Studying the early light curves of SNe Ia

Tony Piro
(Carnegie)

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Why are early light curves important?

1. Cooling of shock-heated white dwarf
2. Interaction of the ejecta with the companion
3. Shallow ^{56}Ni distribution

Rising Light Curve of SN 2011fe

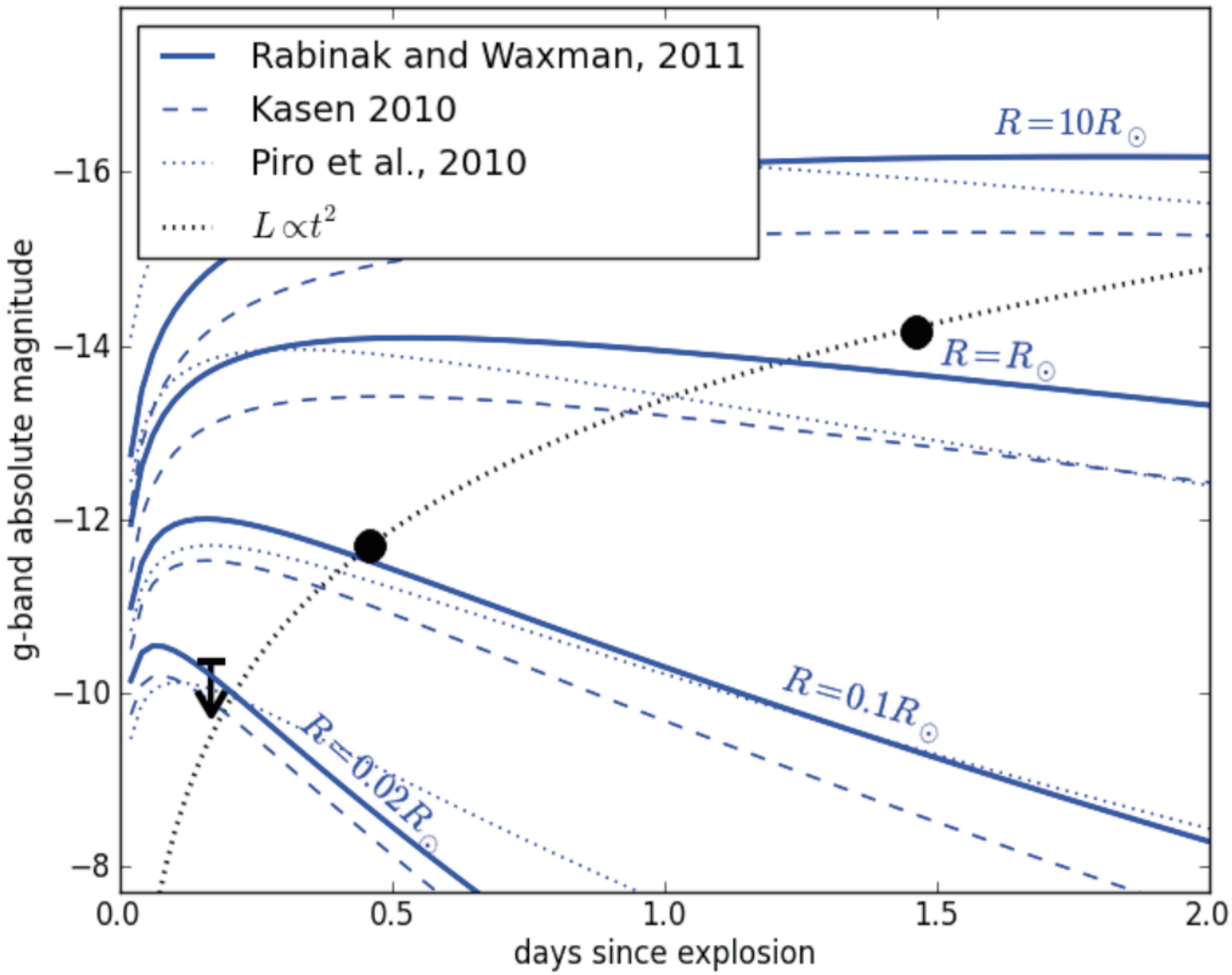
- Luminosity scales with radius (Piro et al. '10)

$$L \sim \frac{R_0 c}{\kappa} \frac{E}{M}$$

- No detection of cooling from shock heating

- Exploding star's radius is less than $2.2R_{Earth}$

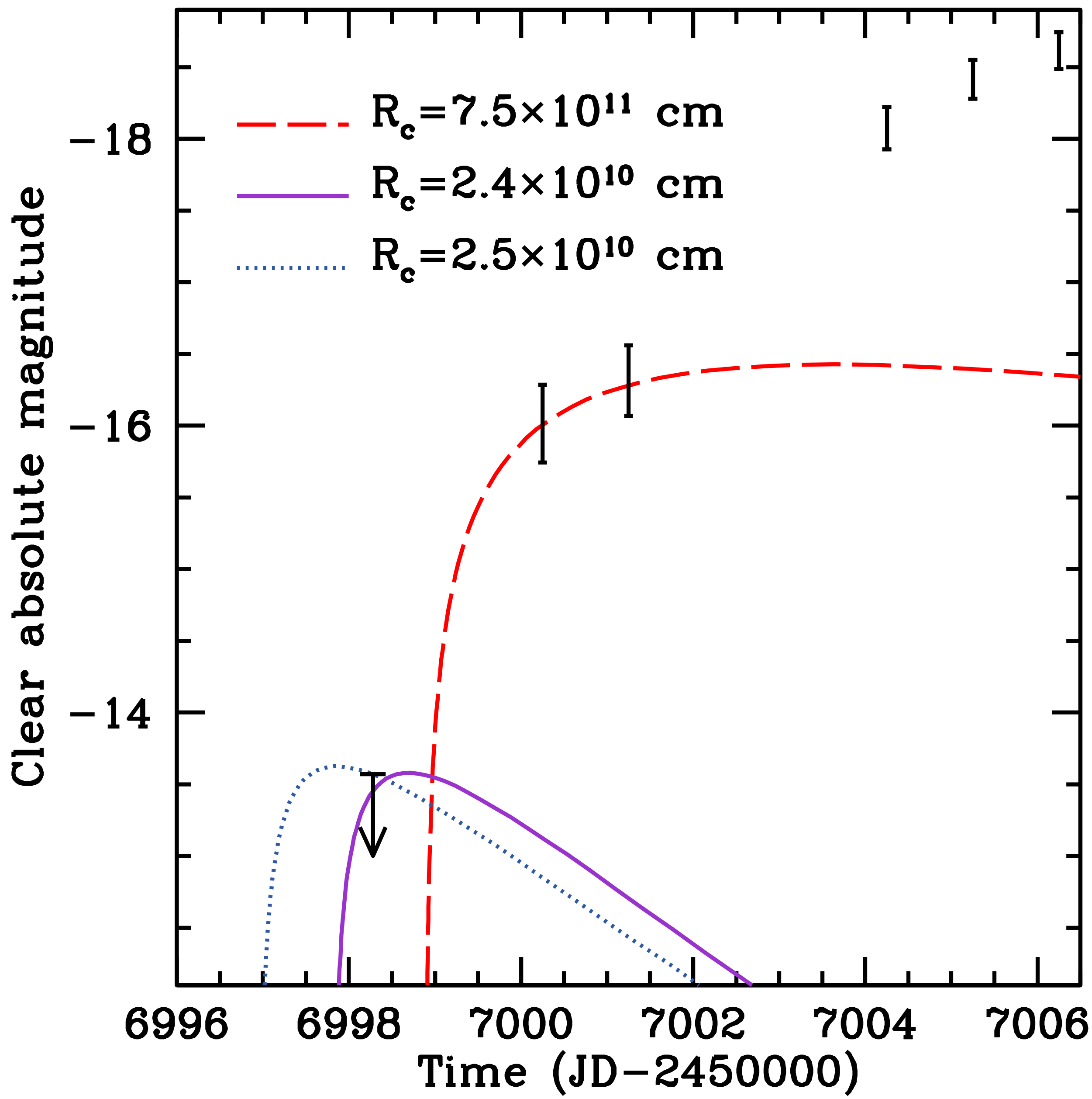
Bloom et al. (2011) ApJL 744 17



The importance of the explosion time

Shappee, Piro, et al. (2015)

- Early light curve provides constraints on companion radius (Kasen '10)
- But constraints depend strongly on **explosion time**
- What are the best ways to constrain the explosion time?



What about a t^2 rise?

Problems:

• t^2 is not generally expected theoretically (Piro '12)

$$L \propto \Delta M_{\rm diff} X_{56} \propto t^{2(1+1/n)/(1+1/n+\beta)} X_{56}$$

$$L \propto t^{1.8} X_{56}$$

• Many bolometric light curves (e.g., Firth et al. 2015, Olling et al. 2015) are not t^2

• Maybe just fit arbitrary power laws? How do you know when you're not fitting out the signal you want?

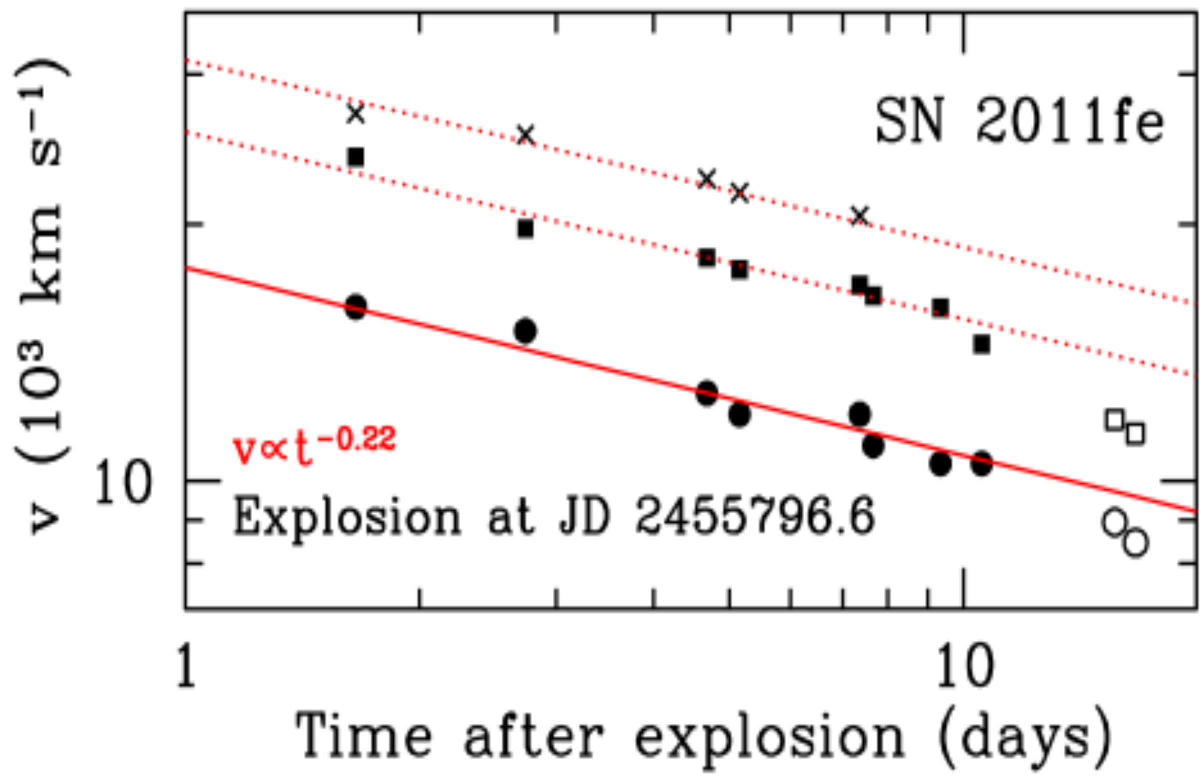
Use velocity evolution?

