

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!!



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Answer

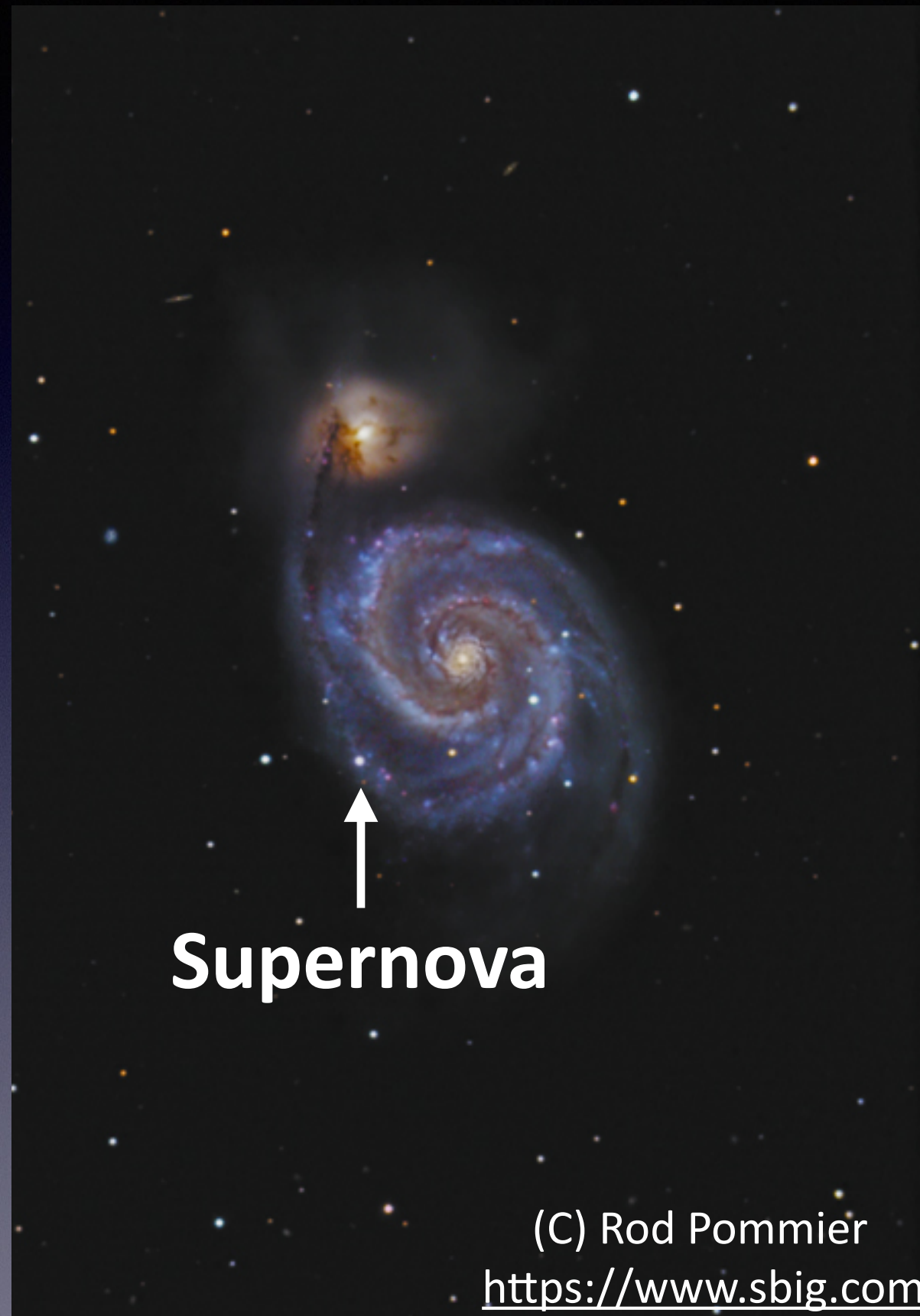


Spot the difference!
(level **)



