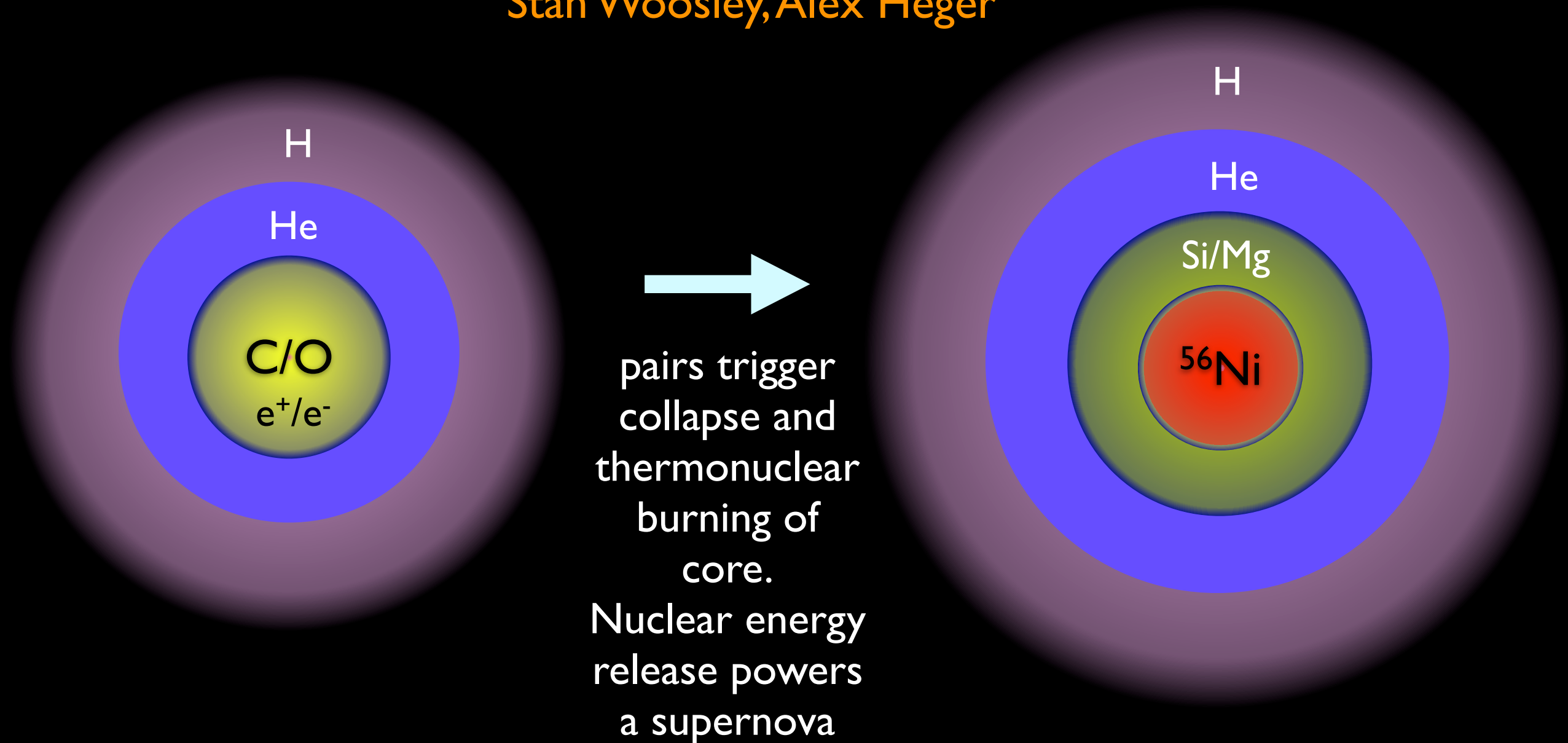


pair instability supernovae: light curves and spectra

Daniel Kasen

Stan Woosley, Alex Heger



pair instability and the fate of massive stars

Rakavy, Shaviv, and Zinamon (1967), Bakrat, Rakavy, and Sack (1967)
Bond, Arnett, and Carr (1984), Umeda and Nomoto (2001)
Heger and Woosley (2002), Scannapeico et al 2005, Woosley (2007)

main seq. mass	He core mass	supernova mechanism	^{56}Ni
$10 < M < 95$	$2 < M < 40$	Fe core collapse	$0 - 7 M_{\text{sun}}$
$95 < M < \sim 150$	$40 < M < 63$	pulsational pair instability + Fe core collapse	$\sim 0 M_{\text{sun}}$
$\sim 150 < M < 260$	$63 < M < 133$	pair instability	$0 - 50 M_{\text{sun}}$
$M > 260$	$M > 133$	black hole	$\sim 0 M_{\text{sun}}$

pair instability and the fate of massive stars

Rakavy, Shaviv, and Zinamon (1967), Bakrat, Rakavy, and Sack (1967)

Bond, Arnett, and Carr (1984), Umeda and Nomoto (2001)

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main seq. mass	He core mass	supernova mechanism	^{56}Ni
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complications/uncertainties

- *IMF* - did (*do?*) stars form in this mass range?
- *mass loss* - metallicity dependent or eta car?
- *convection & dredge up* - red or blue giant?
- *binarity* - lose hydrogen envelope?

modeling of explosive transients



stellar evolution (kepler)



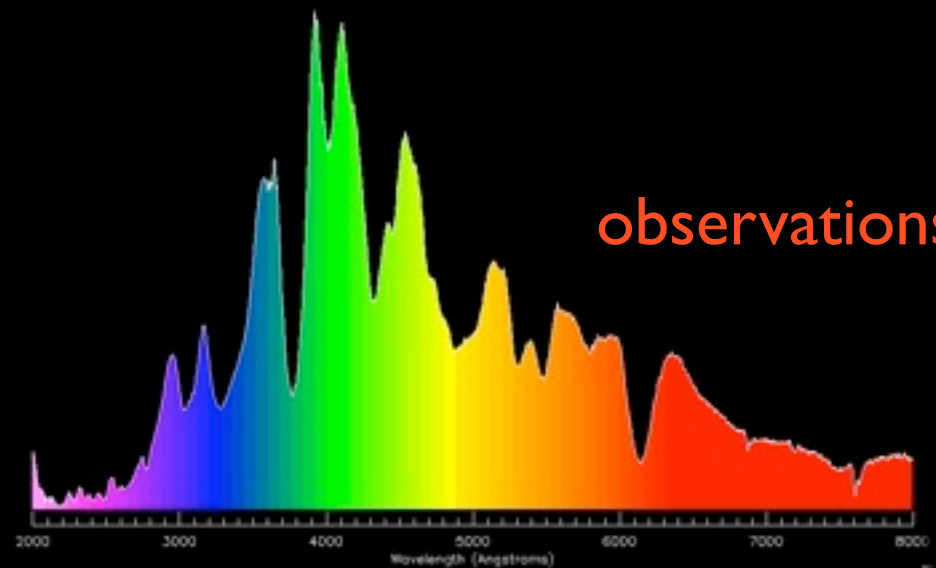
hydrodynamics,
nuclear burning

explosion (kepler/sedona)



expanding ejecta (sedona)

radiative transfer
thermodynamics
radioactive decay



synthetic spectra/light curves

3-D monte carlo radiative transfer

SEDONA code - Kasen et al. *ApJ* (2006), Kasen, *SciDAC* (2008)

stochastic propagation of particles and photons
(gamma-rays, X-rays, optical through infrared)