- Photosphere evolves roughly as

$$v_{\rm ph} \propto t^{-0.22}$$

- Fitting to power-law constrains explosion time
- Unfortunately, power-law index is model dependent and cannot be fit independently

Piro & Nakar (2014)



Explosion time within ~0.5 days of estimate from light curve

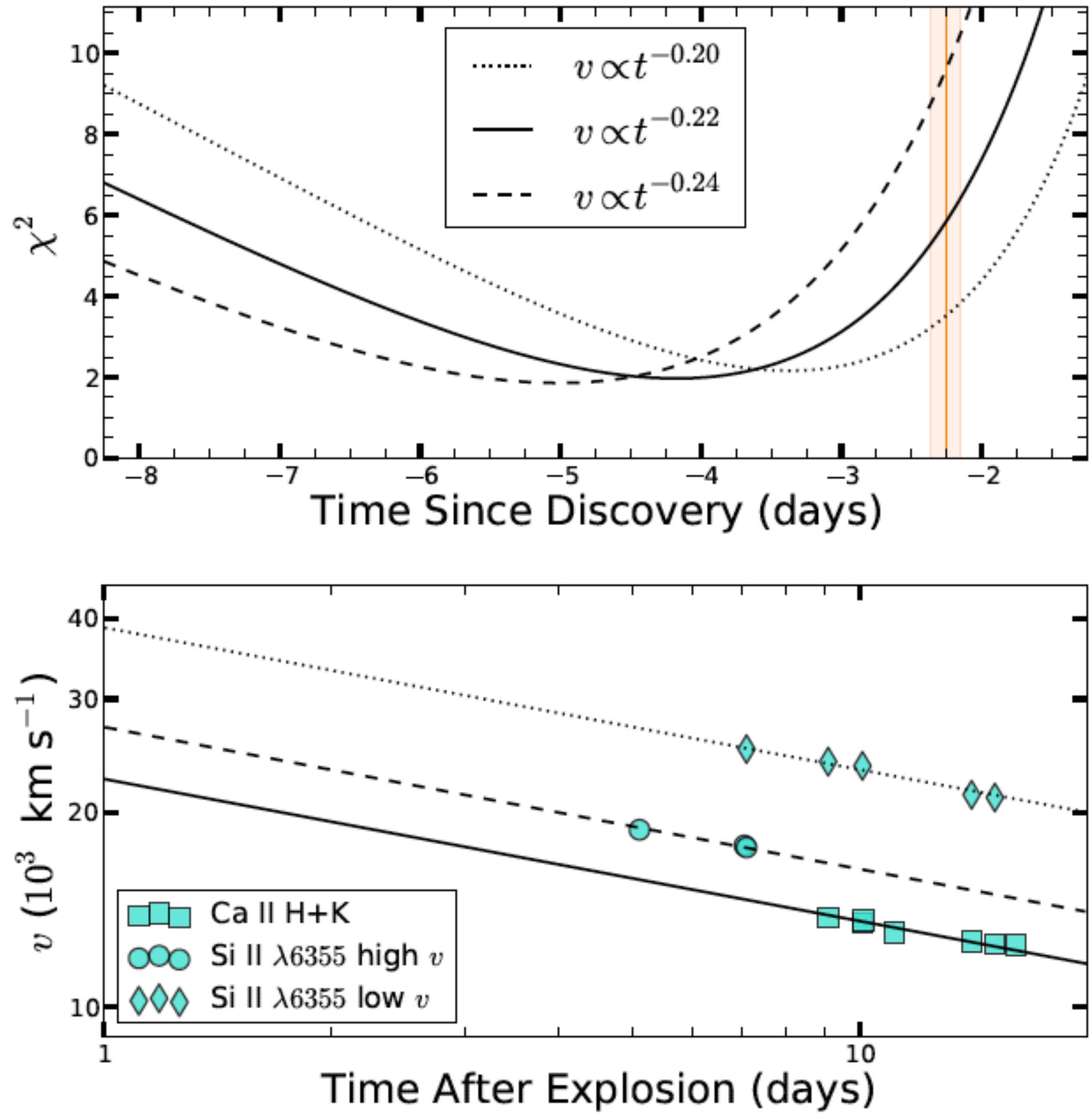
ASASSN-14lp

Shappee, Piro, et al. (2015)

SN Ia with early photometry and spectroscopy

Explosion time estimated by both extrapolating light curve and velocities

Explosion time estimates different by ~2 days!



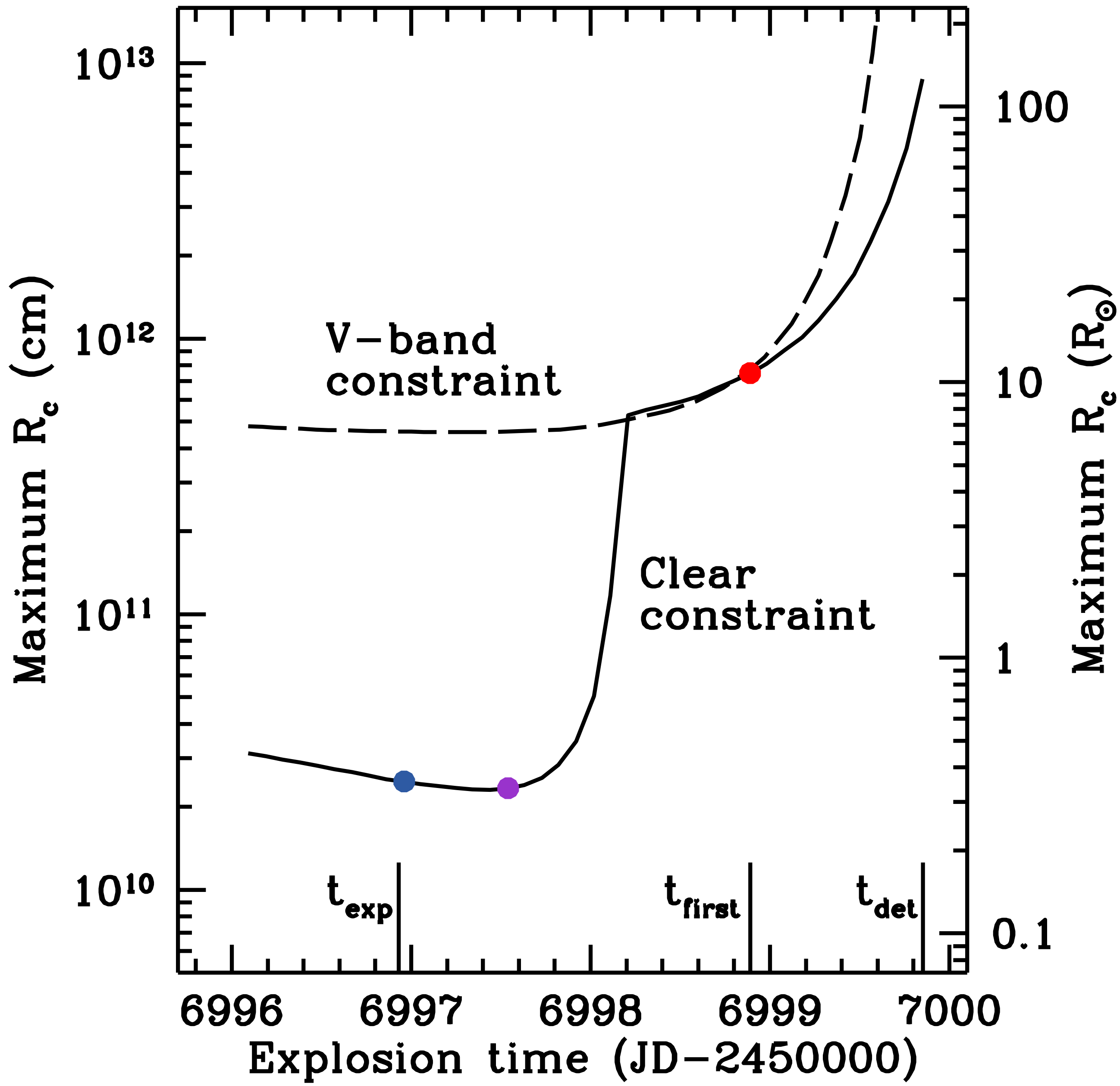
Companion constraints for 14lp

Shappee, Piro, et al. (2015)

