SN Explosions inside Extended Non-Hydrogen Circumstellar Shells

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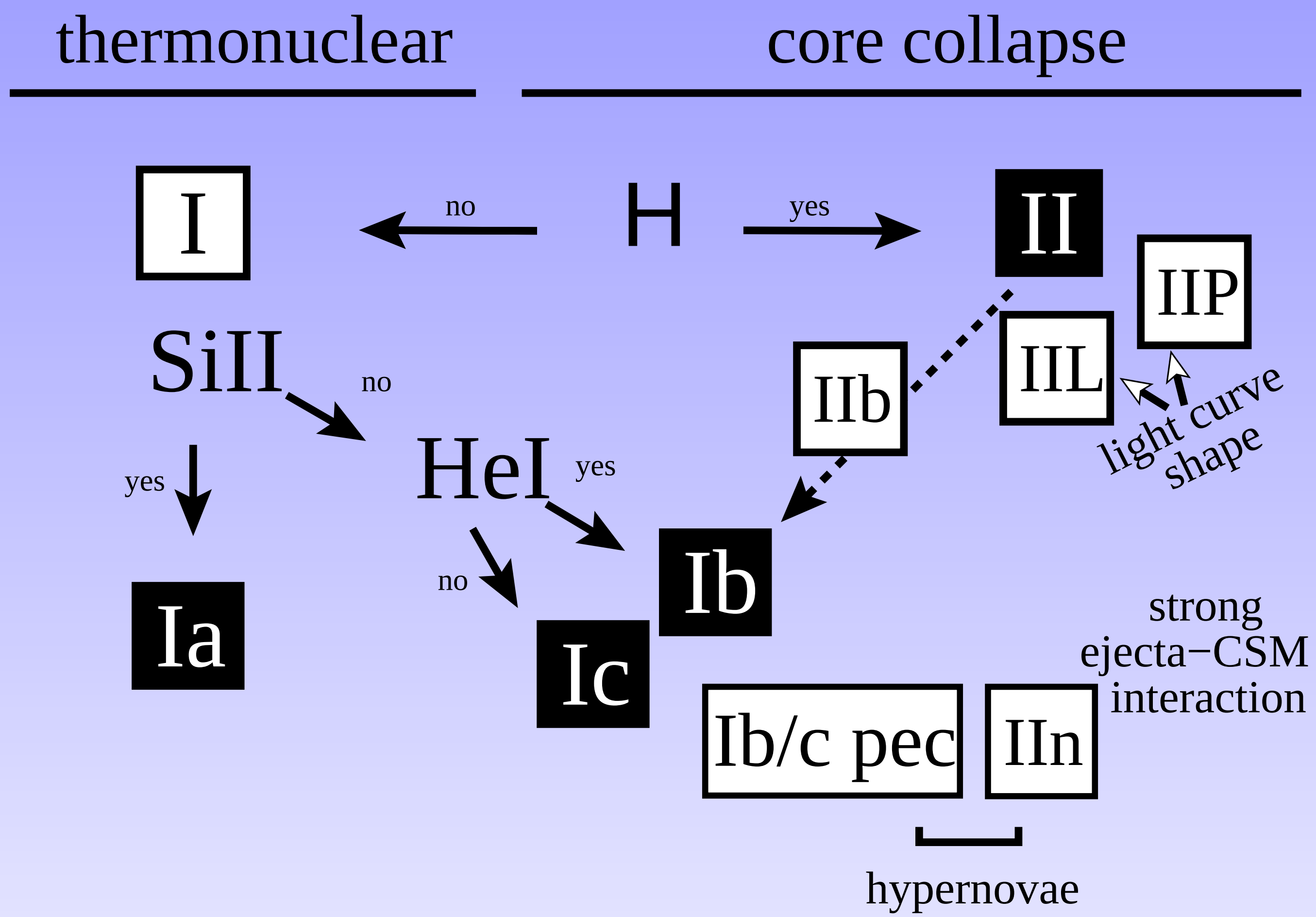
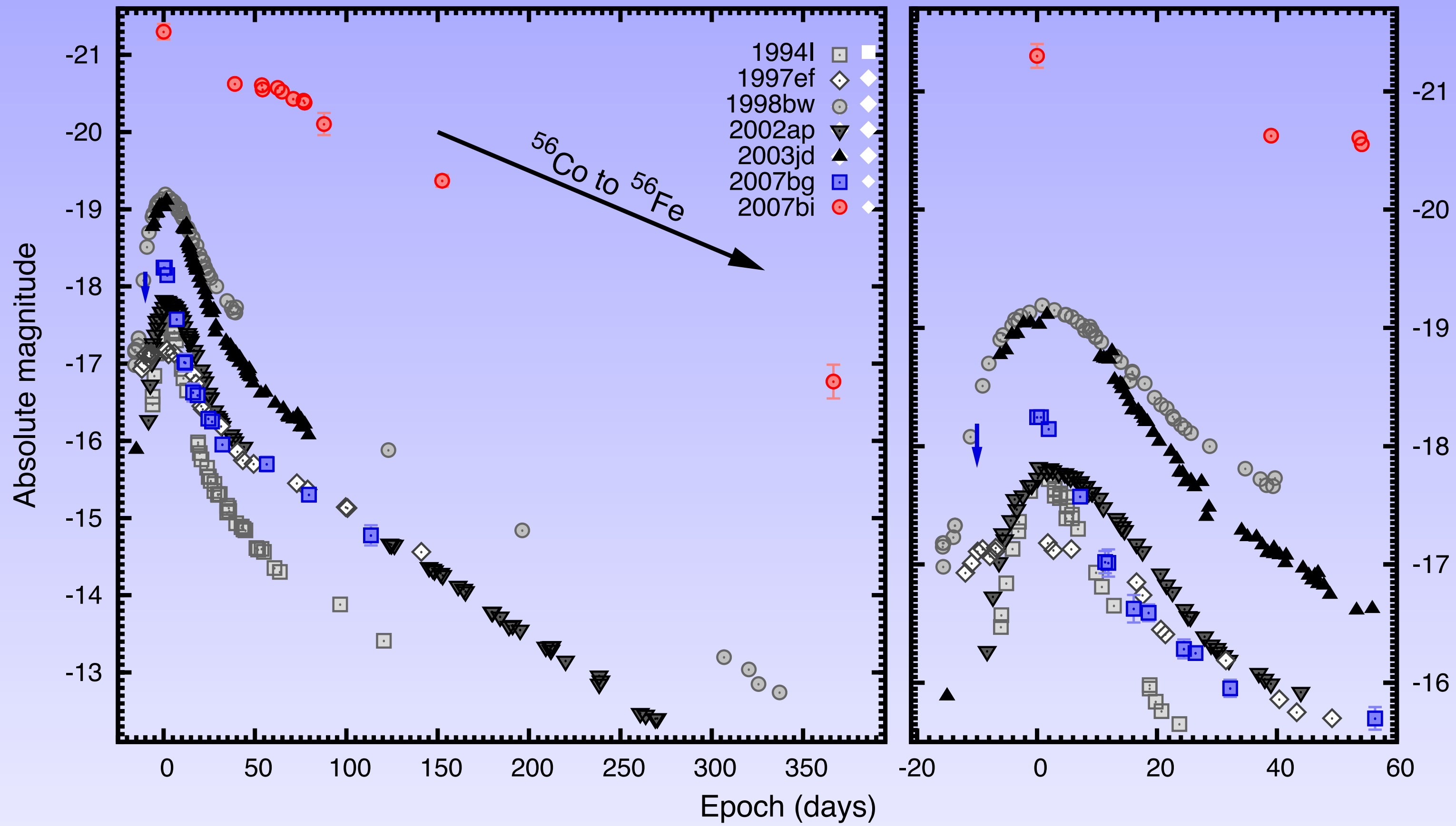
SN classification



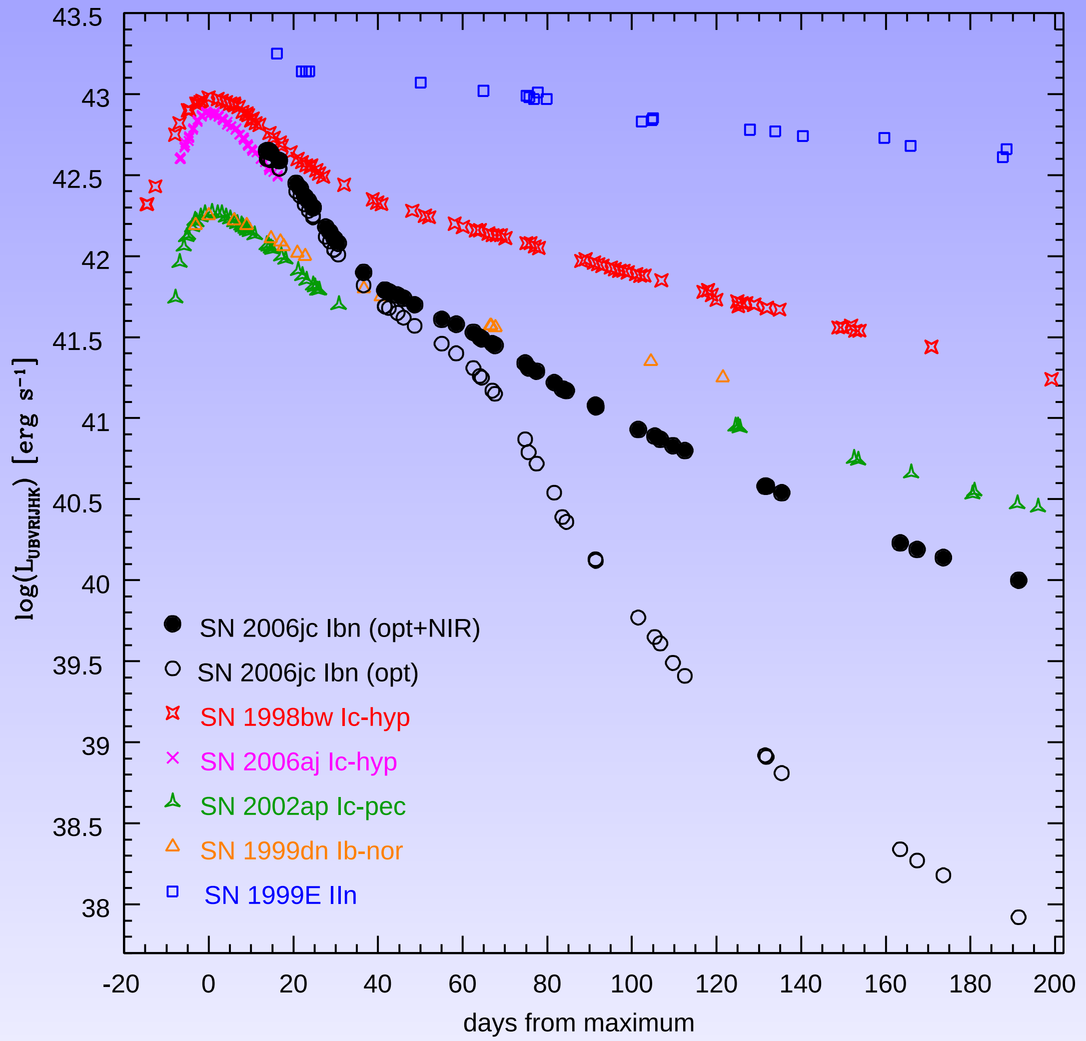
Turrato 2003

Extremely bright Type Ic SNe

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



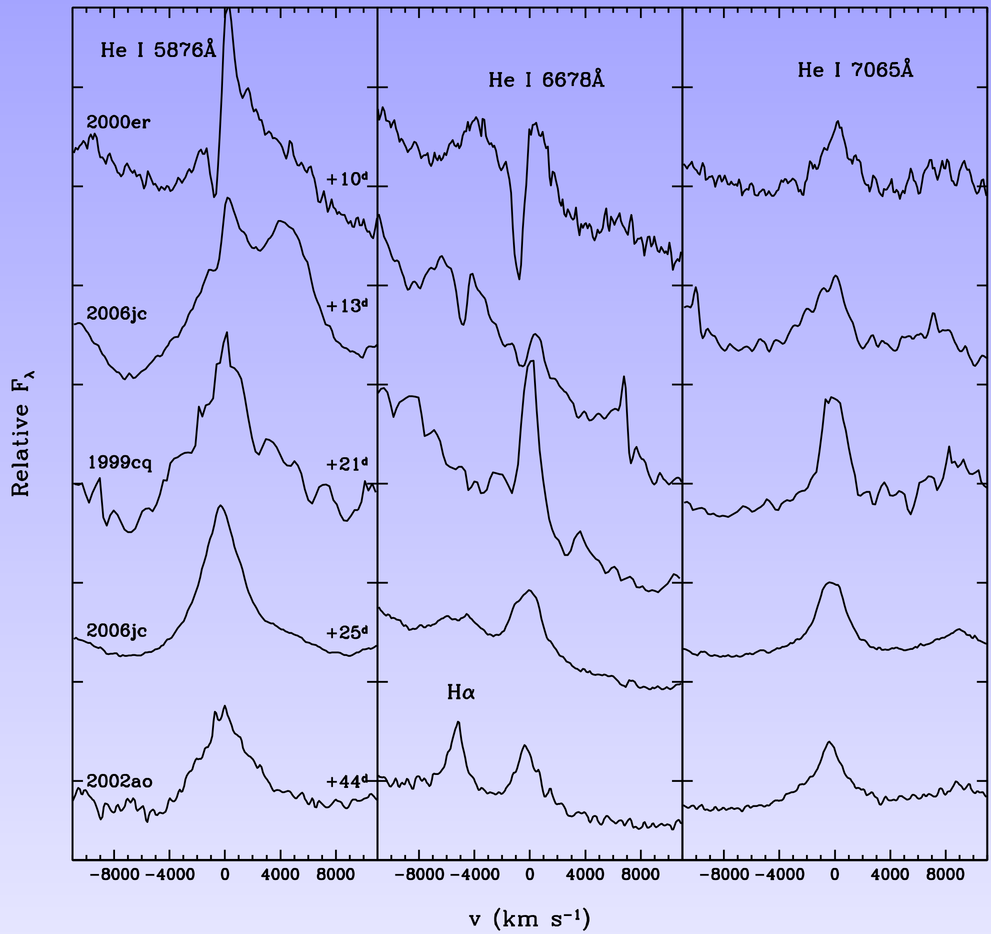
Very bright Type Ib SNe with narrow lines