physical interactions

compton scattering

photoionization

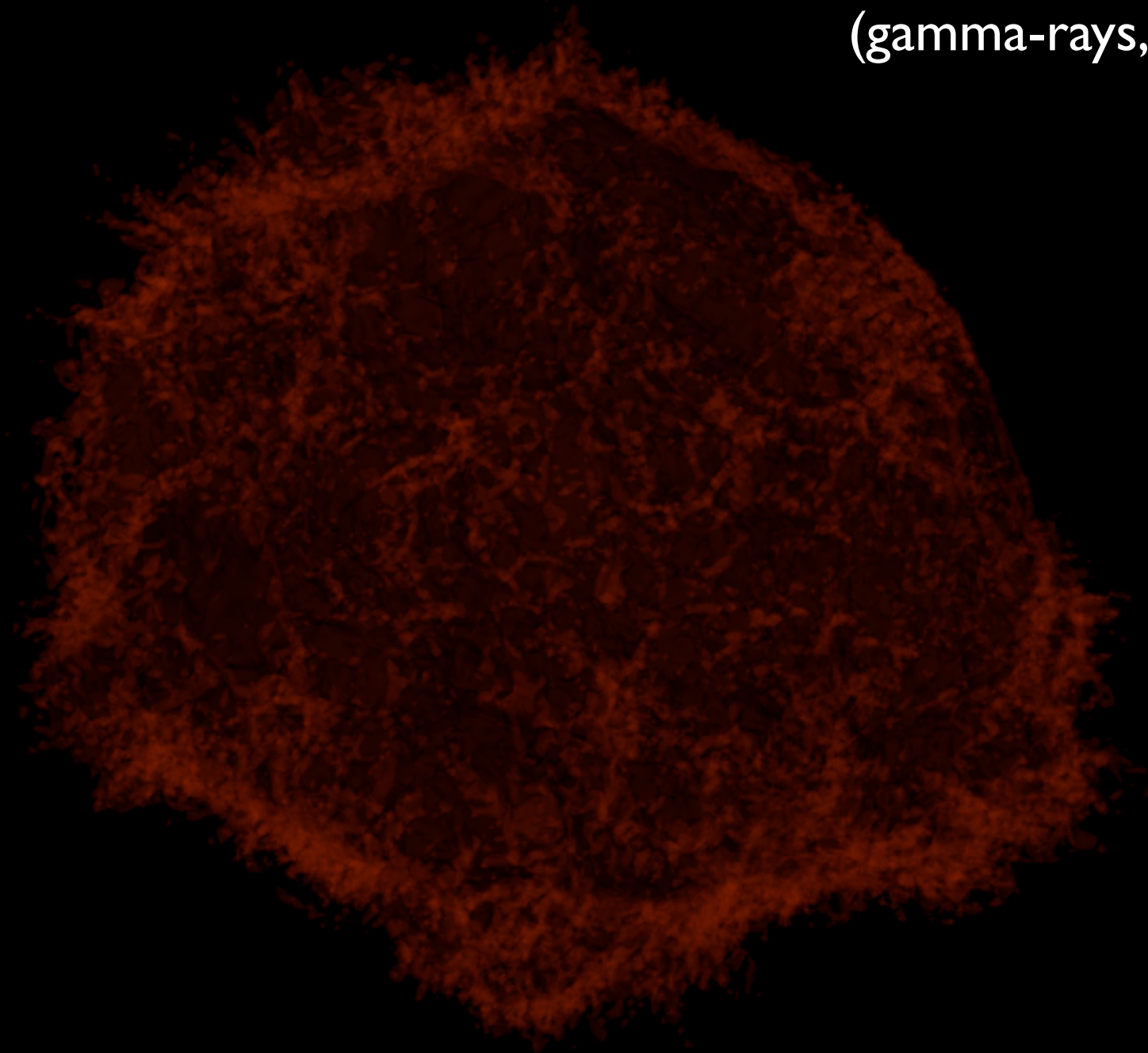
pair production

atomic line opacity

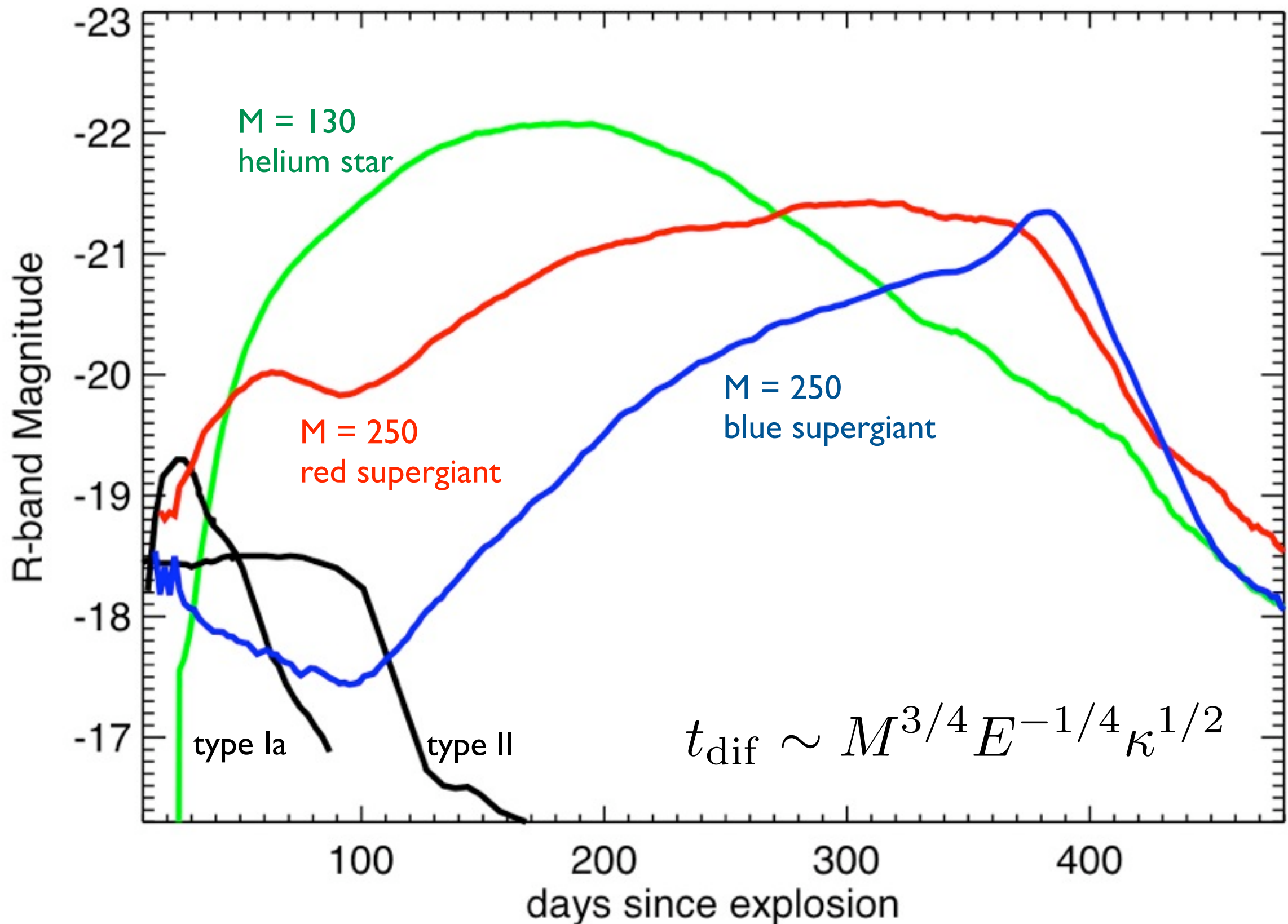
coupled to thermodynamics of
expanding, radioactive, ionizing gas

radiation-hydrodynamic capability
(in 1-D so far)

non equilibrium capability
(though most of these
models assume LTE)