Consider a range of explosion times

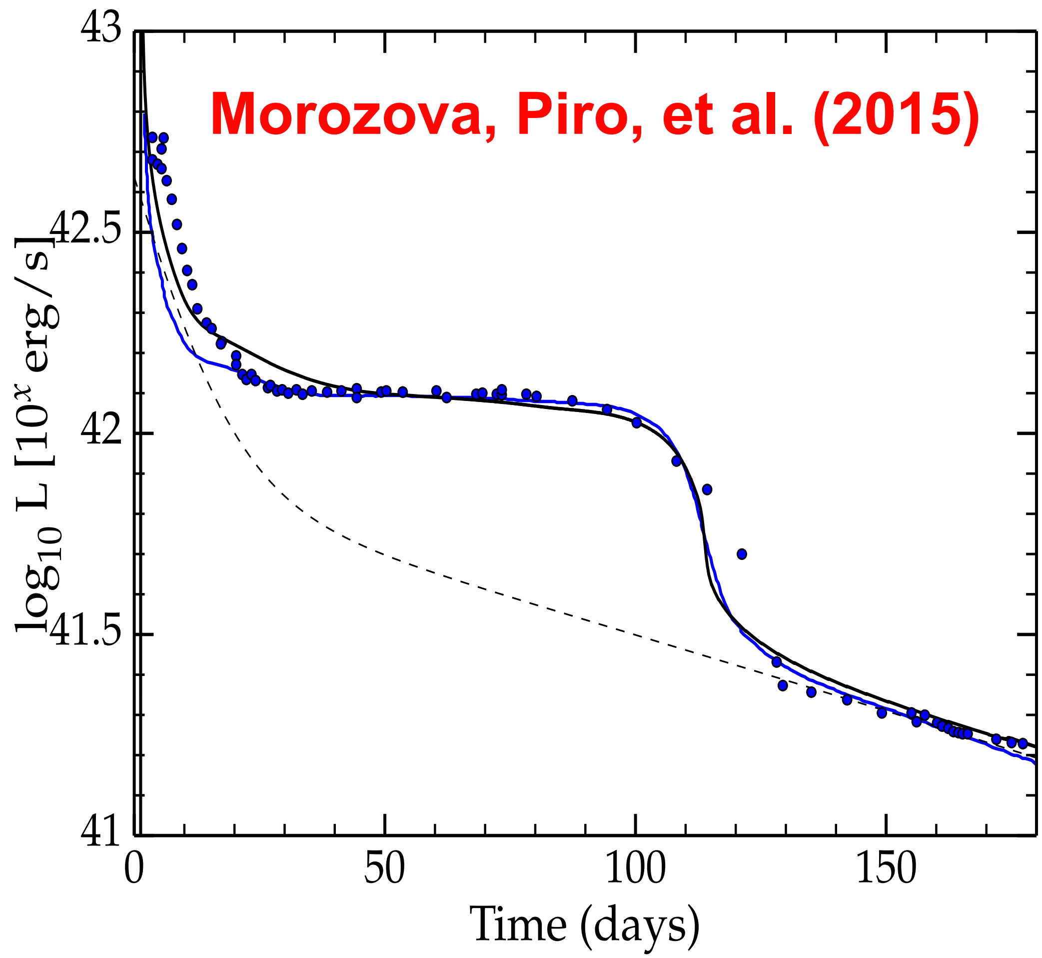
Companion **unlikely to be a red super giant** unless poor viewing angle

What does explosion time discrepancy mean? (also seen for 09ig, but not for 11fe and 12cg)



SuperNova Explosion Code (SNEC)

- 1D Lagrangian hydrodynamics
- Explosions triggered with a thermal bomb or piston
- Hydrodynamics and radiative diffusion solved together
- Thermodynamic equilibrium
- Gray opacity using OPAL, including partial ionization
- Follows gamma-ray diffusion from ^{56}Ni



- Generates both bolometric LCs and specific bands
- Relatively fast which is useful for numerical experiments

OPEN SOURCE! http://stellarcollapse.org/snec

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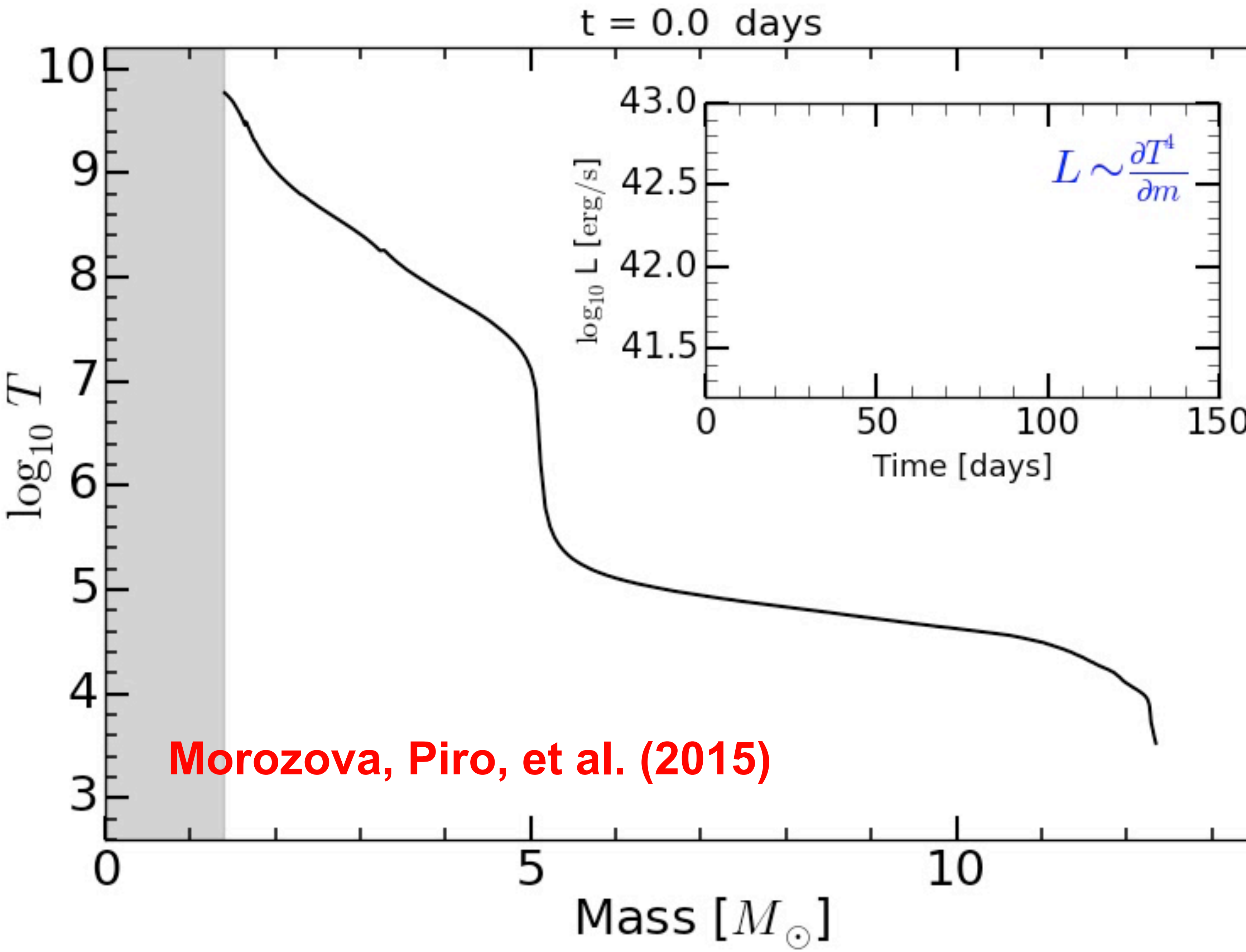
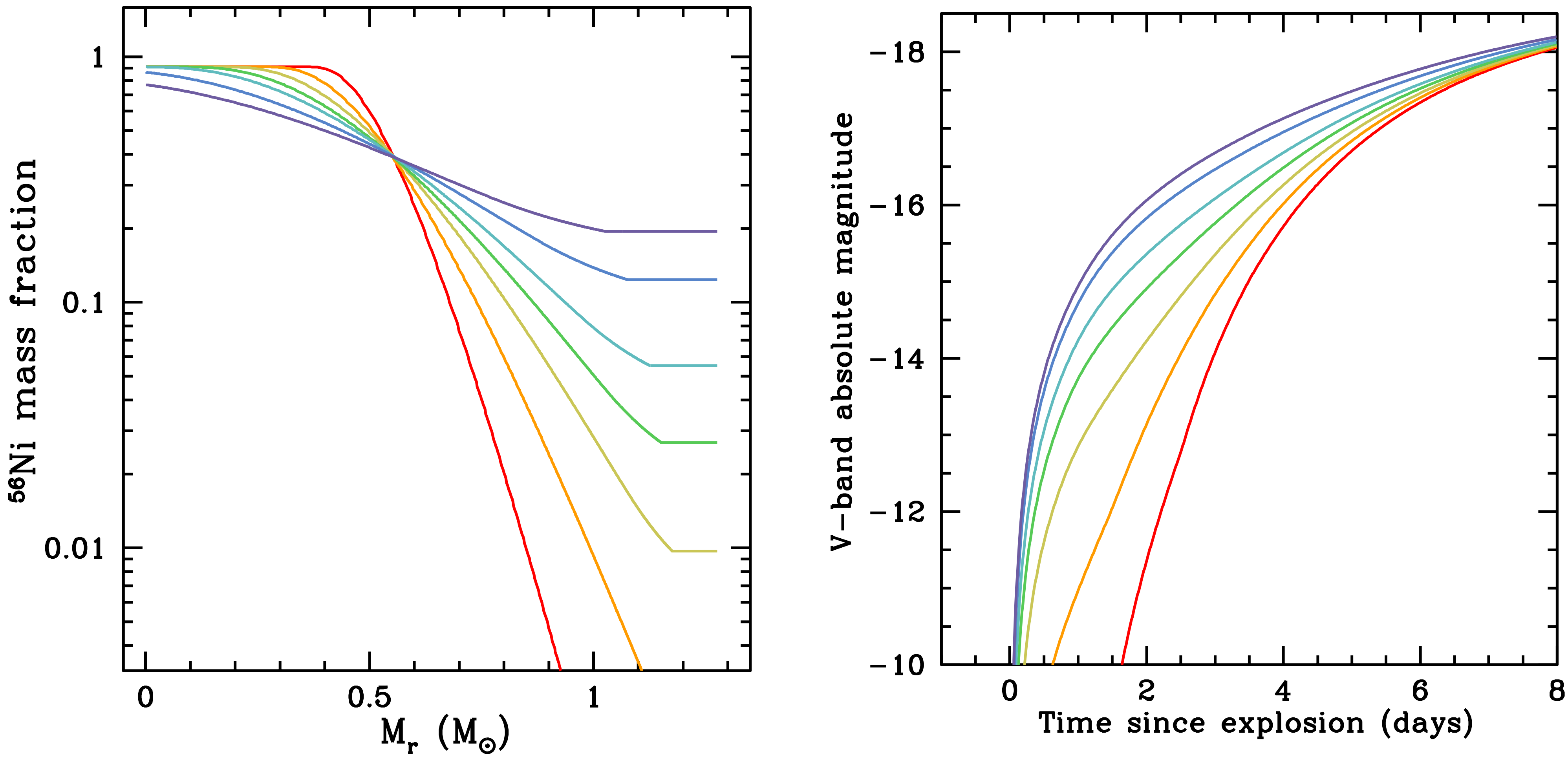


