There are two physical width-luminosity relations for type Ia supernovae
and they favor Collision and sub-Chandrasekhar models

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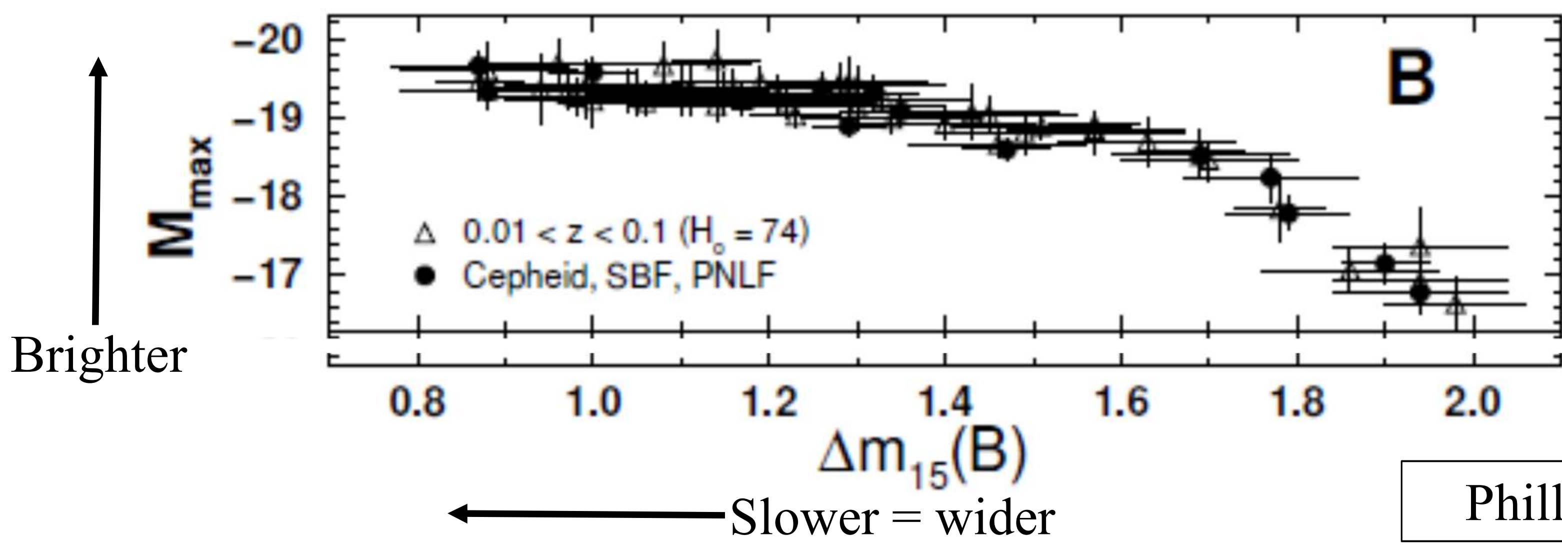
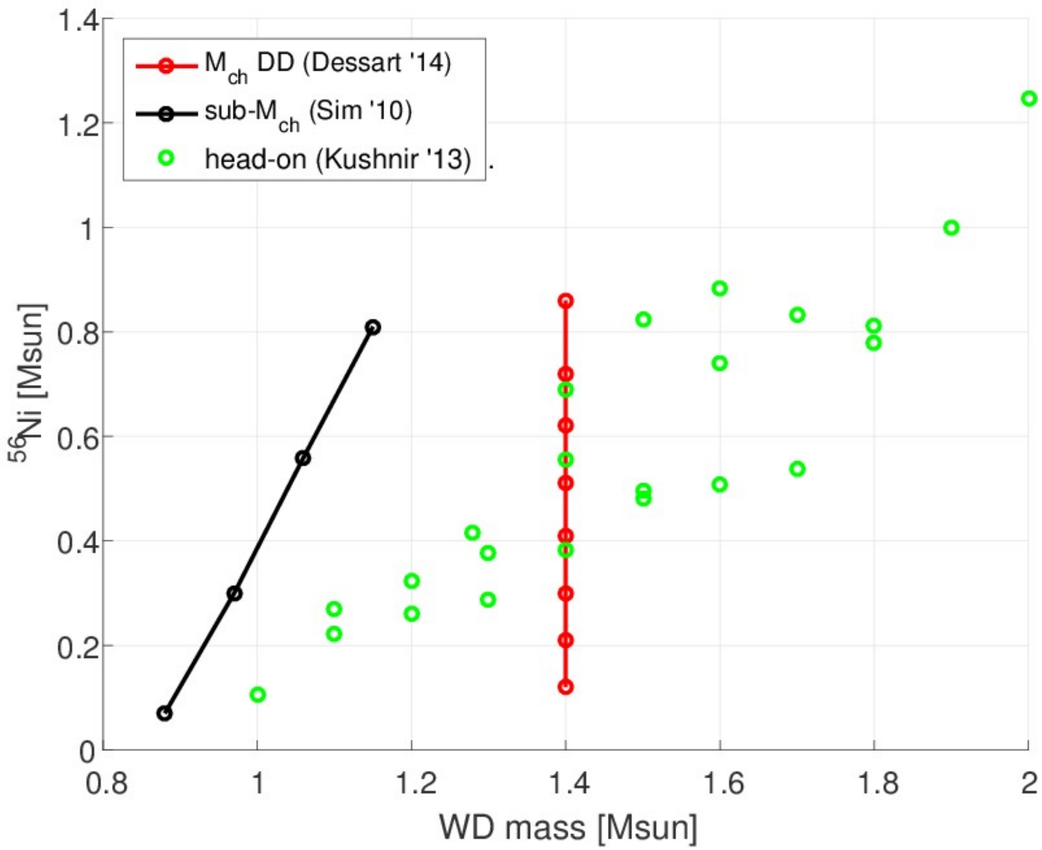
Width Luminosity Relation (WLR) - unsolved problem

- “standard” WLR - B_{max} vs. Δm_{15} (Phillips ‘93): “Brighter is Slower”.

