Section 8.
Radiation from supernovae (I)

8.1 Observations of supernovae

8.2 Power source

Goals of this lecture

- Standard properties of stars
  - Stellar structure and properties
  - Stellar evolution
- Origin of the elements in the Universe
  - Nucleosynthesis in stars and supernovae
  - Explosion mechanism of supernovae
- Topics in time-domain astronomy
  - Radiation from explosive phenomena
  - Multi-messenger astronomy

Minimum required knowledge for galactic astronomy

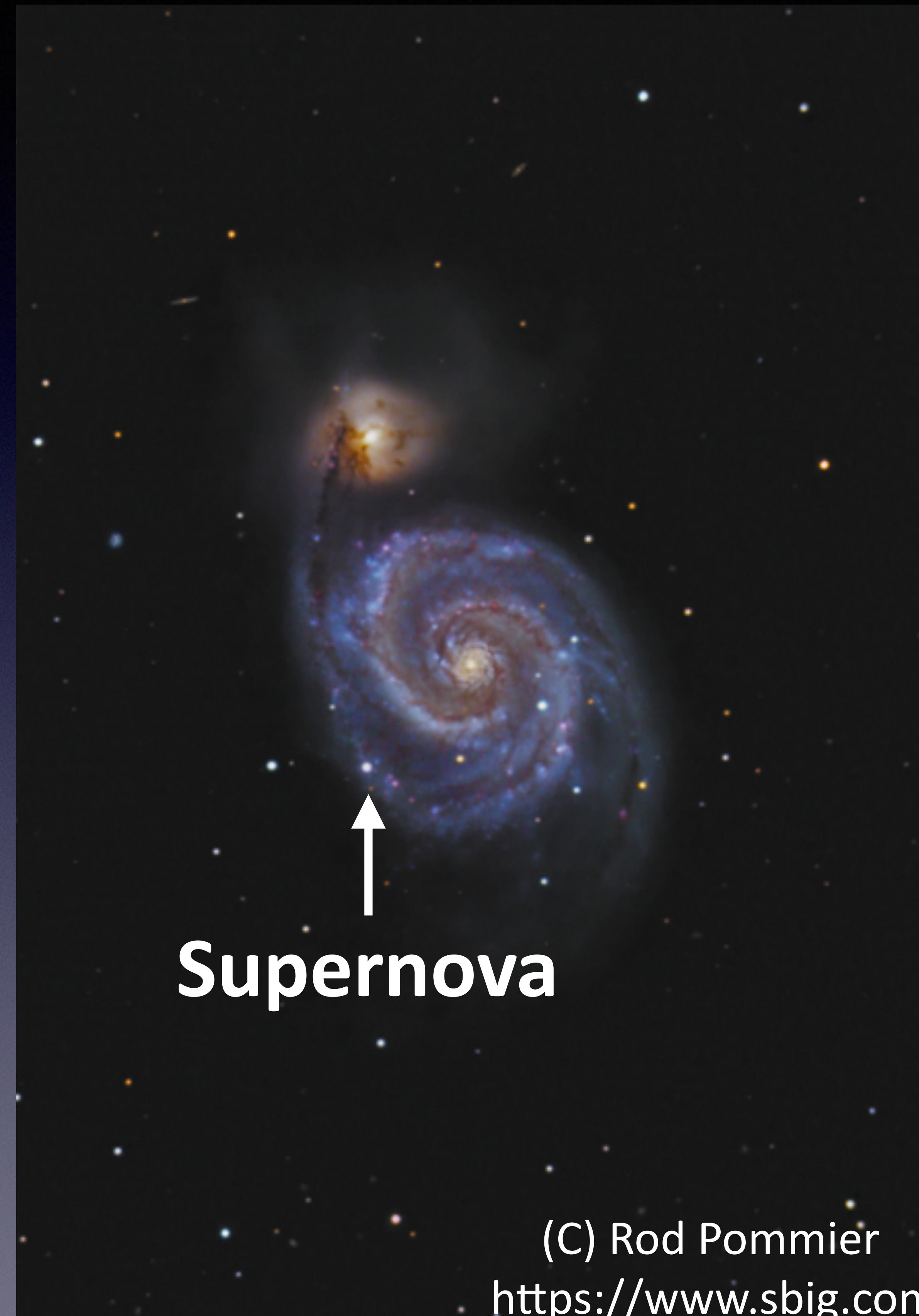
Spot the difference!!

Answer

Spot the difference!
(level **)

(C) Rod Pommier
https://www.sbig.com

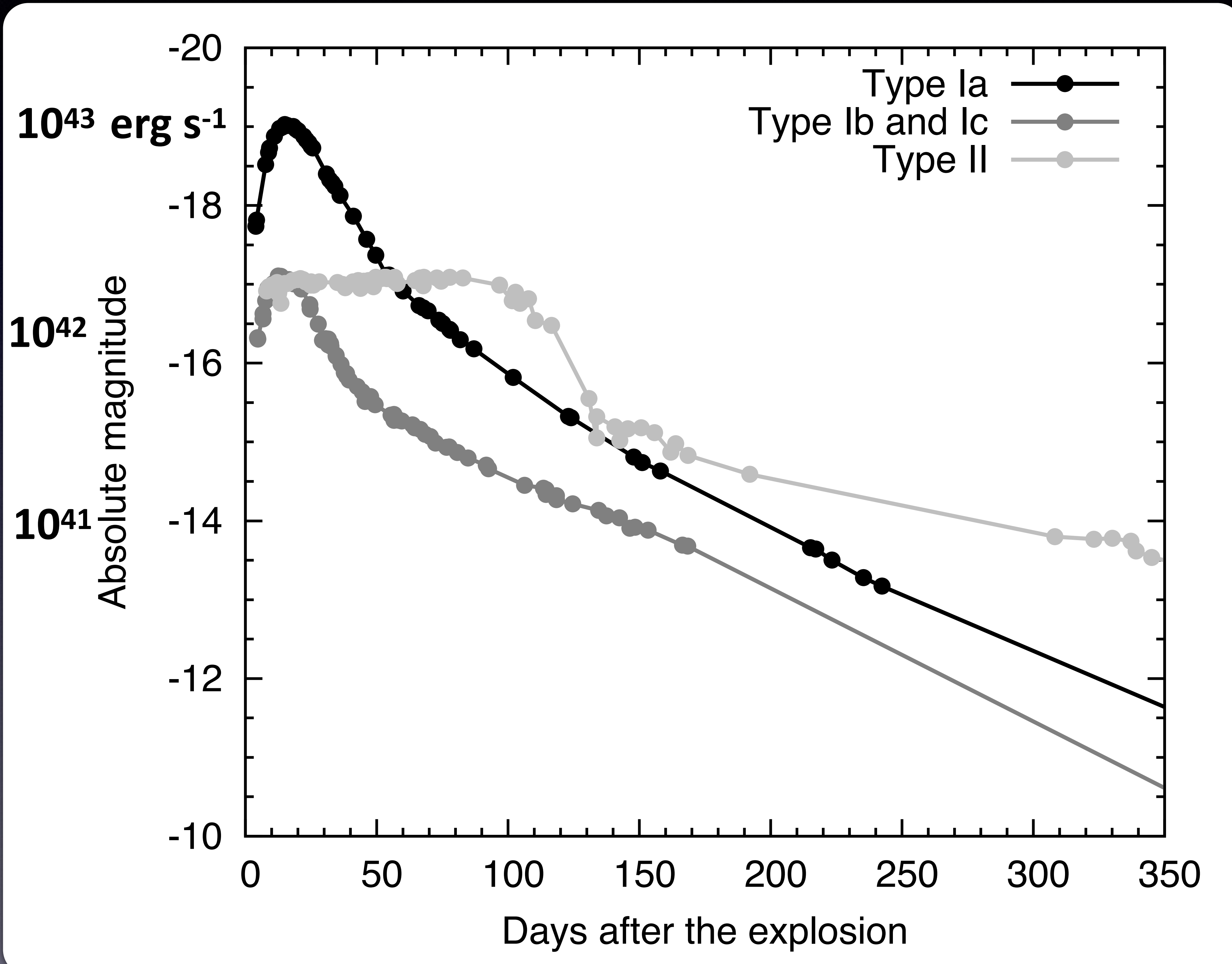
Answer



Observations of transients

- **Light curve**
  - Time evolution of luminosity (total or in a certain band)
- **Spectra**
  - Flux as a function of wavelengths (and their time evolution)

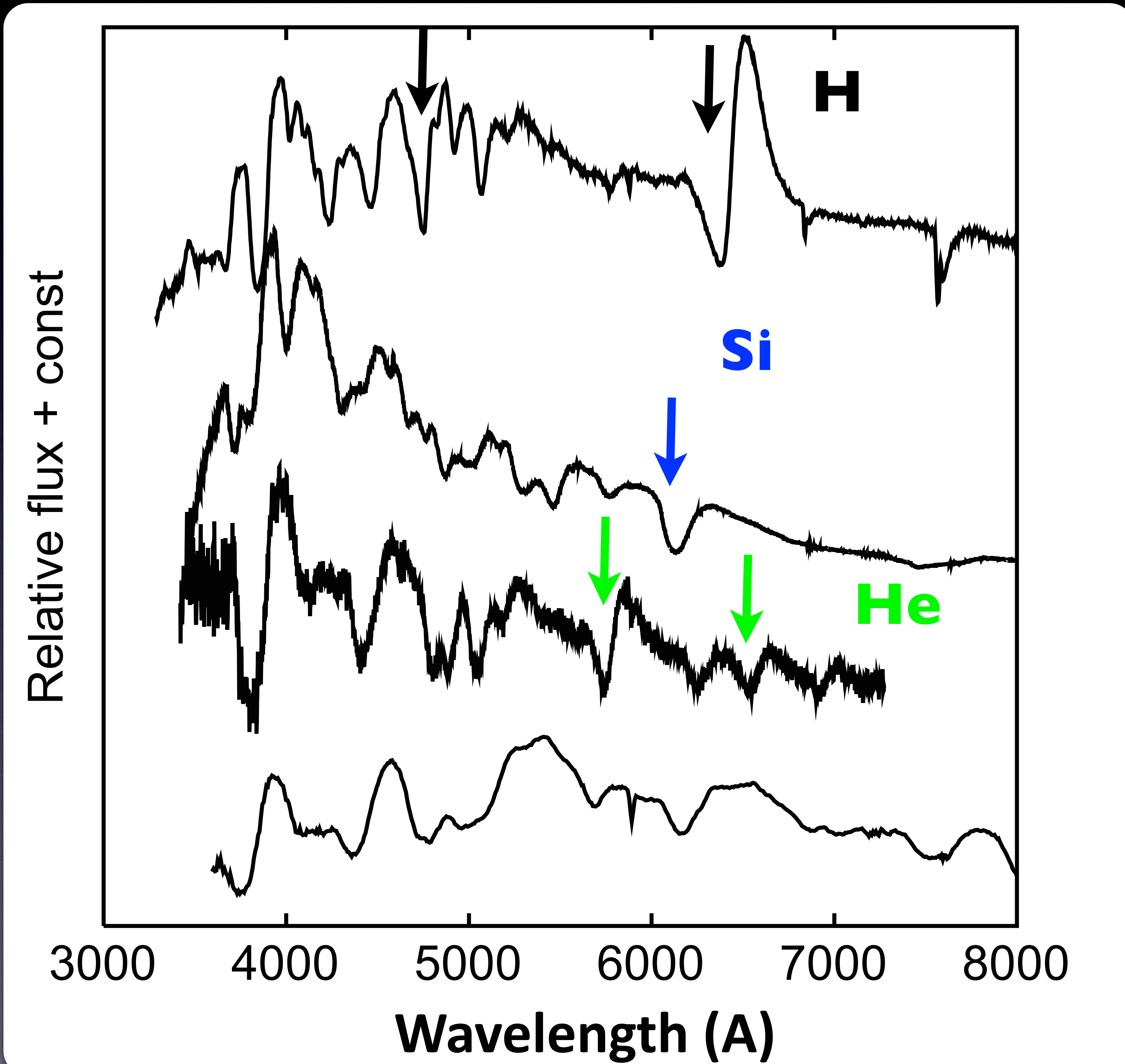
Light curves



Type I
- Peak
- L(Ia) > L(Ib, Ic)

