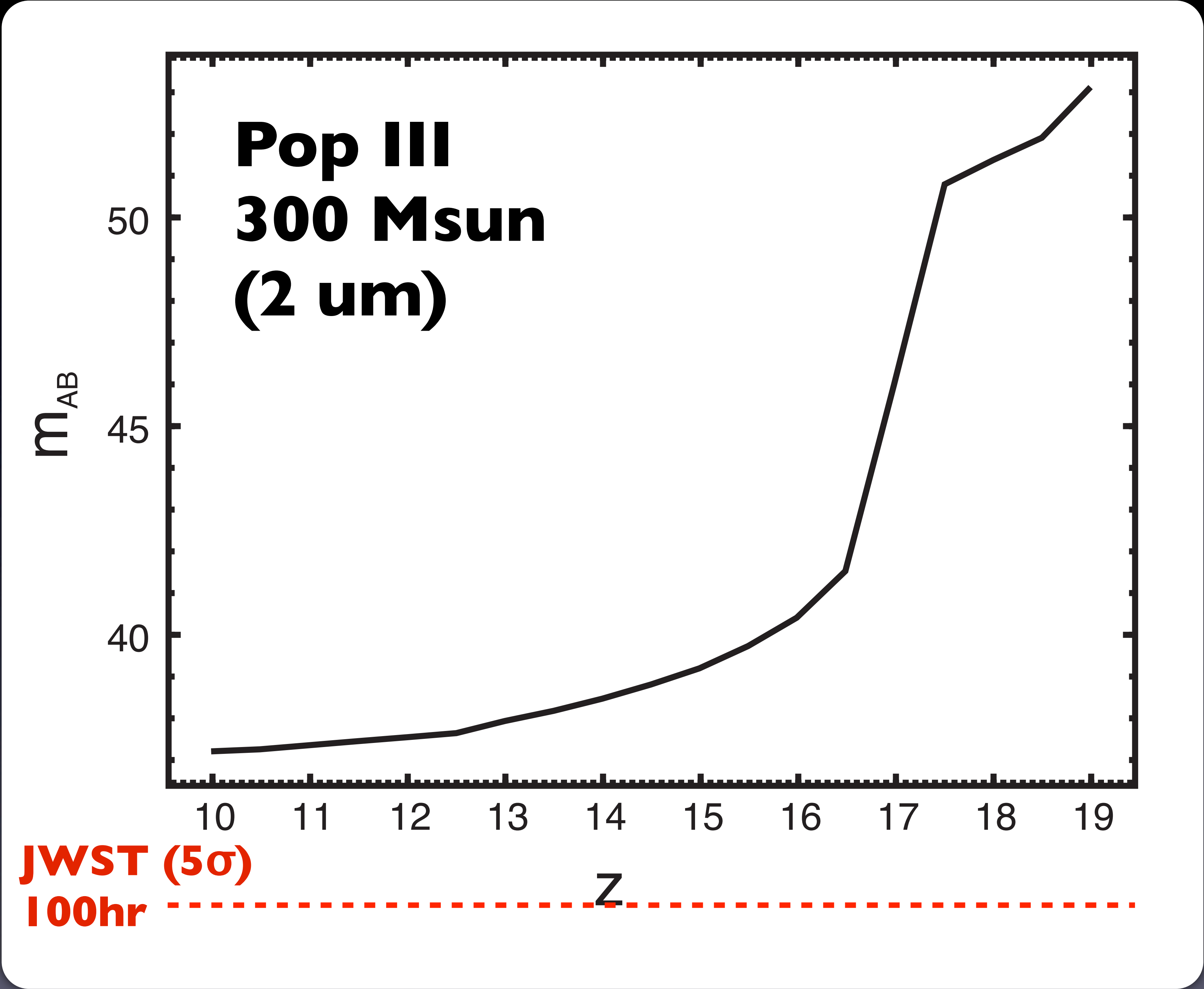
Toward Detection of First Supernovae

- 初代星超新星の検出に向けて -

Masaomi Tanaka
田中 雅臣

First Star

L ~ 10^6 - $10^{7.5}$ Lsun (for 100-1000 Msun)



Taniguchi-san's talk
(e.g., Bromm+01, Stiavelli+09, Bromm & Yoshida 11, Rydberg+11)

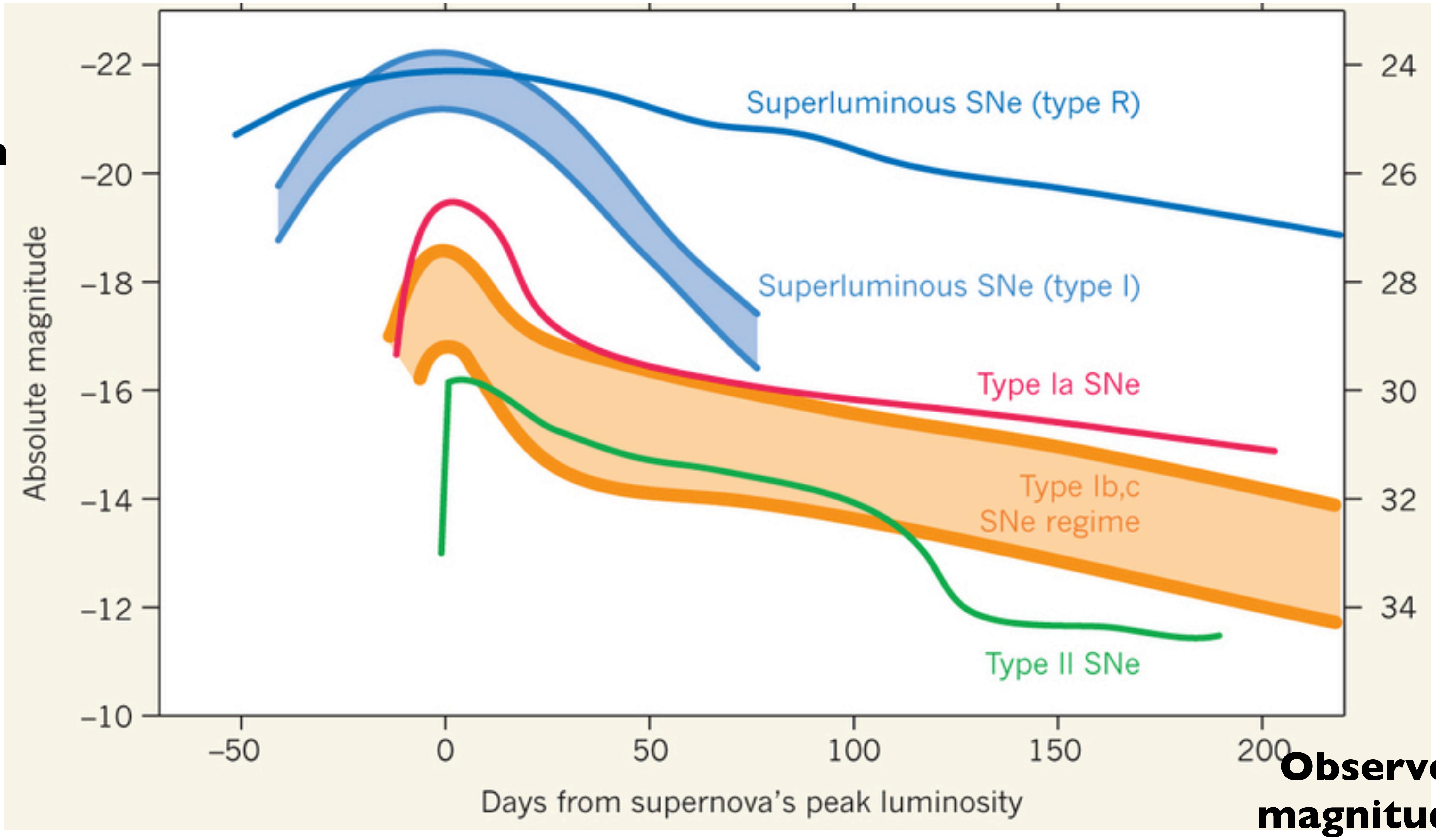
First Supernova   L ~ 10^{8-10} Lsun

10^{10} Lsun

10^9 Lsun

10^8 Lsun

10^7 Lsun

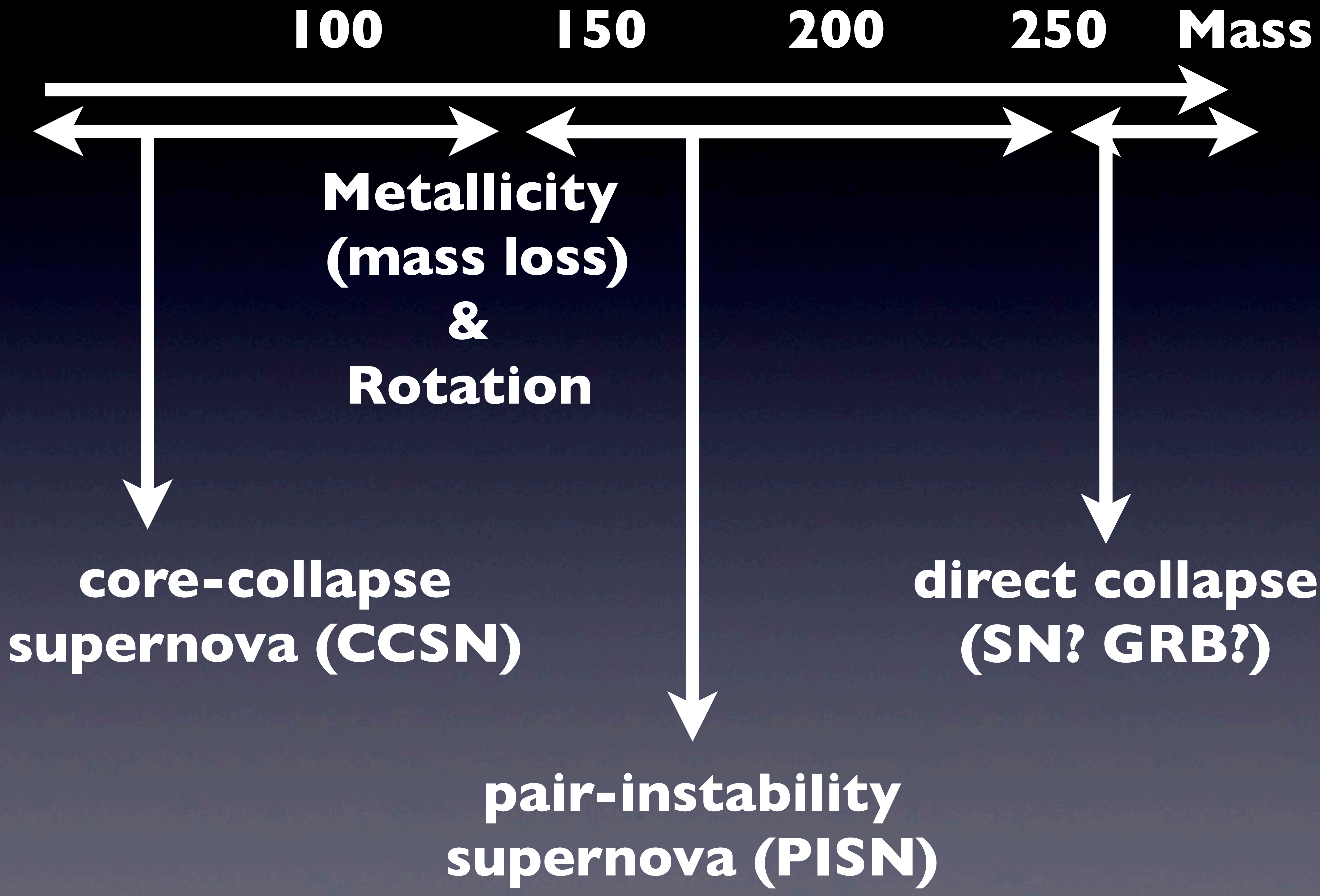


Observed magnitude @ z = 4

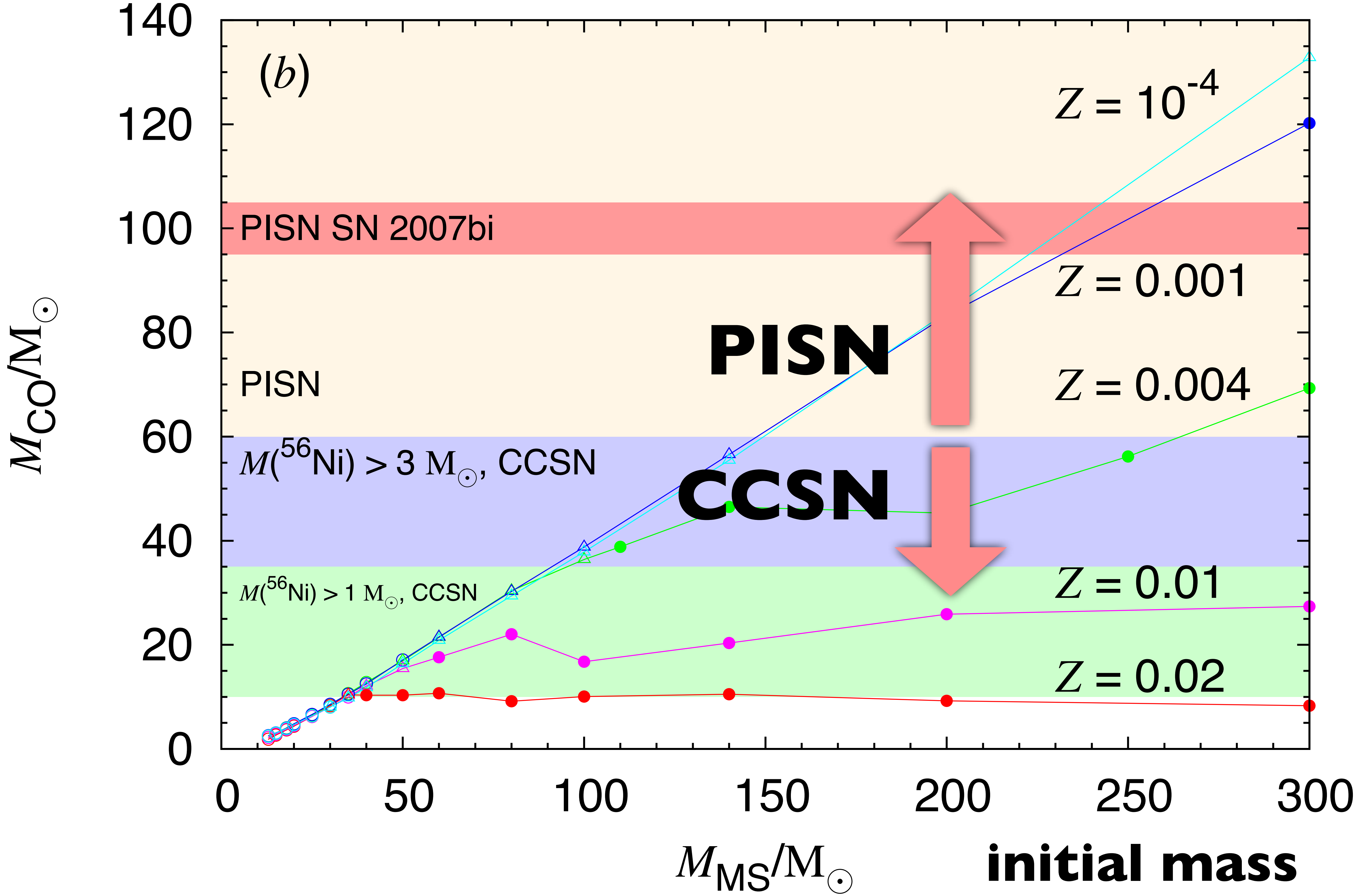
Smartt 2012

Toward Detection of First Supernovae

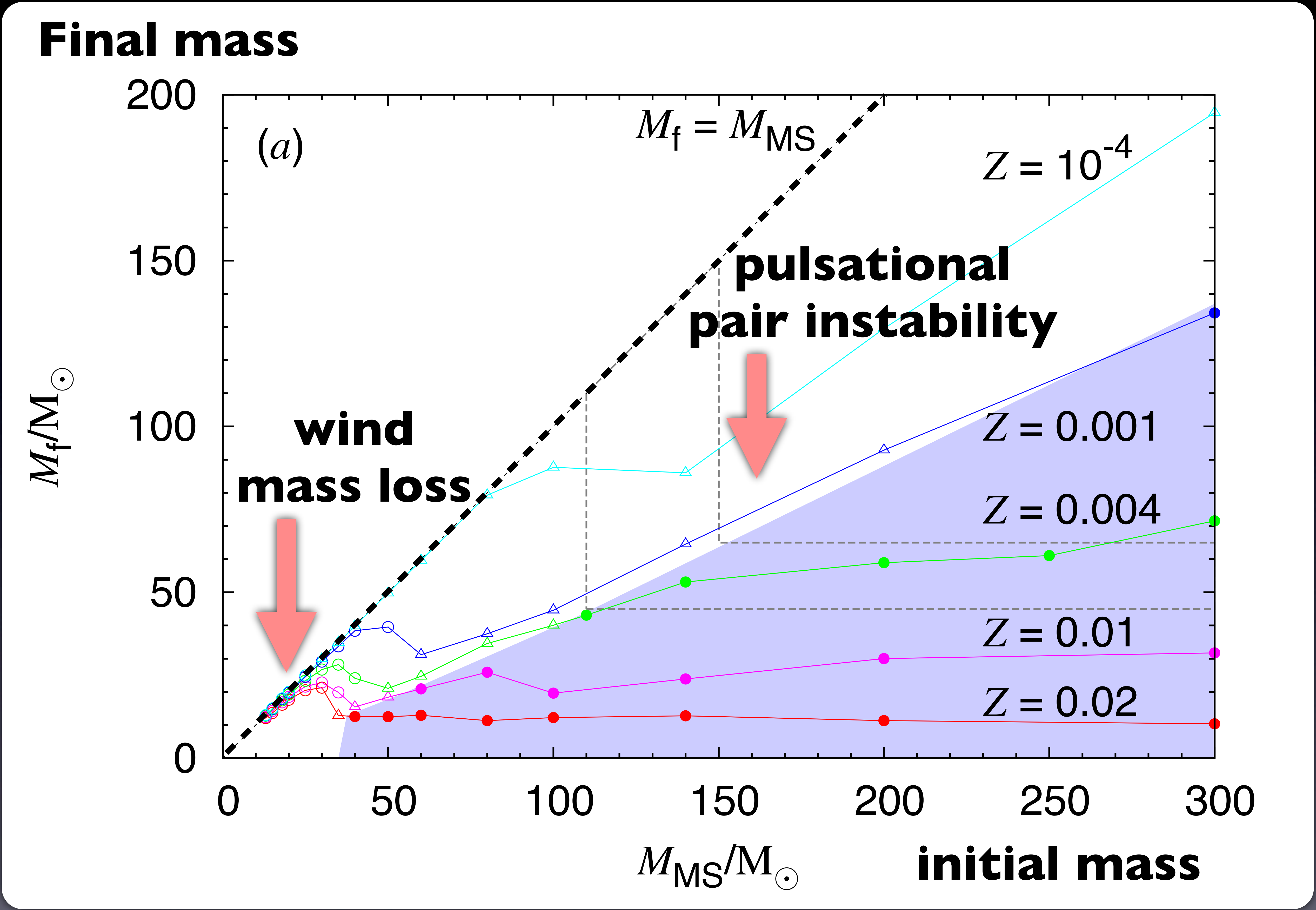
- **Massive star evolution and supernova emission**
- **Superluminous supernova**
- **Survey for first supernovae**


100
150
200
250
Mass
Metallicity
(mass loss)
&
Rotation
core-collapse
supernova (CCSN)
pair-instability
supernova (PISN)
direct collapse
(SN? GRB?)

