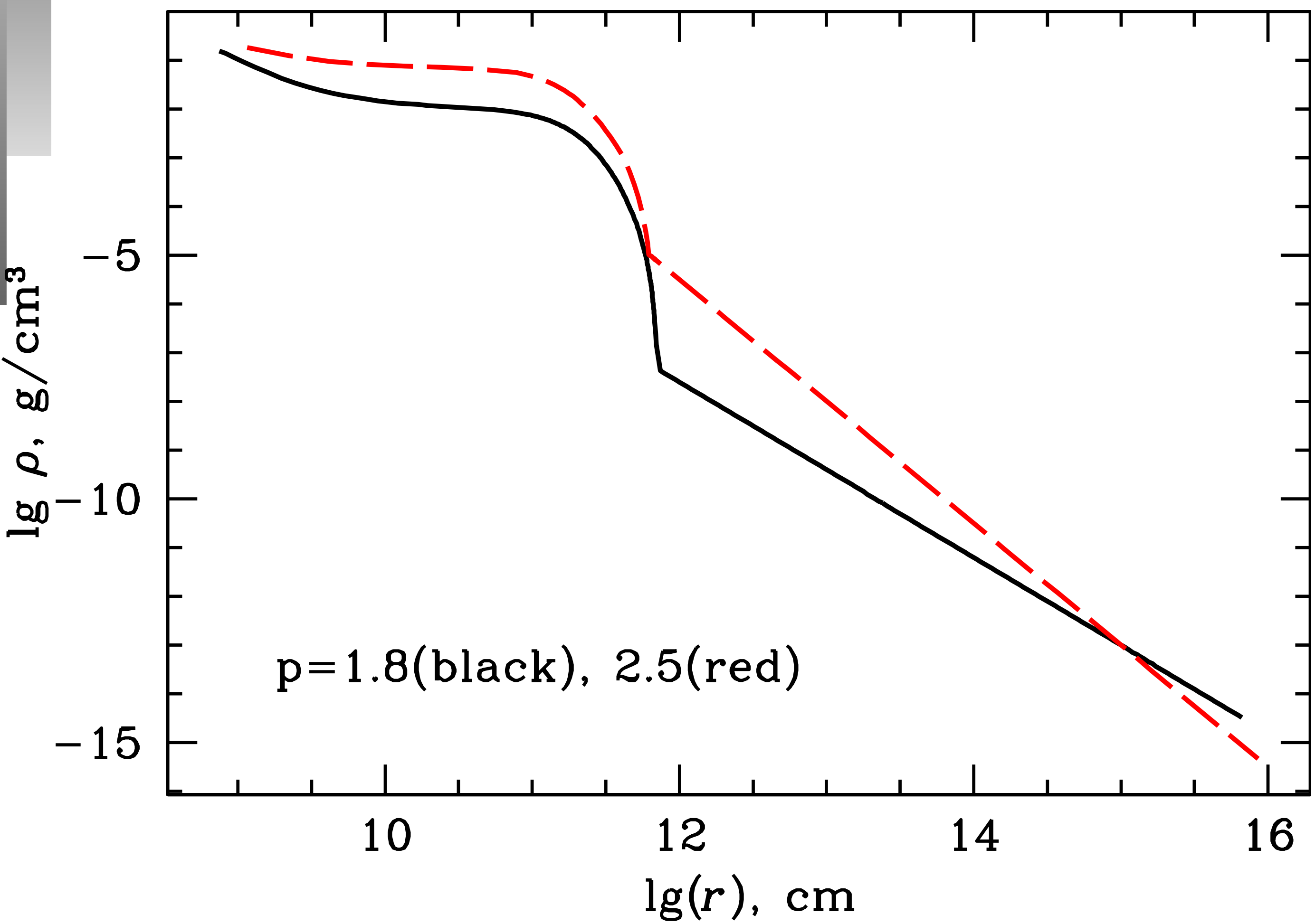
Ejecta: polytropic mass distribution
Parameters: $M_{\rm ej}$, $R_{\rm ej}$, $E_{\rm explosion}$