Type Ibn

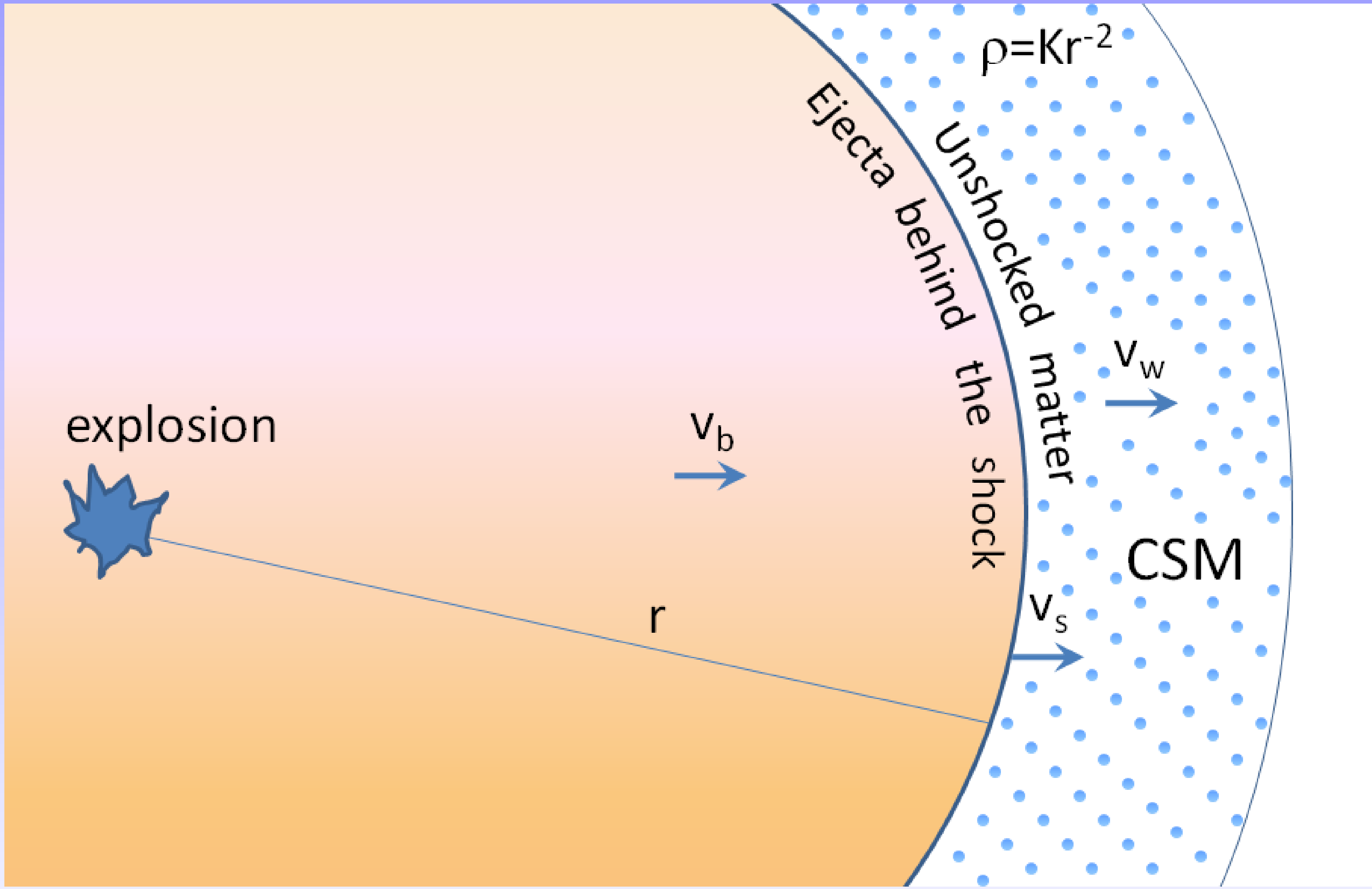
Quasi-bolometric (optical+NIR) (Pastorello et al. 2008)

Very bright Type Ib SNe with narrow lines



Pastorello et al. 2008

Windy models for core collapse SNe



Ofek et al. 2010

Windy models for type Ic SNe

Ejecta: politropic mass distribution;
Wind: $\rho \sim r^{-p}$

Composition: uniform for most of models:
0.5 C + 0.5 O + 1% heavier elements of Solar abundance;
no ^{56}Ni – to check the influence of the pure shock

Velocity: $u = 0$

For future:
– try different composition for the wind (He) and for the ejecta;
– try non-zero velocities for the wind (most probably would correspond to the less energetic explosion)

Windy models for type Ic SNe

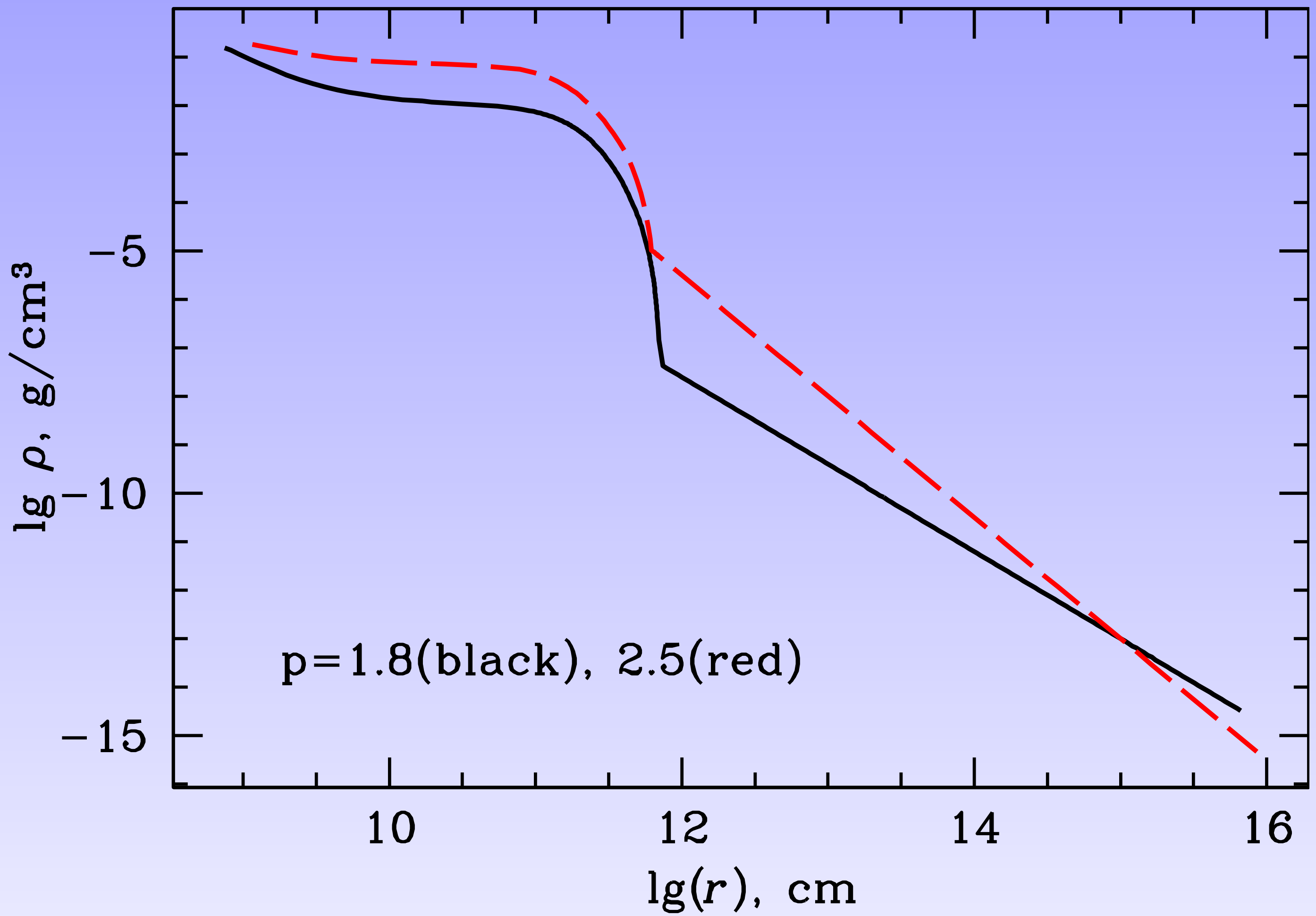
all masses M and radii R are in solar units

Model	$M_{\rm ej}$	$R_{\rm ej}$	$M_{\rm Ni}$	p	$M_{\rm w}$	$R_{\rm w}$	E, foe
`out6esa`	10	$9.1 \cdot 10^3$	0	0	4.15	10^5	1.5
`out7p3`	10	$6.3 \cdot 10^3$	0	3	3.3	10^5	1.5
`out8p3`	10	$5.7 \cdot 10^3$	0	3	6.8	10^5	1.5
`out9p3`	1.7	5	0	3	9.8	$1.2 \cdot 10^5$	1.5; 3
`out10p2`	2	10	0	2	4.5	$1.3 \cdot 10^5$	3
`out11p2`	10	$7.4 \cdot 10^3$	0	2	4	10^5	3
`out12p3`	2	9	0	3	0.45	$1.2 \cdot 10^5$	3
`out13p3`	2	9	0	3	0.52	$1.3 \cdot 10^6$	3
`out14p2`	1	10	0	2	4.5	$1.2 \cdot 10^5$	3
`out15p25`	1	9	0	2.5	2.9	$1.2 \cdot 10^5$	3

and others.....

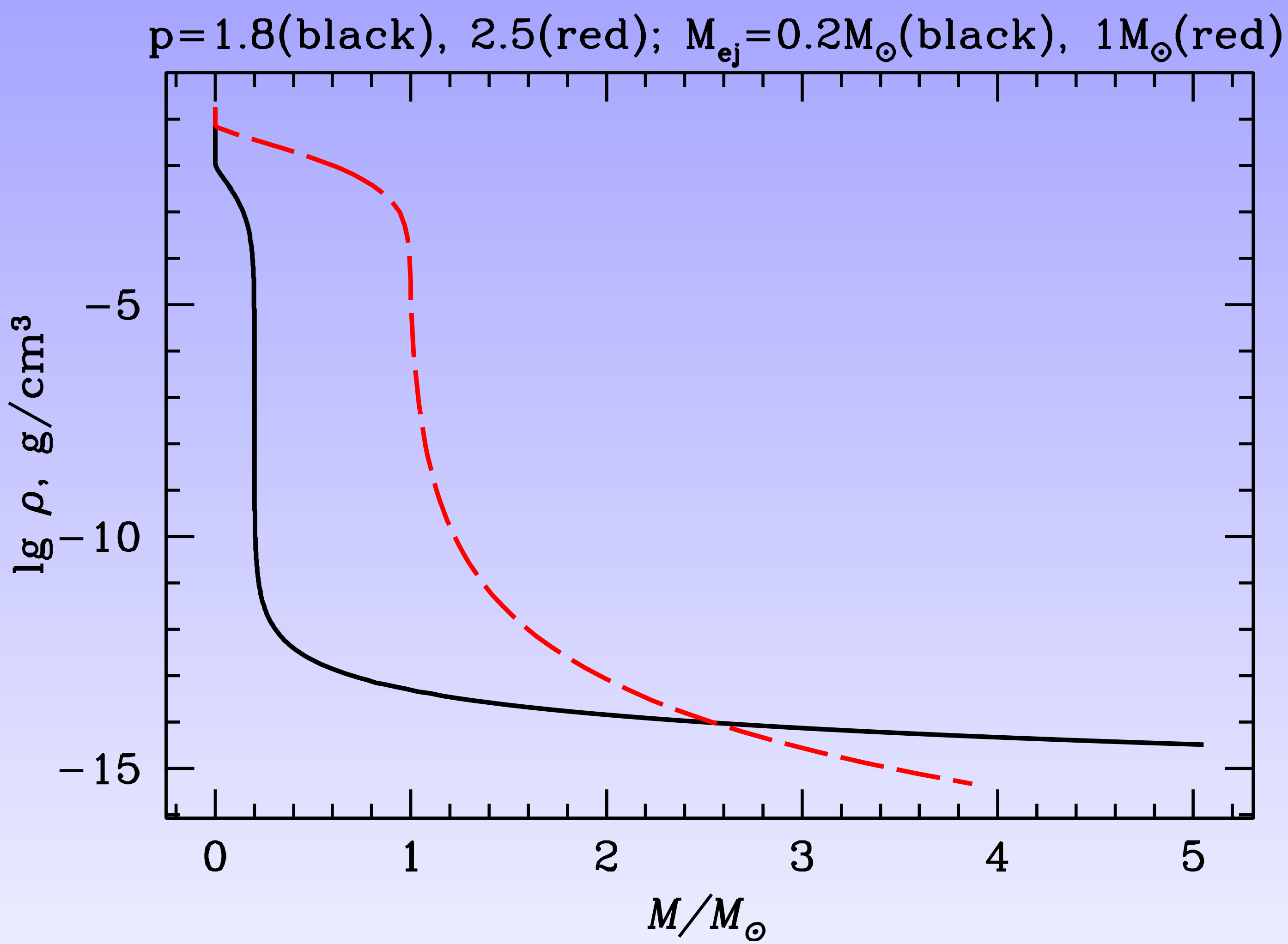
Initial models

Samples of the density distribution

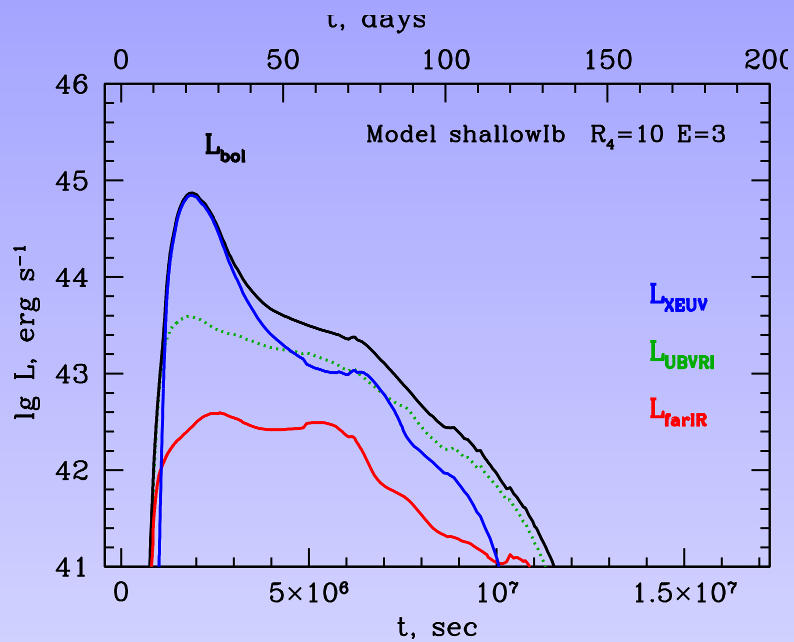


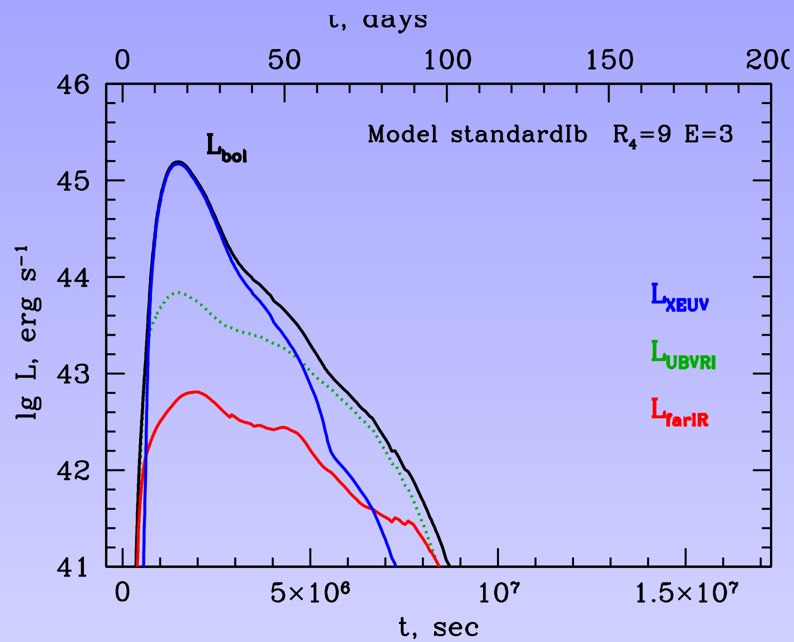
Initial models

Samples of the density distribution



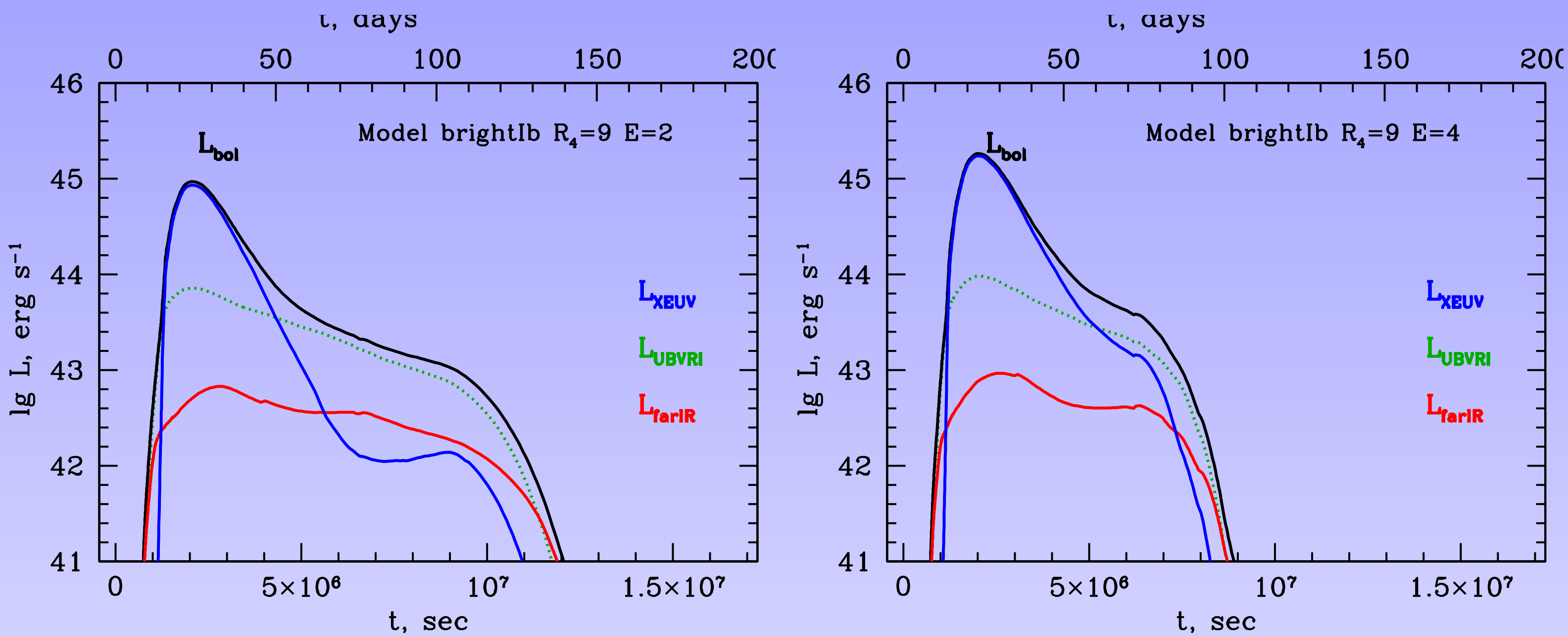
Light curves for different wind structure