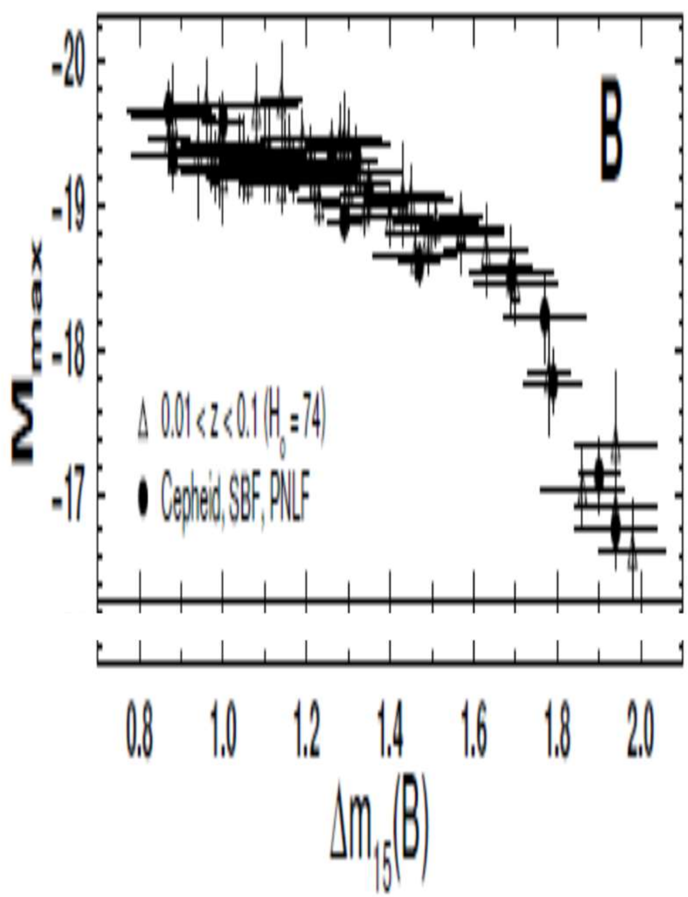


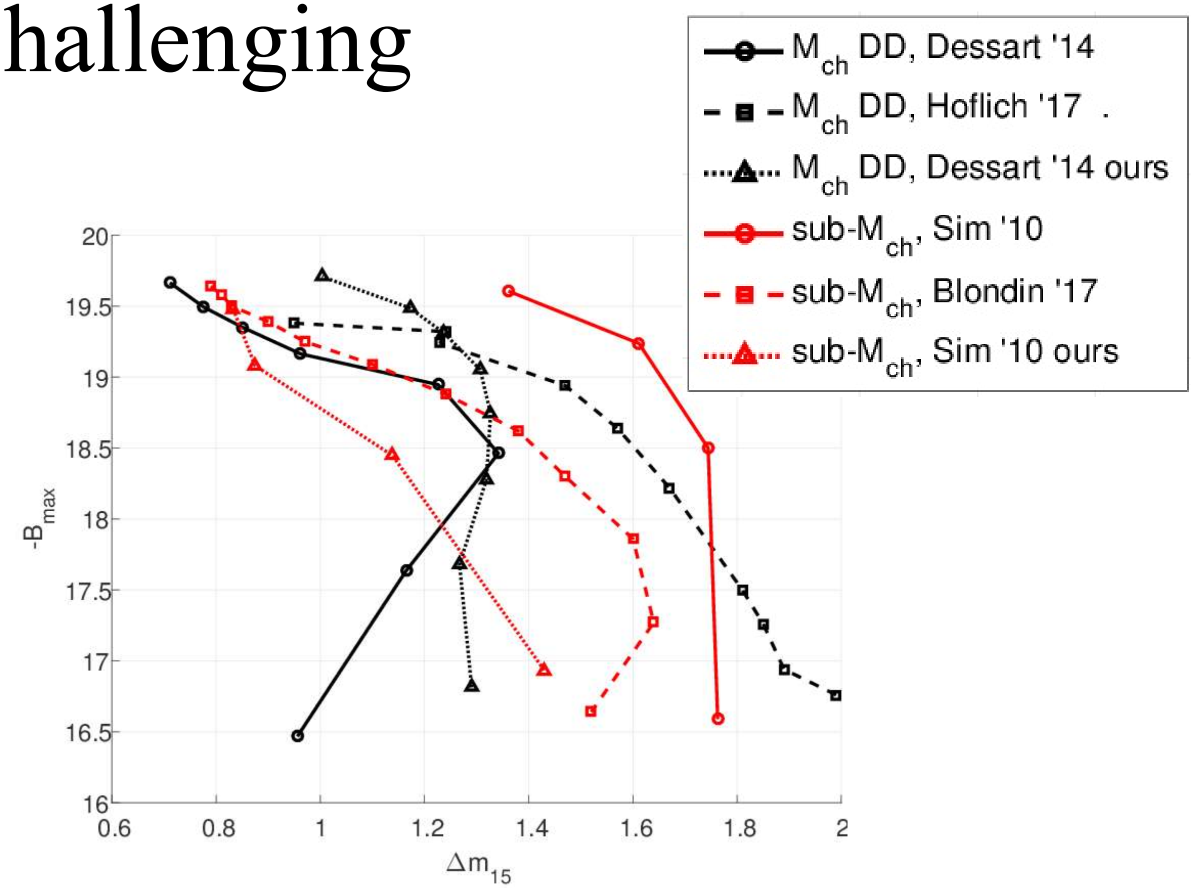
Phillips ‘05

We do not know the progenitor

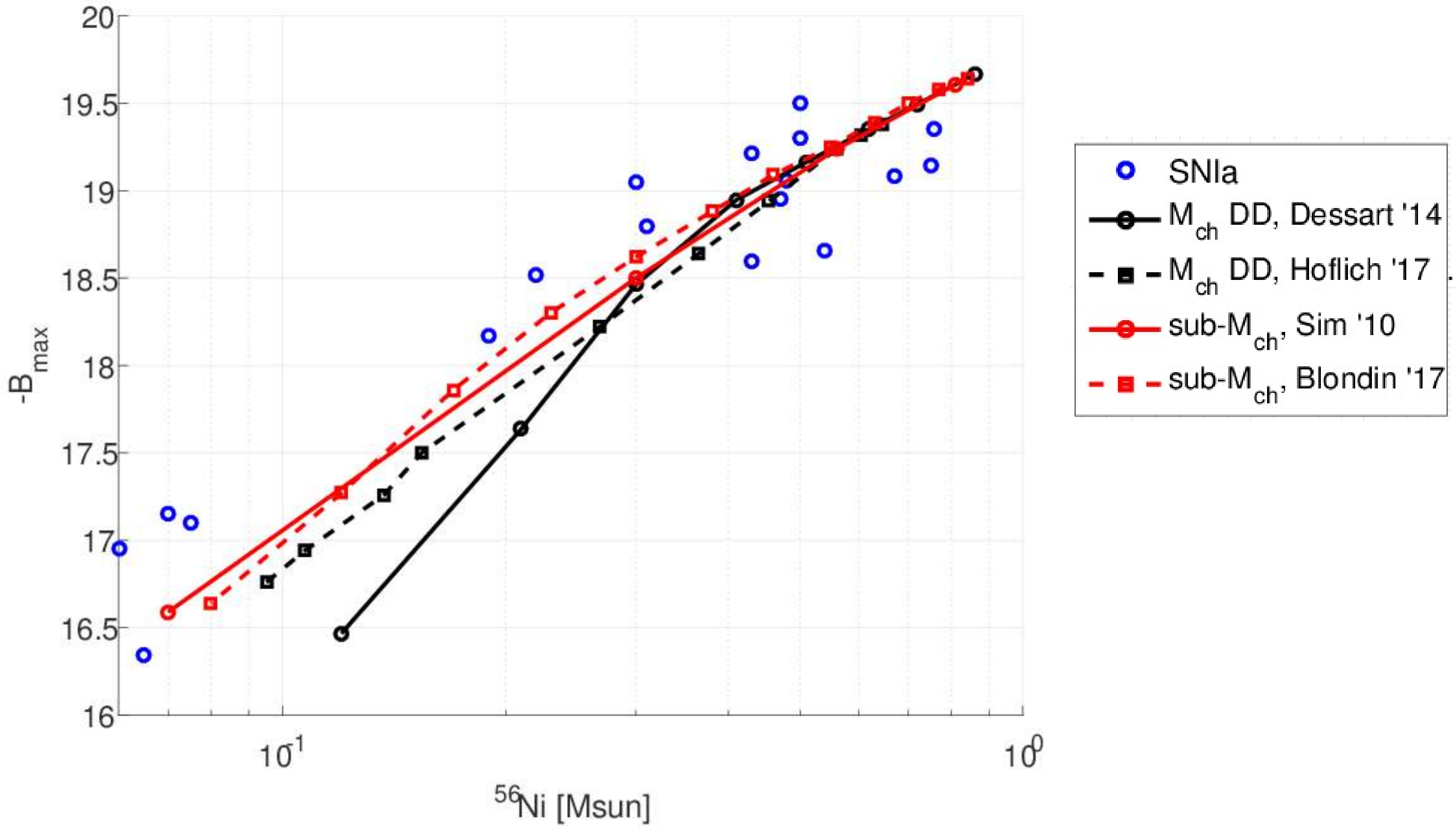


Radiation transfer is challenging





^{56}Ni sets the brightness



But what sets the width?

There are two timescales (widths)

- Bolometric: γ escape time

- Color: Recombination of Ni/Co/Fe (from 2 to 1 ionized)

- Set by two column densities:
  - Total column density.
  - Ni column density.