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

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

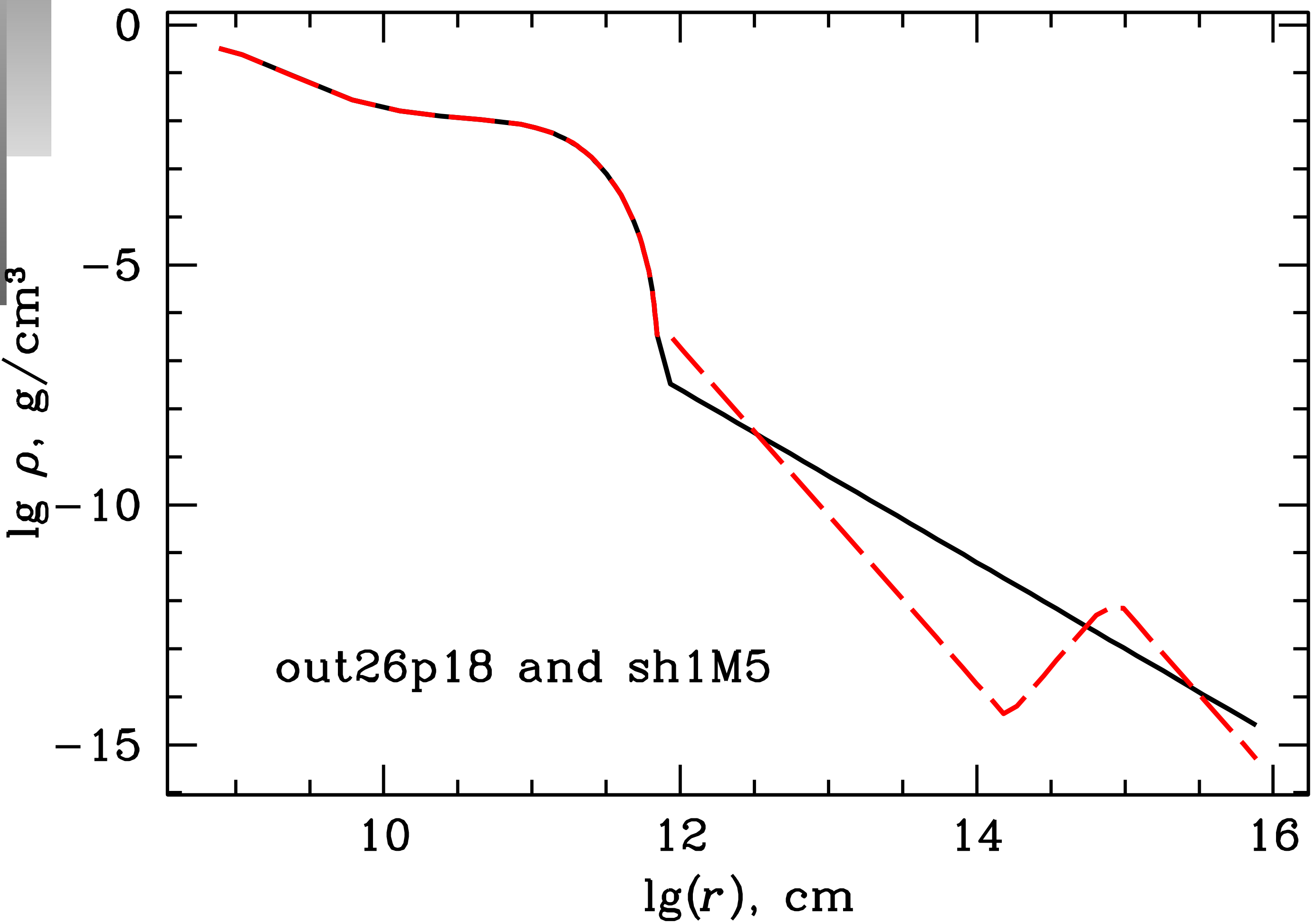
Initial models

Samples of the density distribution



Initial models

Detached envelope



The radiative hydro code STELLA

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- time-dependent equations for the angular moments of intensity (coupled to 1D 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 (sometimes even 1000) 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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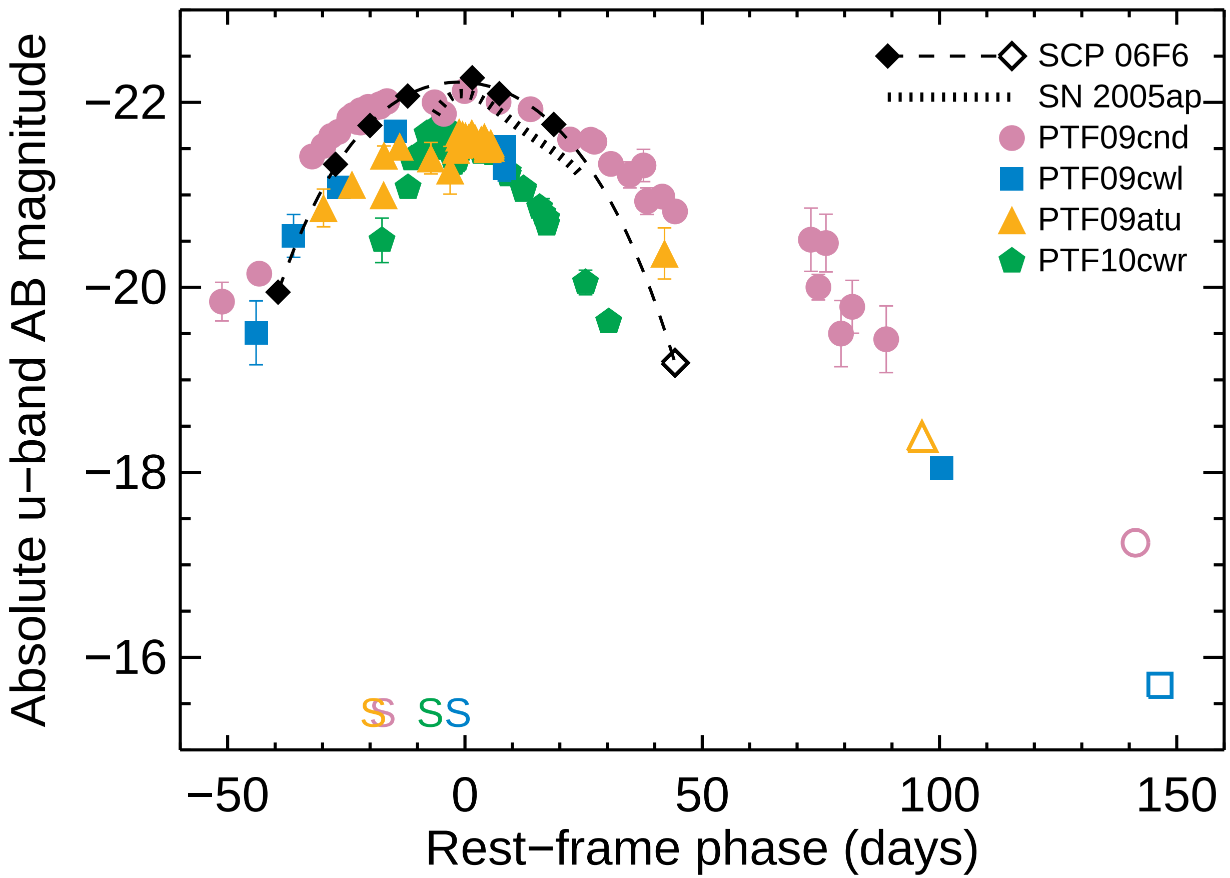
- Local Thermodynamic Equilibrium (LTE) for ionization and atomic level populations is assumed (but radiation is nonequilibrium)
- the effect of line opacity is treated as an expansion opacity according to Eastman & Pinto 1993 (and our new recipes).