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

Answer



Observations of transients

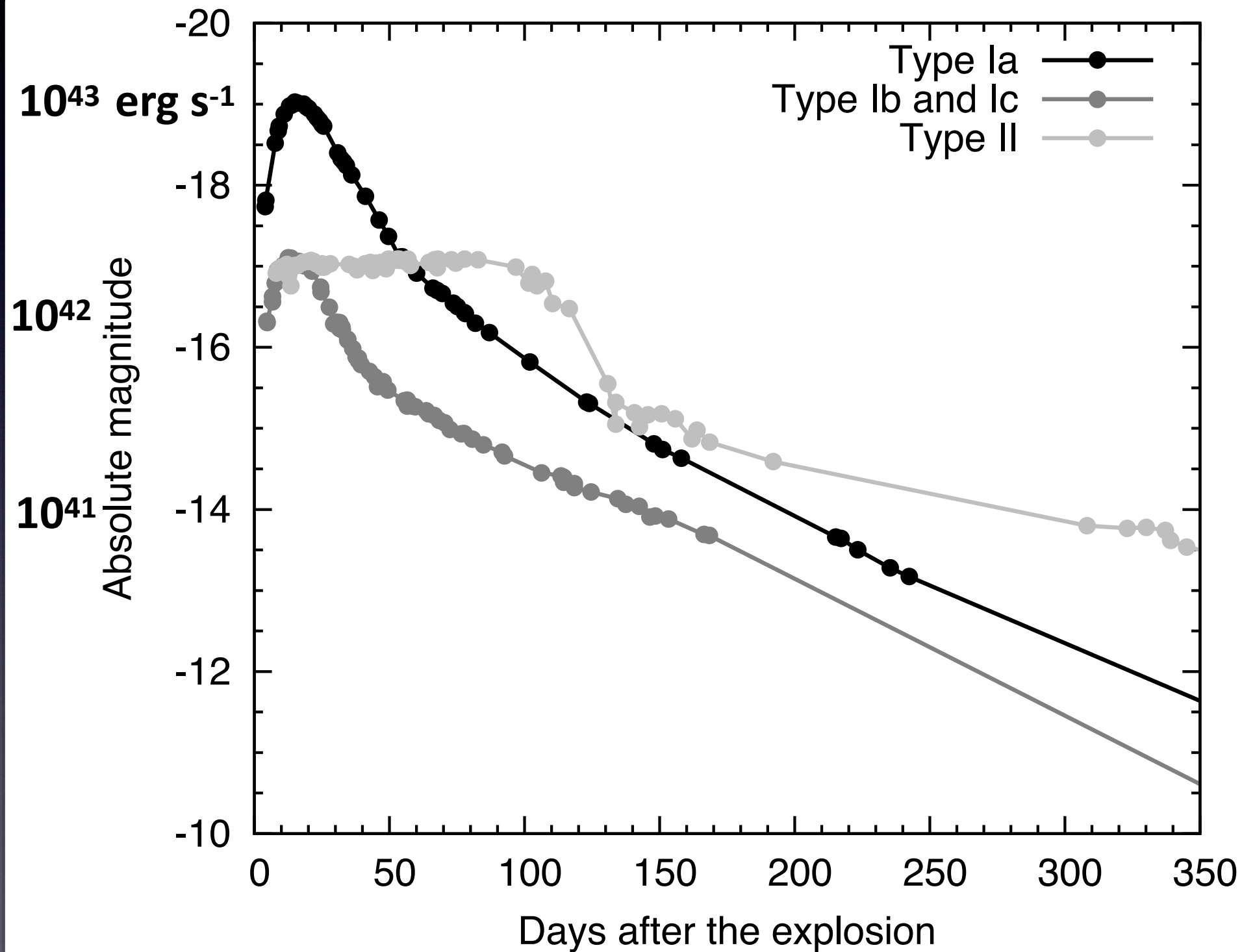
- **Light curve**

- 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

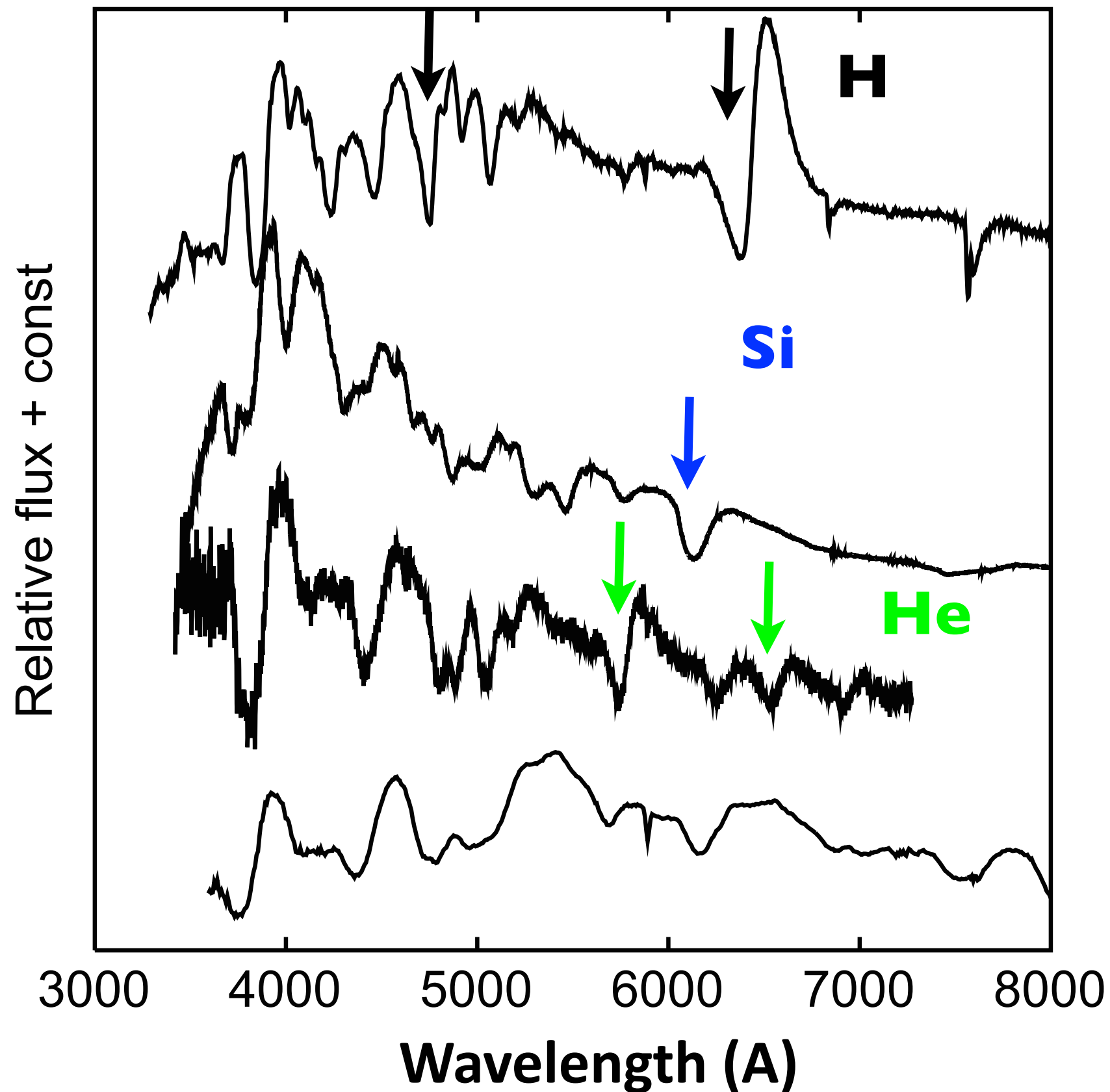
- $L(\text{Ia}) > L(\text{Ib, Ic})$

Type II

- plateau

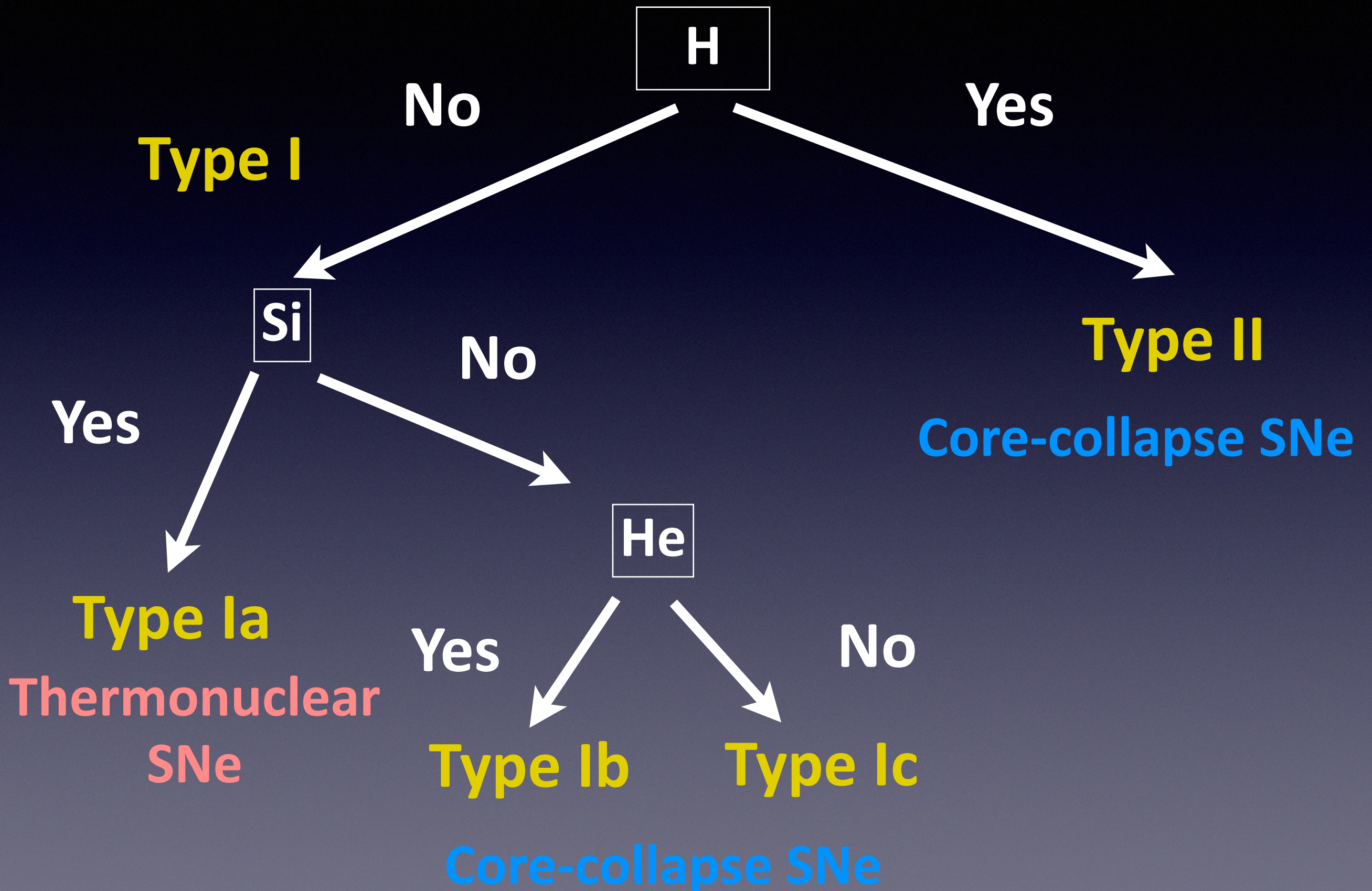
- $L(\text{Ia}) > L(\text{II})$

Spectra of supernovae



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

4 types of supernovae



Core-collapse SNe and their progenitors

Type II

Type Ib

Type Ic

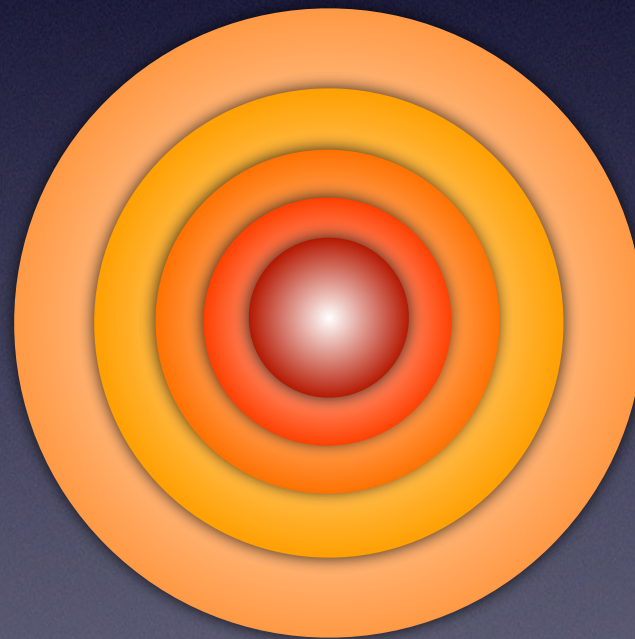
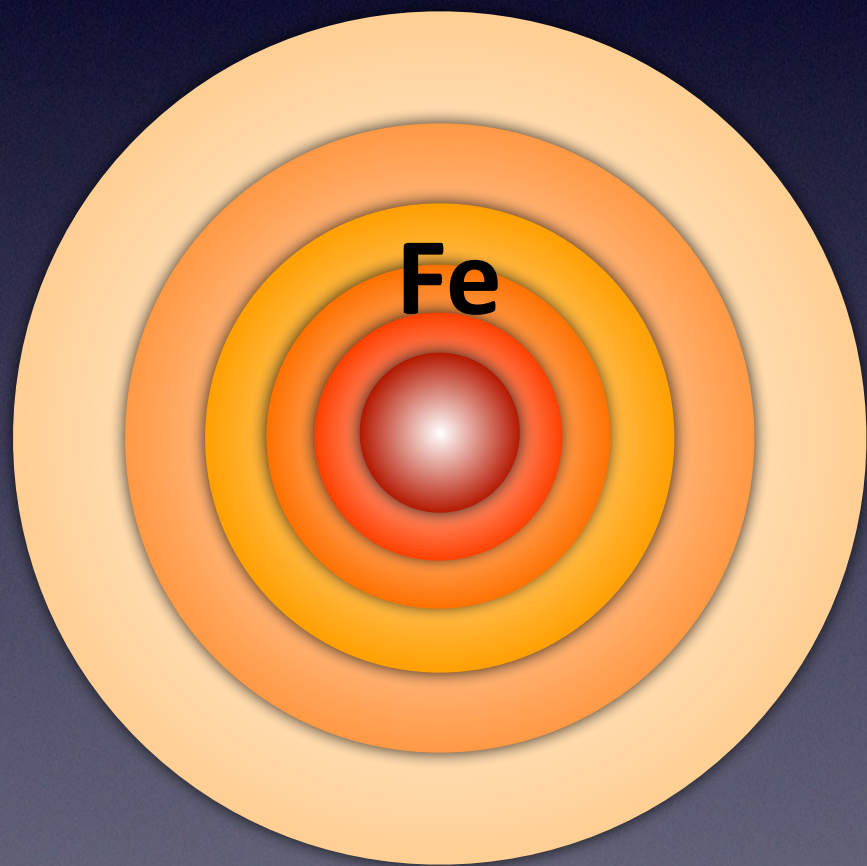
H