There are two timescales (widths)

- Bolometric: γ escape time

- Color: Recombination of Ni/Co/Fe (from 2 to 1 ionized)

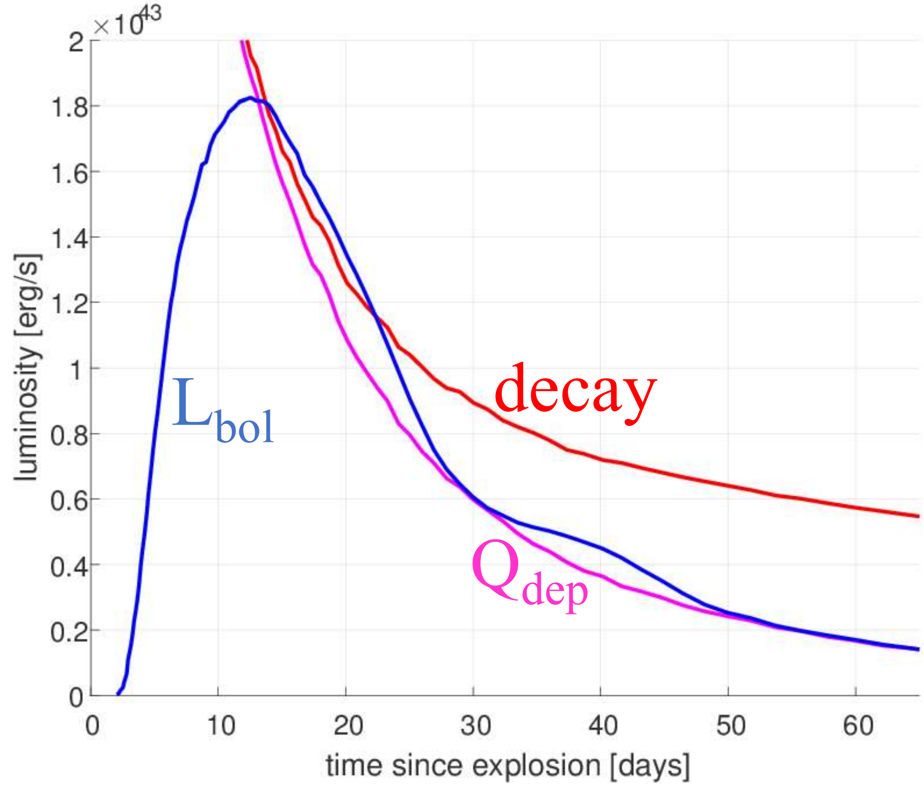
Decay, deposition, bolometric lightvcurve

- At late times ($t_{dif}<t_{dyn}$): $L_{\rm bol}(t) = Q_{\rm dep}(t)$

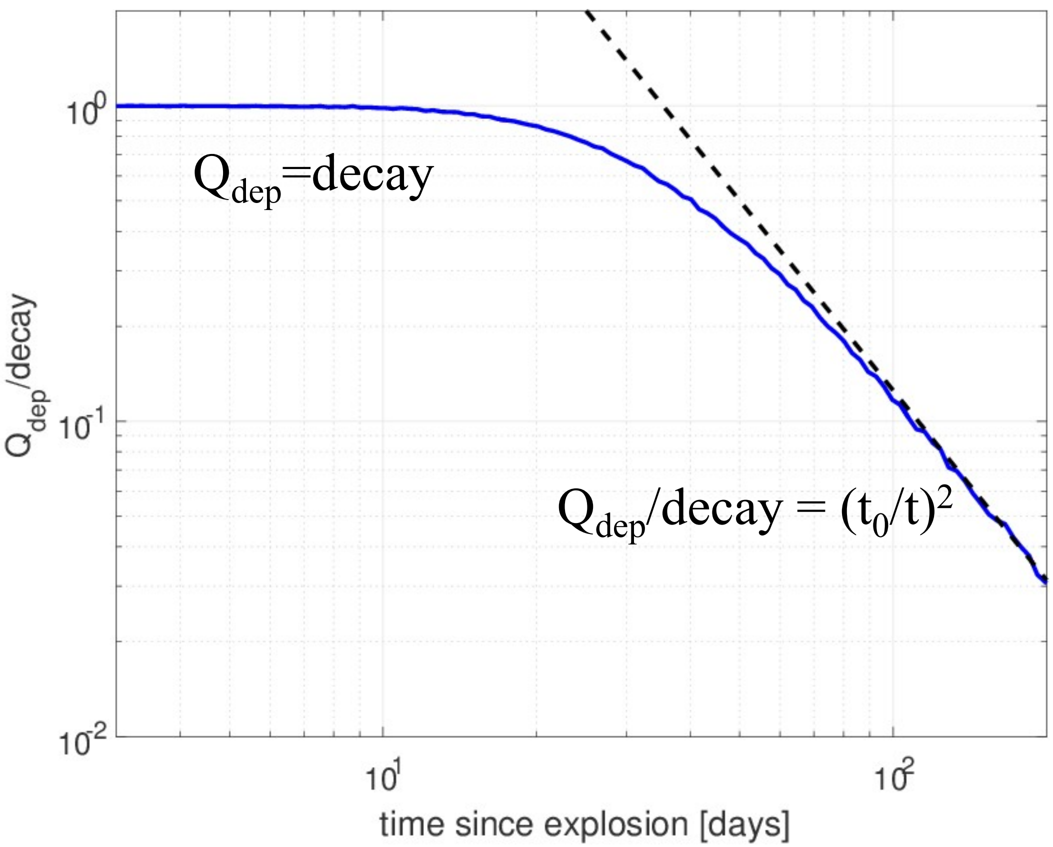
- At late times (no trapped rad) [Katz '13]:

$$\int_0^t dt' t' L_{\rm bol}(t') = \int_0^t dt' t' Q_{\rm dep}(t')$$

- → $$\frac{L_{\rm bol}(t)}{\int_0^t dt' t' L_{\rm bol}(t')} = \frac{Q_{\rm dep}(t)}{\int_0^t dt' t' Q_{\rm dep}(t')} \quad \text{for} \quad t \gg t_{\rm peak}.$$



The gamma-ray escape time t_0

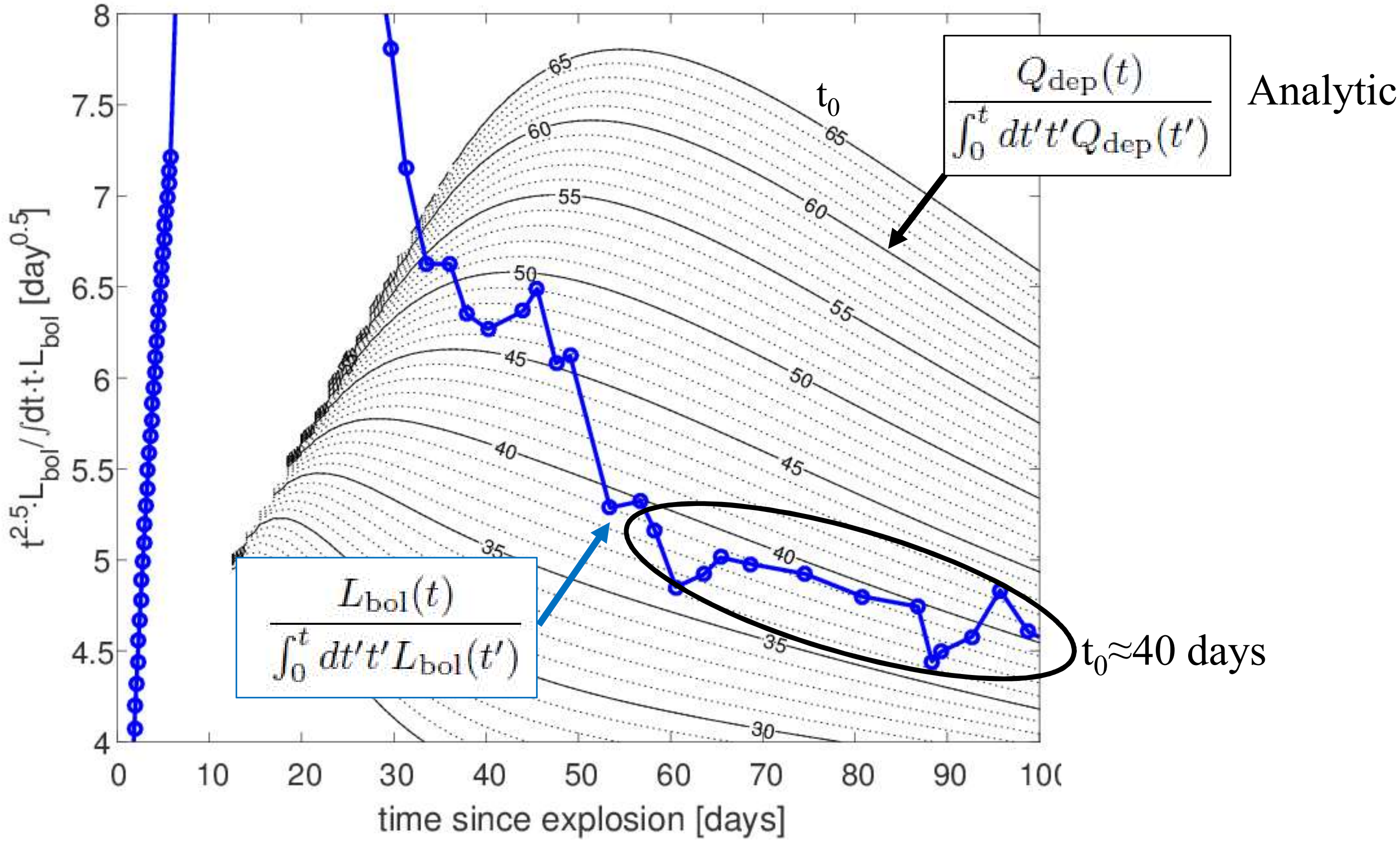


$$Q_{dep} \approx decay \cdot \left(1 - e^{-\left(\frac{t_0}{t}\right)^2}\right) + Qpo_s$$