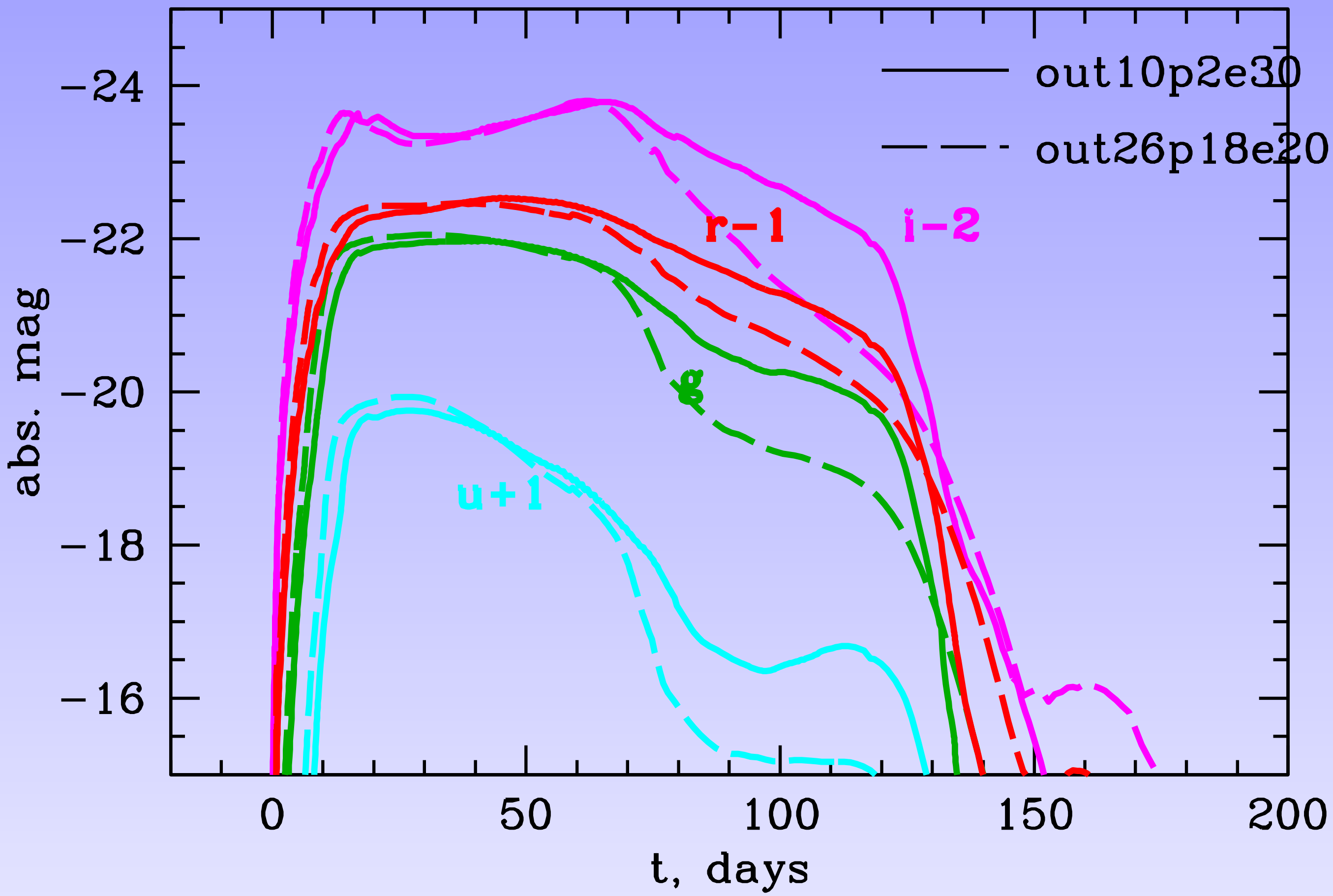
$p = 2.5, M_w = 2.9 M_\odot$ $\quad$ $p = 2, M_w = 3.5 M_\odot$

Light curves for different explosion energies



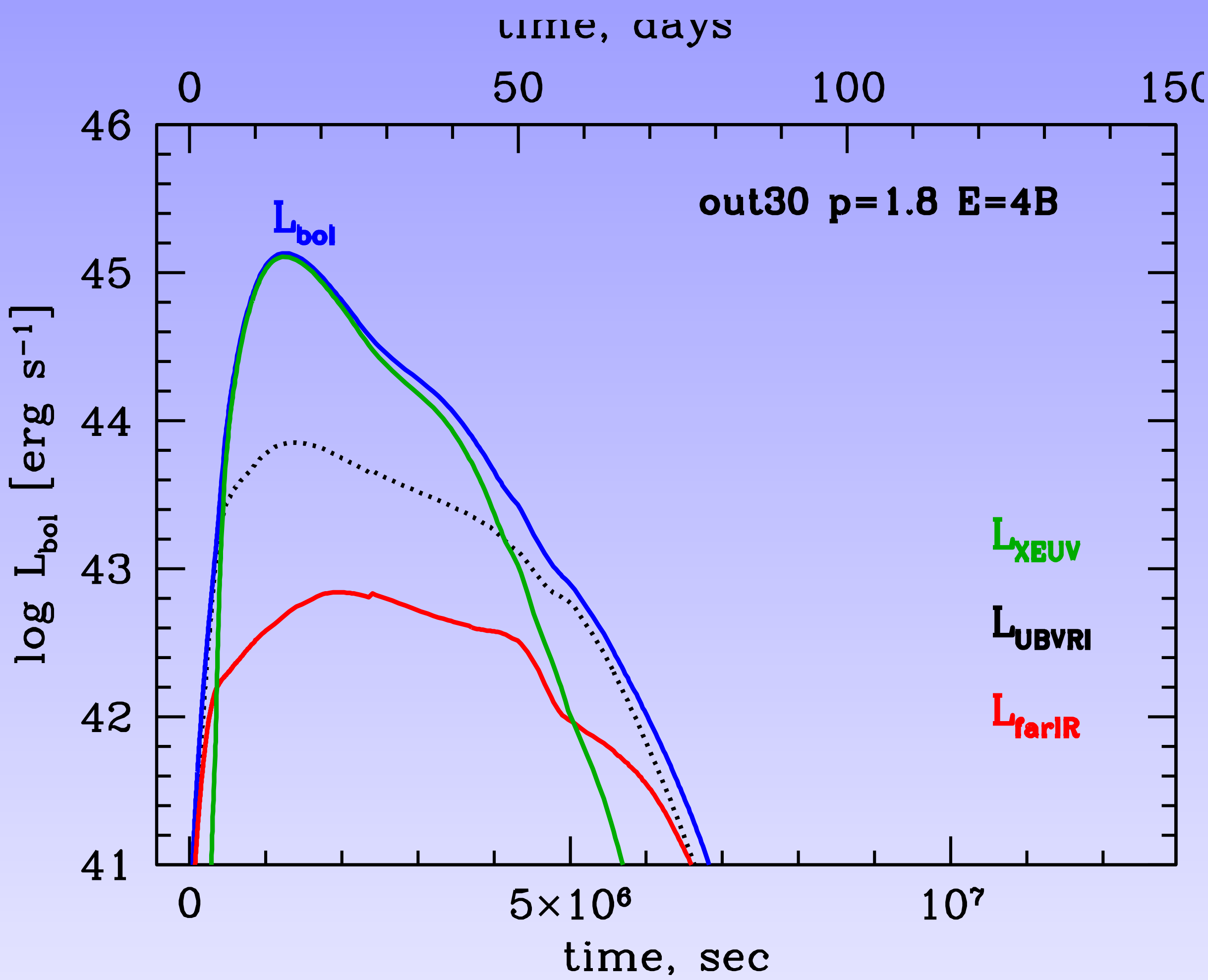
$$p = 1.8, M_w = 4.8 M_\odot$$

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



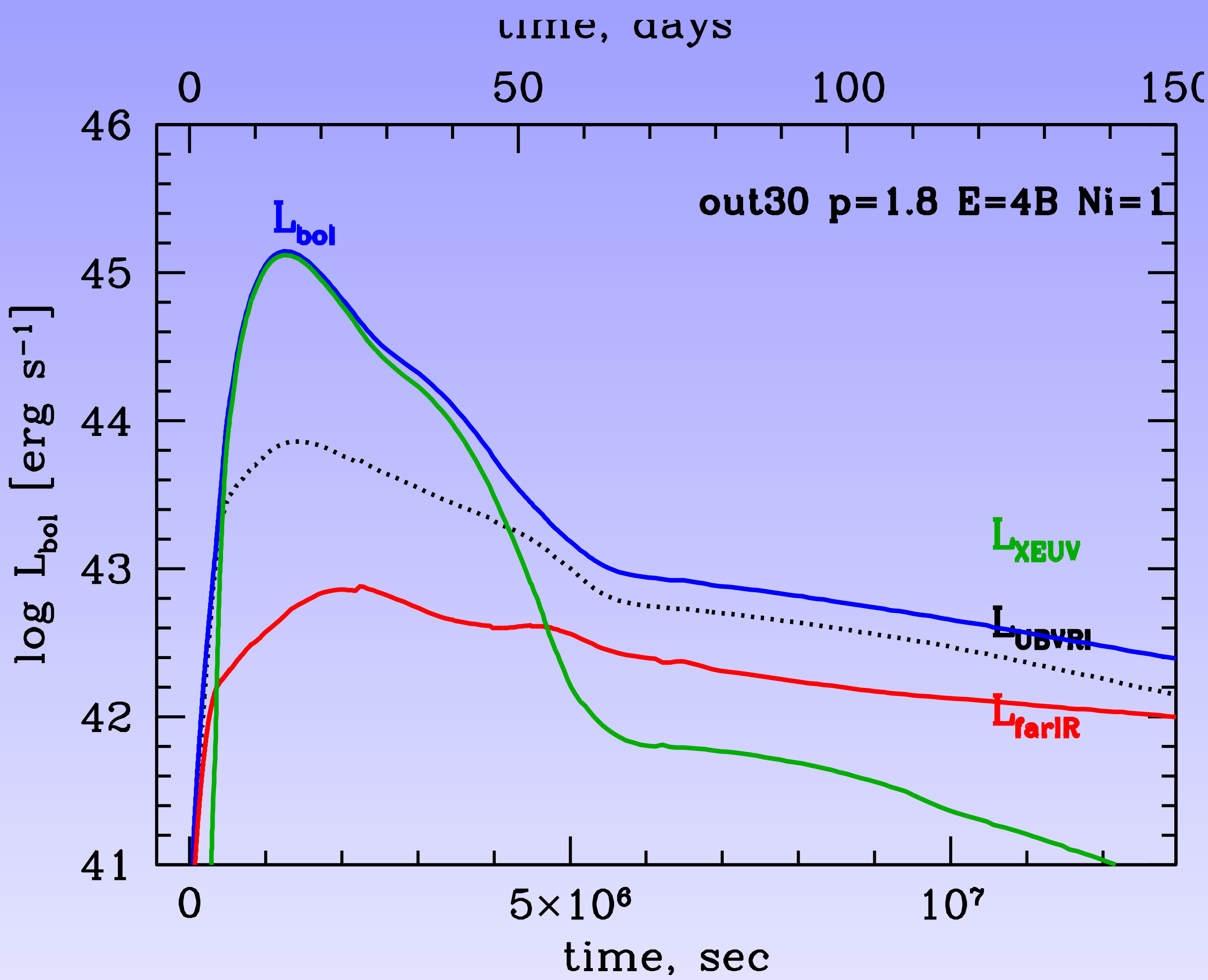
out10: $M_{ej} = 2M_{\odot}, p_w = 2, E = 3$ Bethe
out26: $M_{ej} = 0.2M_{\odot}, p_w = 1.8, E = 2$ Bethe