SN 2010gx and PTF09cnd – the limiting cases

Quimby et al. 2011

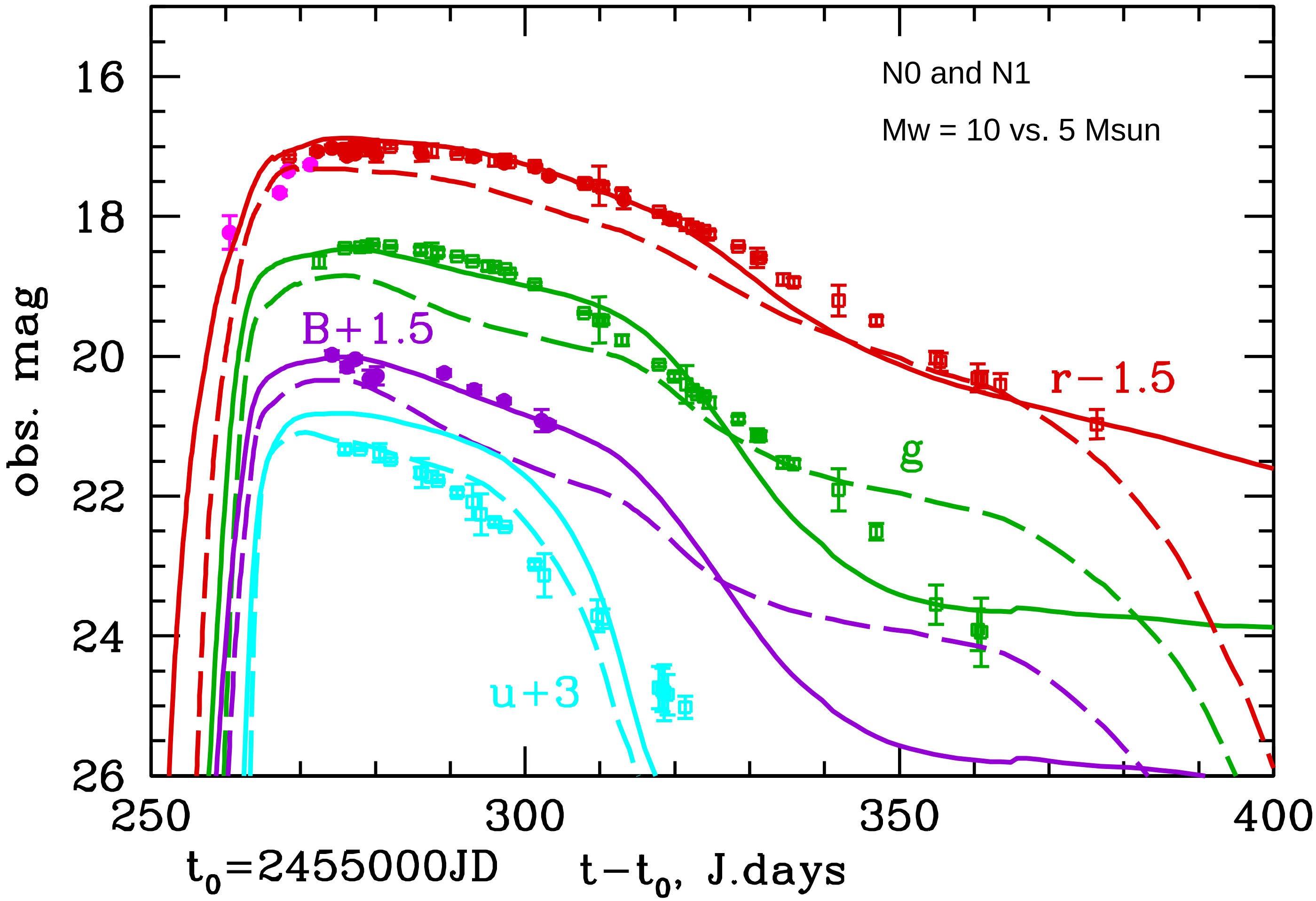


Models for SN 2010gx and PTF09cnd

Model	$M_{\rm ej}$	$R_{\rm ej}$	p	structure	$M_{\rm w}$	$R_{\rm w}$	$E_{\rm expl}$,	$E_{\rm w,kin}$,	Composition
N0	0.2	10	1.8	env	9.7	10^5	2	.04	CO7
N1	0.2	10	1.8	env	4.9	10^5	2	.02	CO7
N2	0.2	10	1.5	env	4.8	10^5	2	.02	CO7
N3	0.2	10	1.8	env	4.9	10^5	2	.02	CO9
N4	0.2	10	1.8	env	4.9	10^5	2	0	CO9
N5	0.2	10	1.8	env	4.9	10^5	3	0	CO9
N6	0.19	10	3.5	sh	9.8	10^5	2	.1	CO9
N7	0.19	10	3.5	sh	9.8	10^5	2	0	CO9
N8	0.19	10	3.5	sh	4.7	10^5	2	0	CO9
B0	5	10	1.8	env	49	10^5	4	0	CO9
B1	5	10	1.8	env	49	10^5	4	.1	CO9
B2	5	10	1.8	env	49	10^5	4	.3	CO9
B3	0.2	10	1.8	env	20	10^5	4	0	He
B4	0.2	10	1.8	env	20	10^5	4	0	CO5
B5	0.2	10	1.8	env	20	10^5	4	0	CO9

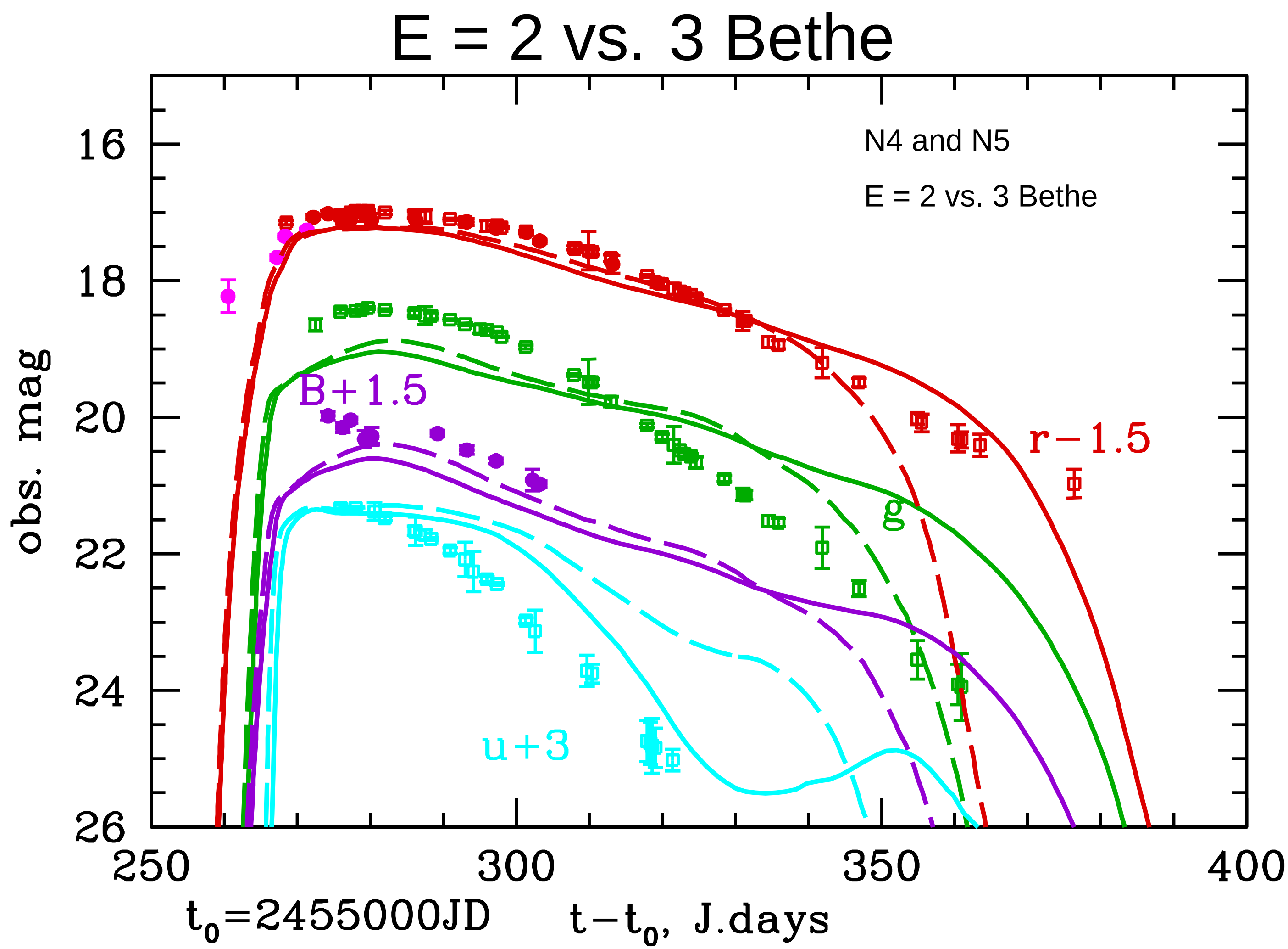
Light curves for SN 2010gx

Mw = 10 vs. 5 $M_\odot$



Sorokina+ (2015)