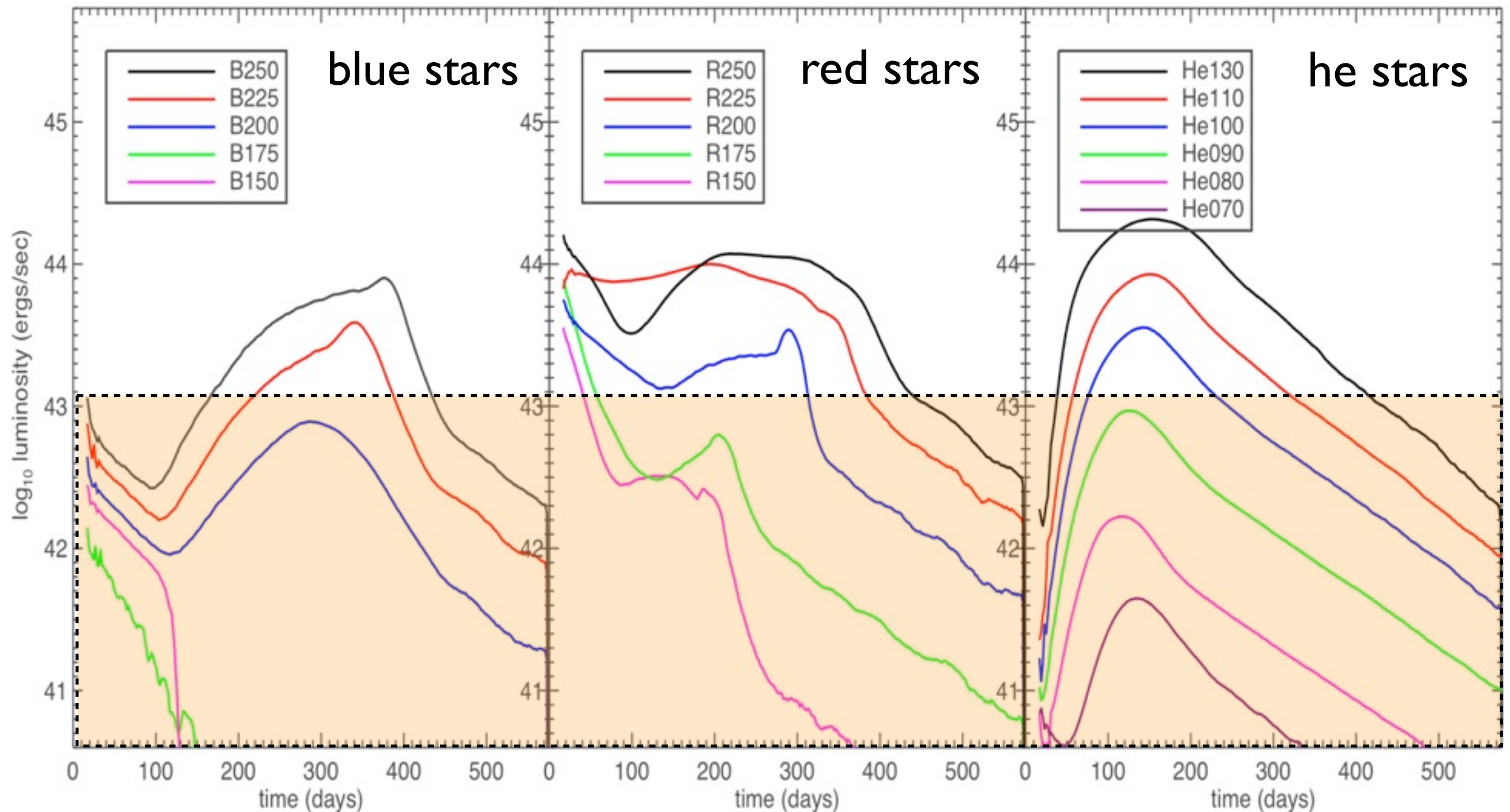


pair instability light curve models



pair instability model light curve survey

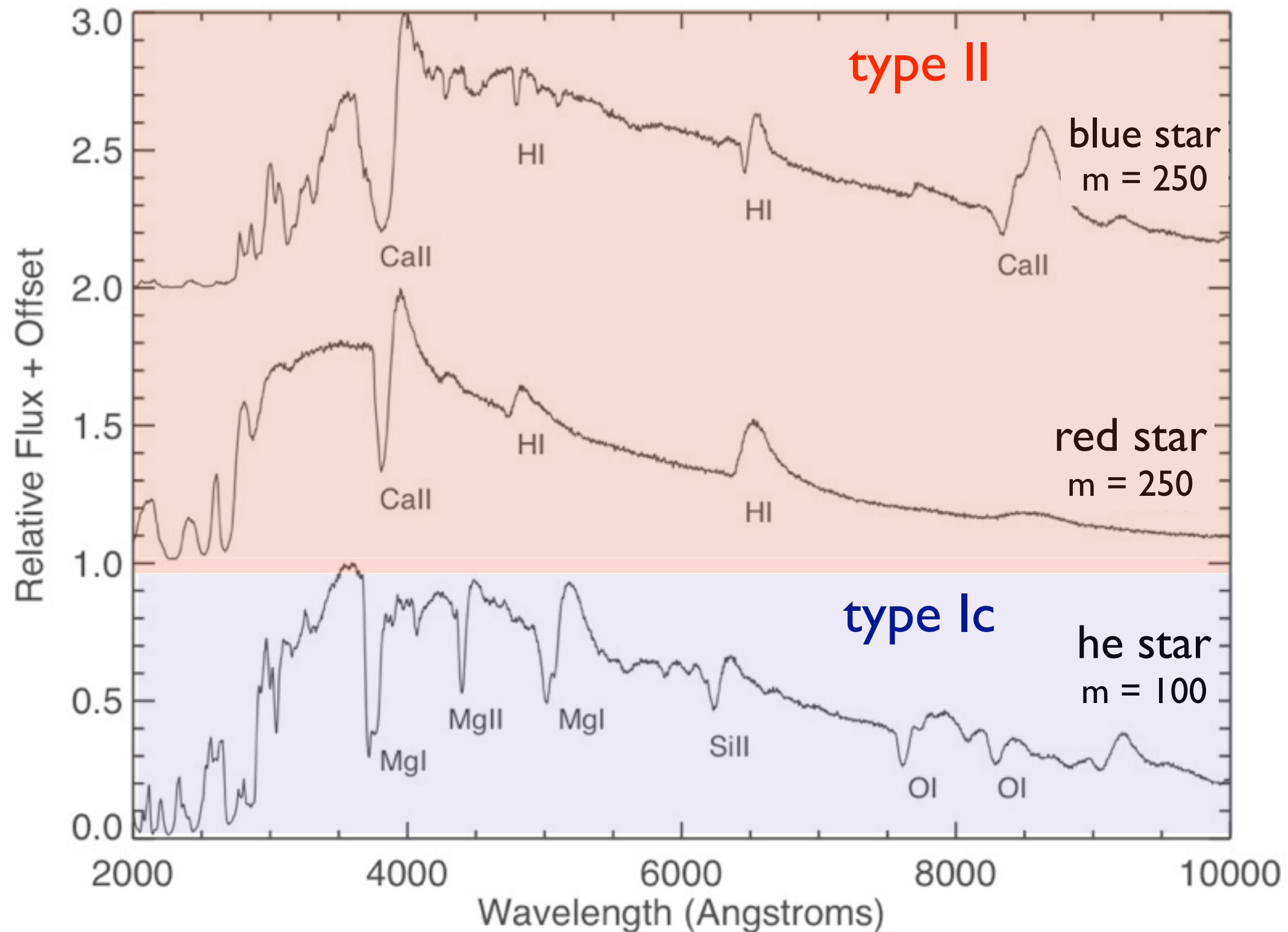
mass sequence masses from 150 - 250 M_{sun}



kasen, woosley, & heger 2010

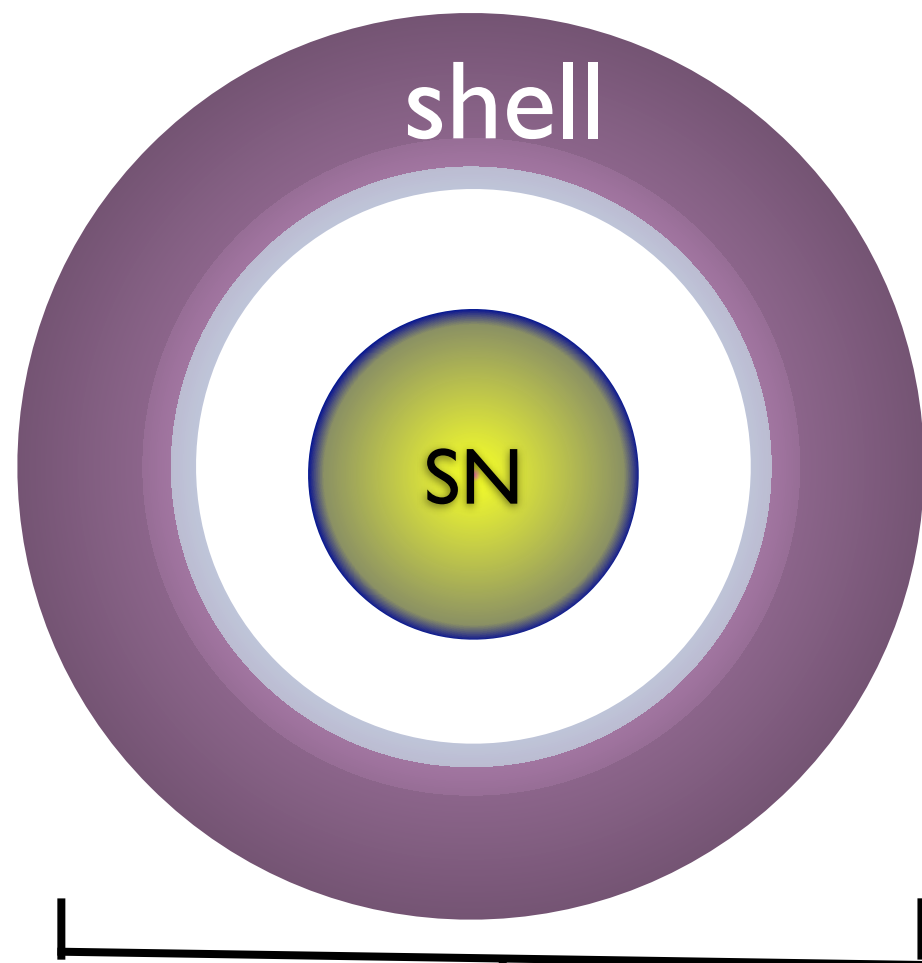
representative model spectra

at peak brightness, kasen, woosley, and heger (2010)

