Non-Hydrogen Windy Models for Superluminous Supernovae

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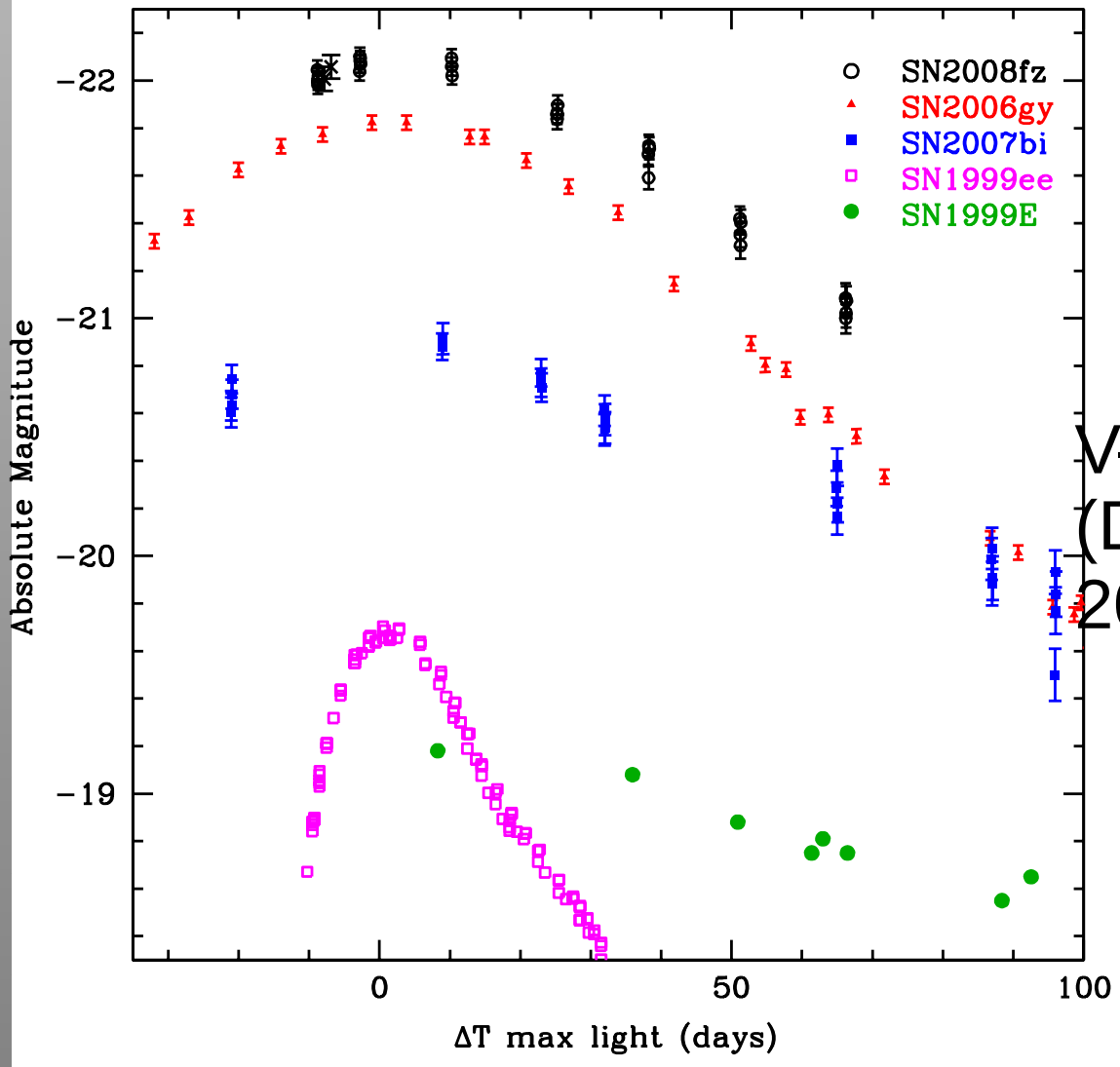
Extremely bright Type IIn SNe



V-band (Drake et al. 2010)

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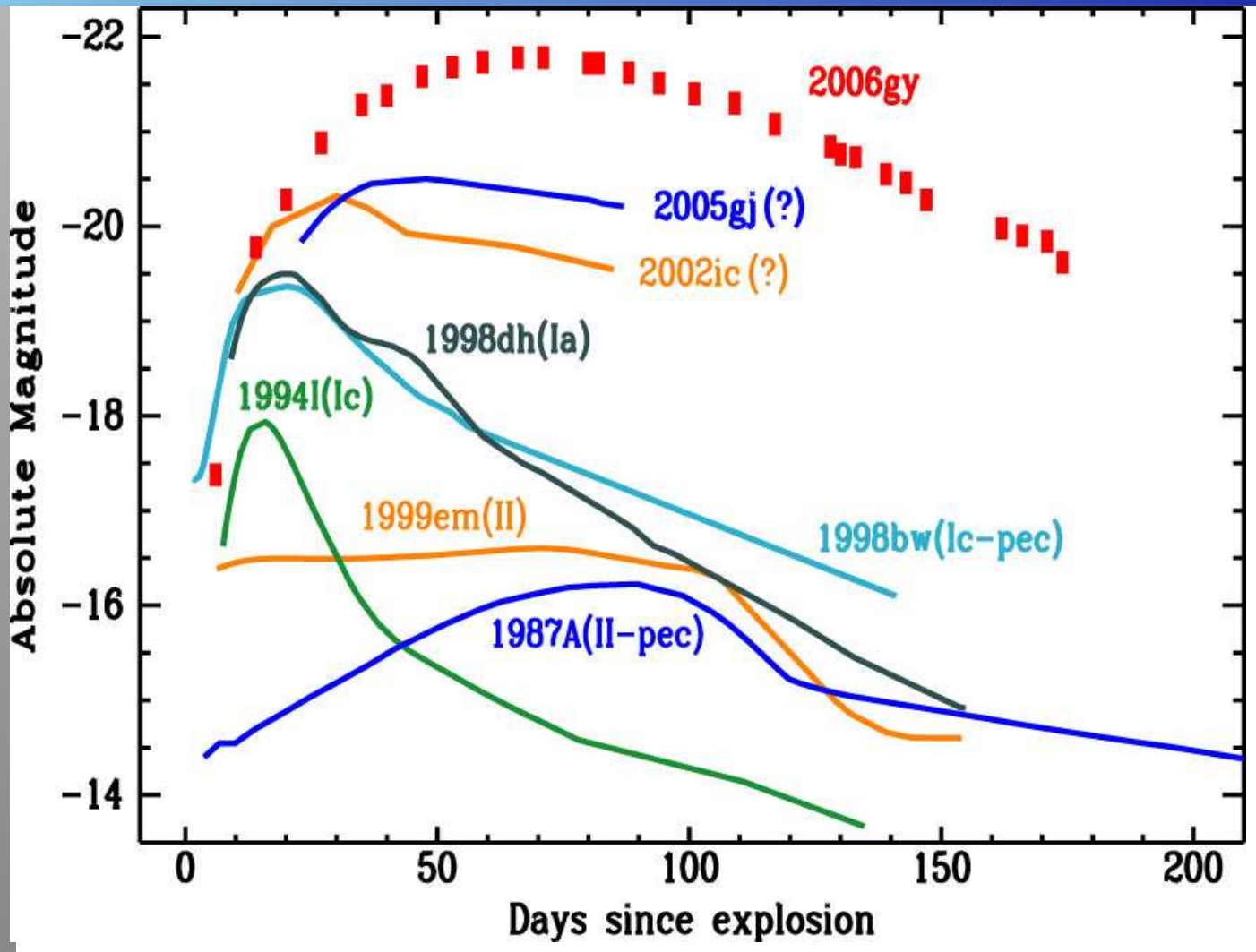
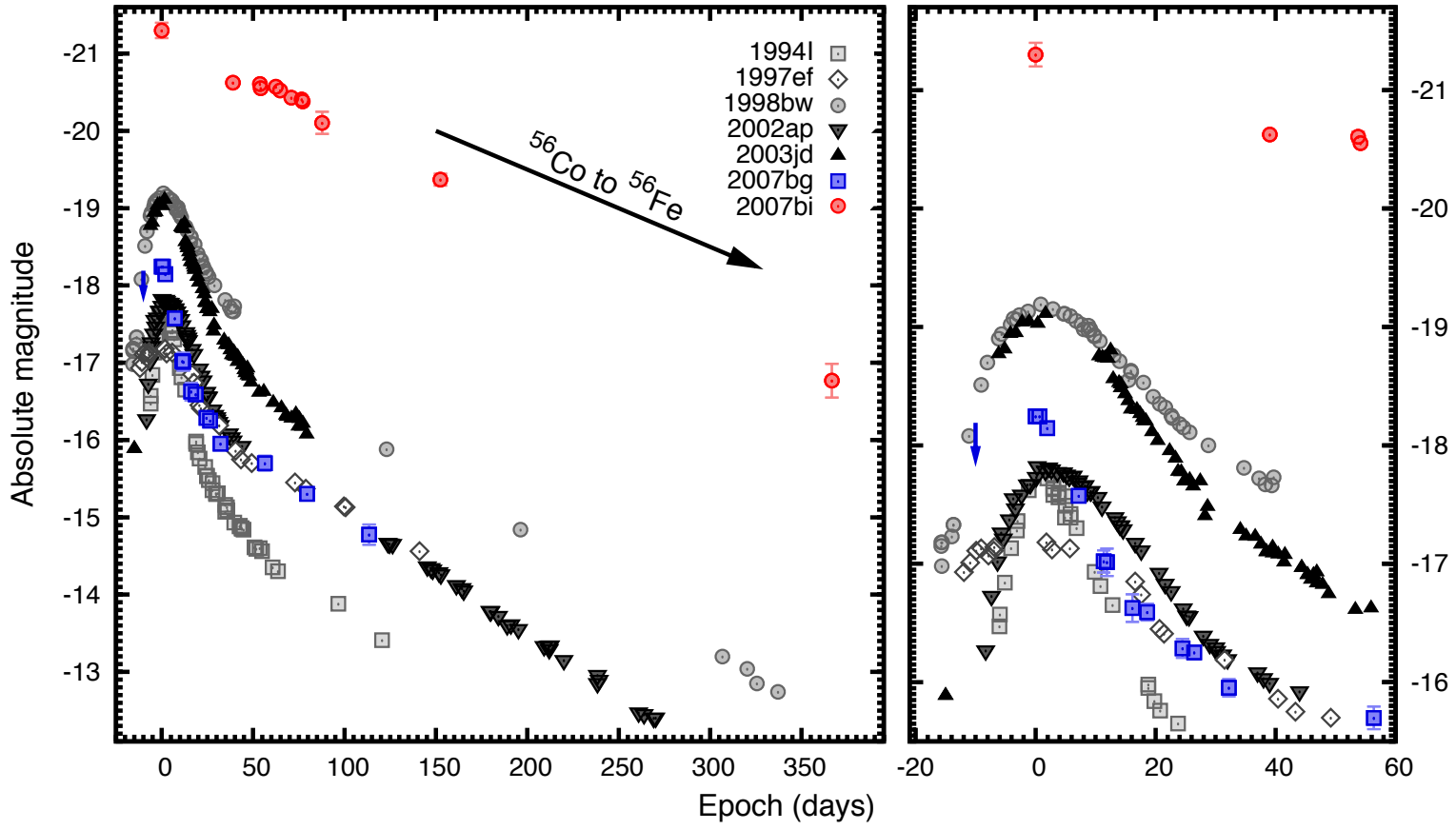


V-band (Drake et al. 2010)