Morozova, Piro, et al. (2015)

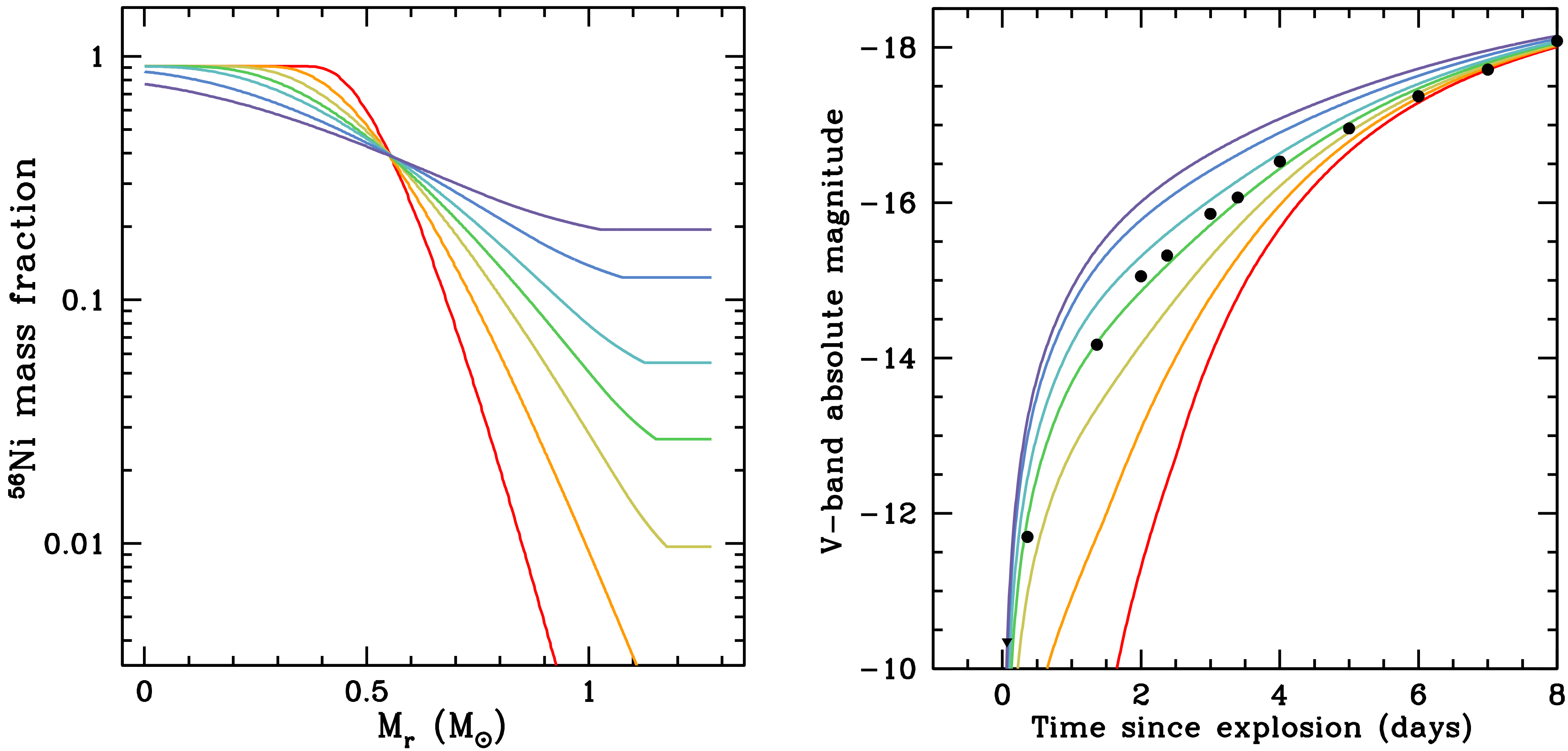
Varying the ^{56}Ni distribution



Shallow ^{56}Ni →

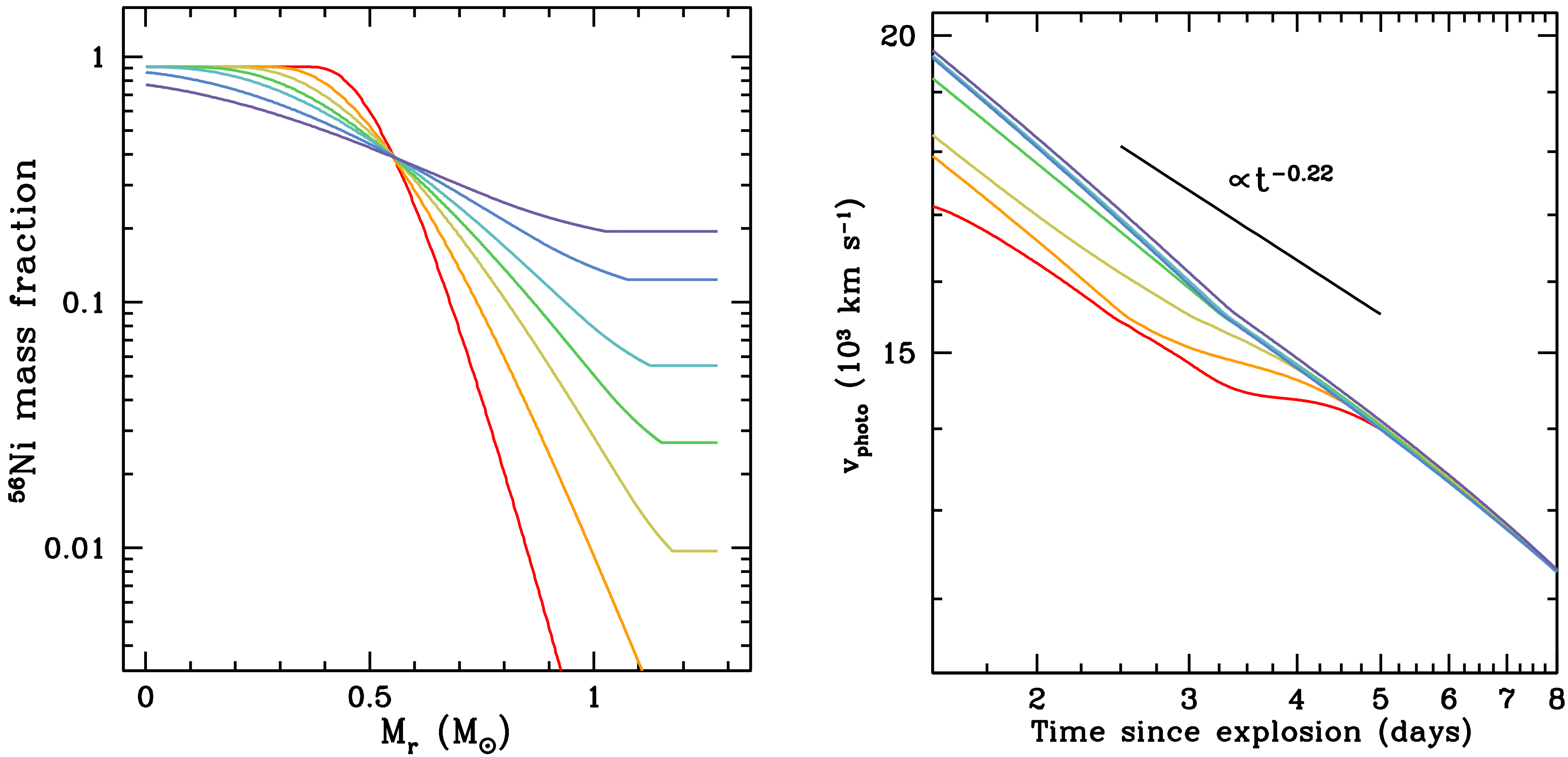
- Steep early light curve
- Less of a “dark phase” (Piro & Nakar 2013)

Comparison with SN 2011fe



- Favors a more highly mixed model
- Shorter dark phase strengthens progenitor radius constraints? (Nugent et al ‘10, Bloom et al ‘11)