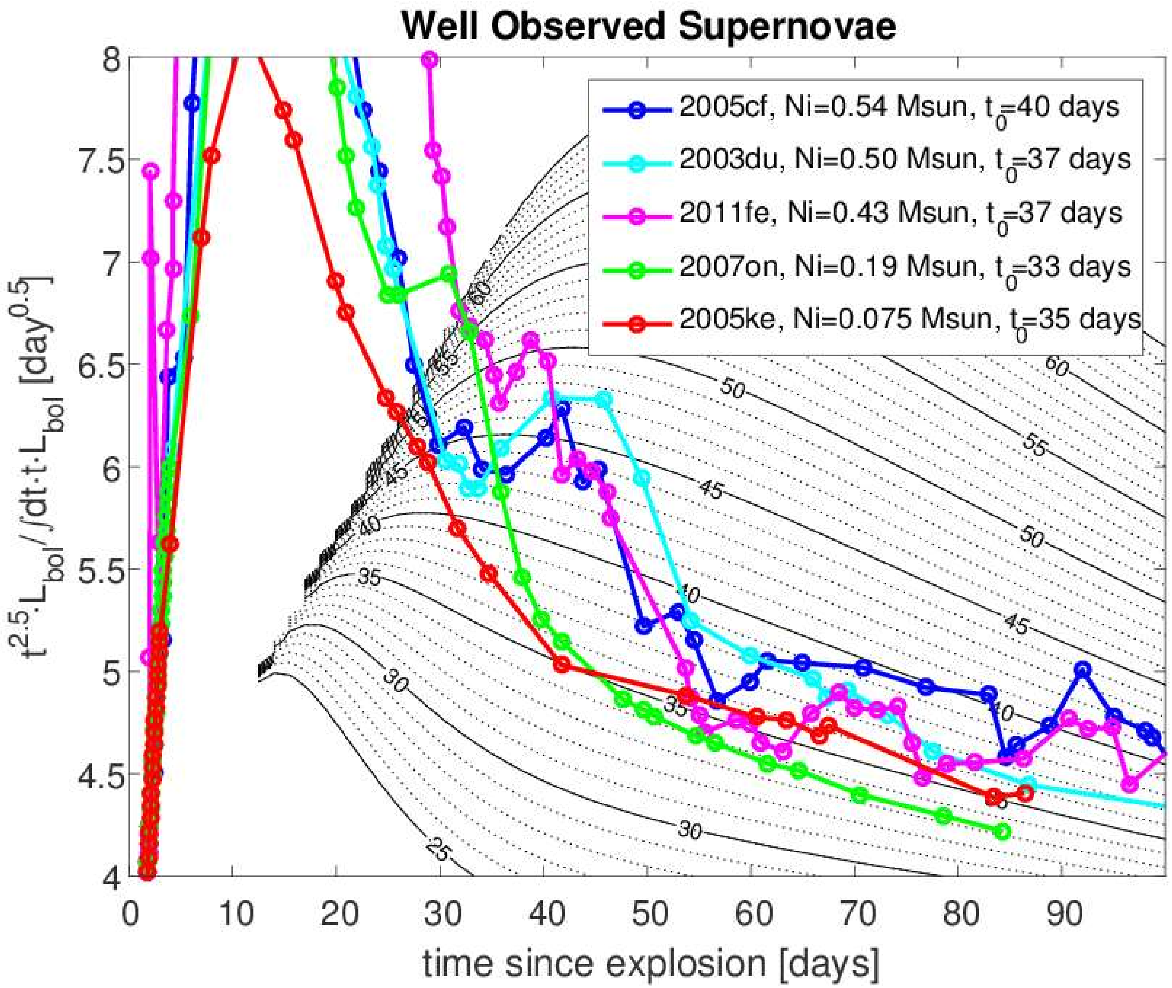
- But t0 is set by ejecta geometry (avg. column density from ^{56}Ni).
- → Late bolometric light curves constrains ejecta geometry.

Extracting t_0 from lightcurves

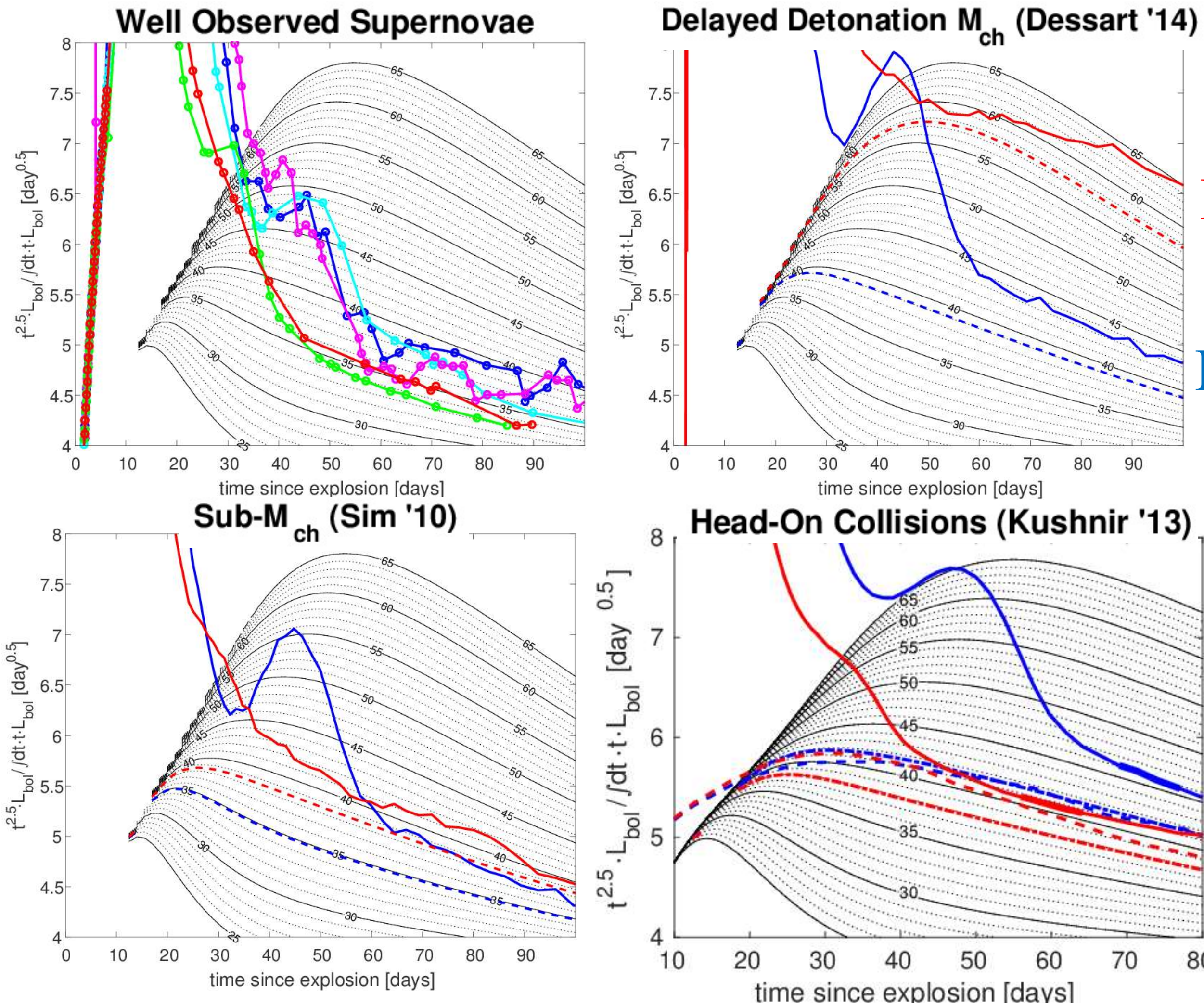
Example: SN2005cf



SNIa have t_0=40



Collisions / sub-M_{ch} consistent, M_{ch} not



Low ^{56}Ni (~0.1 Msun)

