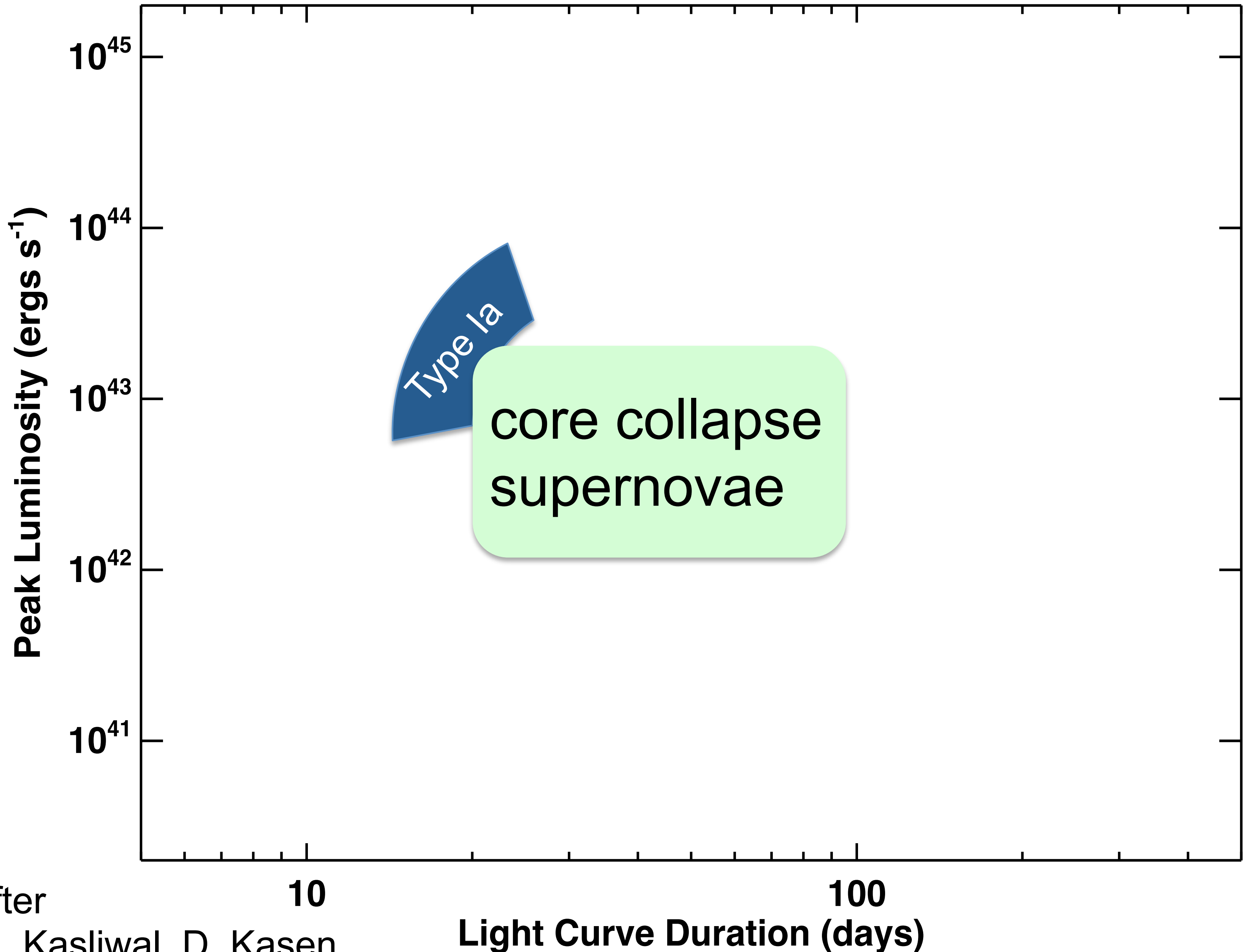
Models for super-luminous supernovae

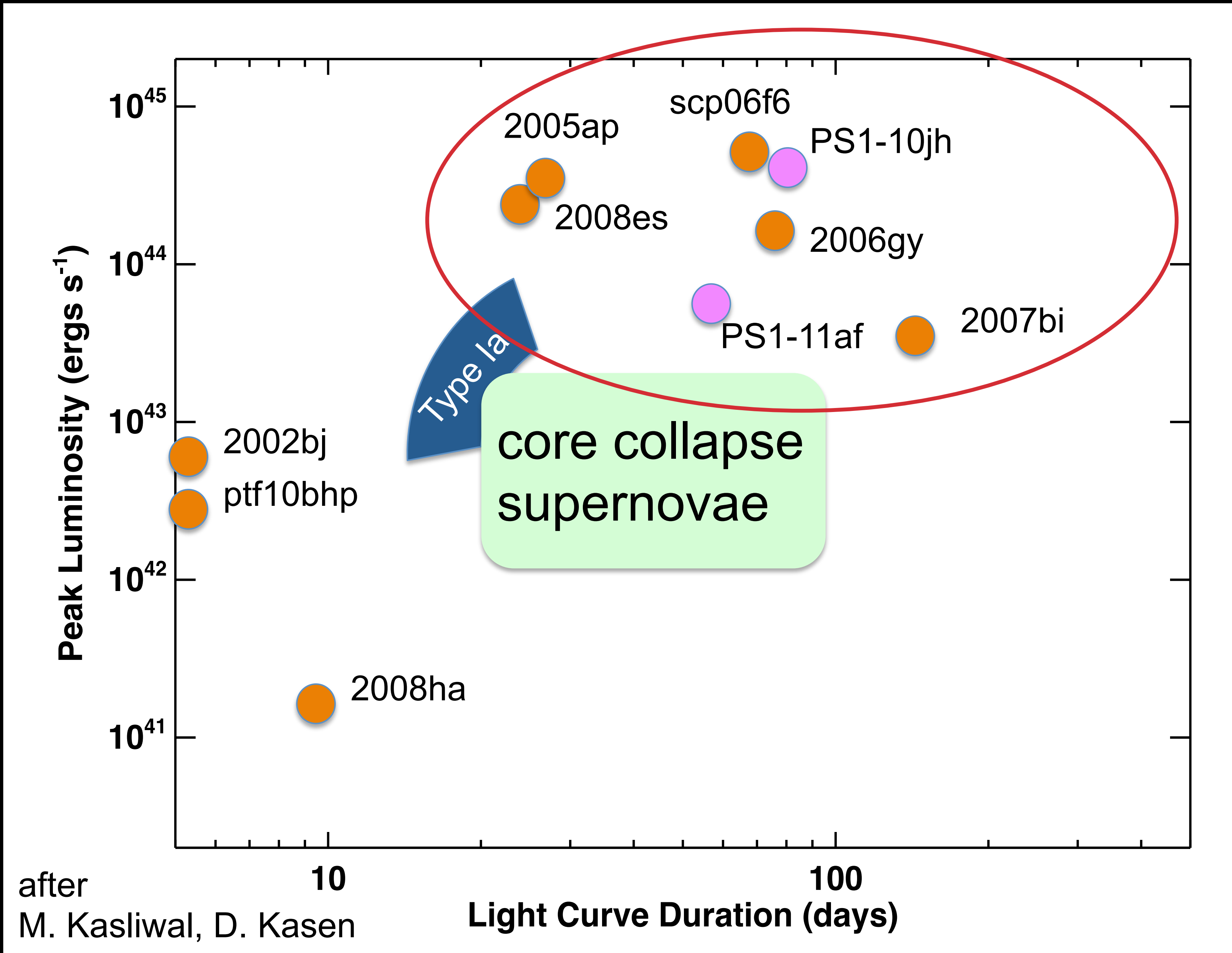
Jason Dexter (with Dan Kasen)
UC Berkeley