He

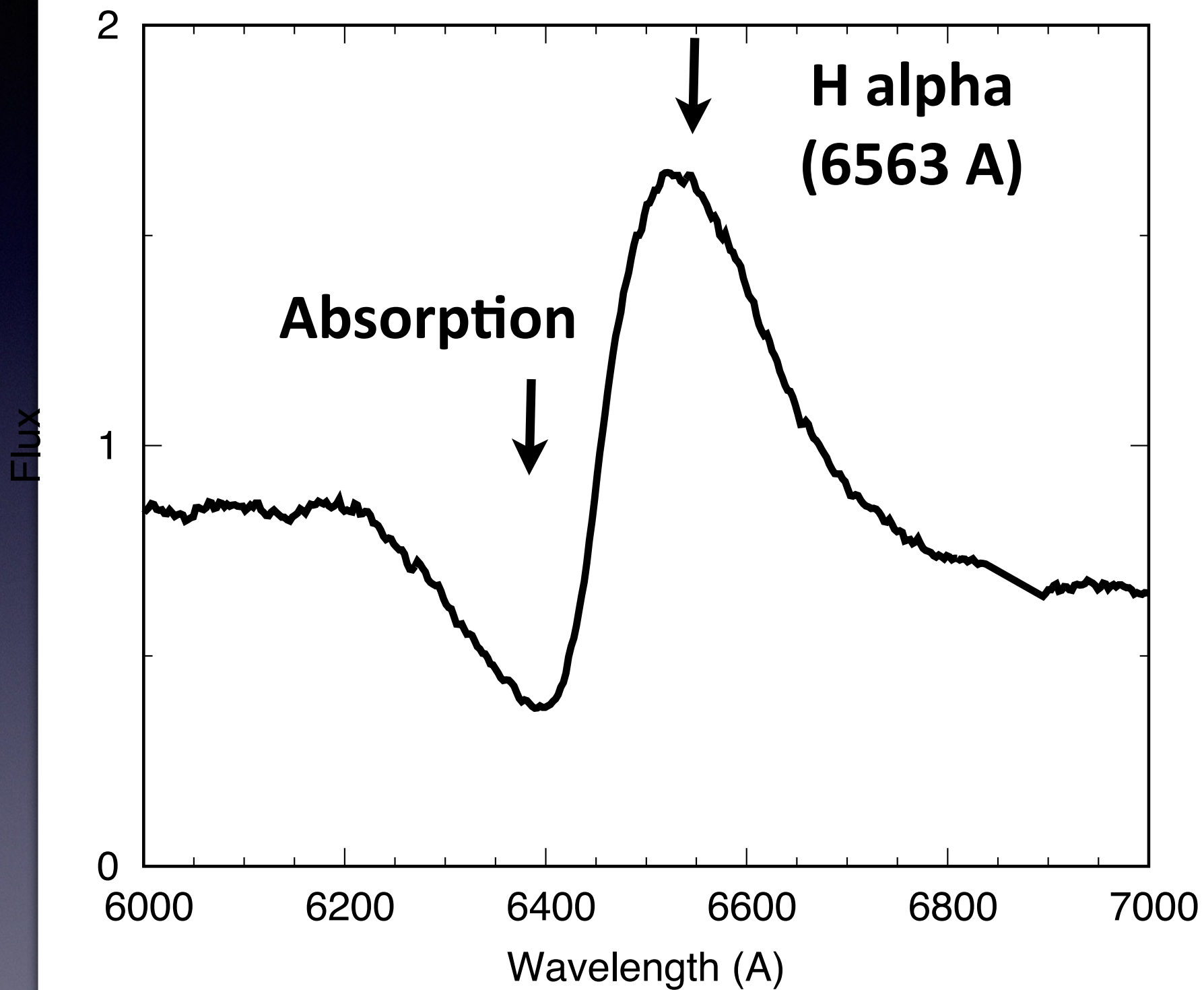
C

Fe

Mass loss due to stellar wind



Line profile



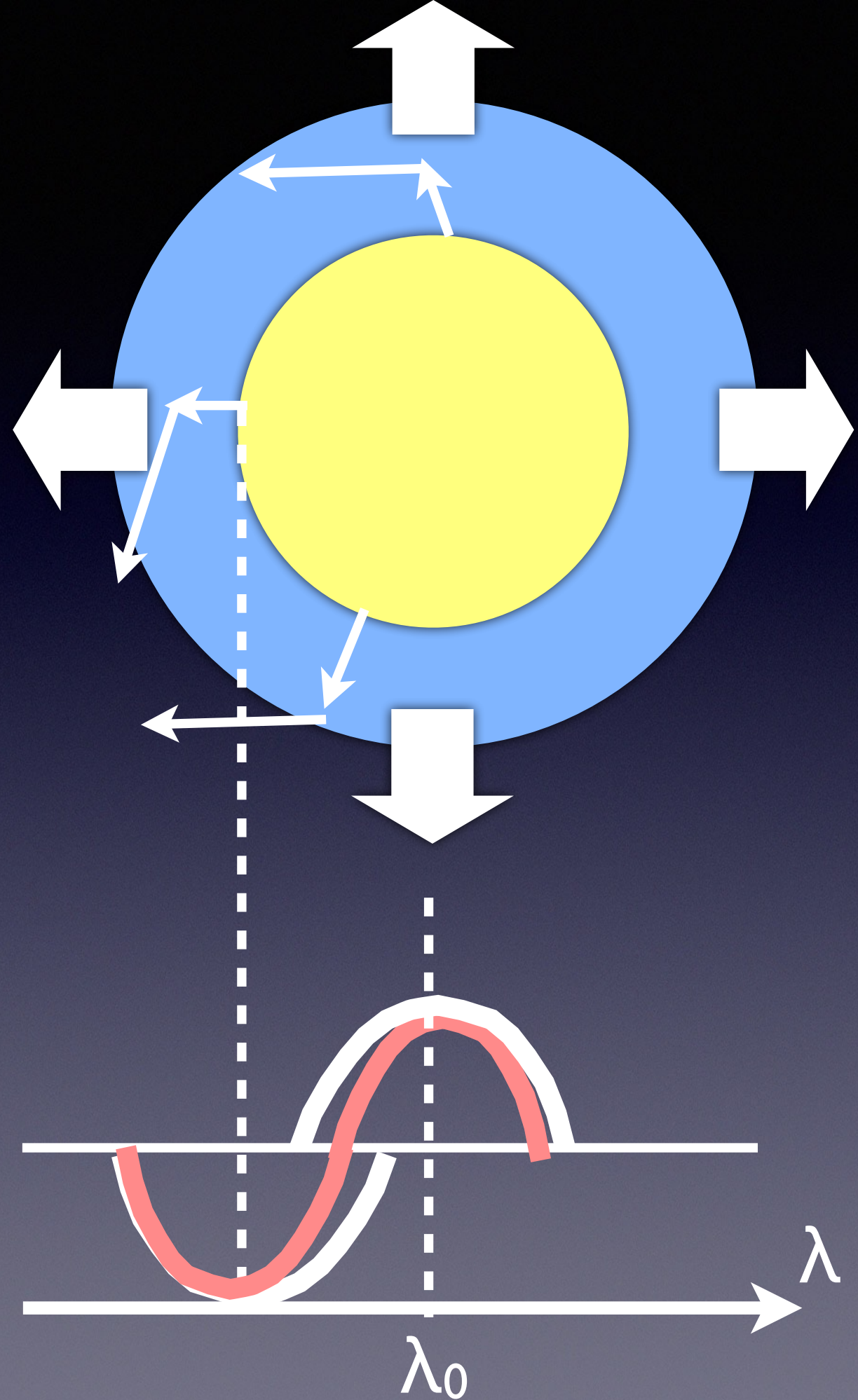
**“P-Cygni”
Profile**

Observer ←

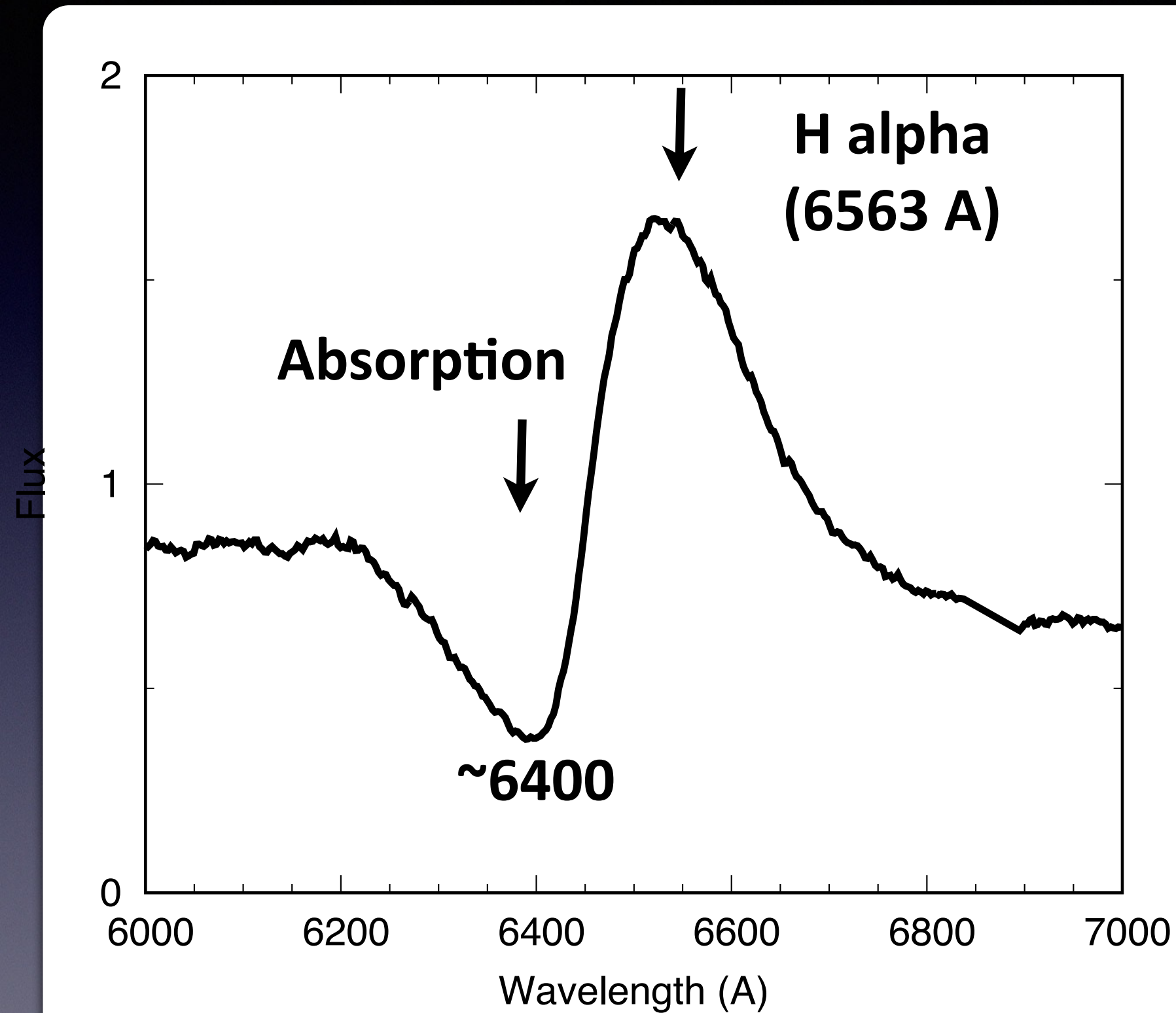
Doppler effects

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

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



H line in Type II SNe

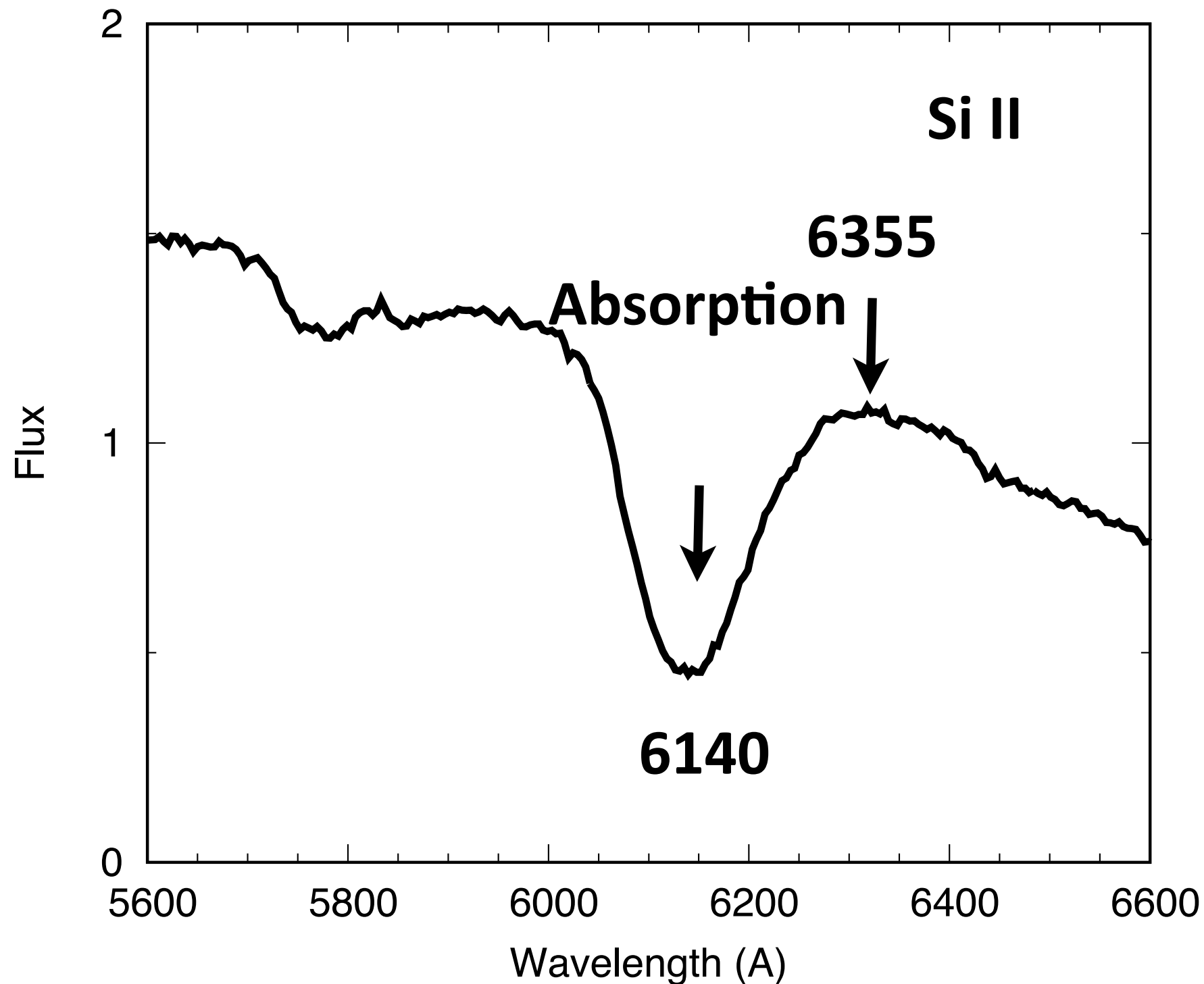


$$v/c = 163/6563$$

$\Rightarrow$

$$v = 0.025 \times c$$
$$\sim 7,000 \text{ km/s}$$

Si line in Type Ia SNe



$$v/c = 215/6355$$

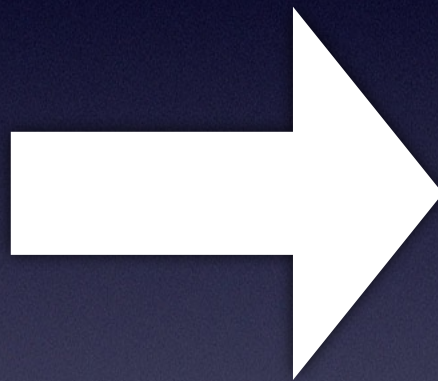
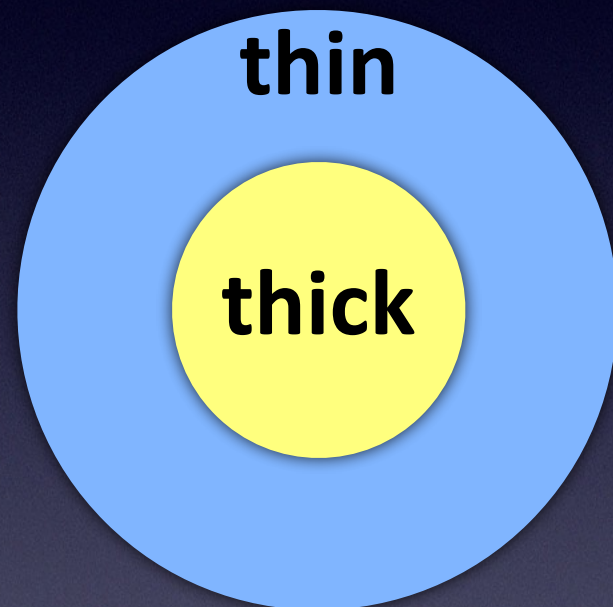
=>