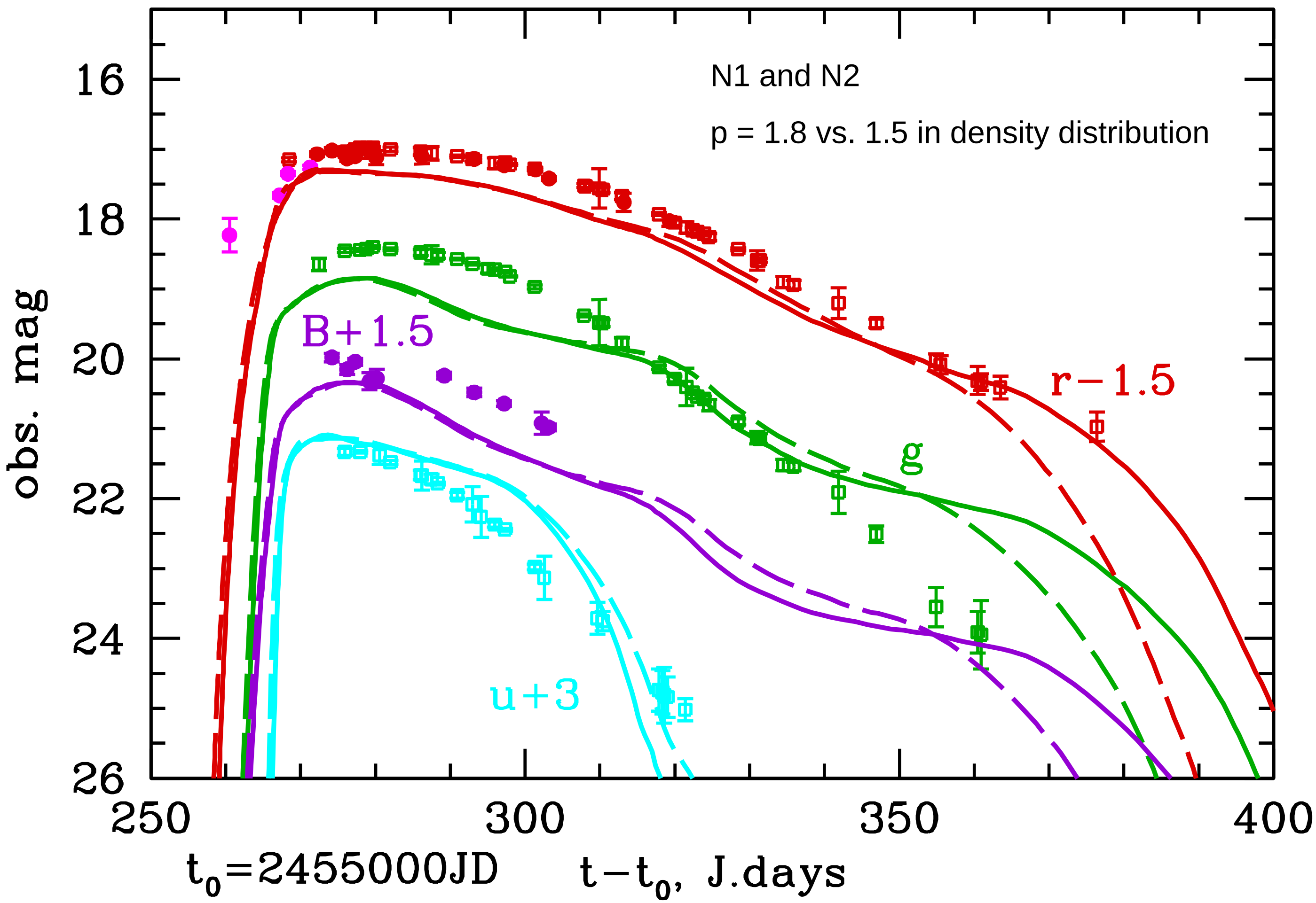
Light curves for SN 2010gx



Sorokina+ (2015)