^{56}Ni vs. Shock wave heating



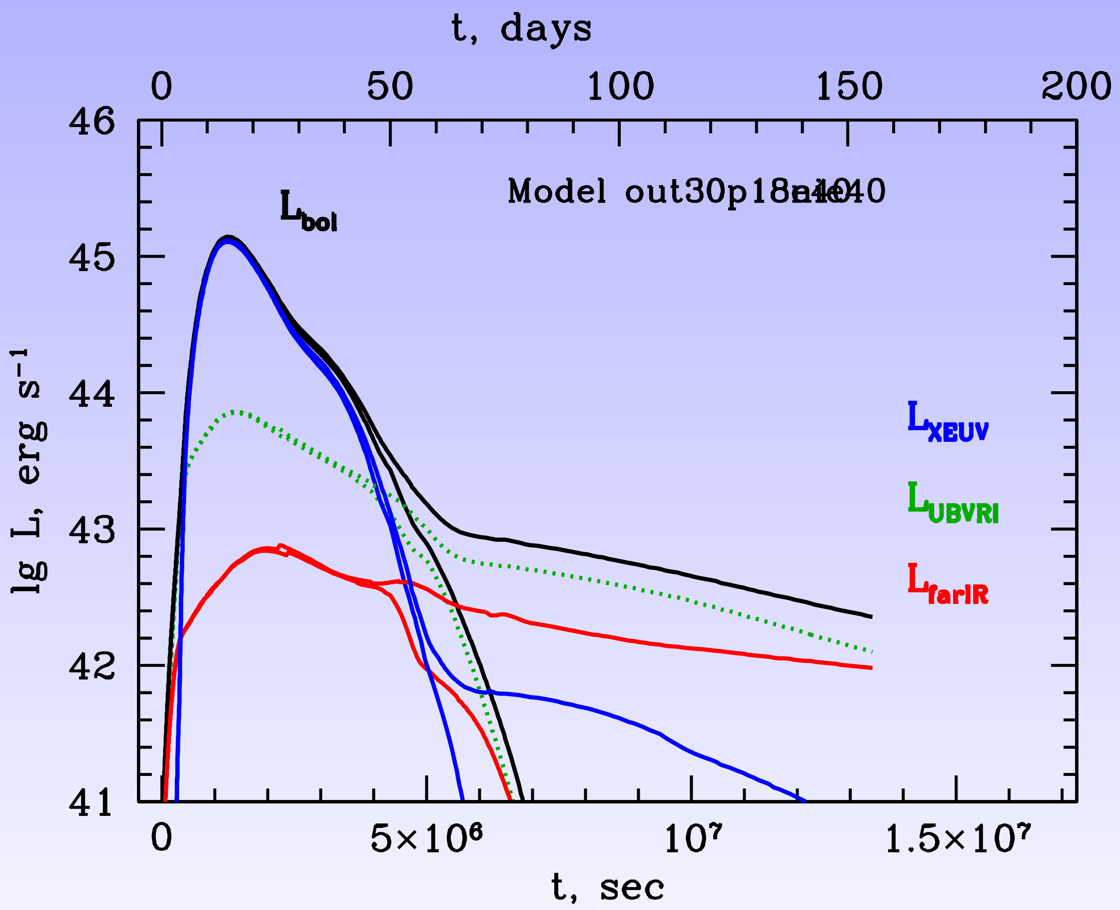
no ^{56}Ni

^{56}Ni vs. Shock wave heating



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

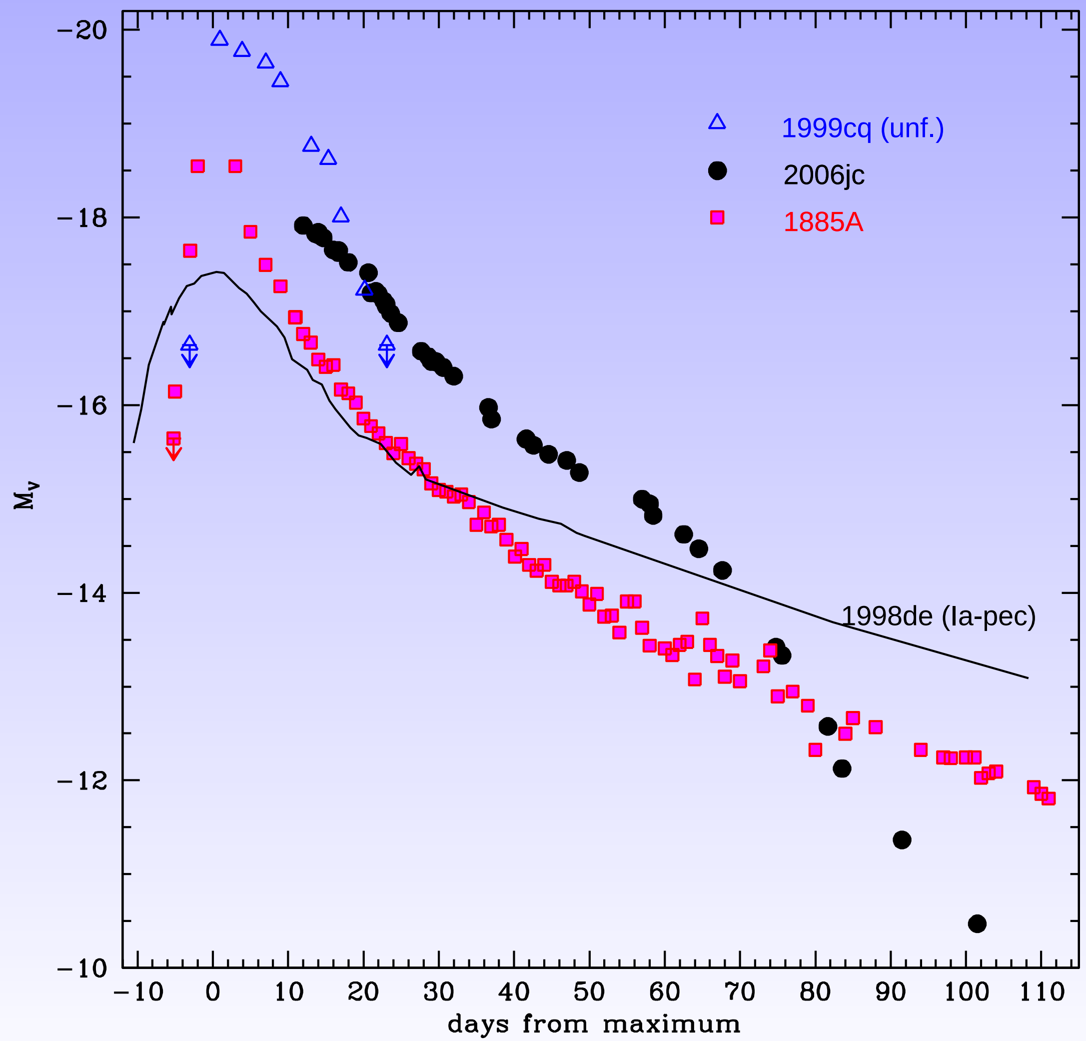
^{56}Ni vs. Shock wave heating



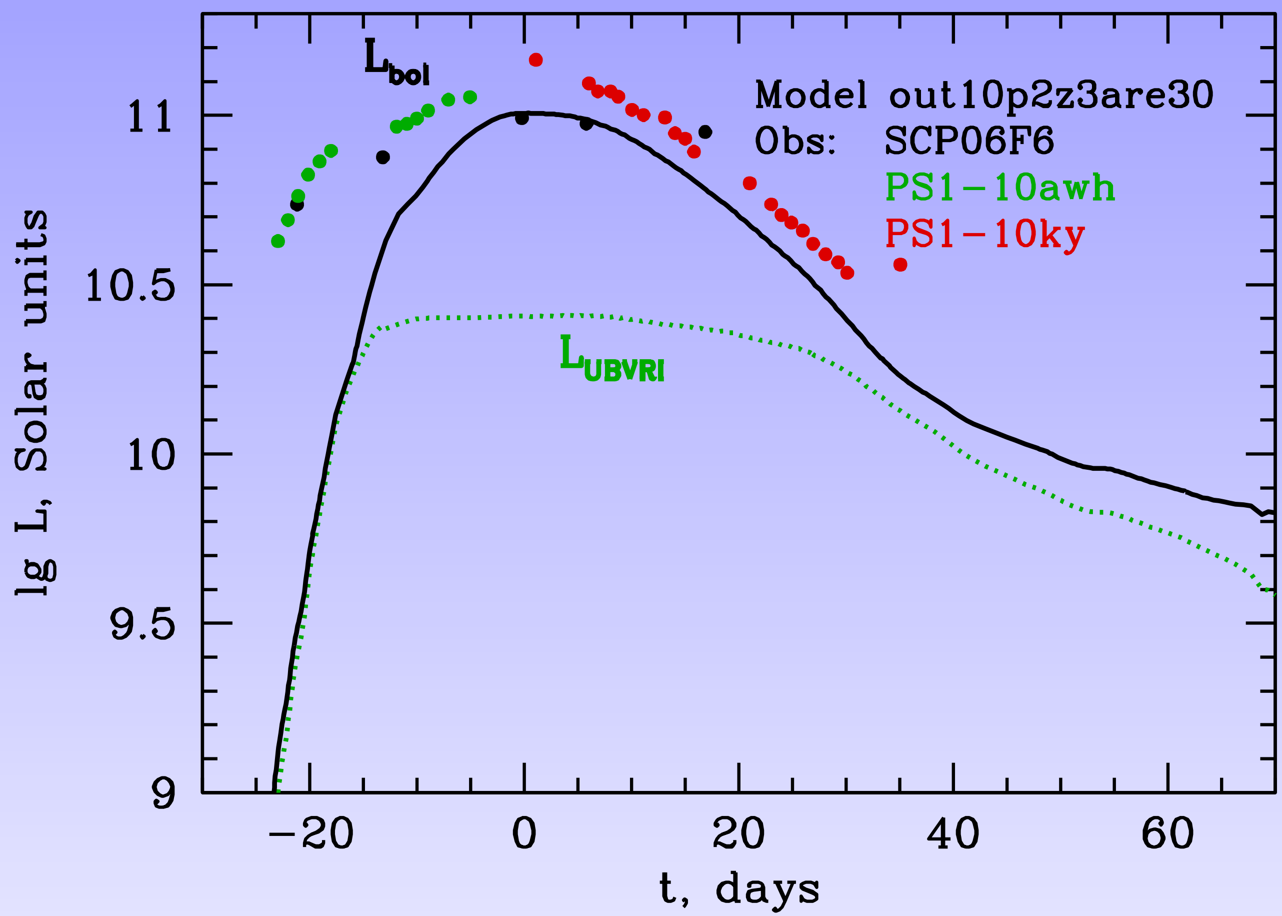
$M(^{56}\mathrm{Ni}) = 1 M_\odot$ added to the ejecta

Ibn SN2006jc without ^{56}Ni slope on the optical tail

Pastorello et al. 2008

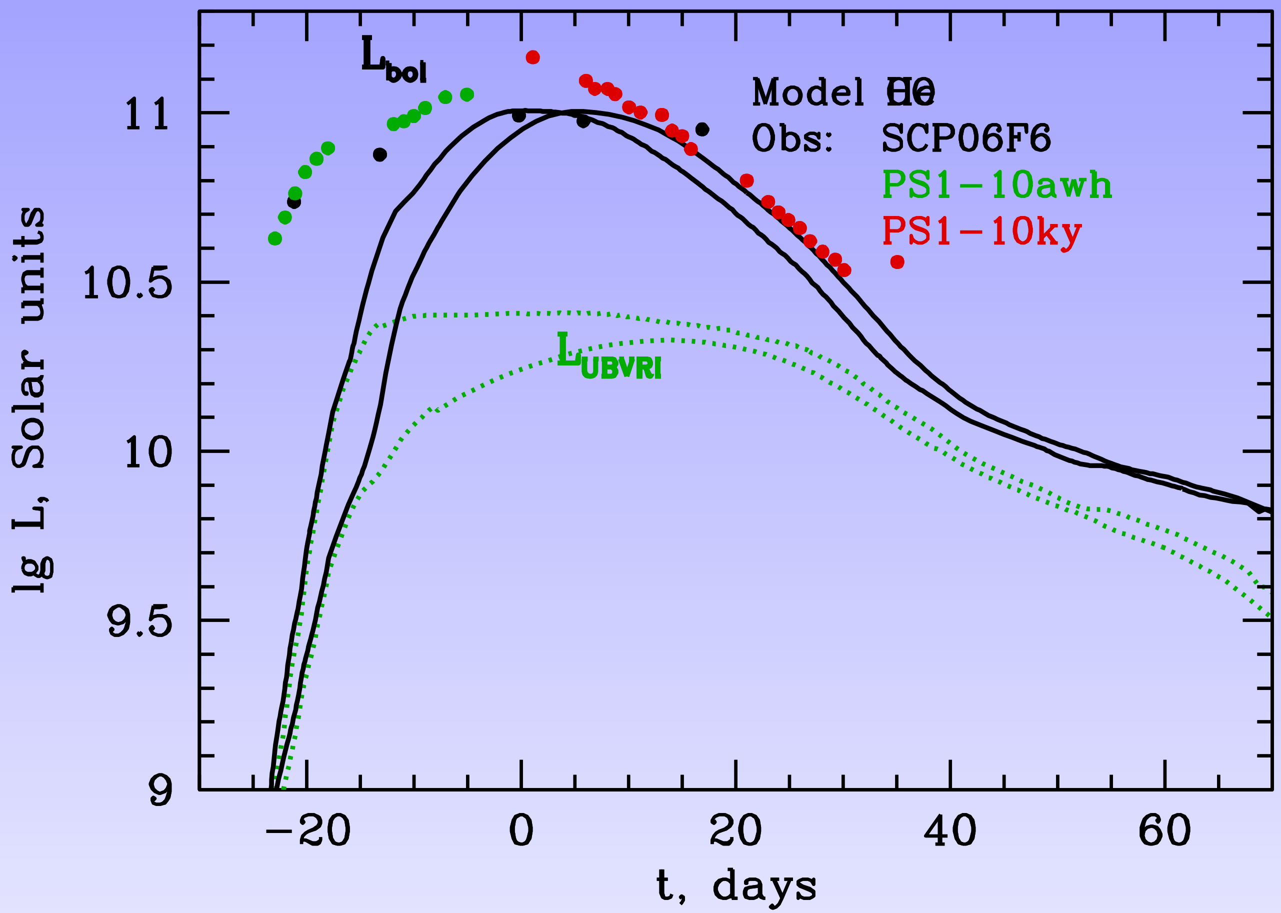


CO vs. He wind



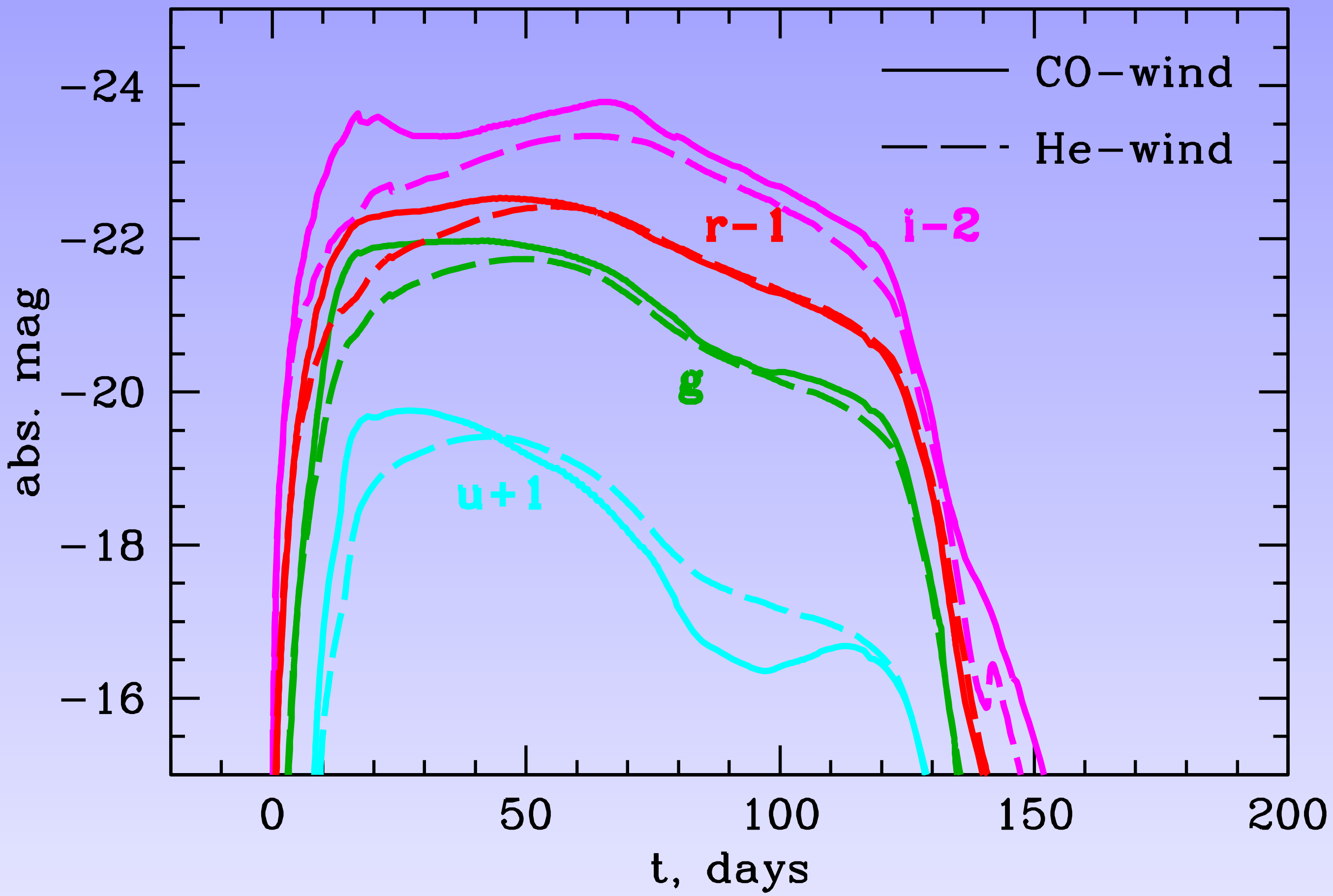
CO wind

CO vs. He wind



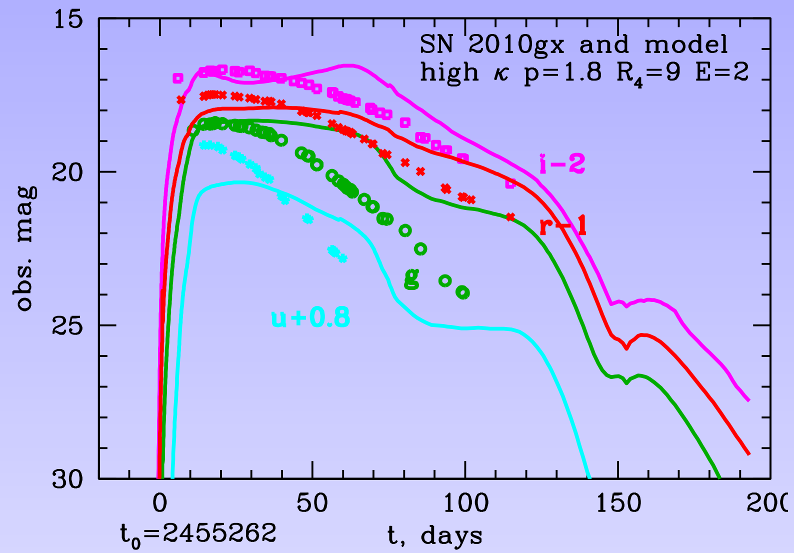
Model with He-wind is more symmetric around maximum light