$$v = 0.033 \times c$$
$$\sim 10,000 \text{ km/s}$$

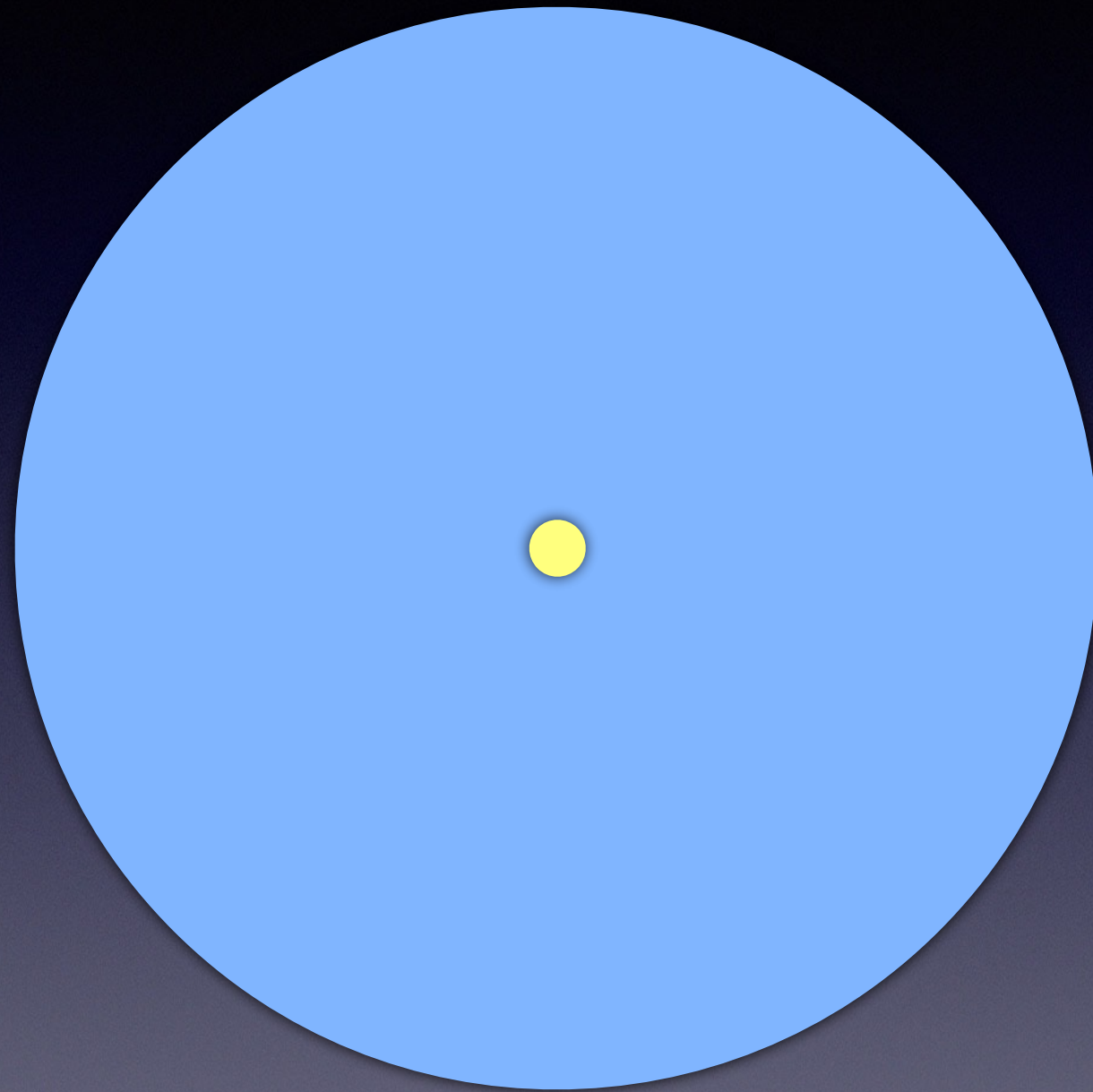
Type Ia > Type II

Time evolution of SN ejecta

$t \sim 20$ days
 $R \sim 10^{15}$ cm



$t \sim 1$ year
 $R \sim 10^{16}$ cm



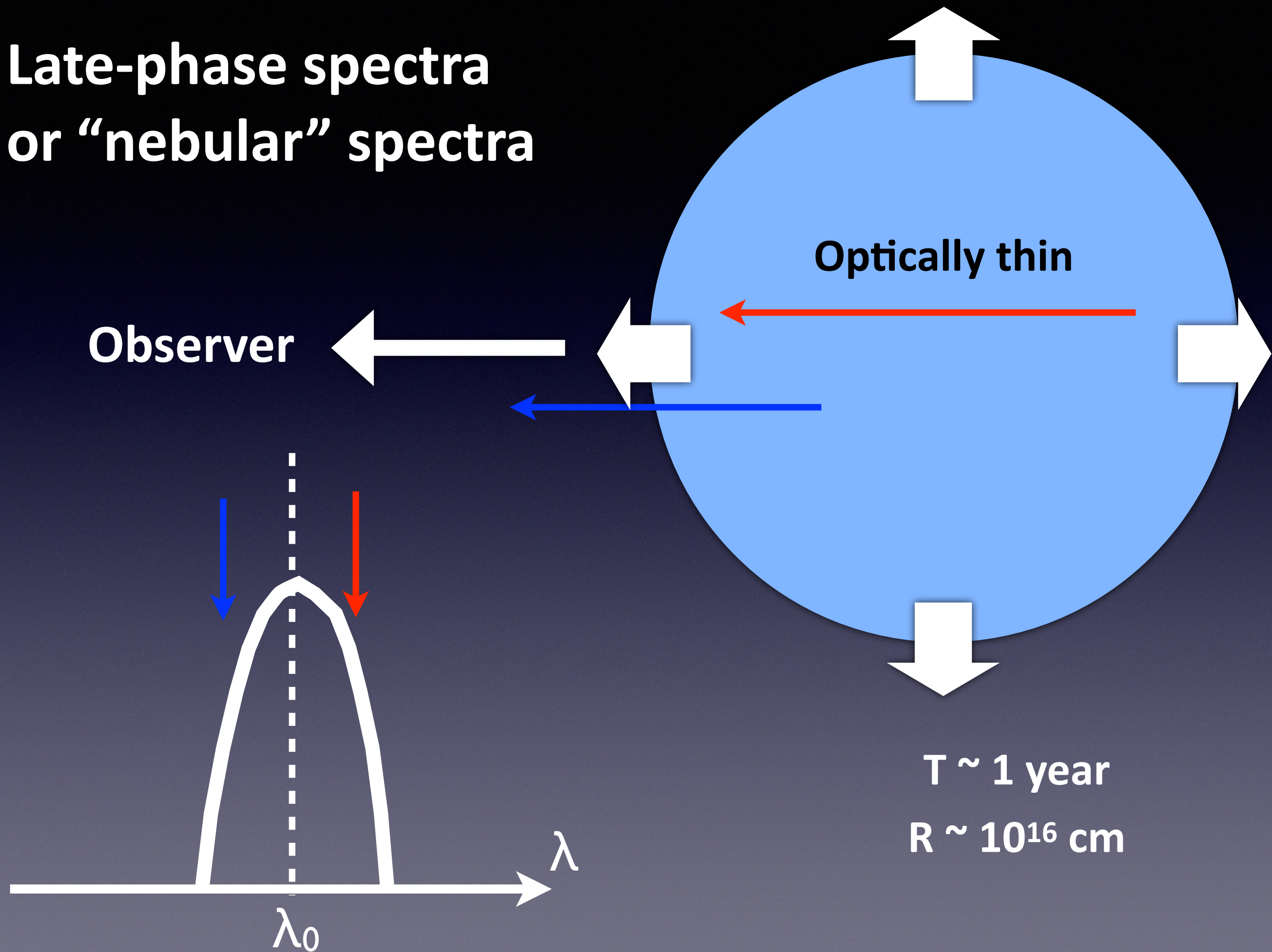
“photosphere”