Final CO core mass



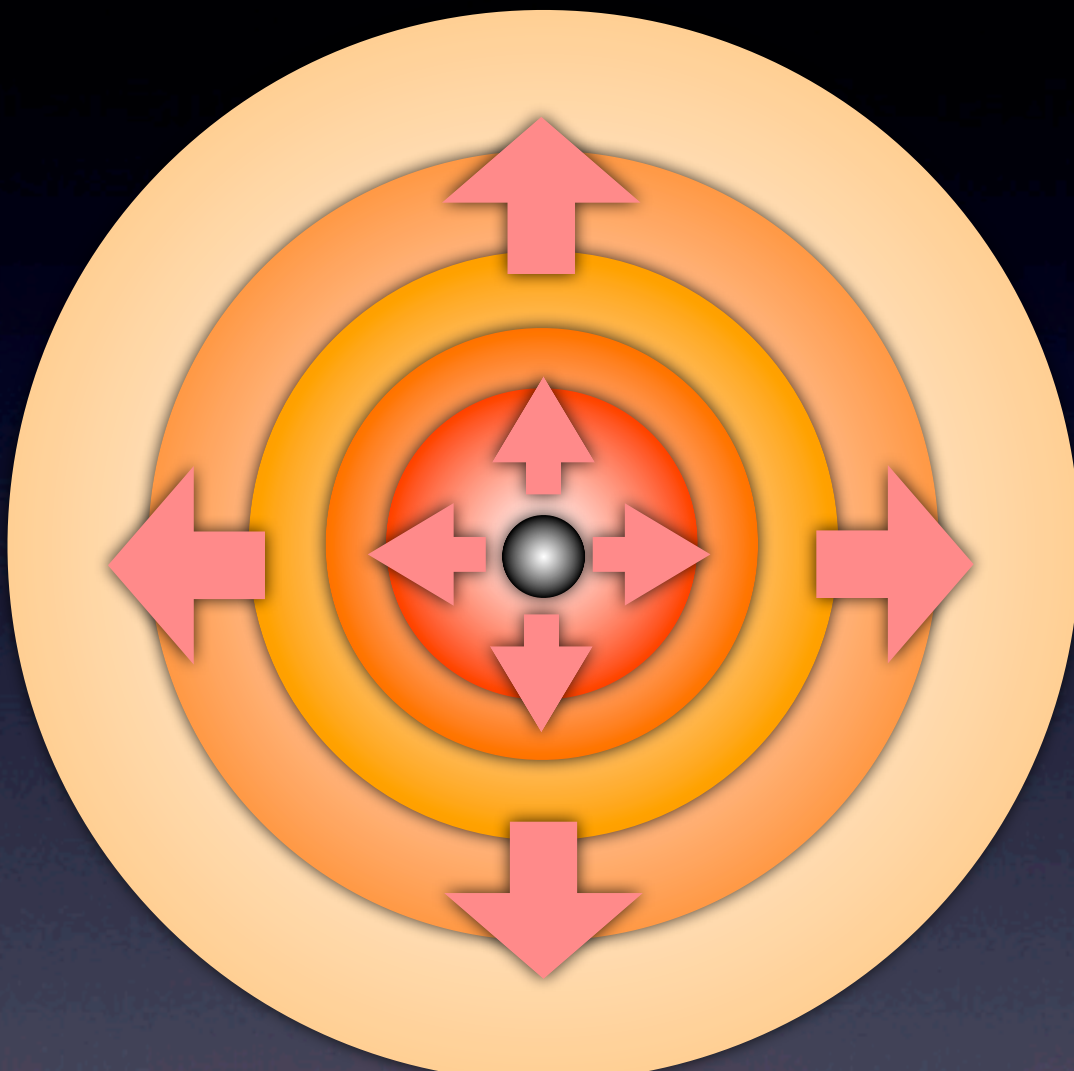
Yoshida+14, see Yoon+12 and Chatzopoulos+12 for the effect of rotation



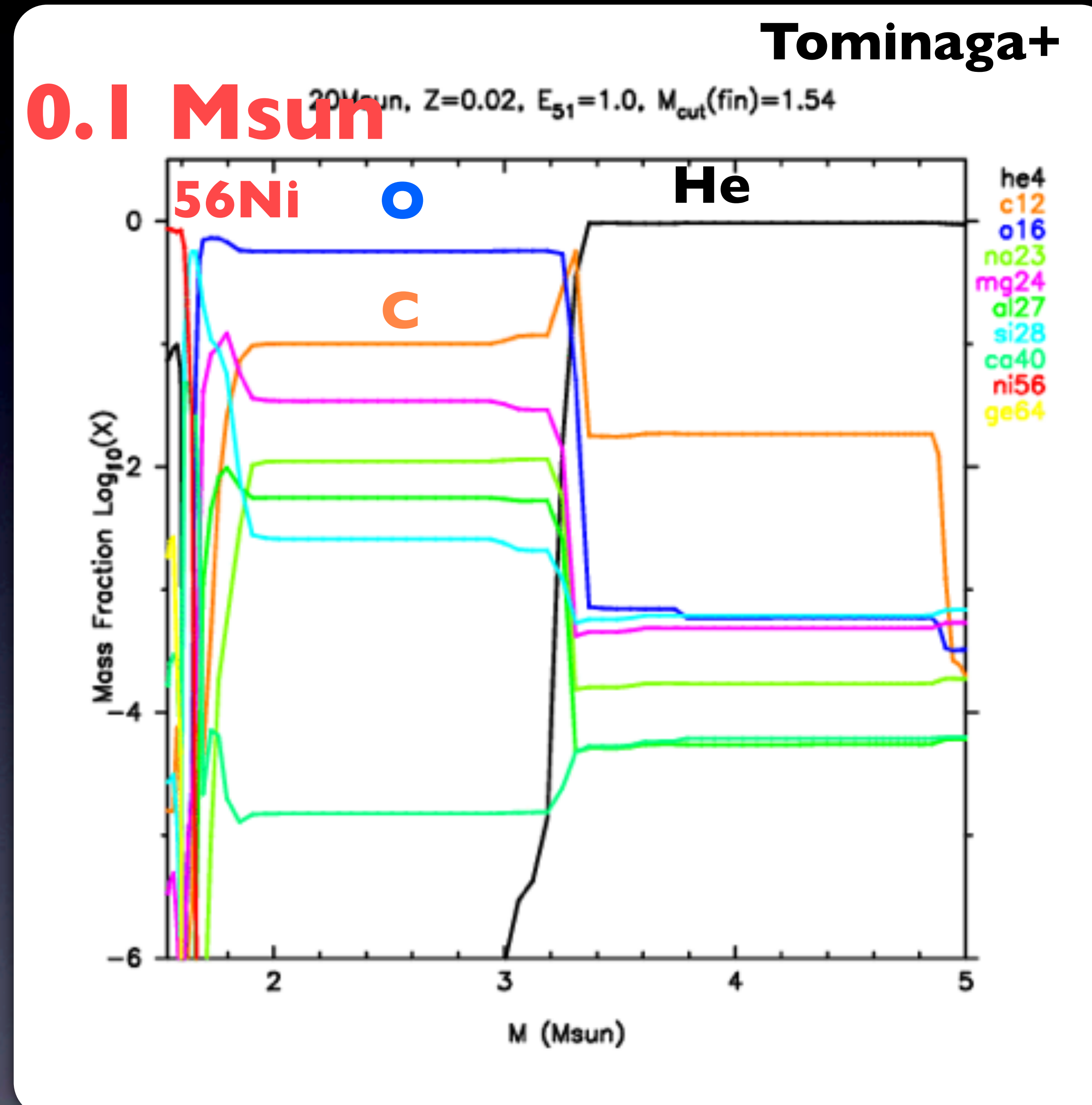
Final mass
200
150
100
50
0
(a)
$M_f = M_{MS}$
$Z = 10^{-4}$
pulsational
pair instability
$Z = 0.001$
$Z = 0.004$
$Z = 0.01$
$Z = 0.02$
wind
mass loss
$M_f/M_\odot$
0
50
100
150
200
250
300
$M_{MS}/M_\odot$
initial mass

Yoshida+14

Core-collapse supernova

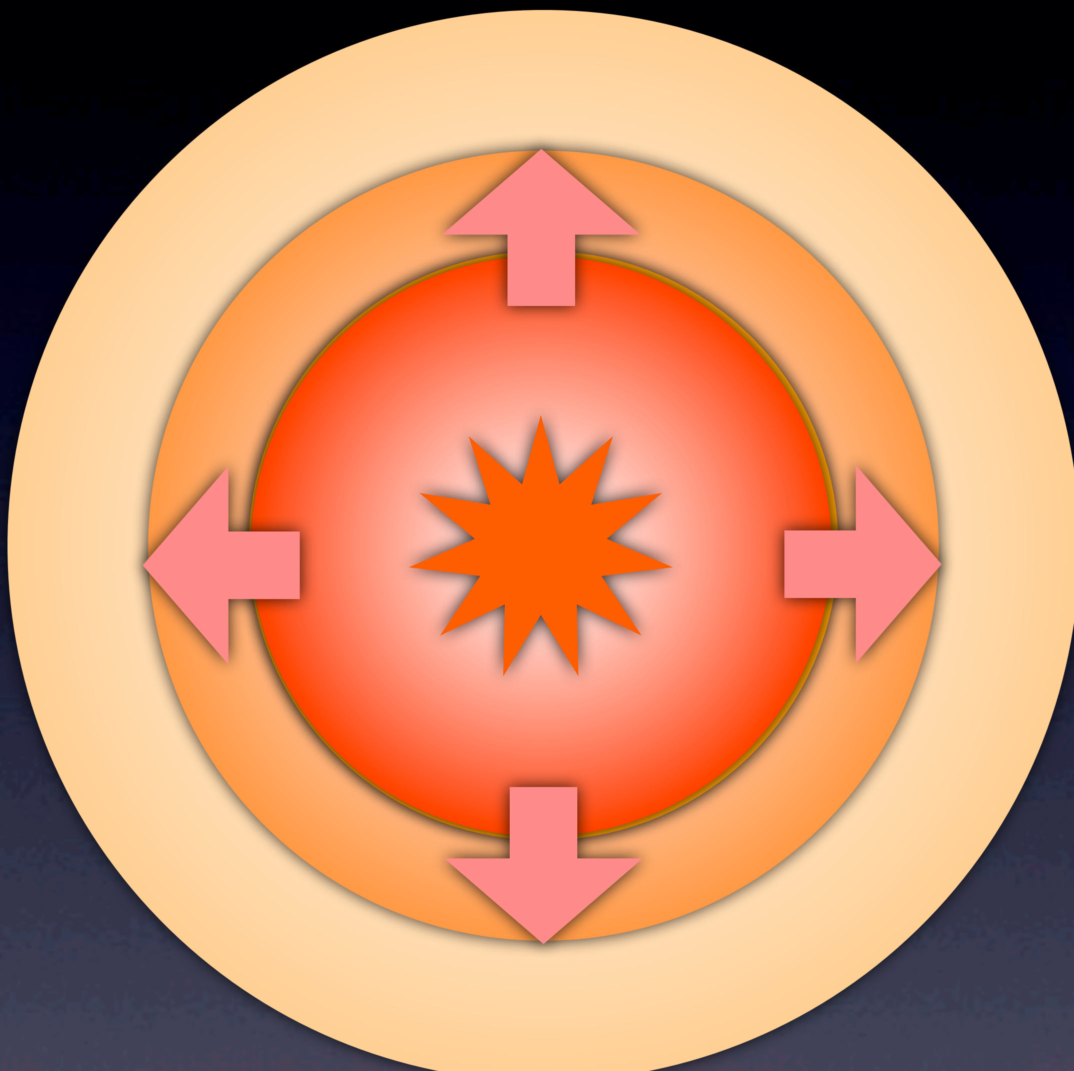


Shock breakout
(~ 1d for red supergiant)
$E_k \sim E_{int} \sim 10^{51}$ erg

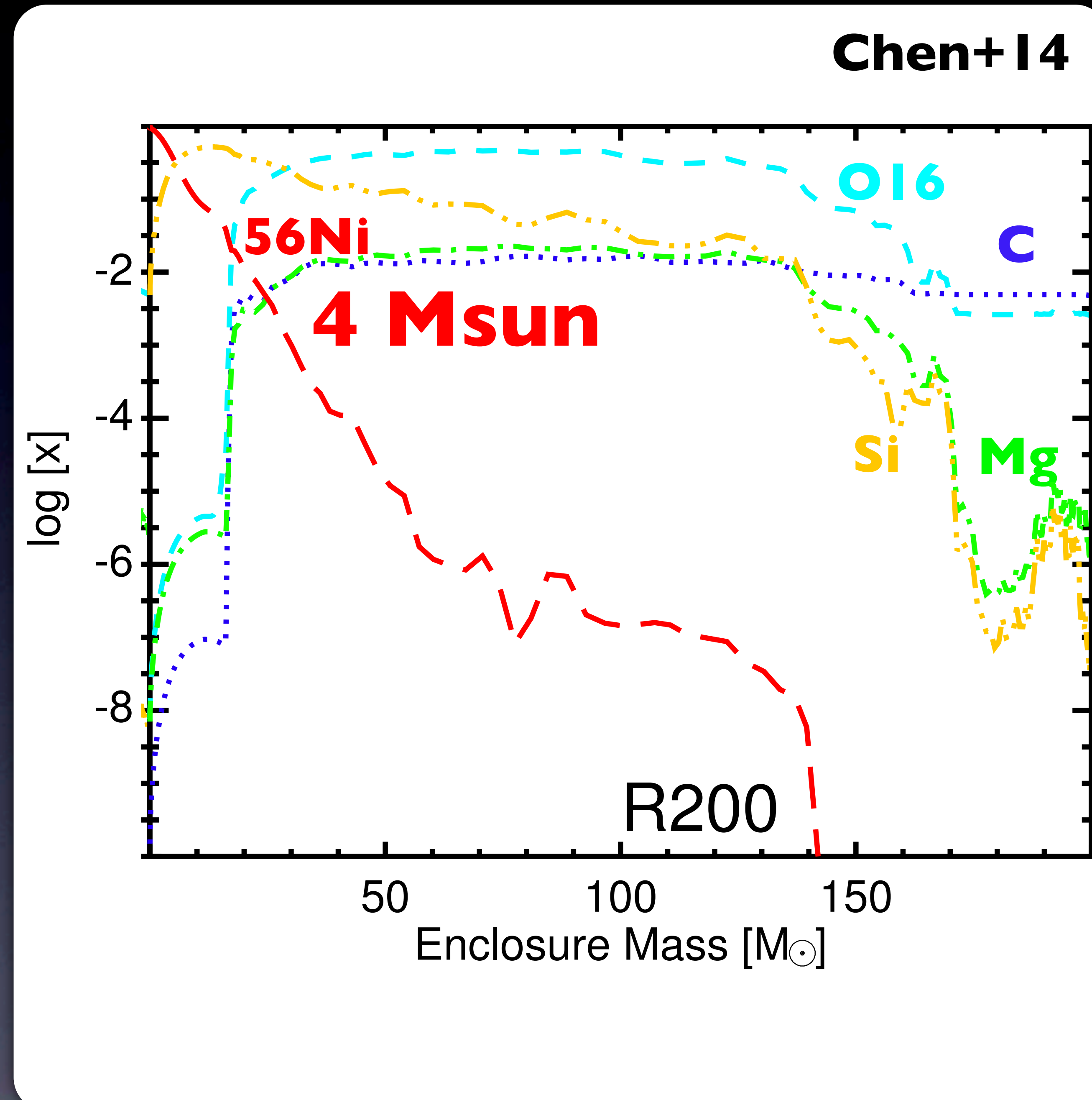


Element distribution
after explosion

Pair-instability supernova
(Takahashi-san's talk)