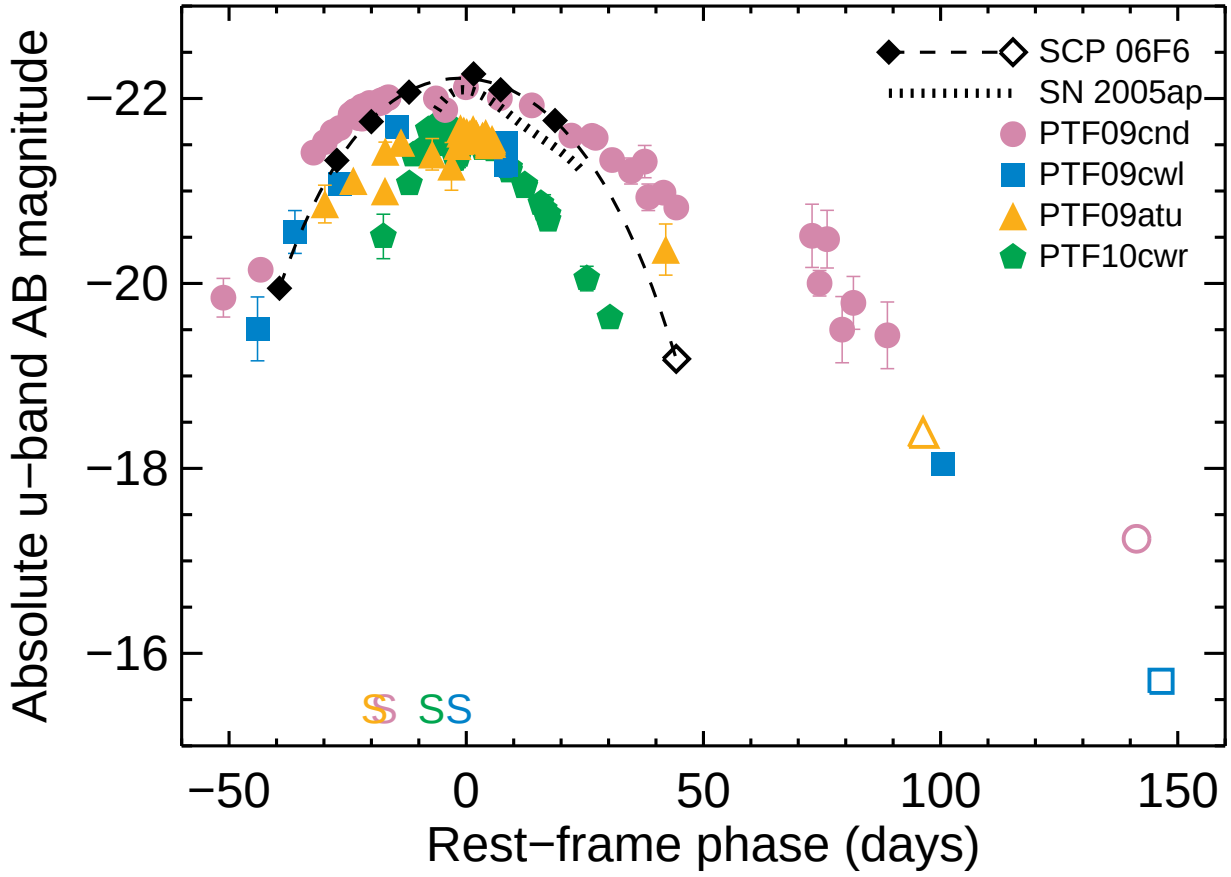
Extremely bright Type Ic SNe

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

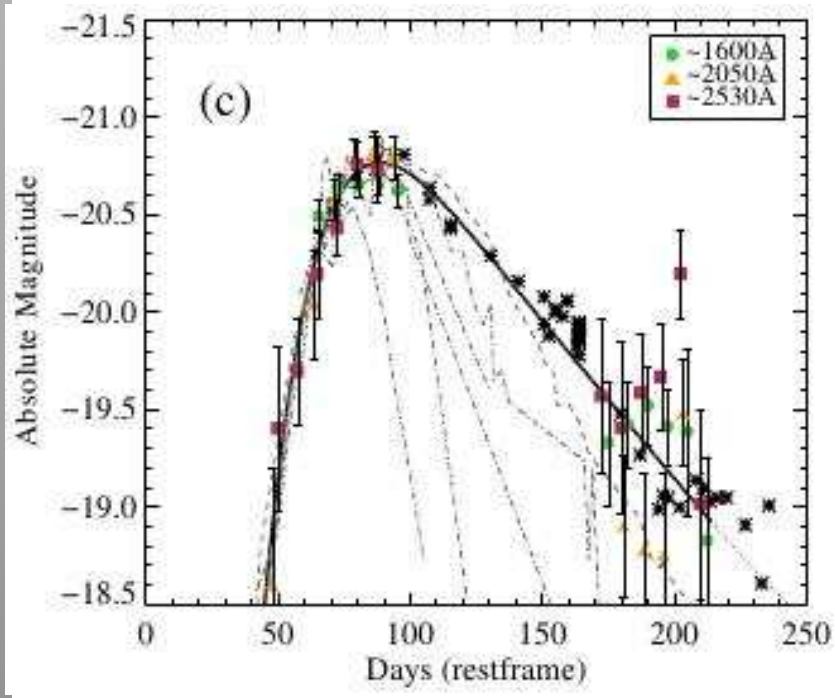


Observations of the superluminous SNe

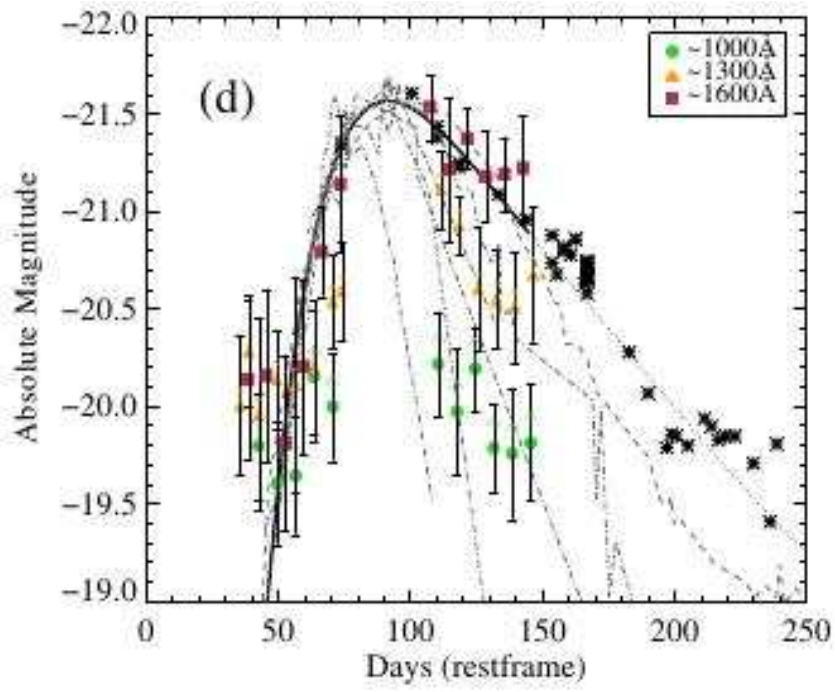
Quimby et al. 2011



More exotic case – High-z SNe



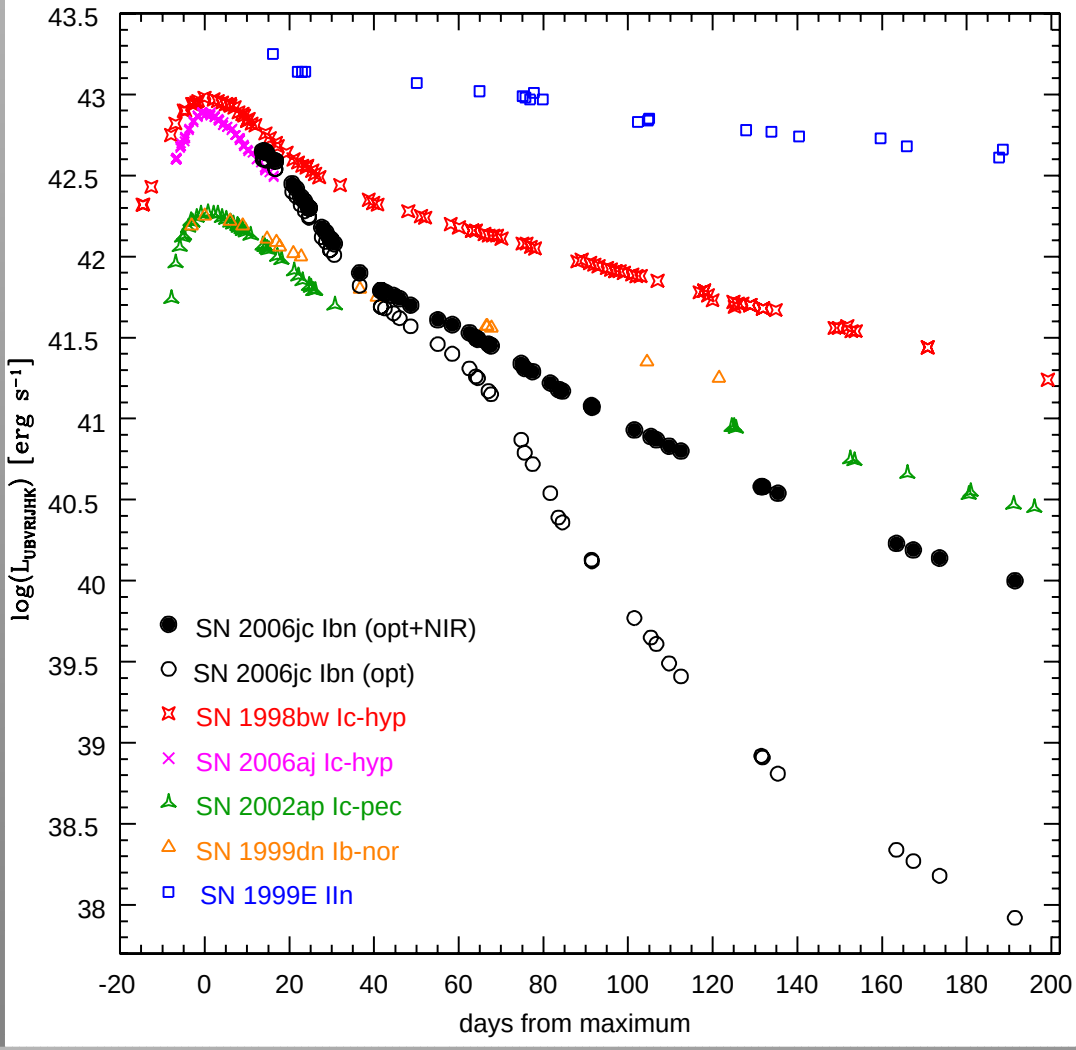
$z = 2.05$



$z = 3.9$

Cooke+ 2012

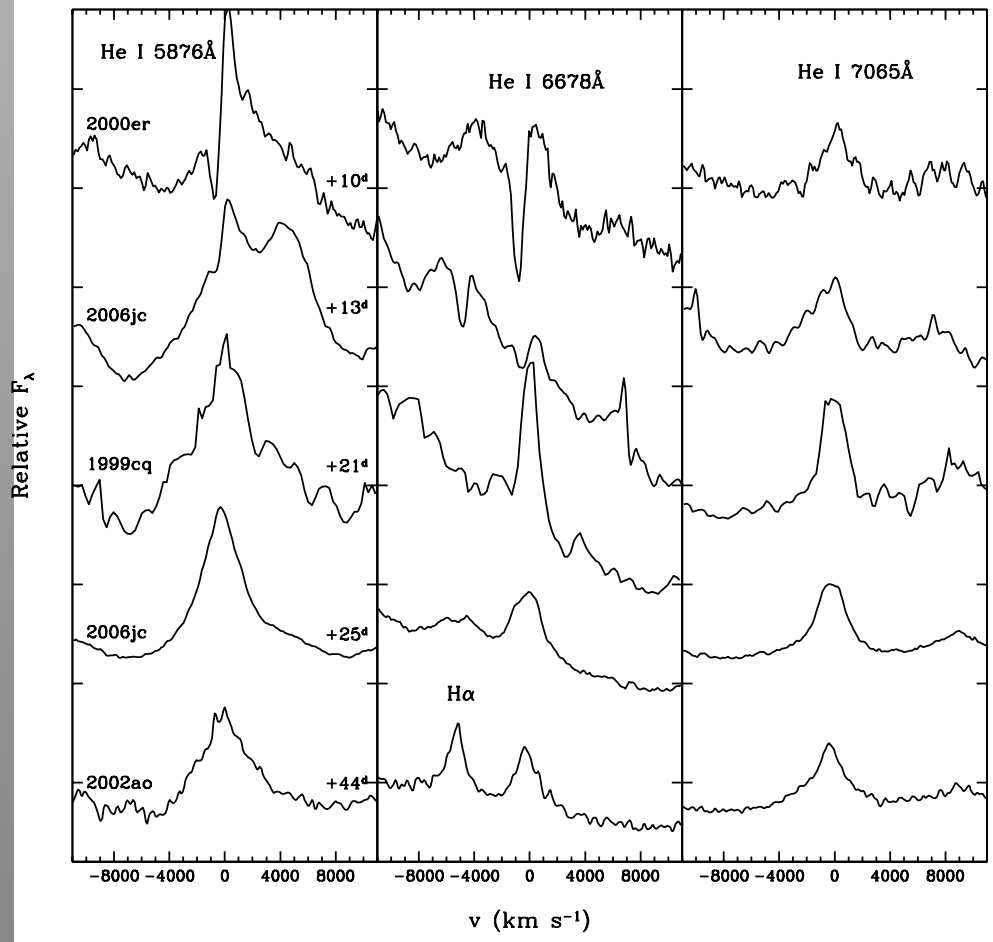
Very bright Type Ib SNe with narrow lines



Type Ibn

Quasi-bolometric (optical+NIR) (Pastorello et al. 2008)