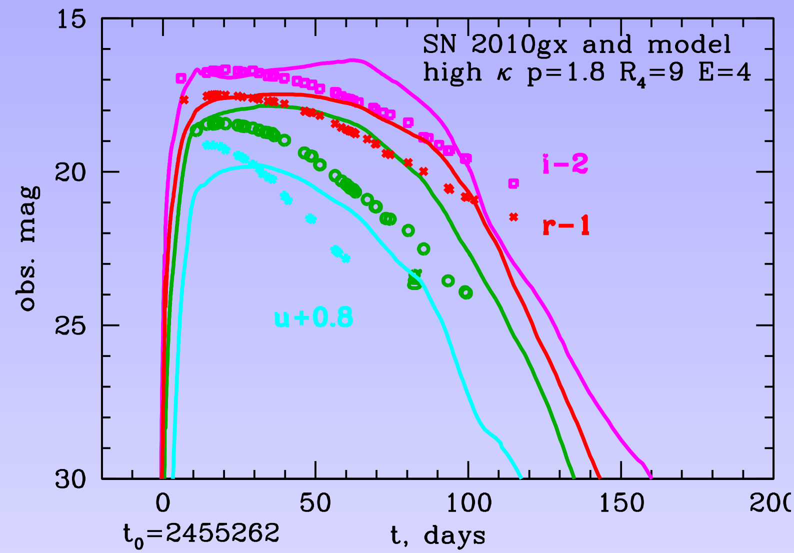
CO vs. He wind



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

Expansion opacity enhanced

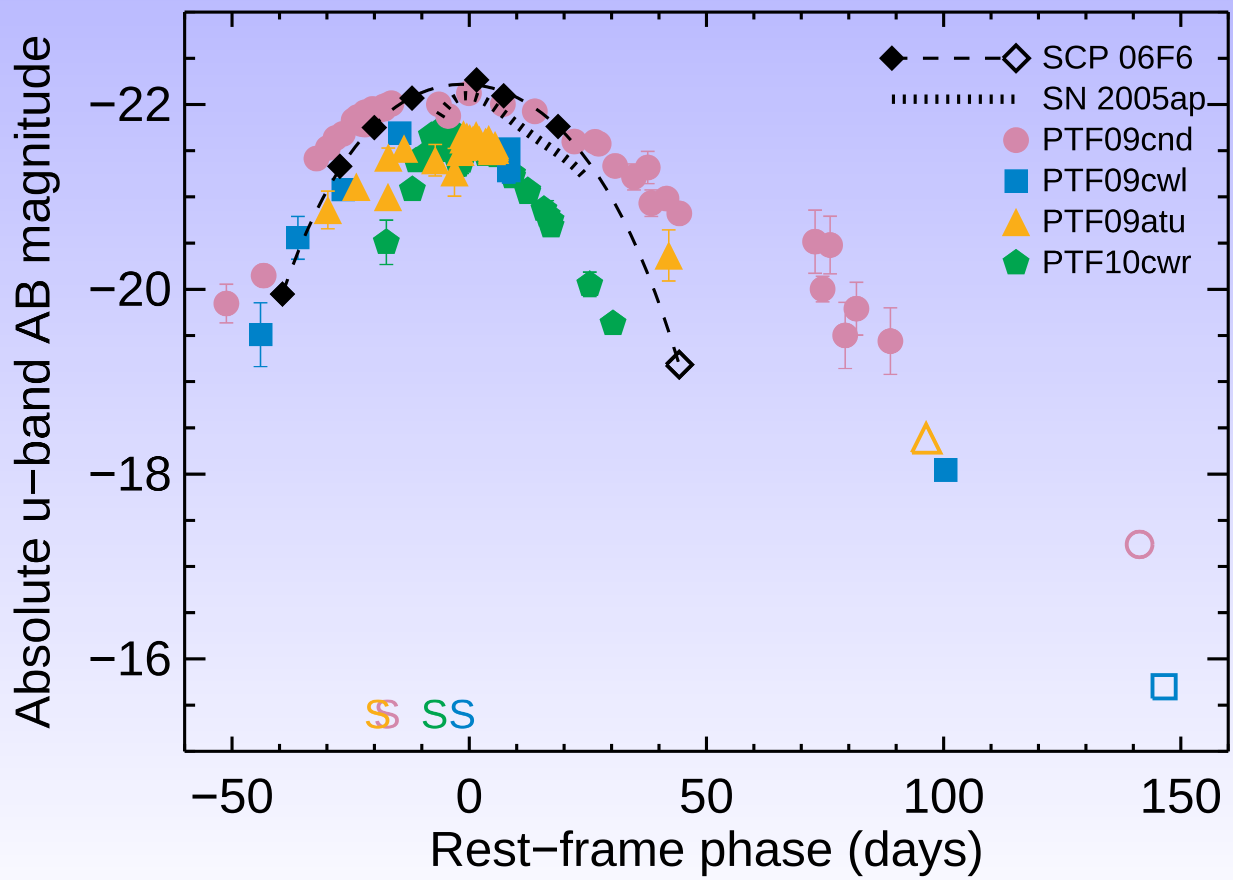




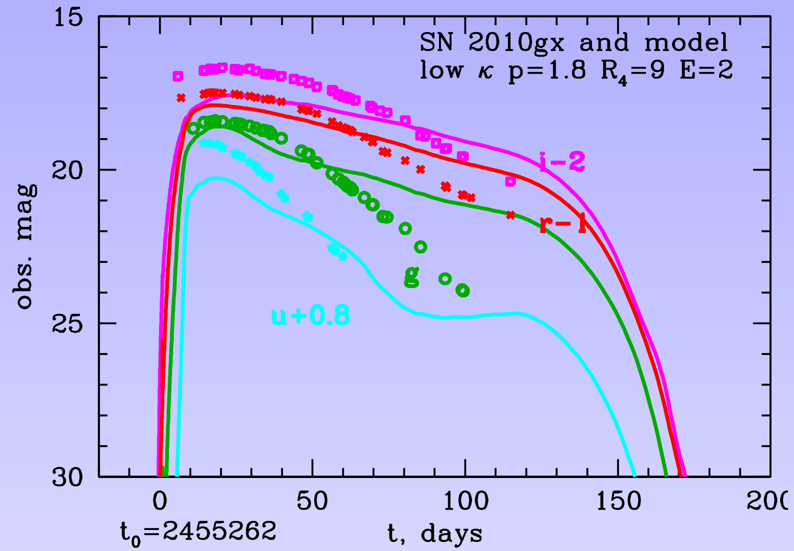
Opacity is taken as for $dv/dr = 1/t = 1/1\text{day}$

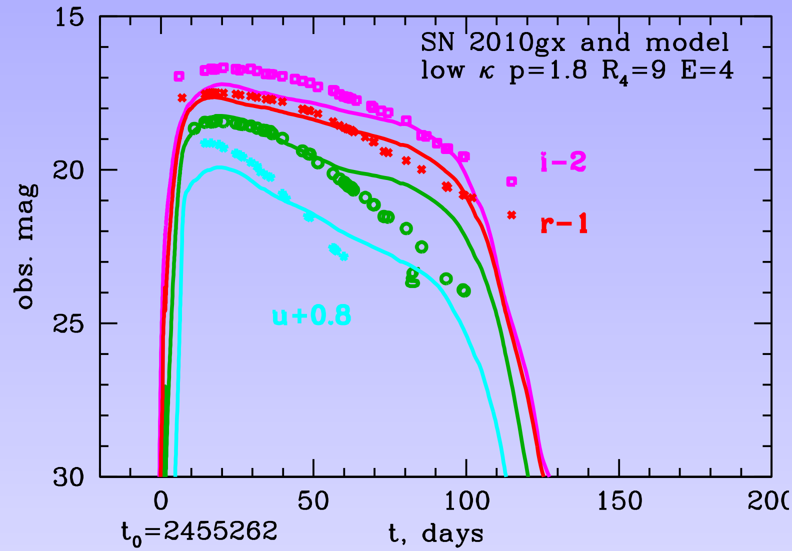
Observations of the superluminous SNe

Quimby et al. 2011

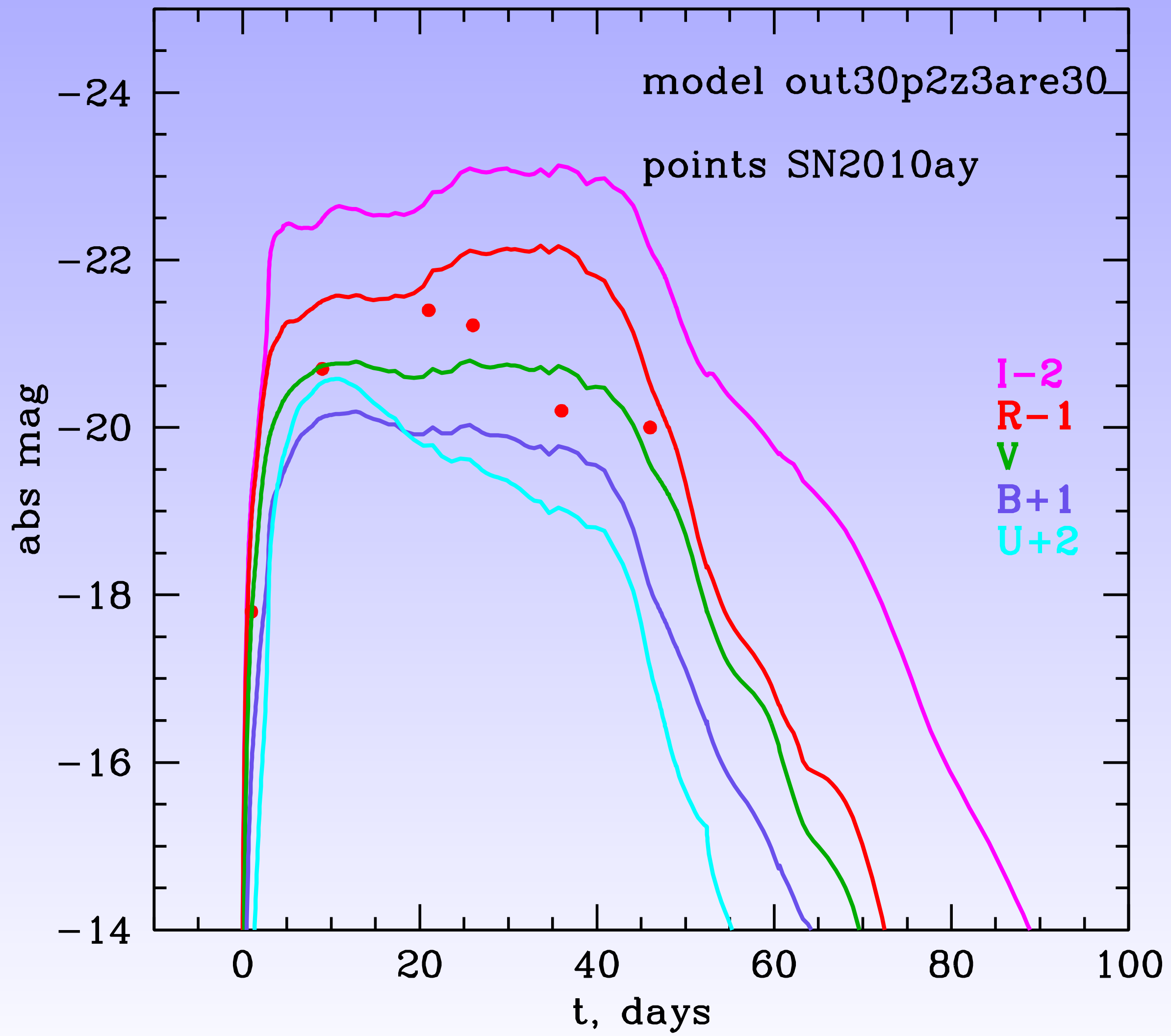


Best models for SN 2010gx



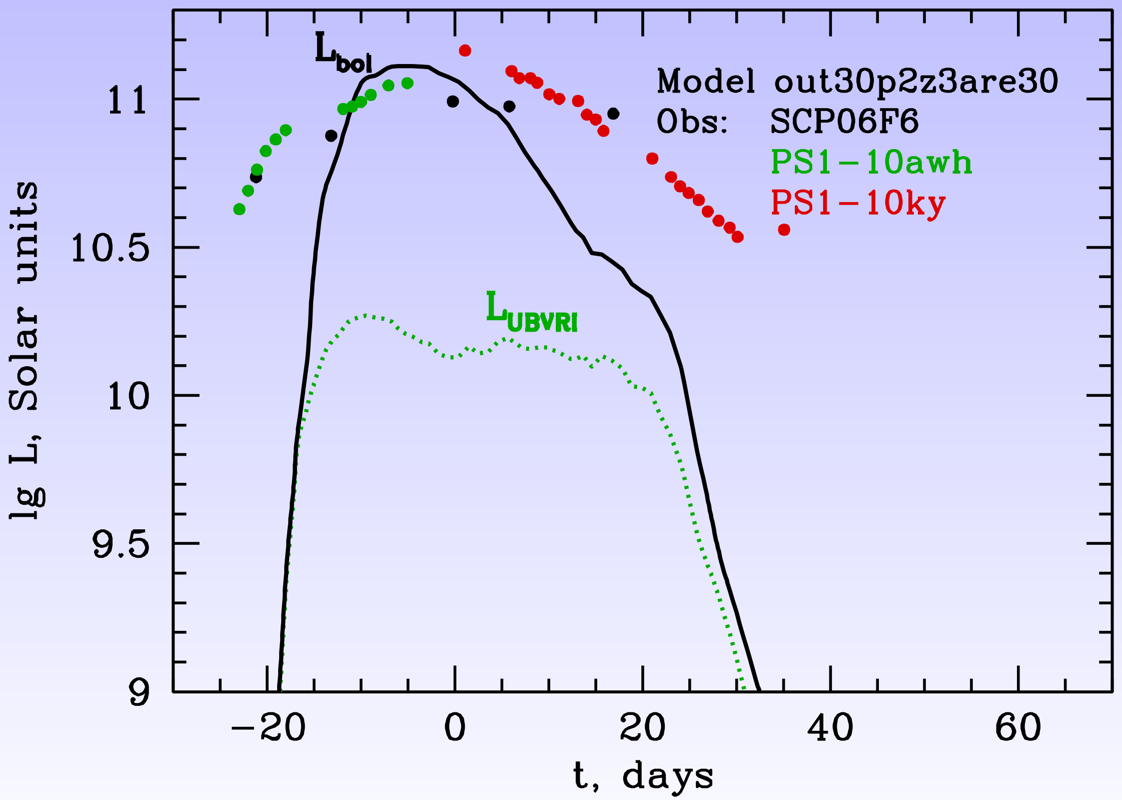


SN 2010ay



model out30p2z3are30
points SN2010ay
I−2
R−1
V
B+1
U+2
abs mag
−24
−22
−20
−18
−16
−14
0
20
40
60
80
100
t, days

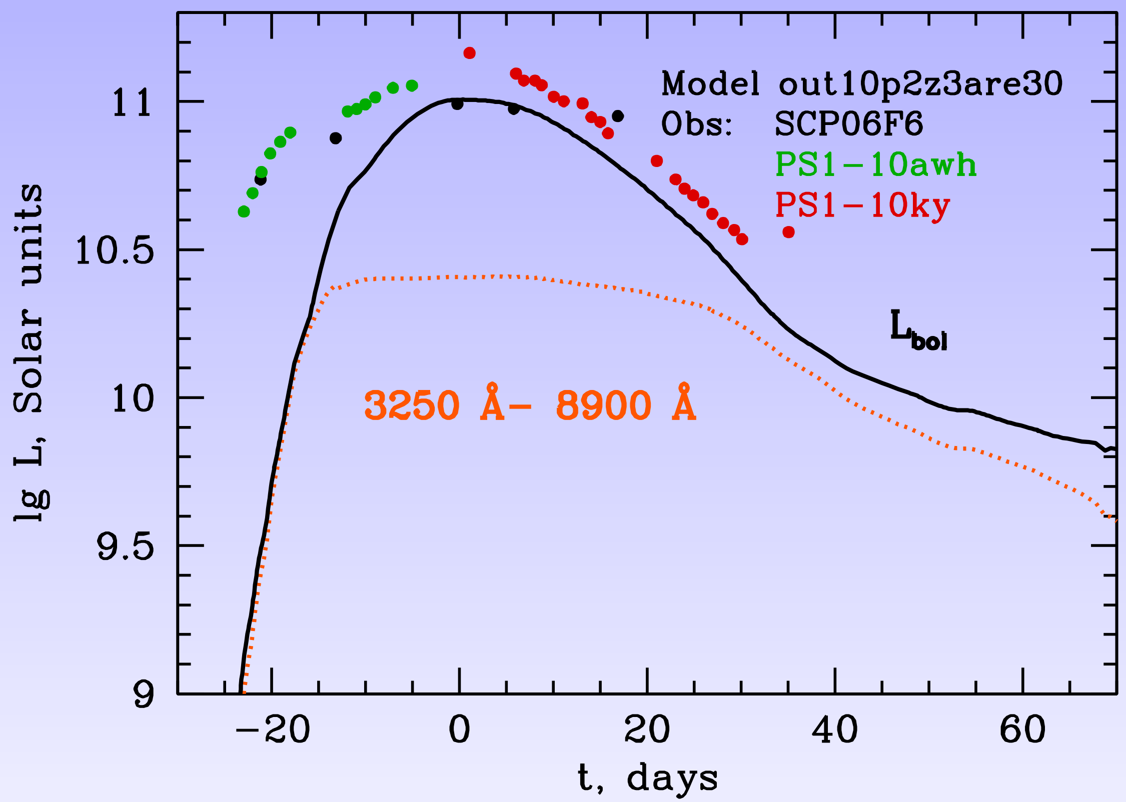
Model vs. observations



BUT

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

What is bolometric?