Explosive O/Si burning
$E_{nuc} \sim 10^{53}$ erg
$E_k \sim 10^{52}$ erg



Element distribution after explosion

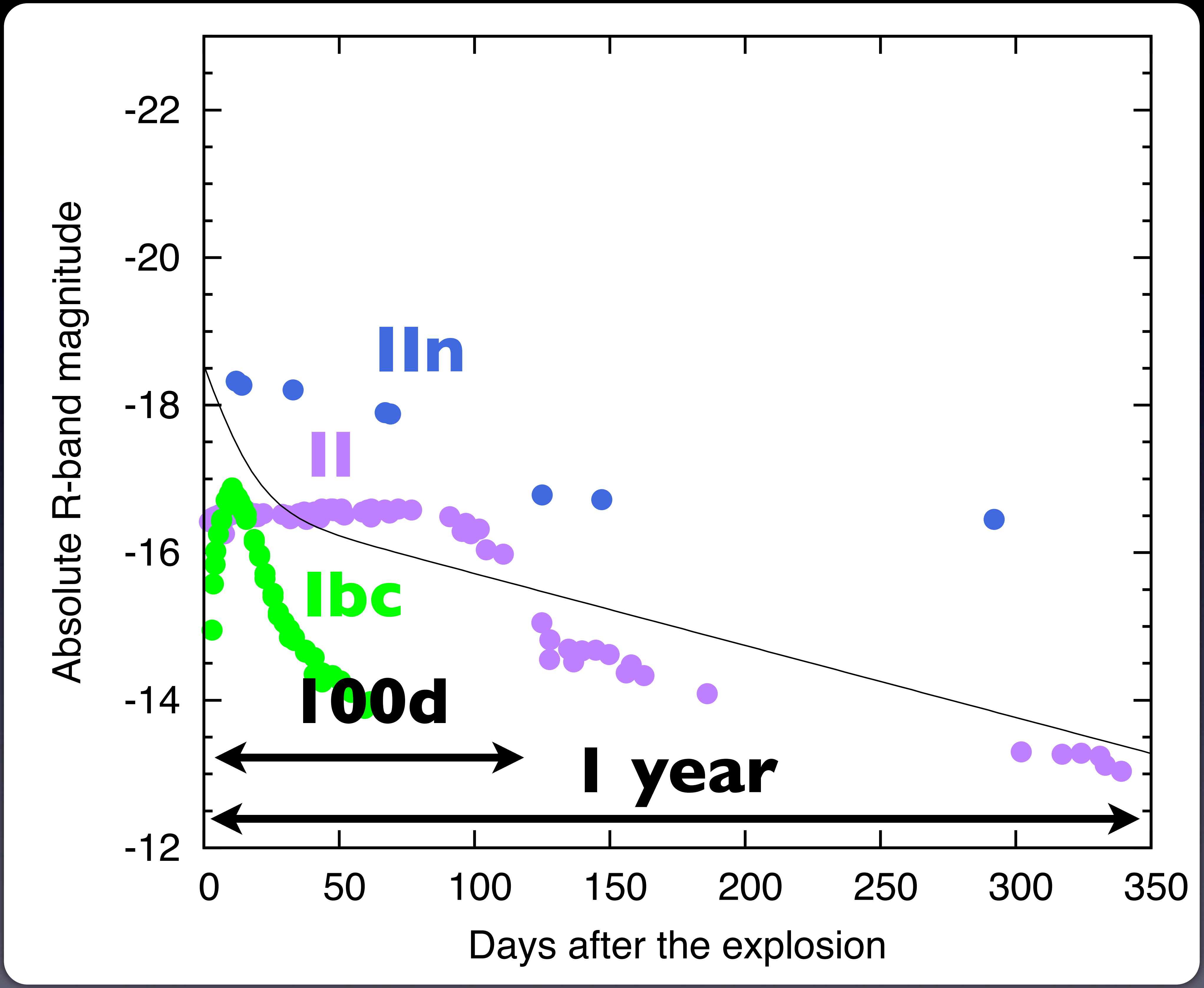
10^{11} Lsun

10^{10} Lsun

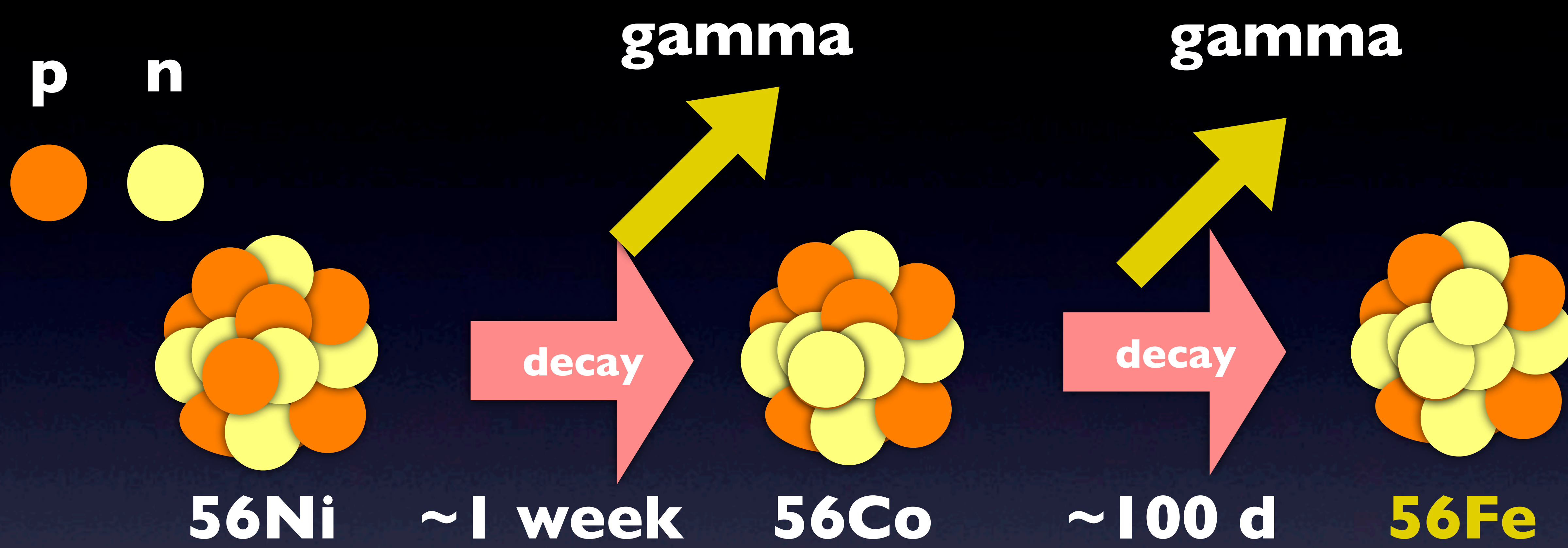
10^{9} Lsun

10^{8} Lsun

10^{7} Lsun



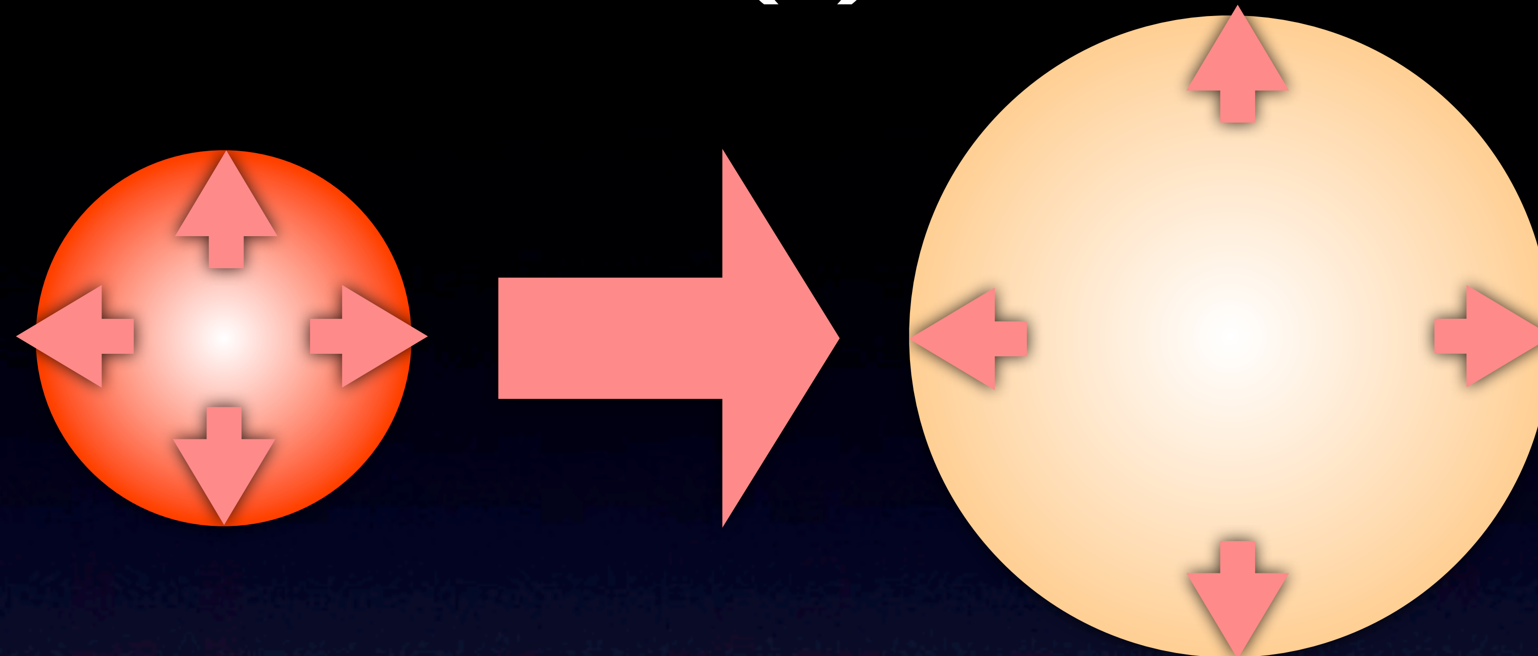
Energy source of SN (I) radioactivity



$$L = \left[1.7 \times 10^9 e^{(-t/8.8\mathrm{d})} + 3.8 \times 10^8 e^{(-t/111\mathrm{d})}\right] \left(\frac{M_{56\mathrm{Ni}}}{0.1 M_\odot}\right) L_\odot$$

0.1 Msun ejection => ~ 5 x 10^8 Lsun @ 20d

Energy source of SN (2) internal energy



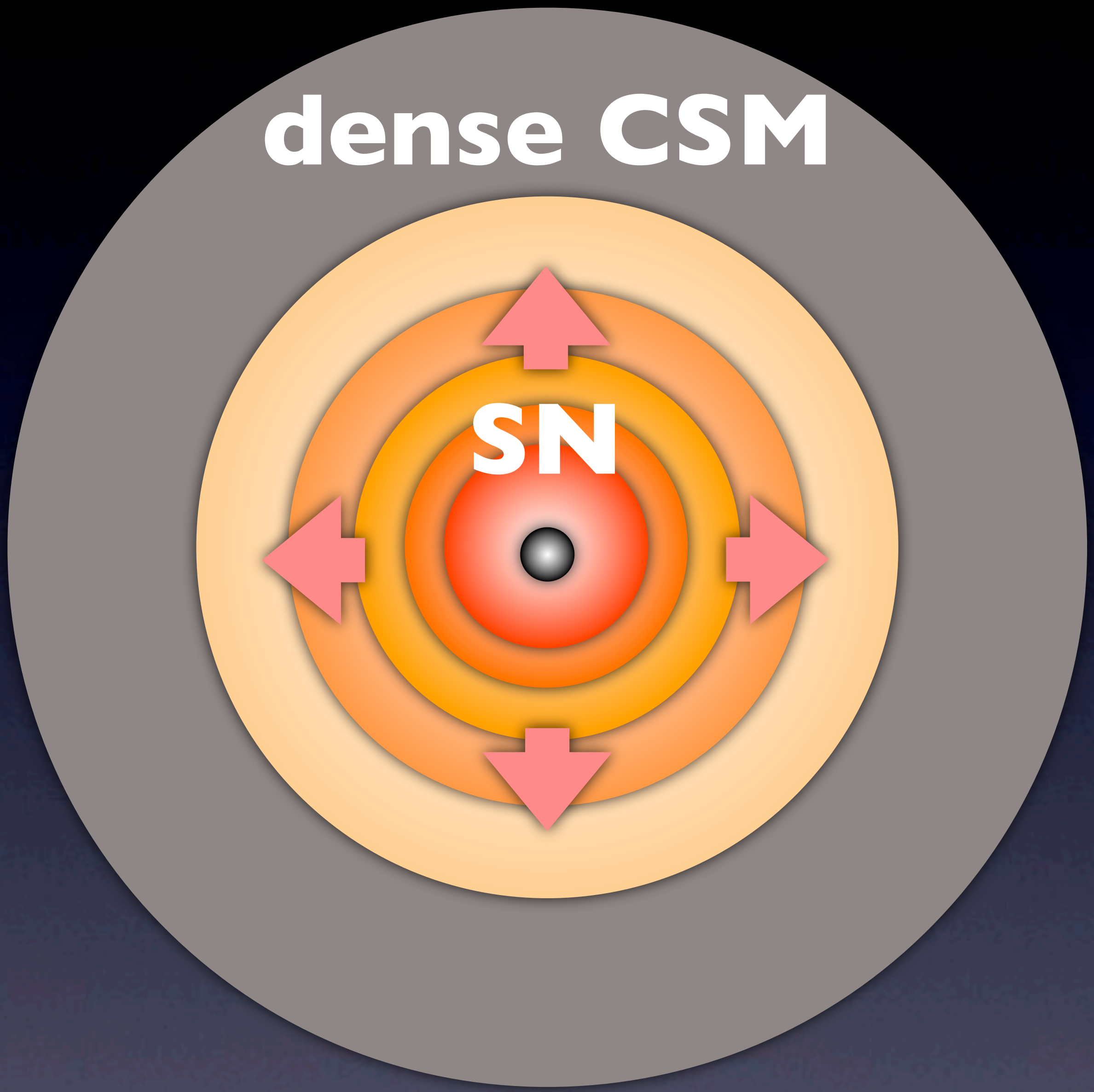
$$L \sim E_{\rm int} \left(\frac{t_{\rm b}}{t}\right) \frac{1}{\Delta t}$$

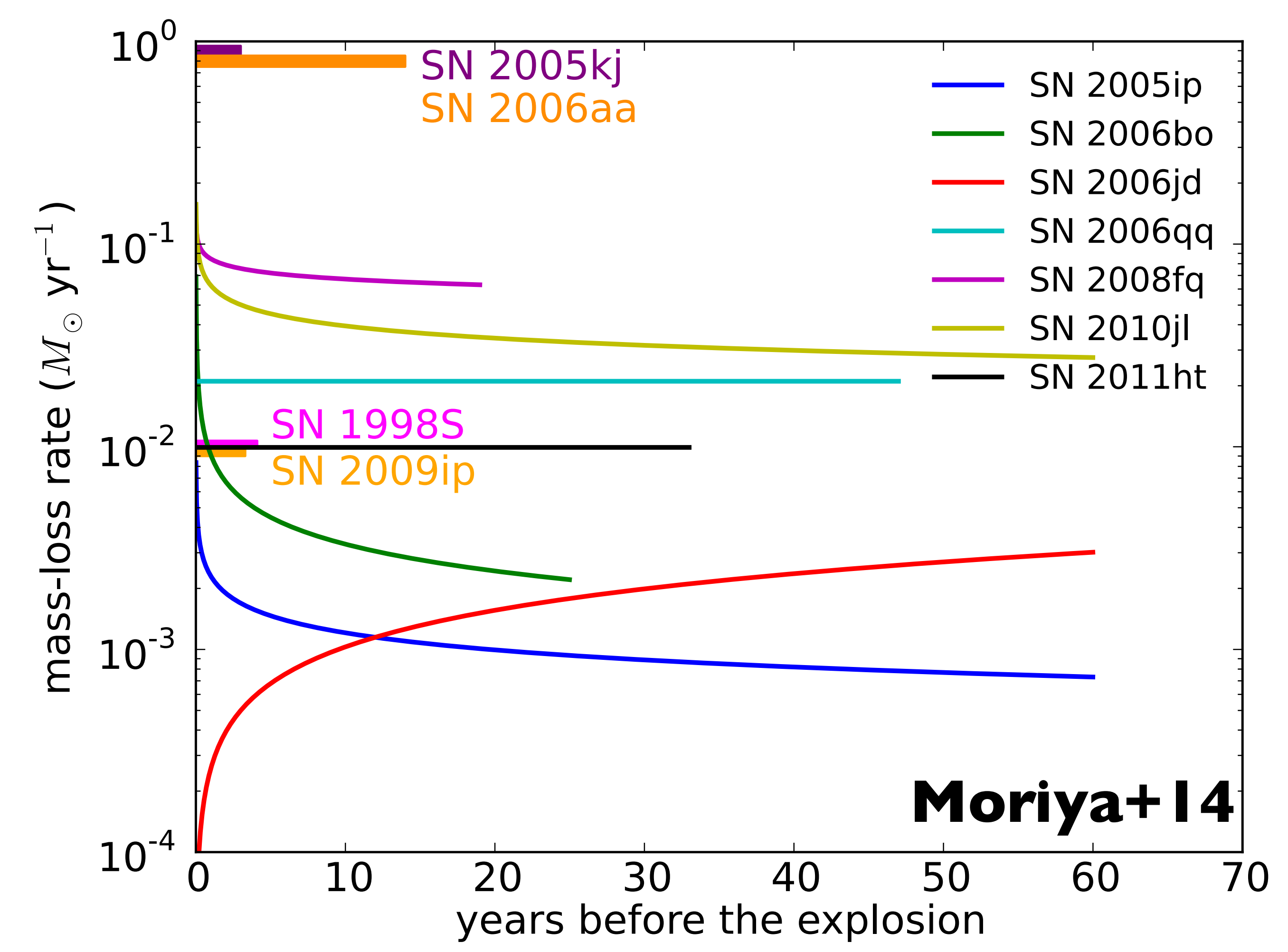
$$\sim 3 \times 10^{8} L_{\odot} \left(\frac{E_{\rm int}}{10^{51}{\rm erg}}\right) \left(\frac{t_b}{1{\rm d}}\right) \left(\frac{t}{100{\rm d}}\right)^{-2}$$

t_b ~ 1d for RSG (R ~ 1000 Rsun)

t_b ~ 0.001d for WR (R ~ 1 Rsun)
(negligible)

Energy source of SN (3) kinetic energy





High mass loss rate
(> 10^{-3} Msun/yr)
~100 yr before the explosion

$$L \sim 10^9 L_\odot \left(\frac{\alpha}{0.1}\right) \left(\frac{E_\mathrm{k}}{10^{51}\mathrm{erg}}\right) \left(\frac{\Delta t}{1\mathrm{yr}}\right)$$