Very bright Type Ib SNe with narrow lines



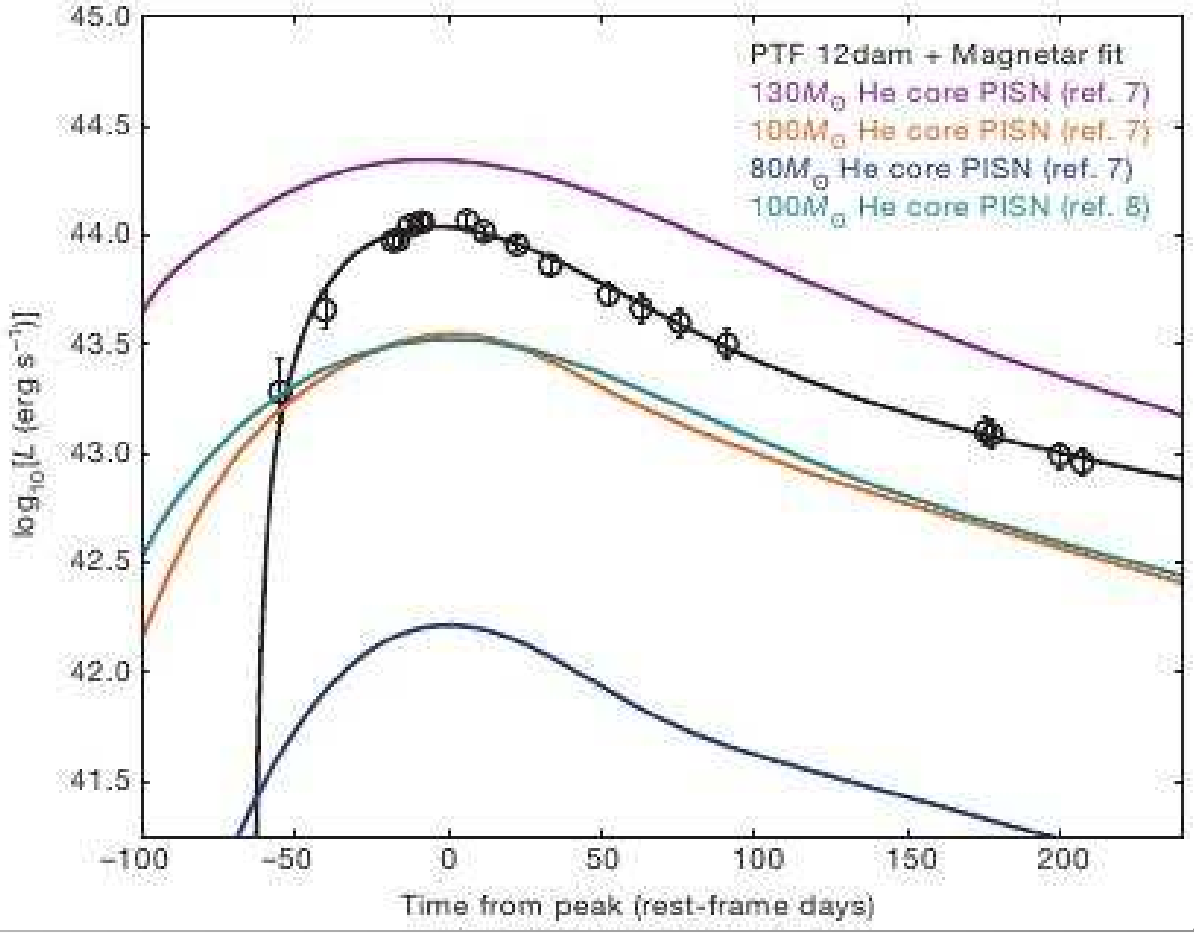
Pastorello et al. 2008

Possible models for SLSNe

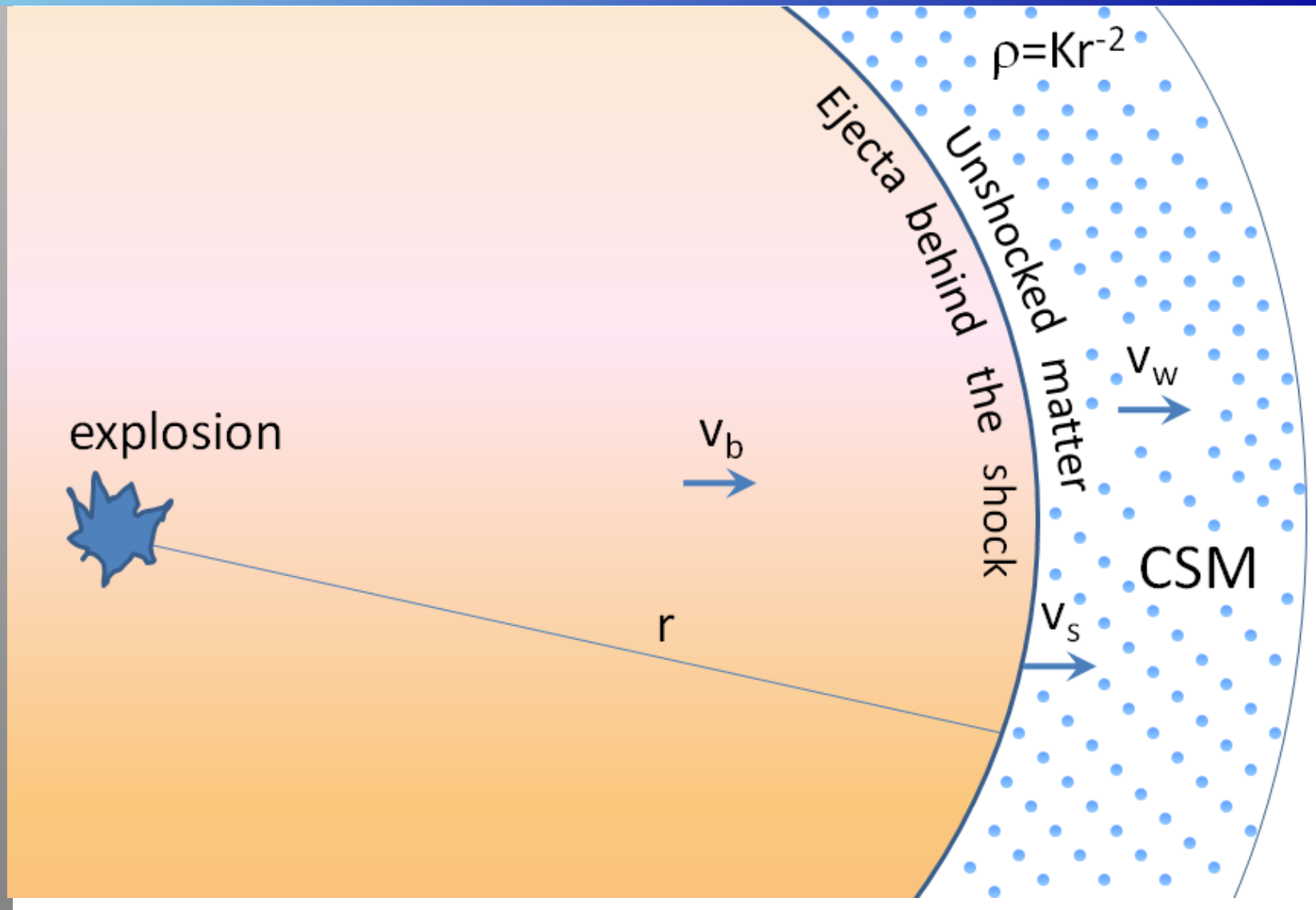
- Pair instability SNe
- Magnetar energy pumping
- Interaction with CSM

PISN vs. magnetar model

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



Windy model for core collapse SNe



Ofek et al. 2010

Windy models for type Ib/c SNe

Ejecta: polytropic mass distribution

Parameters: $M_{\rm ej}$, $R_{\rm ej}$.

Wind: power-law mass distribution $\rho \sim r^{-p}$

Parameters: $M_{\rm w}$, $R_{\rm w}$, p

(only 2 of them are independent).

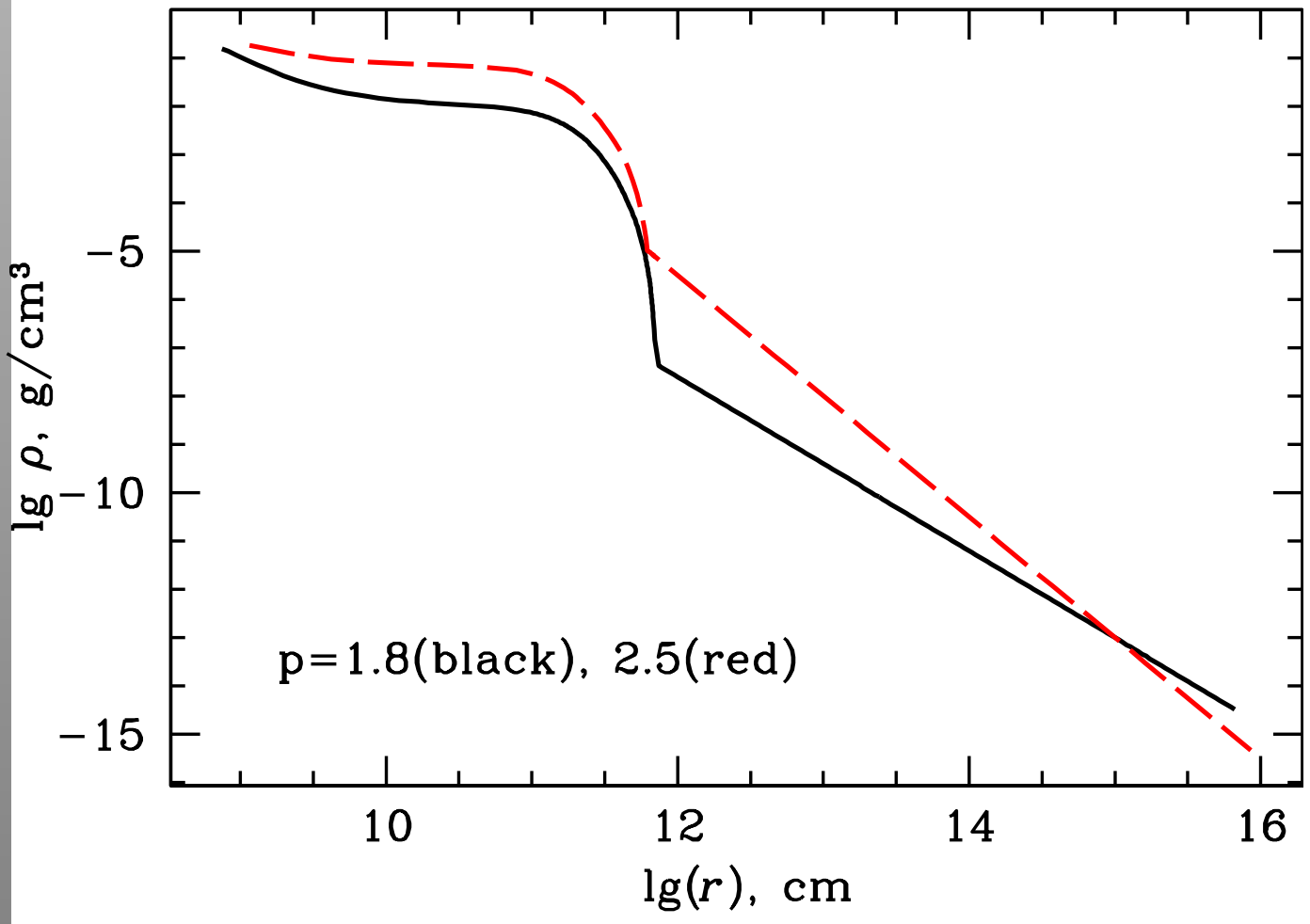
For the nearest future: detouched envelope

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;

CSM velocity: mostly $u = 0$ or linear increase with R

Initial models

Samples of the density distribution



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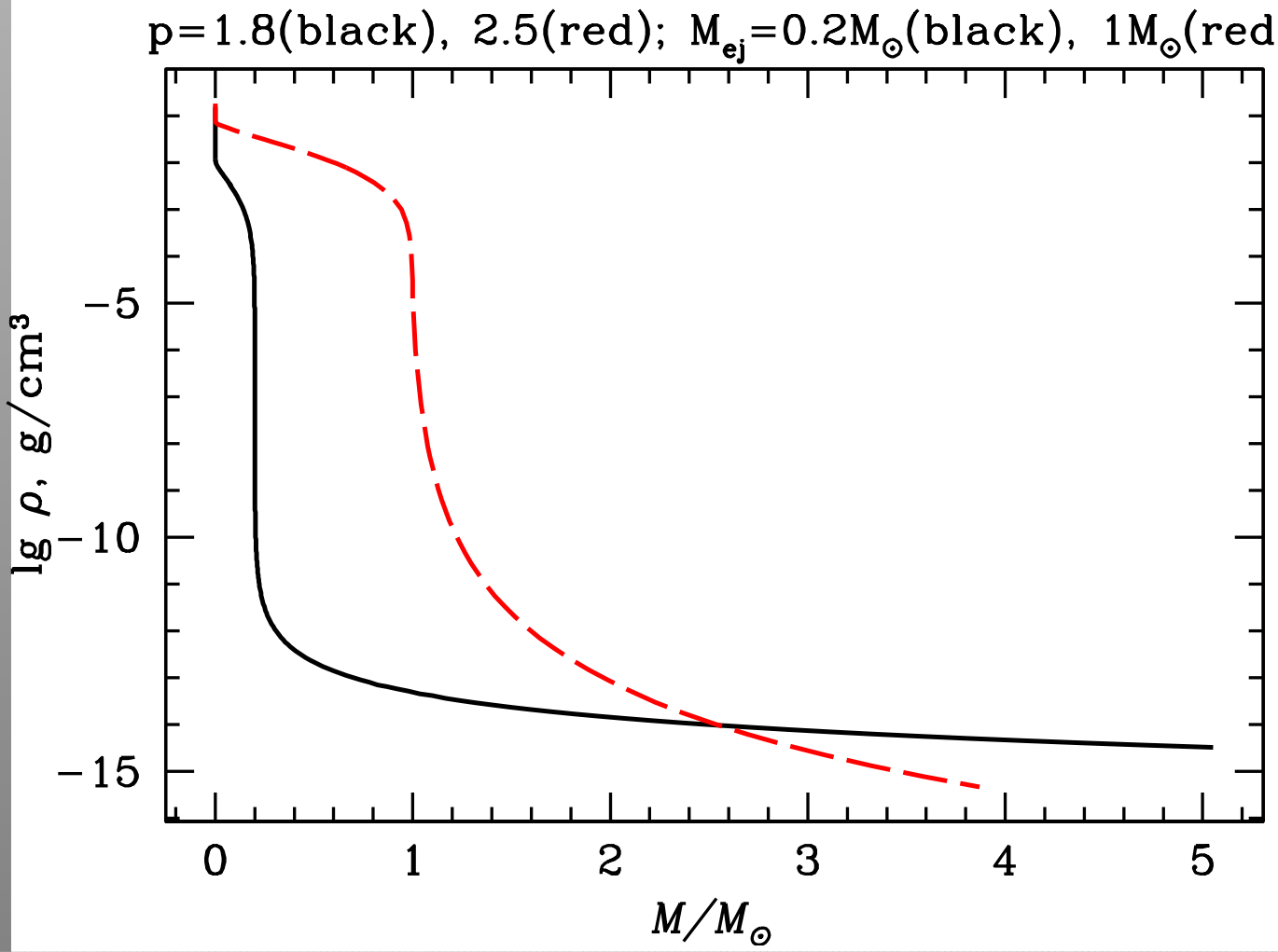

Code STELLA

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

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- up to ~ 400 zones for the Lagrangean coordinate and up to 200 frequency bins are used

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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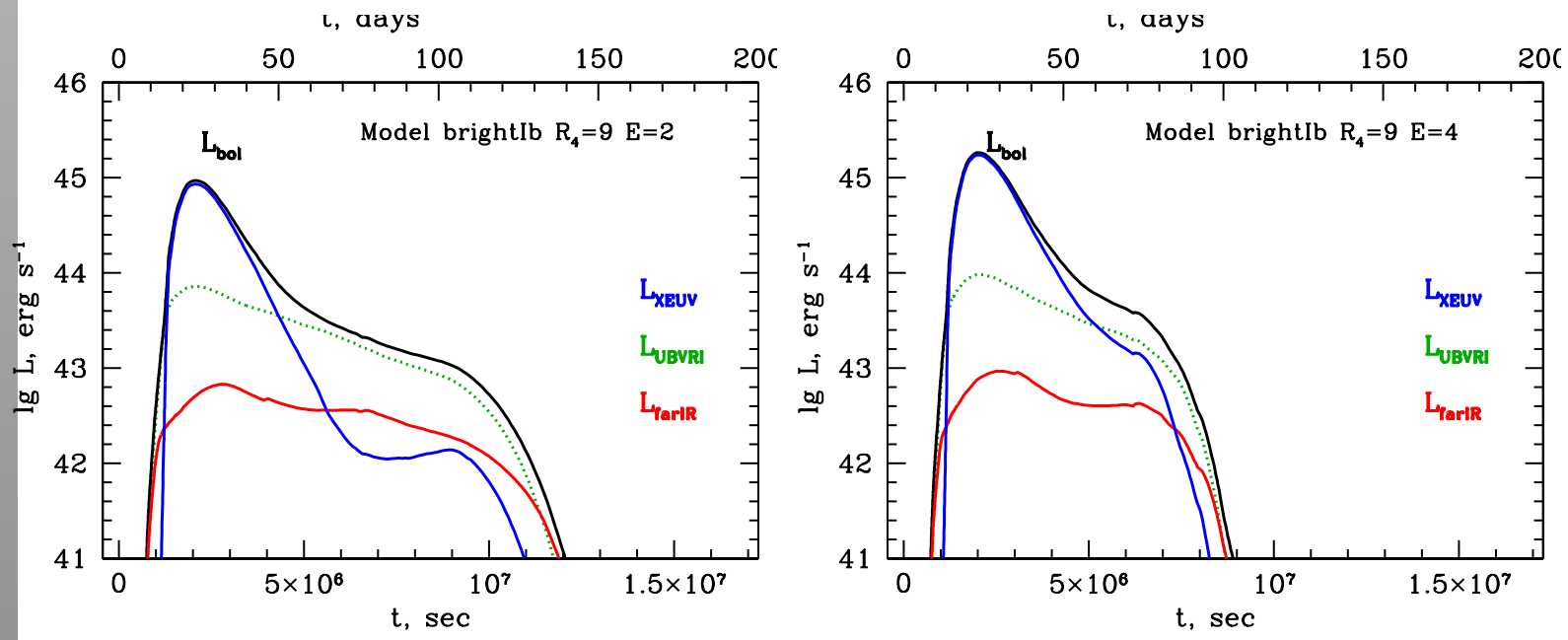
- Local Thermodynamic Equilibrium (LTE) for ionization and atomic level populations is assumed (but radiation is nonequilibrium)
- the effect of line opacity is treated as an expansion opacity according to Eastman & Pinto 1993 (and our new recipes).