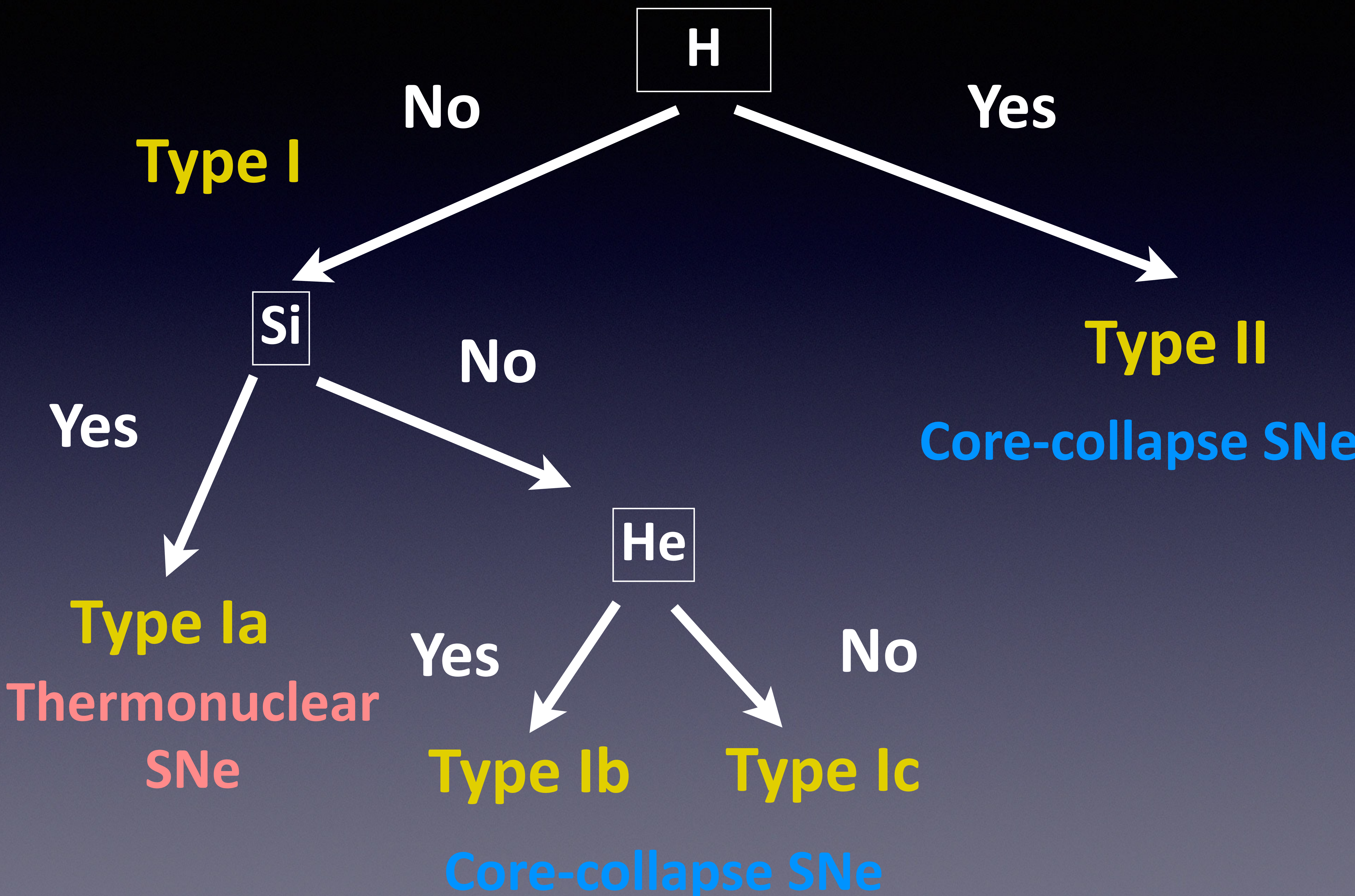
Type II
- plateau
- L(Ia) > L(II)

Spectra of supernovae

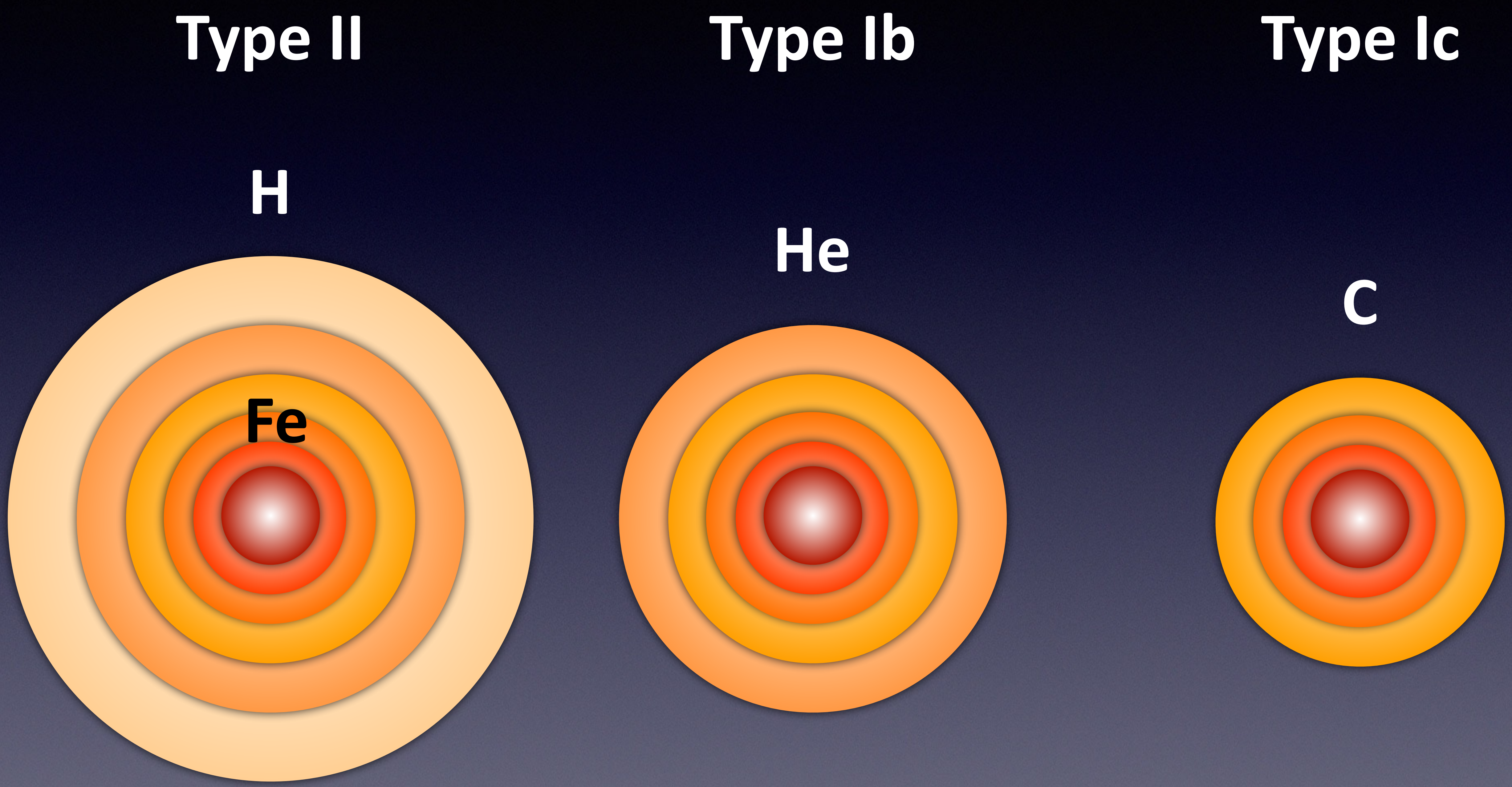


- Thermal continuum
- Broad absorption
- Doppler shift
- Associated with emission component