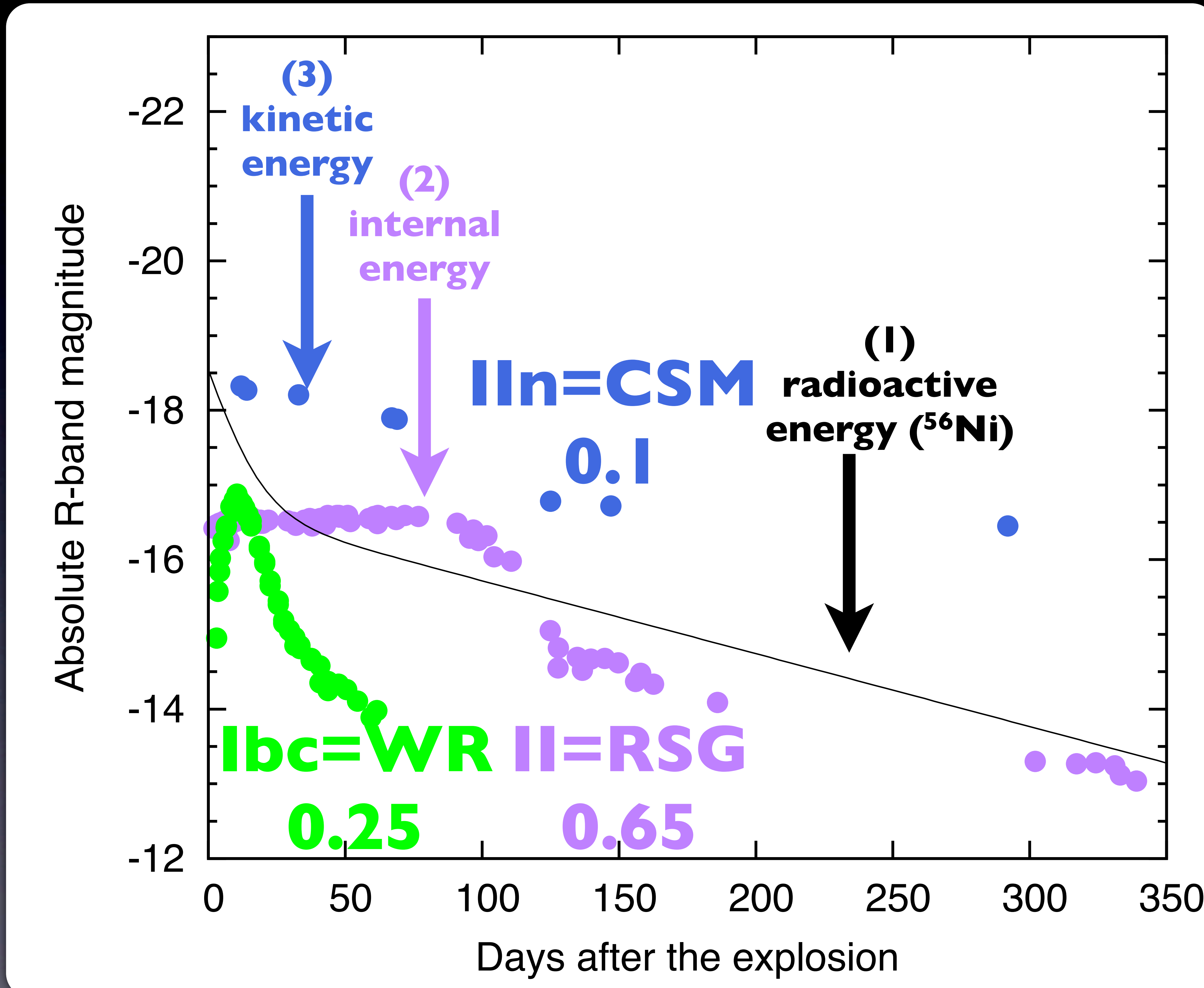
10^{11} Lsun

10^{10} Lsun

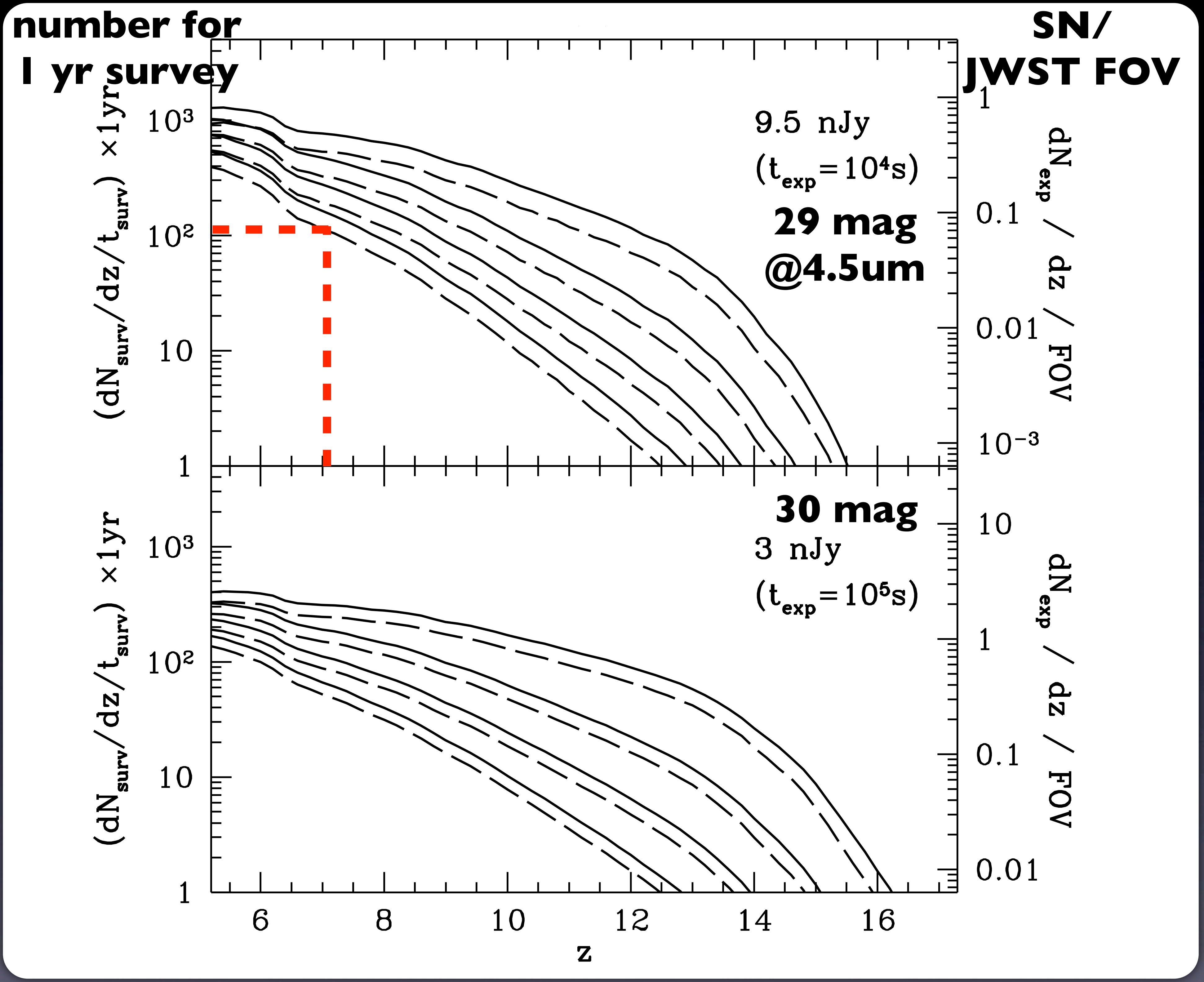
10^{9} Lsun

10^{8} Lsun

10^{7} Lsun



First supernovae...



JWST t_{survey} = 1 yr, t_{exp} = 0.1 - 1 d

Number of fields = $t_{survey}/2t_{exp}$

Mesinger+06

Toward Detection of First Supernovae

- Massive star evolution and supernova emission
- Superluminous supernova
- Survey for first supernovae

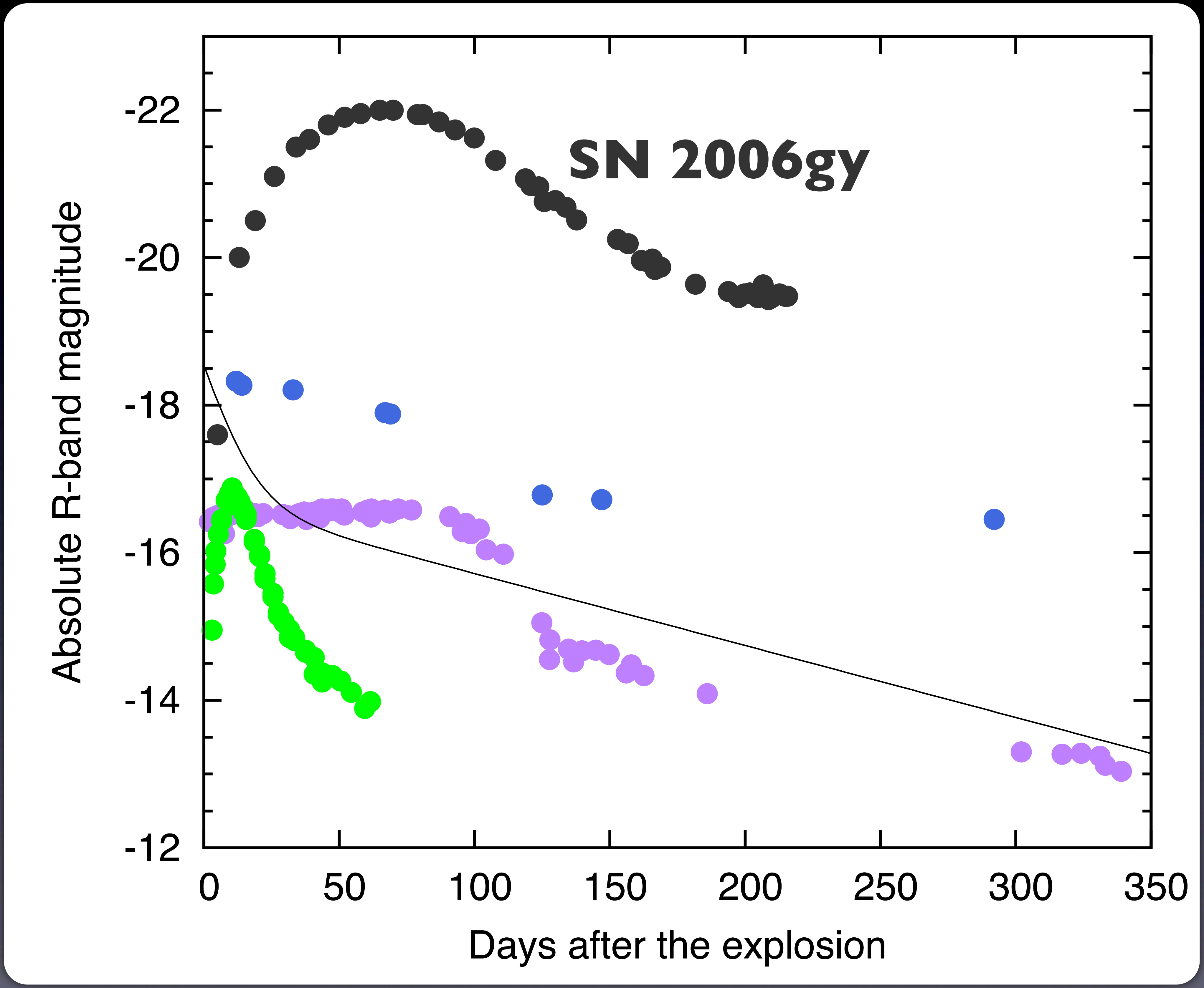
10^{11} Lsun

10^{10} Lsun

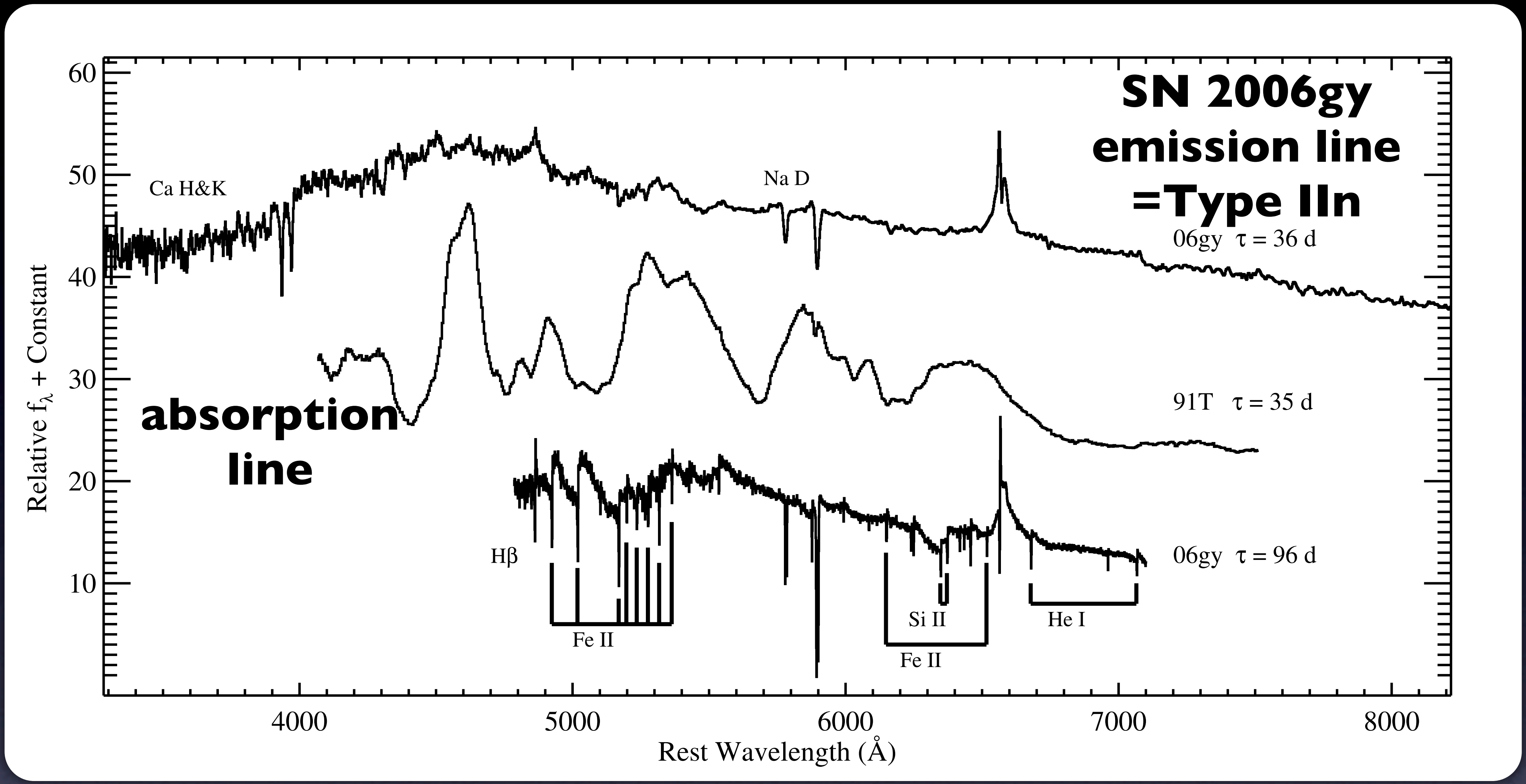
10^{9} Lsun

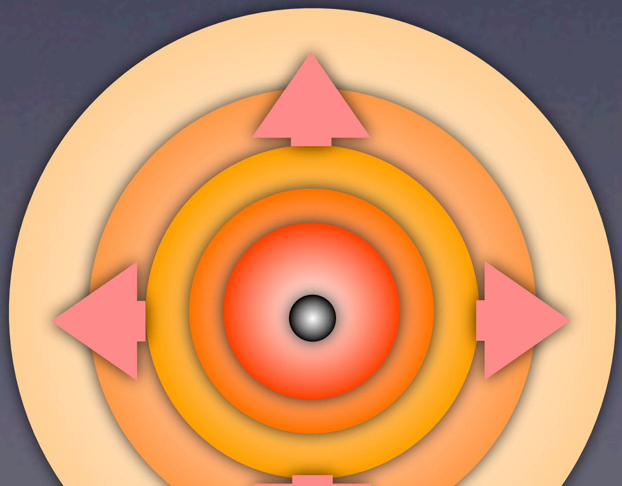
10^{8} Lsun

10^{7} Lsun

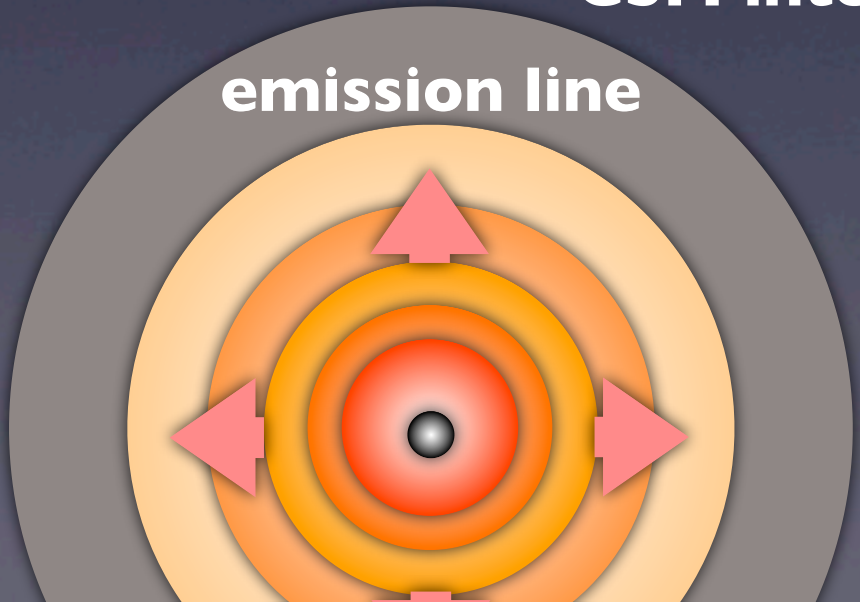


Kinetic-energy powered





CSM interaction



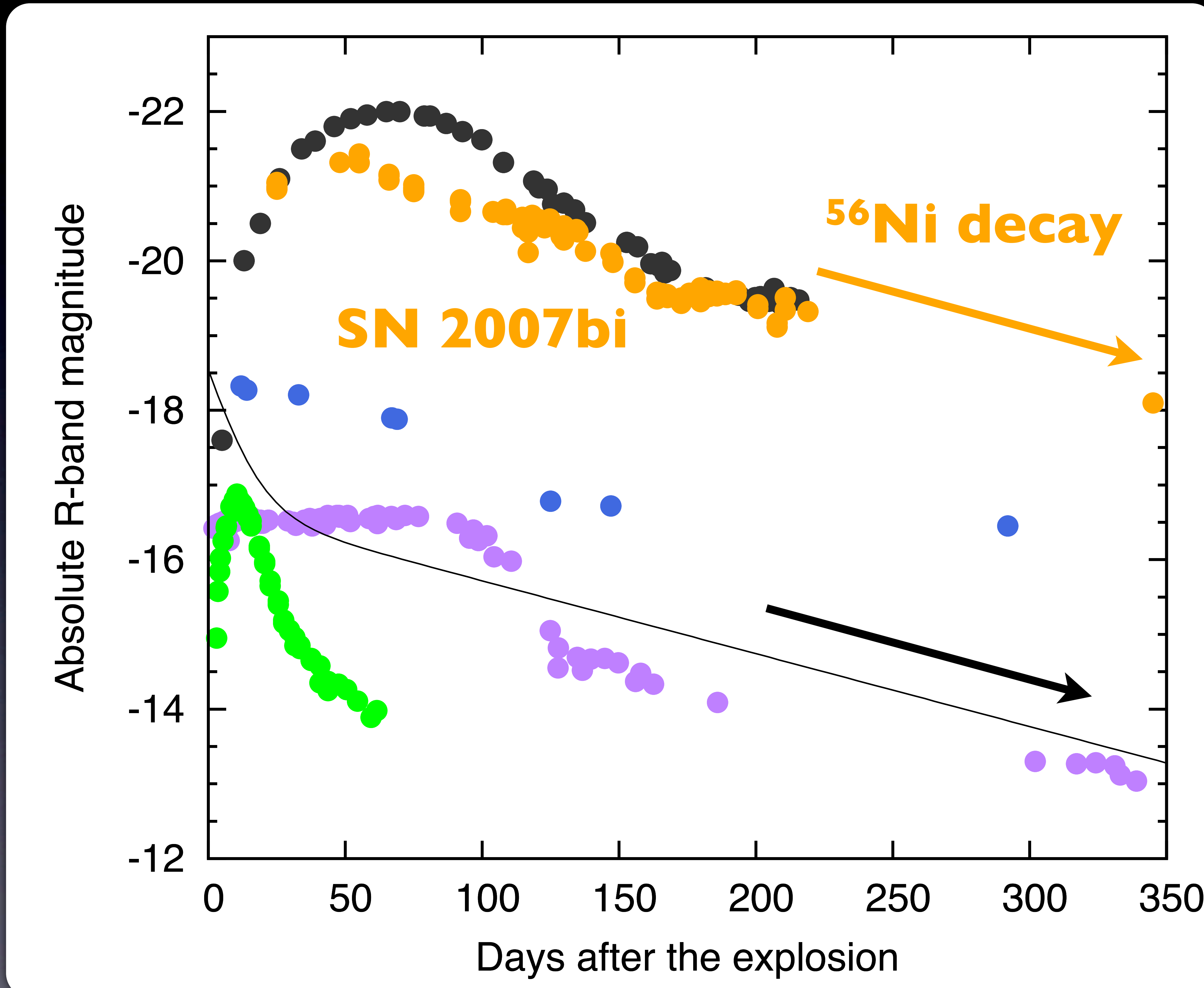
10^{11} Lsun

10^{10} Lsun

10^{9} Lsun

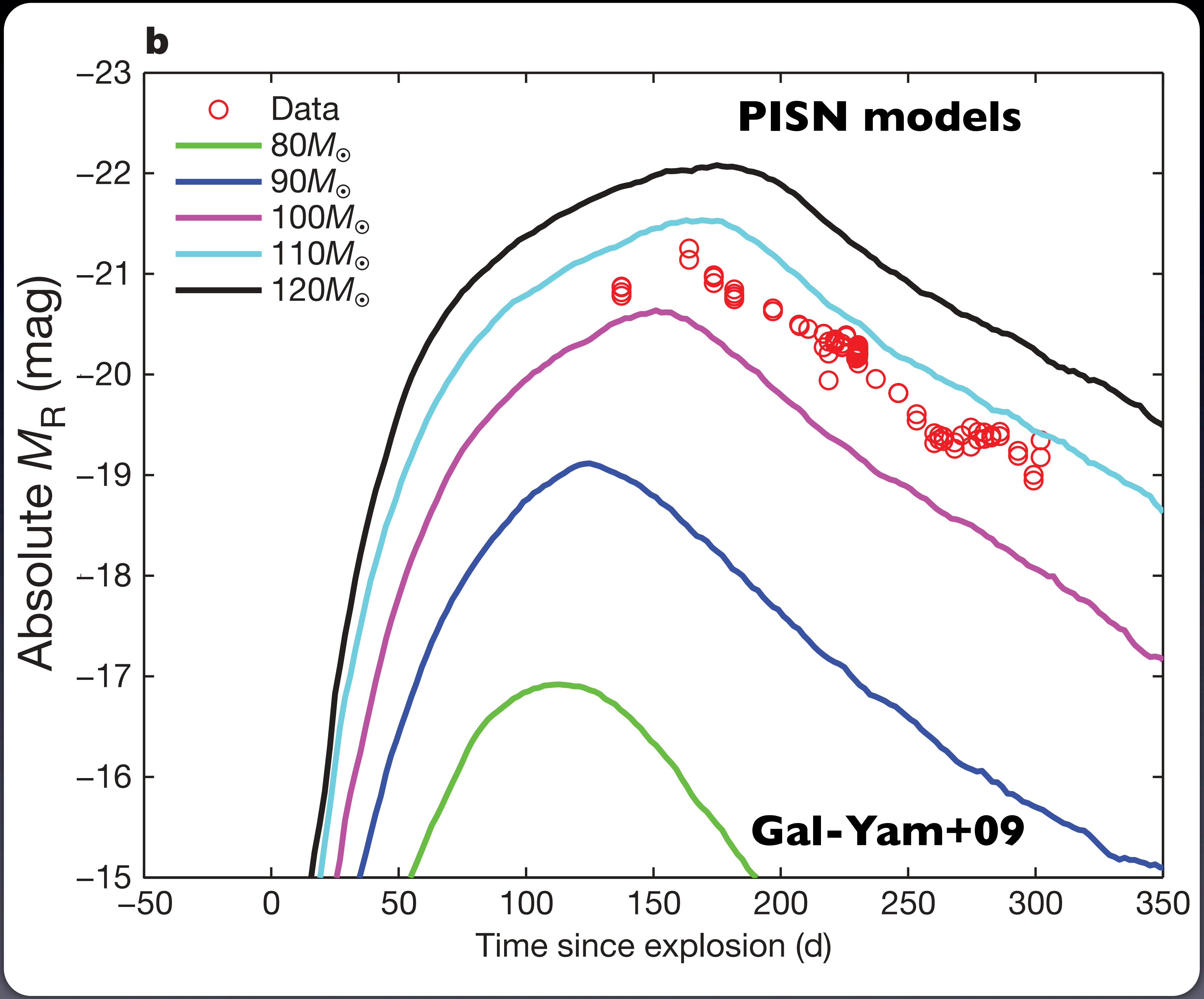
10^{8} Lsun

10^{7} Lsun



Possibly PISN??