Optical transients then

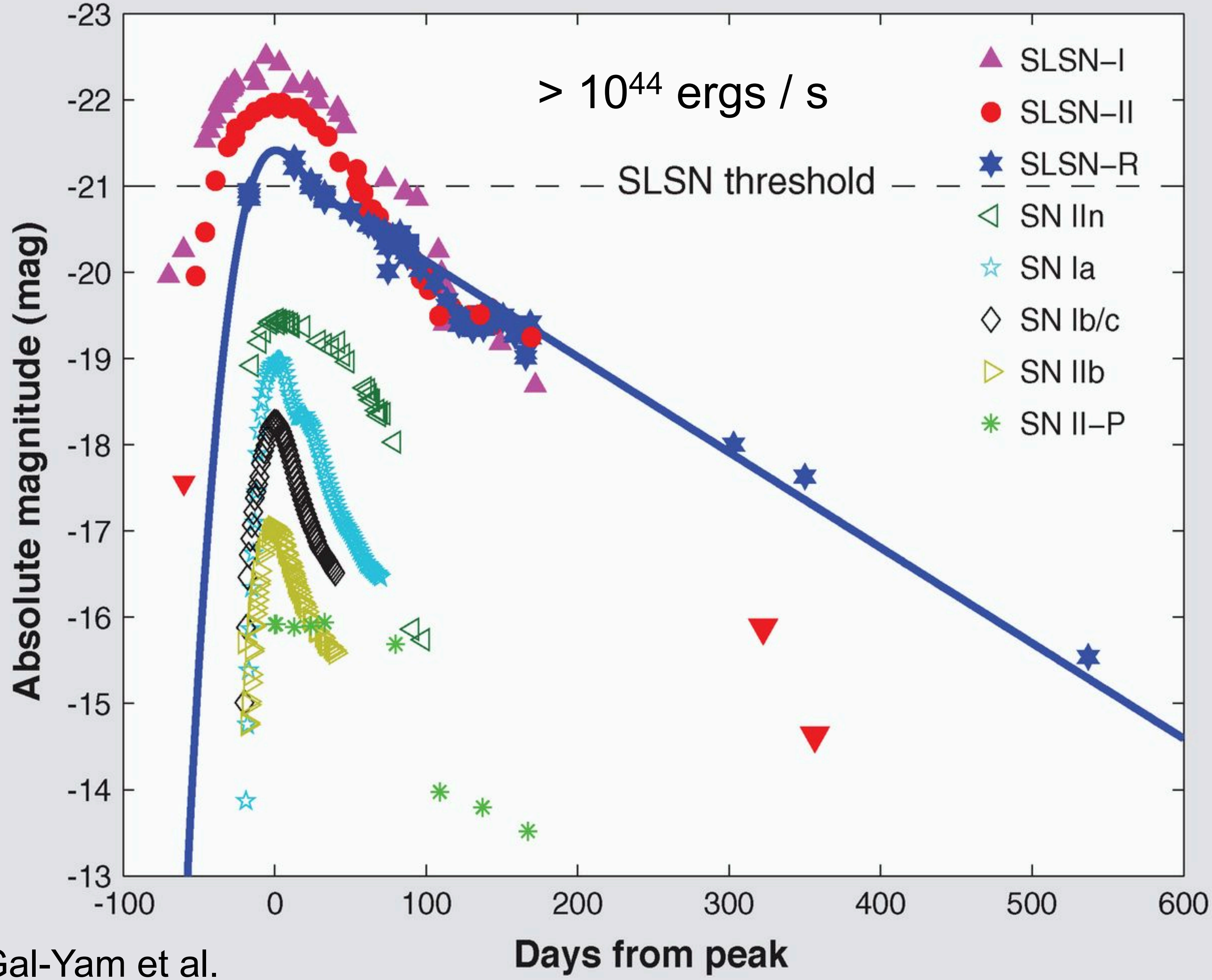


after
M. Kasliwal, D. Kasen

Optical transients now



Supernova light curves



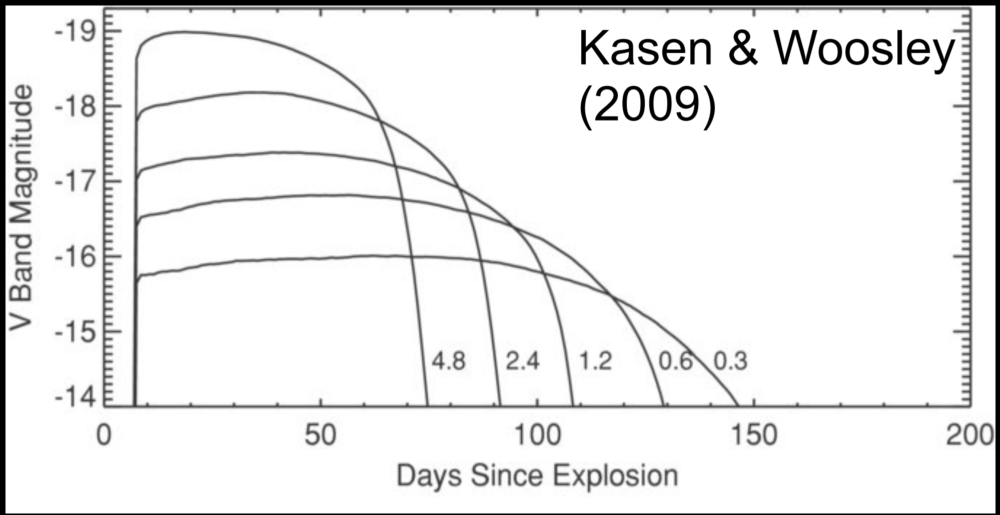
Gal-Yam et al.

Powering supernova light curves

- Thermal

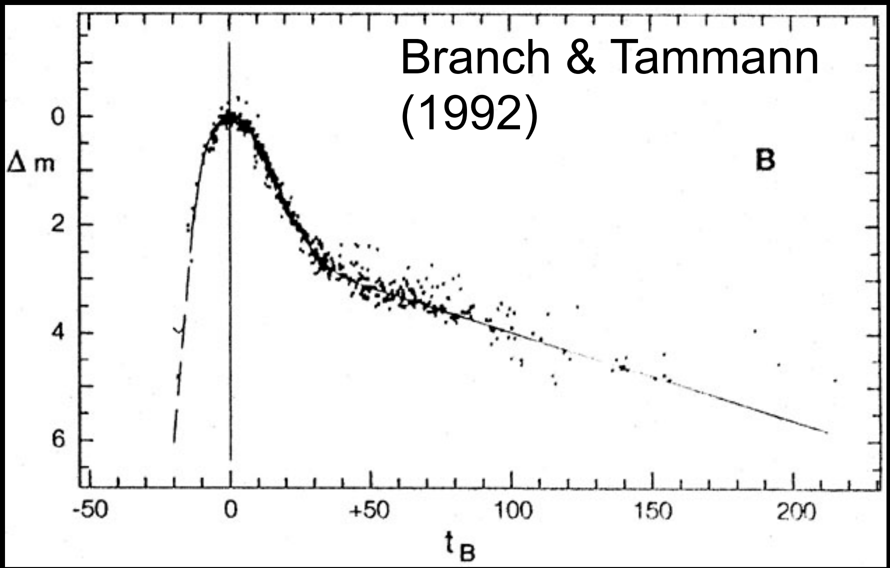
$$L_p = \frac{E_0}{t_p}\frac{R_0}{vt_p}$$

Efficiency



- Radioactive (^{56}Ni)