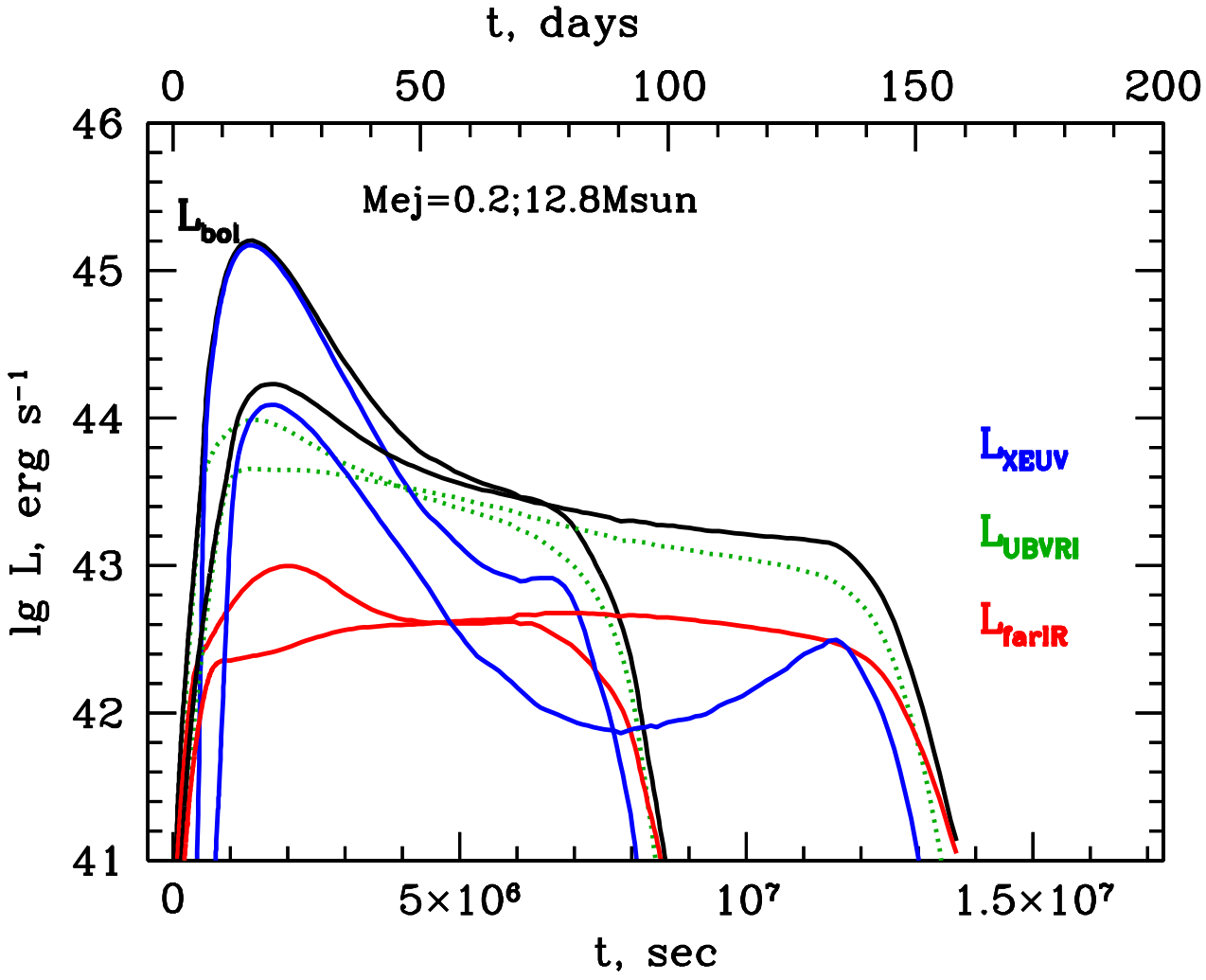
Light curves for different explosion energies