Light curves for SN 2010gx

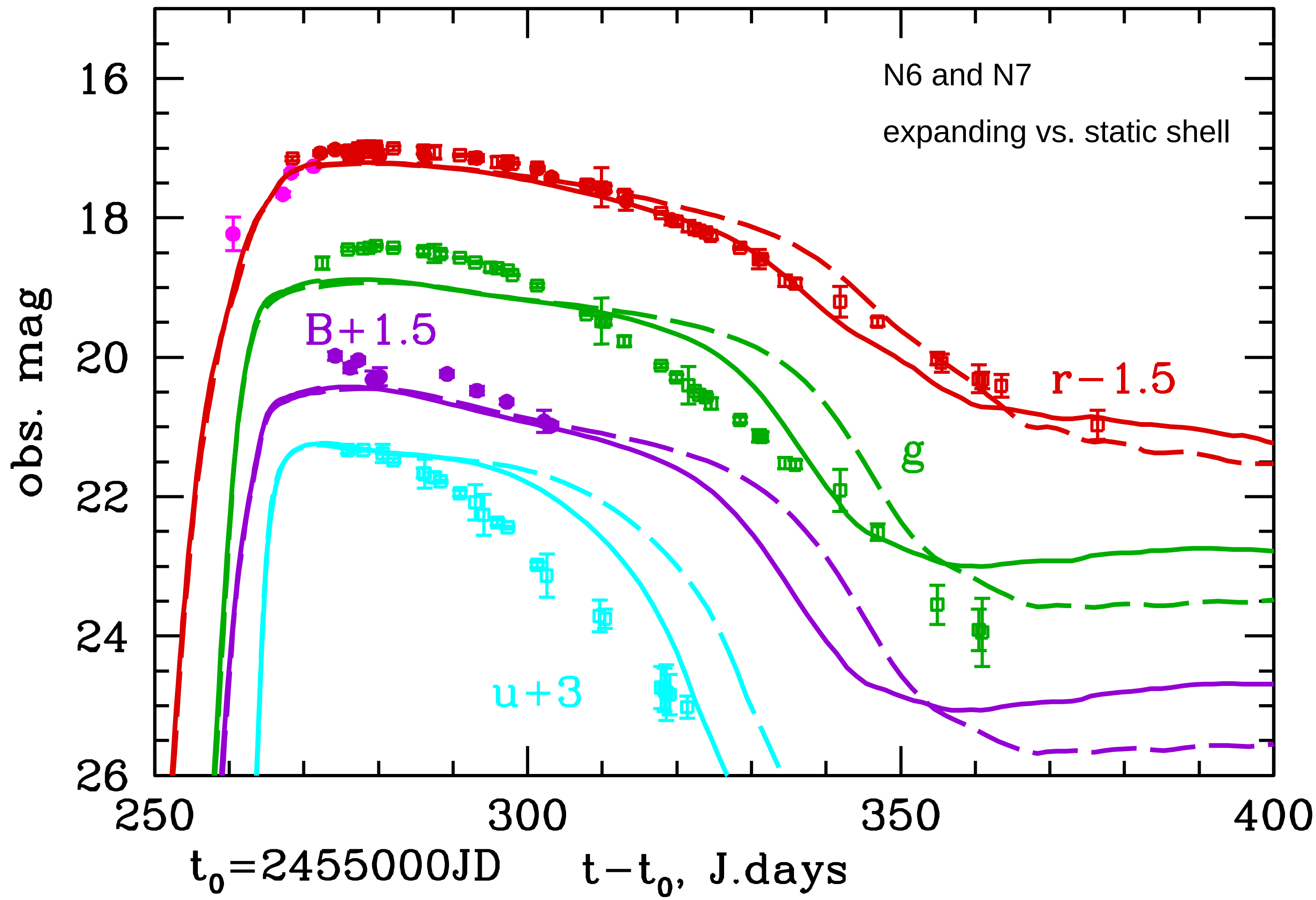
p = 1.8 vs.1.5 in $\rho_w \sim r^{-p}$



Sorokina+ (2015)

Light curves for SN 2010gx

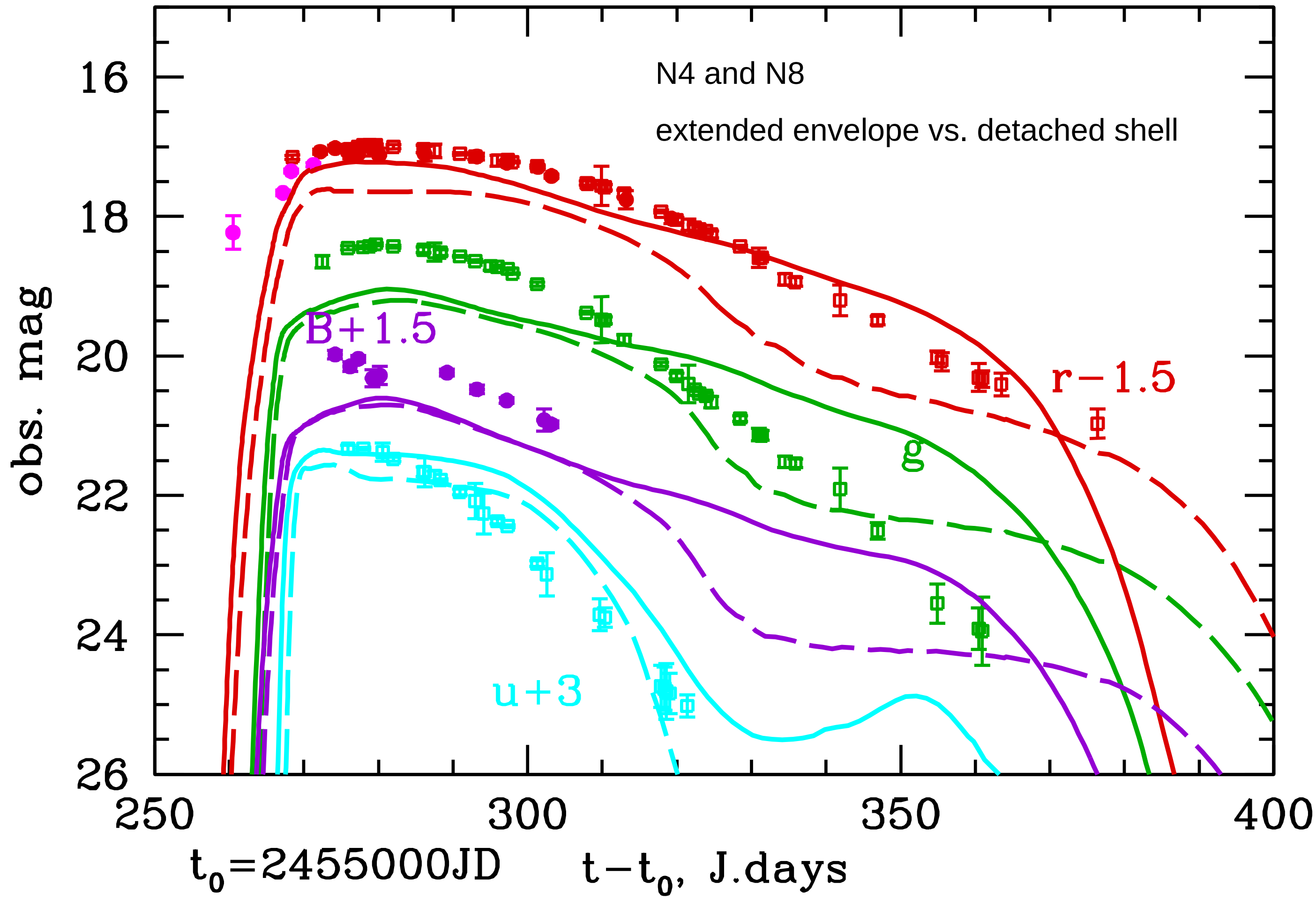
Ew = 0.1B ($v_{\rm max}$=1,800km/s) vs. *STATIC*



Sorokina+ (2015)