High ^{56}Ni (~0.8 Msun)

— Full L_{bol}

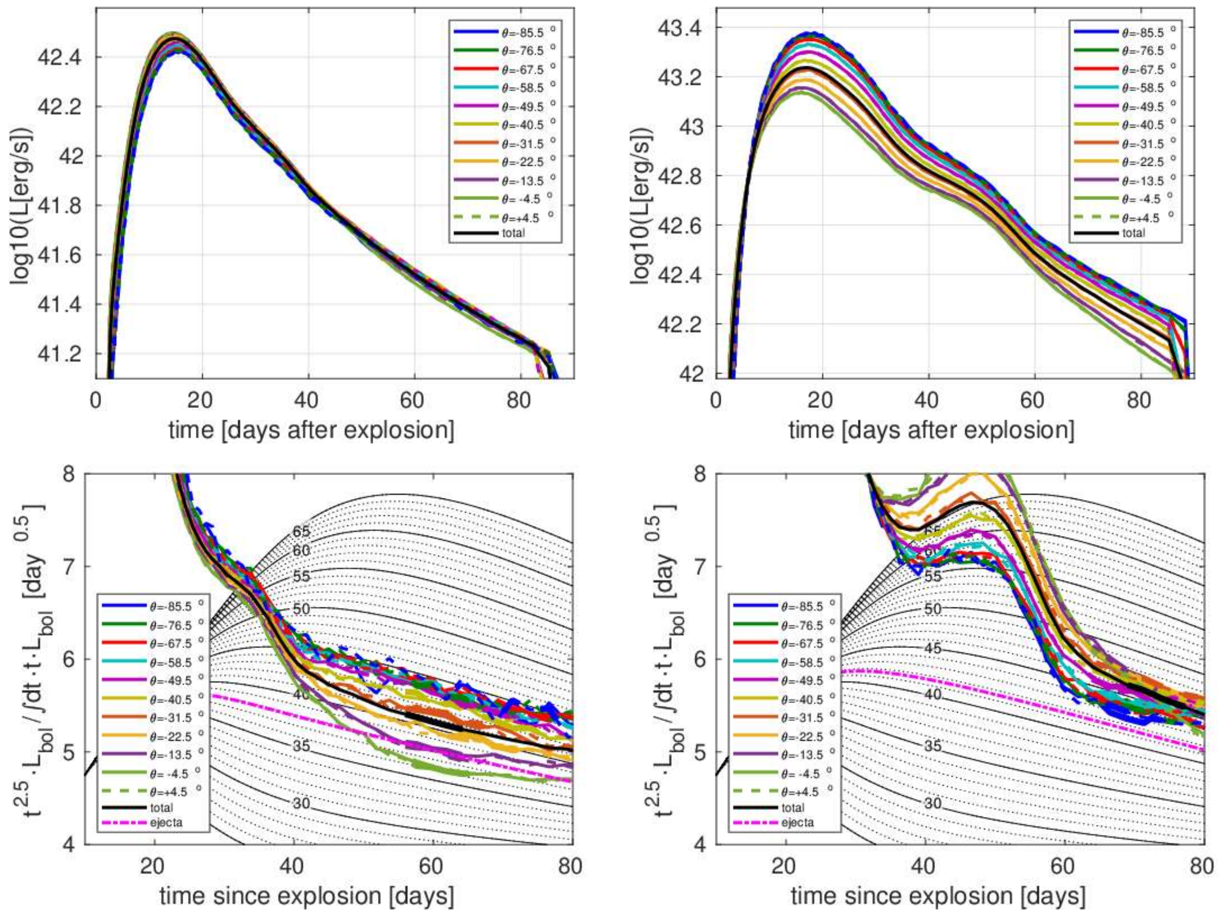
--- Analytic Q_{dep}

A word on 2D effects (for collisions)

Low ^{56}Ni (~0.1 Msun) High ^{56}Ni (~0.8 Msun)

Bolometric

Inferring t_0



- Up to ~30% difference in bolometric light curves (even at late time).

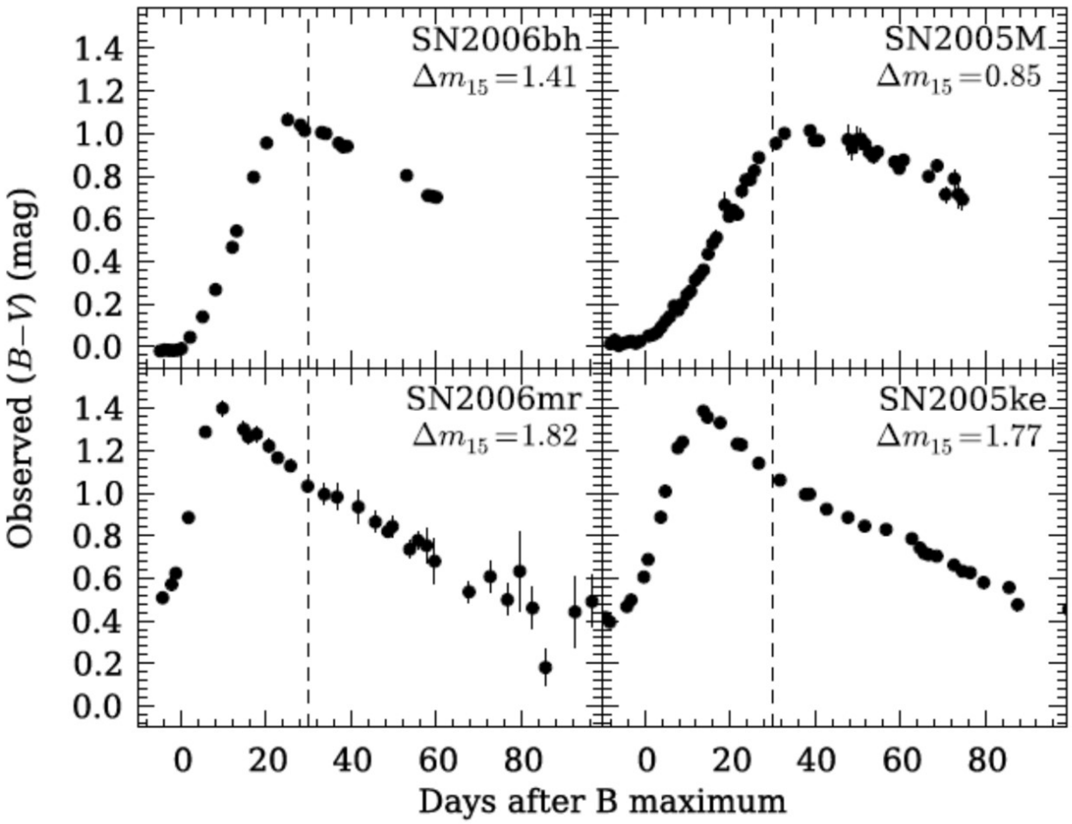
- Additional ~10% scatter in t_0
  (and ~25% in ^{56}Ni).