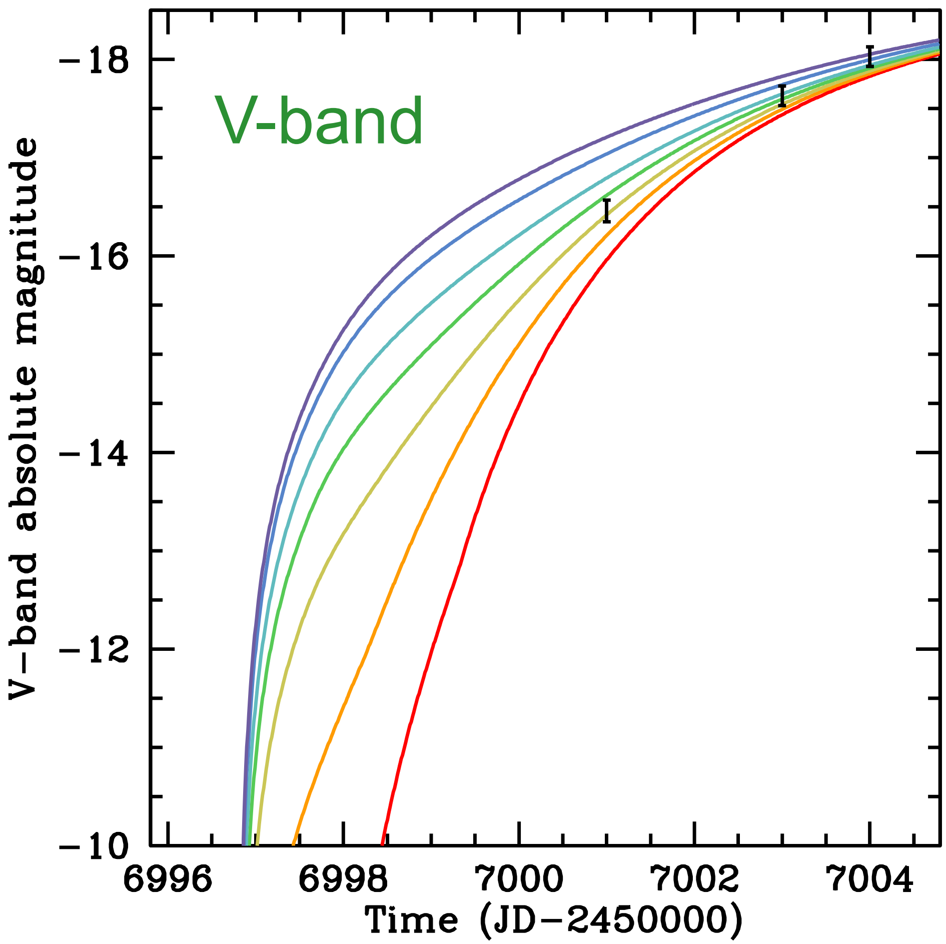
Impact on photospheric velocity

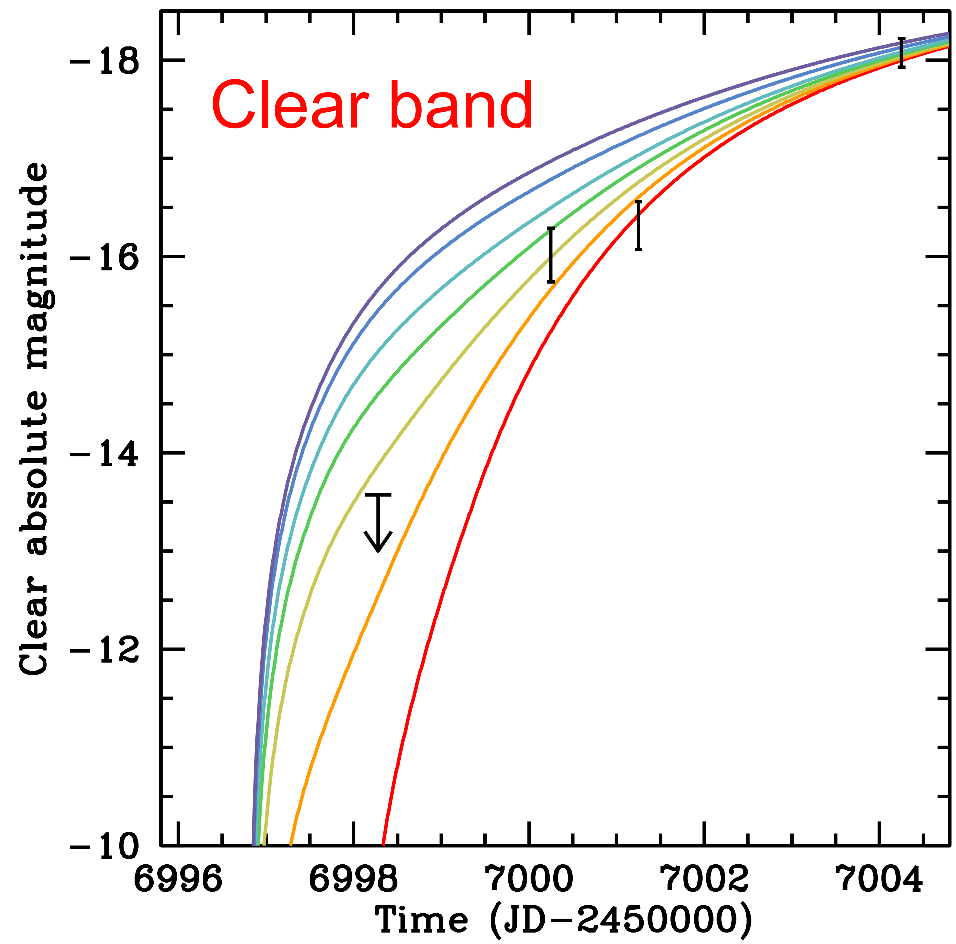


- Power law evolution once nickel heating is important
- Slightly steeper than previous analytic result
- Can this provide explosion time constraint?

Revisiting ASASSN-14lp

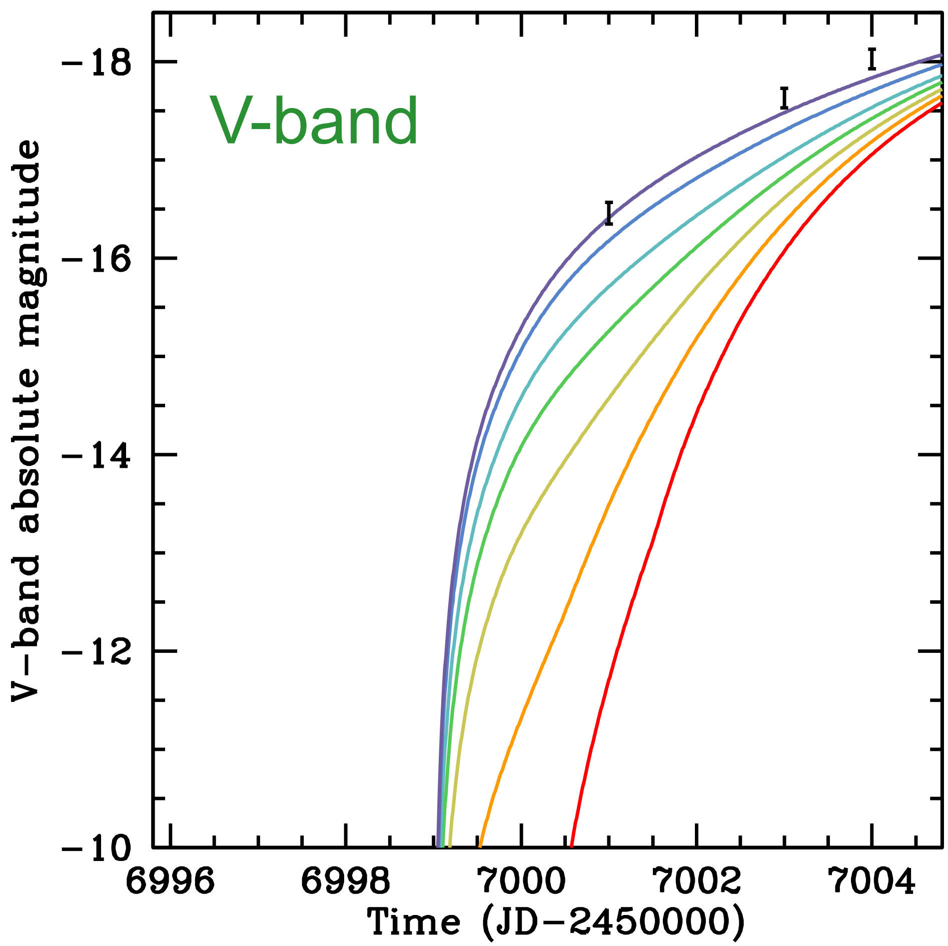
Comparison with **EARLY** explosion time