$$L_p = \frac{\epsilon_{nuc} M_{nuc} e^{-(t_p/t_{nuc})}}{t_p}$$



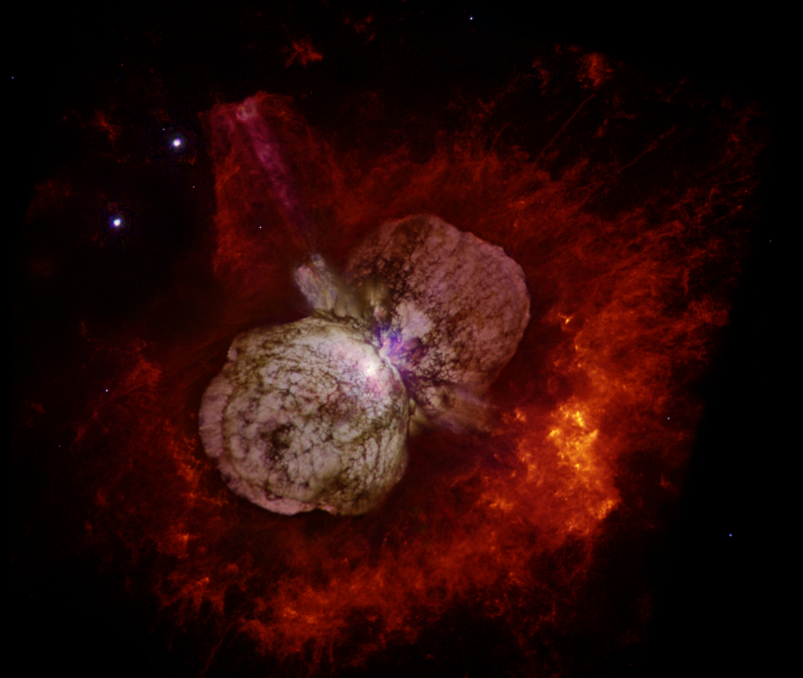
Circumstellar Interaction

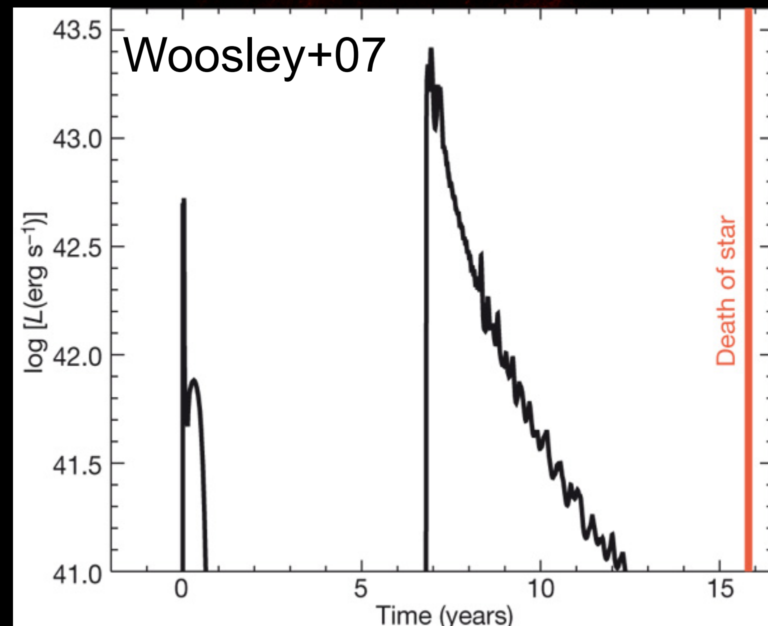
- Interaction of ejecta with material at large radius resets internal energy

Efficiency

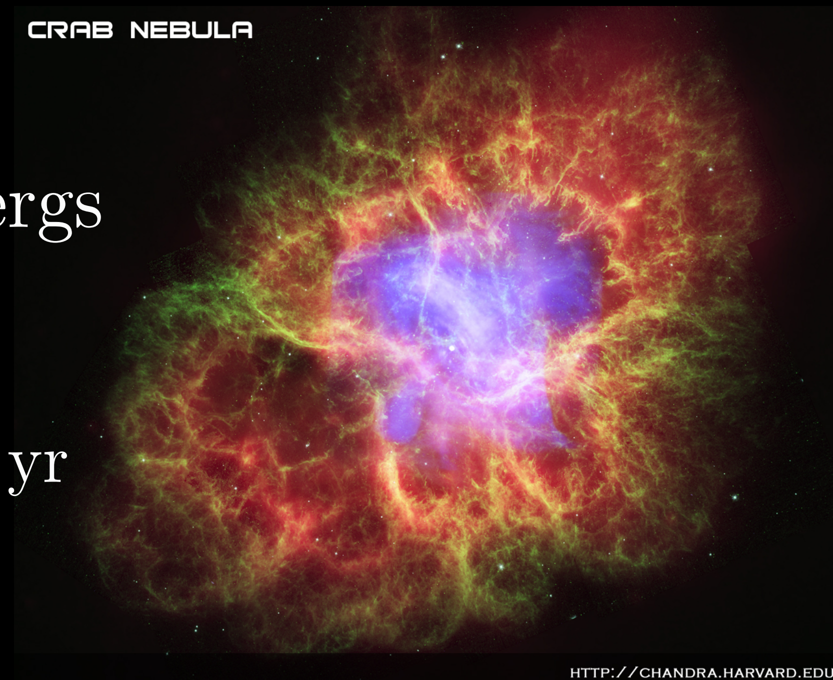
$$L_p = \frac{E_0}{t_p}\frac{R_{sh}}{vt_p}$$

- Large if $R_{sh} >> R_0$





Magnetar Spindown Power

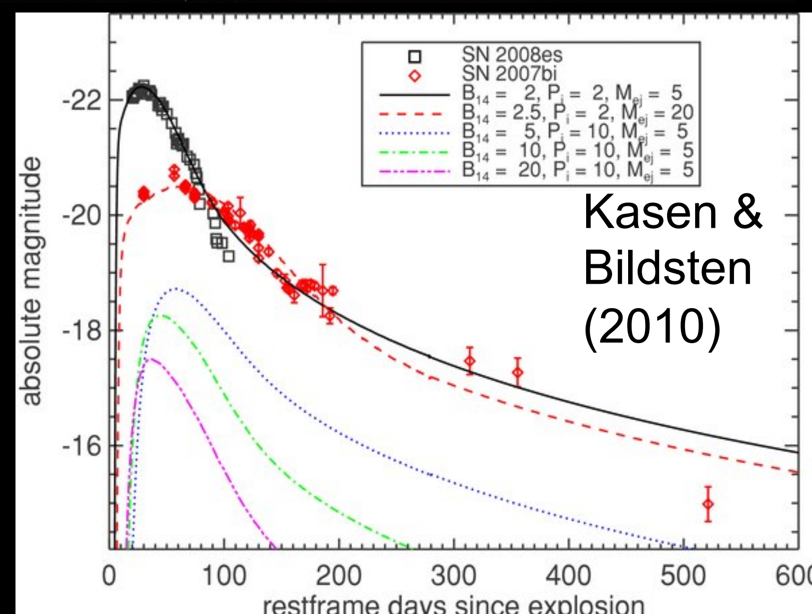


$$E_{rot} \equiv \frac{1}{2} I_{ns} \Omega^2 \simeq 10^{50} \left(\frac{P}{10\text{ms}} \right)^{-2} \text{ergs}$$

$$t_m \equiv \frac{E_{rot}}{L_{mag}} \simeq 1 \left(\frac{B}{10^{14}\text{G}} \right)^{-2} \left(\frac{P}{10\text{ms}} \right)^{2} \text{yr}$$

$$L_p \sim \frac{E_{rot}}{t_p} \frac{t_m}{t_p}$$

$$\simeq 5 \times 10^{43} \left(\frac{B}{10^{14}\text{G}} \right)^{-2} \left(\frac{t_p}{100\text{d}} \right)^{-2} \text{ergs s}^{-1}$$



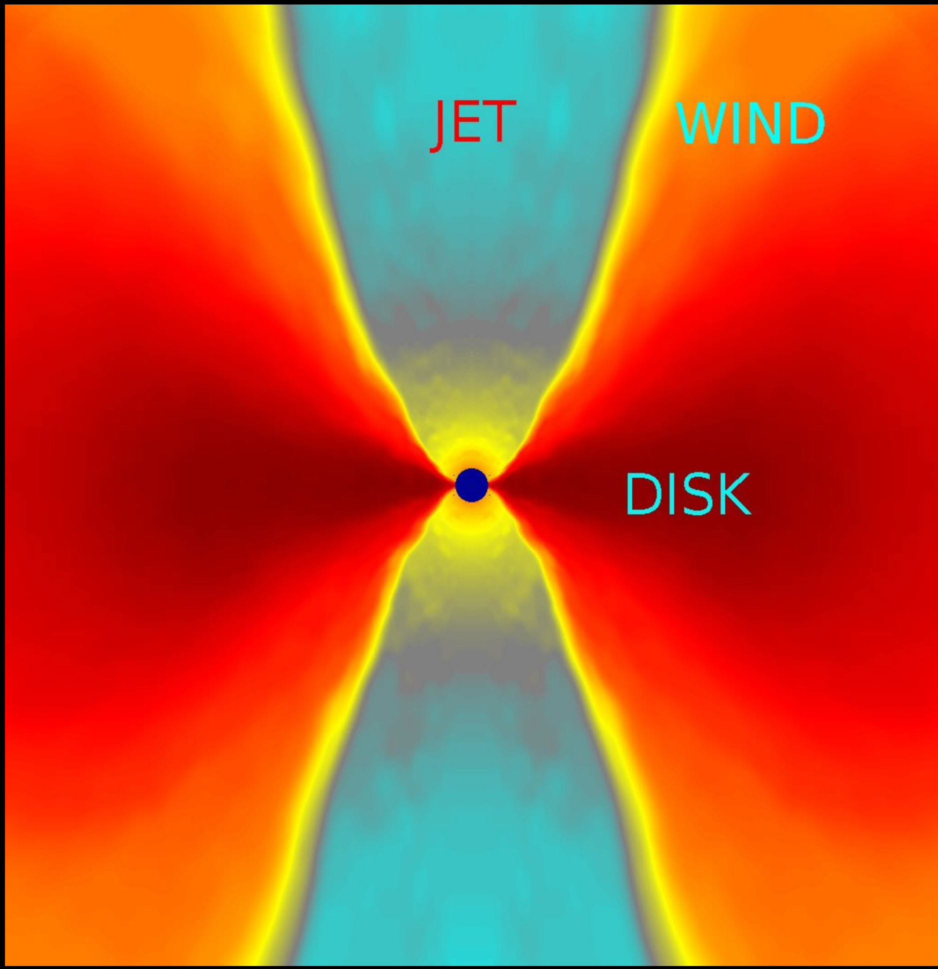
Kasen & Bildsten (2010)