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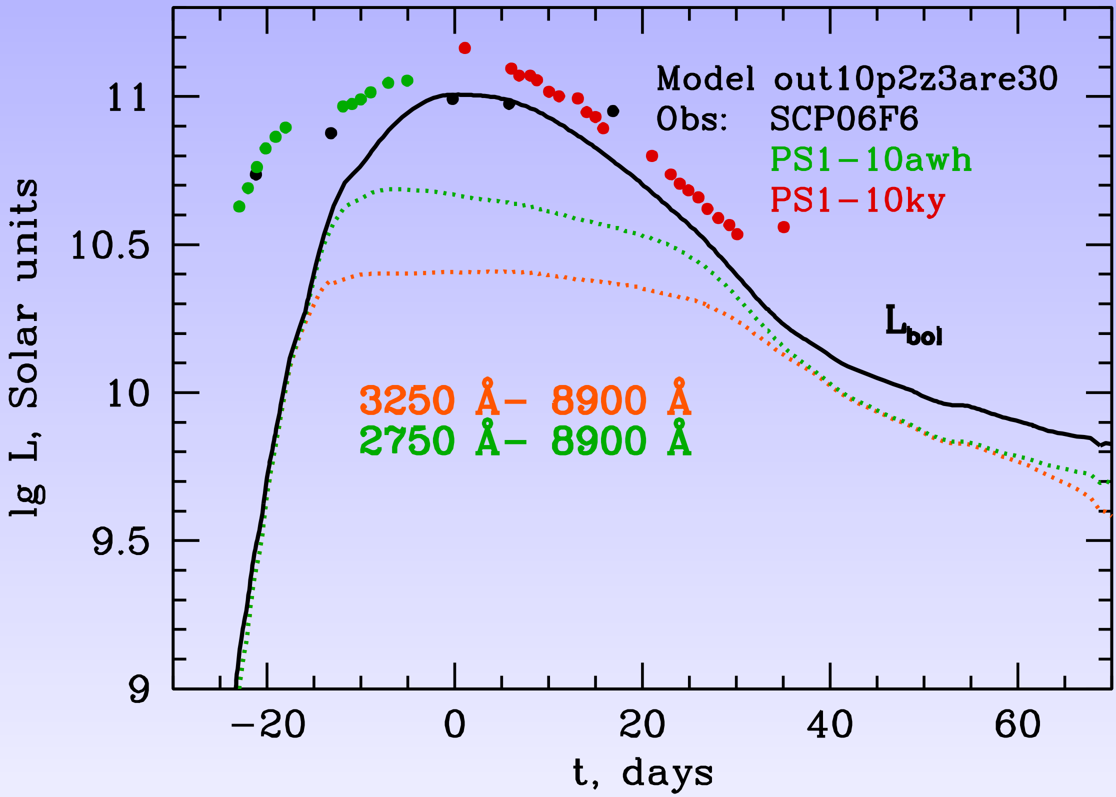

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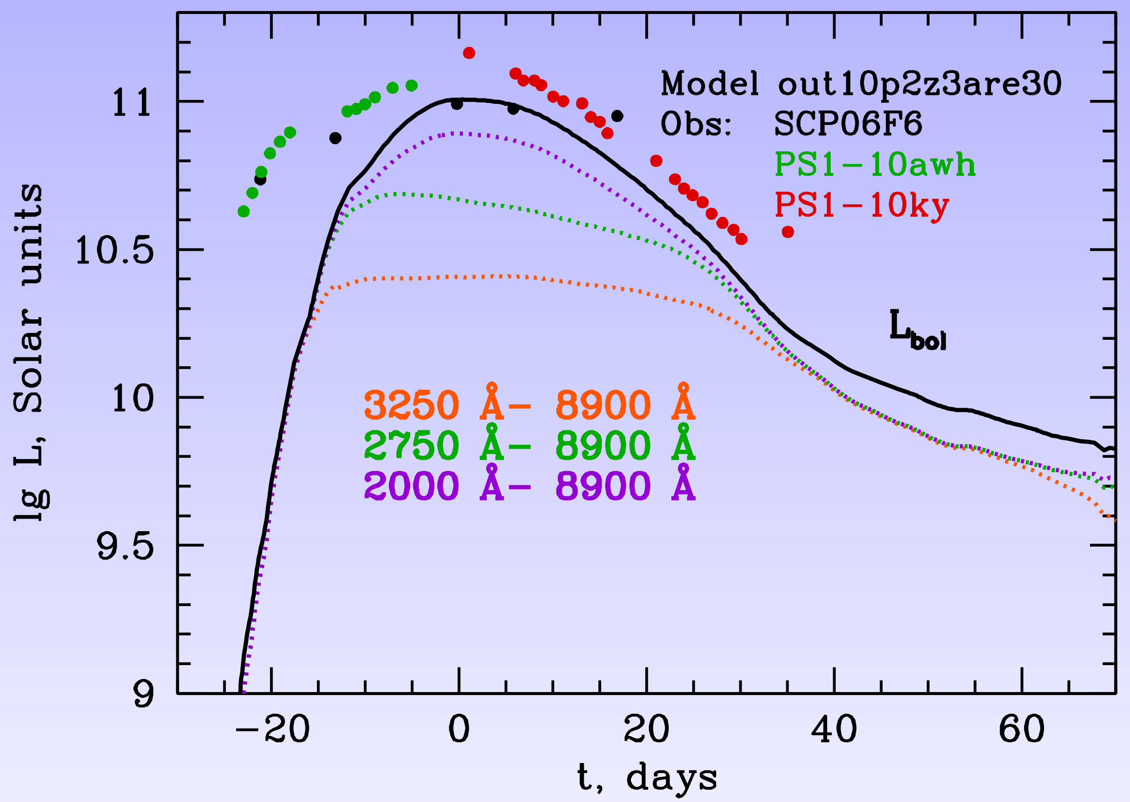

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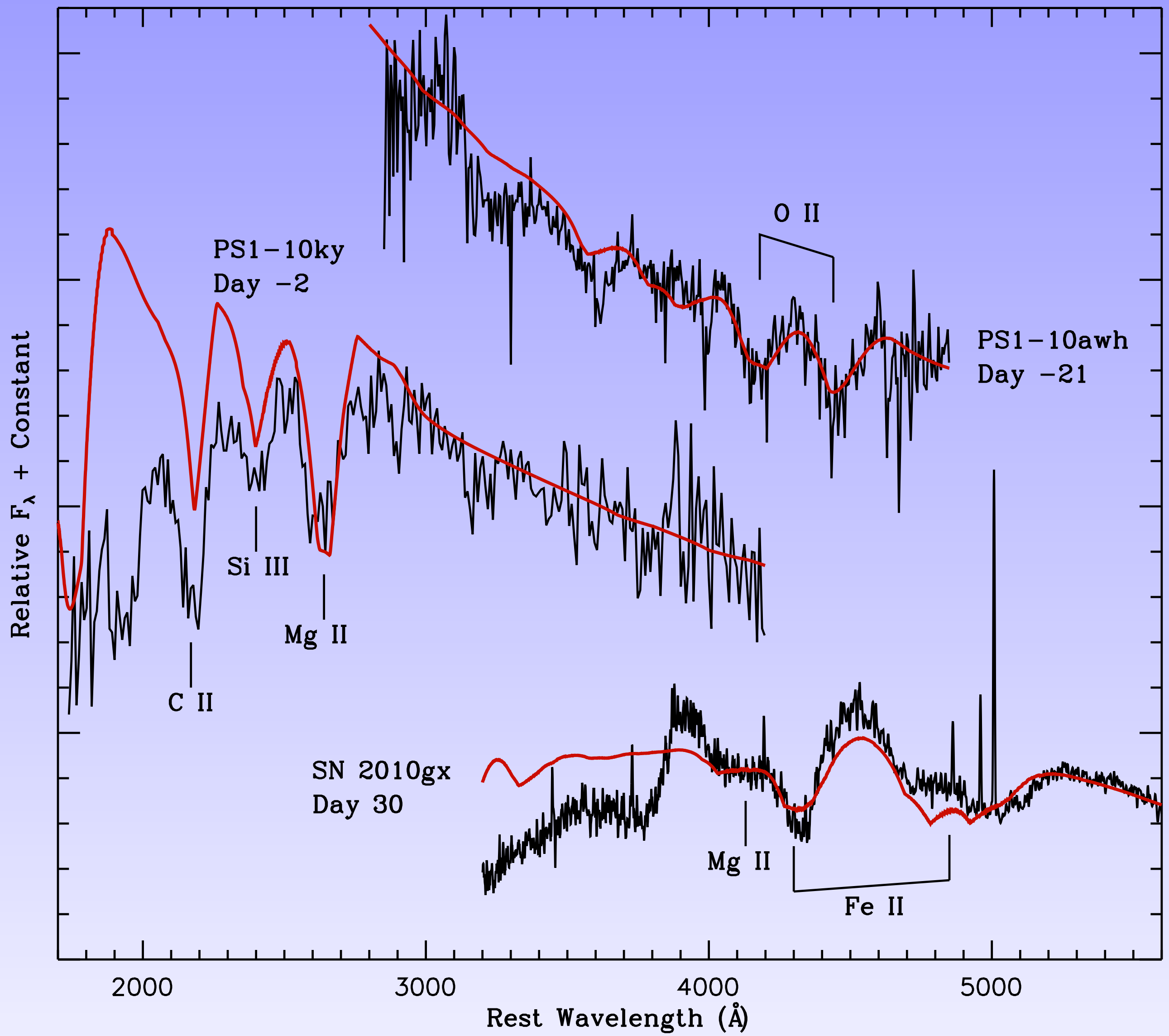
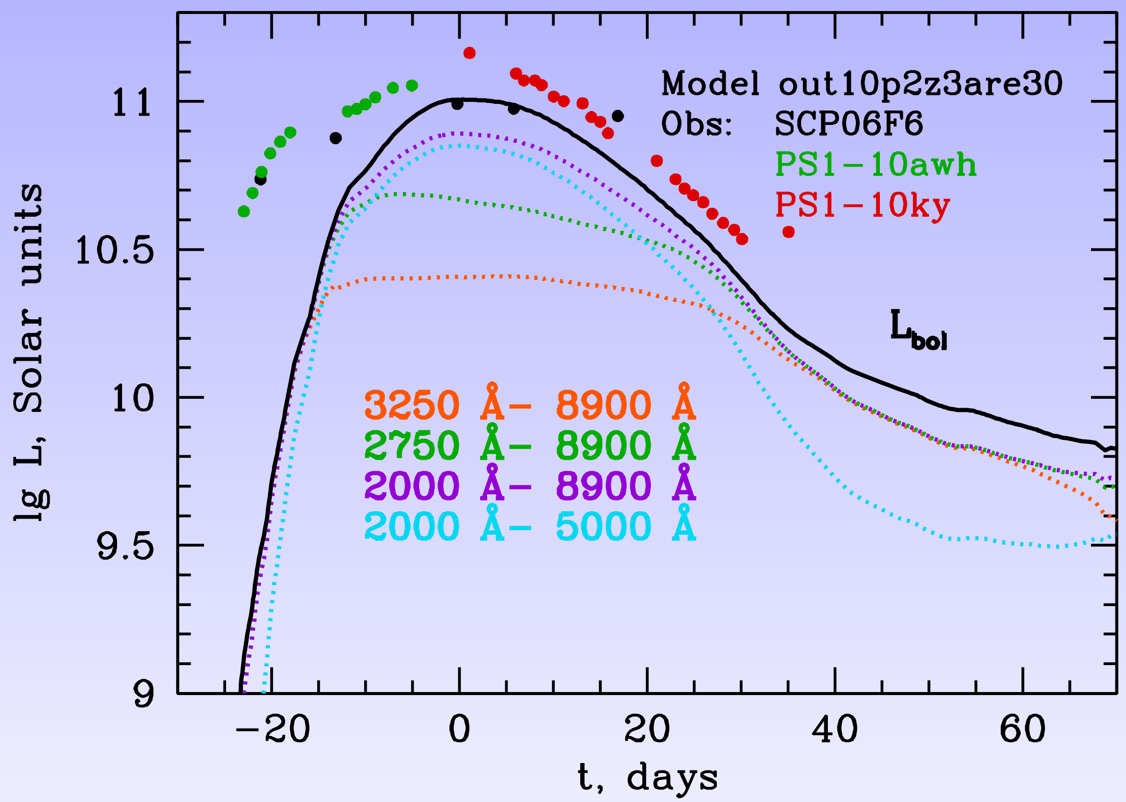
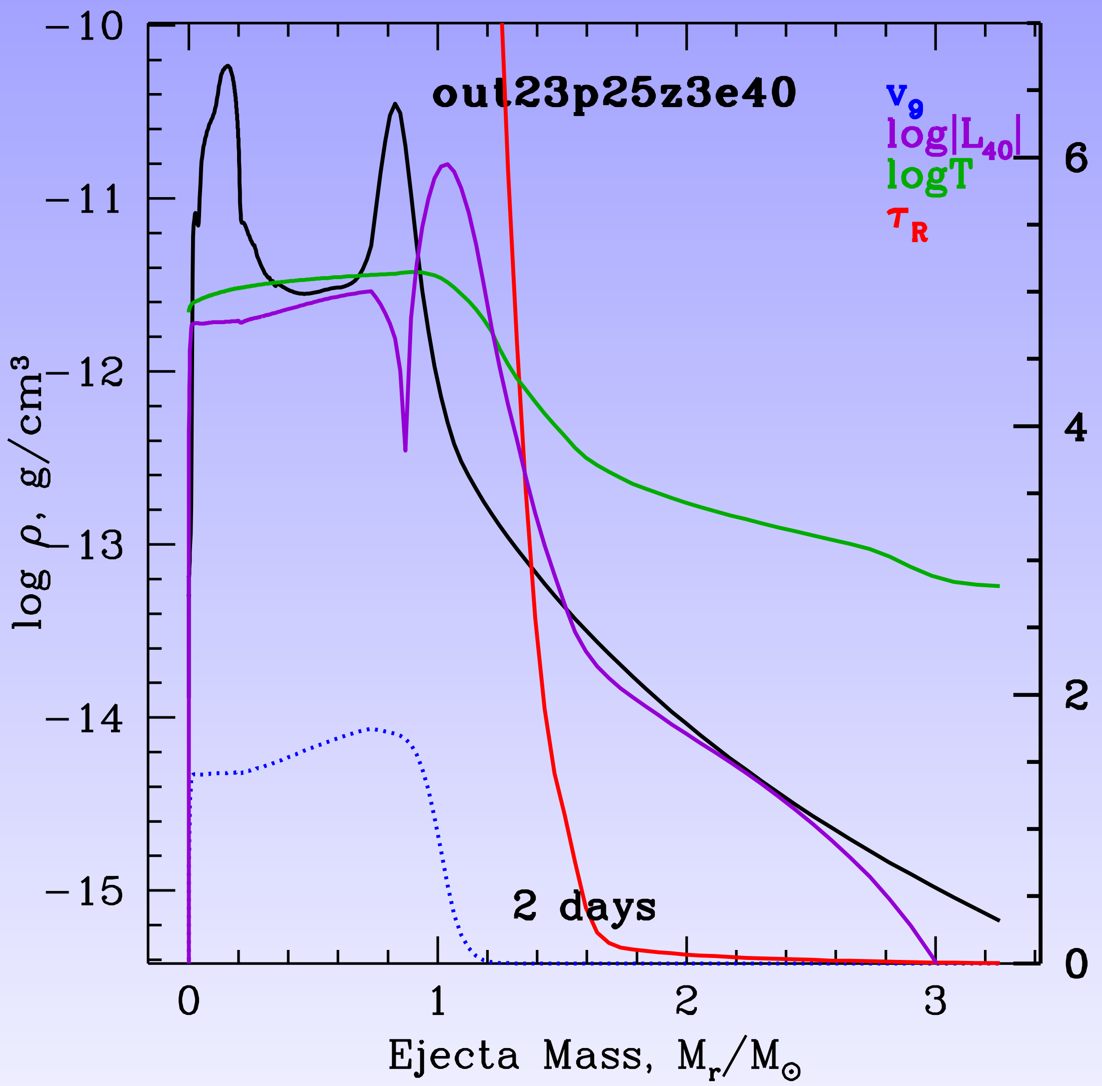