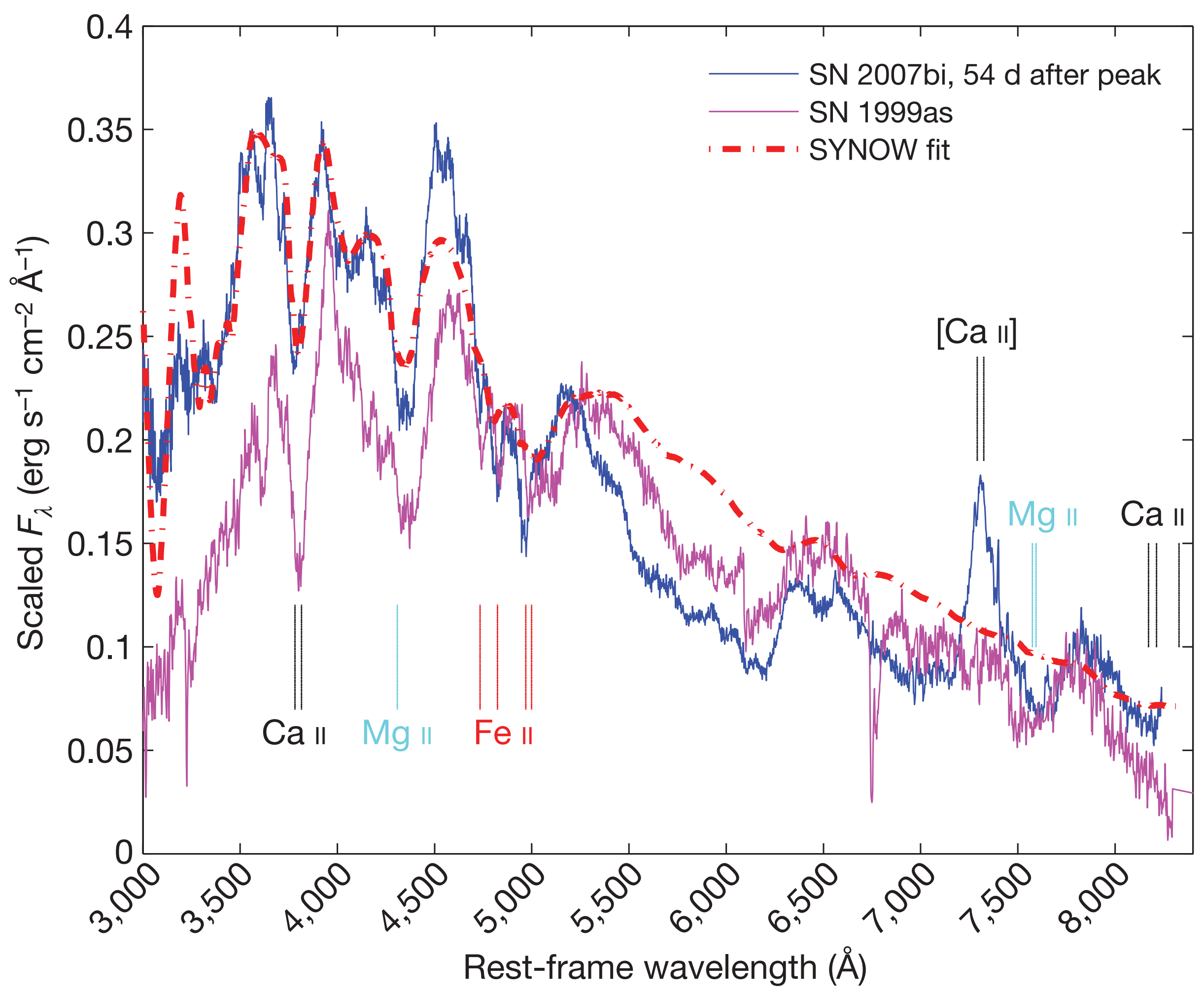
M(^{56}Ni) ~ 3 Msun



But see Moriya+10, Yoshida+11 for core-collapse interpretation

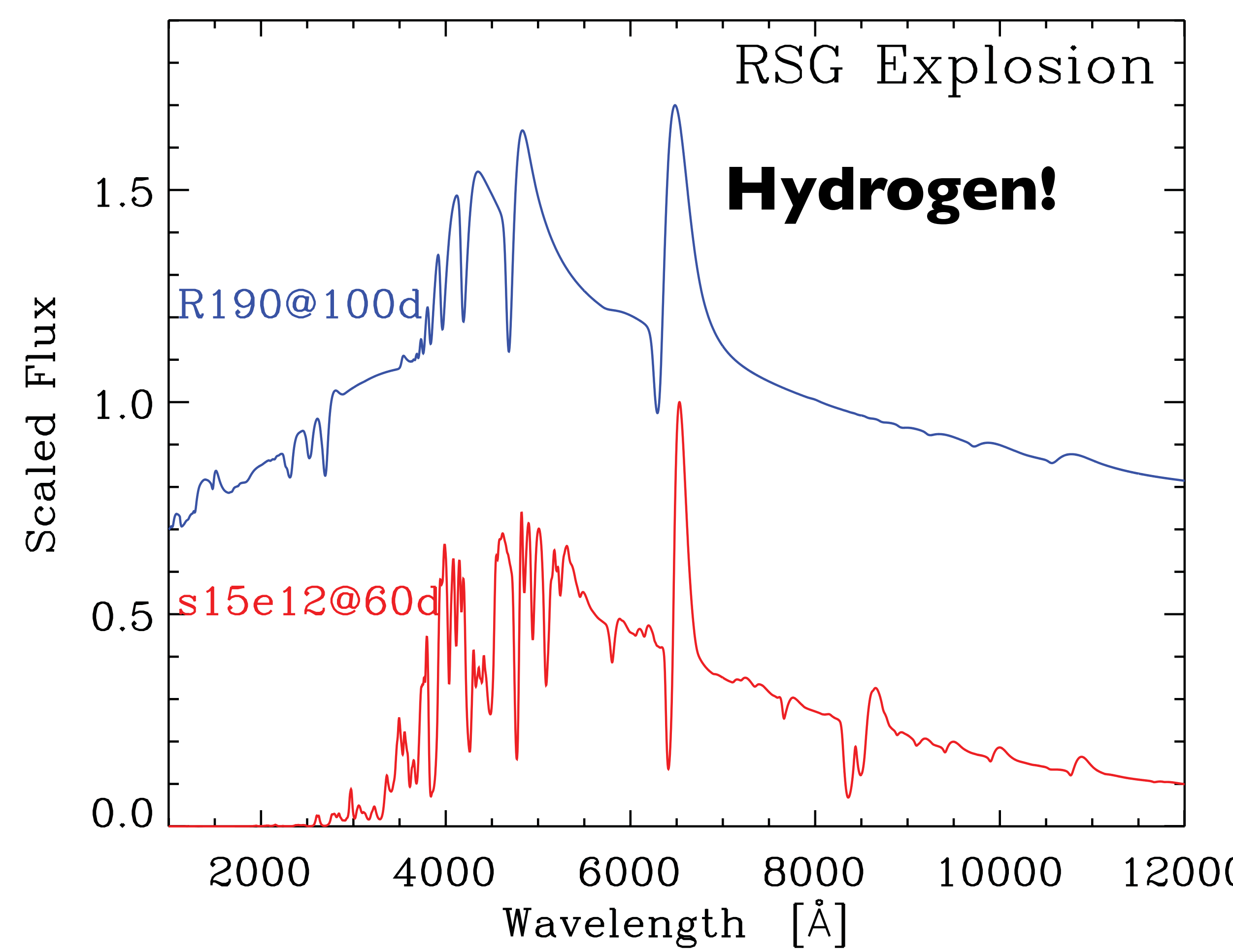
Spectrum: No hydrogen

Observed



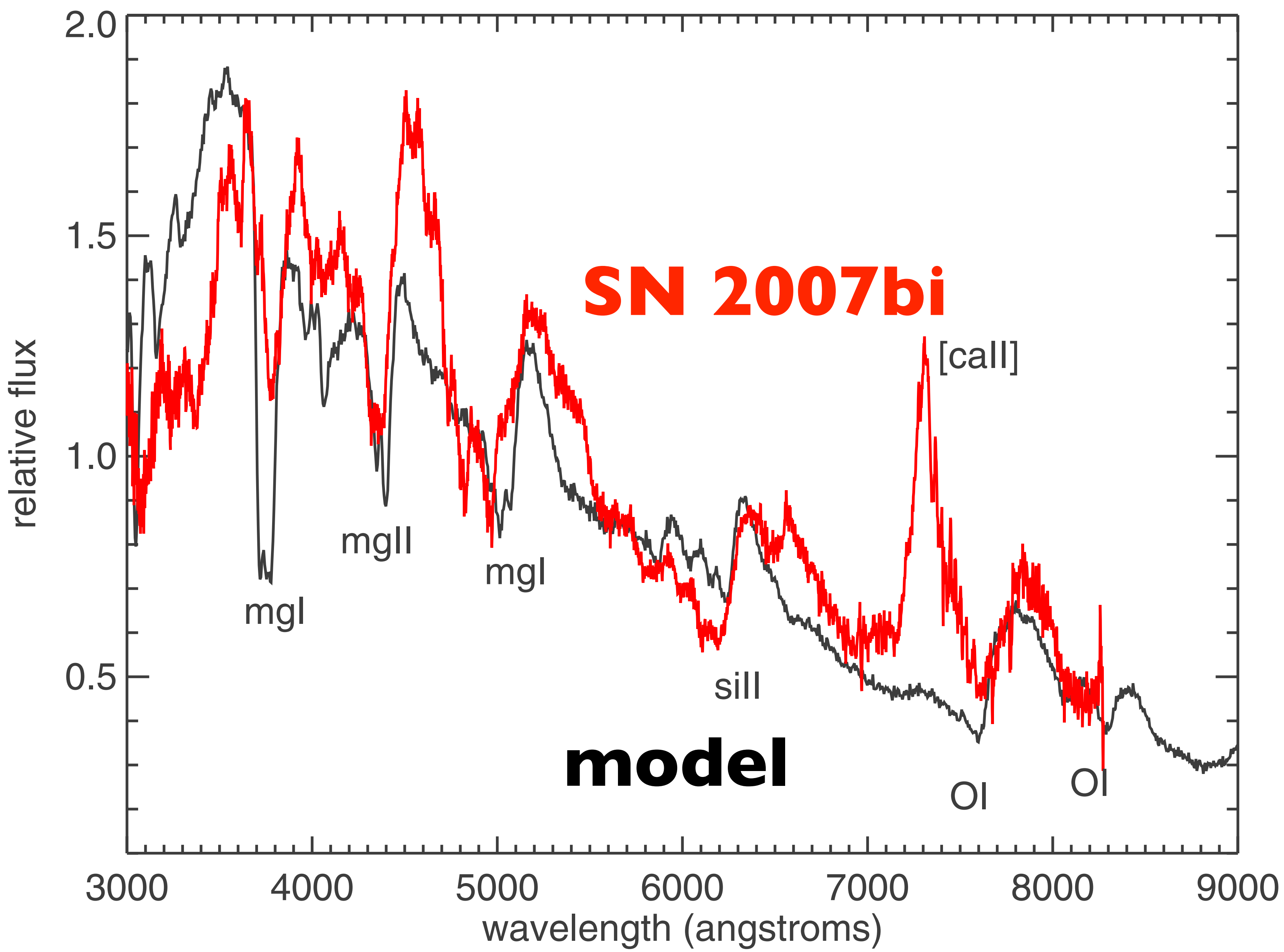
Gal-Yam+09

Theory



Dessart+13

PISN without H...?



Kasen+11

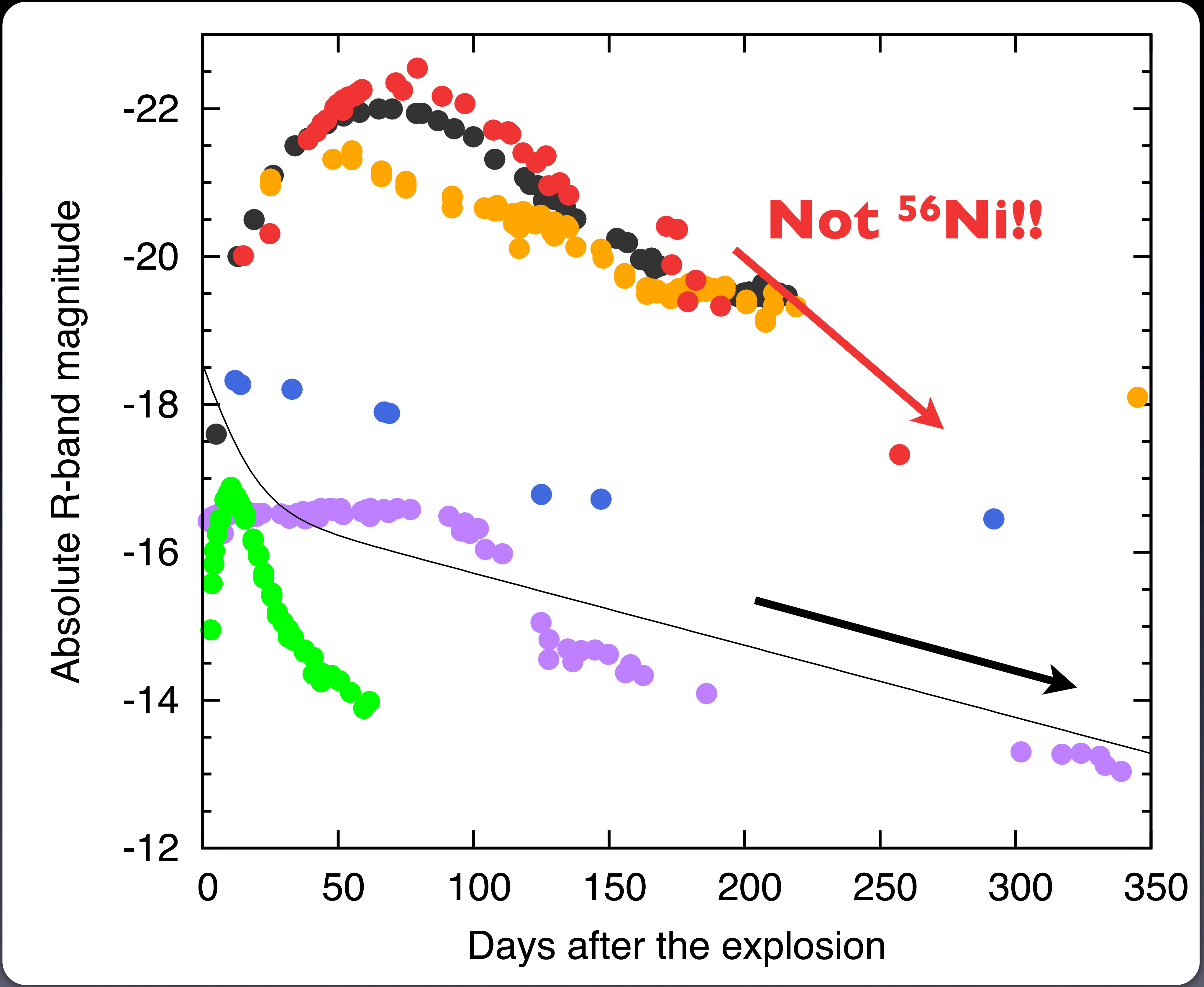
10¹¹ Lsun

10¹⁰ Lsun

10⁹ Lsun

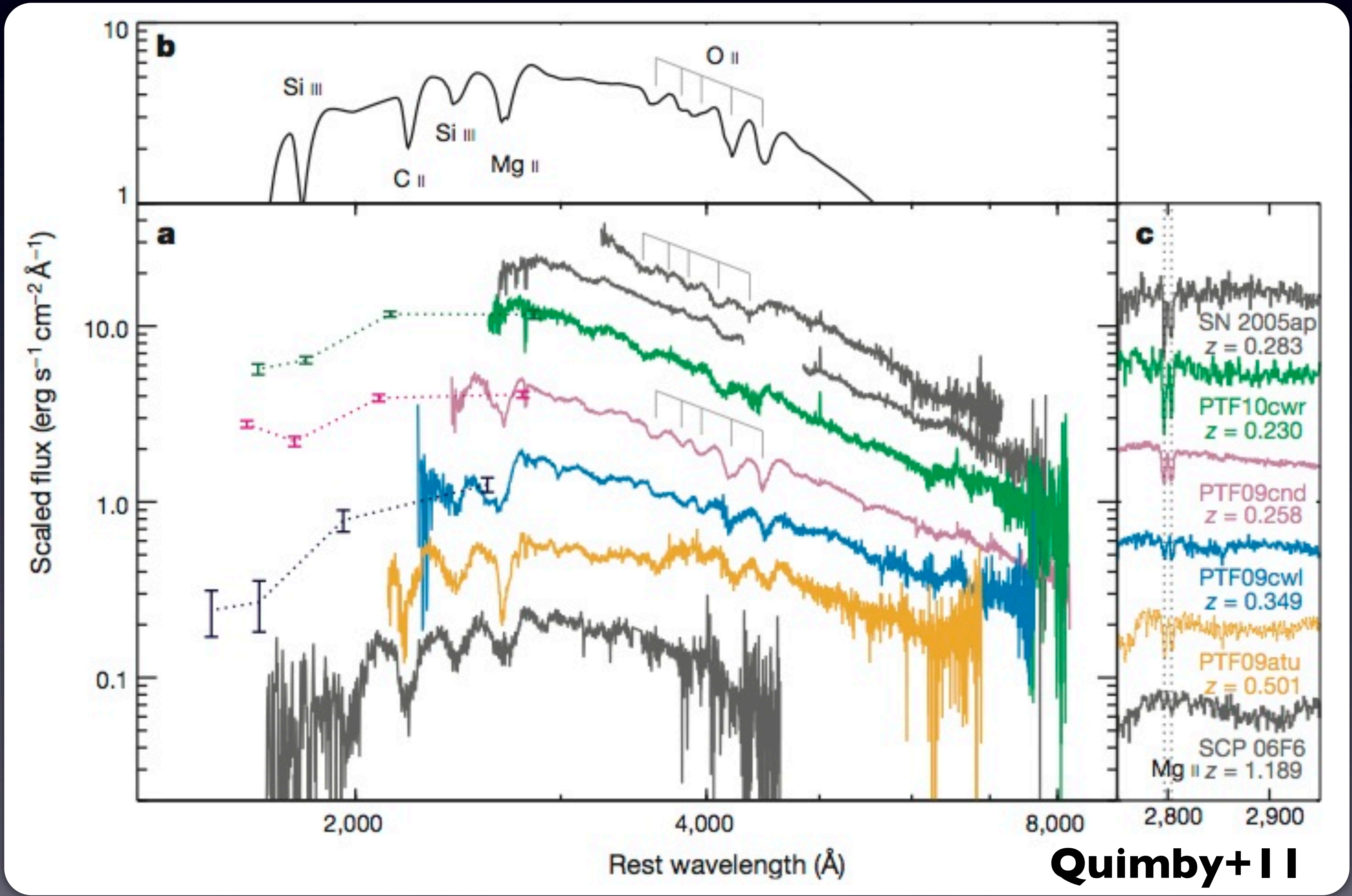
10⁸ Lsun

10⁷ Lsun



What powers this type...??