Accretion Energy

$$\mathbf{L_p = \epsilon \dot{M}(t_p)\, c^2}$$

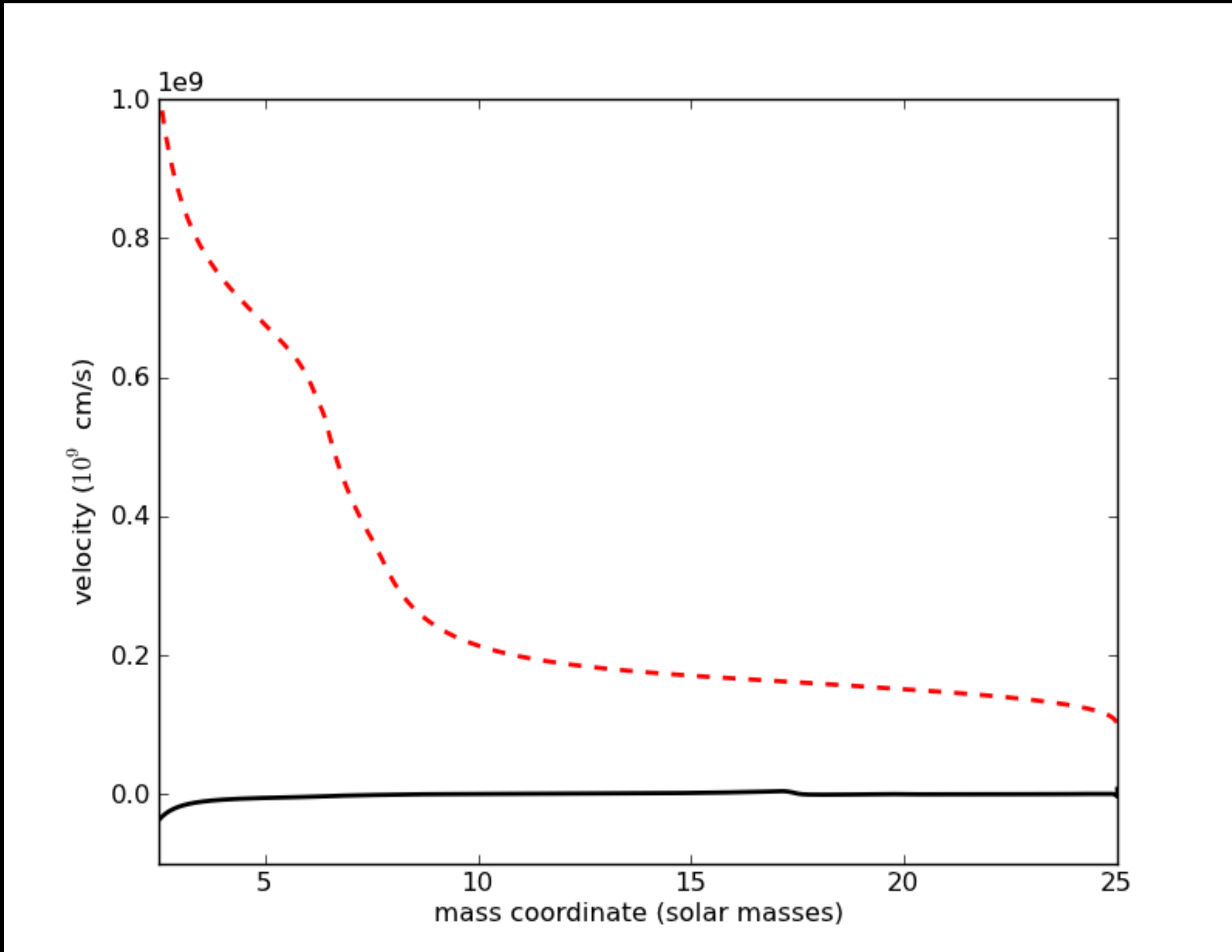
$$\mathbf{\sim \frac{\epsilon M_{fb} c^2}{t_p}}$$