Absorption lines

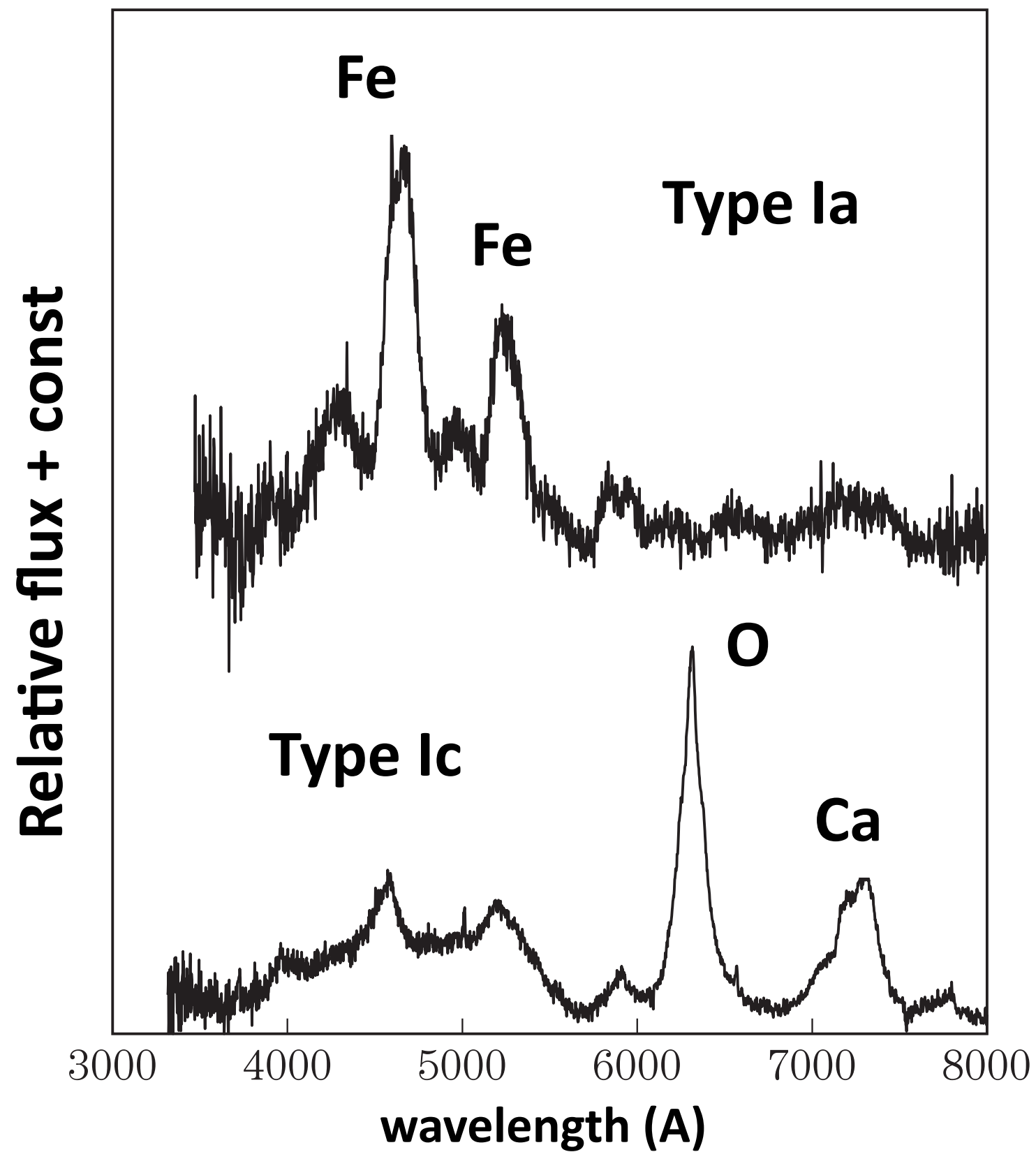
No photosphere

Emission lines

Late-phase spectra or “nebular” spectra



Nebular spectra

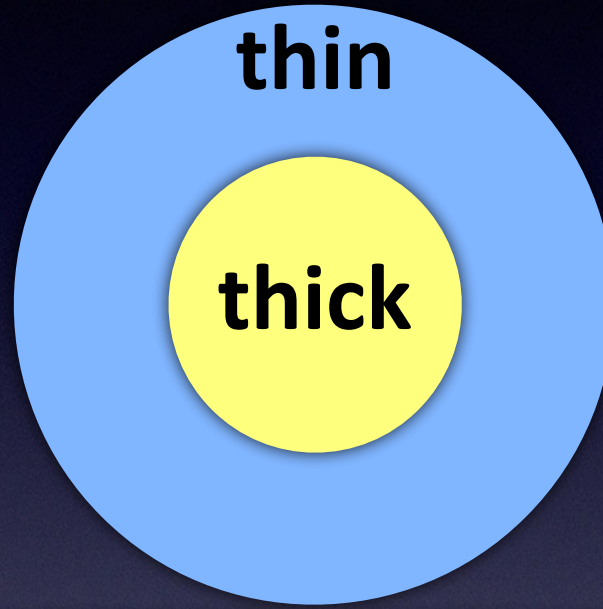


Abundance profiling

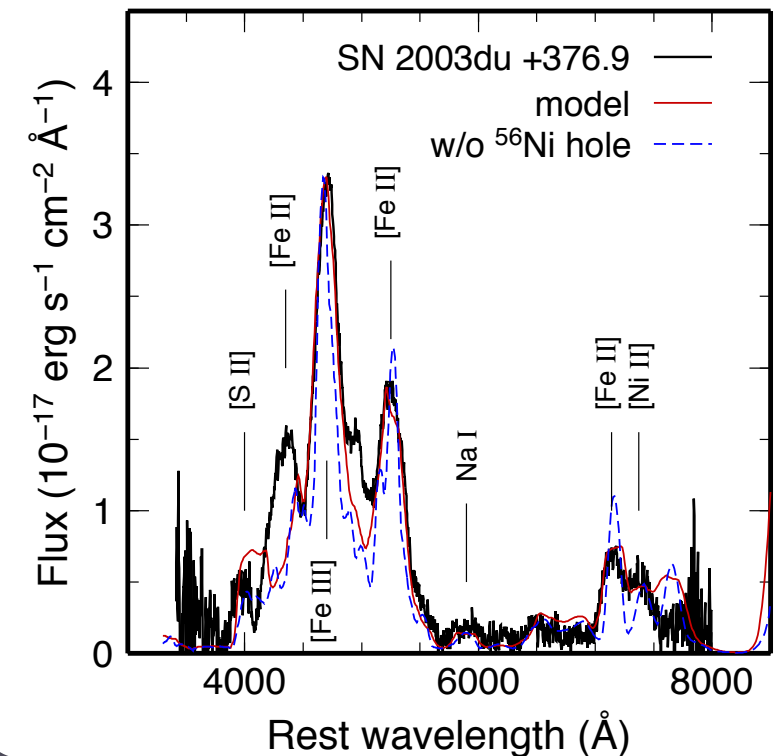
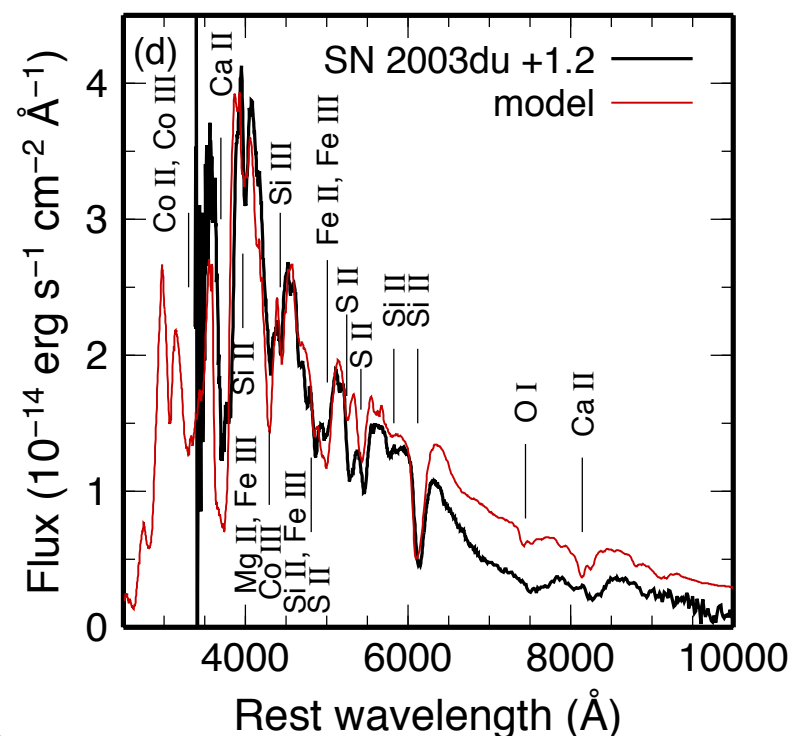
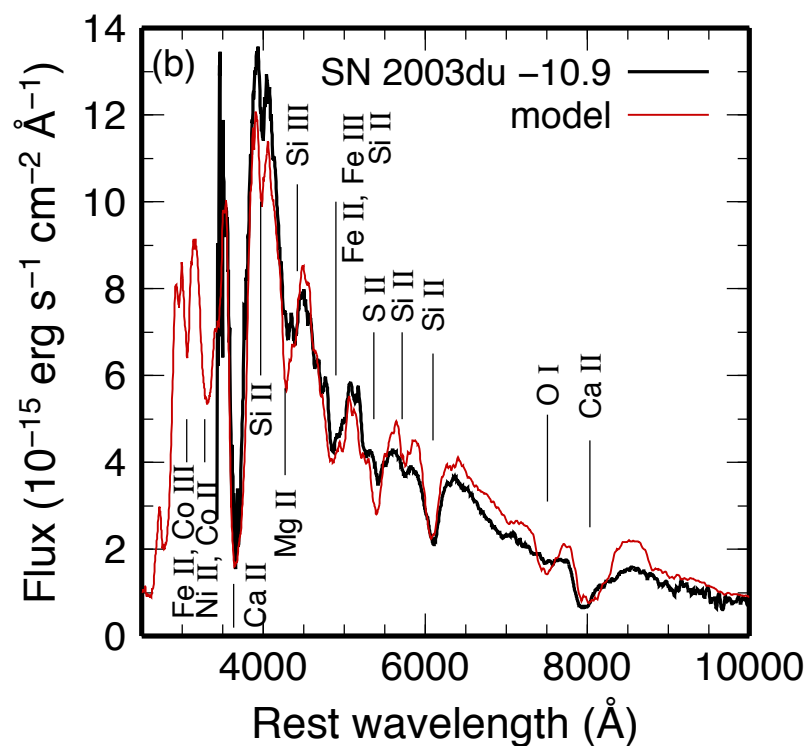
~ a few days