4 types of supernovae

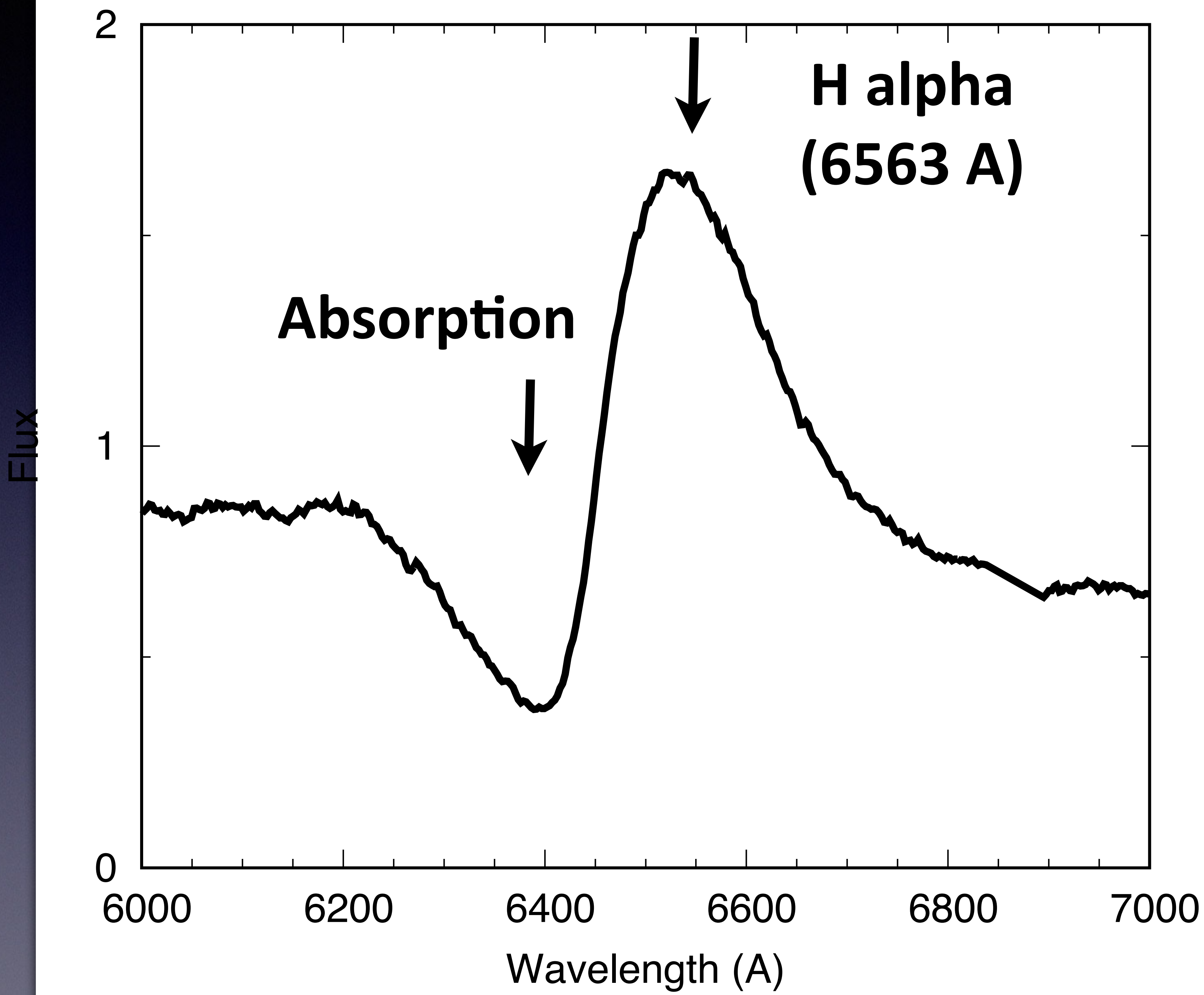


Core-collapse SNe and their progenitors



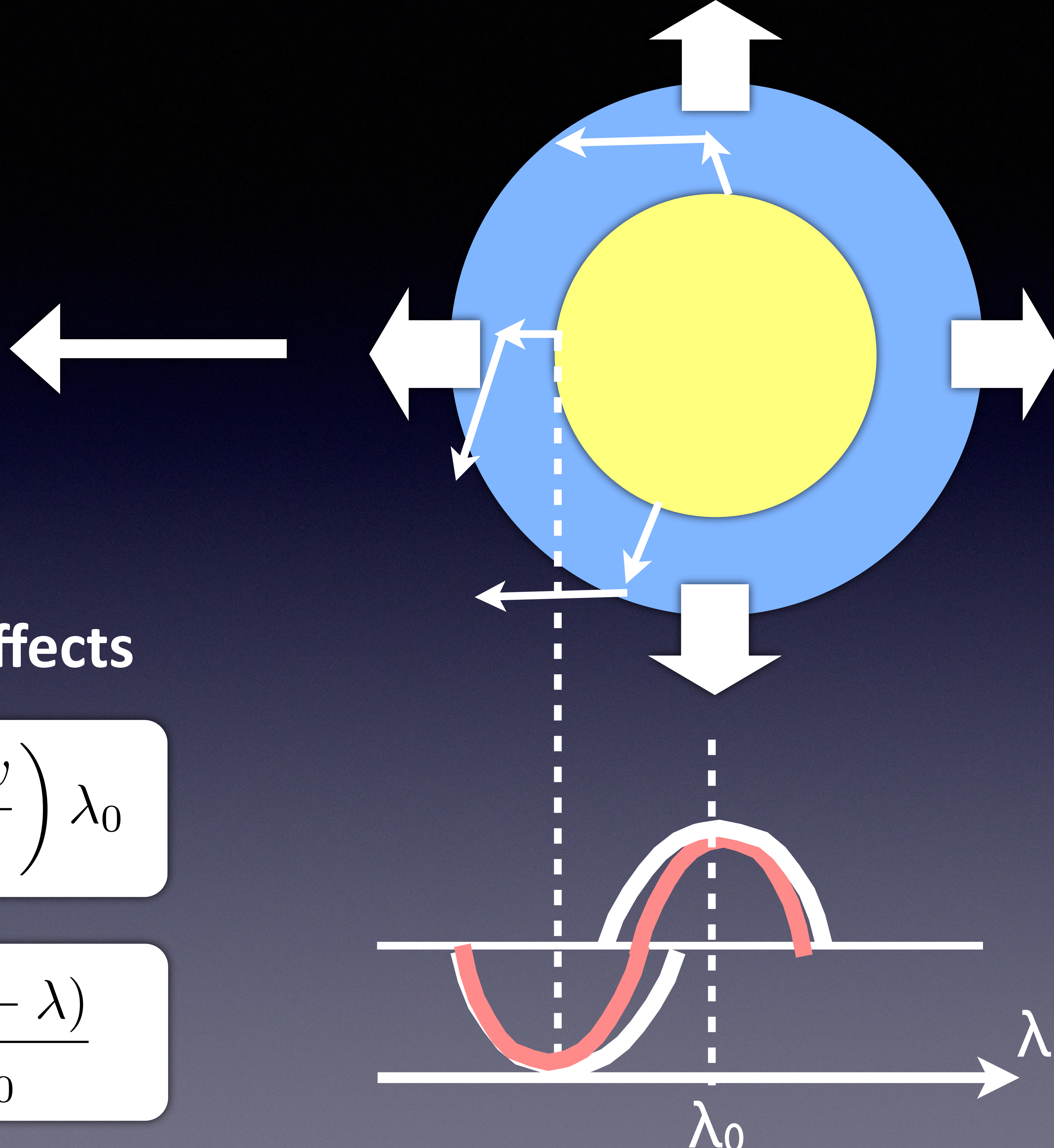
Mass loss due to stellar wind

Line profile



“P-Cygni” Profile

Observer

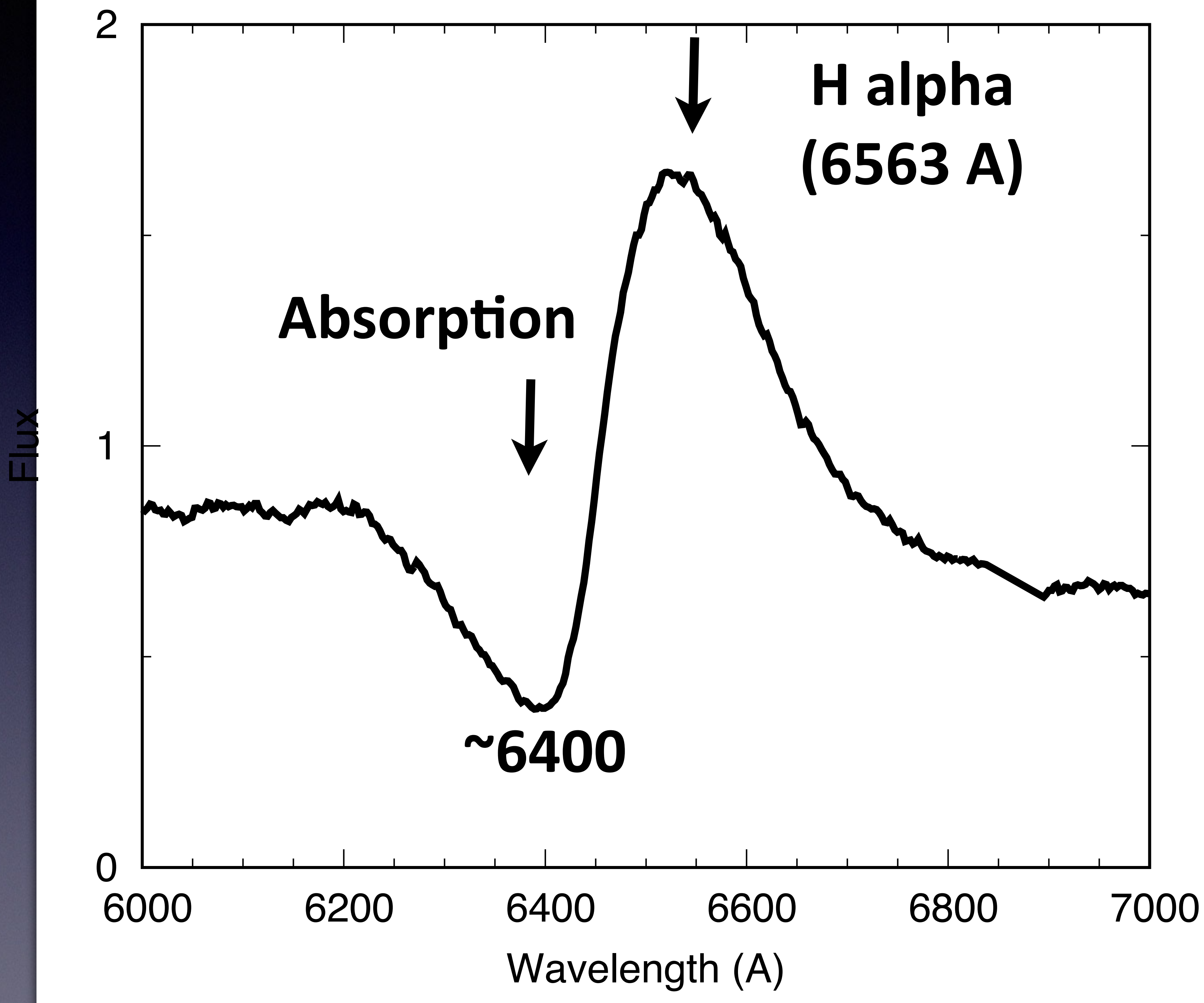


Doppler effects

$$\lambda = \left(\frac{c-v}{c}\right)\lambda_0$$

$$\frac{v}{c} = \frac{(\lambda_0 - \lambda)}{\lambda_0}$$