- Need: disk, M_{fb}, outflow

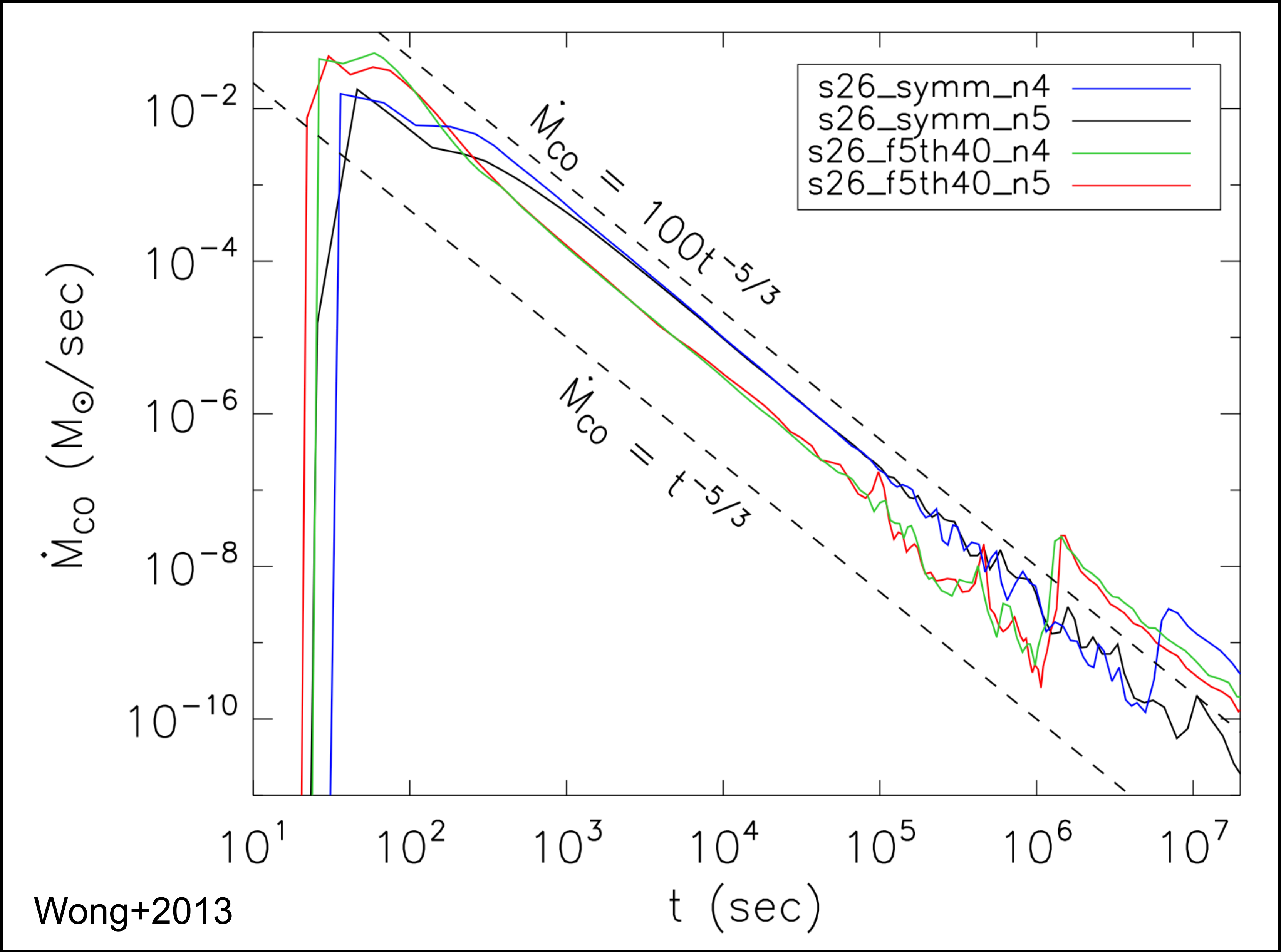


Alexander Tchekhovskoy

Fallback in a supernova explosion



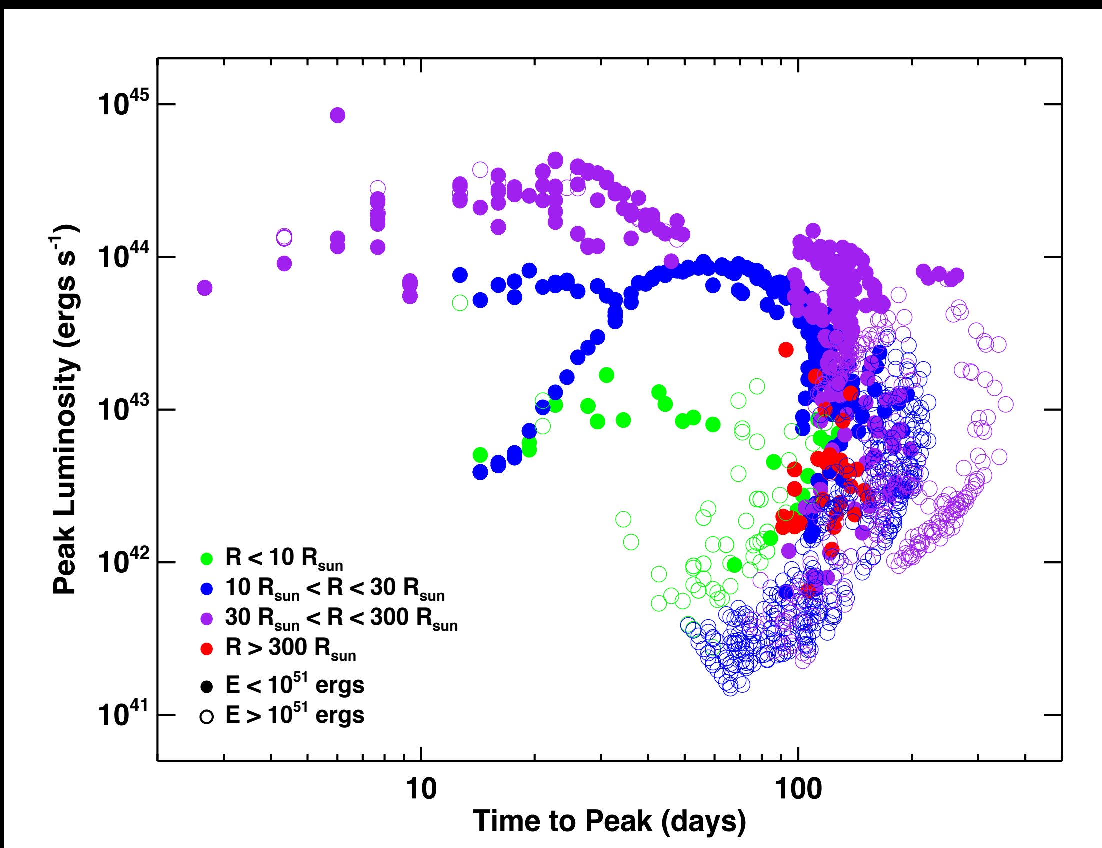
Fallback accretion rate

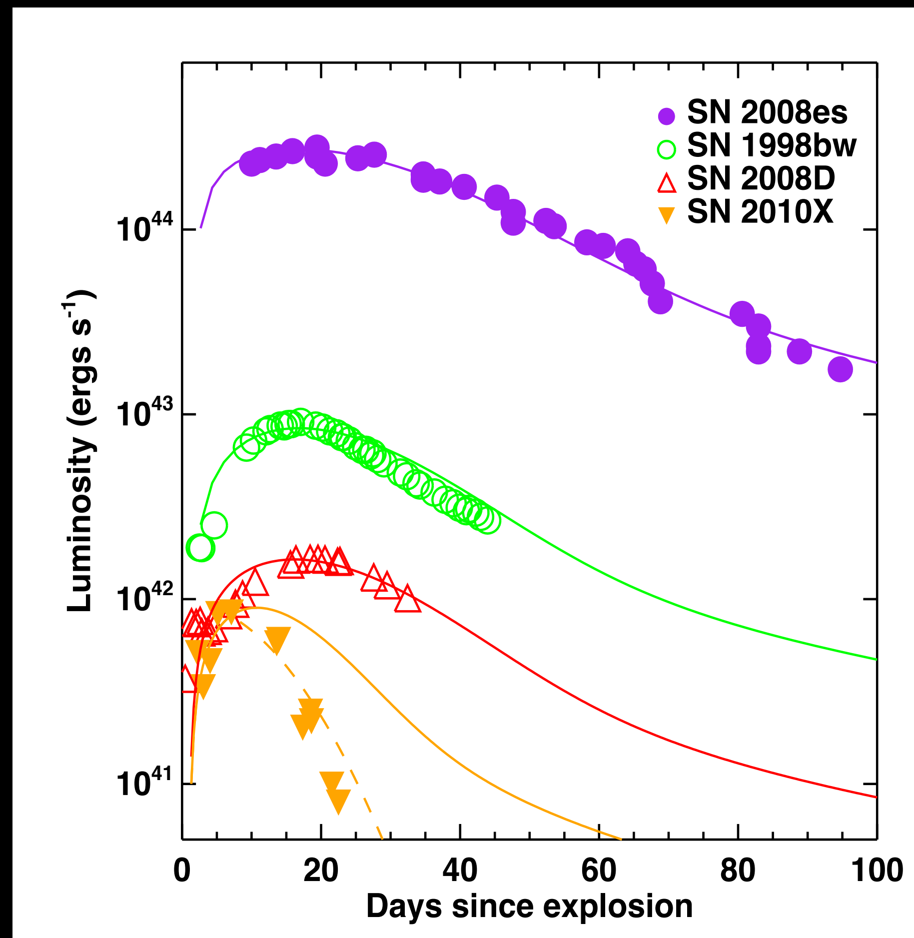


Accretion powered supernovae

- Accretion disk wind collides with ejecta, deposits energy

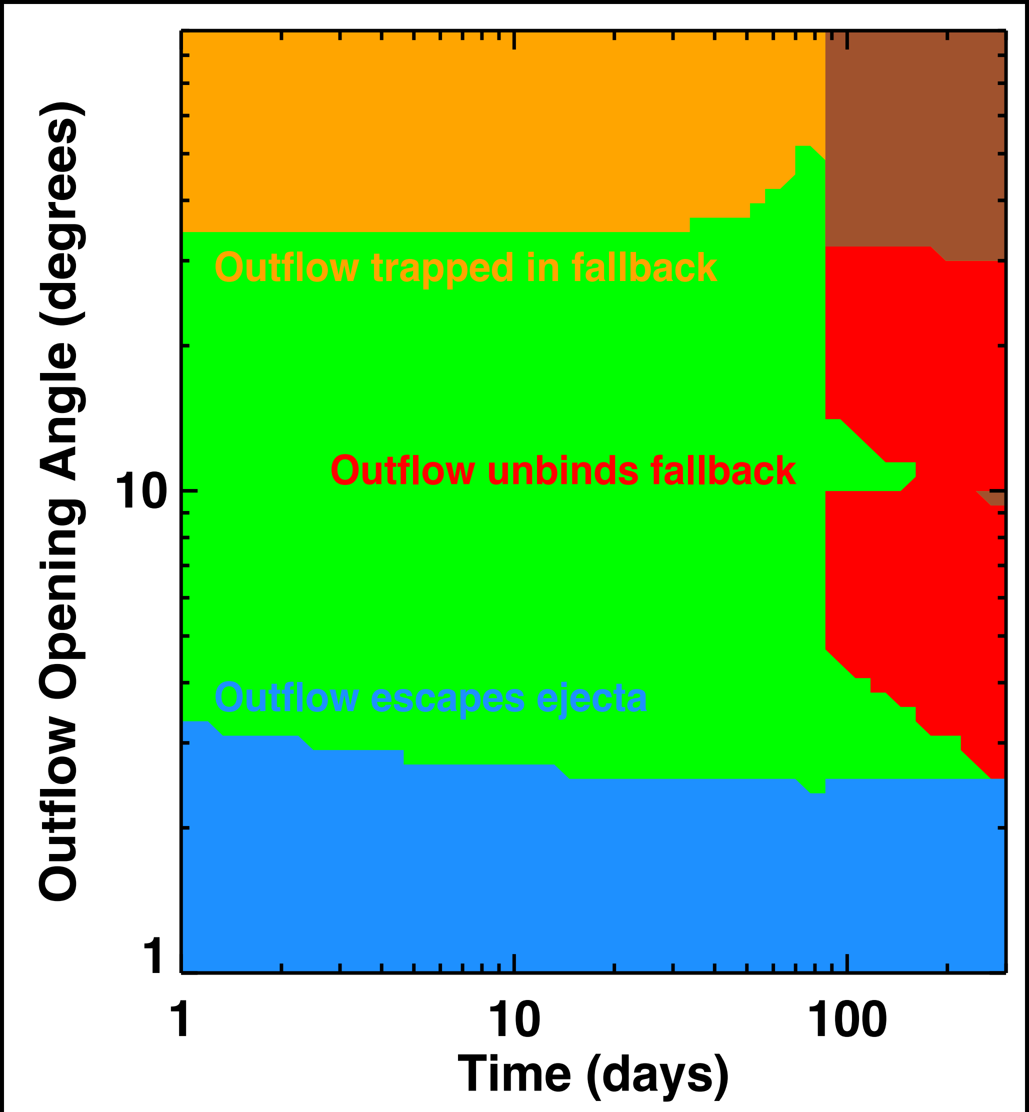