- Not ^{56}Ni
- Not internal energy (no H)
- Not (clearly) interaction
- magnetar...???



Quimby+11

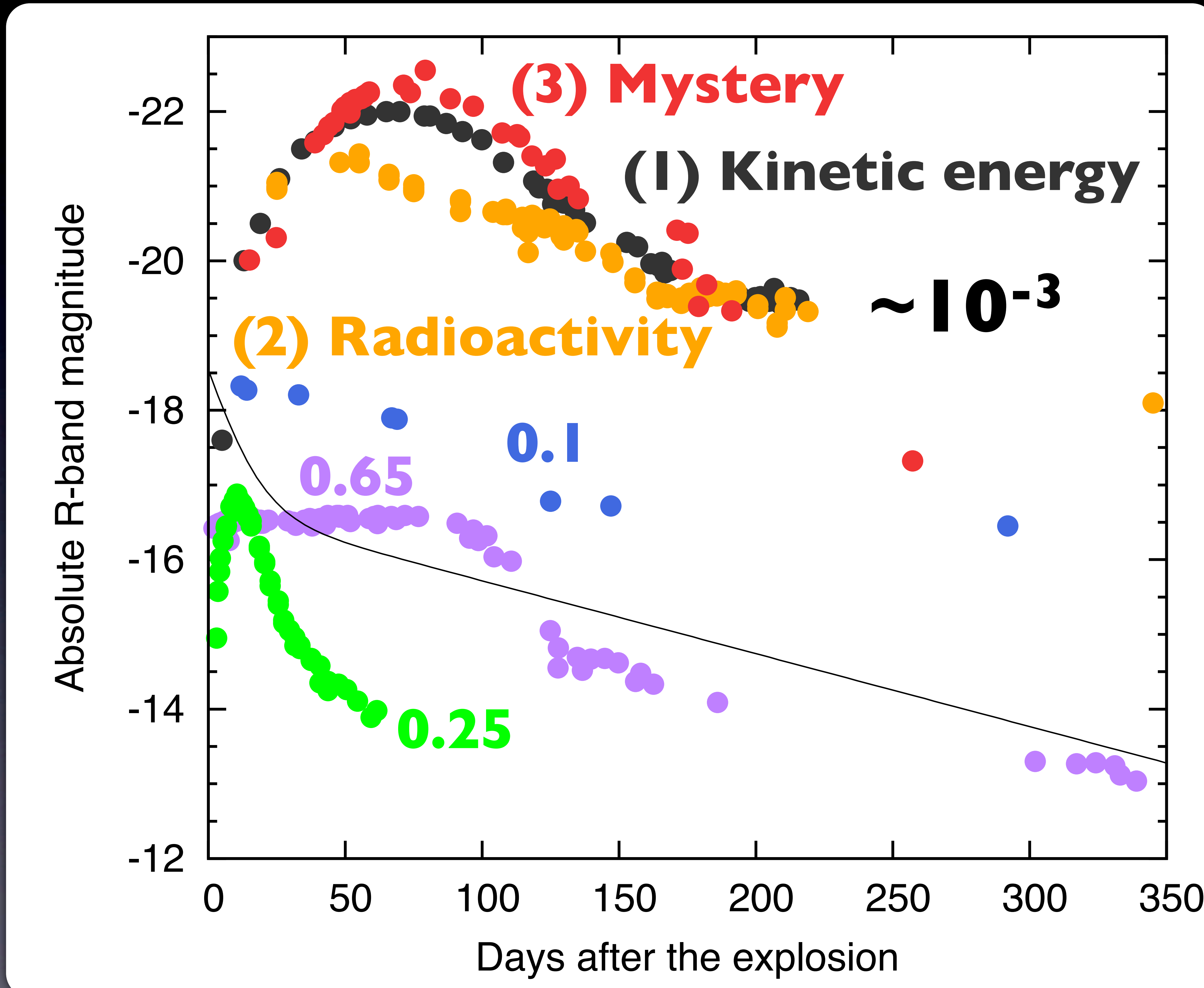
10^{11} Lsun

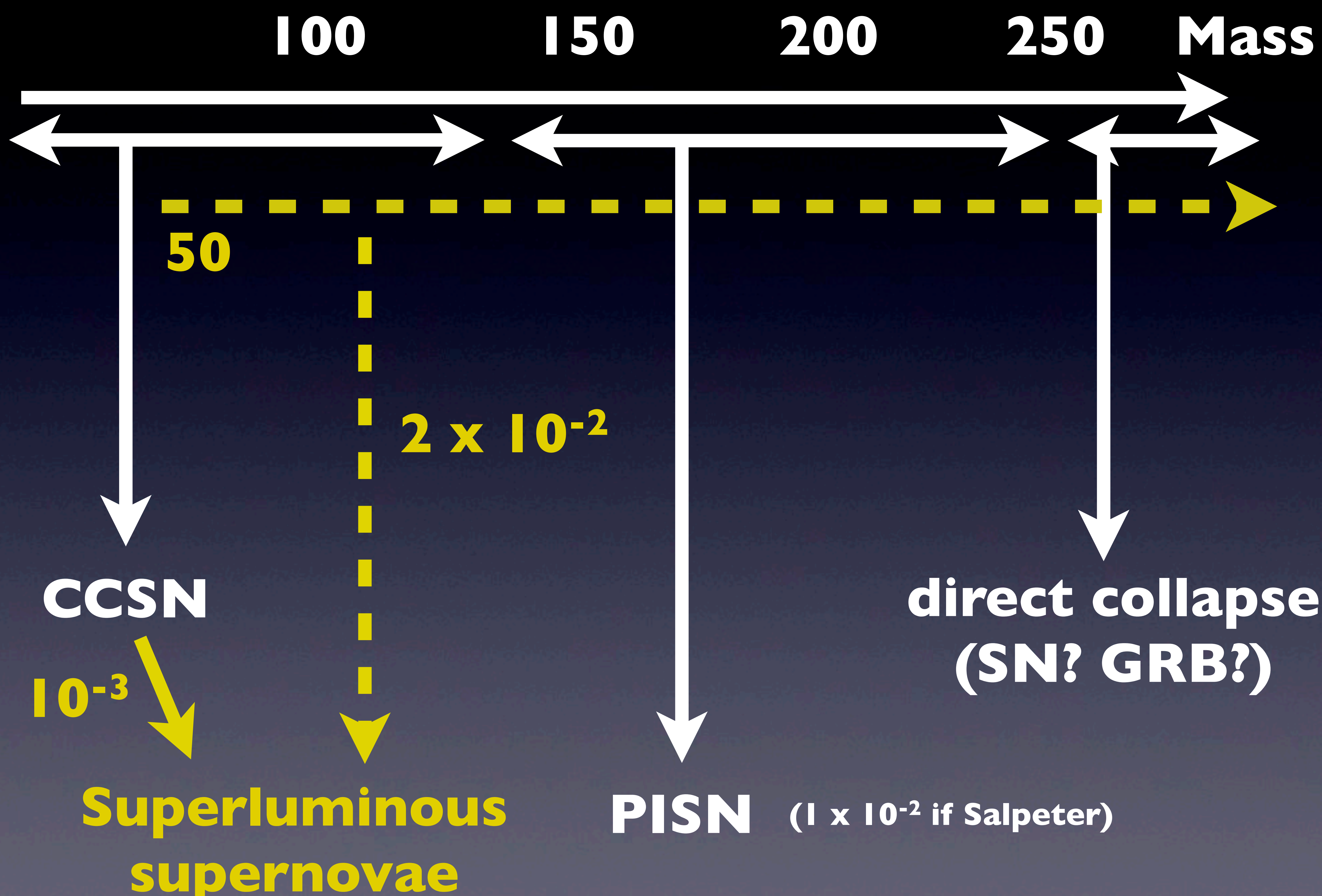
10^{10} Lsun

10^{9} Lsun

10^{8} Lsun

10^{7} Lsun



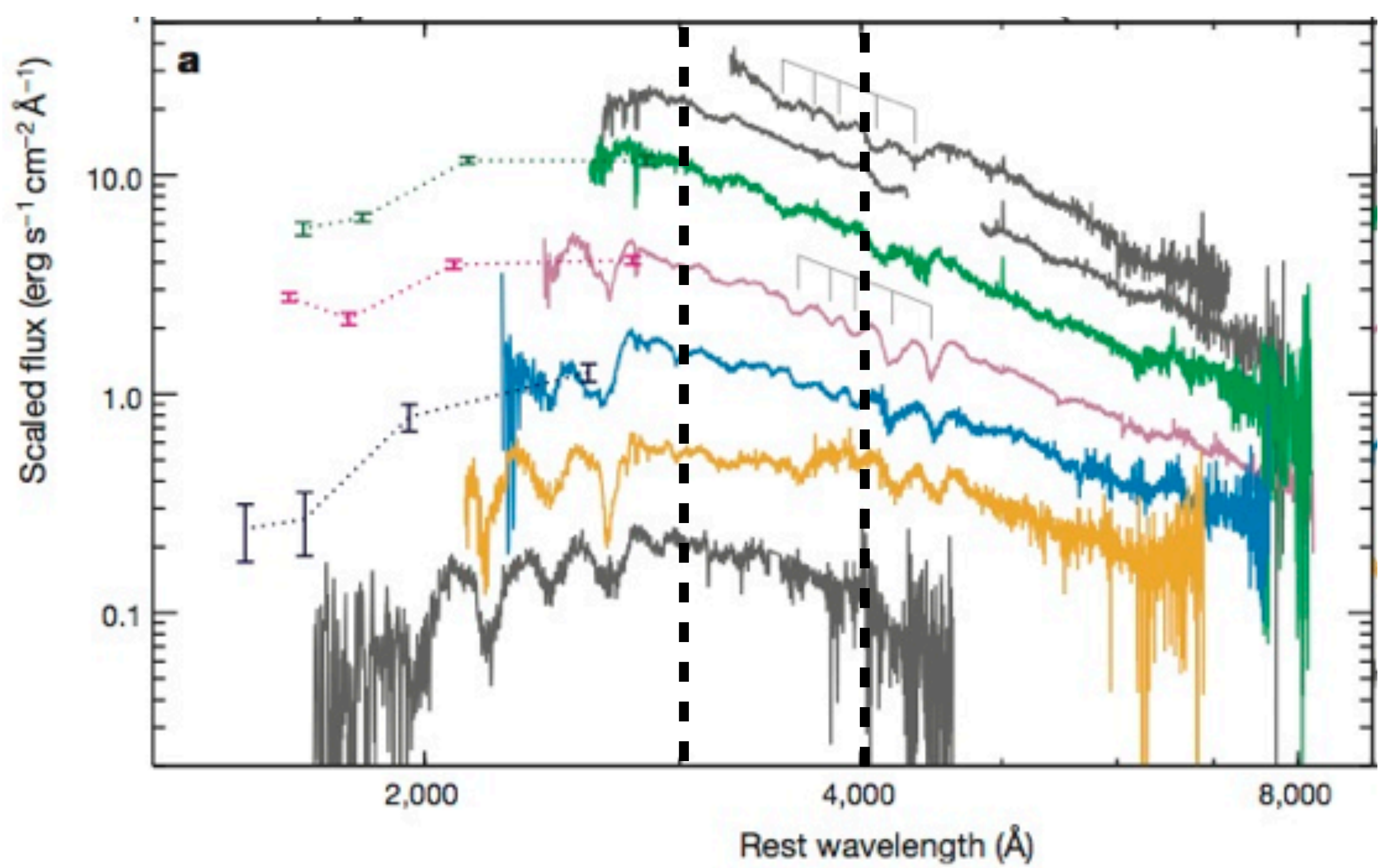

100
150
200
250
Mass
50
2 x 10-2
CCSN
10-3
Superluminous supernovae
PISN
(1 x 10-2 if Salpeter)
direct collapse
(SN? GRB?)

Toward Detection of First Supernovae

- Massive star evolution and supernova emission
- Superluminous supernova
- Survey for first supernovae

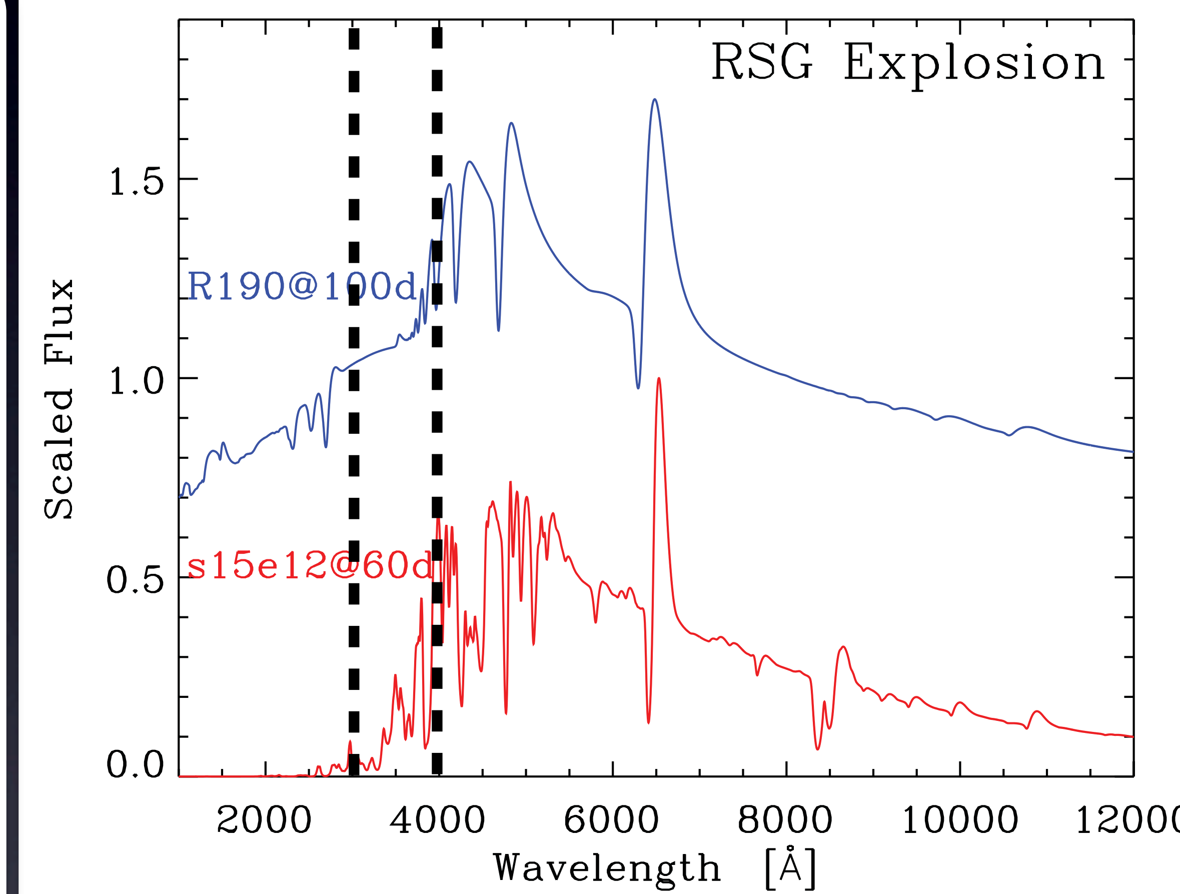
Type	brightness	color	progenitor
Normal SN	x	x	o
SLSN (kinetic energy)	o	o (bright in UV)	? (need CSM)
SLSN ~ PISN(?) (radioactivity)	o	x (faint in UV)	? (H?)
SLSN (??)	o	o (bright in UV)	??