Chomiuk et al. 2009

What is bolometric?



Evolution of model structure



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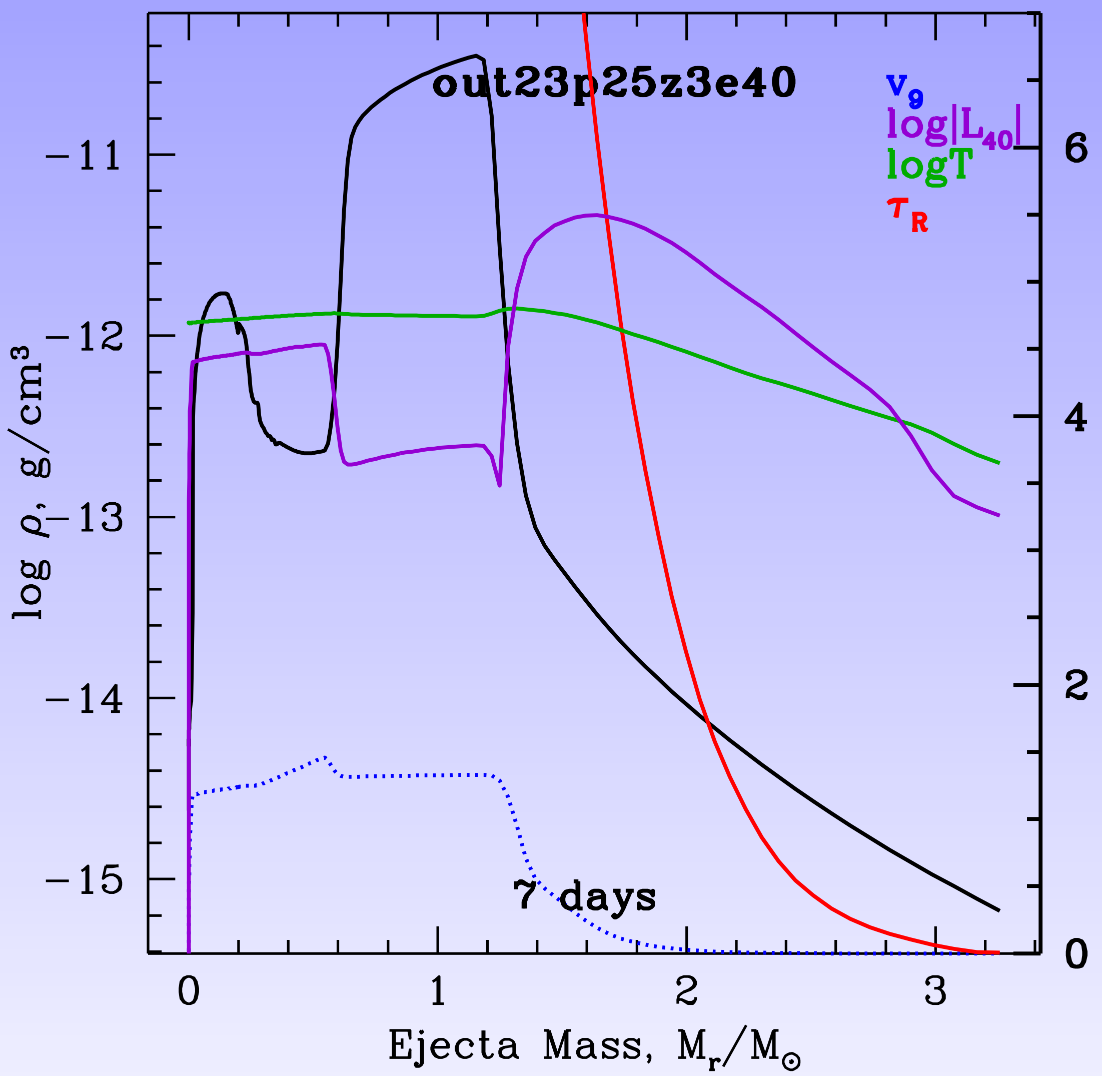

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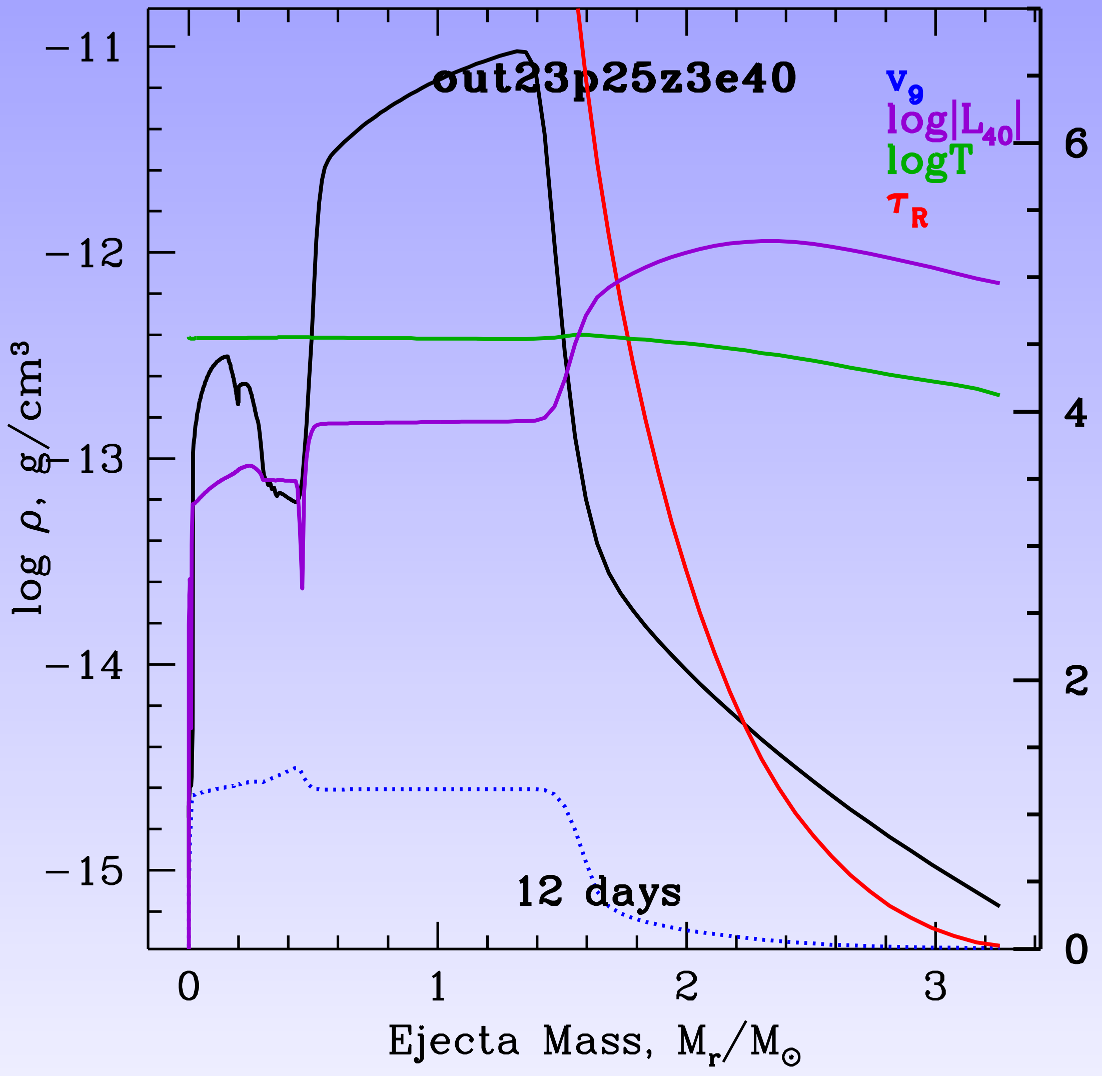

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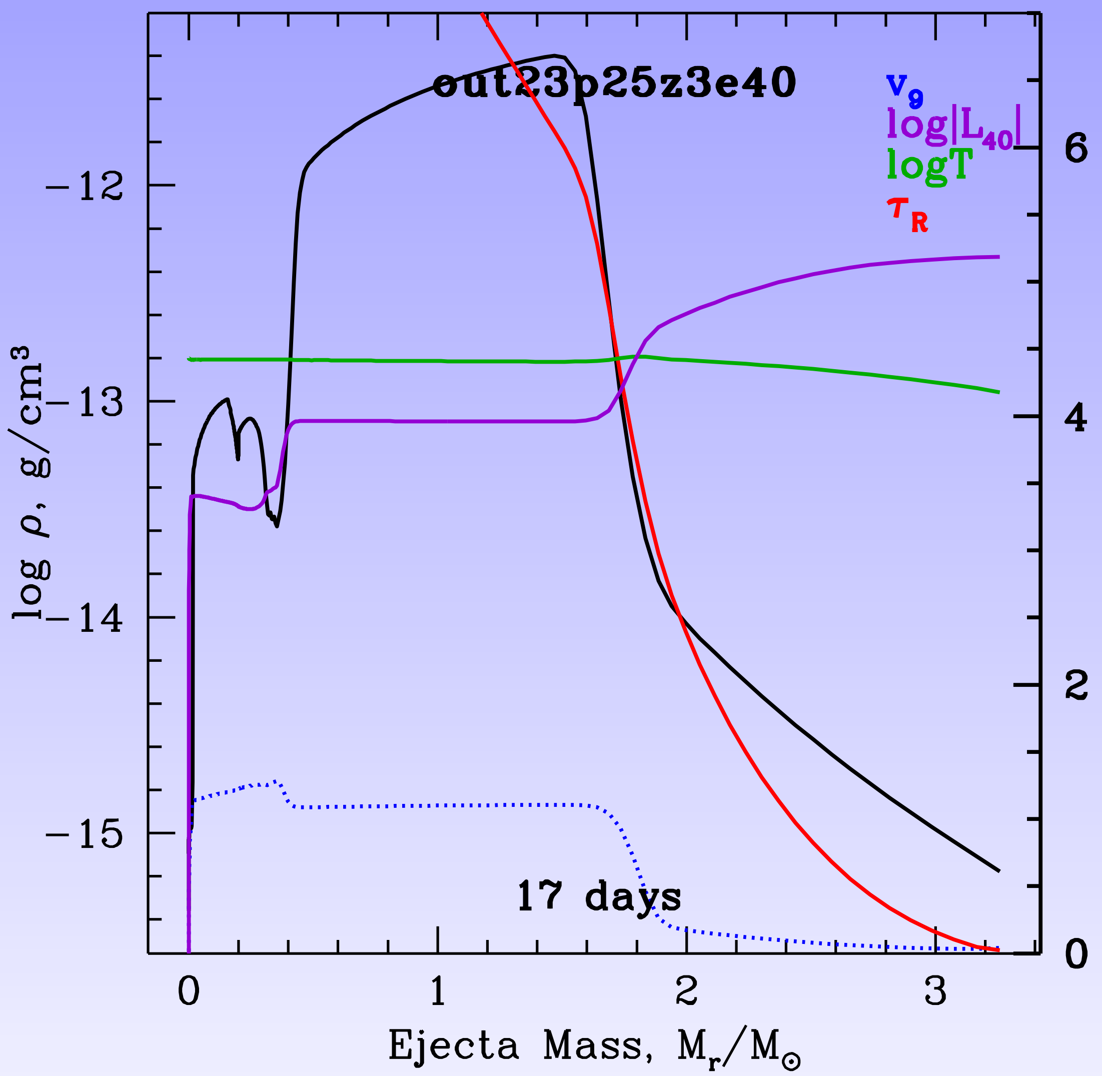

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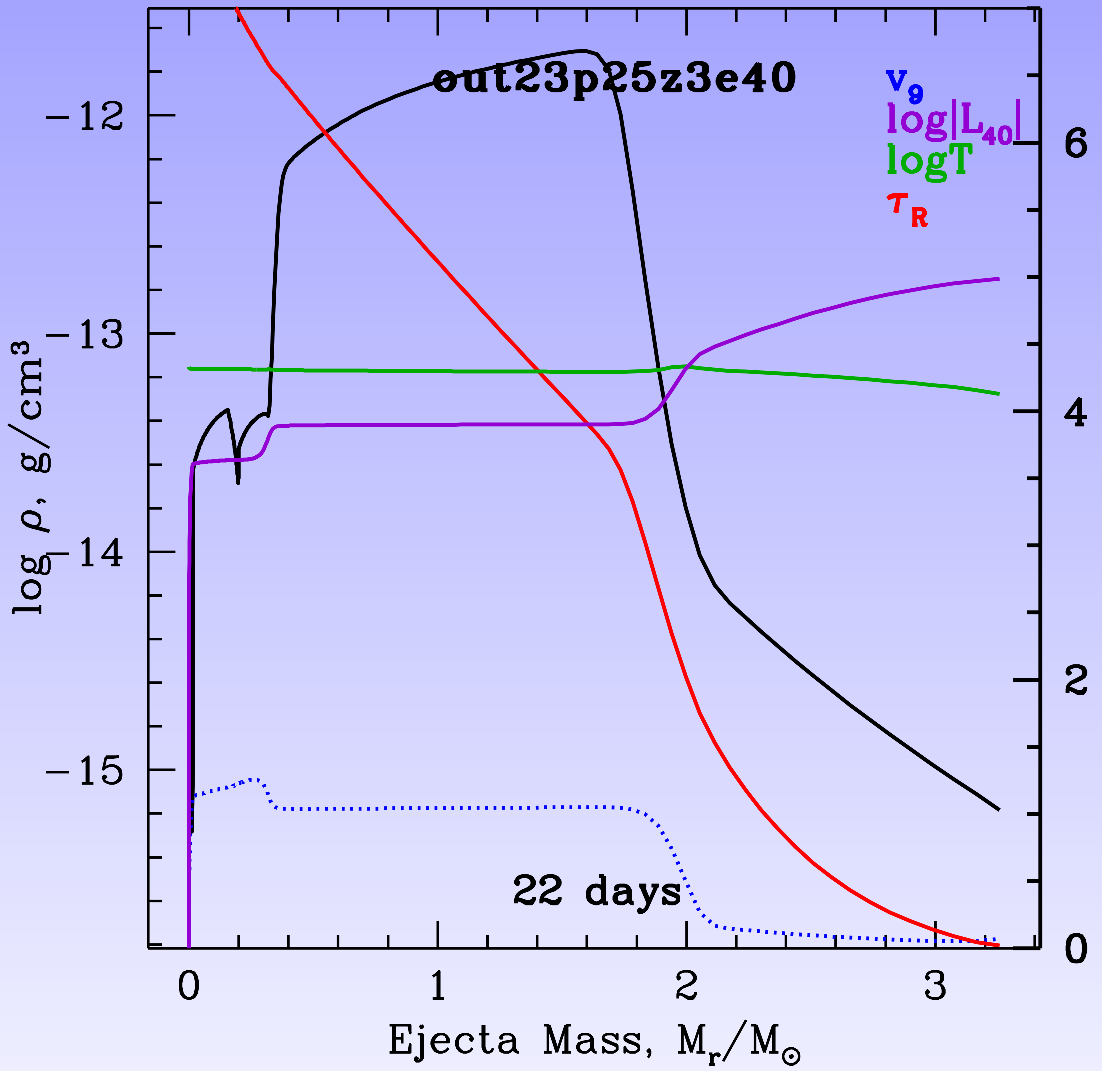