$$p = 1.8, M_w = 4.8 M_\odot$$

Different $M_{\rm ej}$

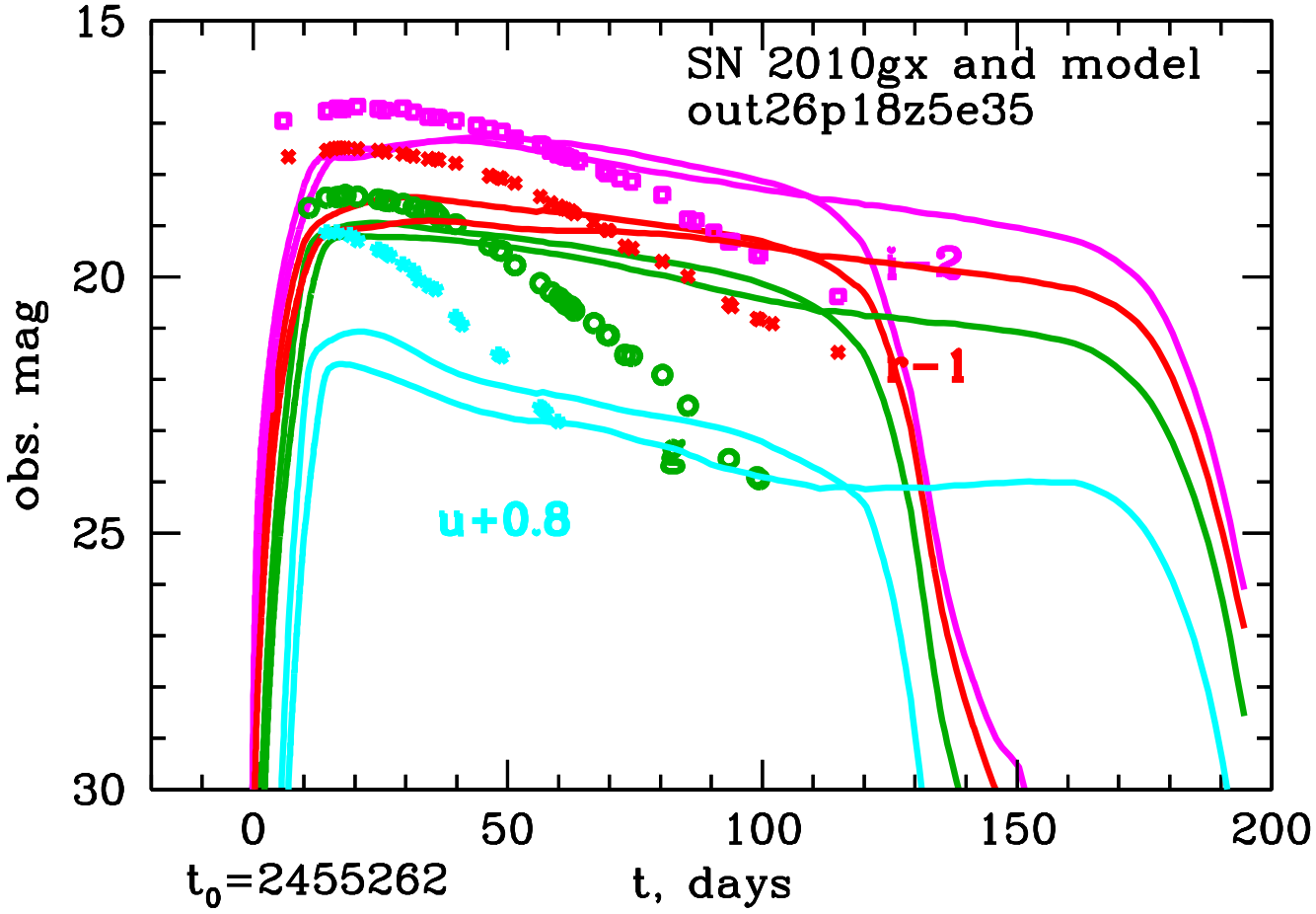
0.2 Msun and 12.8 Msun



More massive - dimmer and wider

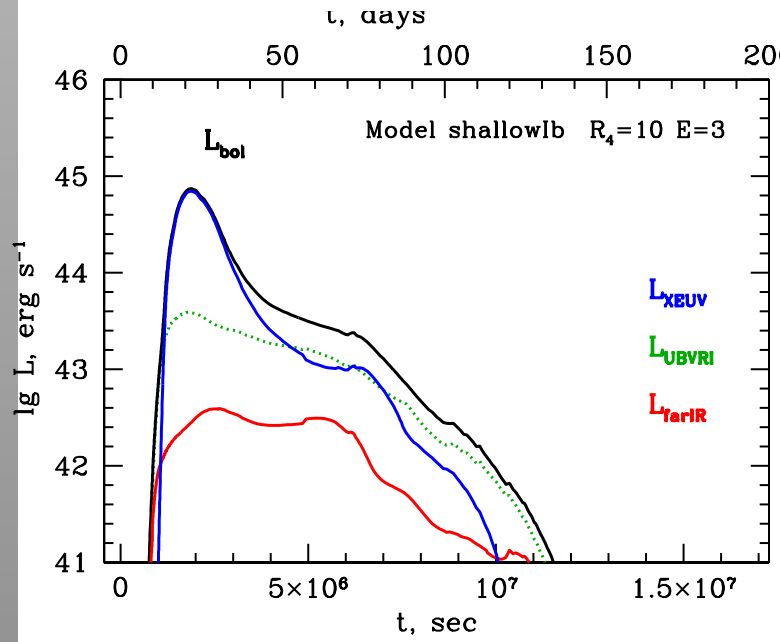
Different $M_{\rm ej}$

3.2 Msun and 12.8 Msun

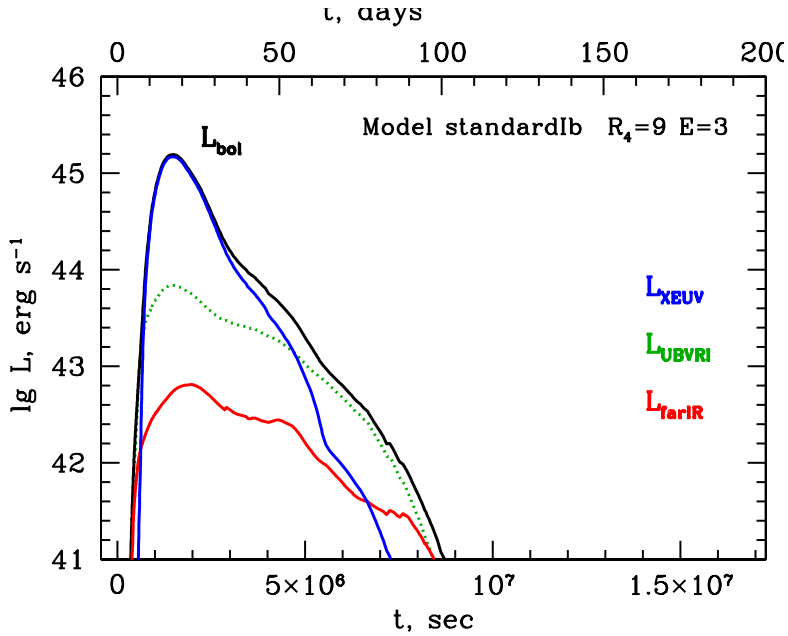


More massive - dimmer and wider

Light curves for different wind structure

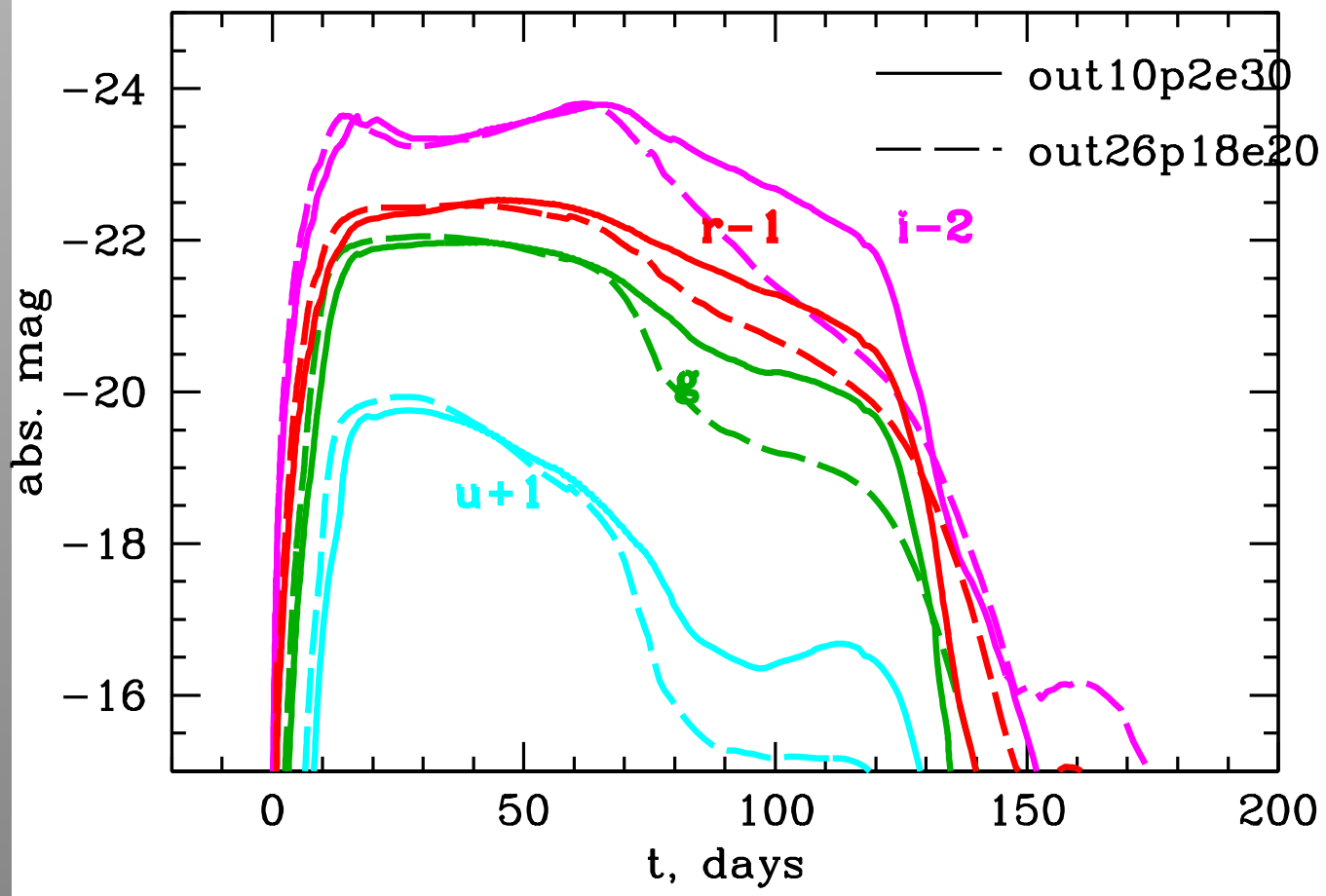


$p = 2.5, M_w = 2.9 M_\odot$



$p = 2, M_w = 3.5 M_\odot$

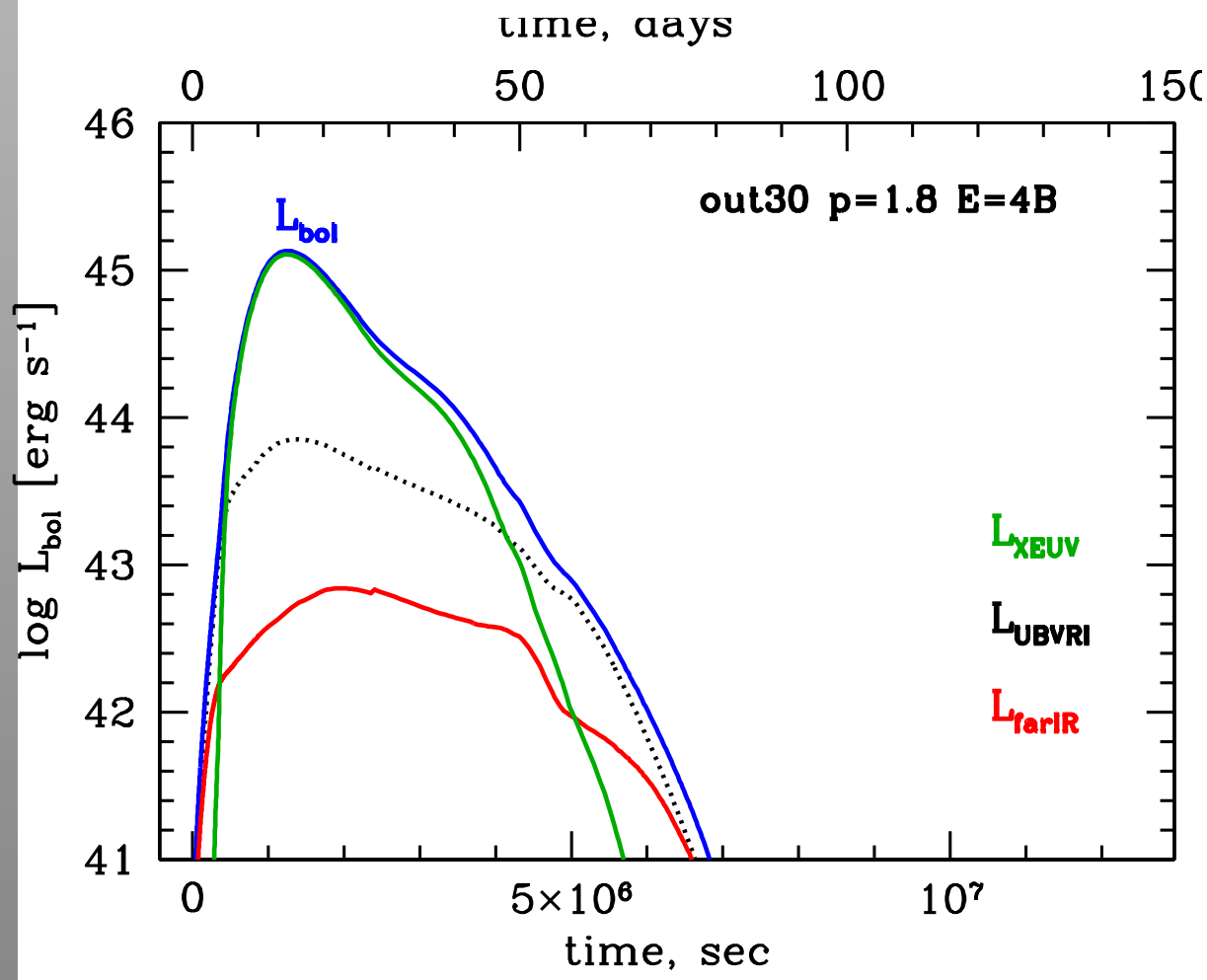
Light curves for different E and $\rho(r)$



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

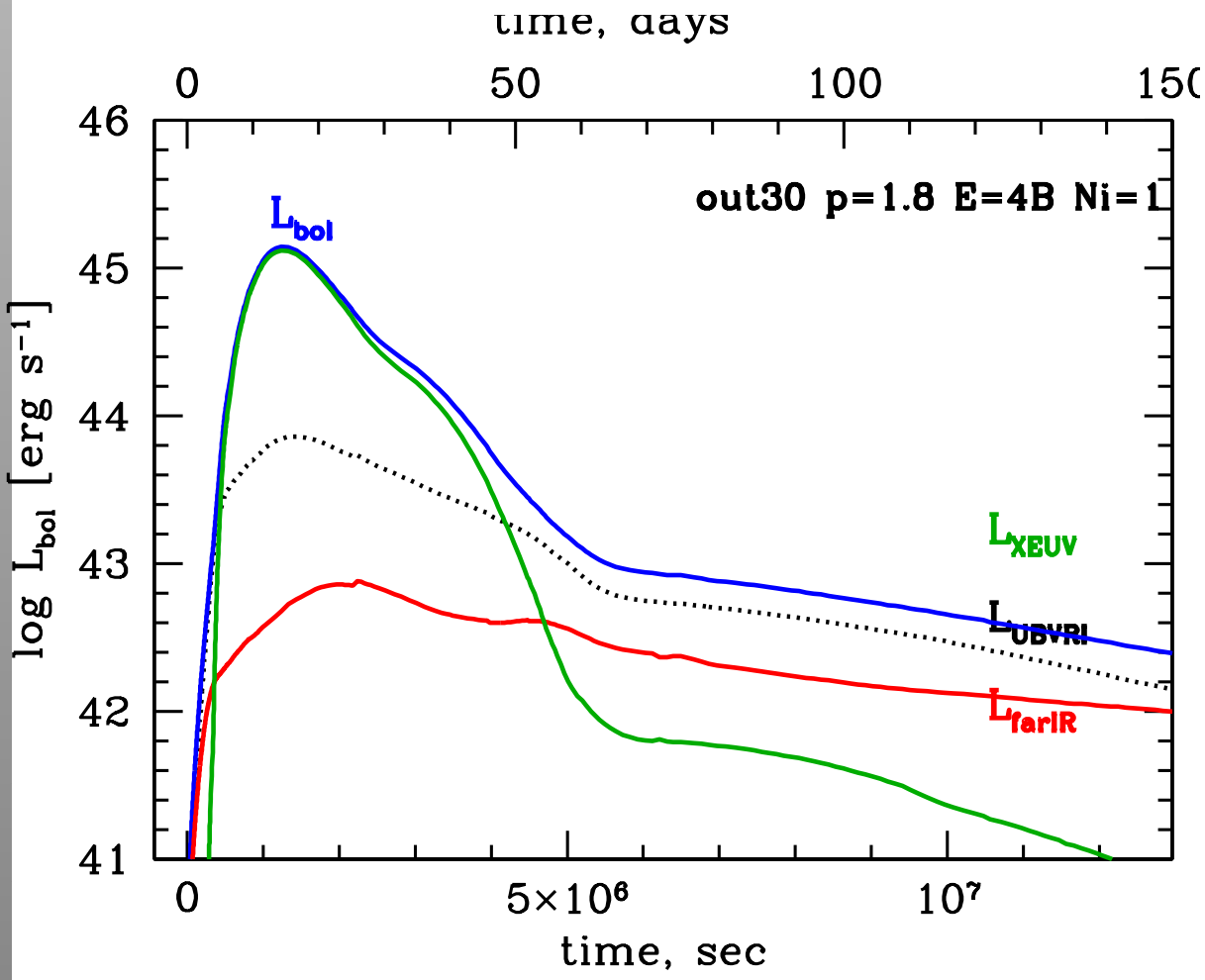
out26: $M_{ej} = 0.2M_\odot, p_w = 1.8, E = 2$ Bethe

^{56}Ni vs. Shock wave heating



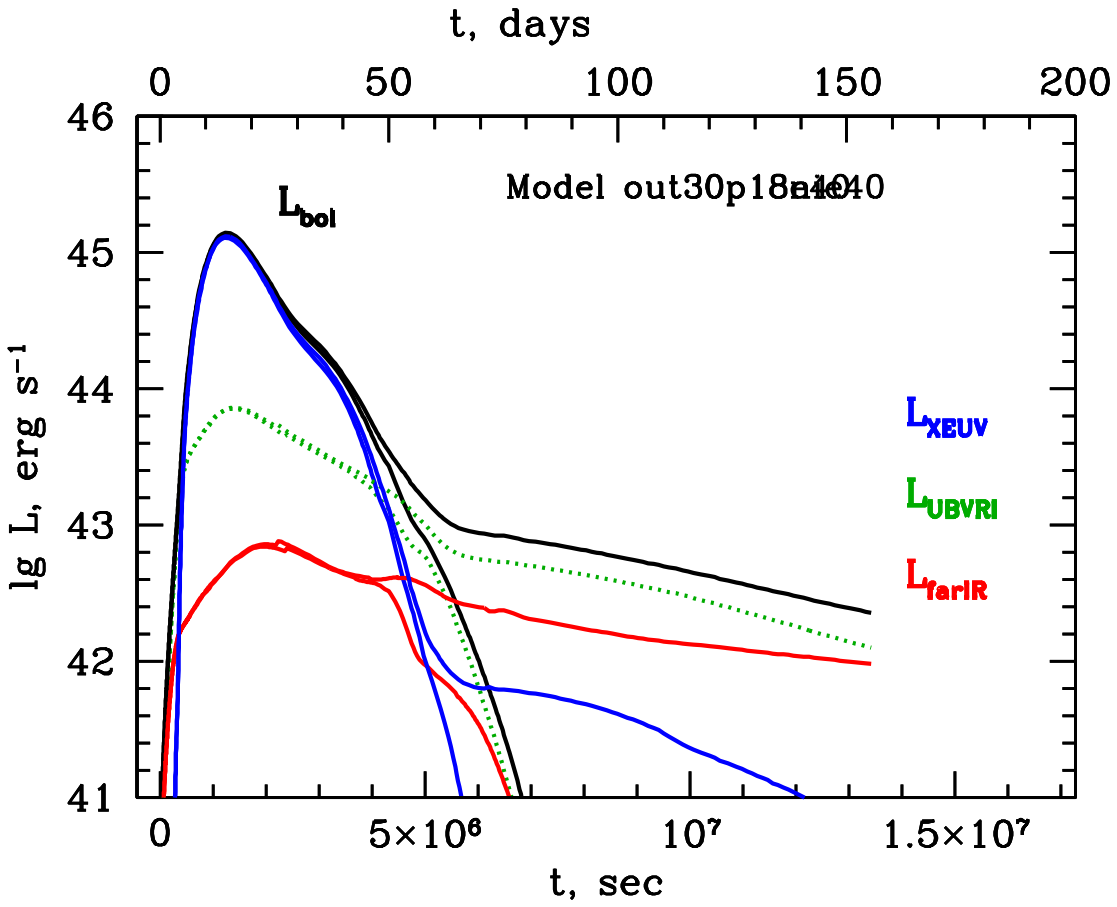
no ^{56}Ni

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



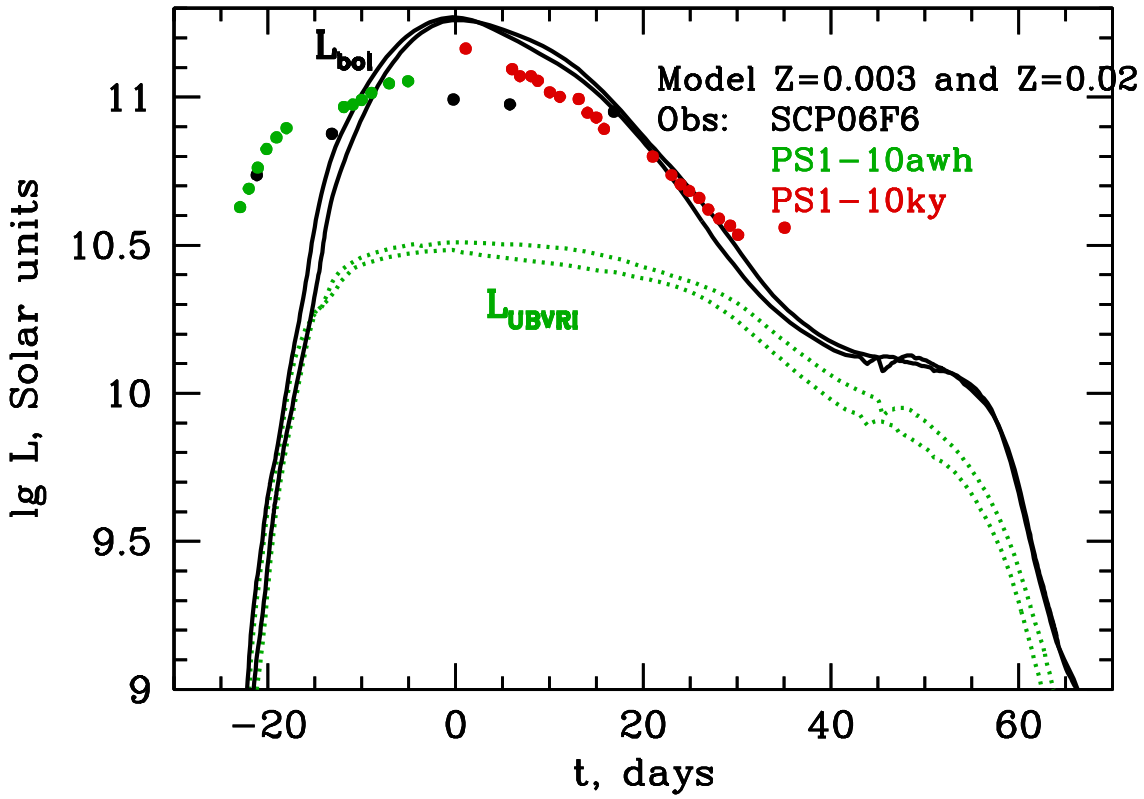
$M(^{56}\mathrm{Ni}) = 1M_{\odot}$ in the ejecta