H line in Type II SNe



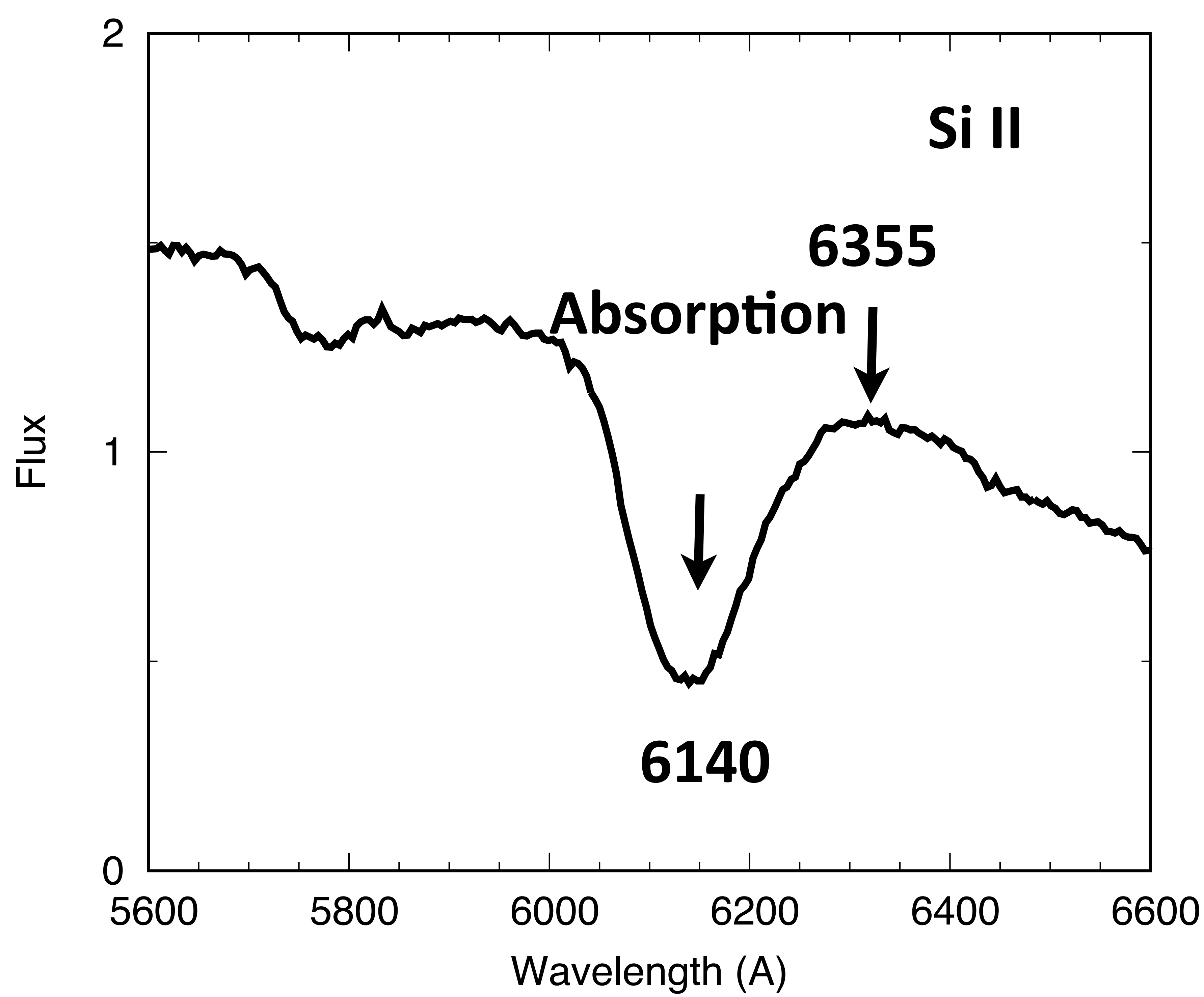
v/c = 163/6563

=>

v = 0.025 x c

~ 7,000 km/s

Si line in Type Ia SNe



v/c = 215/6355

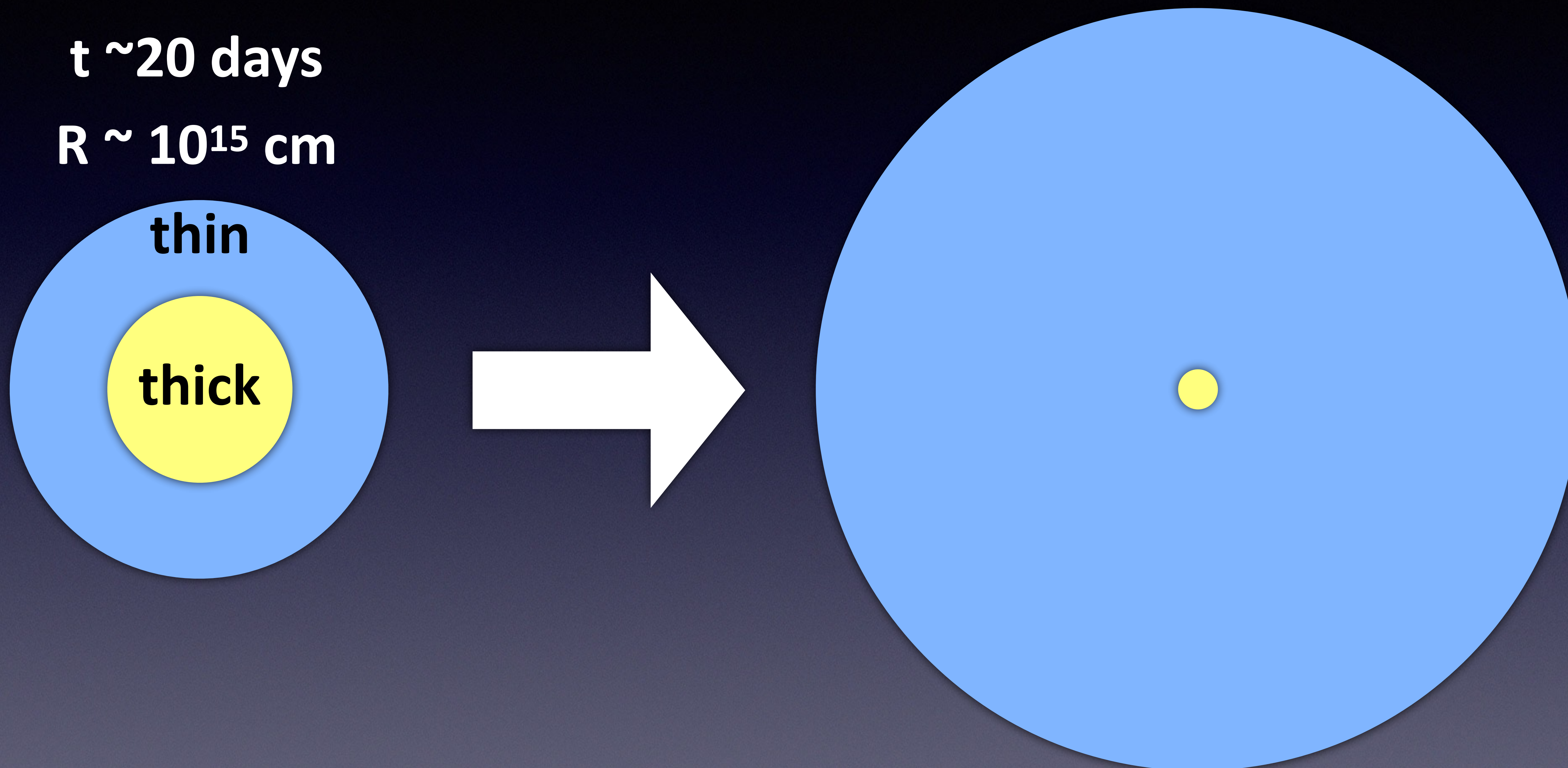
=>

v = 0.033 x c

~ 10,000 km/s

Type Ia > Type II

Time evolution of SN ejecta



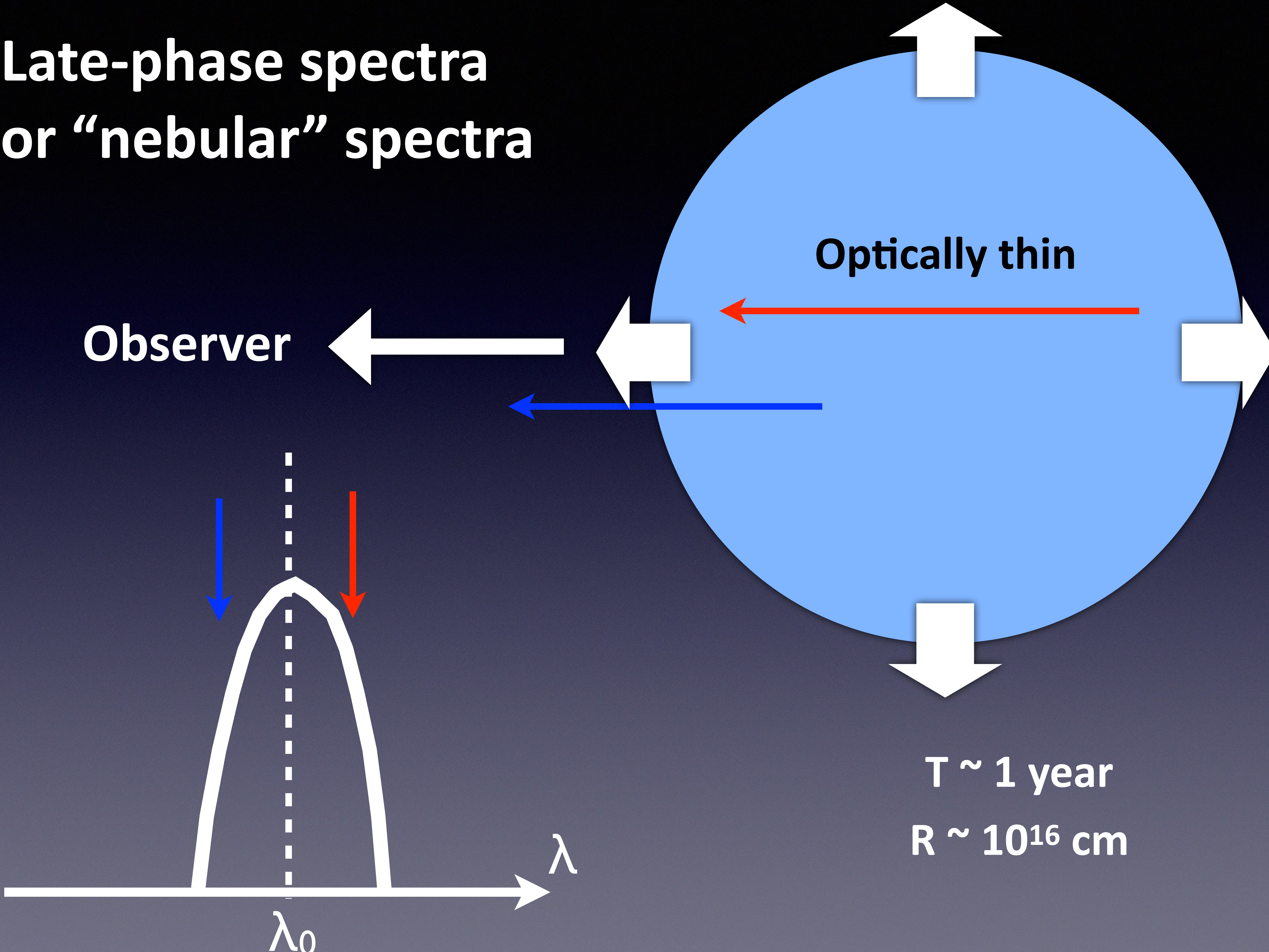
"photosphere"