Observed SLSN



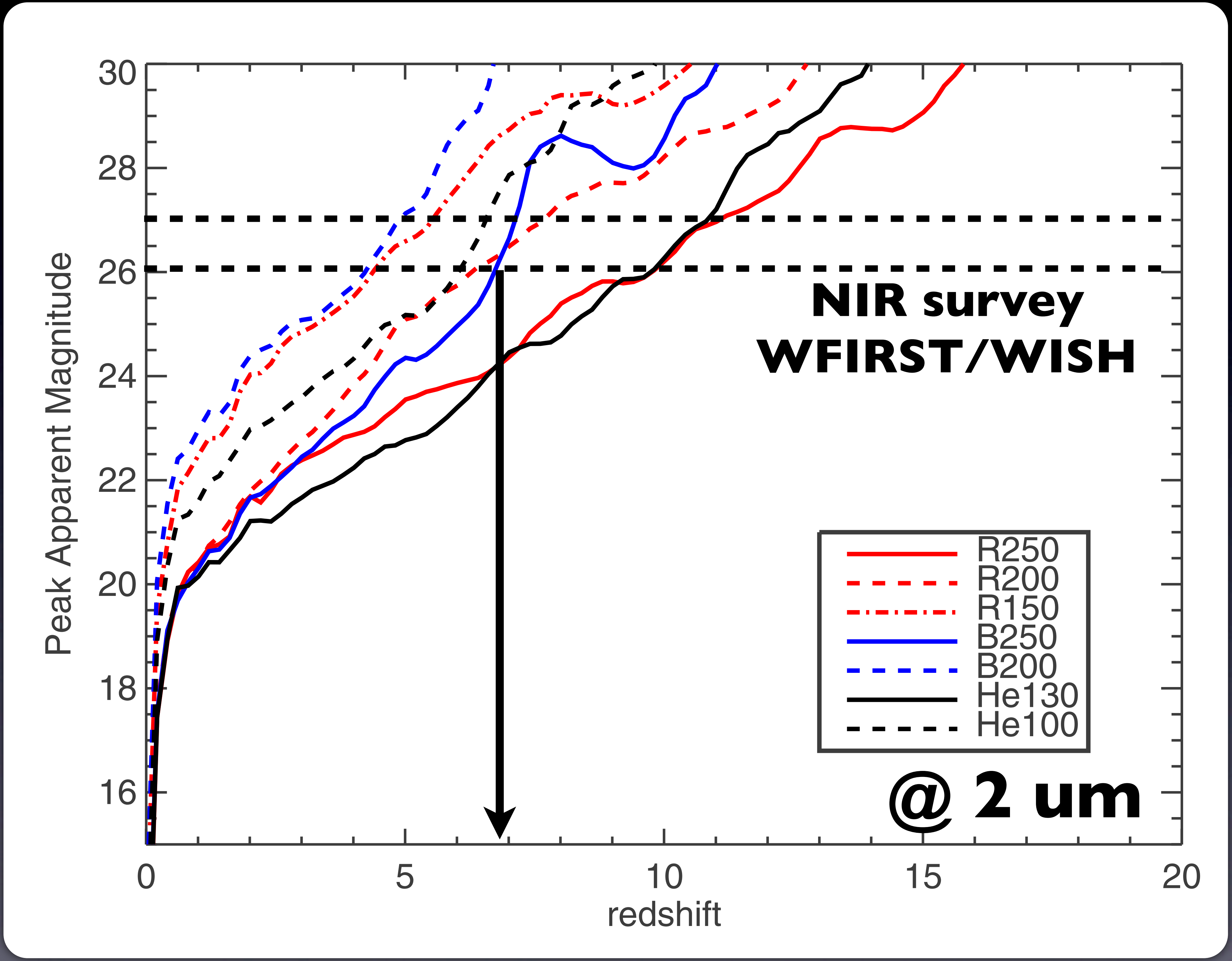
Quimby+11

PISN model



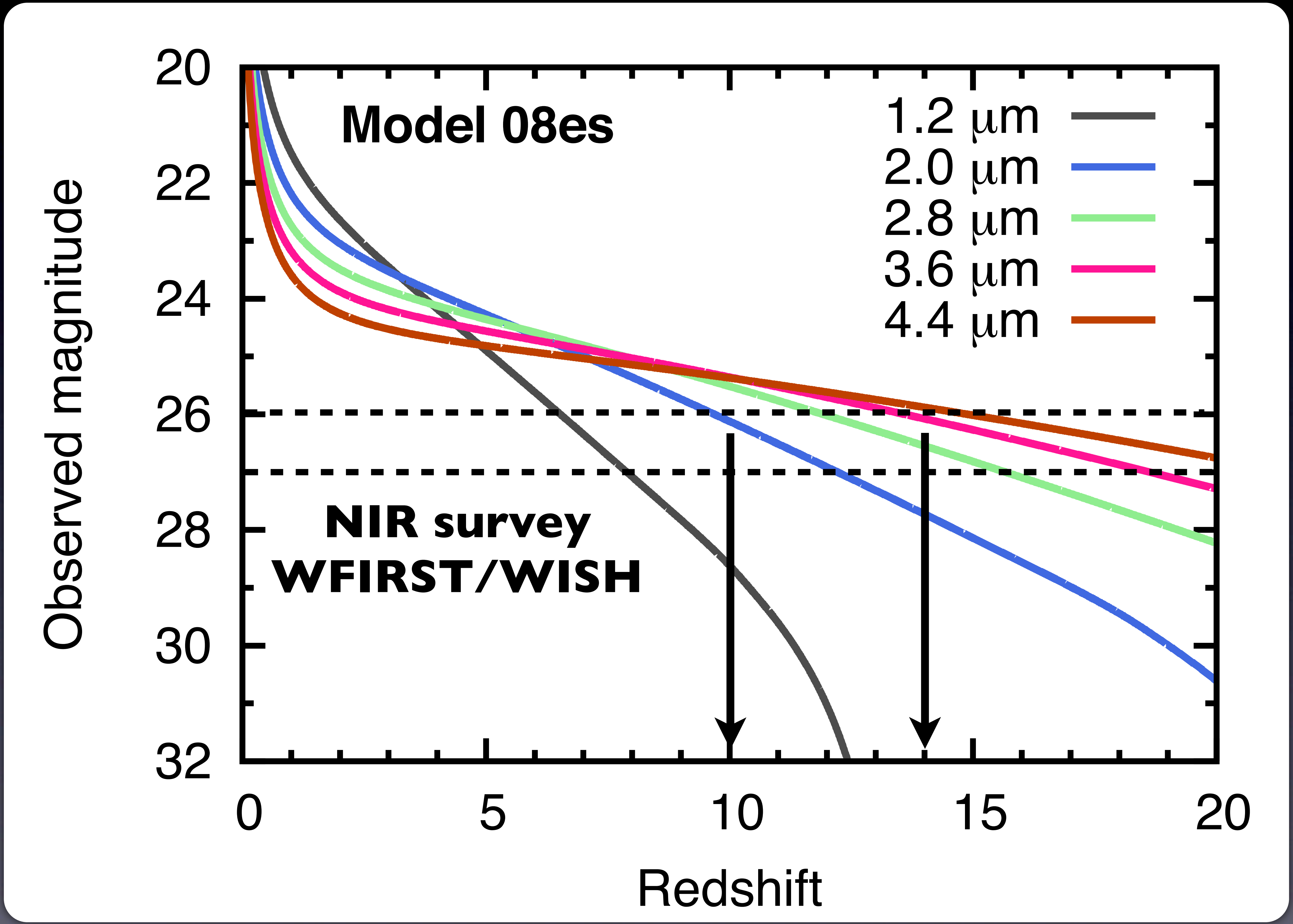
Dessart+13

“Genuine” PISN may be difficult

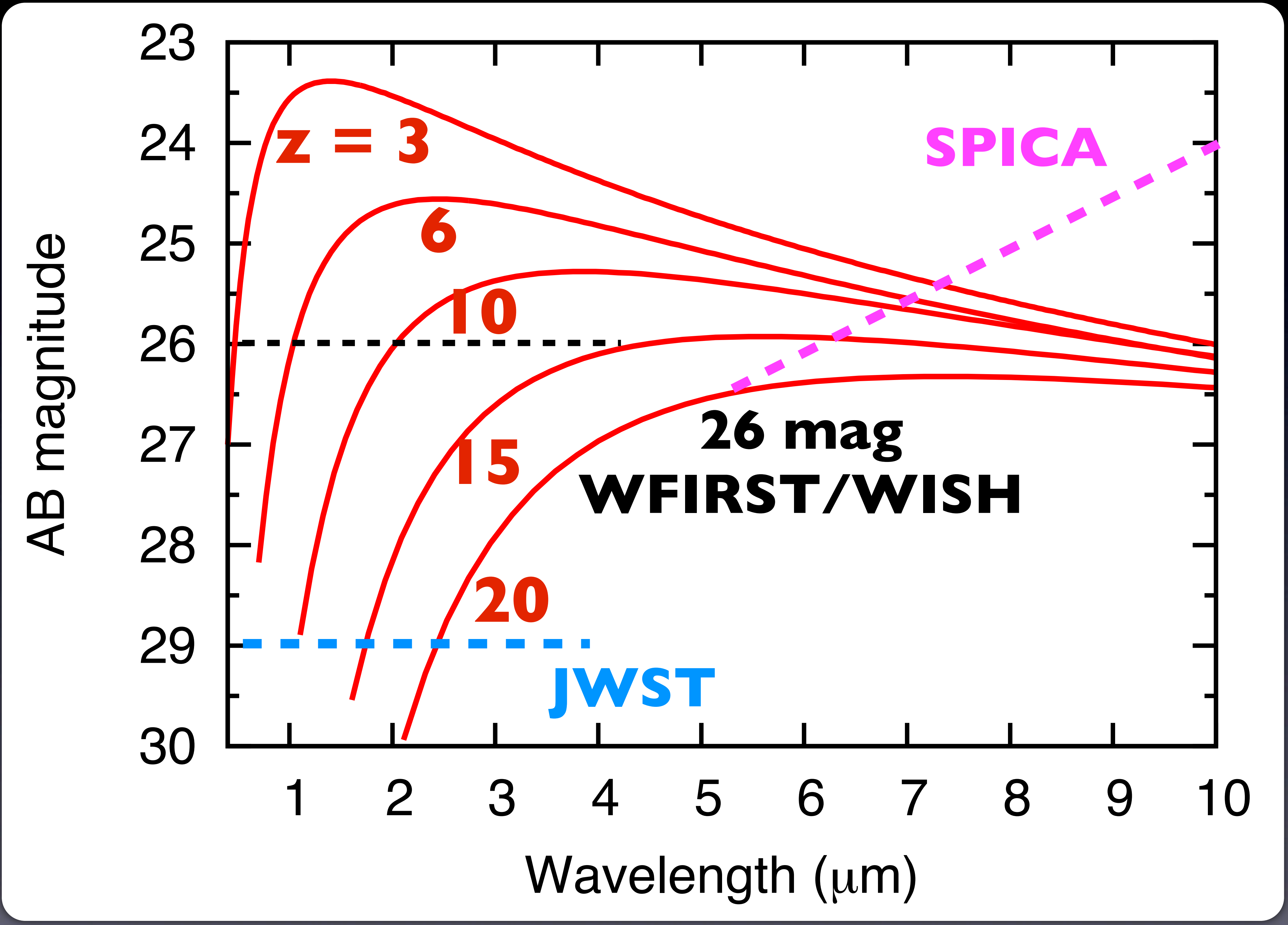


Kasen+11, see also Dessart+13

“Observed” SLSNe are detectable @ z > 10

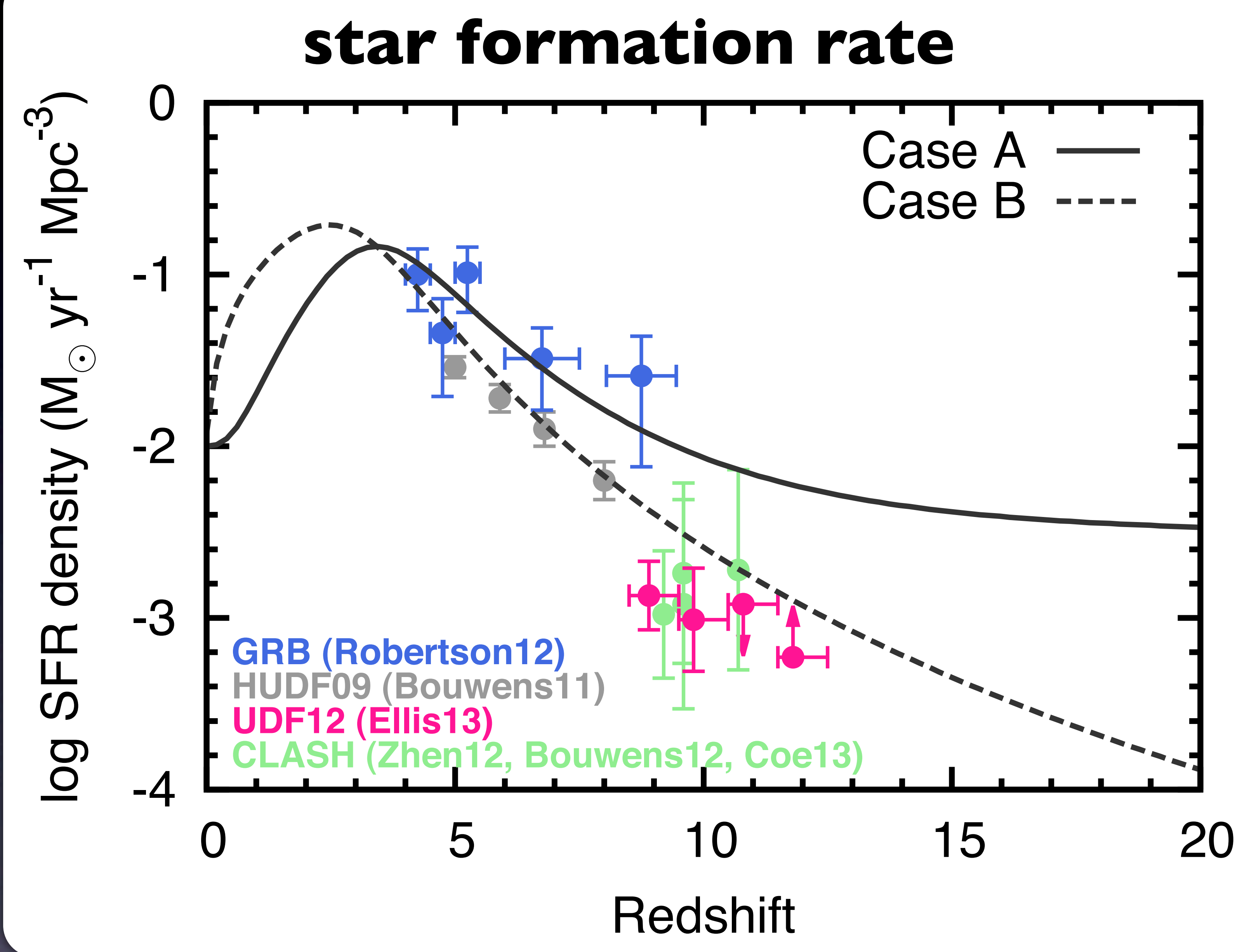


MT, Moriya, Yoshida+13



MT, Moriya, Yoshida+13

Survey simulation

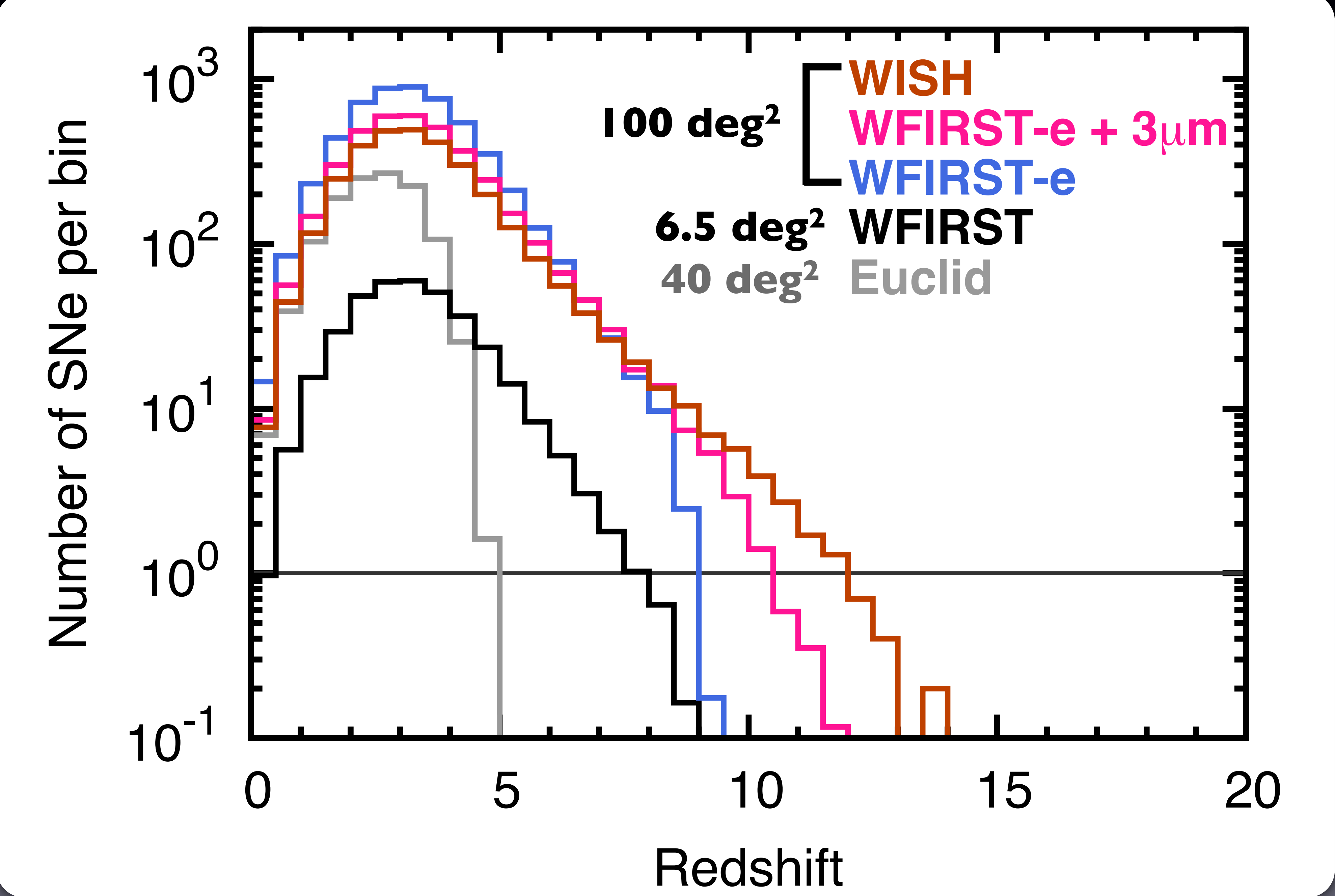


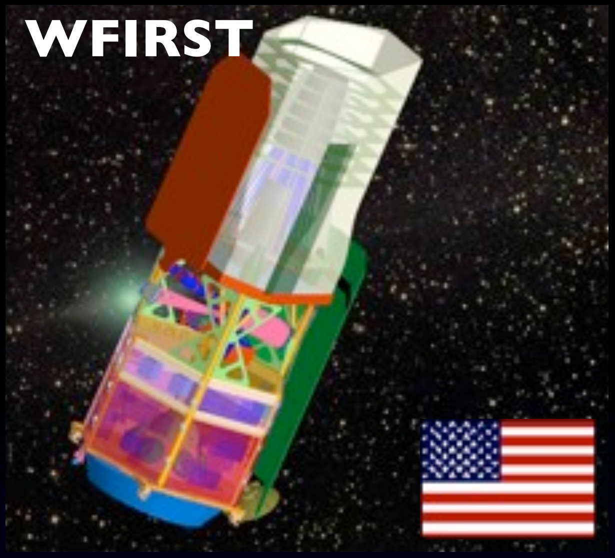
10^{-3}

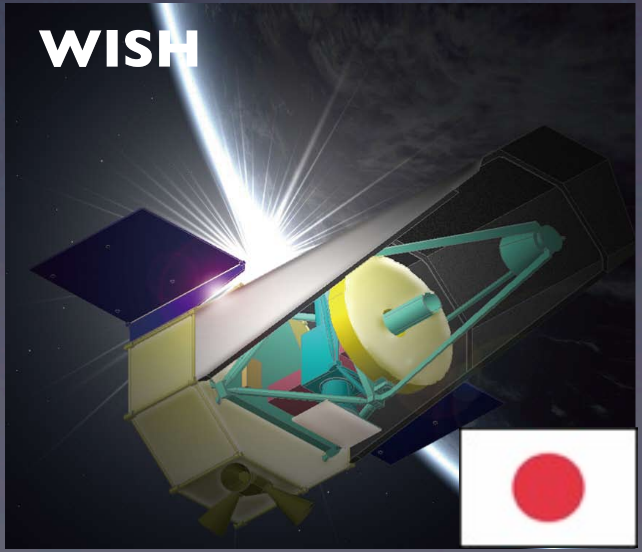
$$R_{\rm SLSN}(z) = f_{\rm SLSN}\,\rho_*(z)\,\frac{\int_{M_{\rm min,SN}}^{M_{\rm max,SN}} \psi(M){\rm d}M}{\int_{M_{\rm min}}^{M_{\rm max}} M\psi(M){\rm d}M}$$