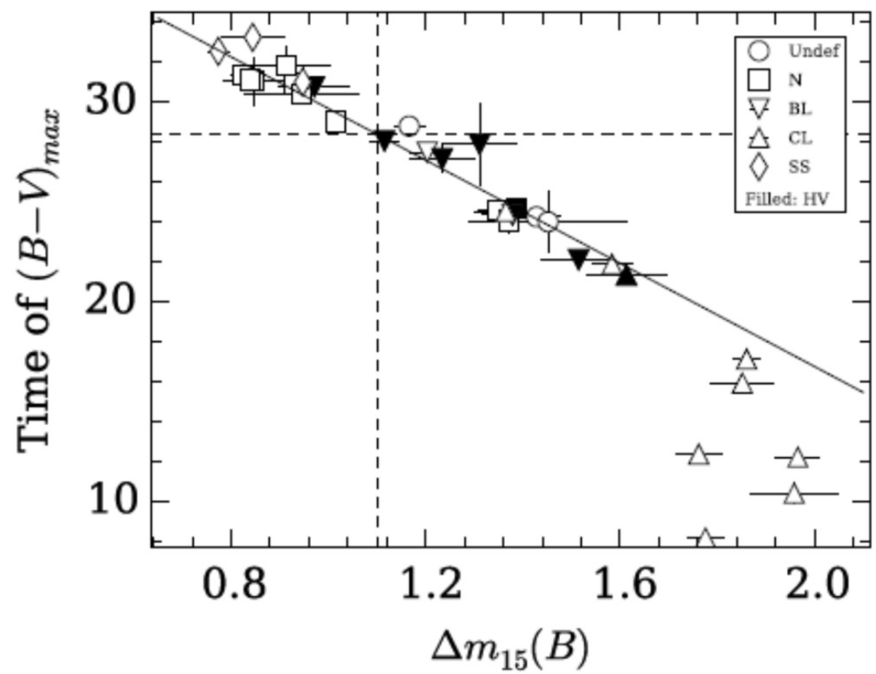
There are two timescales (widths)

- Bolometric: γ escape time
- Color: Recombination of Ni/Co/Fe (from 2 to 1 ionized)

Color: striking break in B-V

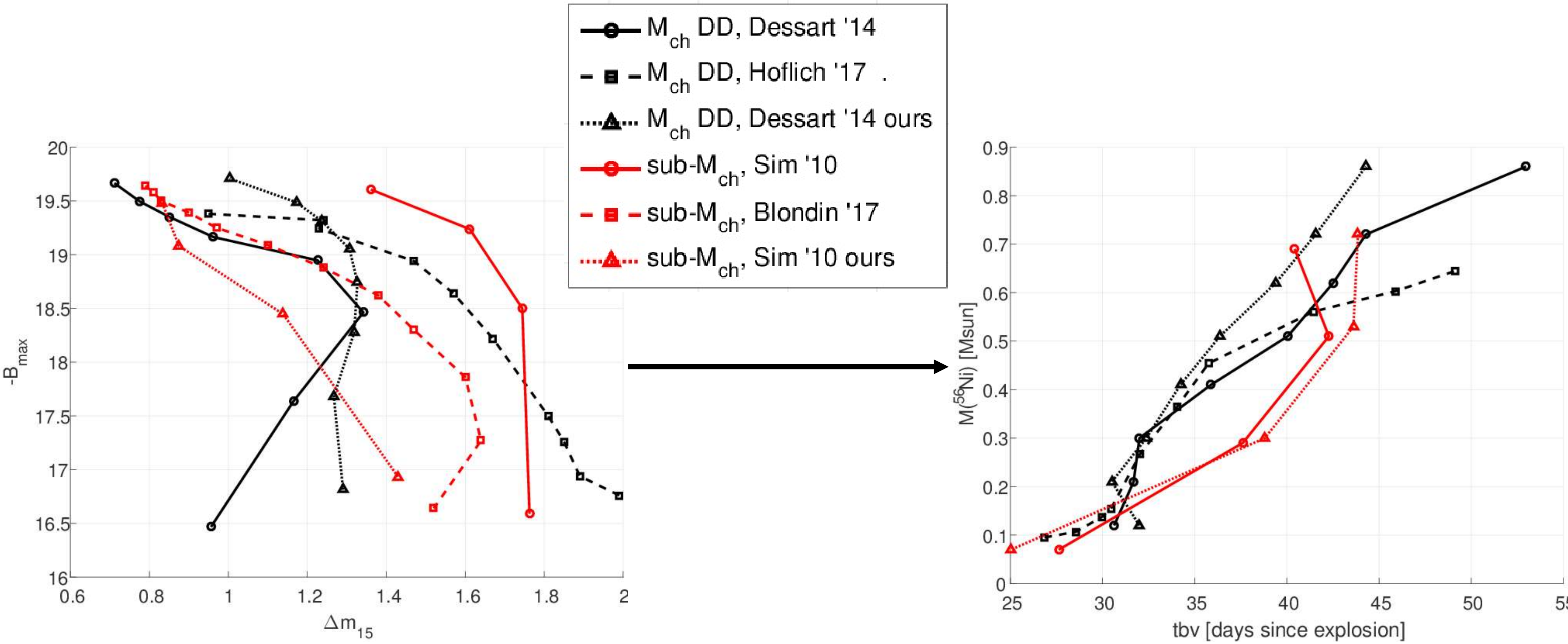
Burns '14



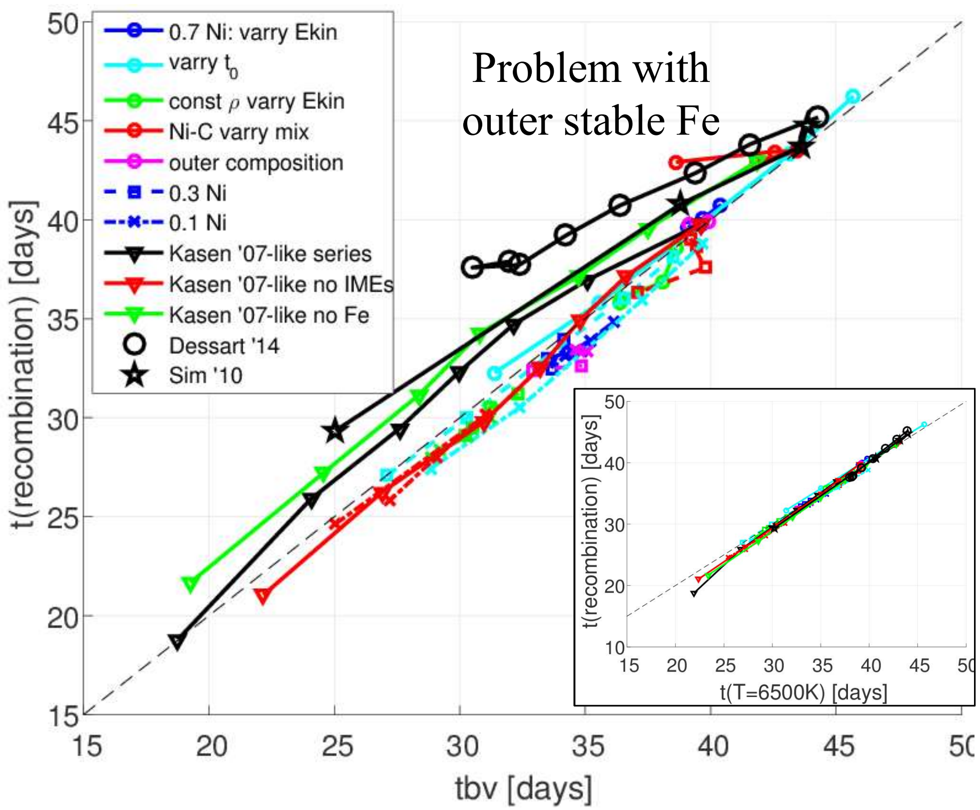


Note - Pskovskii '77

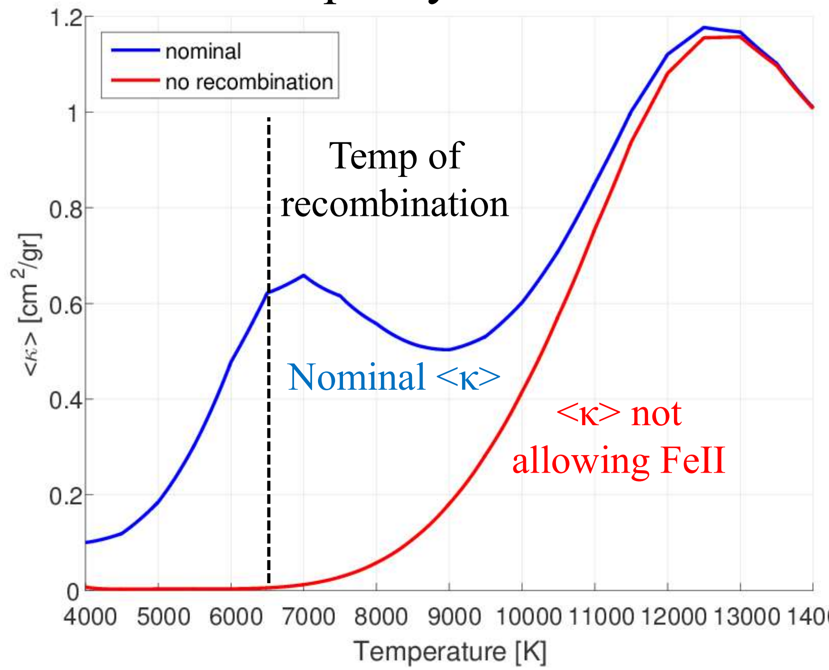
tbv is robust



Color break time (tbv) is recombination



<κ> as function of Temp. - opacity "cliff"



Break in B-V = recombination of Ni = 6500K

Due to sudden drop in κ as ejecta cools.