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

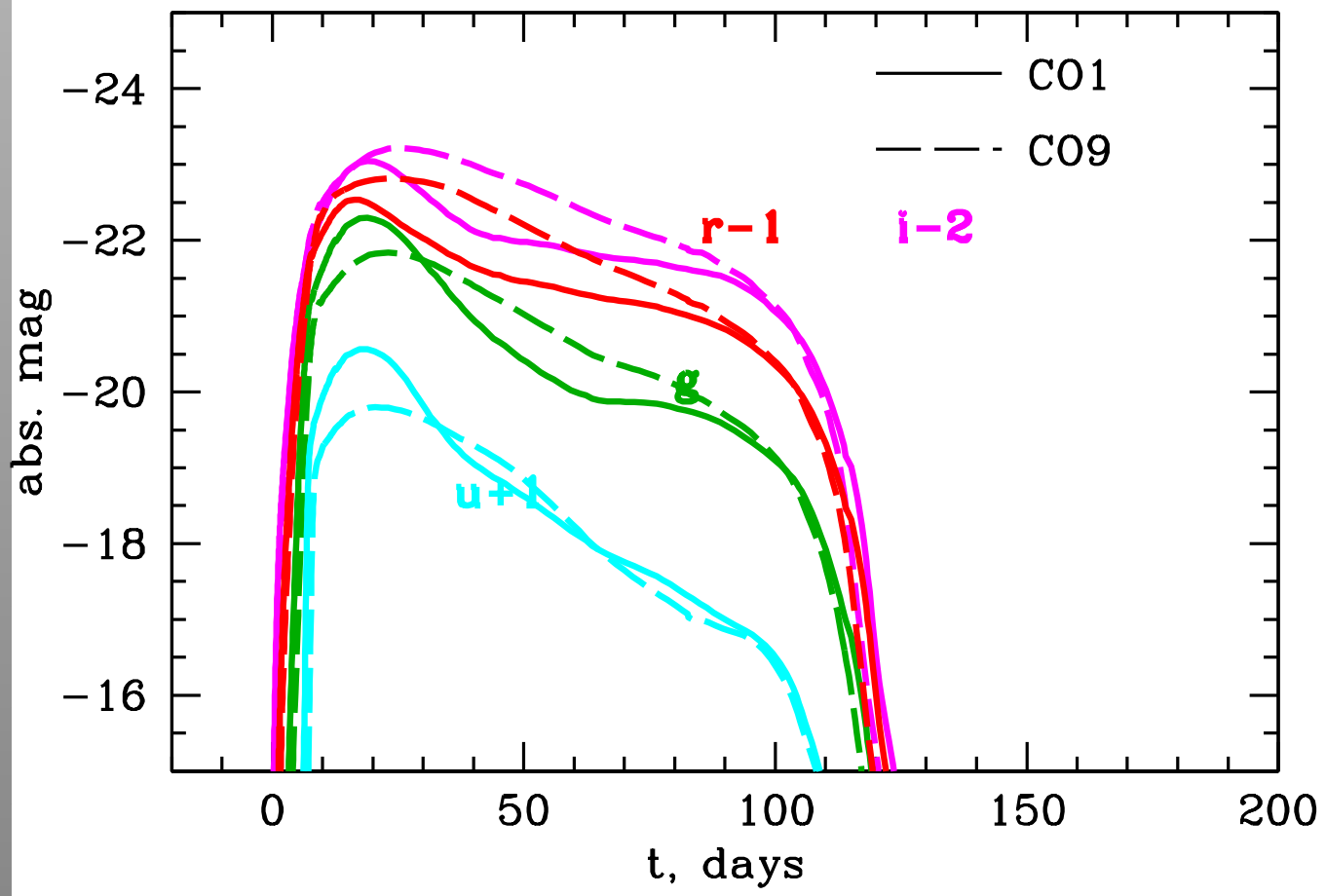


$M(^{56}\mathrm{Ni}) = 1M_\odot$ added to the ejecta

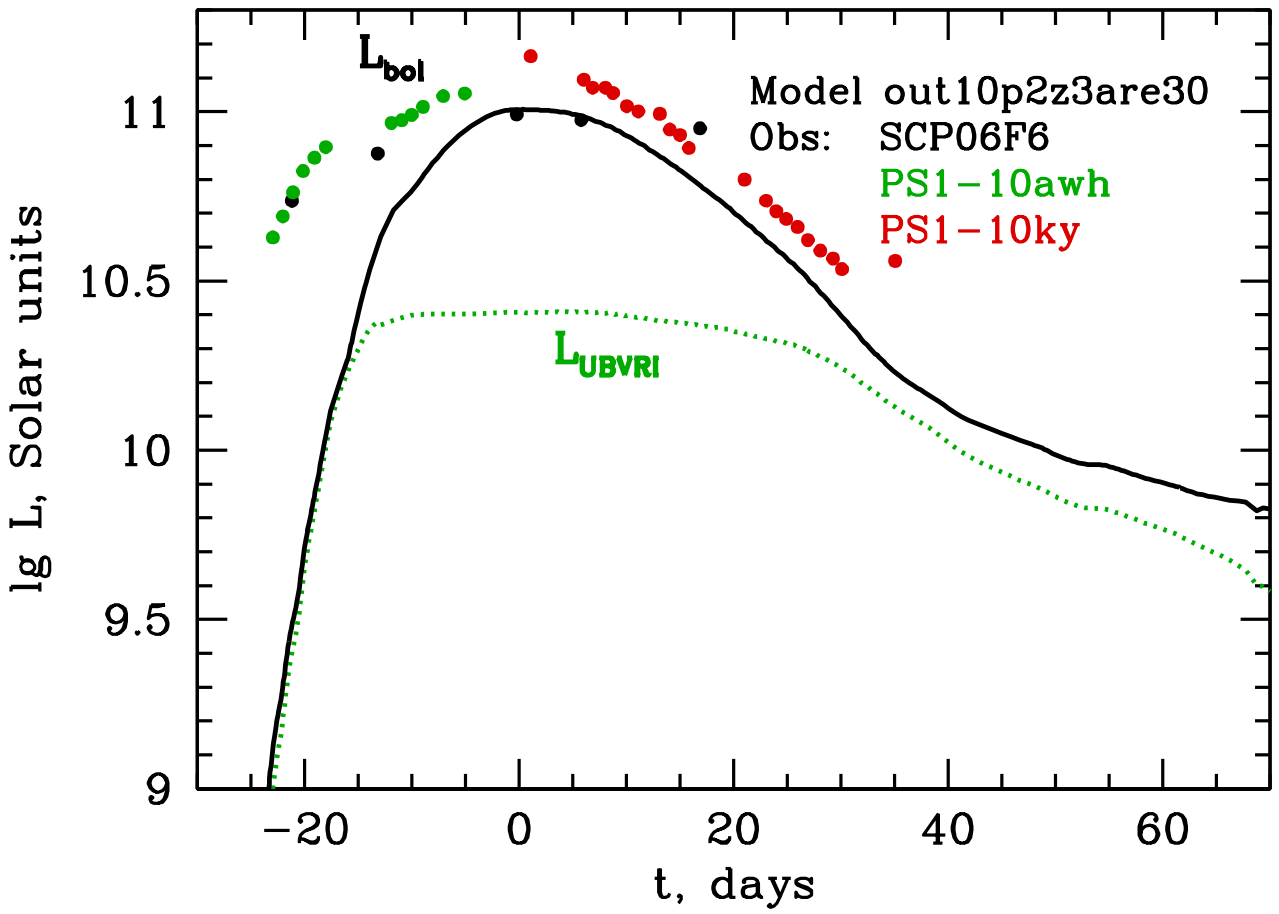
Metallicity



Different C/O ratio

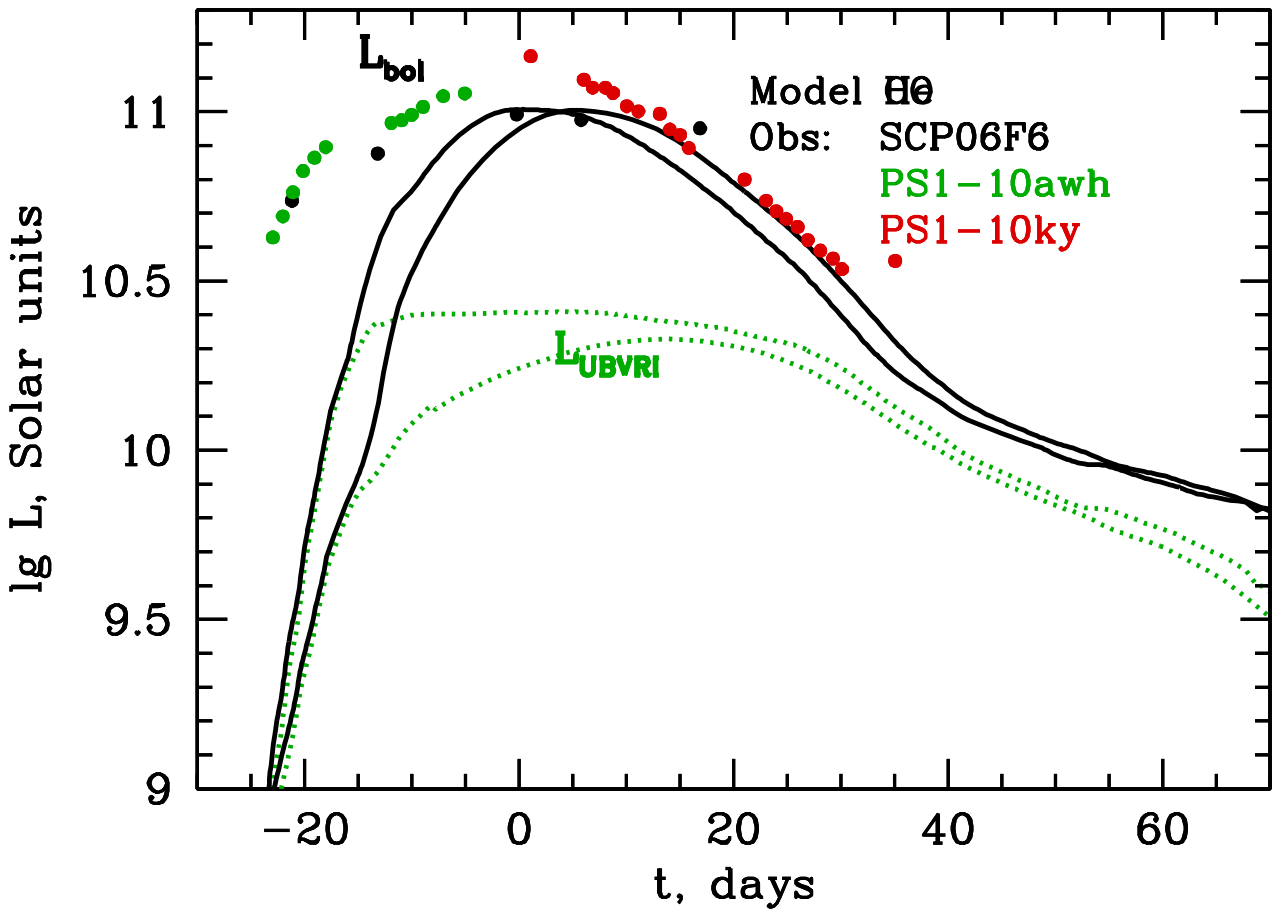


CO vs. He wind



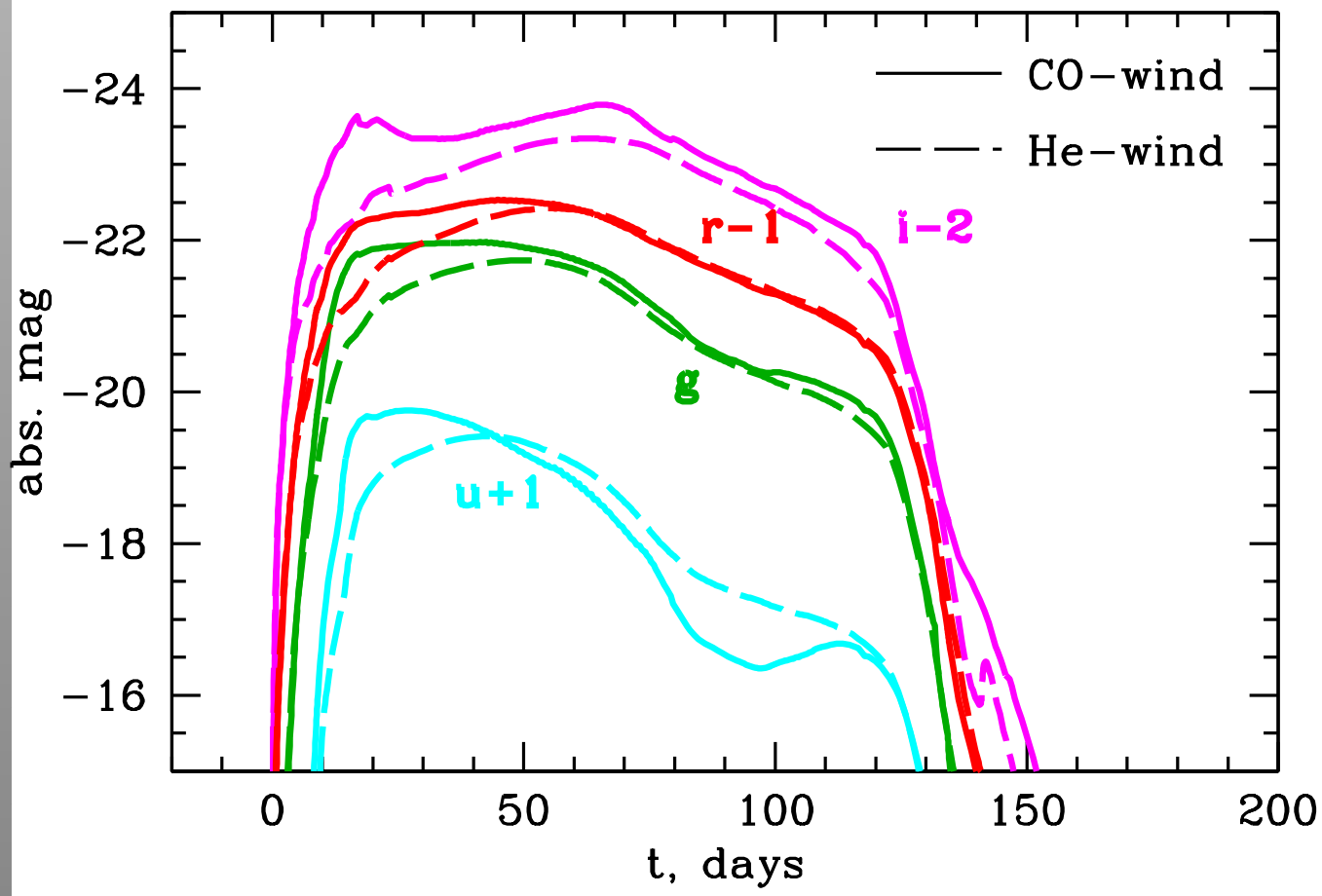
CO wind

CO vs. He wind



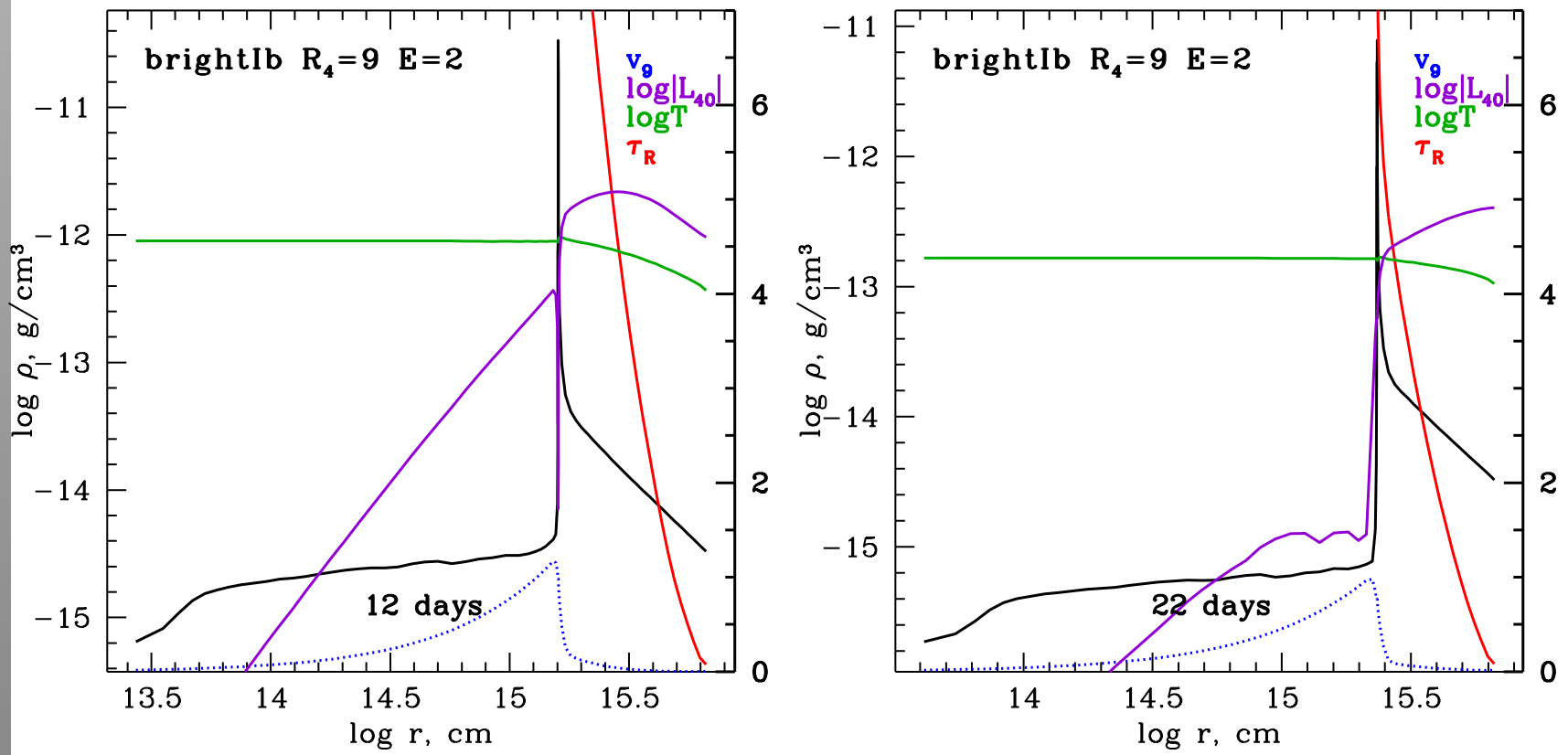
Model with He-wind is more symmetric around maximum light

CO vs. He wind

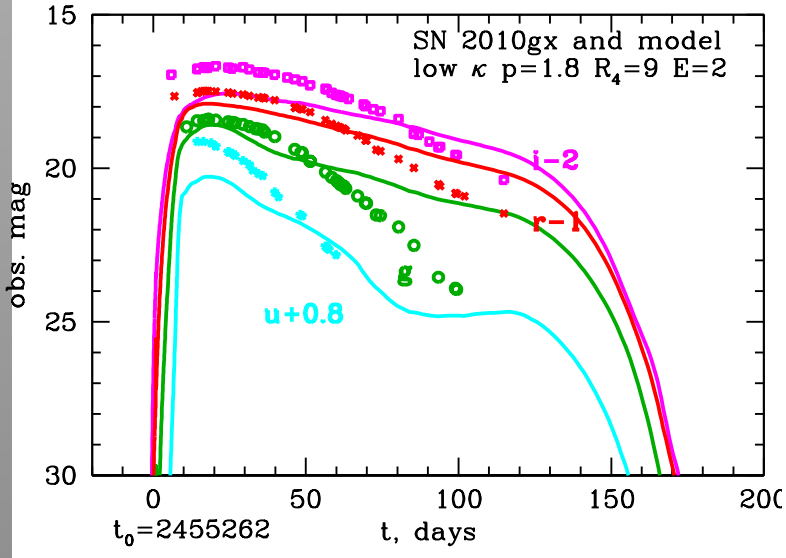

CO−wind
He−wind
r−1
i−2
g
u+1
z
abs. mag
−24