Quimby+13

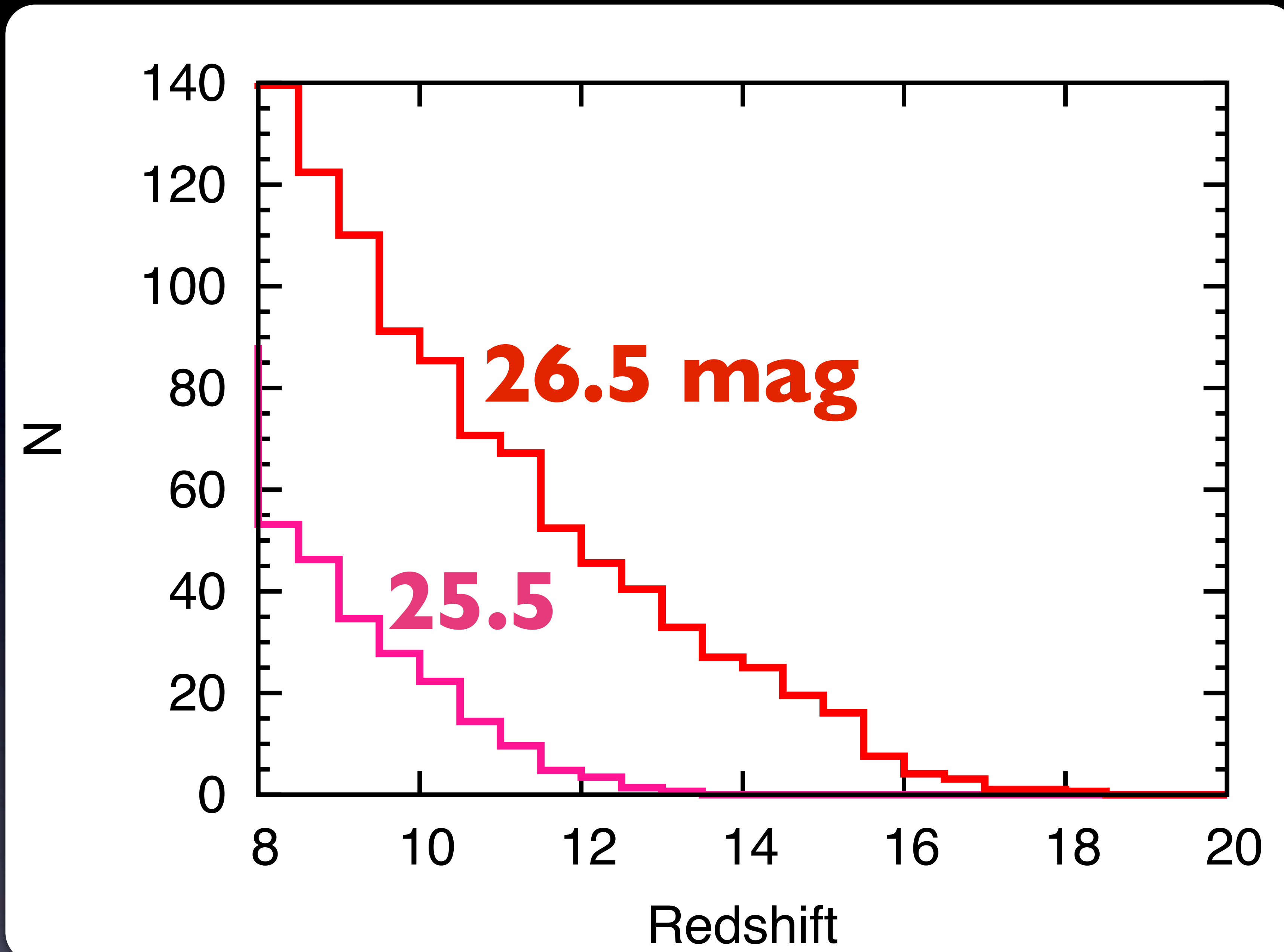
Up to z ~ 10 with planned strategy





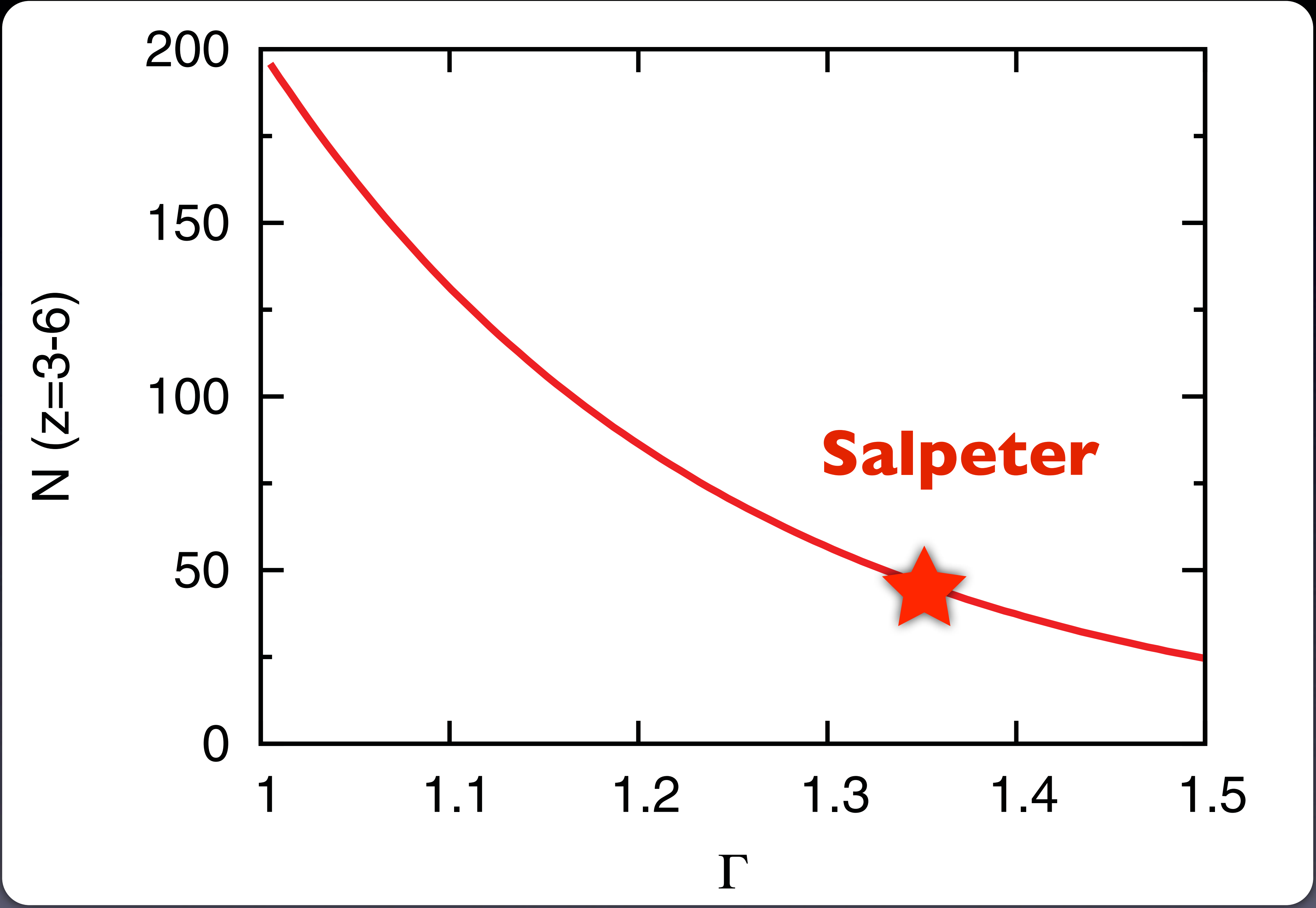


To detect supernovae @ z ~ 15



AB = 26.5 mag (@ 1-4 um)
2000 deg^2
6 visits in 0.5 yr

Studying IMF by number count

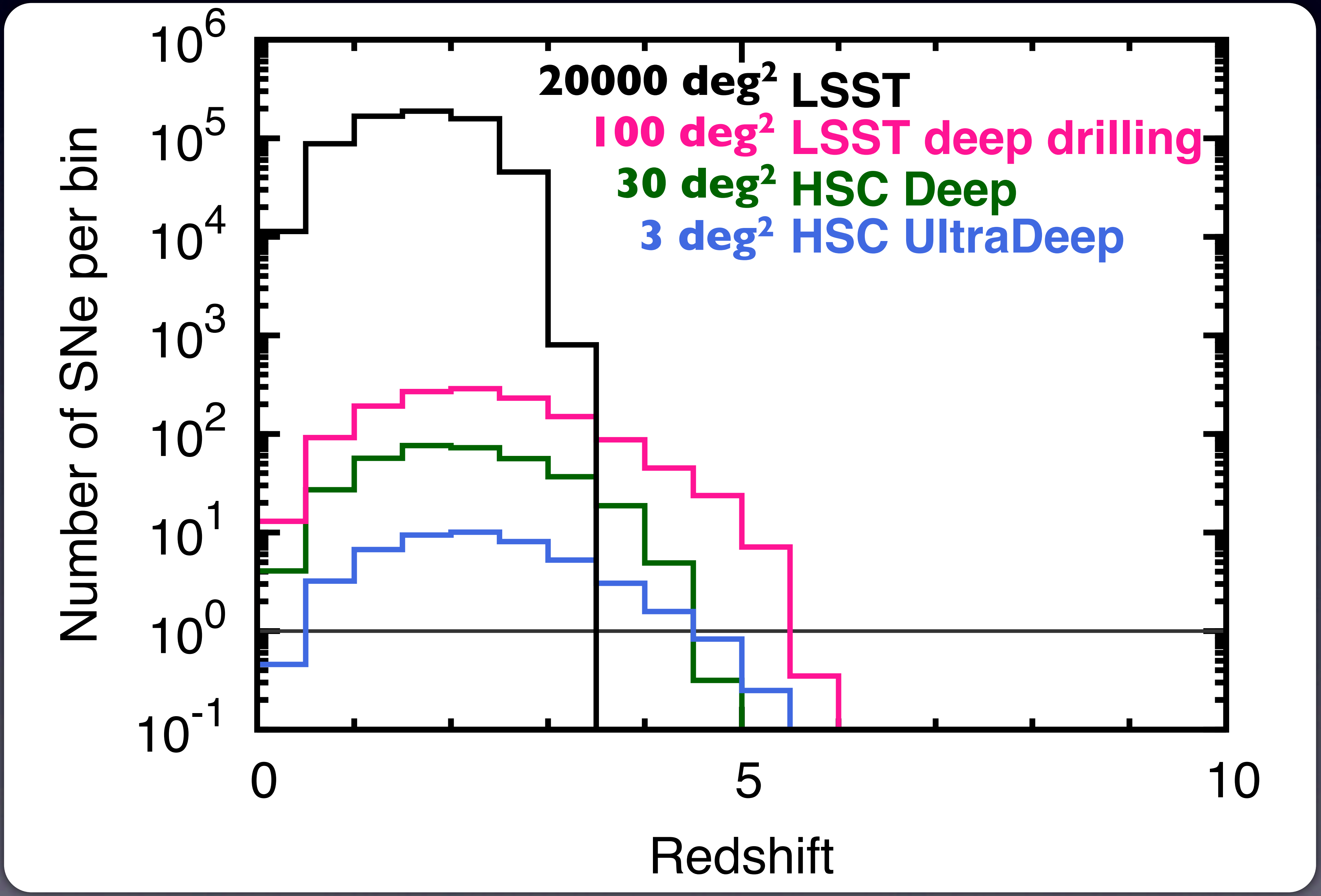


!! Caveats !!

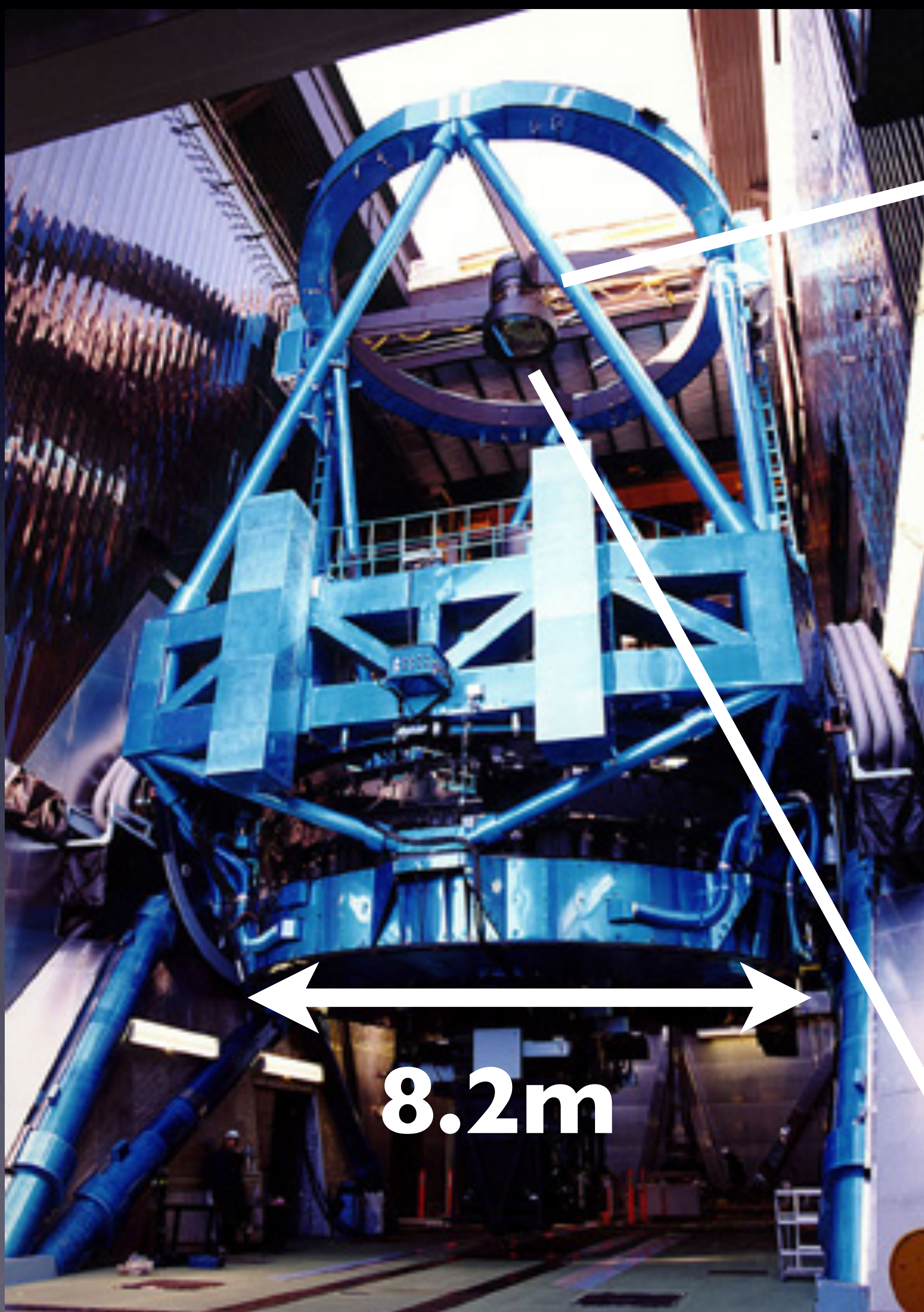
- **Star formation rate**
  => Needs galaxy survey (z >~ 10)
- **"Mysterious" objects**
  - **Progenitor (minimum mass?)**
  - **Metallicity dependence**
    => # of SN/SFR as a function of redshift
- **Completeness**
  => Needs well-controlled "missed" fraction

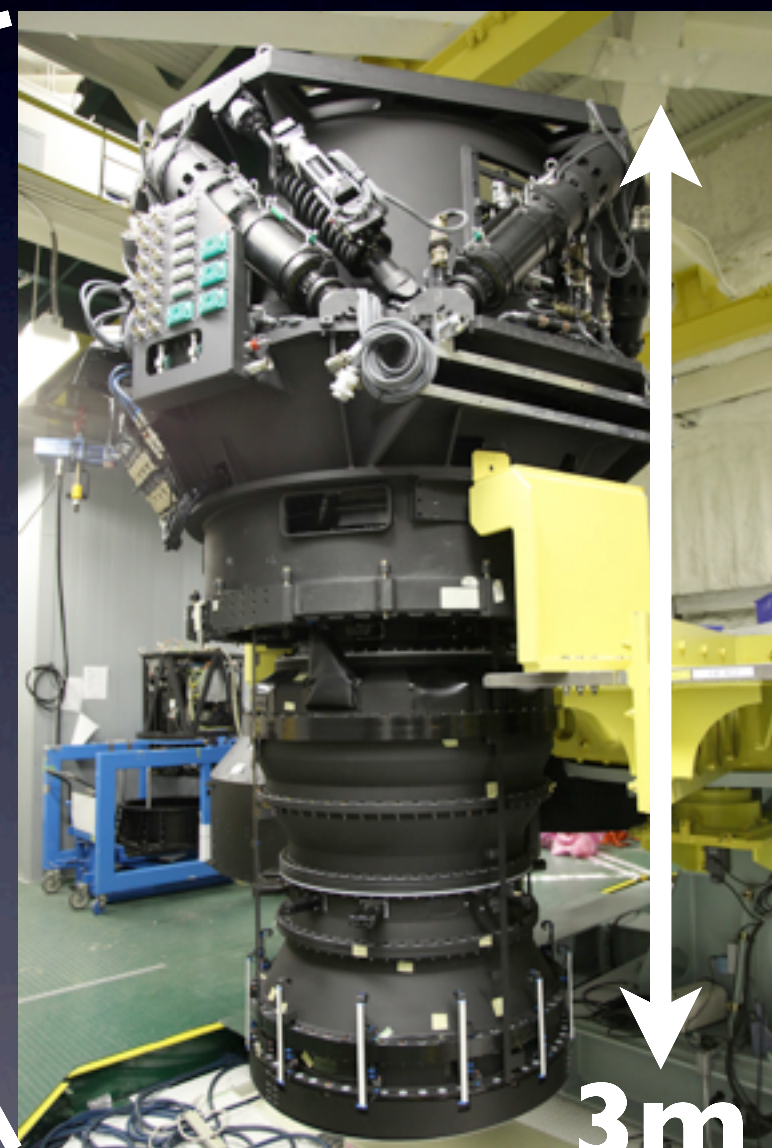
Transient survey with Subaru/HSC (2014-)

Superluminous supernovae at z ~ 5-6

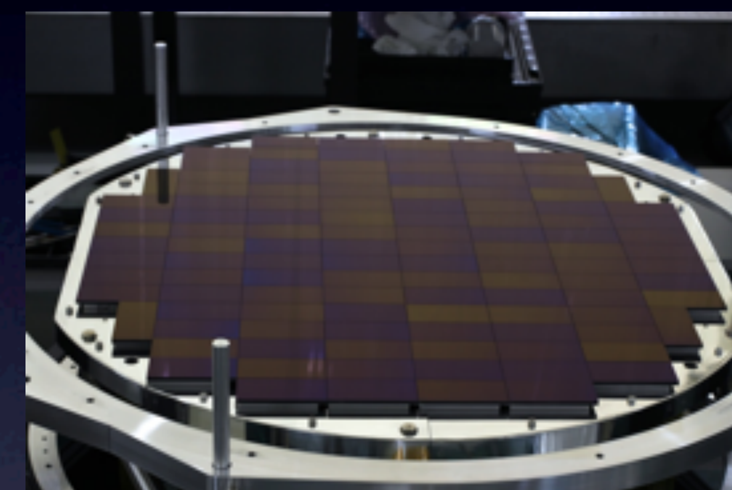


Subaru and Hyper Suprime-Cam





3t !



104 CCDs

~ 900 Megapixel

Summary

- "Normal" supernovae: difficult to detect @ $z > 6$
- "Superluminous" supernovae
  - kinetic powered, radioactively powered, and...
  - Detail of the progenitor is still mystery
- Planned NIR survey can detect SLSNe up to $z \sim 10$
  - Late 2010 and 2020-
  - $z \sim 15$ with dedicated NIR survey (2000 deg^2)
- Lower-redshift survey is critical
  - progenitor, metallicity dependence, and completeness
  - Survey with Subaru is ongoing