No photosphere

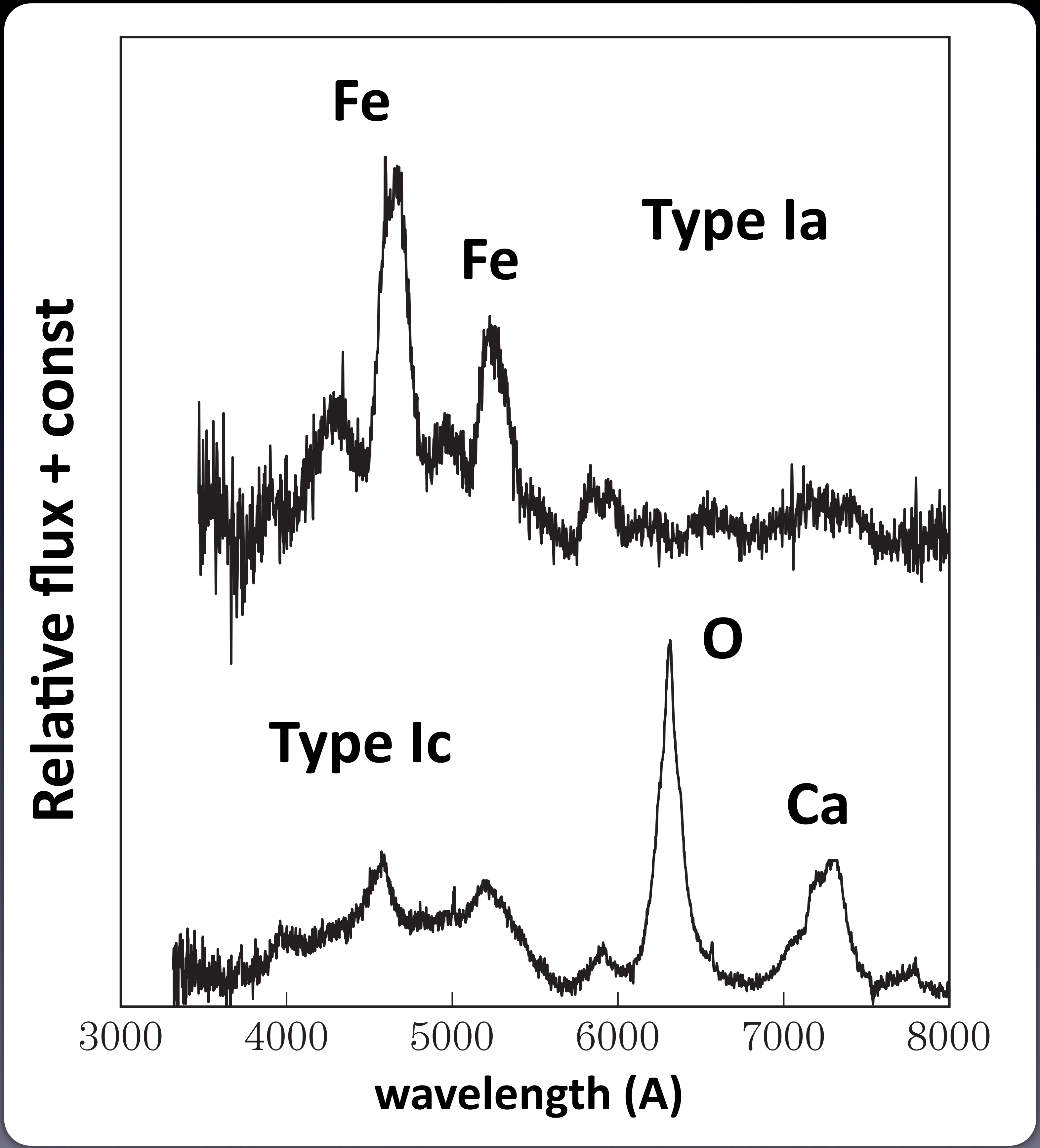
Absorption lines

Emission lines

Late-phase spectra or "nebular" spectra

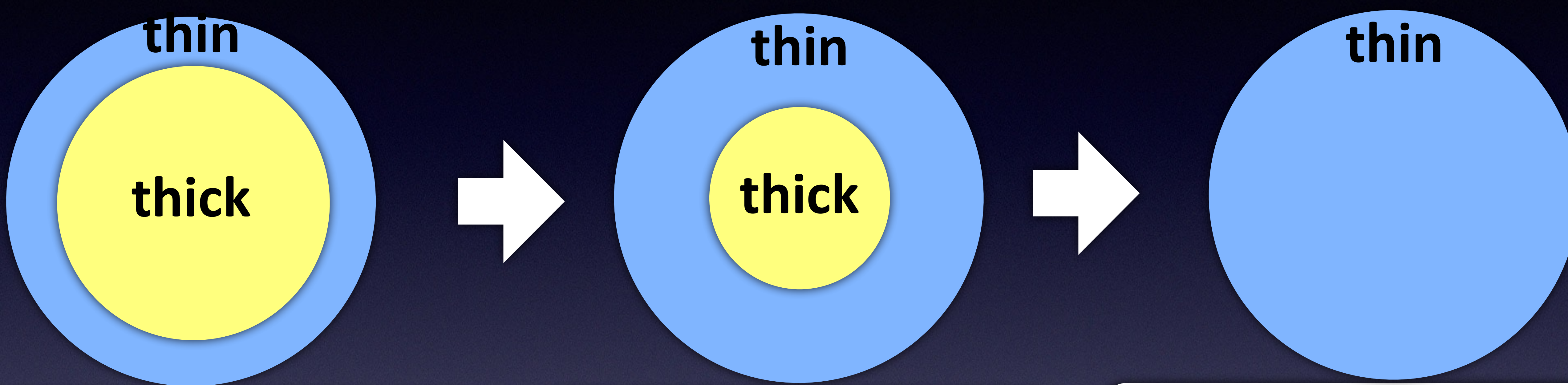


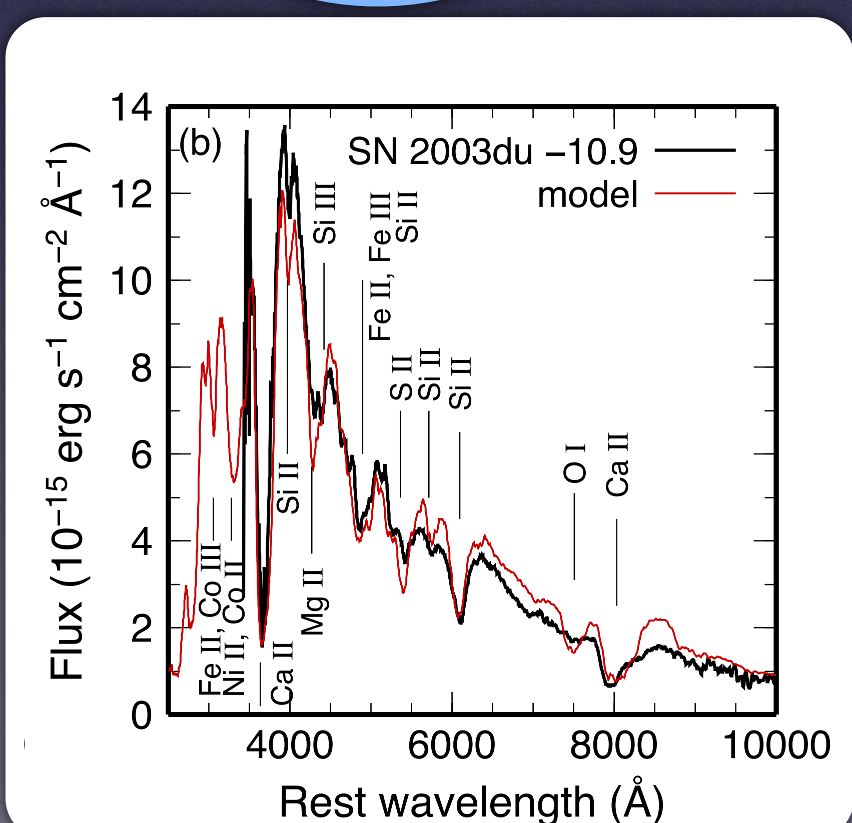
Nebular spectra

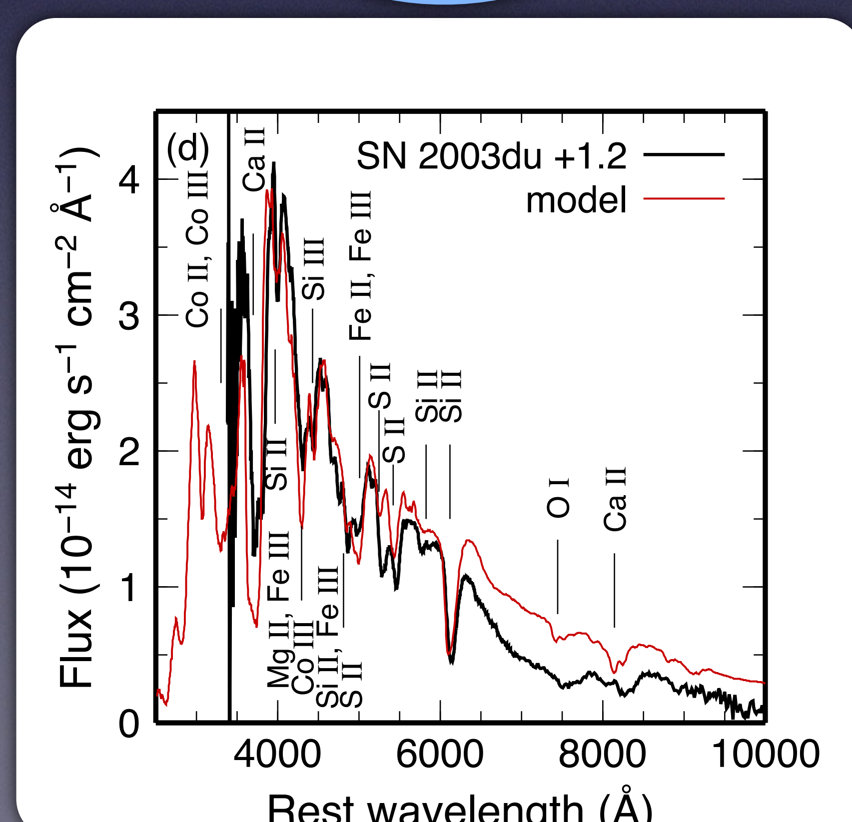


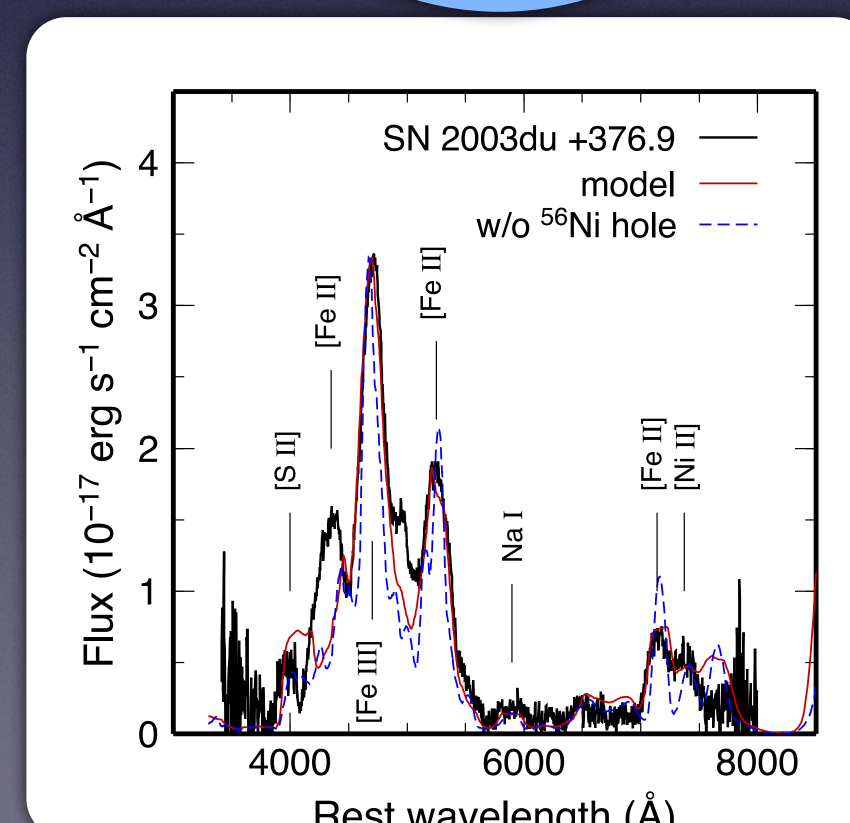
Abundance profiling

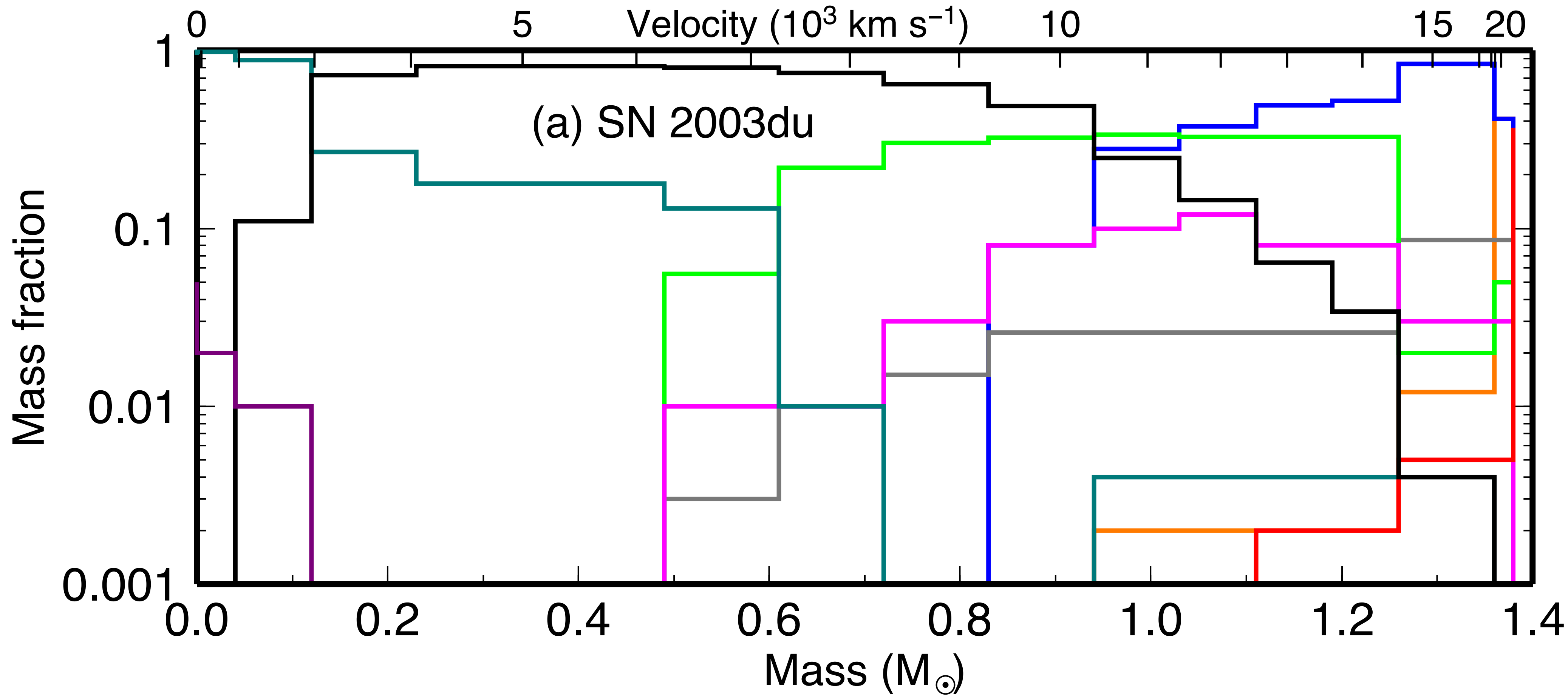
~ a few days ~ 20 days ~ 1 year



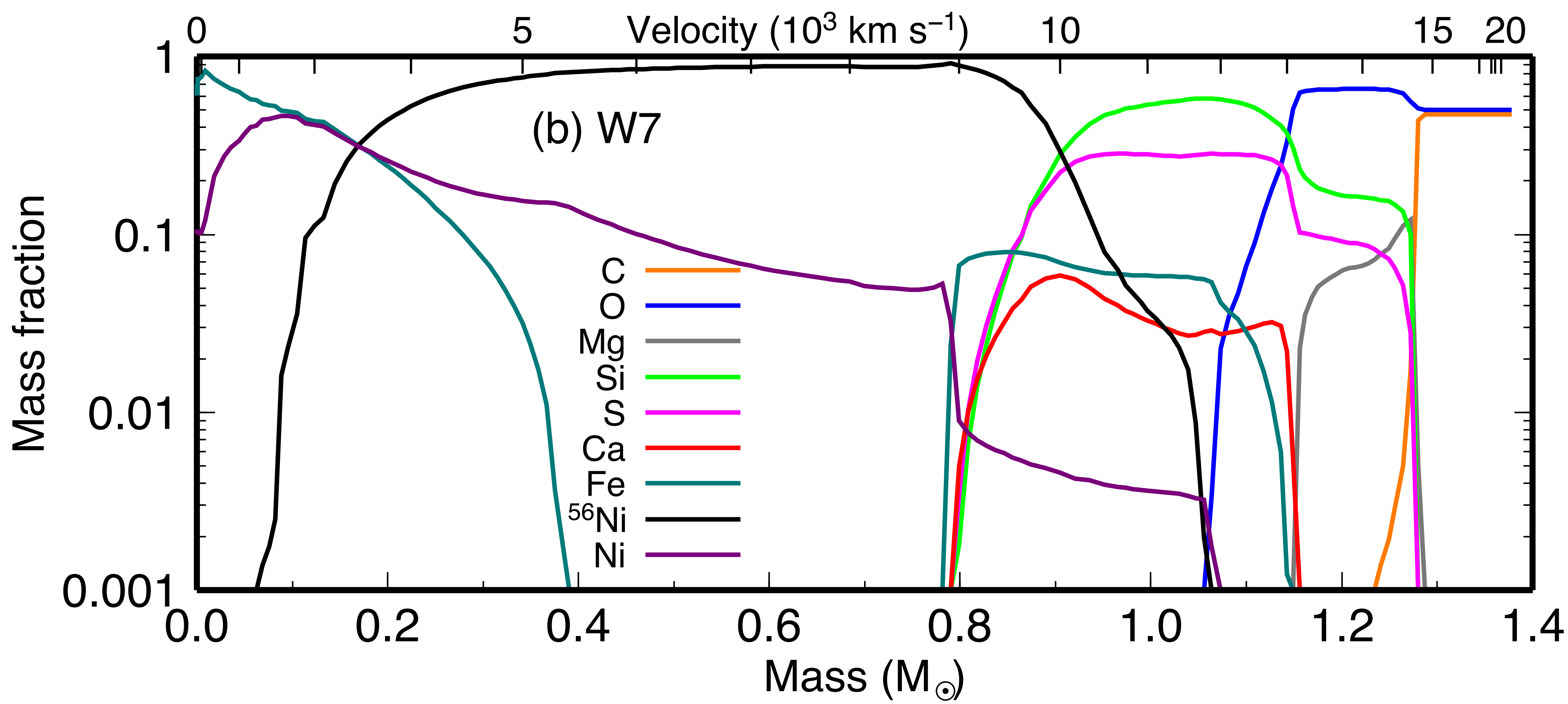








Obs