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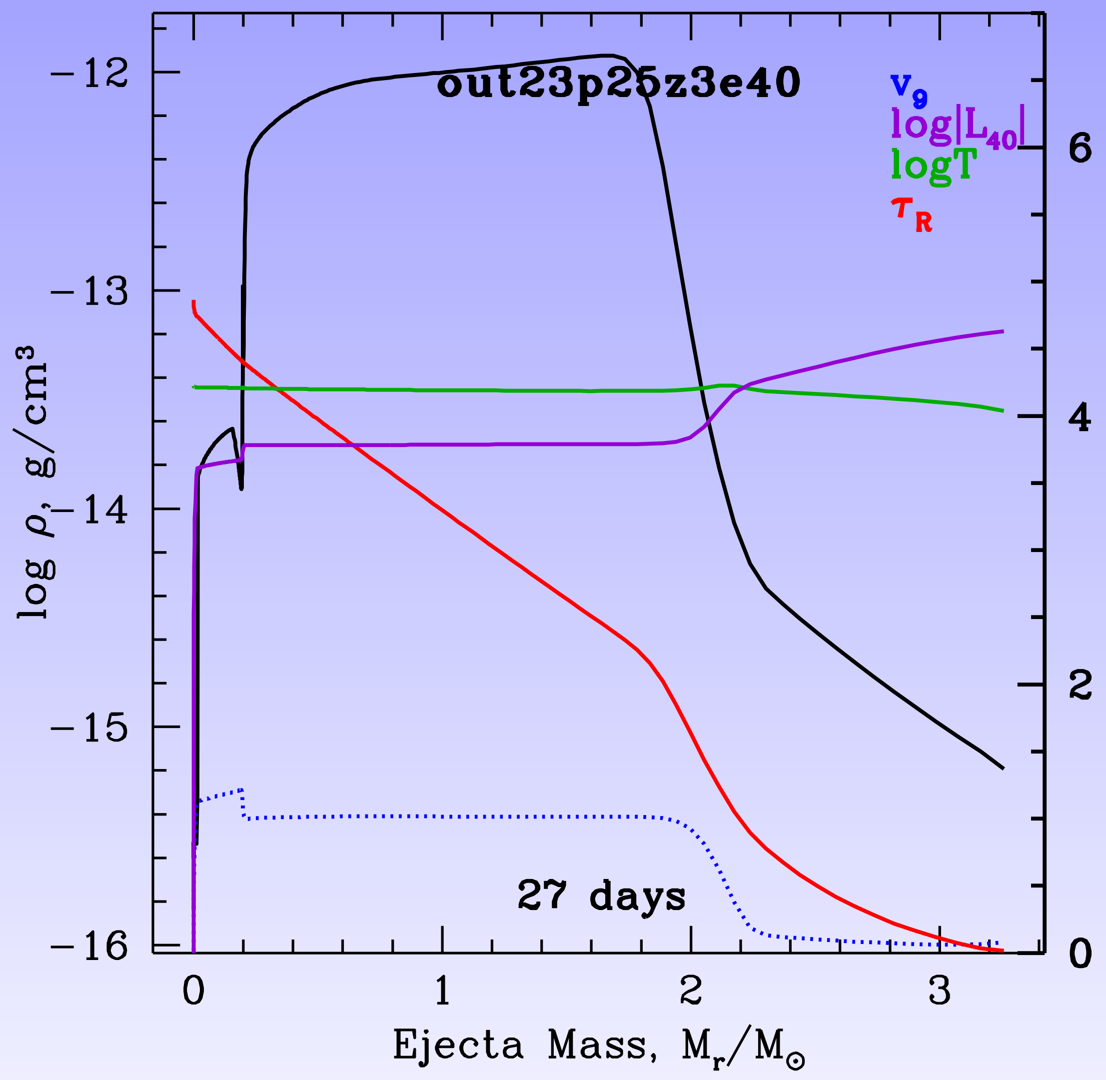

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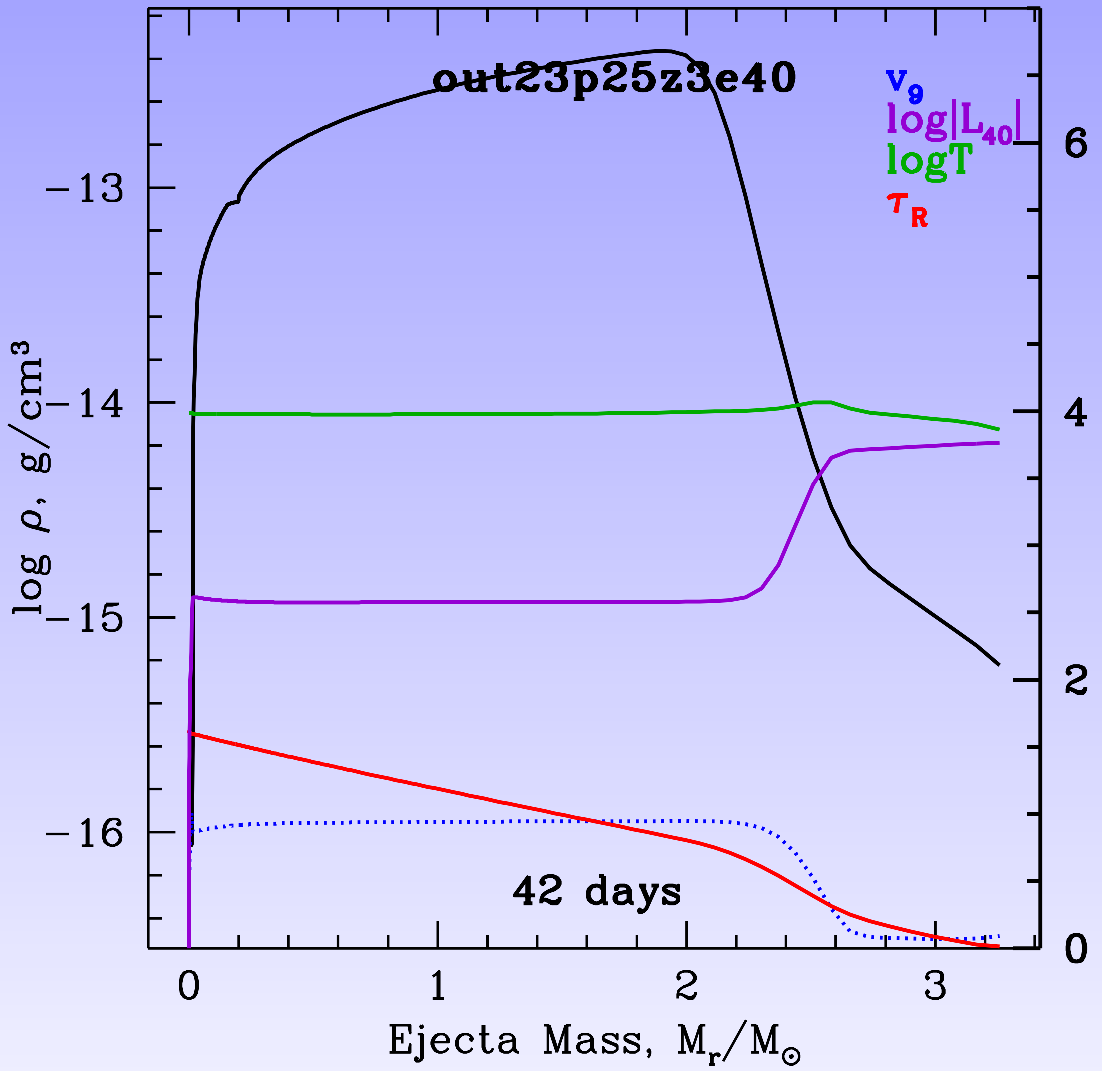

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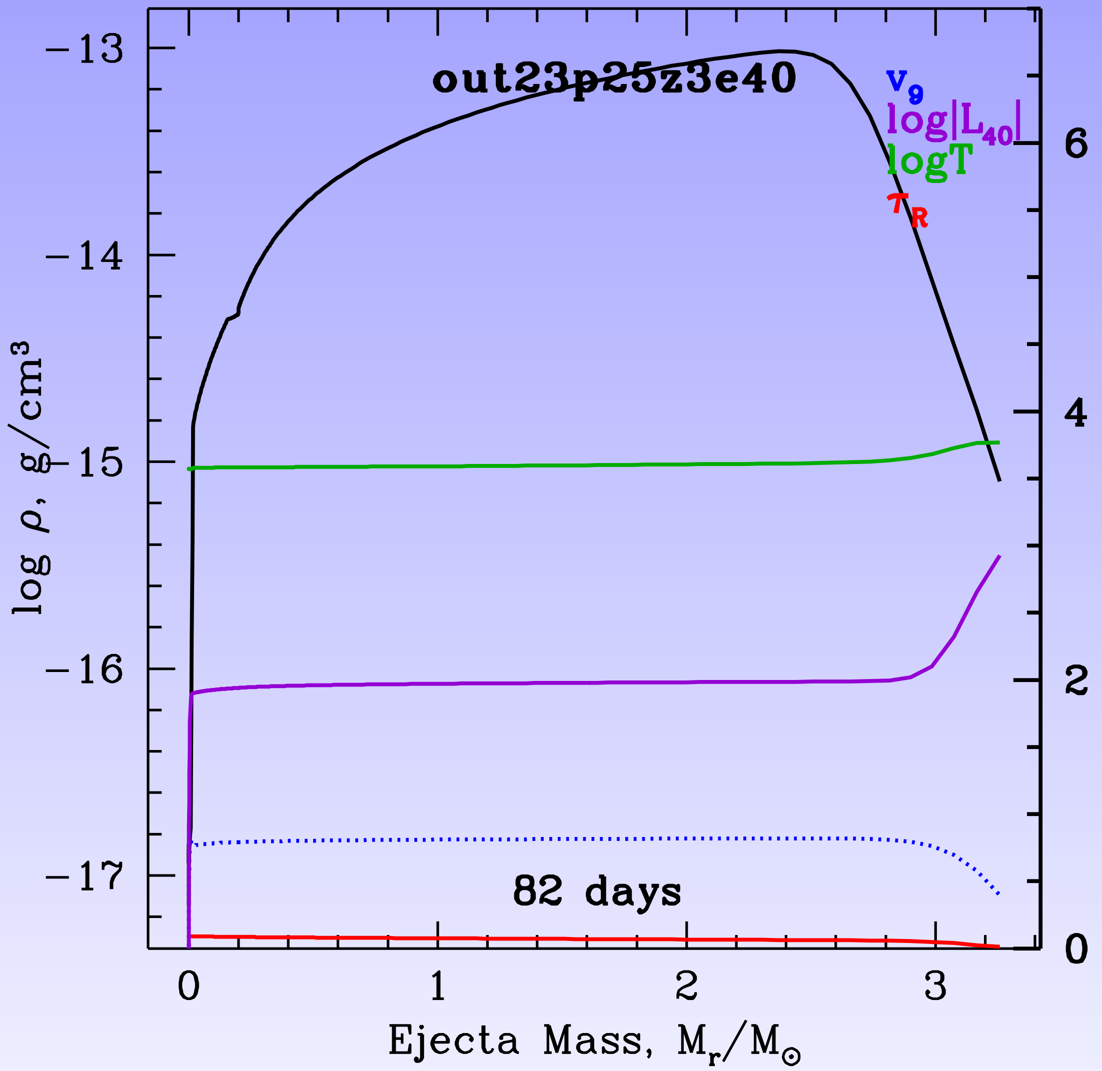
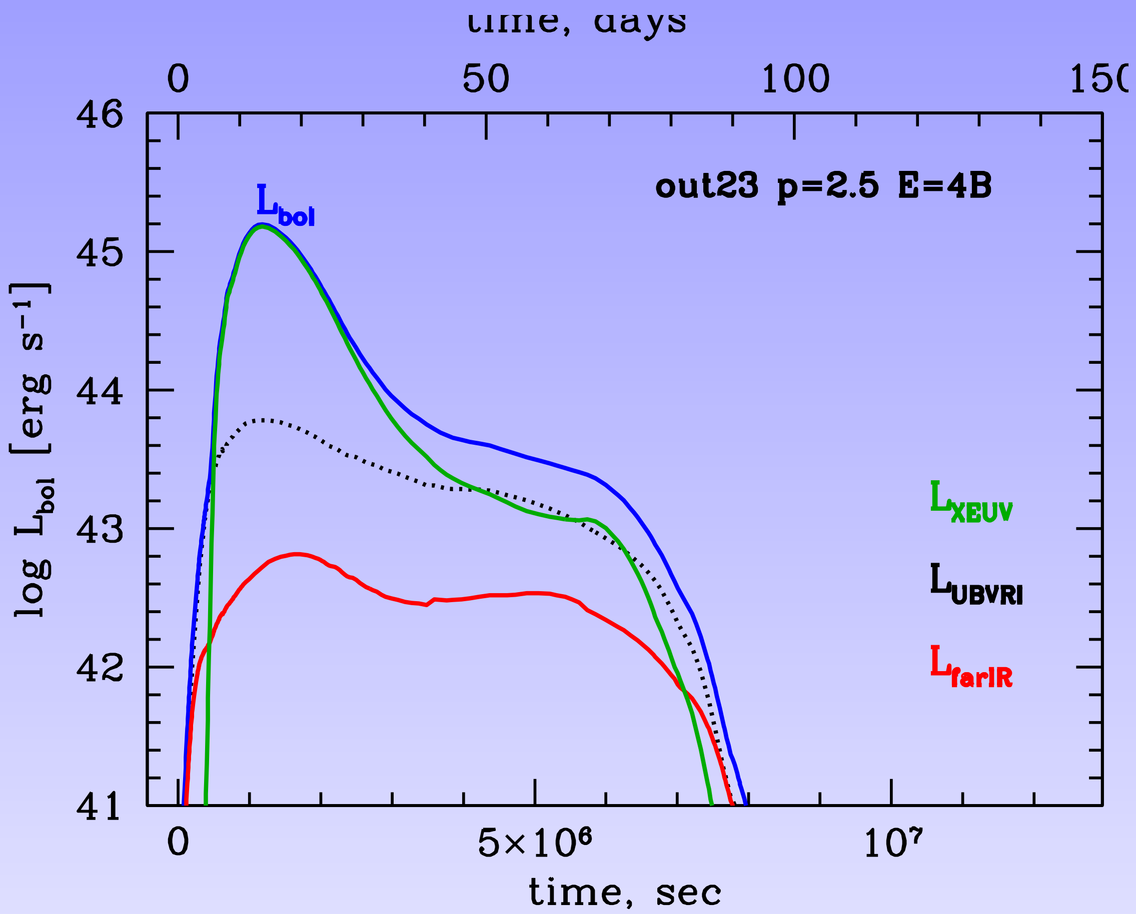


The light curve for the last model



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