2D effects - B-V curves and break time

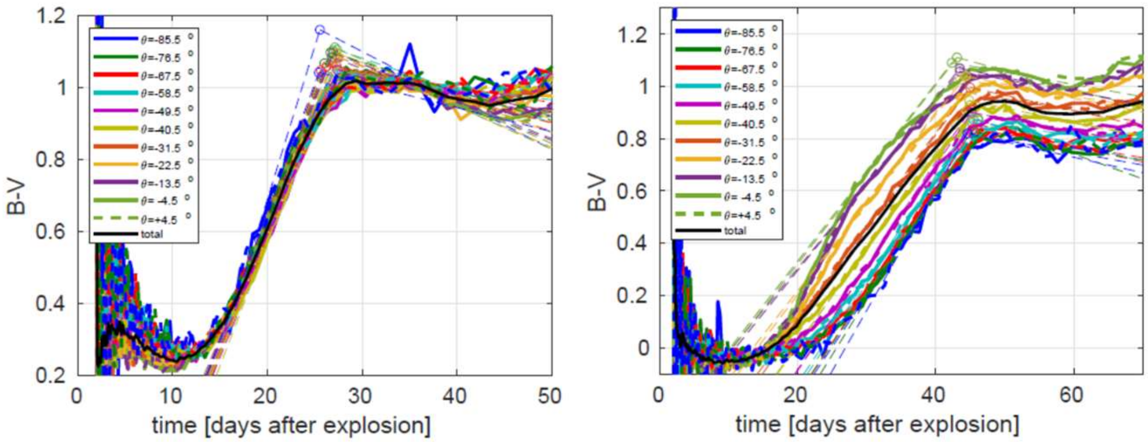


Figure 10. 05-05 and 08-08 collisions - B-V

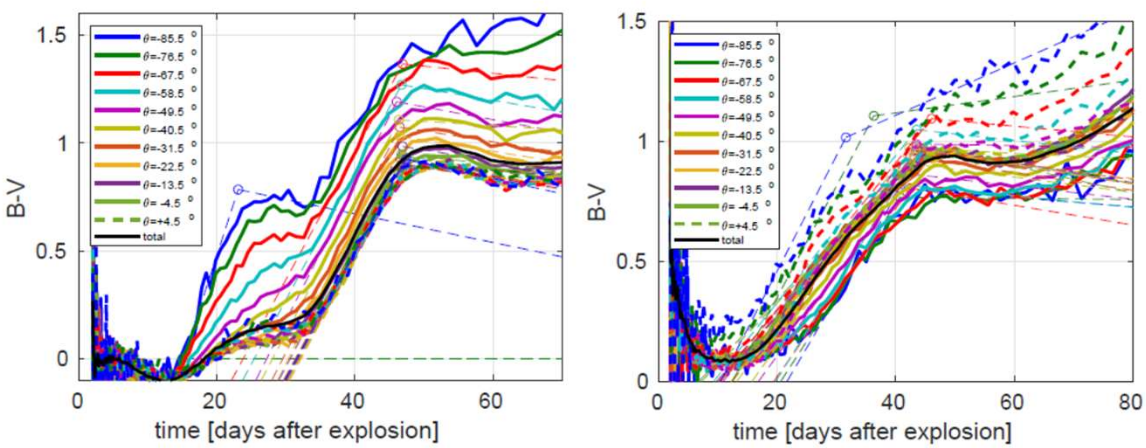


Figure 11. 10-05 and 07-06 collisions - B-V

Recombination can be simply predicted

Simple photospheric model
(Marginally optically thin).

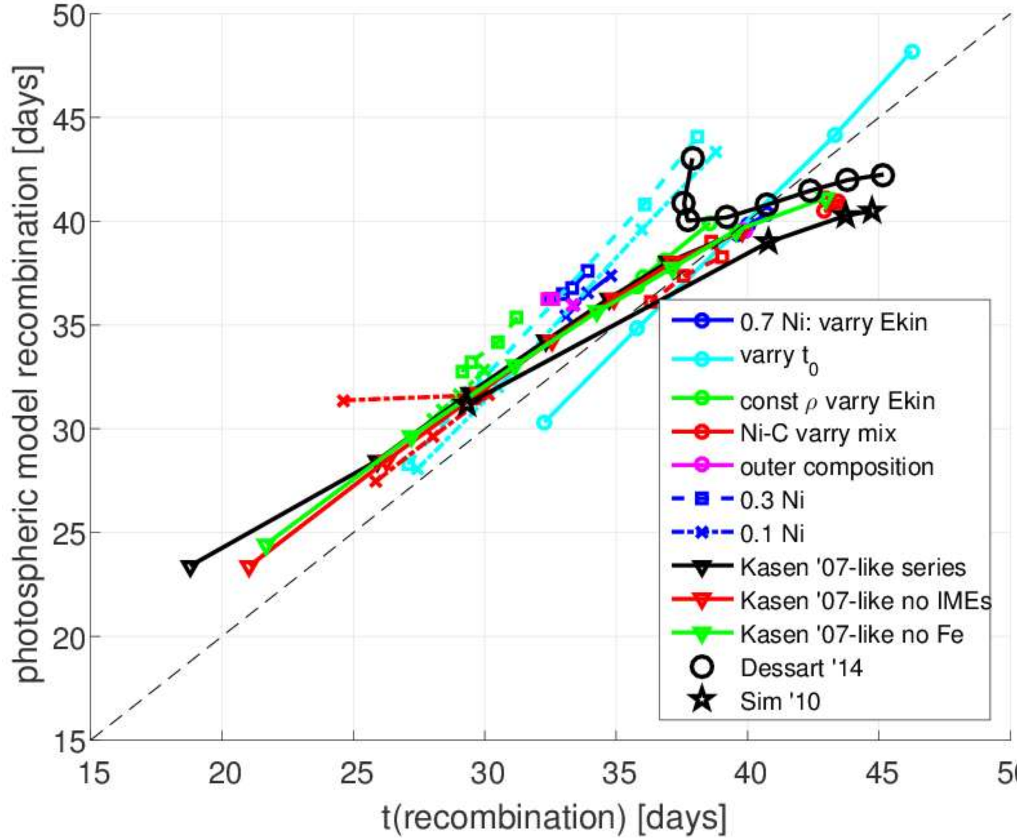
$$L_{\rm bol} \sim 4\pi R_{\rm Ni}^2 \sigma_{sb} T_{\rm Ni}^4.$$