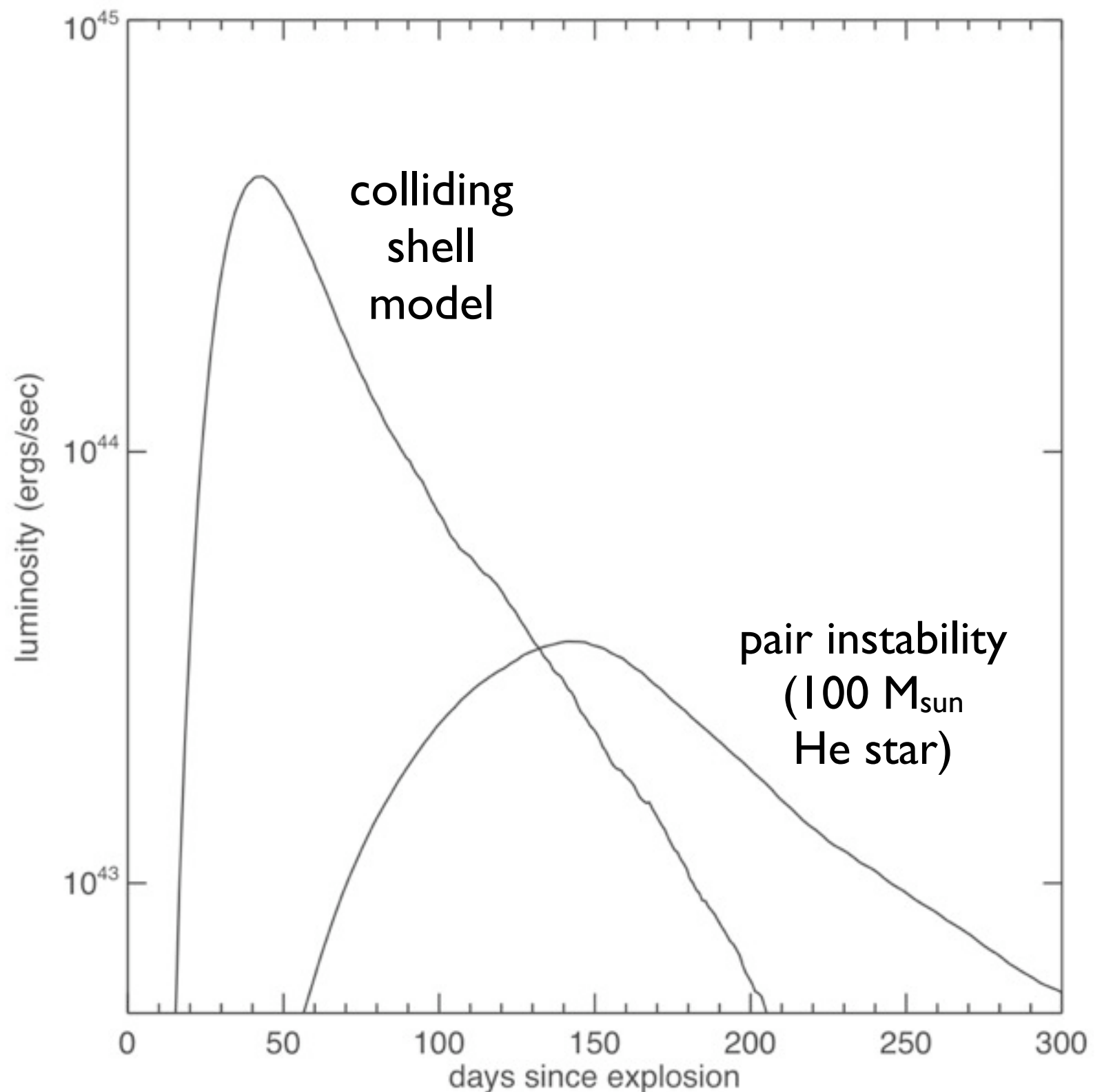


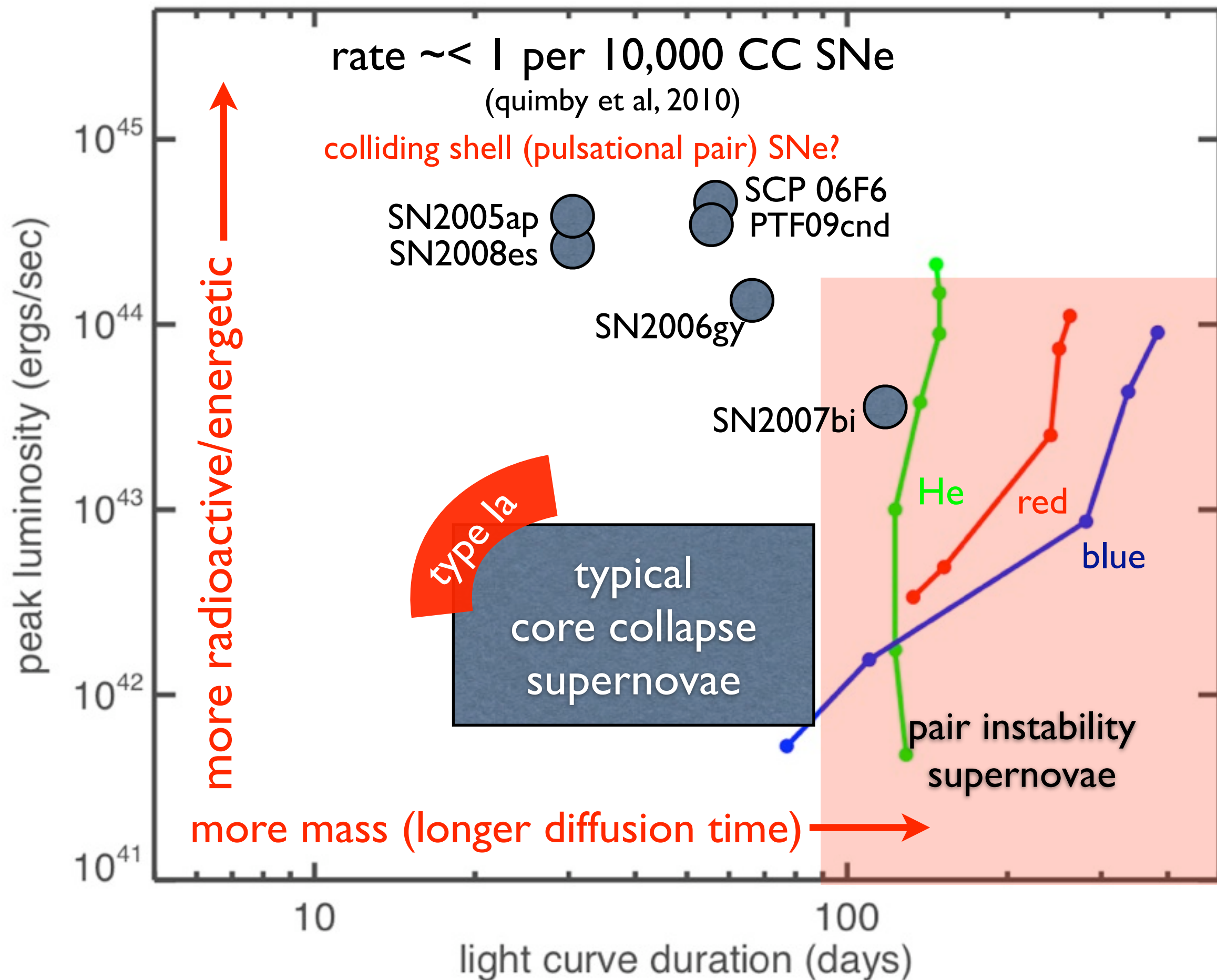
colliding shell supernovae

pulsational pair ($M < 150 M_{\text{sun}}$) or eta car-like LBV's



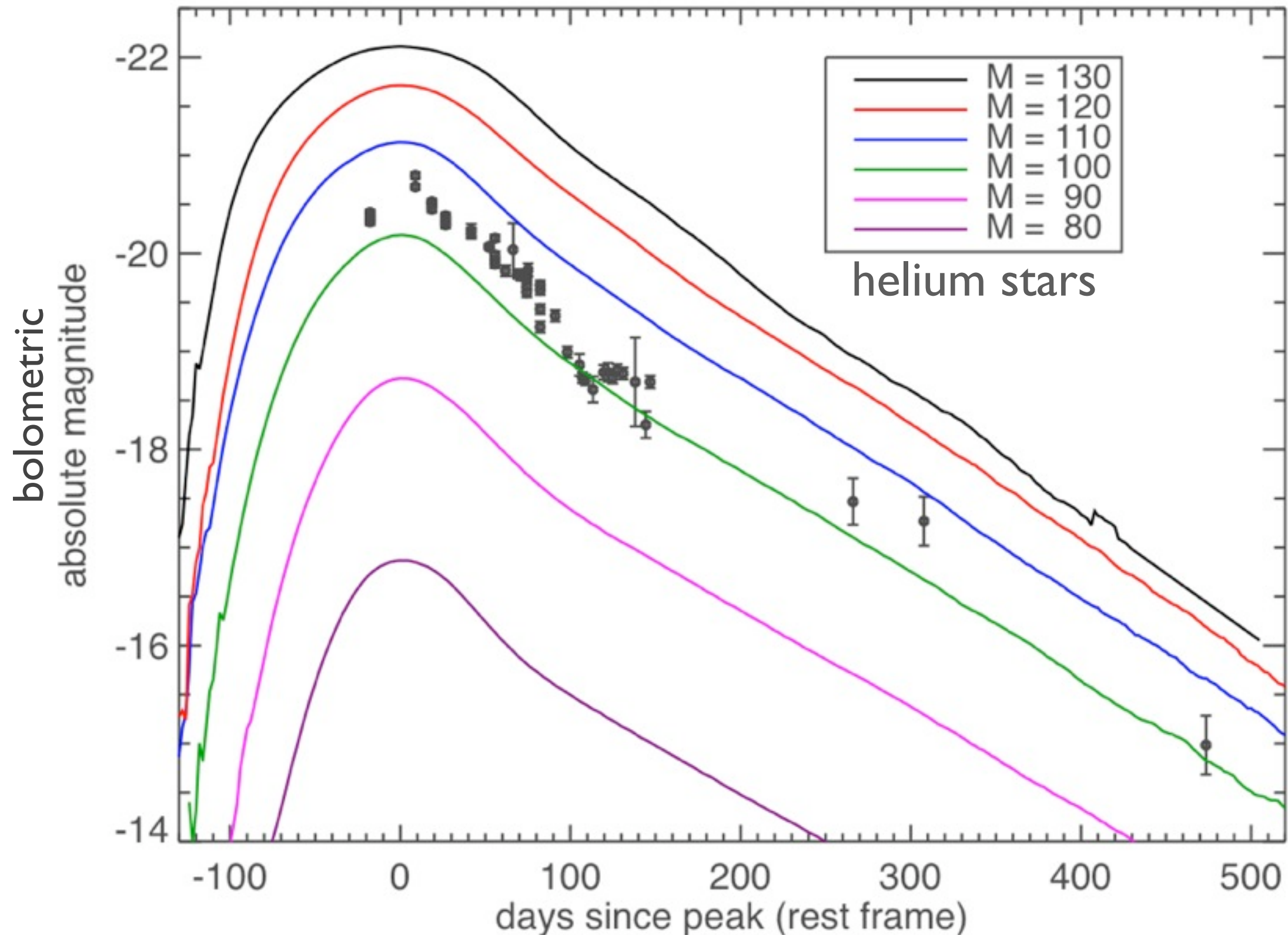