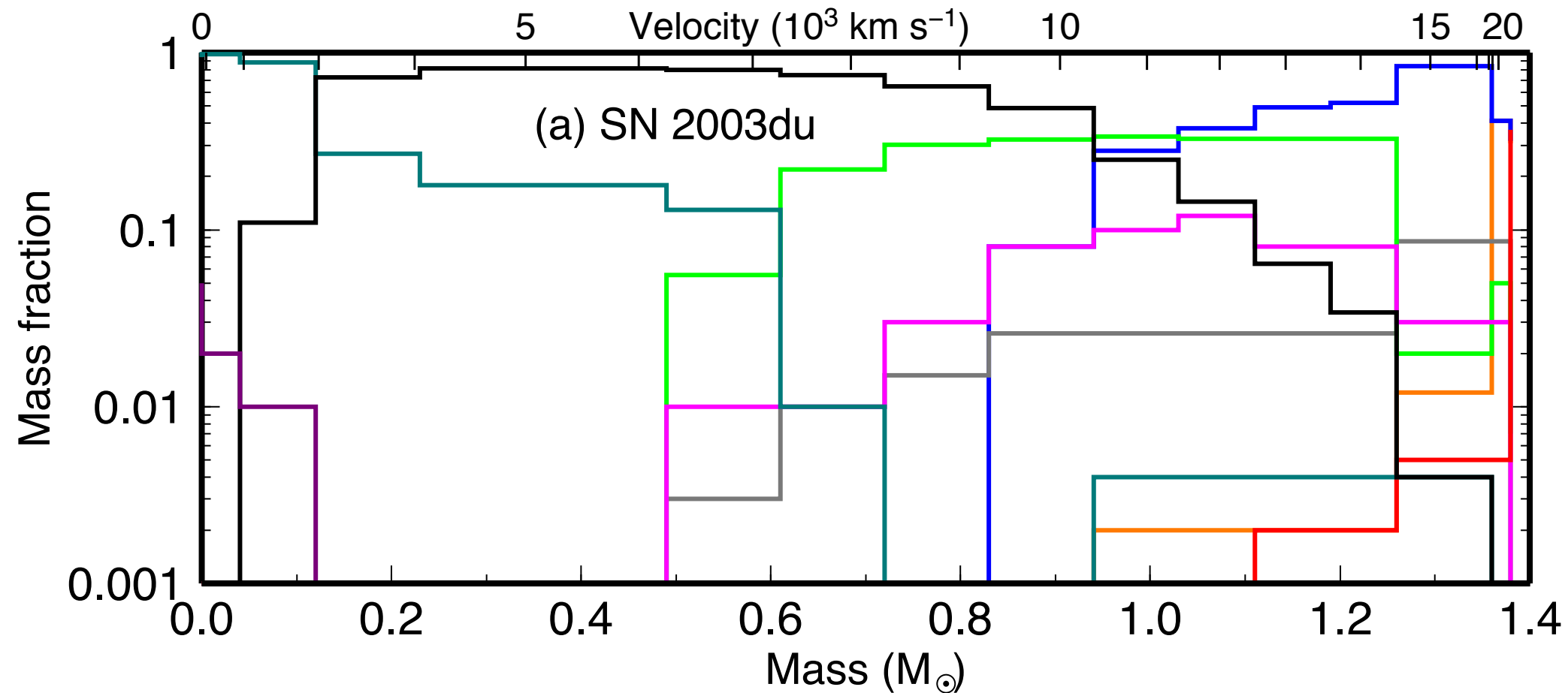


~ 20 days

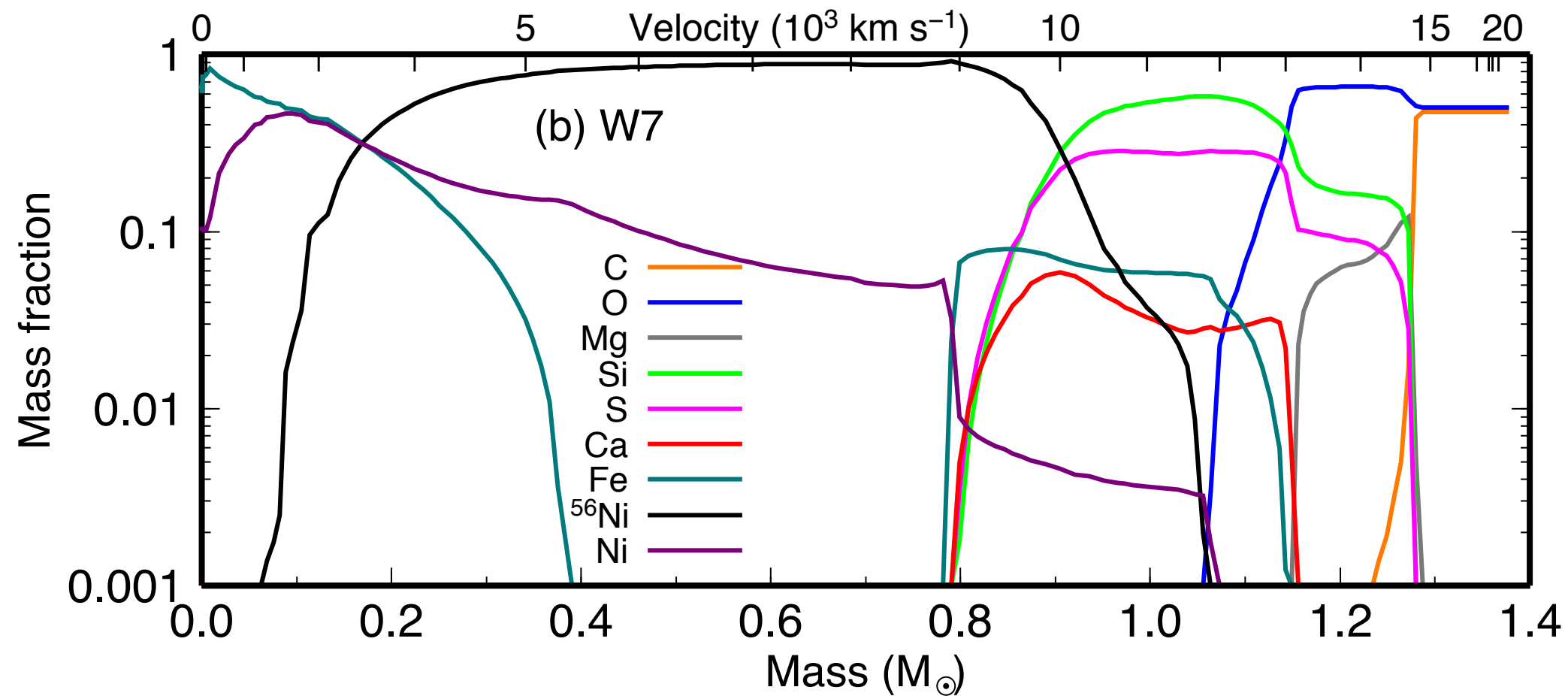


~ 1 year





Obs



Theory

Tanaka+10

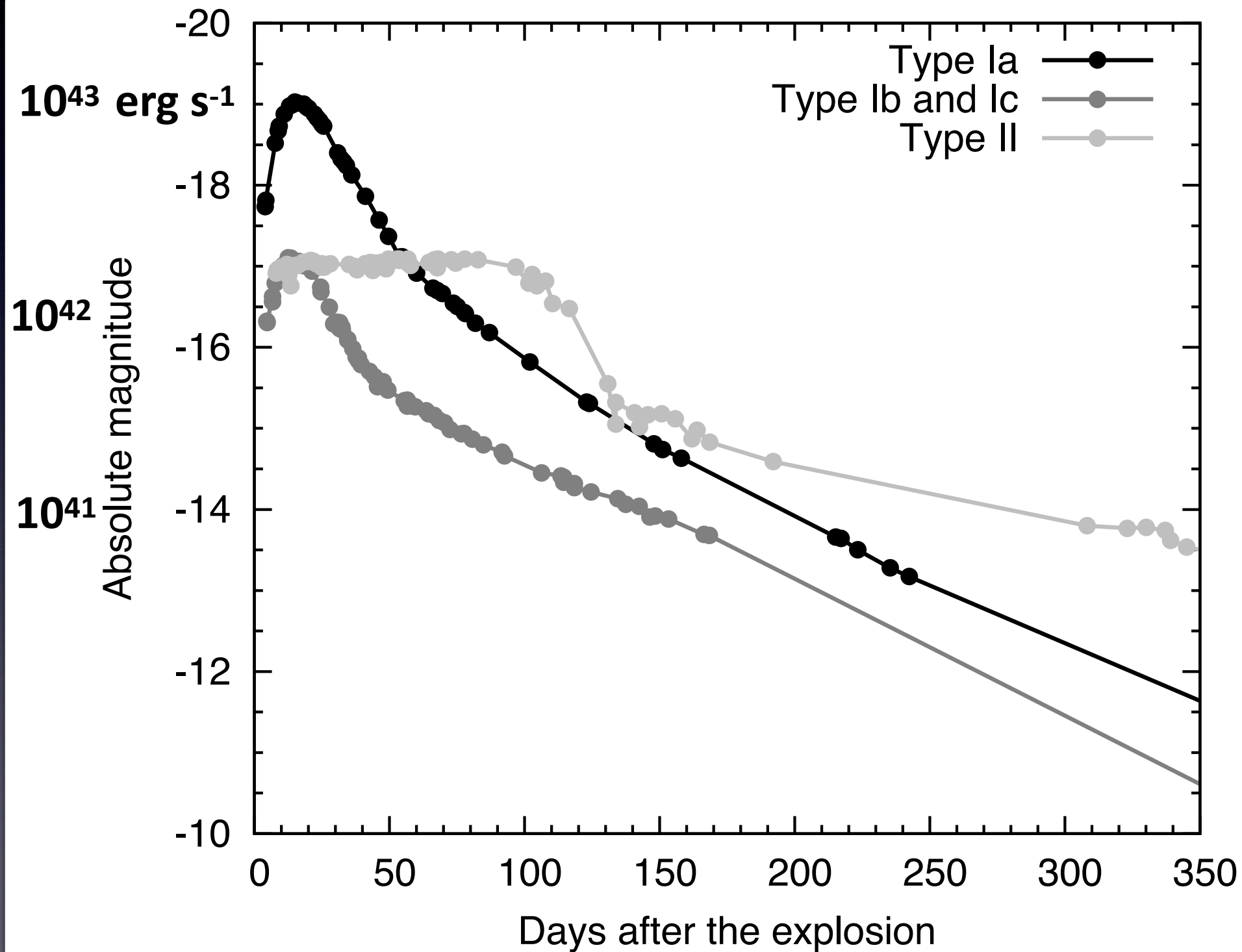
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Light curves



Type I

- Peak

- $L(\text{Ia}) > L(\text{Ib, Ic})$

Type II

- plateau

- $L(\text{Ia}) > L(\text{II})$



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)

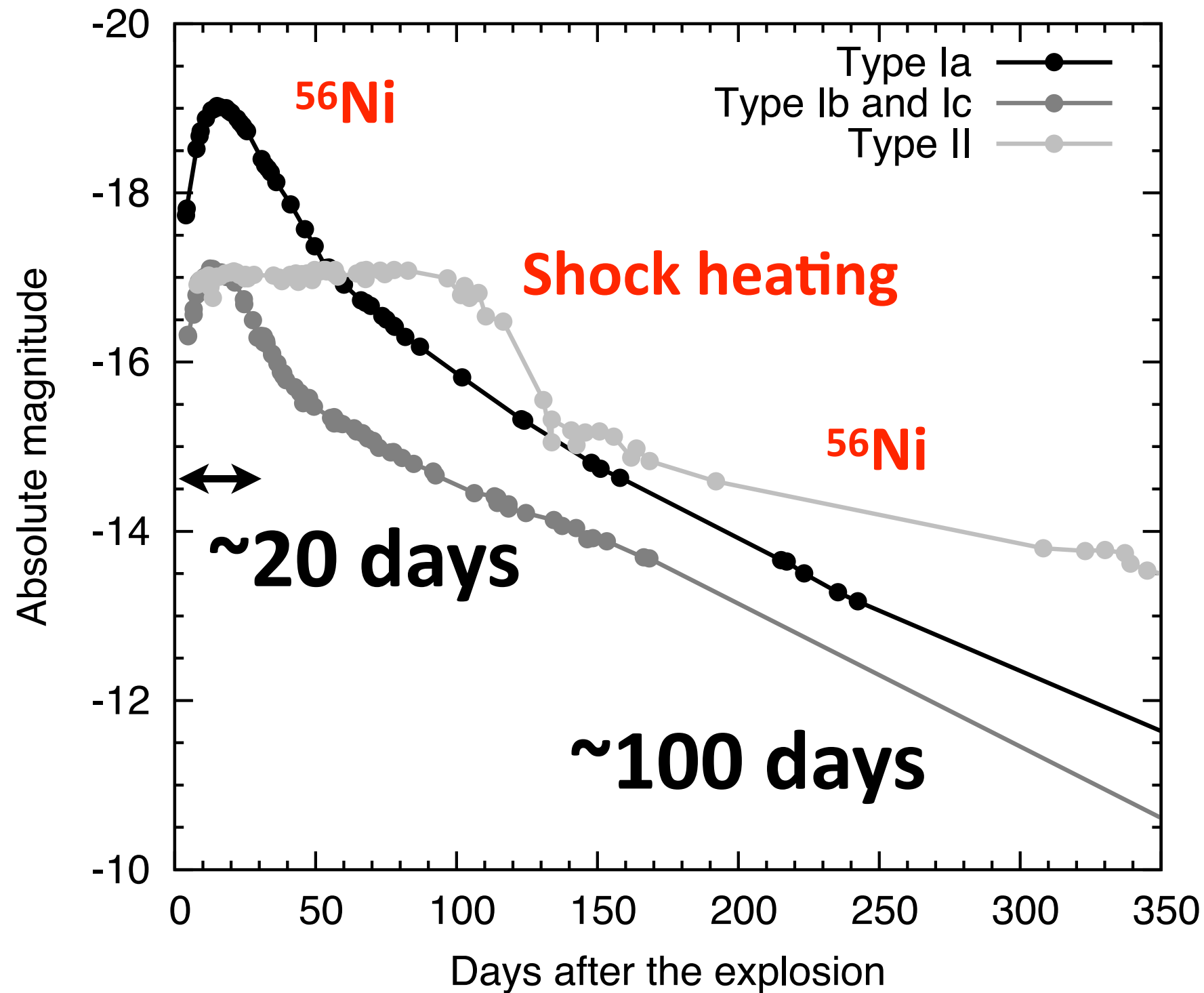
3. Interaction with CSM

$E_{\text{kin}} \Rightarrow E_{\text{th}}$ (Type IIn)