Dexter & Kasen (2013)





Open Issues

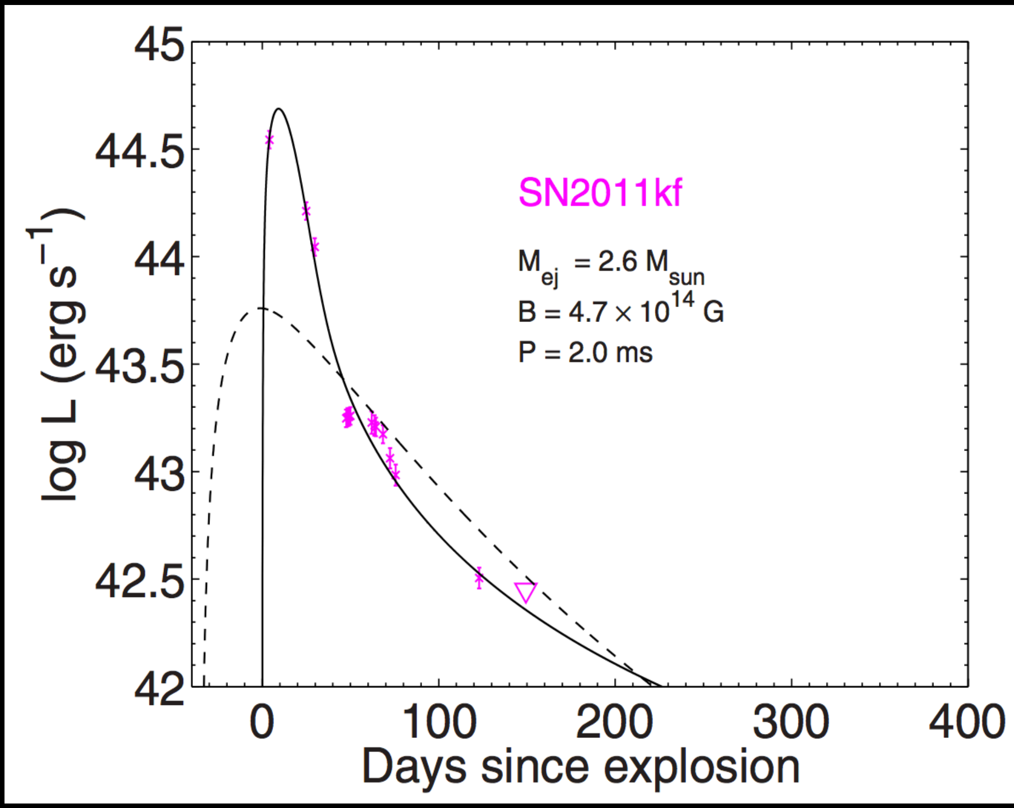
- Fallback rate
- As in magnetar model:
  - Energy deposition in ejecta
- As in collapsar GRBs:
  - Disk formation
  - Outflow properties
  - Interaction of outgoing, infalling material



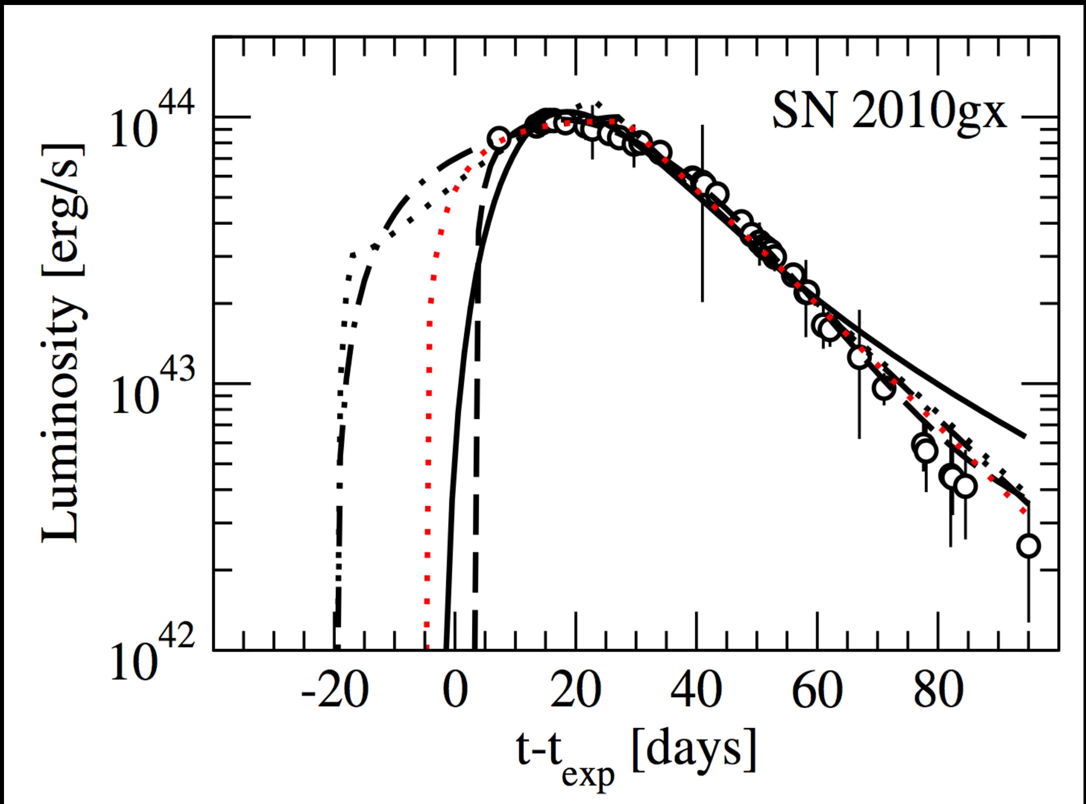
Evidence of central engines?