Light curves for SN 2010gx

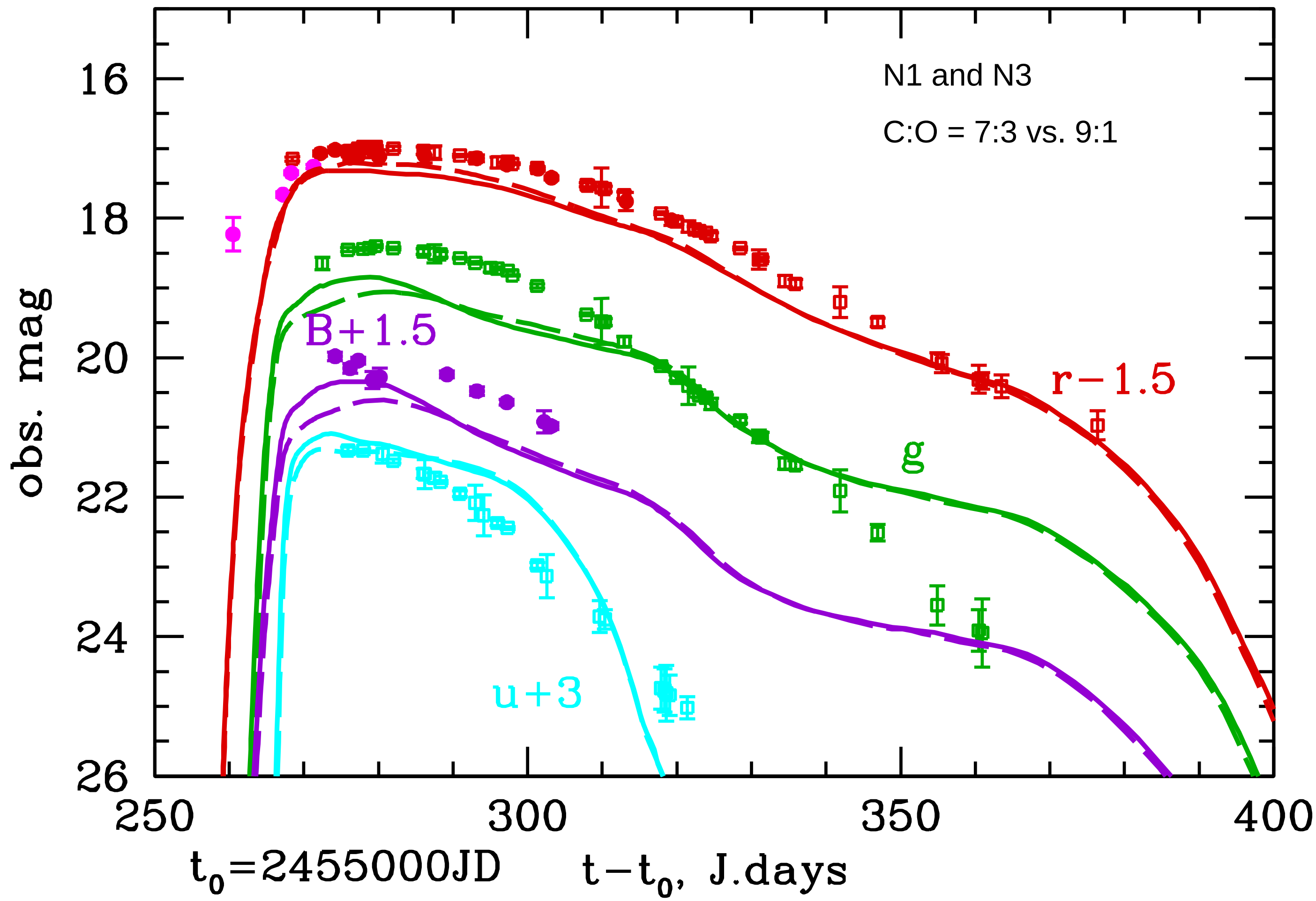
Extended envelope vs. detached shell



Sorokina+ (2015)

Light curves for SN 2010gx

C : O = 7 : 3 vs. 9 : 1



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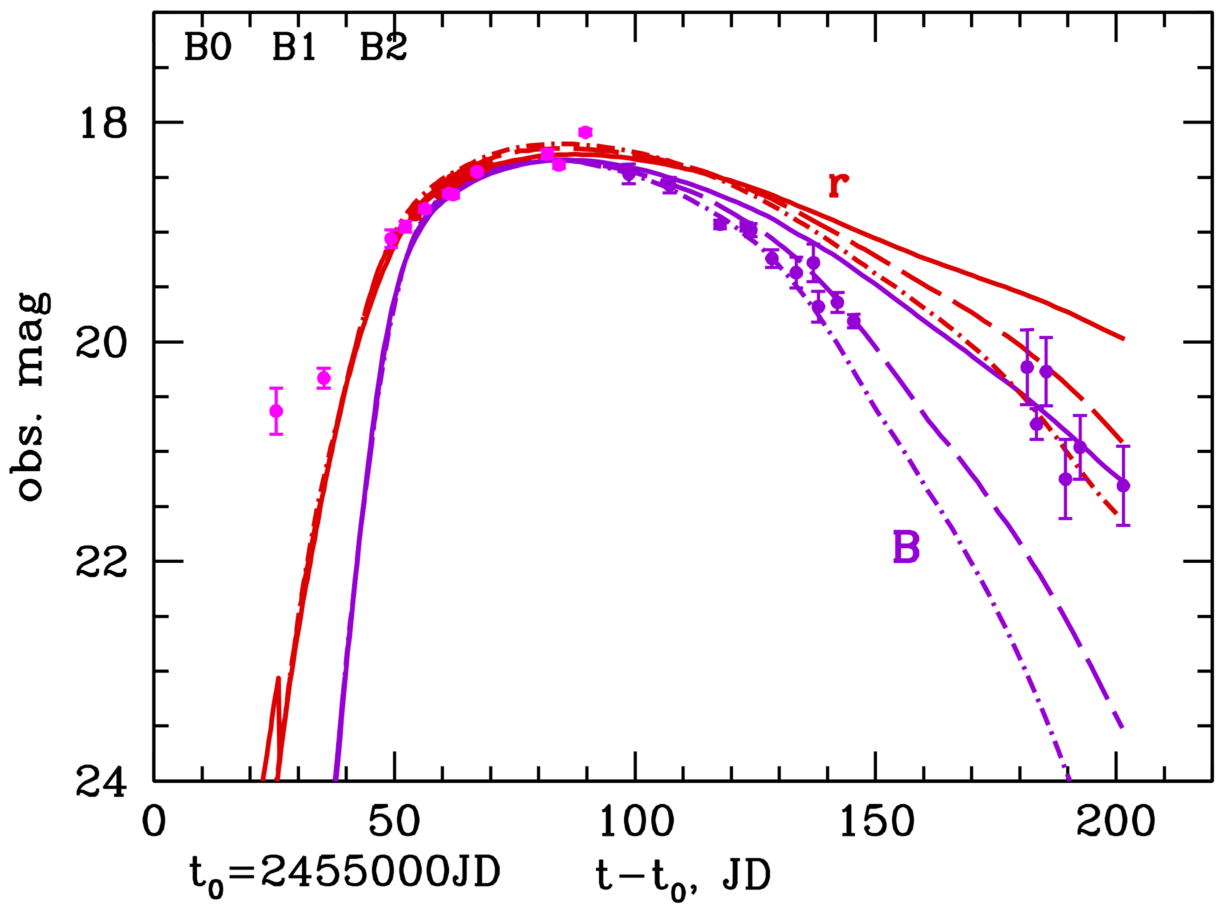
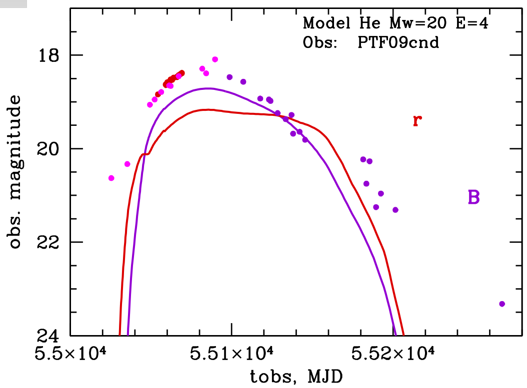
Light curves for PTF09cnd