4. Magnetar?

$E_{\text{rot}} \Rightarrow$ energy loss by spin down

Light curves



$10^{43} \text{ erg s}^{-1}$

$10^{42} \text{ erg s}^{-1}$

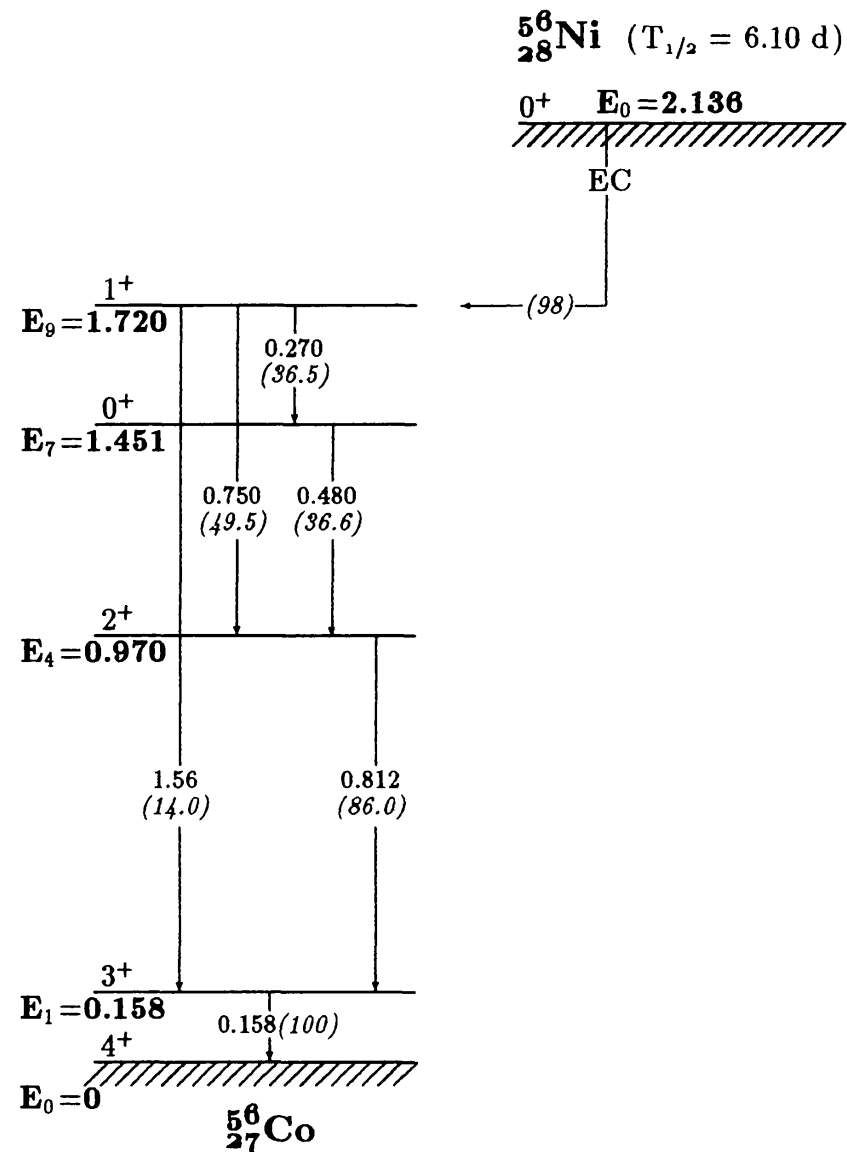
**Type Ia SNe eject
more ^{56}Ni**

⁵⁶Ni

e capture

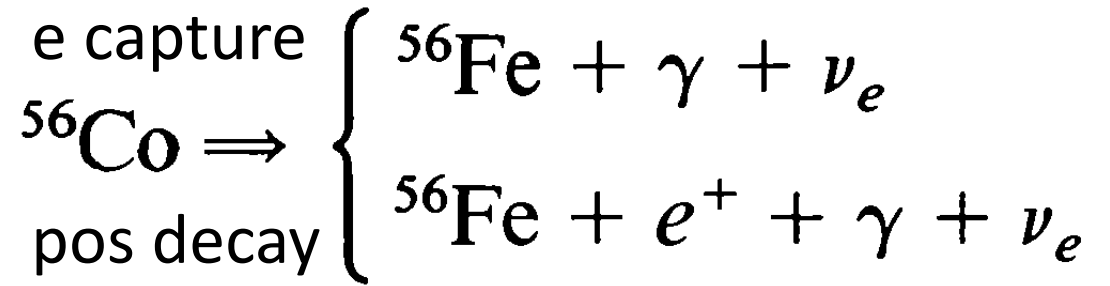


$\tau = 8.8$ days

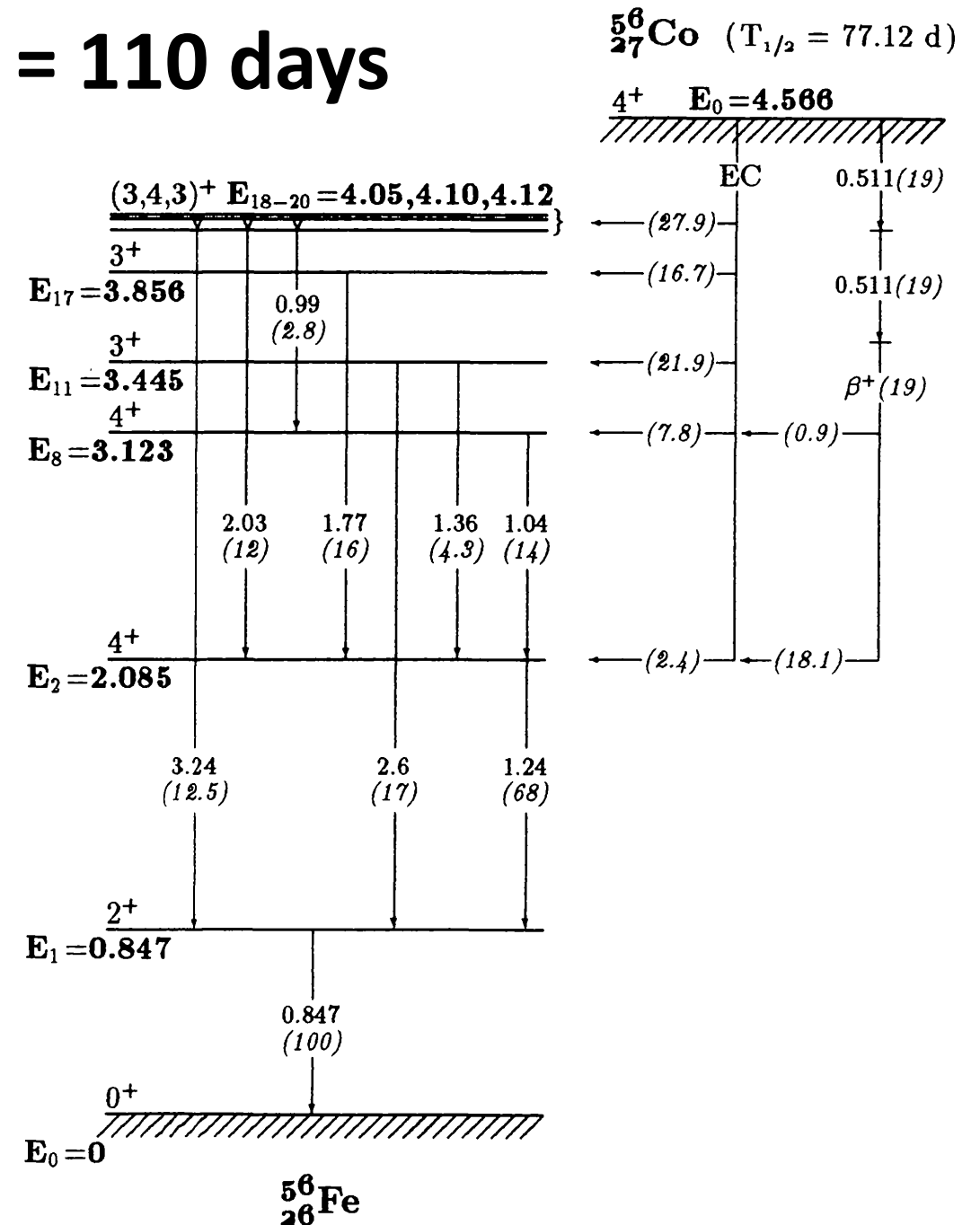


⁵⁶Co

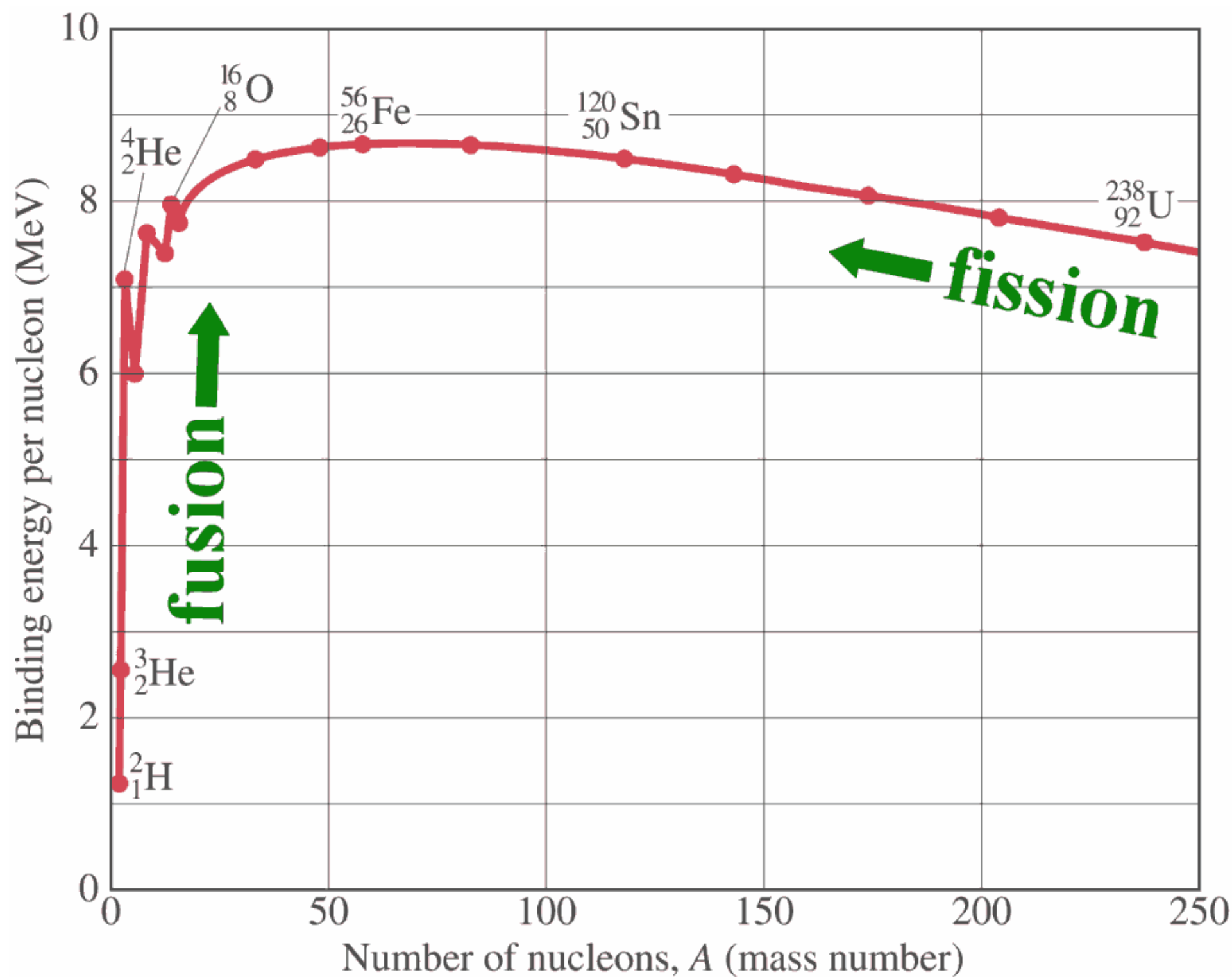
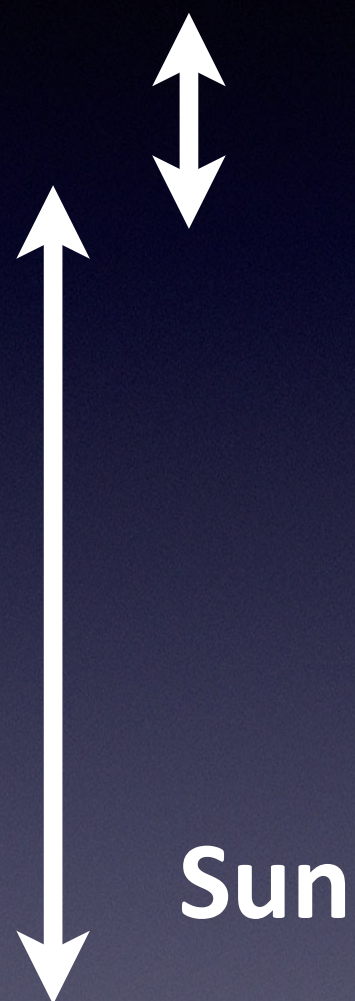
Nadyozhin 94