$R_{\text{shell}} \sim 10^{15} \text{ cm}$
interaction of
a supernova with
a previous ejected shell
produces bright emission
(e.g., woosley et al., 2007)





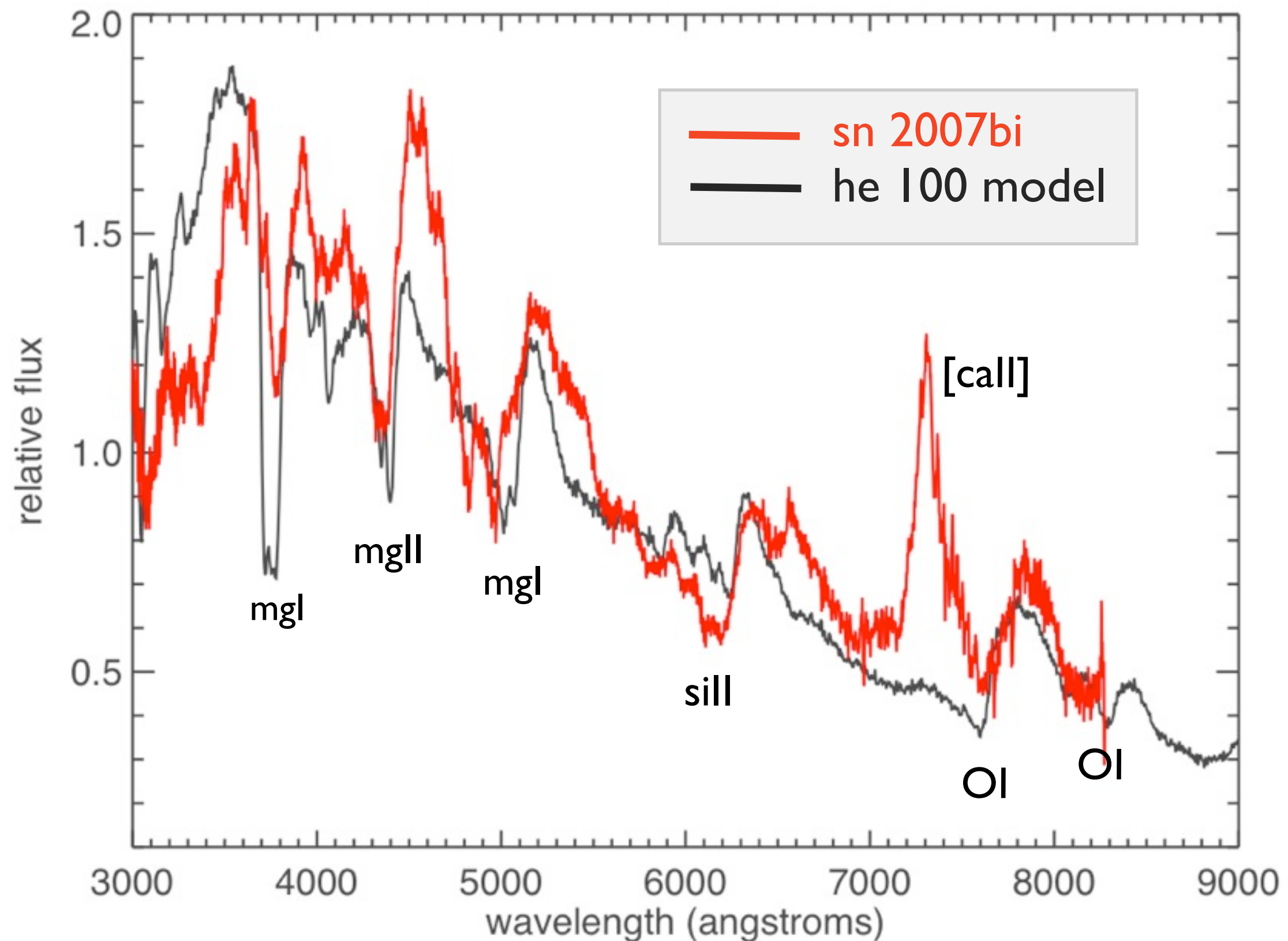
SN2007bi as a pair instability SN?