−22
−20
−18
−16
0
50
100
150
200
t, days

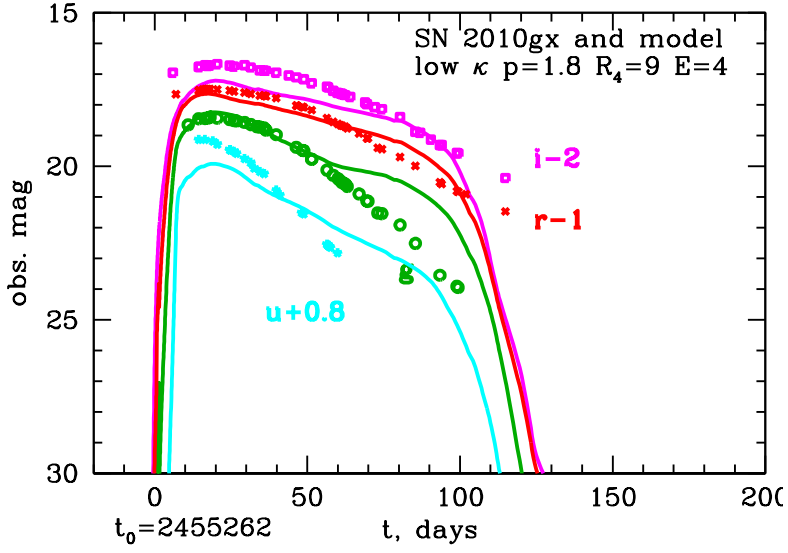
Difficulties in the windy models

Very thin layer contains almost all mass

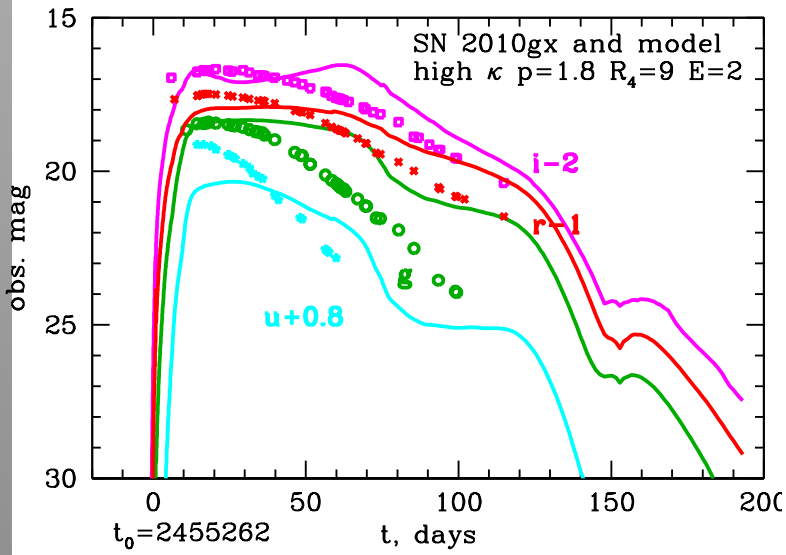


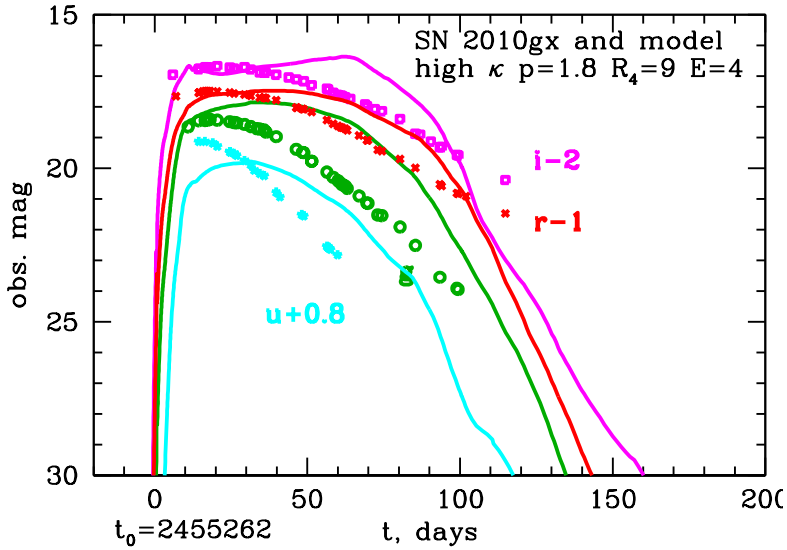
Best models for SN 2010gx





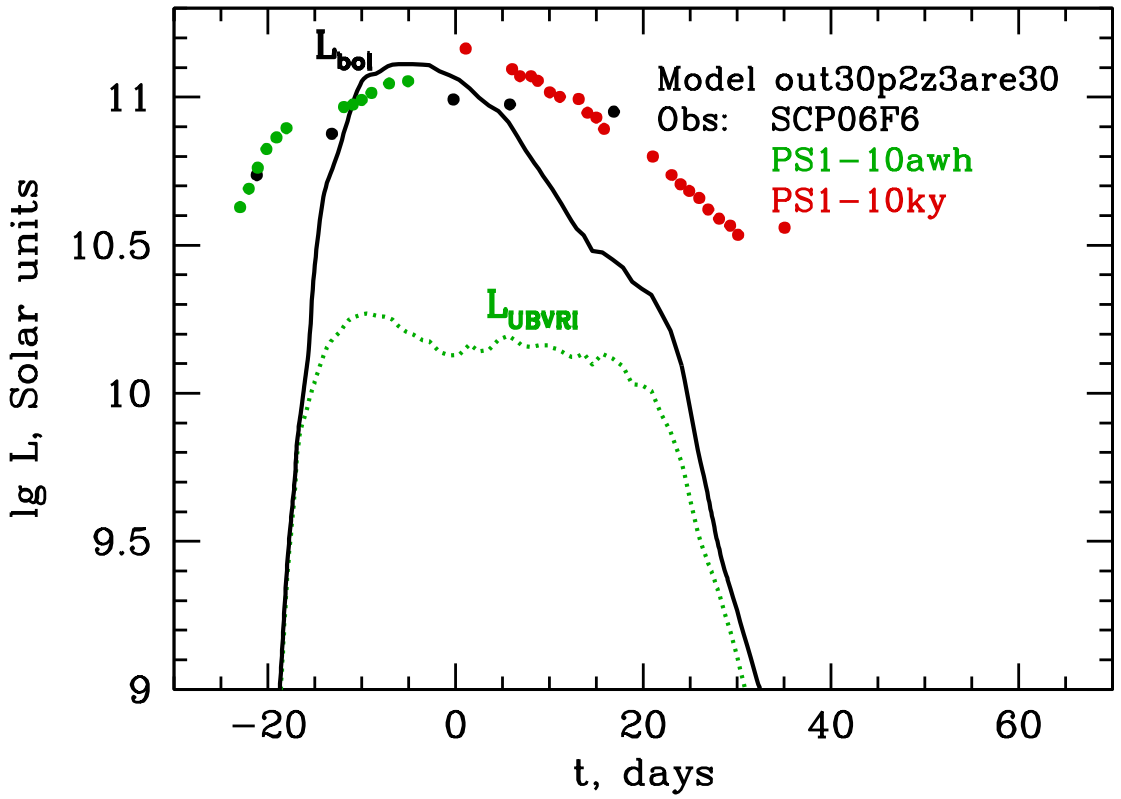
Uncertainty in expansion opacity





Opacity is taken as for $dv/dr = 1/t = 1/1\text{day}$

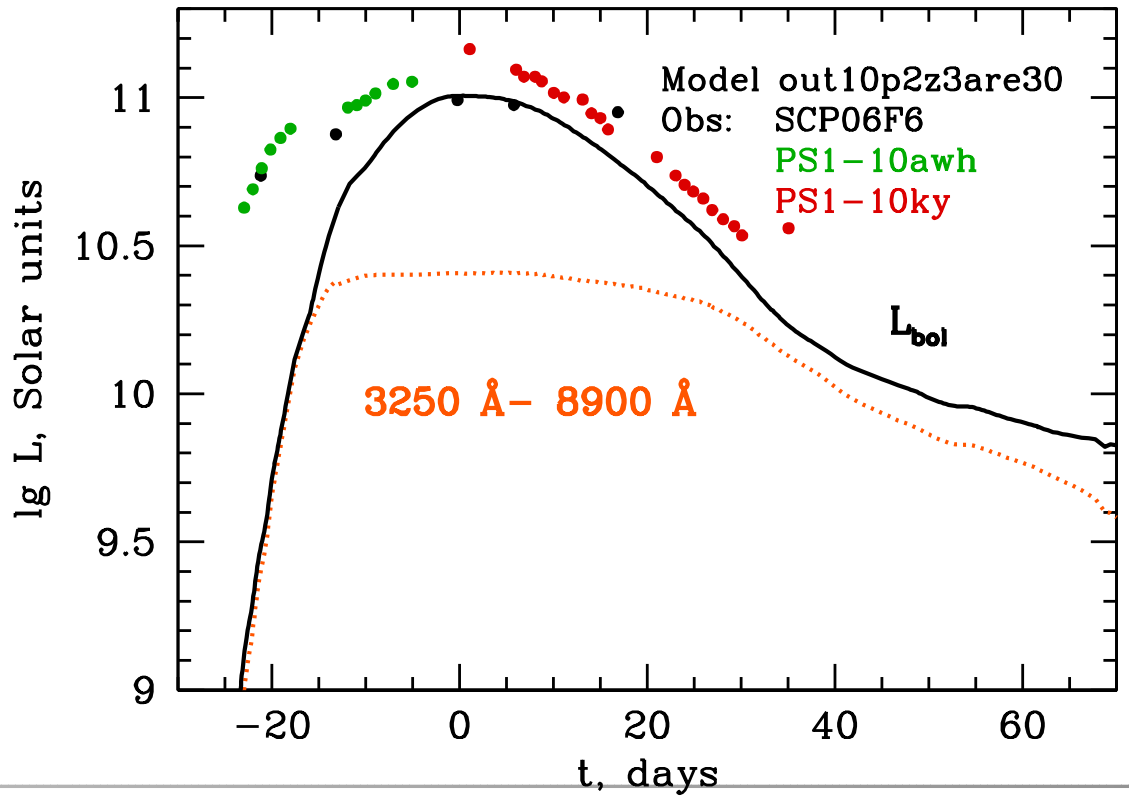
Model vs. observations



BUT

What does it mean “BOLOMETRIC” for cosmological SNe, when spectra are redshifted?