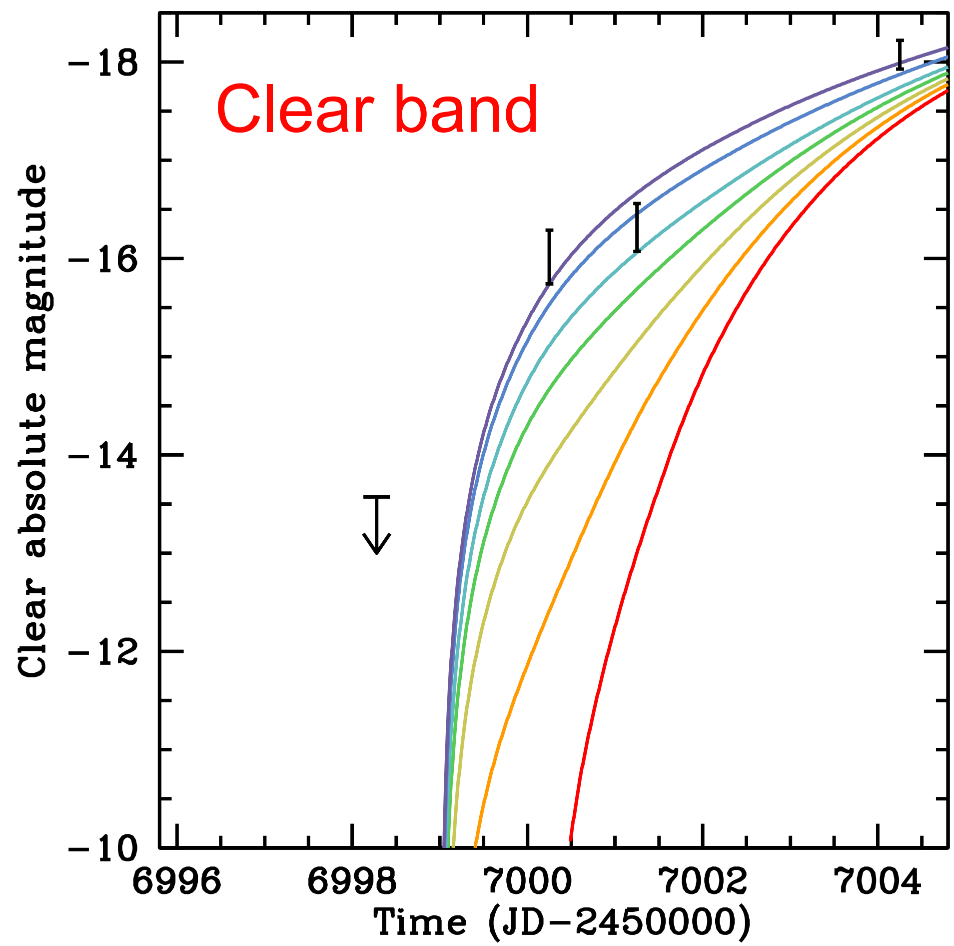




Revisiting ASASSN-14lp

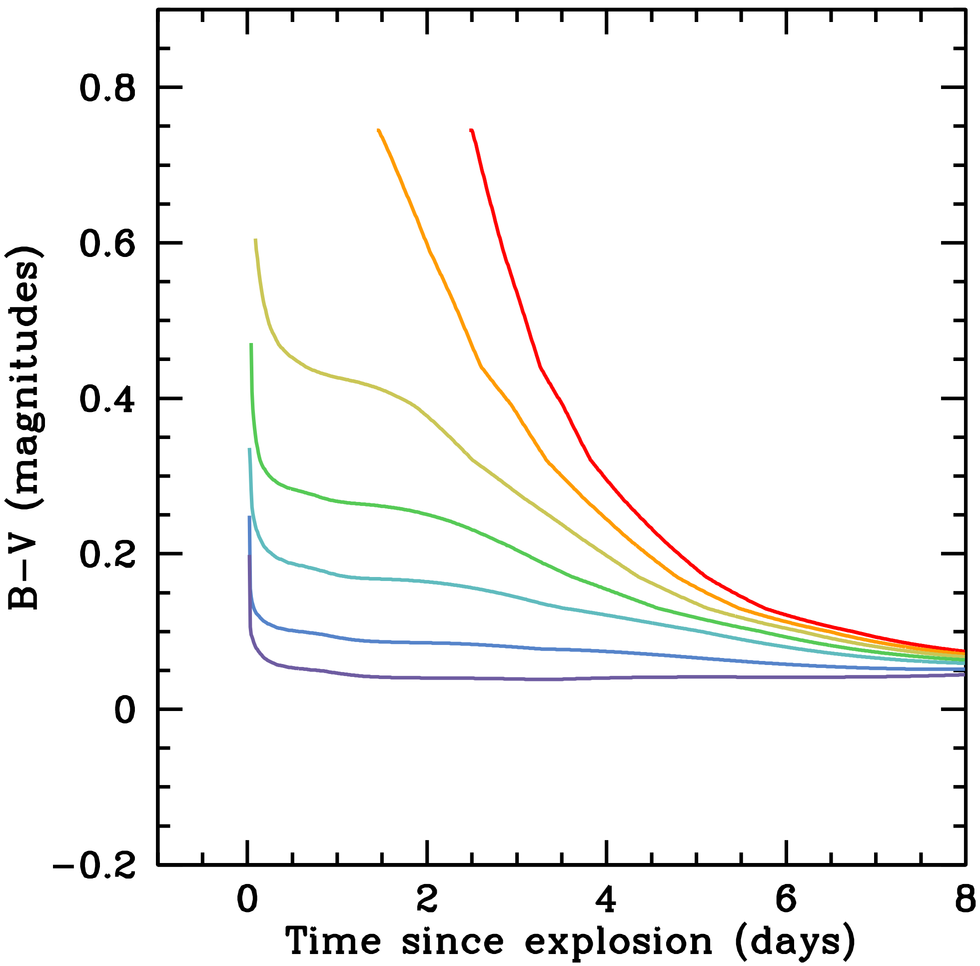
Comparison with **LATE** explosion time

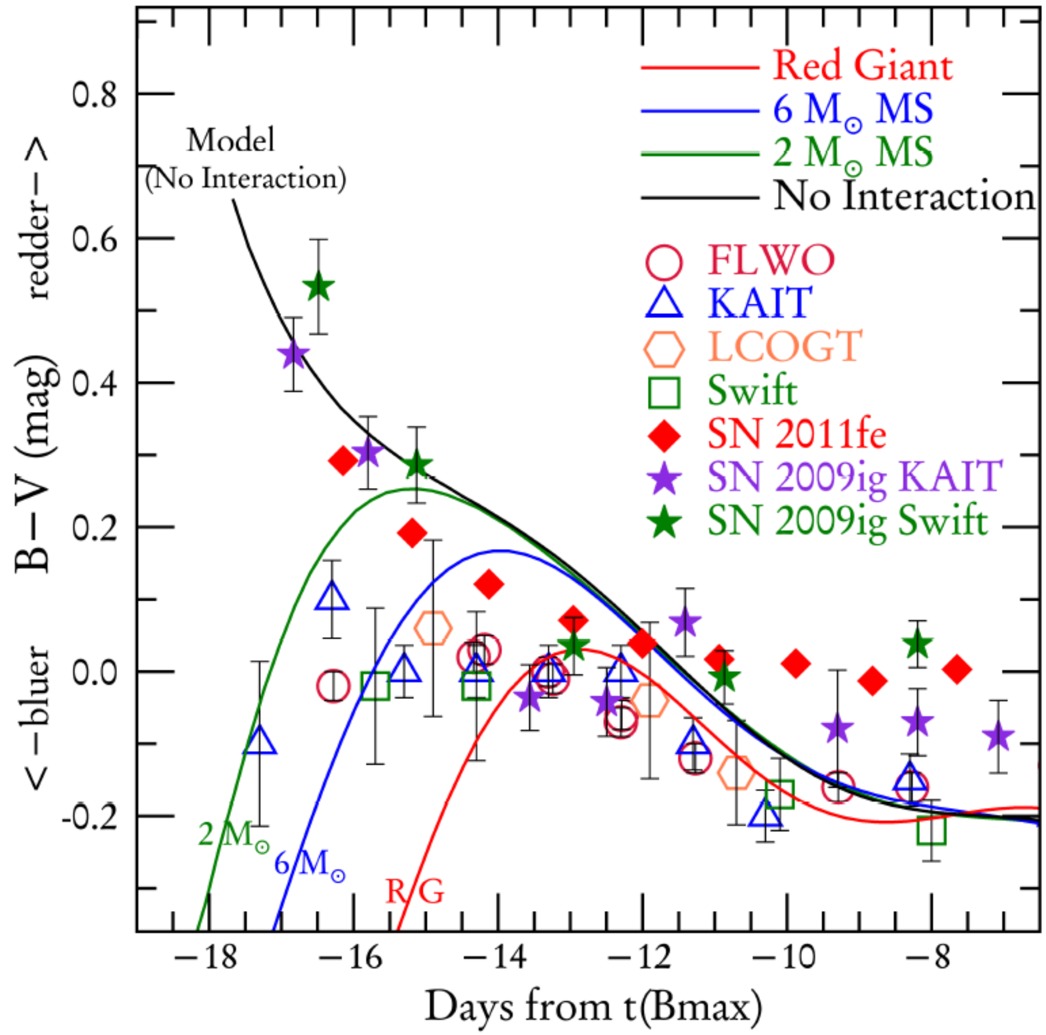




Clues from color evolution?

Marion, et al. (2015)





Flatter color evolution indicates more shallow ^{56}Ni

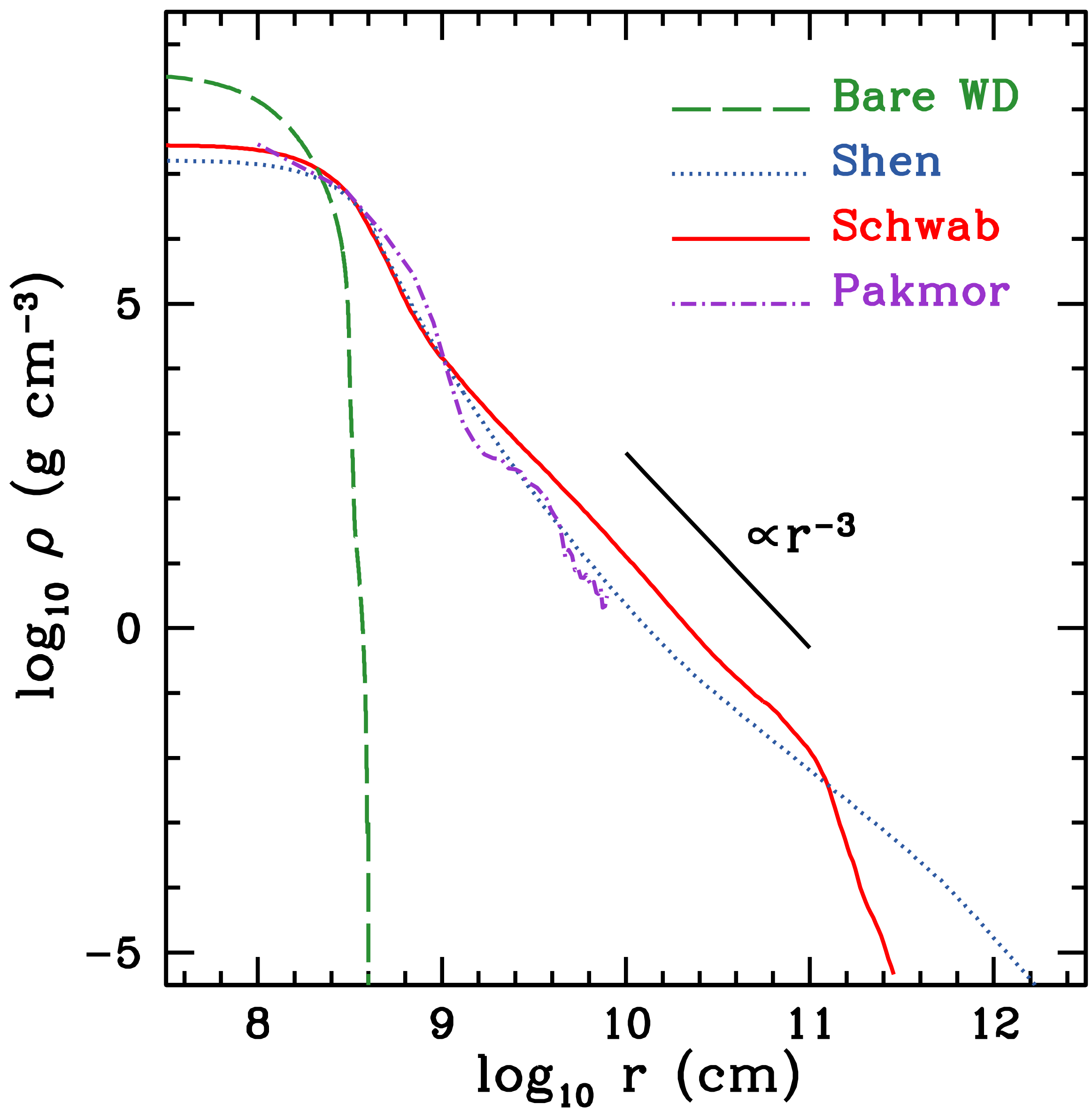
(Note: scaling with peak makes comparison by eye difficult!)

Circumstellar material?