Gal Yam et al, *Nature* (2010)



SN2007bi spectrum comparison

gal-yam et al., (2010), kasen, woosley, and heger (2010)



alternatives to pair instability?

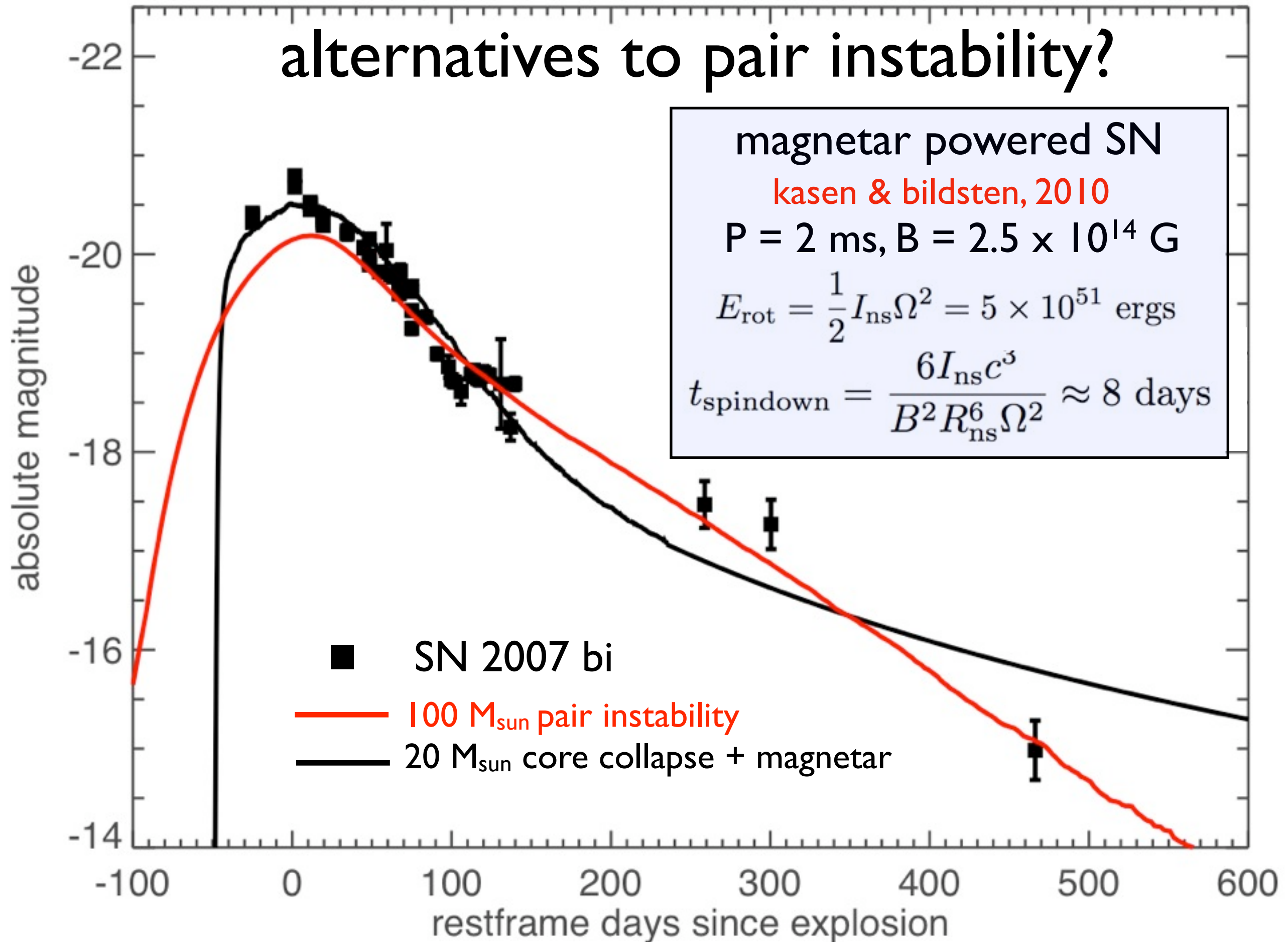
magnetar powered SN

kasen & bildsten, 2010

$$P = 2 \text{ ms}, B = 2.5 \times 10^{14} \text{ G}$$

$$E_{\text{rot}} = \frac{1}{2} I_{\text{ns}} \Omega^2 = 5 \times 10^{51} \text{ ergs}$$

$$t_{\text{spindown}} = \frac{6 I_{\text{ns}} c^3}{B^2 R_{\text{ns}}^6 \Omega^2} \approx 8 \text{ days}$$



SN2007bi as a pair instability supernova?

gal yam et al., 2010; young et al., 2010

observed light curves and spectra are well fit by a pair instability explosion of a bare helium core

$$M_{\text{progenitor}} = 240 M_{\text{sun}}$$

$$M_{\text{ejected}} = 100\text{-}110 M_{\text{sun}}$$

$$M_{56\text{Ni}} = 5 M_{\text{sun}}$$

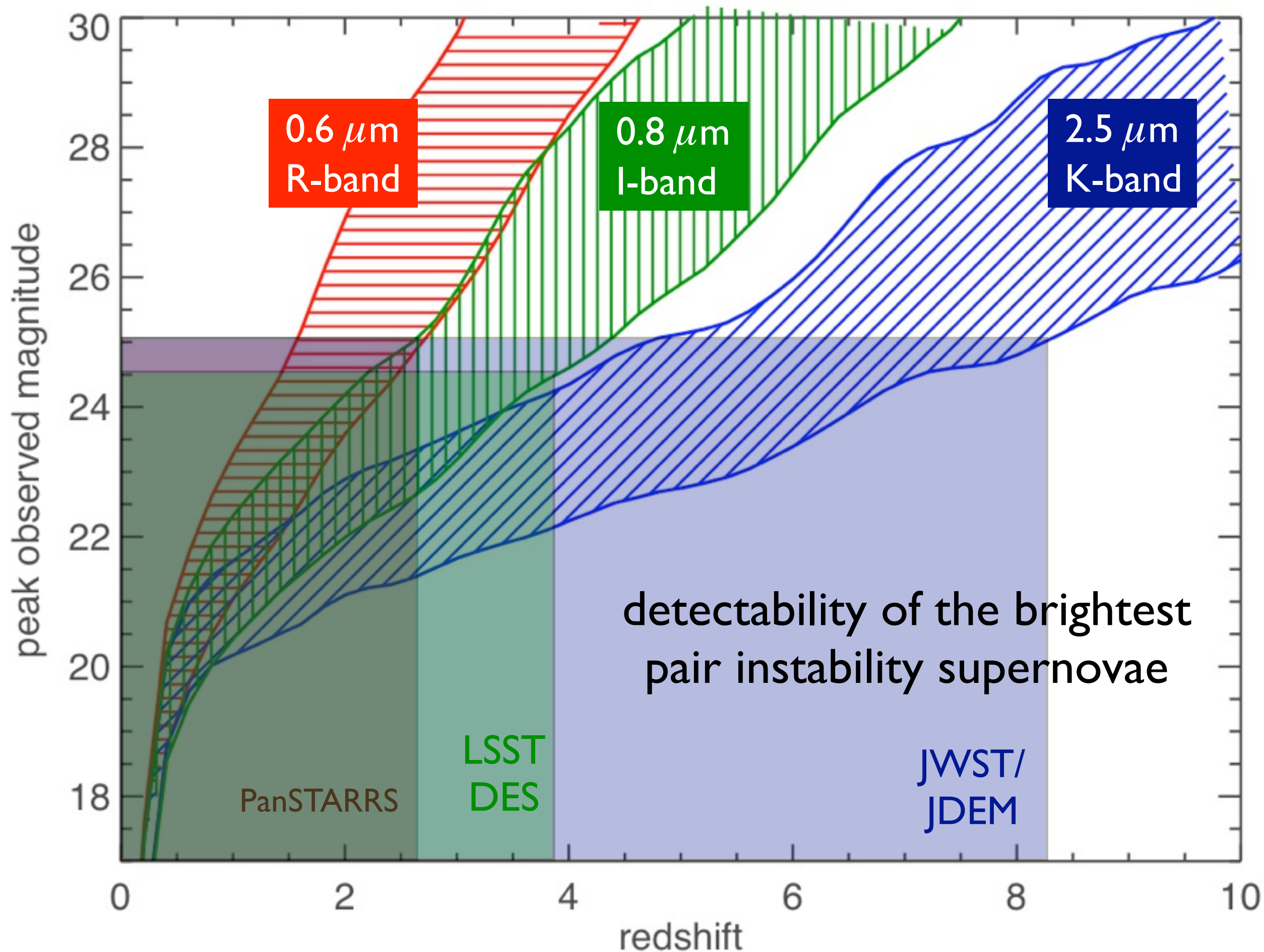
$$\text{energy} = 10^{53} \text{ ergs}$$

challenges, surprises?