What is bolometric?



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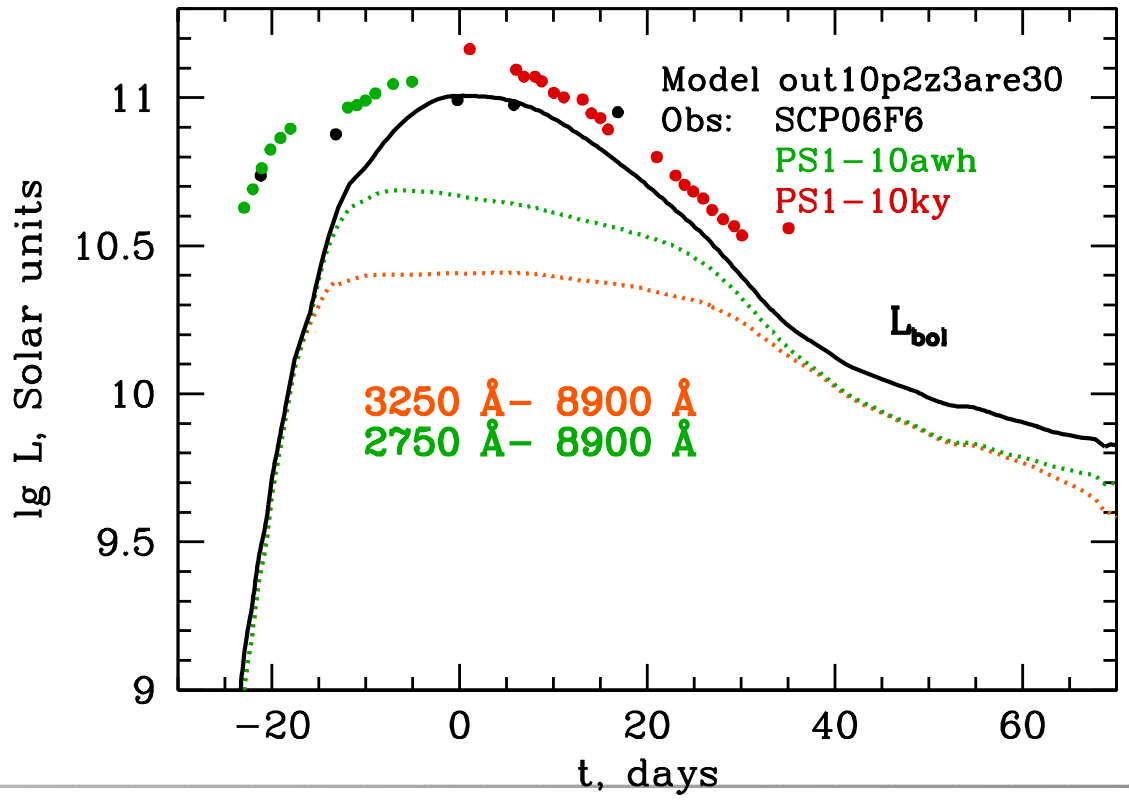

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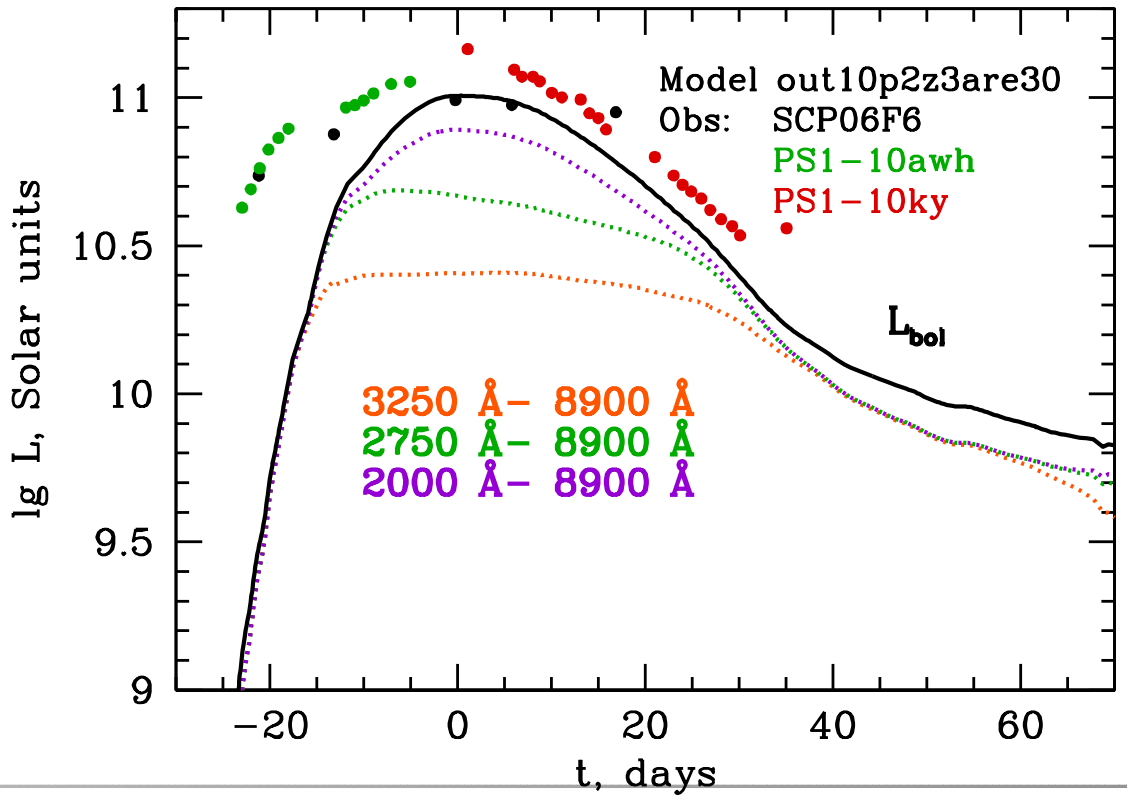

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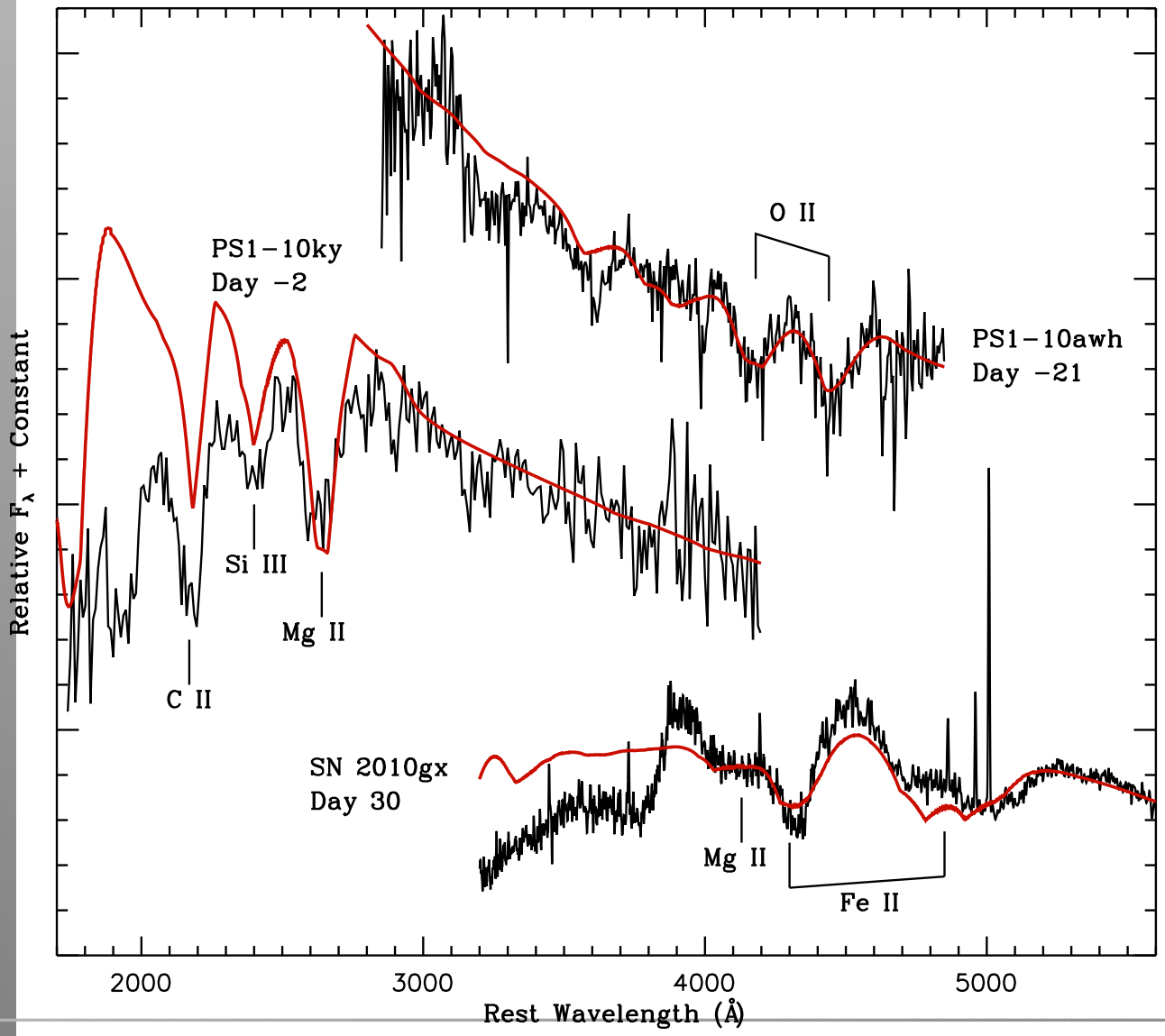

Chomiuk et al. 2009

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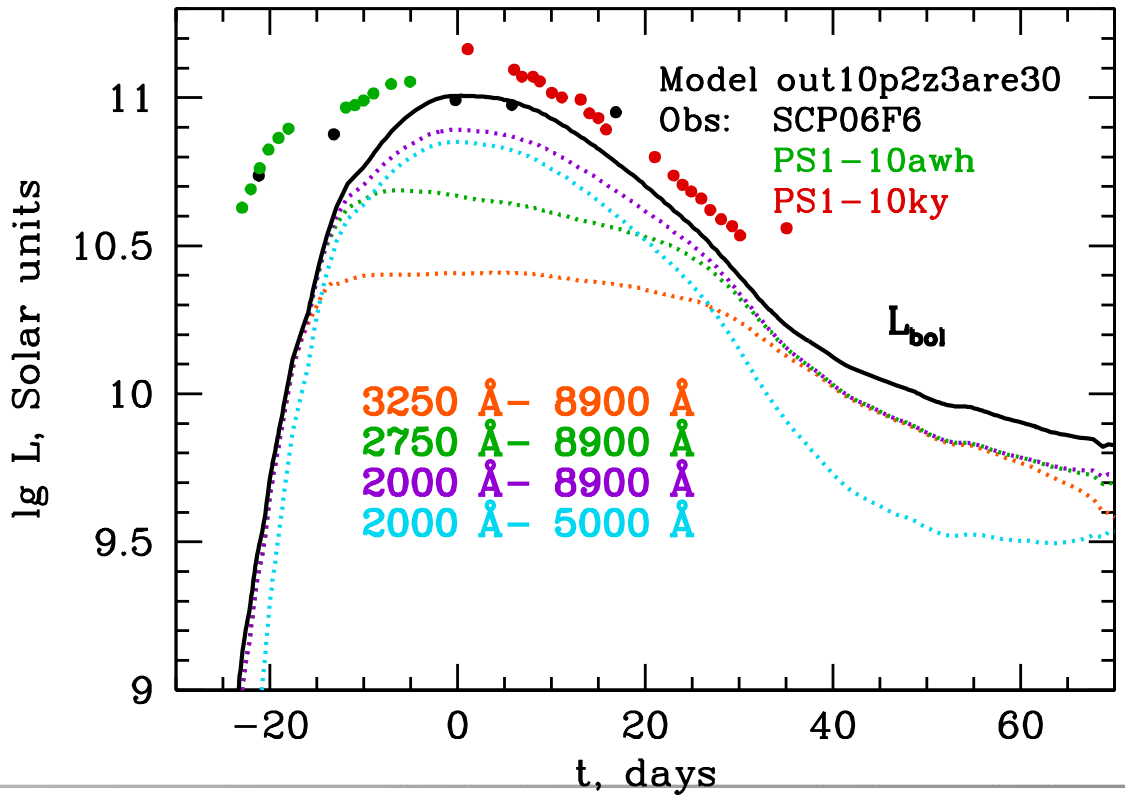

Conclusions

- 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 $M = 3 - 5 M_{\odot}$ and $R < 10^{16}$cm.
  The brightness and the duration of the light curve maximum strongly depends on the mass and structure of the envelope.

Conclusions

- Questions on the latest phases of star evolution arise:
  - Is it possible to form so big and dense envelopes? And how?
  - Time scale for such a formation
  - How far can the envelope extend?
  - Density and temperature profiles inside the envelope right before the explosion
- Question to observetions: try to find traces of such shells for bright explosions.
  (There are spectral evidence of circumstellar shells for type IIn and Ibn SNe. Is it possible to find C–O envelopes as well?)

Conclusions

- Many technical problems in light curve calculations:
  - line opacities;
  - dimensionality: 3D is preferable, since the envelope can most probably be clumpy;
  - NLTE spectra