B0(static); B1(Ew=.1B,Vmax=750km/s);
B2(Ew=.3B,Vmax=1,300km/s)

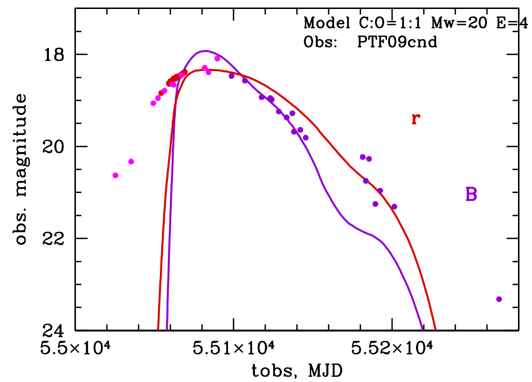


Sorokina+ (2015)

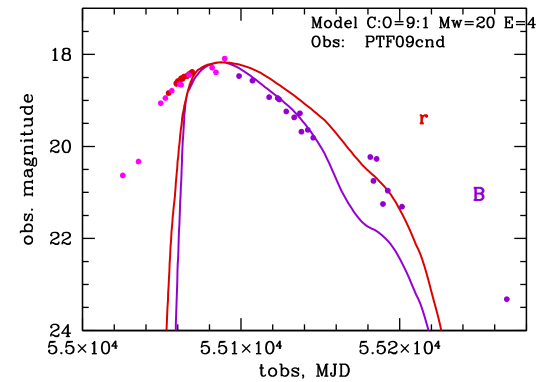
Different composition



Helium



C:O=1:1



C:O=9:1

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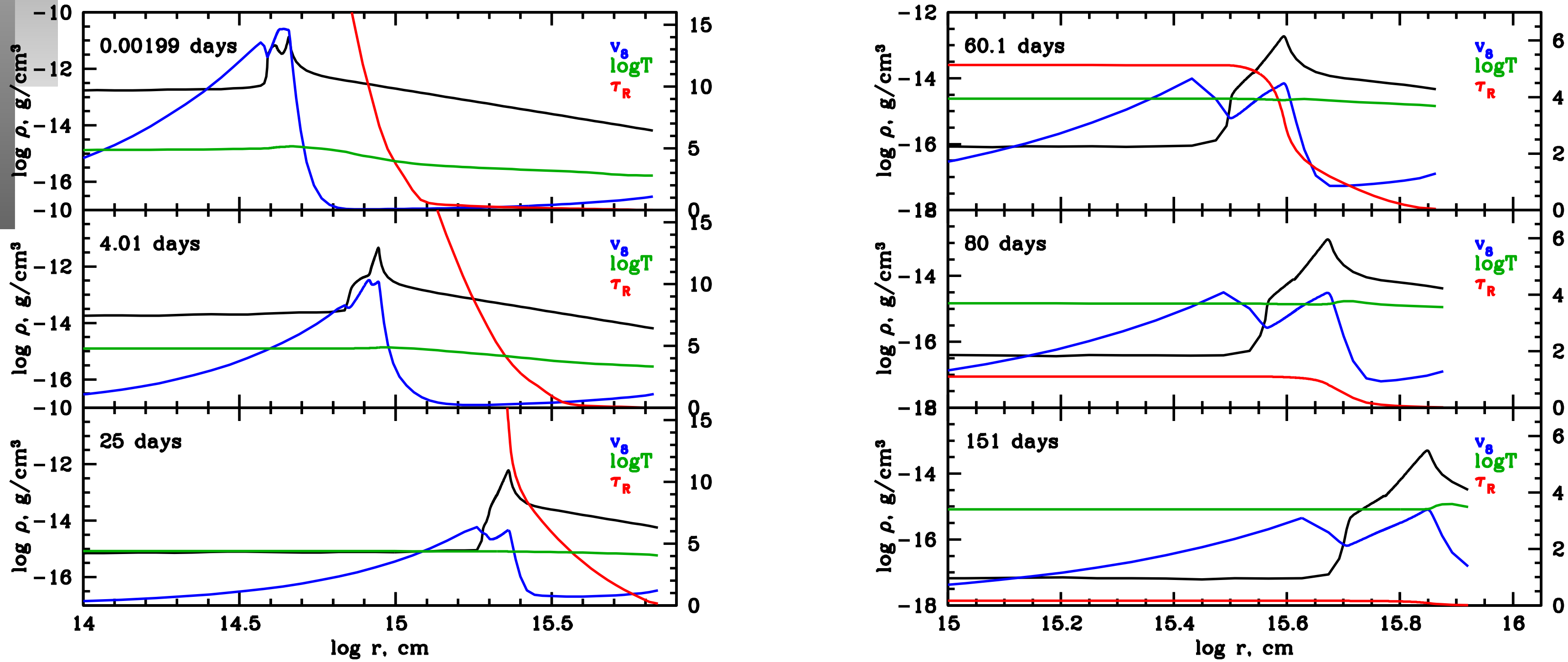
Hydro evolution