Theory

Tanaka+10

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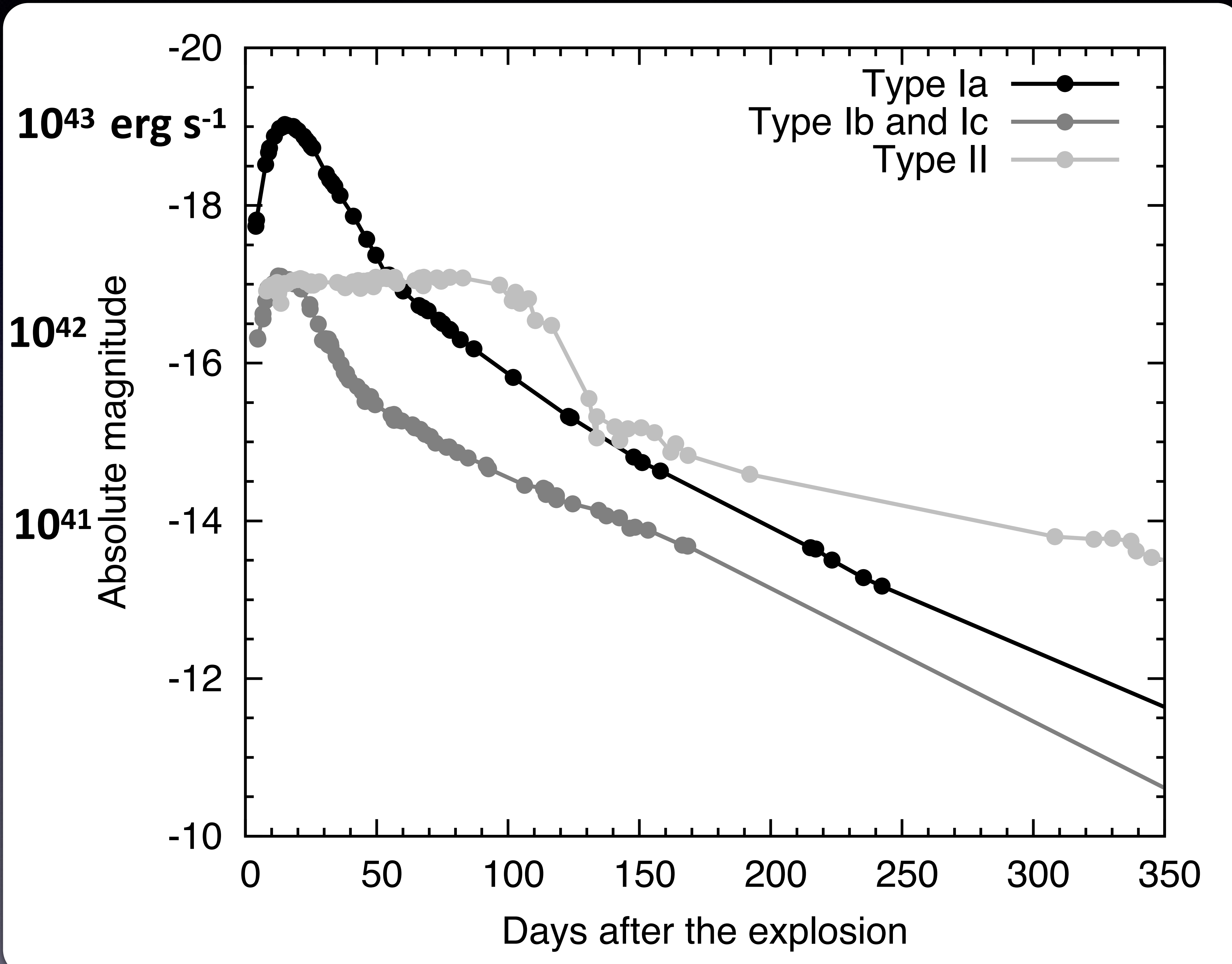
8.2 Power source

Light curves



Type I
- Peak
- L(Ia) > L(Ib, Ic)

Type II
- plateau
- L(Ia) > L(II)

What powers the extreme luminosity of supernovae?

What can we learn from observations?

Heating source of supernovae

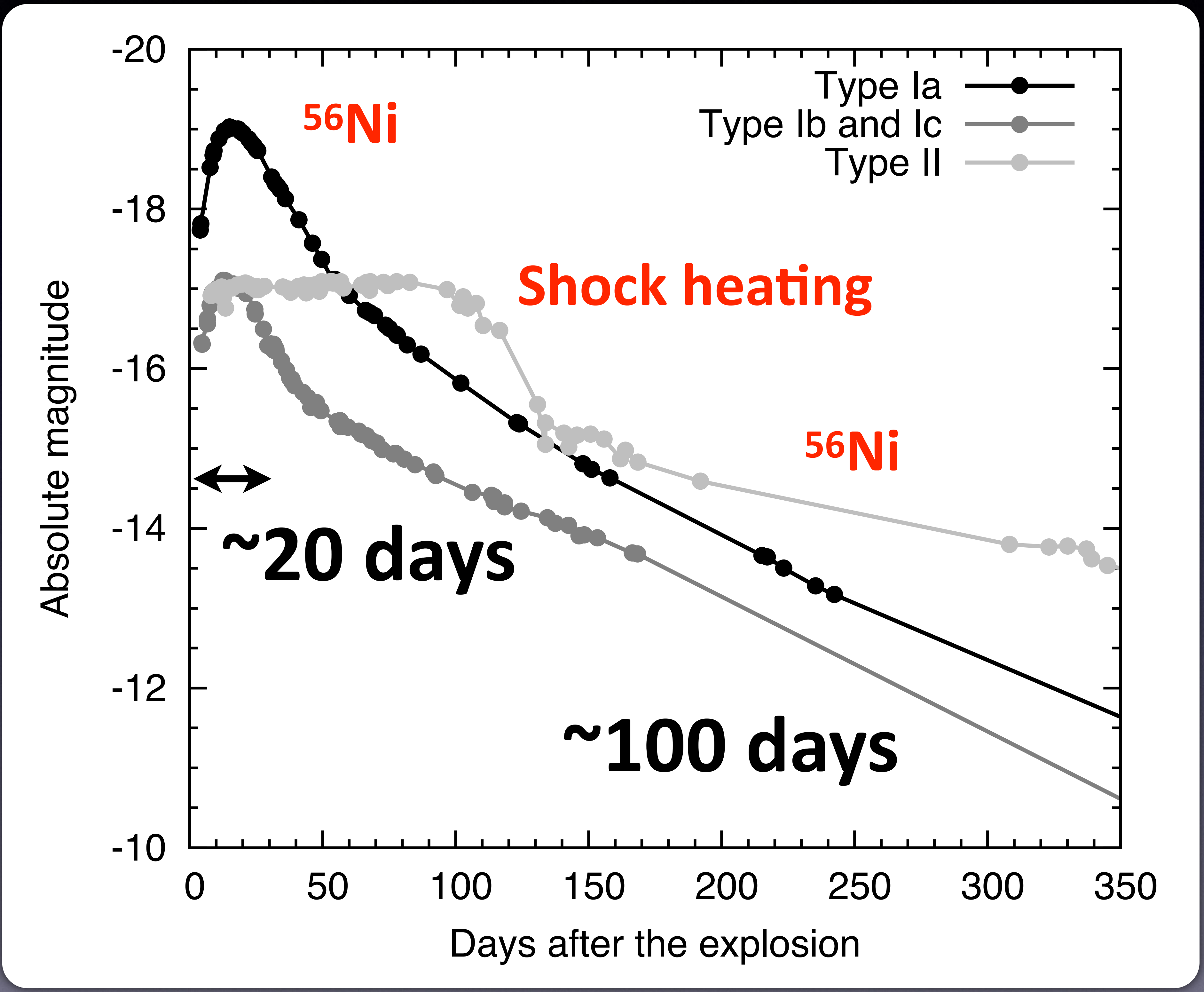
1. **Radioactivity (^{56}Ni)**
   Important in all the types
   Type Ia > Core-collapse