$\tau = 110$ days

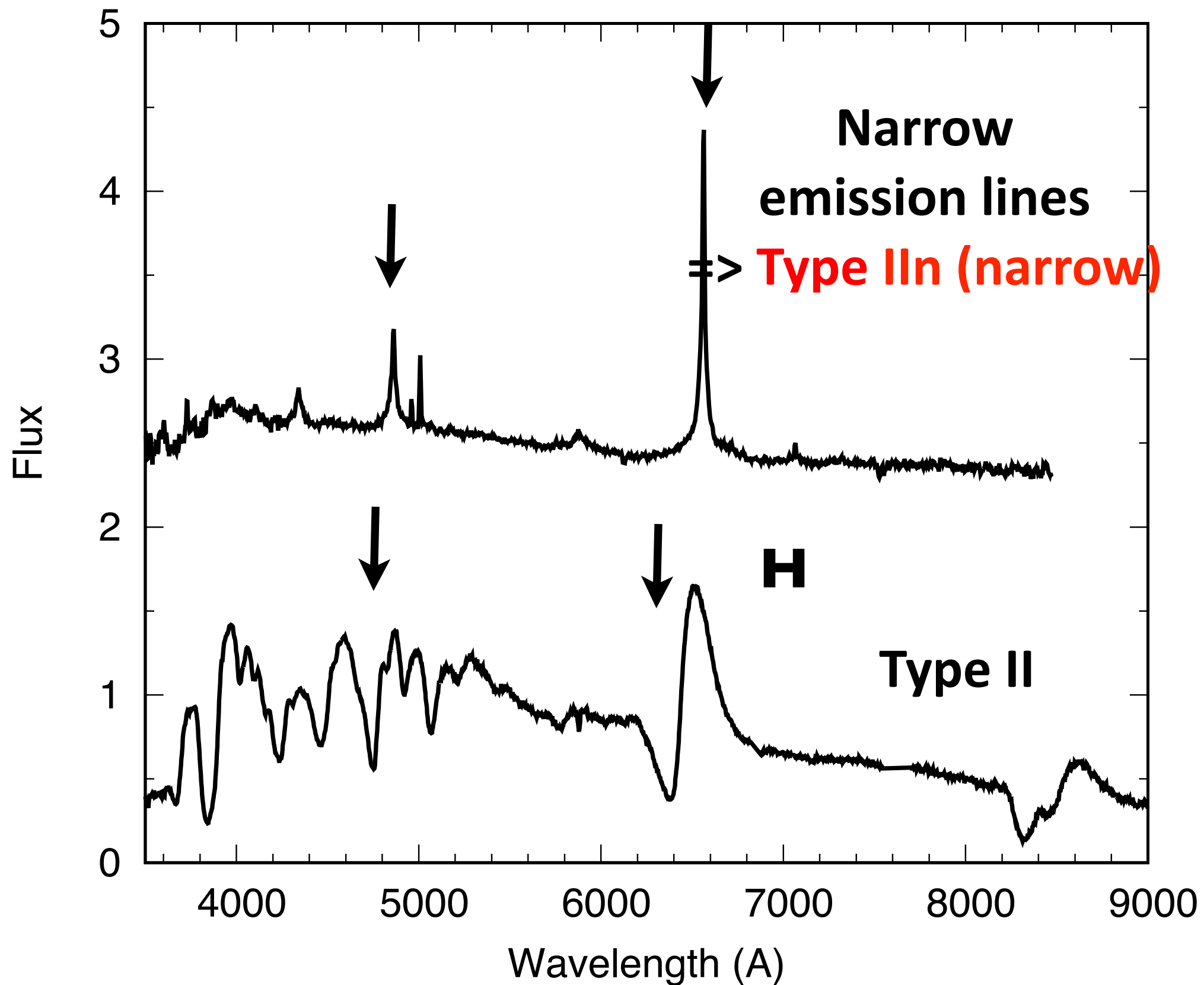


Type Ia ^{56}Ni
SN

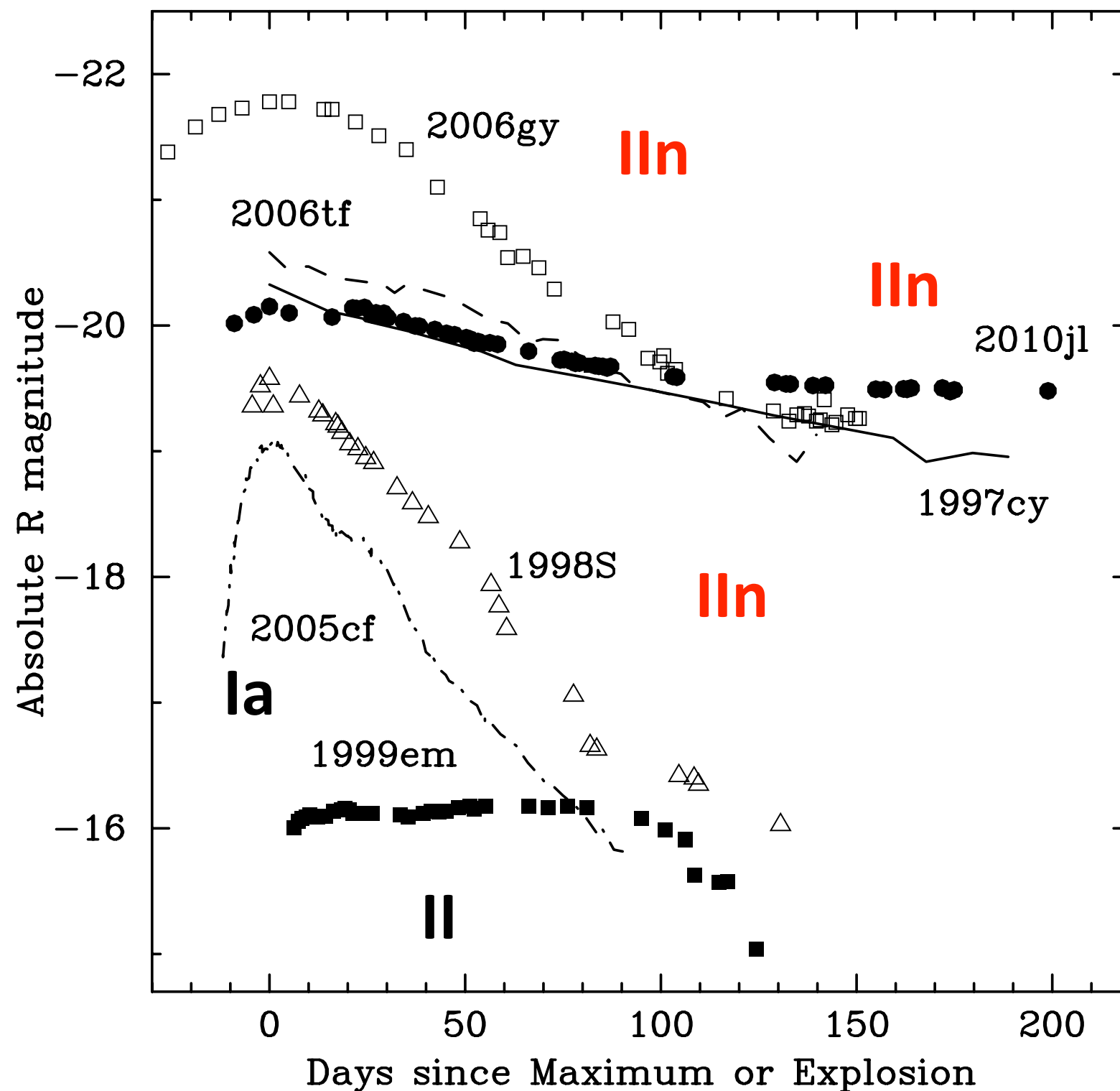


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Signature of CSM interaction



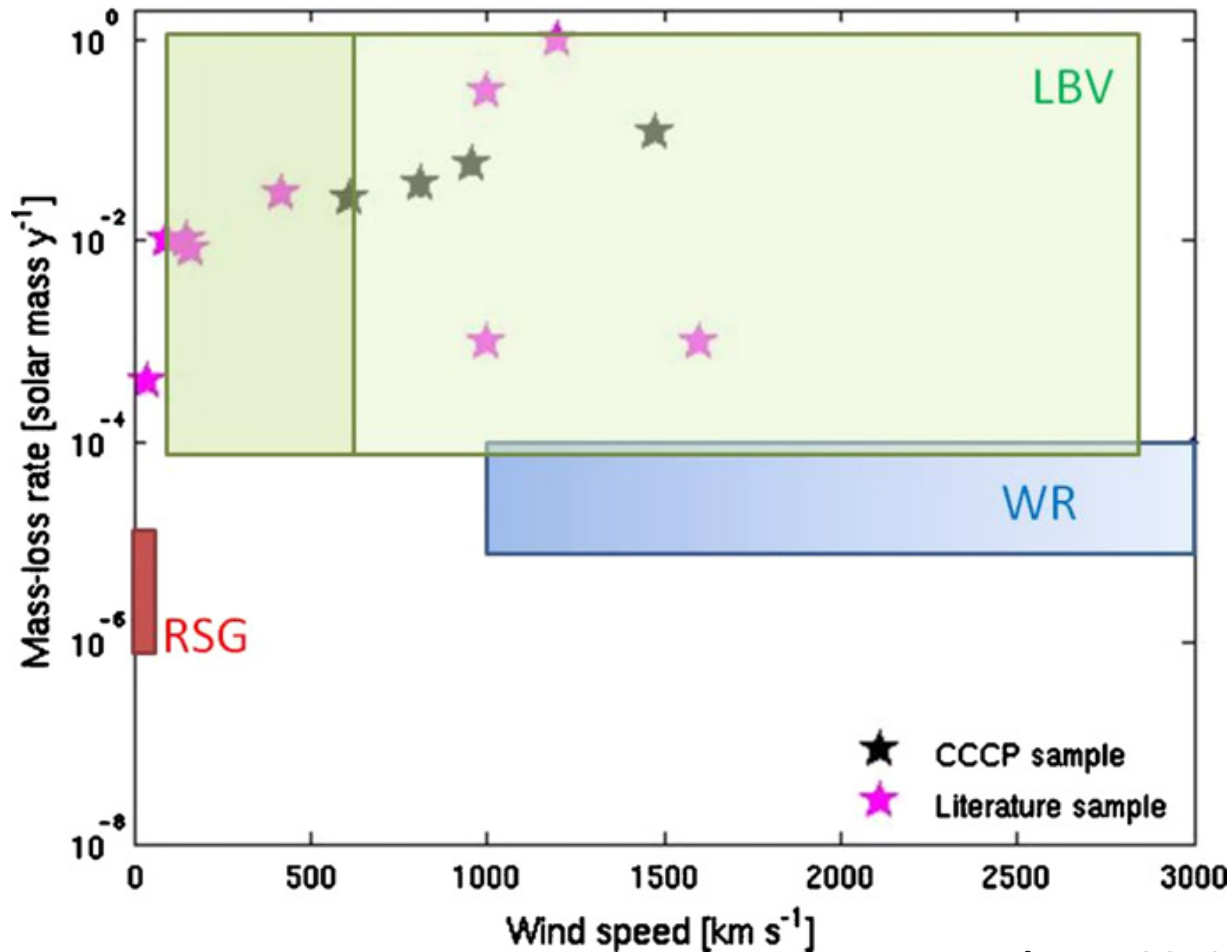
Type IIn SNe: powered from CSM interaction



- 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 $\sim 10^{49}$ erg**
 $\ll E_{\text{kin}} (10^{51} \text{ erg}) \ll E_{\text{grav}} (10^{53} \text{ erg})$
- **Power source**
 - Radioactivity (^{56}Ni)
 - Shock heating
 - Interaction with CSM, magnetar, ...
- **Lessons from observations**
 - $M_{\text{Fe}} (\text{Type Ia SN}) > M_{\text{Fe}} (\text{CC SN})$
 - $R (\text{Type II SN}) > R (\text{Type Ibc SN}) > R (\text{Type Ia SN})$