- Magnetar model explains many Type I SL SN light curves, high velocities, but not unique

Inserra+2013

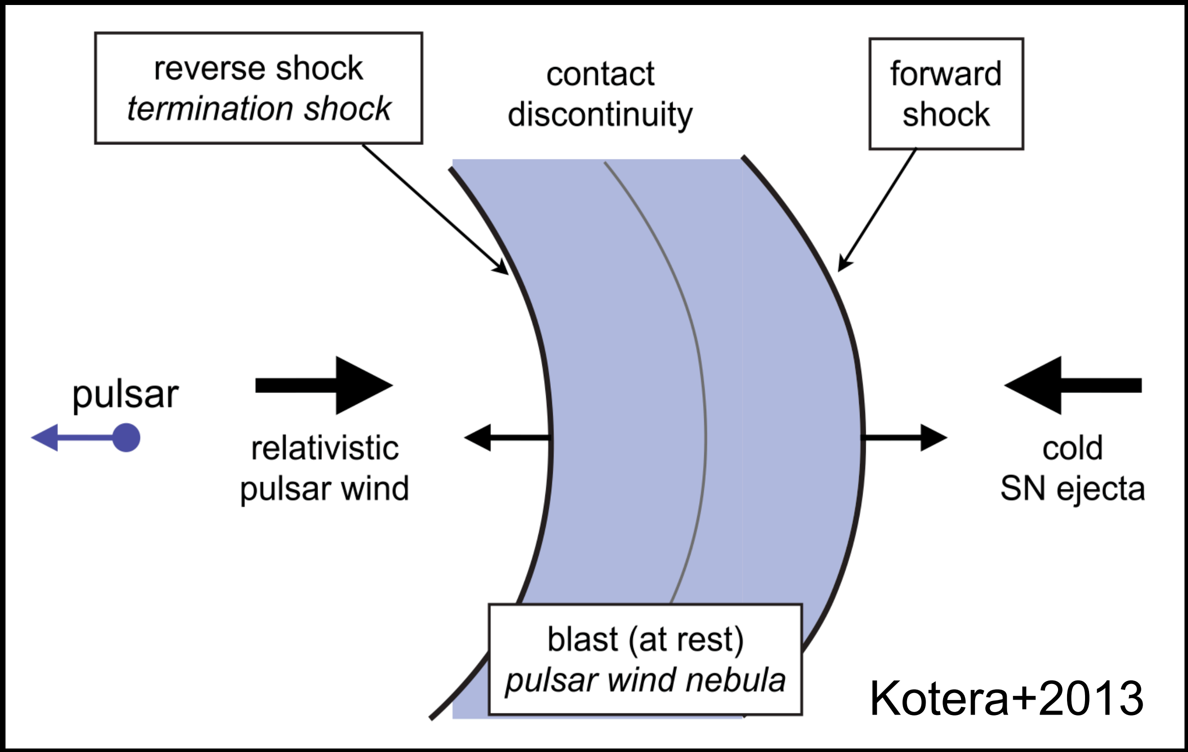


Chatzapoulos+2012



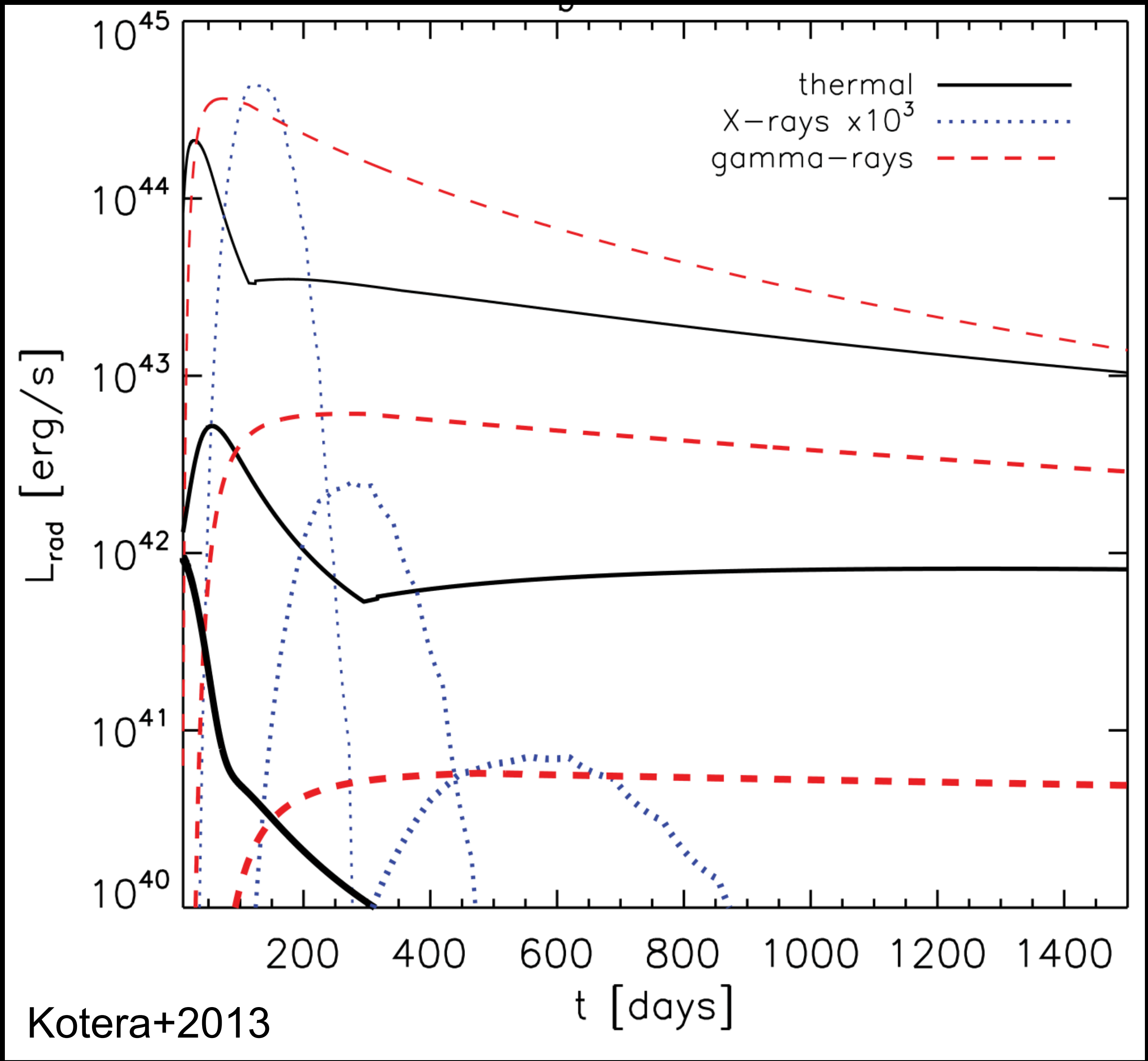
Signatures of central engines

- Central engine should "shine through"
- Sources of thermalization:
  - Free-free (IR), lines (optical), photoabsorption (UV/soft X-ray), Compton scattering (high energy)