2. **Shock heating**
   Important for large-radius star (Type II)

3. **Interaction with CSM**
   Ekin => Eth (Type IIn)

4. **Magnetar?**
   Erot => energy loss by spin down

Light curves



10^{43} erg s^{-1}

10^{42} erg s^{-1}

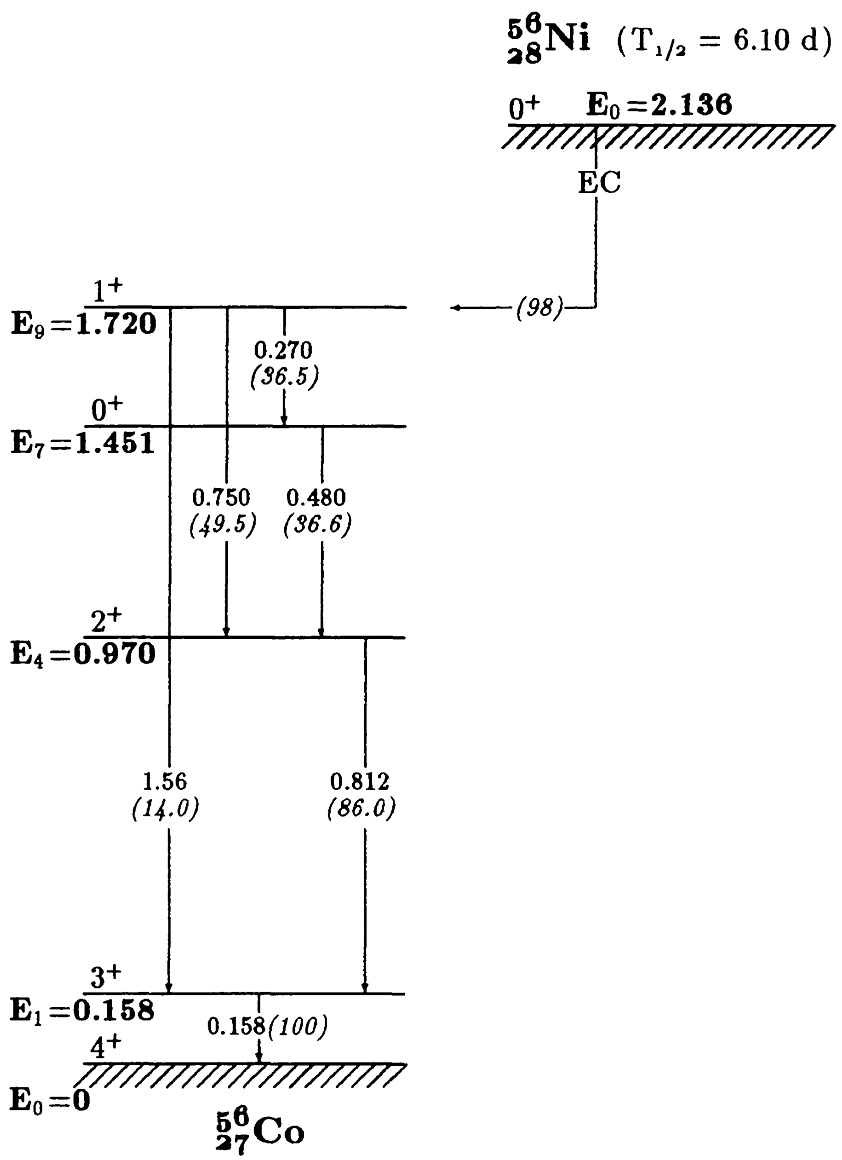
Type Ia SNe eject more ^{56}Ni

^{56}Ni

e capture

$$^{56}\text{Ni} \Longrightarrow {}^{56}\text{Co} + \gamma + \nu_e \, .$$

τ = 8.8 days



^{56}Co

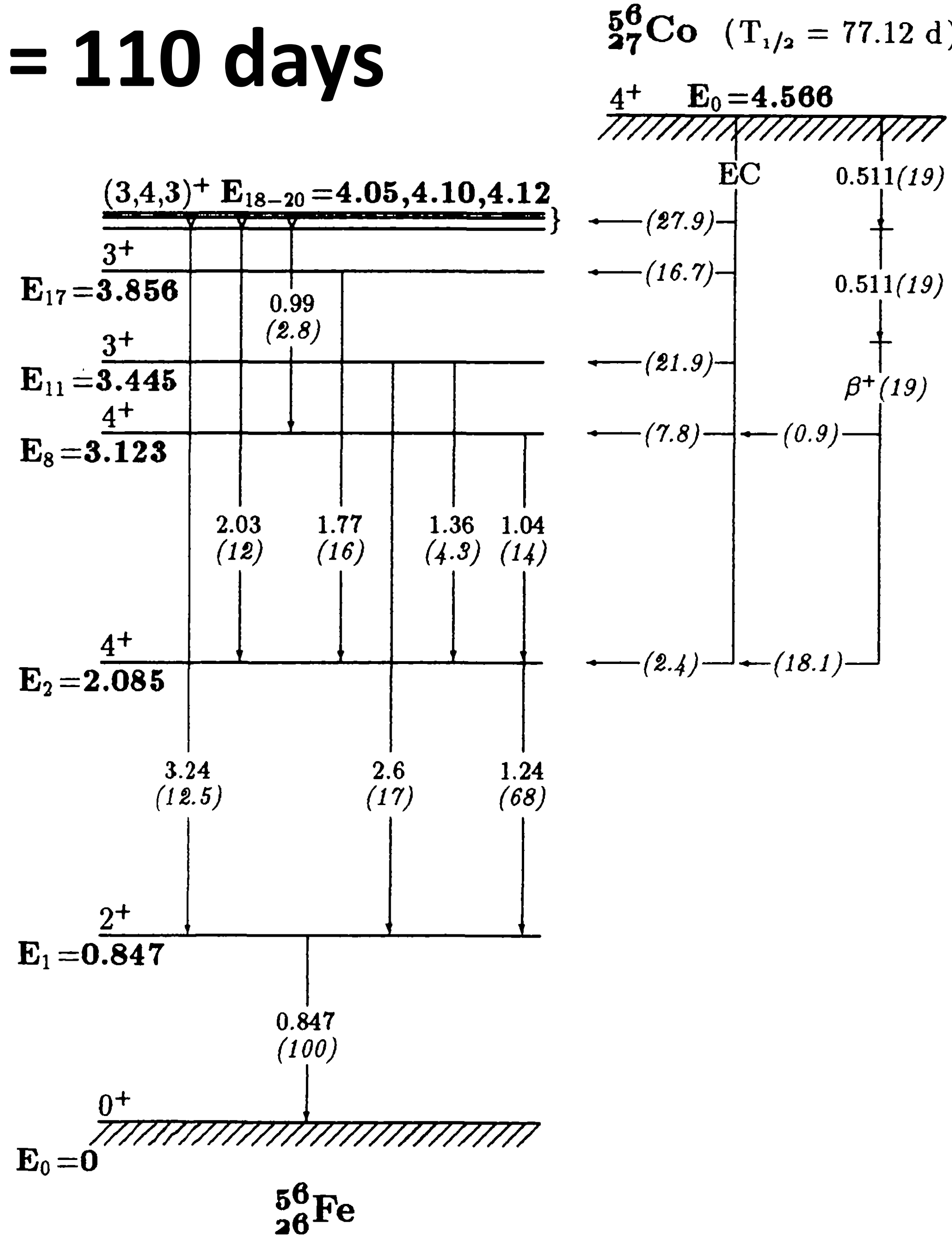
Nadyozhin 94

e capture

pos decay

$$^{56}\text{Co} \Longrightarrow \begin{cases} {}^{56}\text{Fe} + \gamma + \nu_e \\ {}^{56}\text{Fe} + e^{+} + \gamma + \nu_e \end{cases}$$