relatively nearby $z = 0.127$ (dwarf galaxy host)

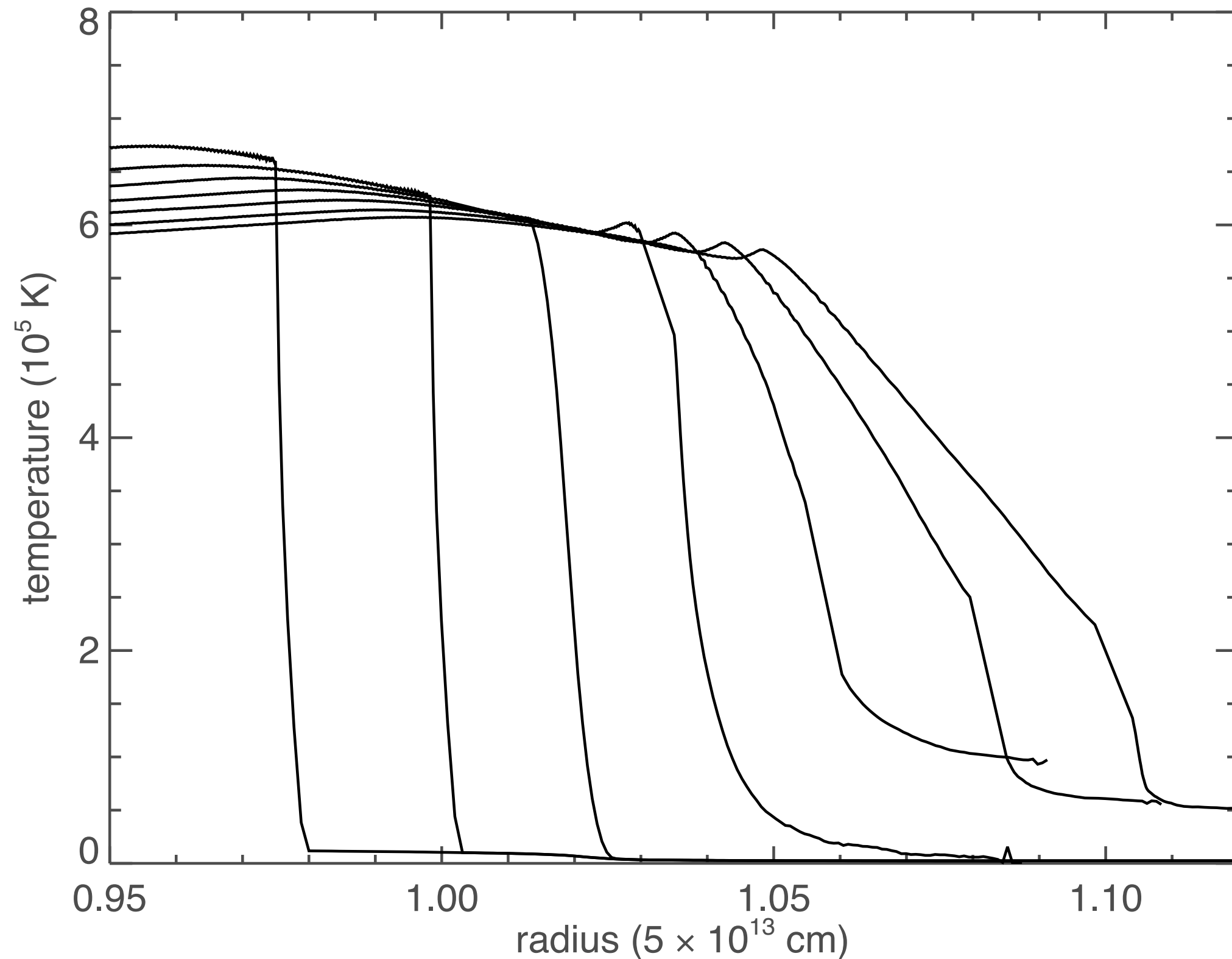
low, but not *that* low metallicity: $12 + \log[\text{O}/\text{H}] \sim 8.75$

SN lacks hydrogen envelope (binary interaction?)