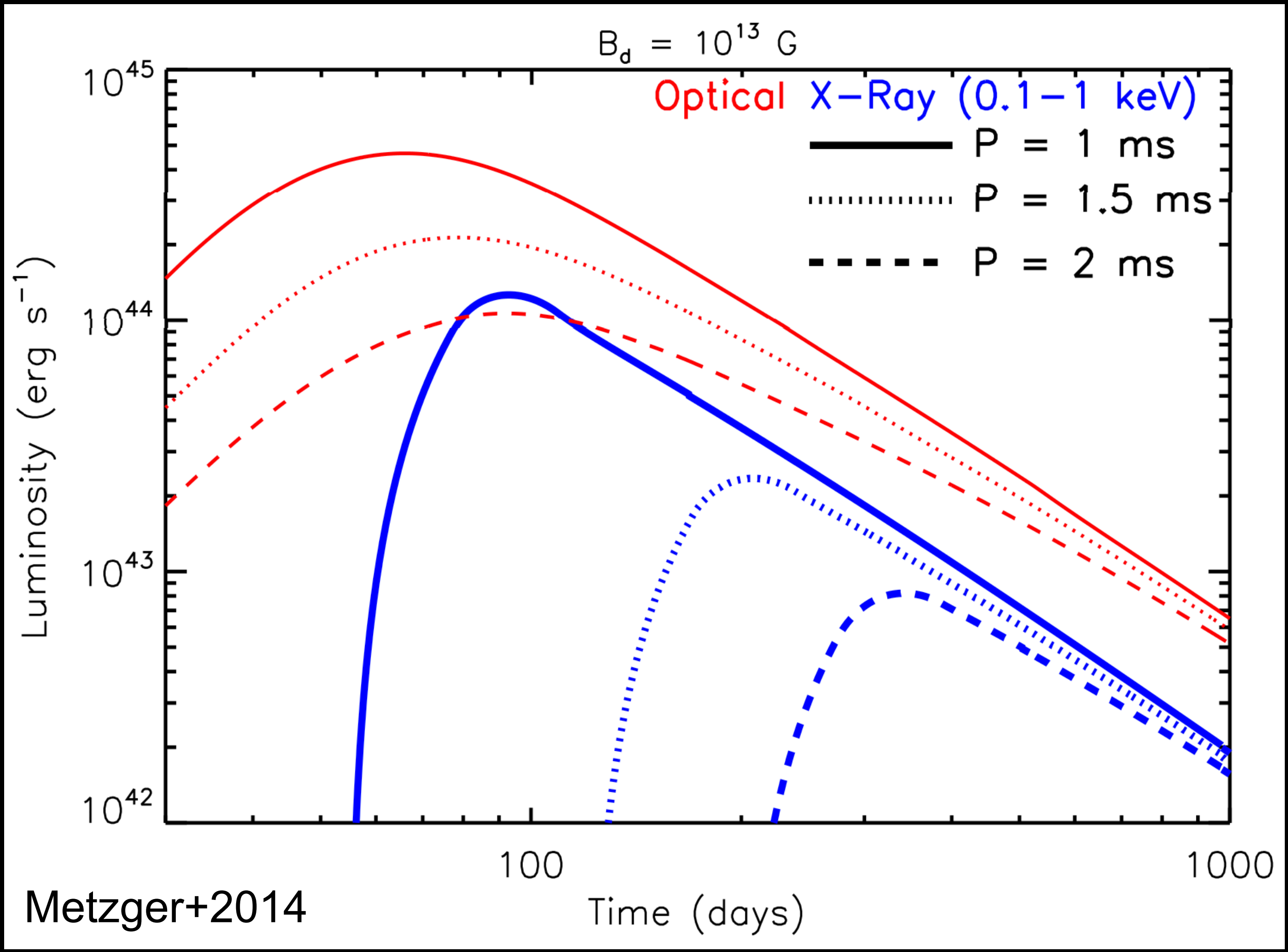
Hard X-rays, gamma rays

- For low field strengths, can be significant high energy emission at late times



Soft X-ray flash?

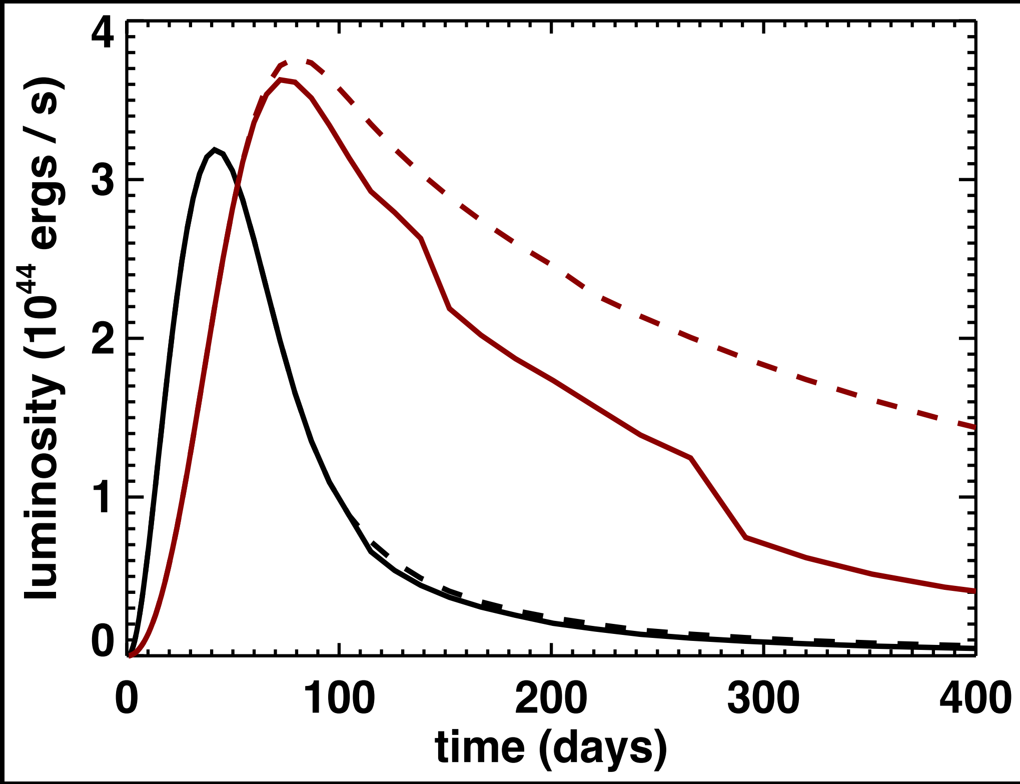
- Pulsar could completely ionize ejecta near peak, allowing X-rays to escape



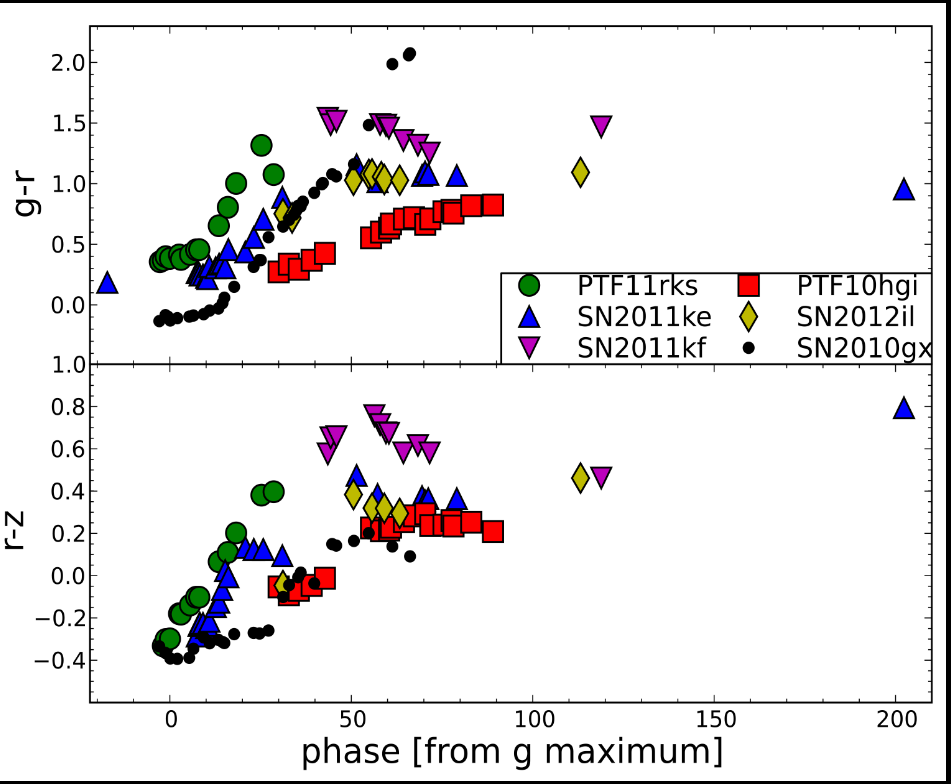
Optical/UV colors

- Excess UV from early ionization of He, O
- Sharp drops in optical from loss of thermalization

Dexter & Kasen, in prep.



Inserra+2013



Summary

- New classes of supernovae
  - (some) superluminous require new energy source
- Models: circumstellar interaction, neutron star or black hole central engines
- Observational signatures of central engine (esp. magnetar)
- Possible information about final stage of stellar evolution and/or compact object birth