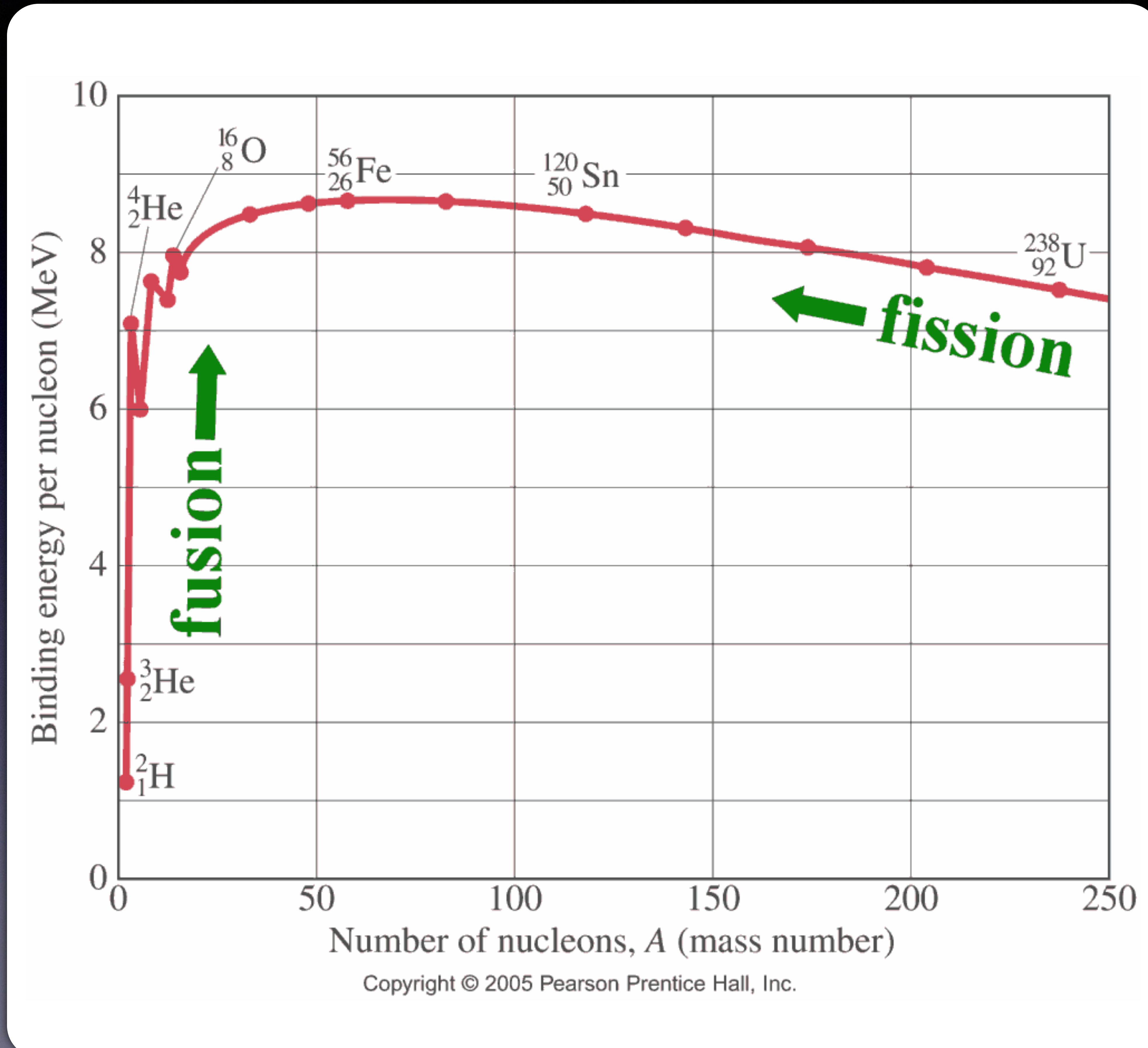
τ = 110 days



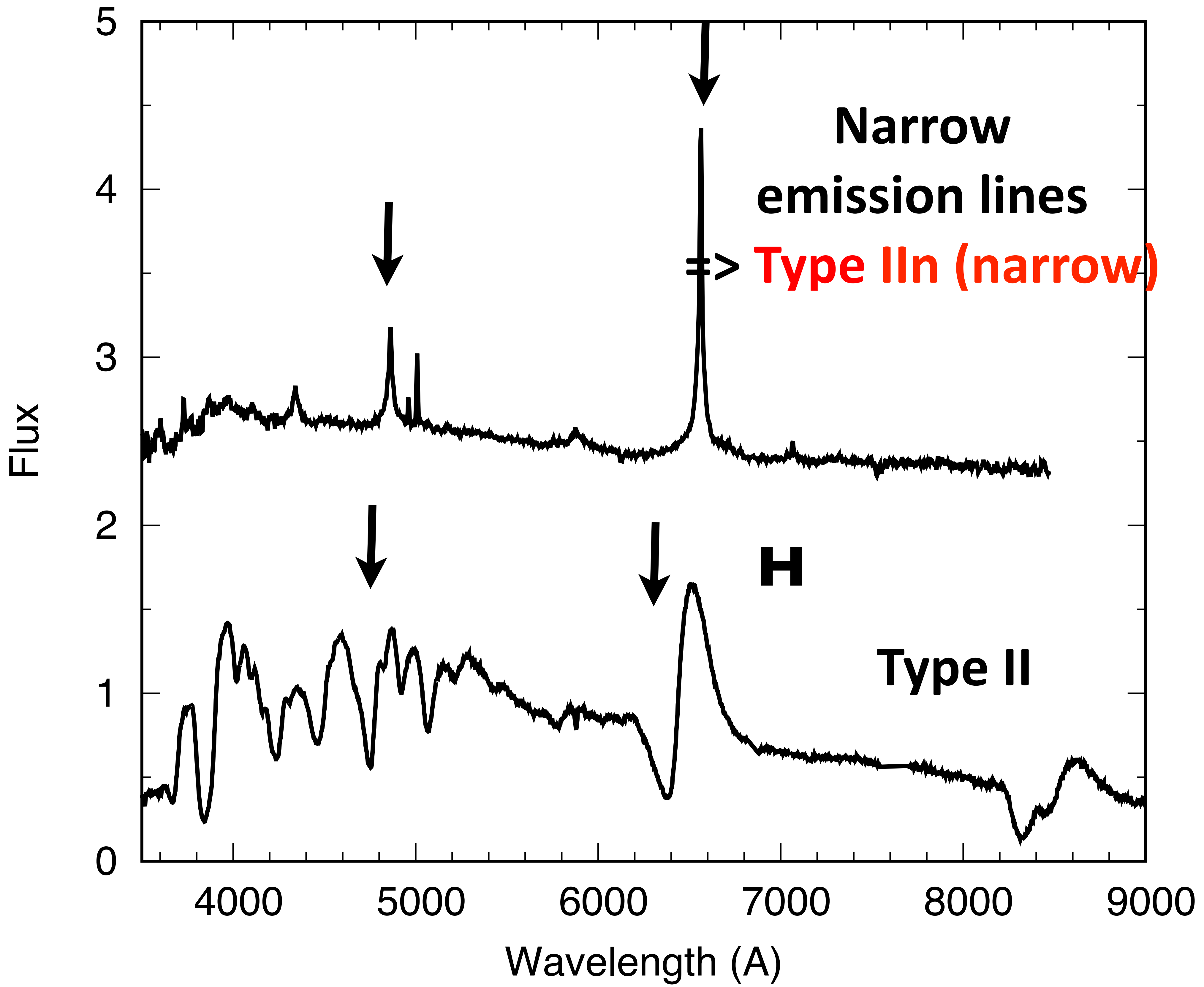
Type Ia SN

^{56}Ni

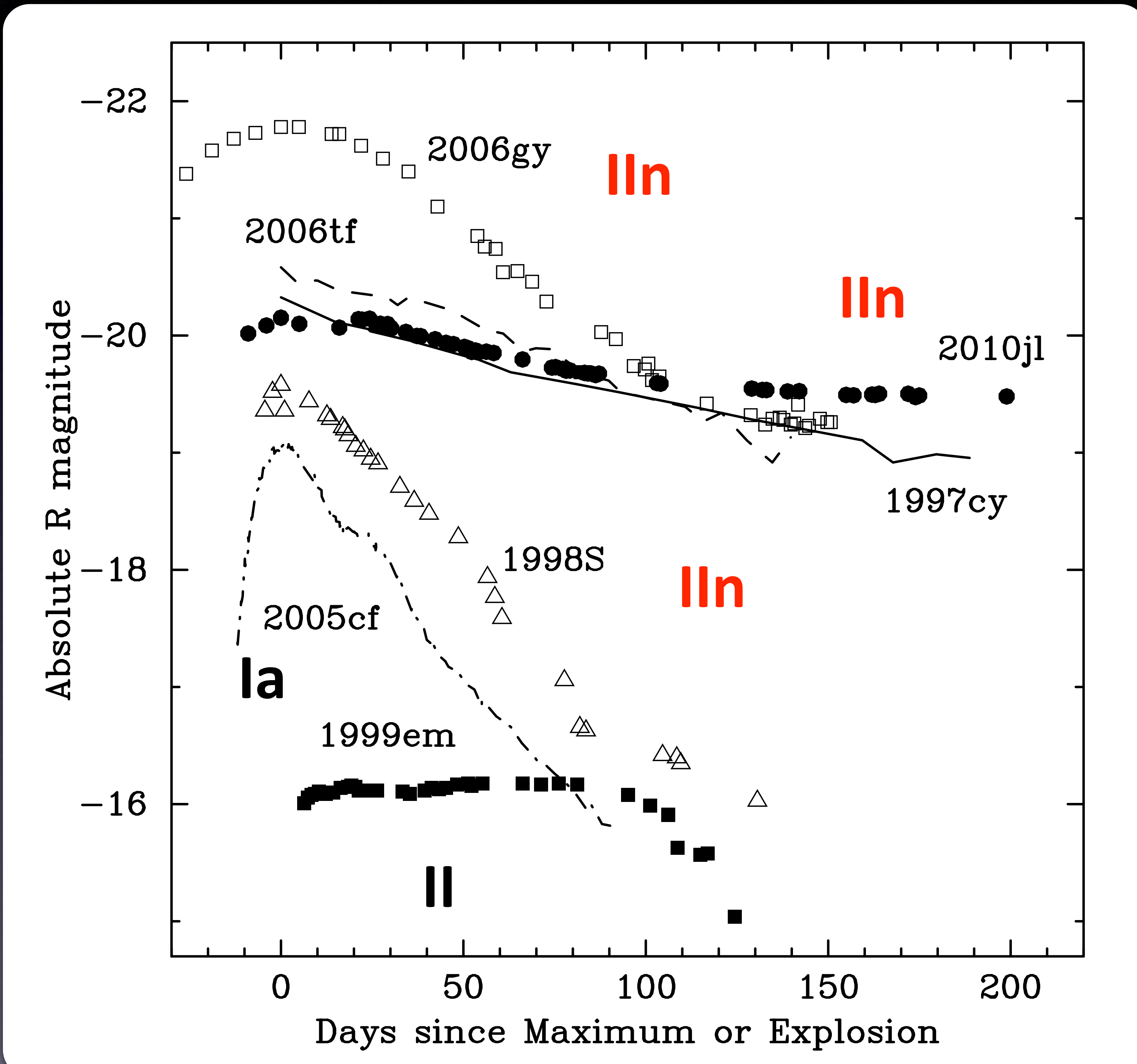
Sun



Signature of CSM interaction



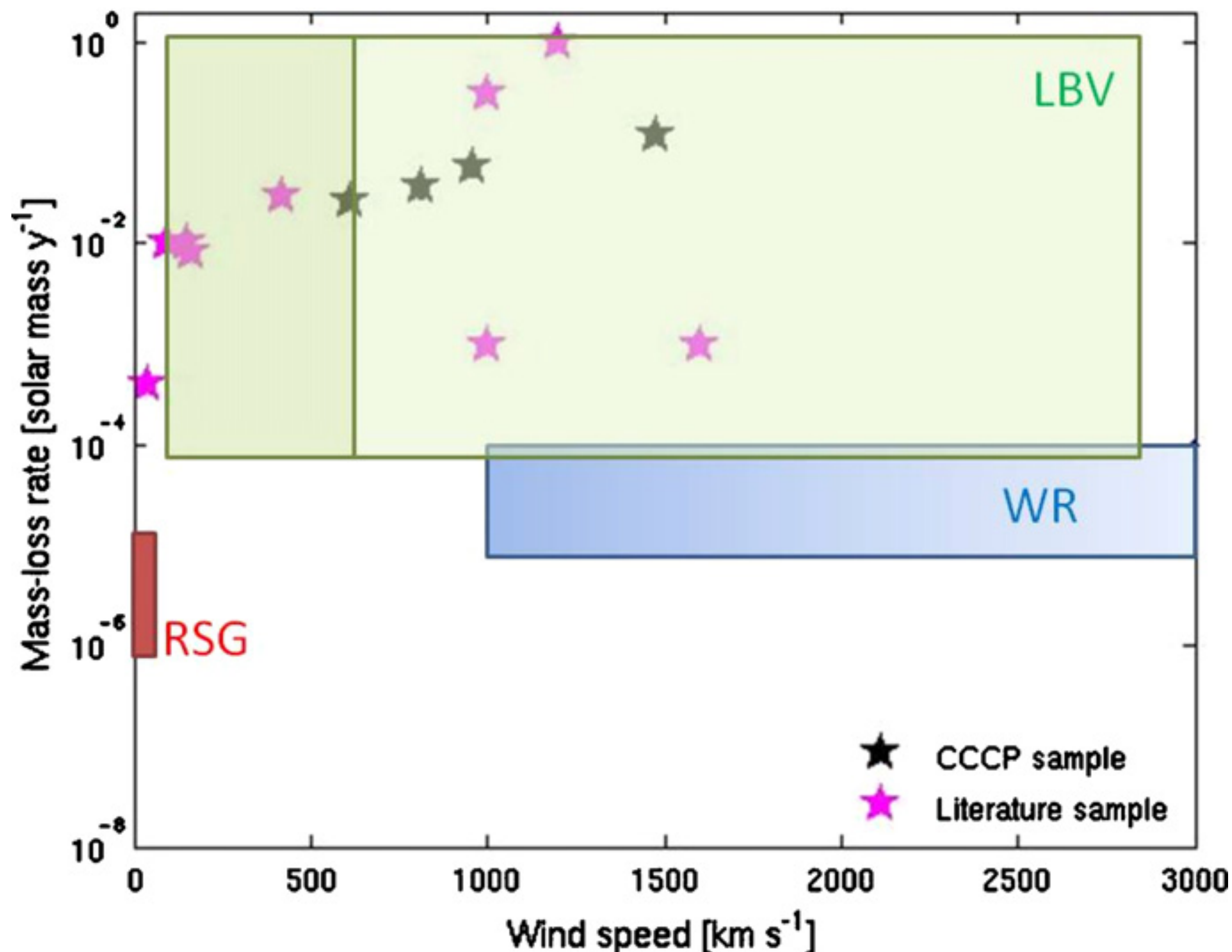
Type IIn SNe: powered from CSM interaction



Type IIn SN
- More luminous than Type II SN
- Slower evolution
- Large diversity

Zhang+12

Estimate of mass loss rate



Kiewe+2012

Signature of strong mass loss just before the explosion

Summary: Radiation from supernovae (I)

- **Erad ~ 10^{49} erg**
  << Ekin (10^{51} erg) << Egrav (10^{53} erg)
- **Power source**
  - Radioactivity (^{56}Ni)
  - Shock heating
  - Interaction with CSM, magnetar, ...
- **Lessons from observations**
  - M_Fe (Type Ia SN) > M_Fe (CC SN)
  - R (Type II SN) > R (Type Ibc SN) > R (Type Ia SN)