Lots of potential progenitors imply circumstellar material:

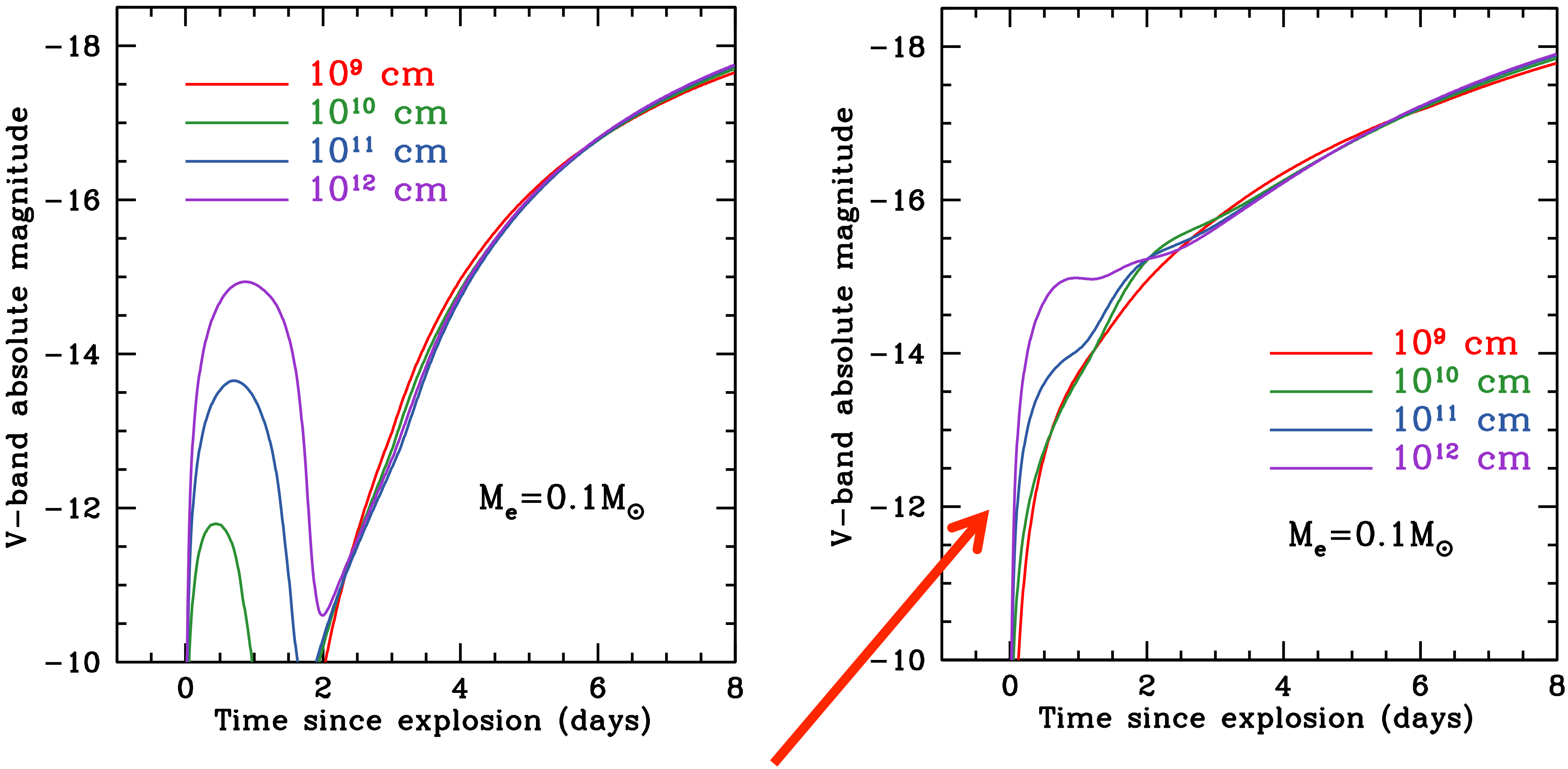
- Mass transfer material?
- Nova material?
- Remnant merger material?

Is there any impact on the early LC?



Shock cooling of circumstellar material

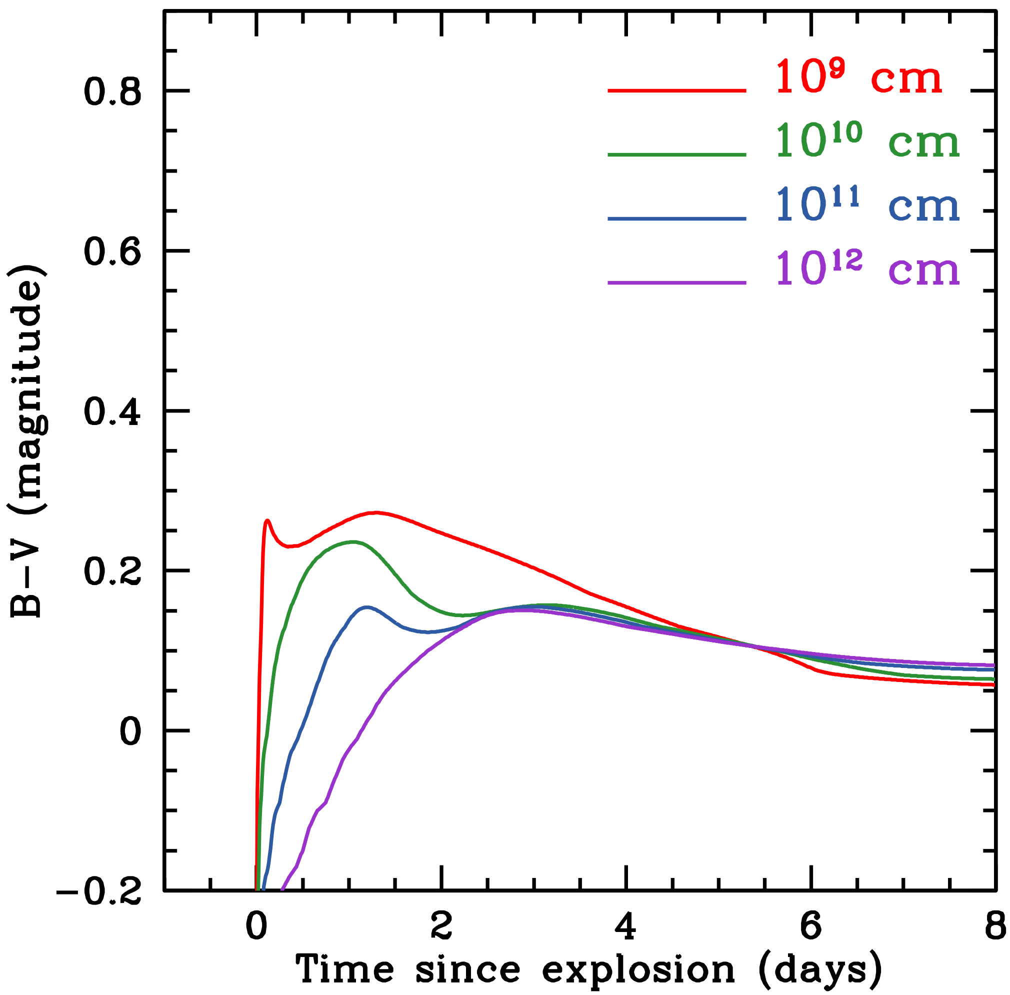
Double-peaked light curve, much like SNe IIb
(Woosley ‘94, Bersten ‘12, Nakar & Piro ‘14, Piro ‘15)

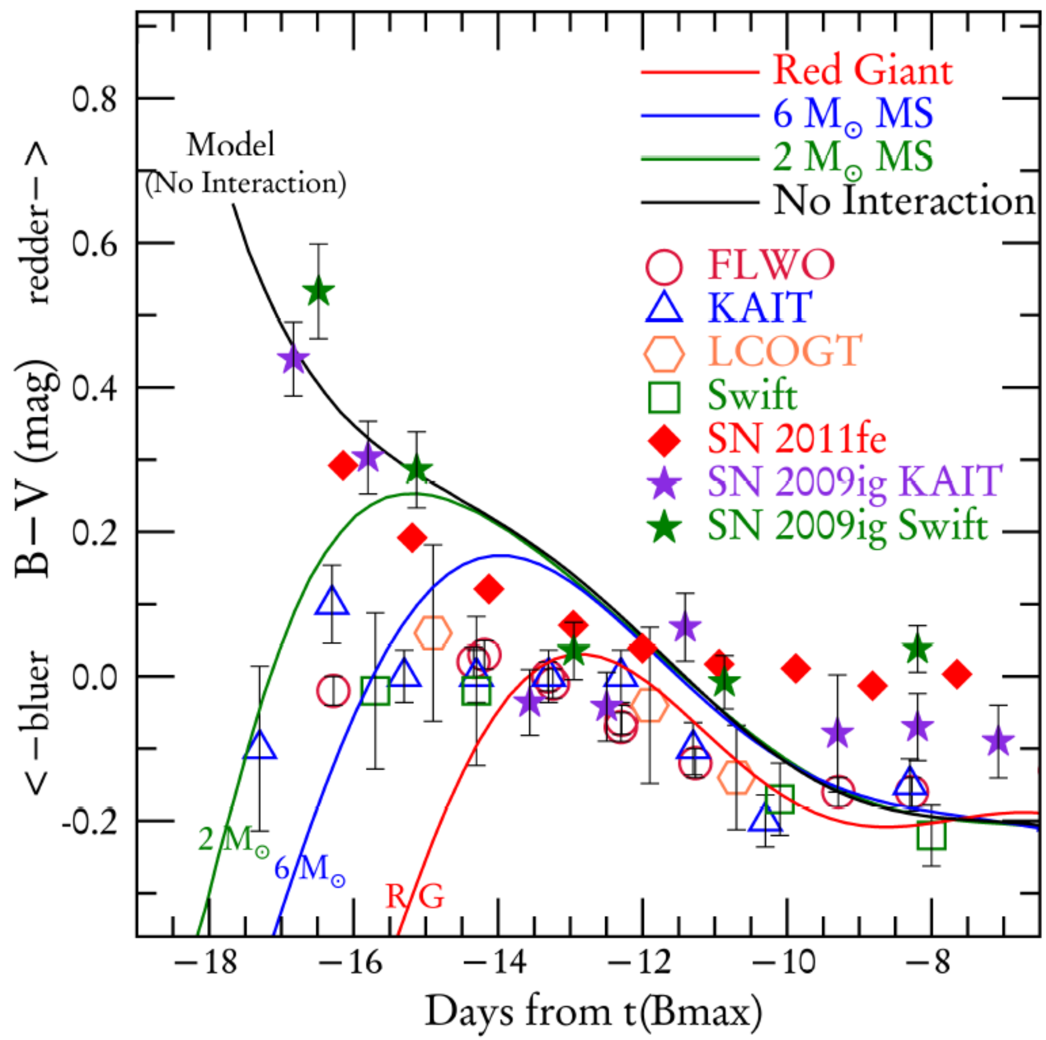


But this could be smeared out by mixing nickel

More clues from color evolution?