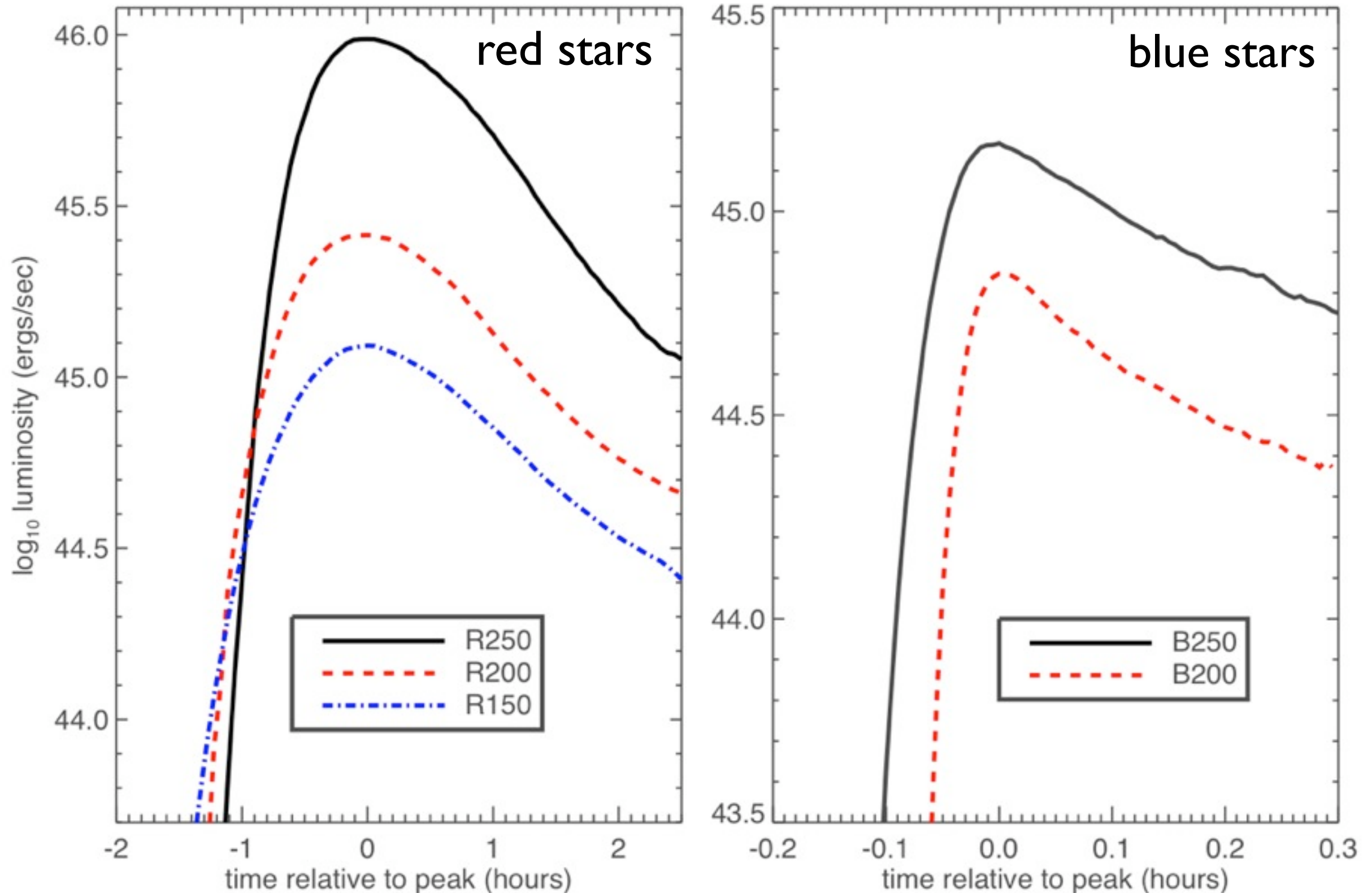
shock breakout - x-ray bursts

post-shock radiation escapes when diffusion time $\cong$ dynamical time



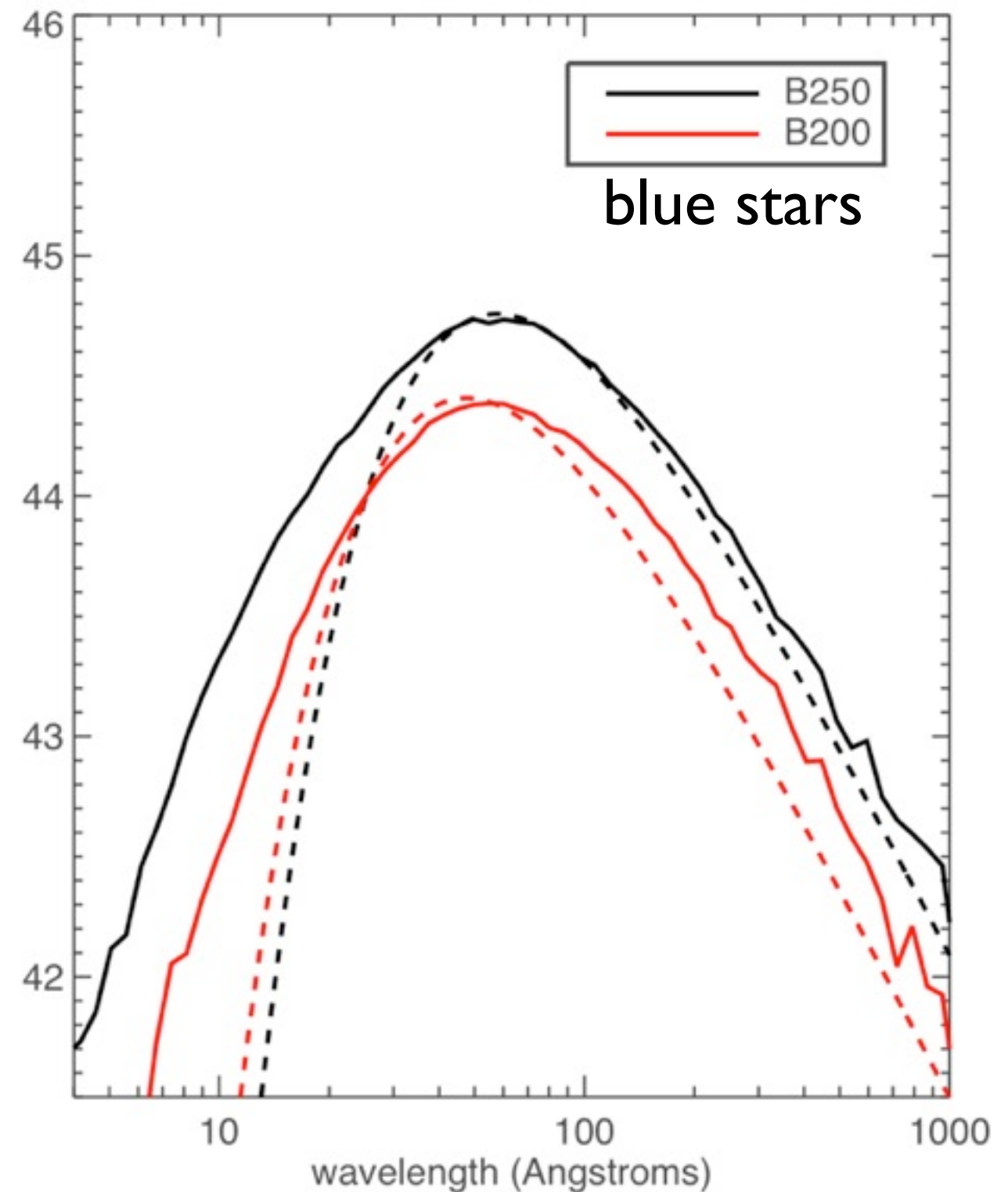
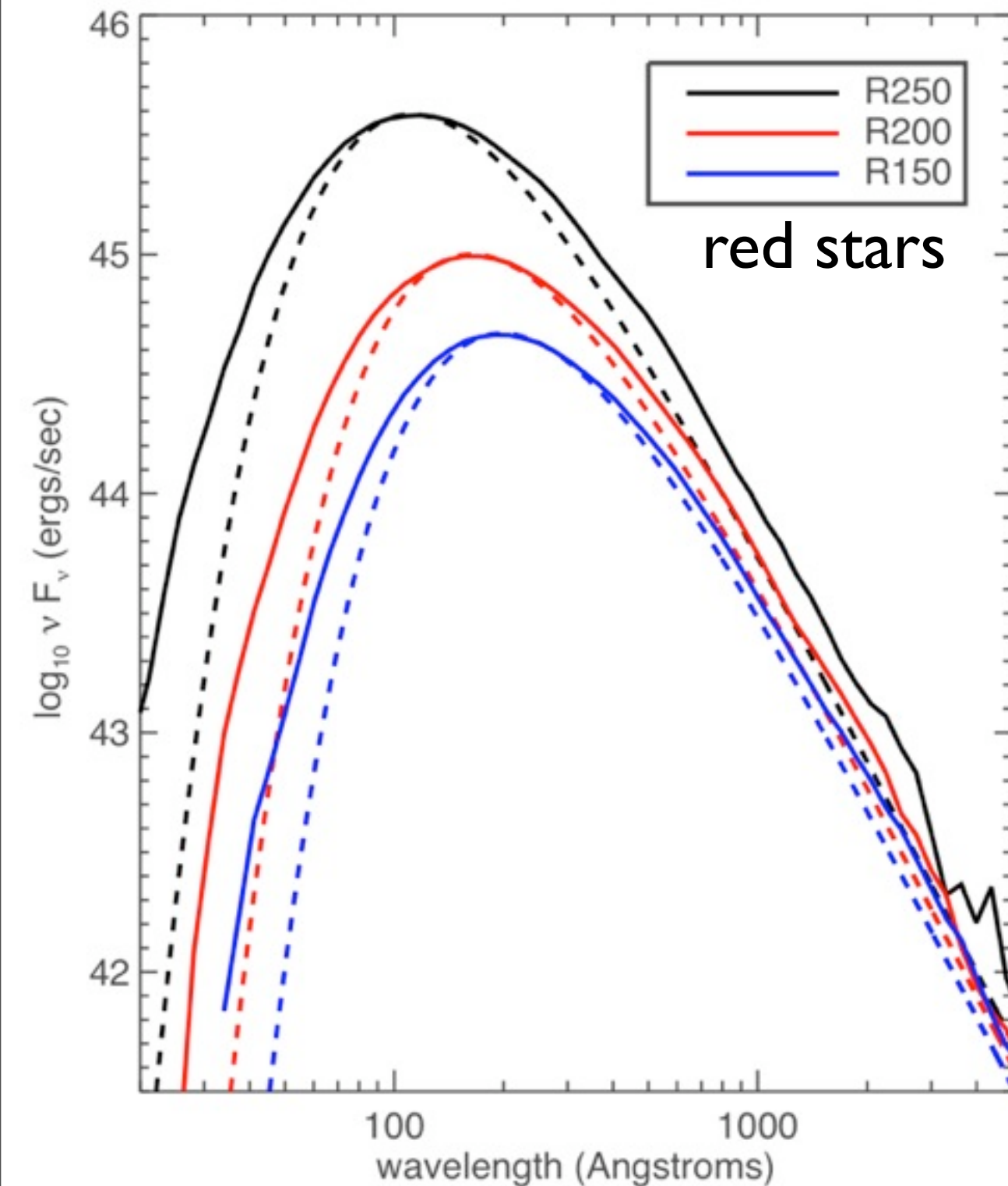
shock breakout bursts - light curves

multi-wavelength multi-angle I-D rad-hydro calculations (kasen et al., in prep)



shock breakout bursts - spectra

non-equilibrium rad-hydro calculations (kasen et al., in prep)



detectability of shock breakout peak