Model N0



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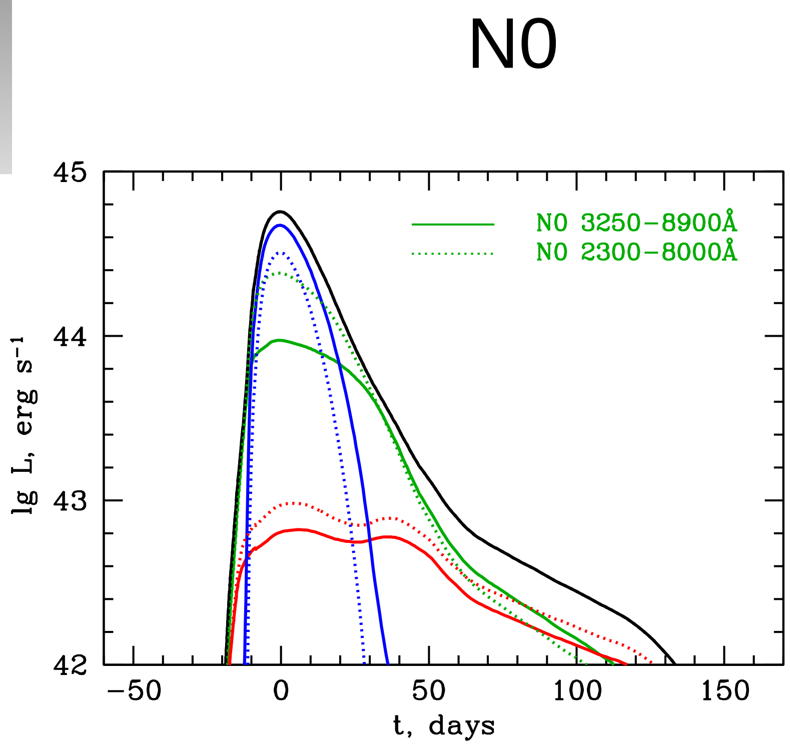
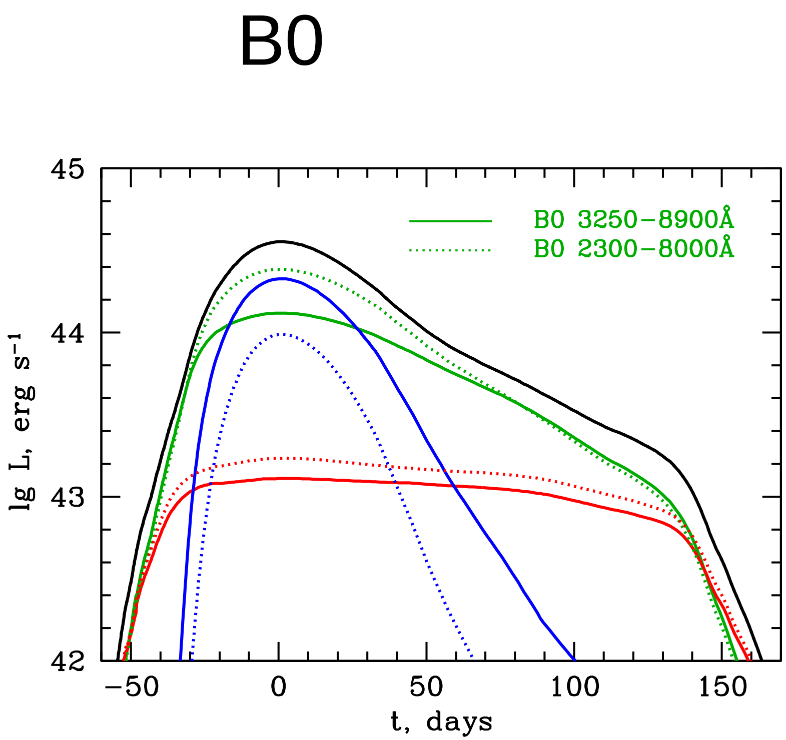
Bolometric light curves





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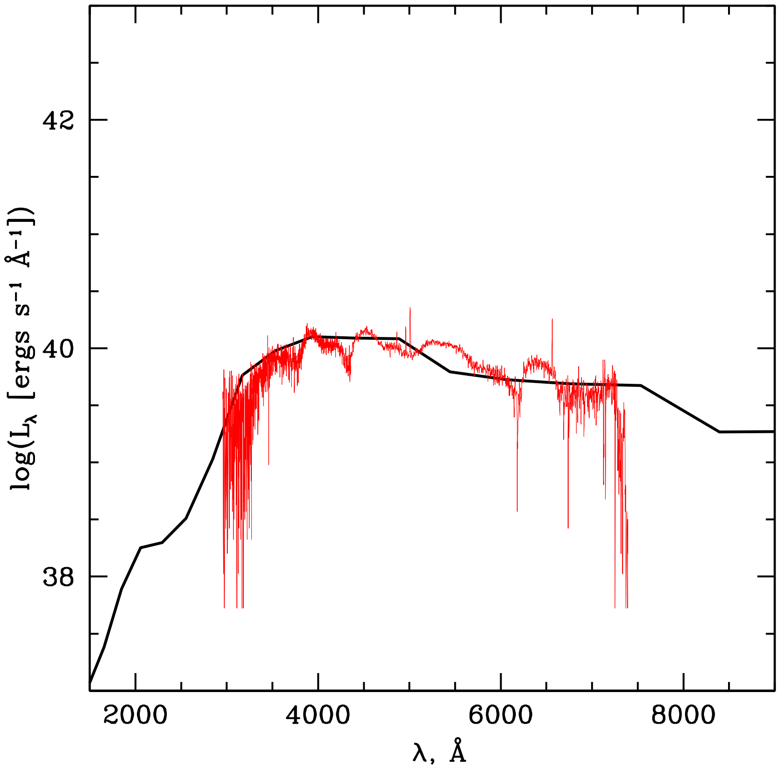
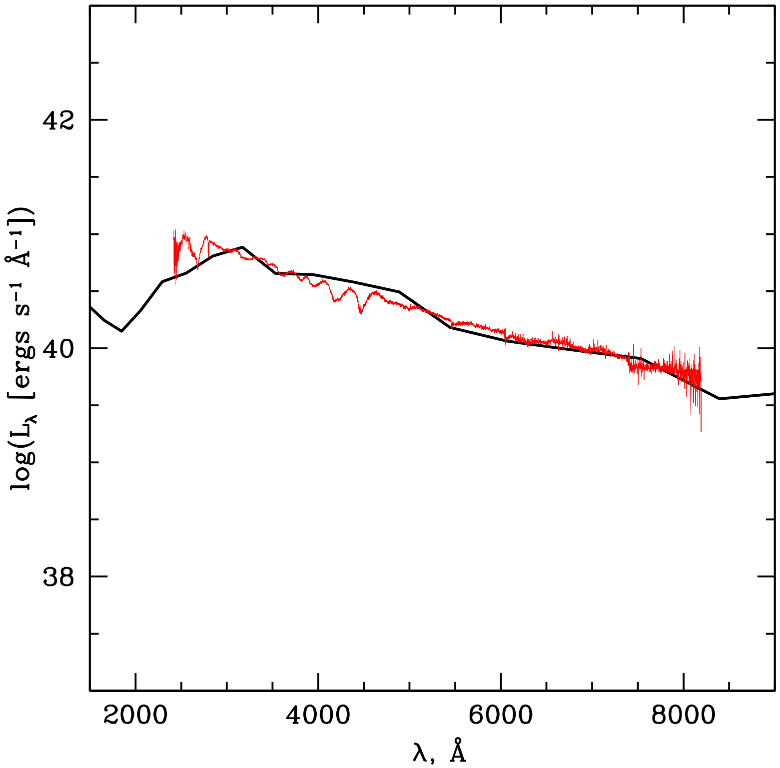
Spectra

SN 2010gx at day +27
N0 at day +32



PTF09cnd at day -20
B0 at day -20



Sorokina+ (2015)

Conclusion

Light curves and spectra for both SN 2010gx and PTF09cnd can be fitted by interacting model, which means that the bulk of SLSNe Ic can come from interaction of SN ejecta with rather dense and extended envelope the origin of which is not well understood yet.

It must be rare event since the model requires large amount of carbon surrounding the exploding star - challenge for stellar evolution theory.

Thank you!