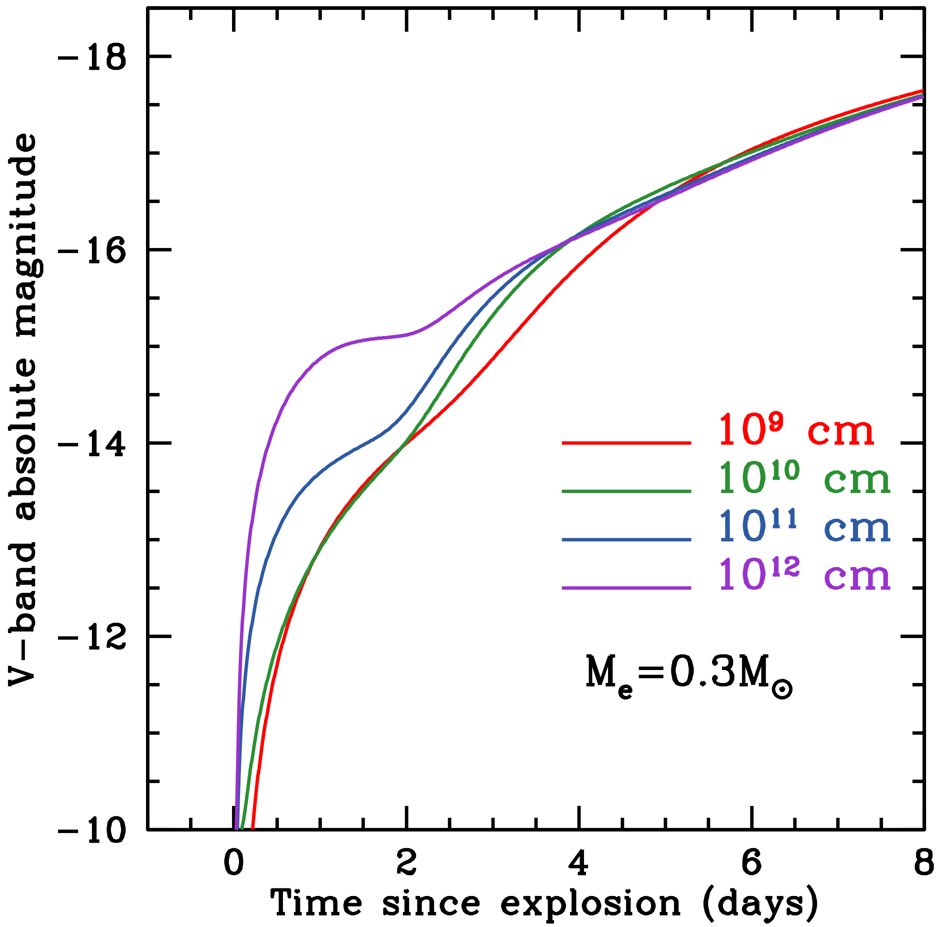
Marion, et al. (2015)

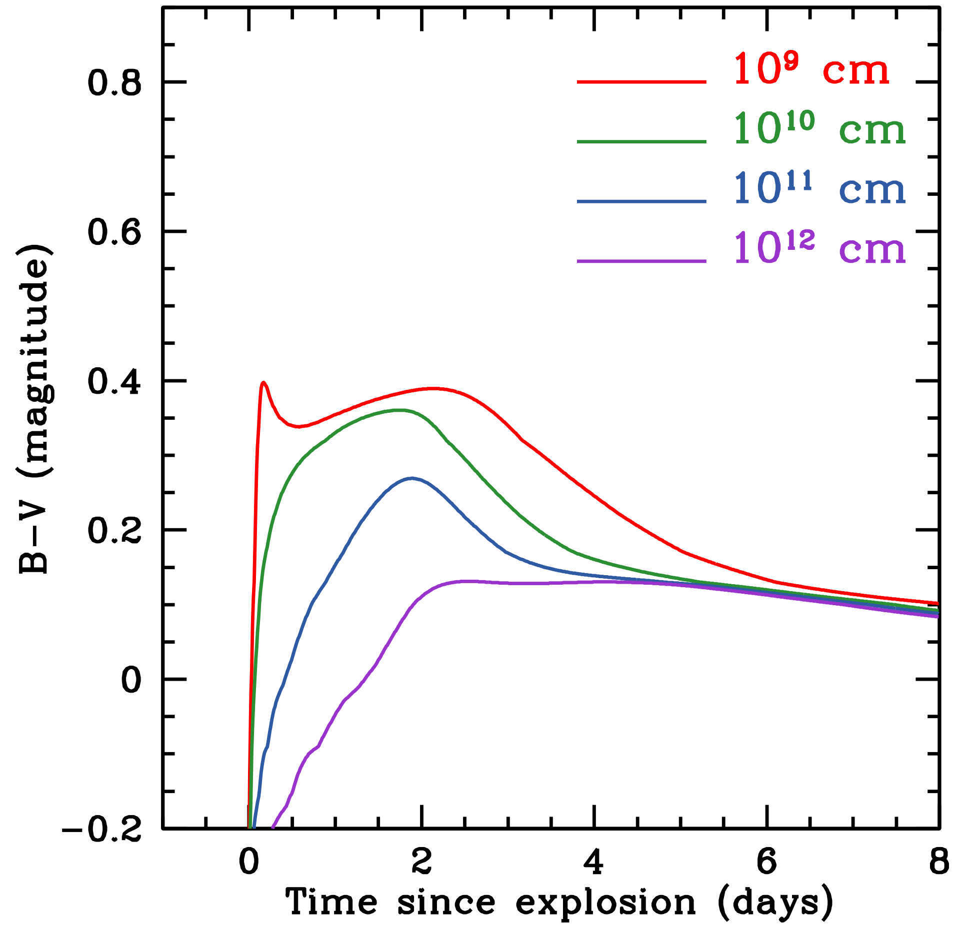




Shock cooling makes it bluer at early times
(but maybe nickel suppresses UV emission?)

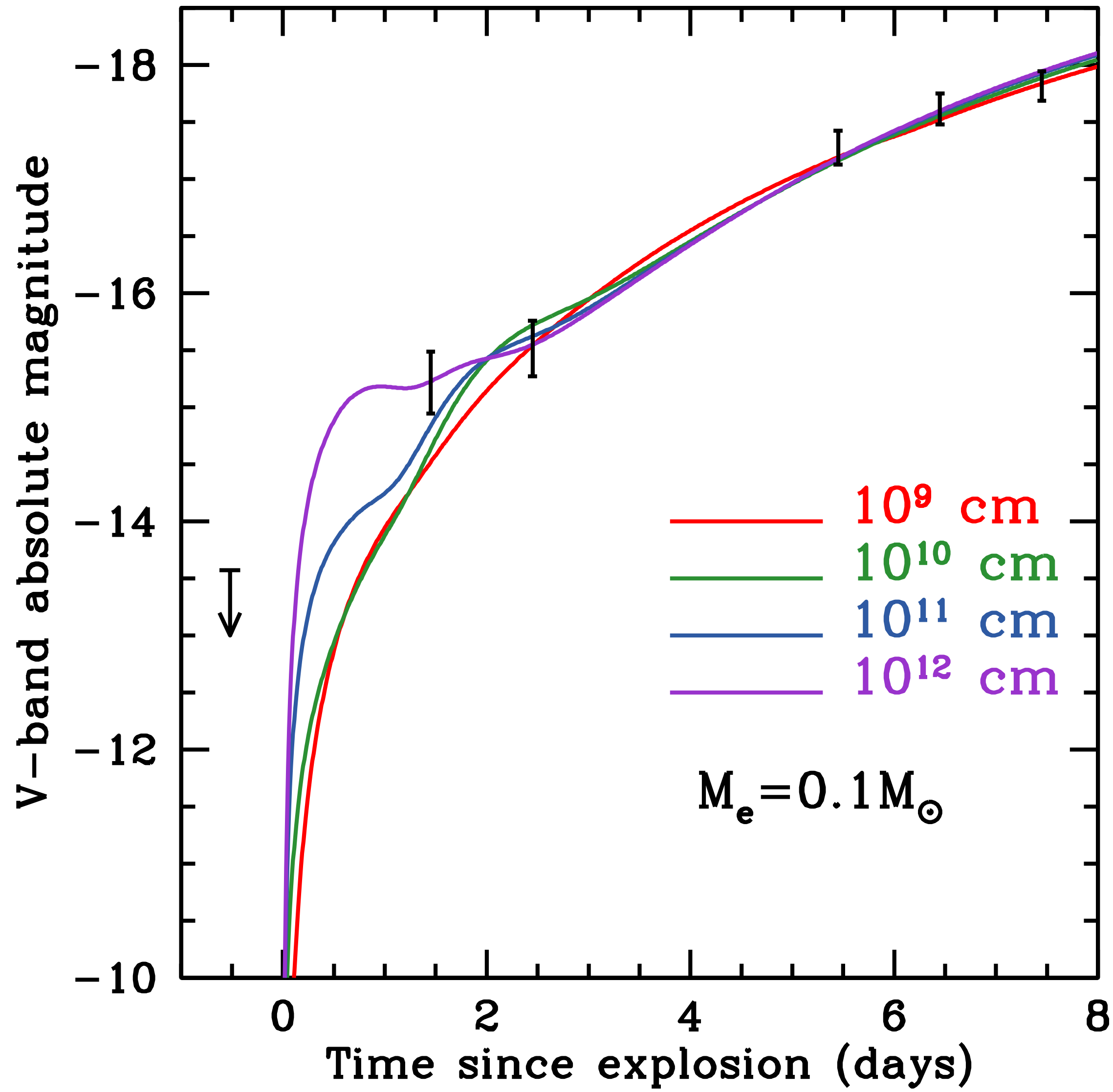
0.3 M_{sun} examples





Super speculative!

- The first r-band point in ASASSN-14lp is slightly bright
- Evidence for circumstellar material?
- Do Zheng et al. double Gaussian fits (2013dy, 2014J) have any physical meaning?



Conclusions

- Companion constraints for ASASSN-14lp
- Importance of constraining explosion time
- Studying impact of nickel distribution and circumstellar material on early light curves and colors

Questions:

What is the range of circumstellar material and shallow nickel expected?

How should this connect with progenitors and environments?