$$L_{\rm bol}(t_{\rm rec}) = Q_{\rm dep}(t_{\rm rec})$$

$$R_{\rm Ni} \equiv \langle r \rangle_{56\,Ni} \;=\; v_{\rm Ni} \times t$$

$$T_{\rm Ni} \equiv \langle T \rangle_{56\,Ni} = 6500K.$$

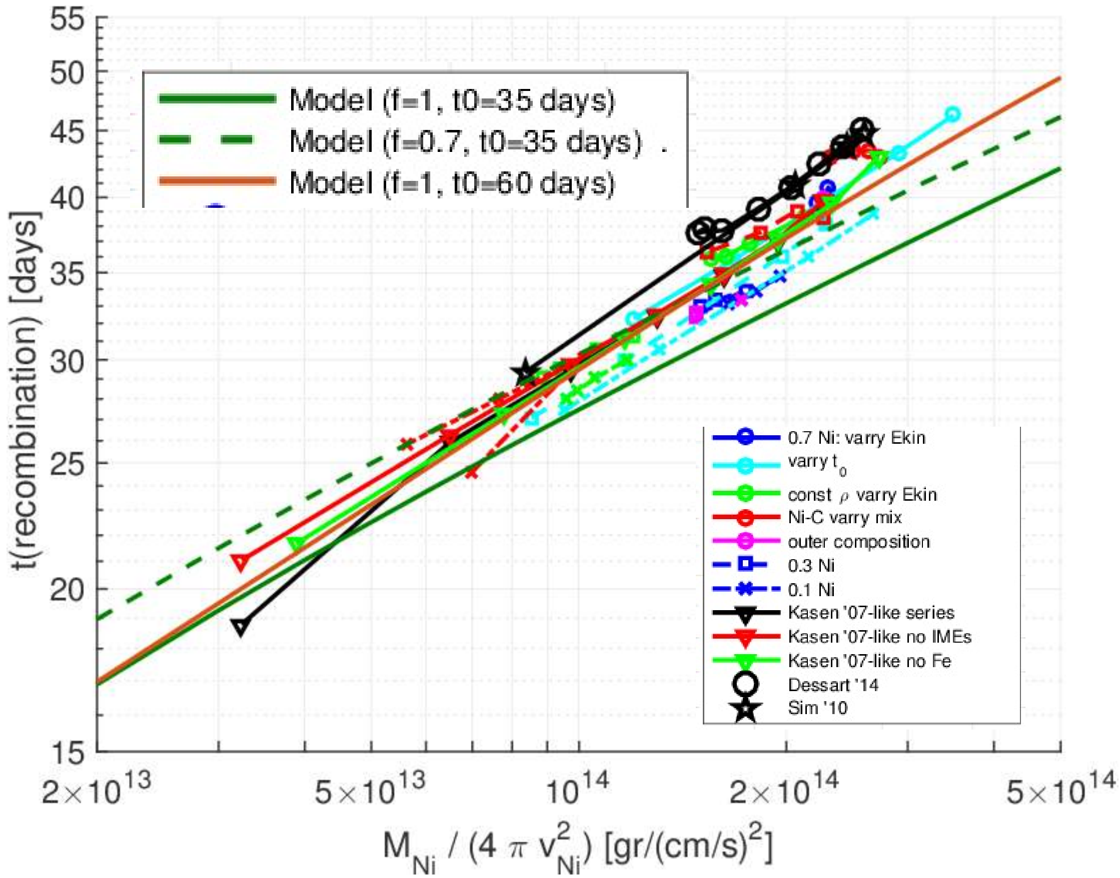
$$Q_{\rm dep}(t) = f \cdot 4\pi (v_{\rm Ni} \cdot t)^2 \sigma_{\rm sb} \cdot 6500K^4$$



$$q_\gamma(t)(1 - e^{-\frac{t_0^2}{t^2}}) + q_{\rm pos}(t) = f \left(\frac{M_{\rm Ni56}}{4\pi v_{\rm Ni}^2} \right)^{-1} \sigma_{\rm sb}\; 6500K^4\; t^2$$

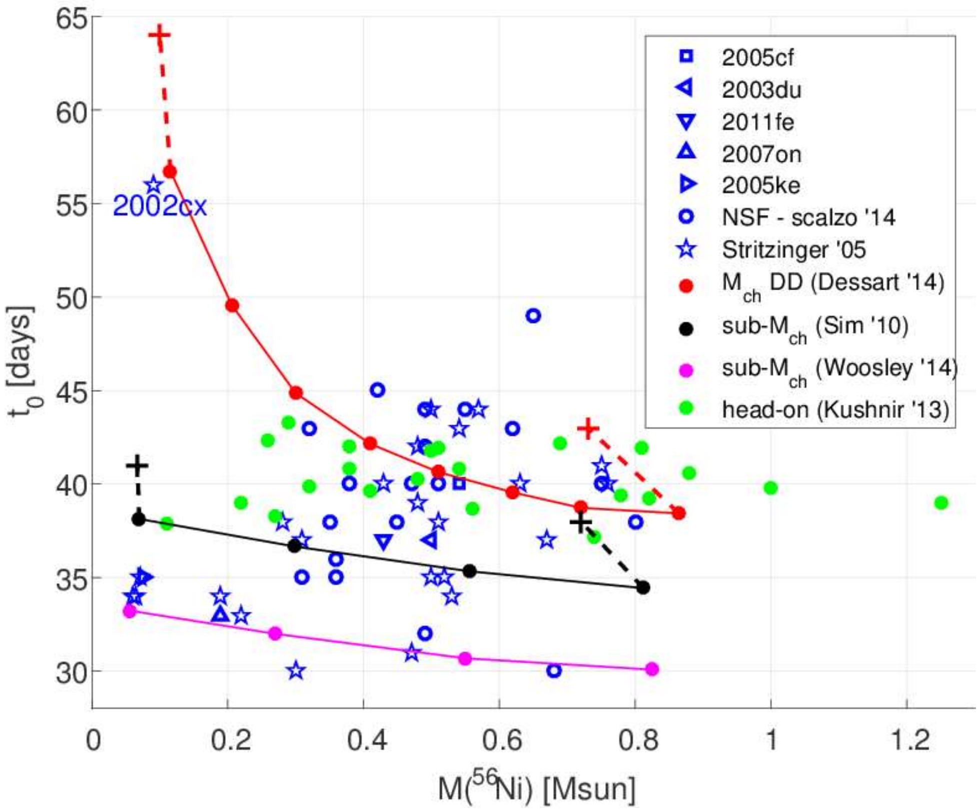
So what is the WLR?

- B-V break is recombination
- Recombination time is set by Ni column density.

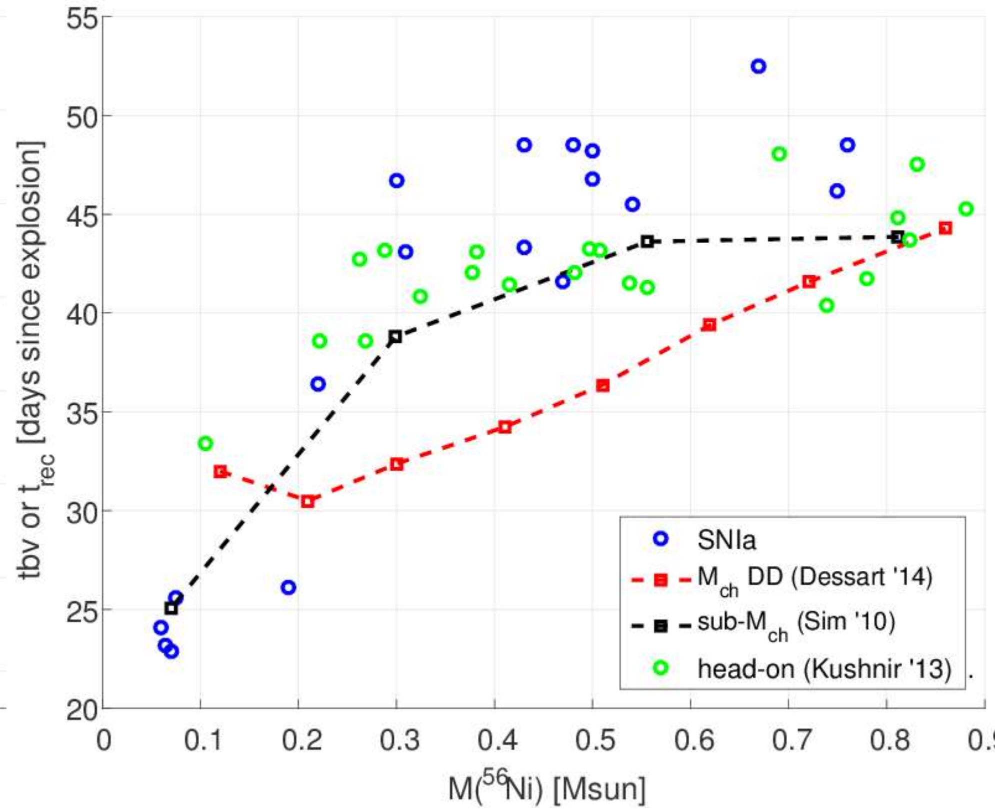


Summary - two WLRs:

Bolometric - γ escape time
Set by total column density



Color - Fe recombination
Set by Ni column density



Thank you!