Section 11.
Radiation from supernovae

11.1 Observations of supernovae

11.2 Radiation mechanism of supernovae

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

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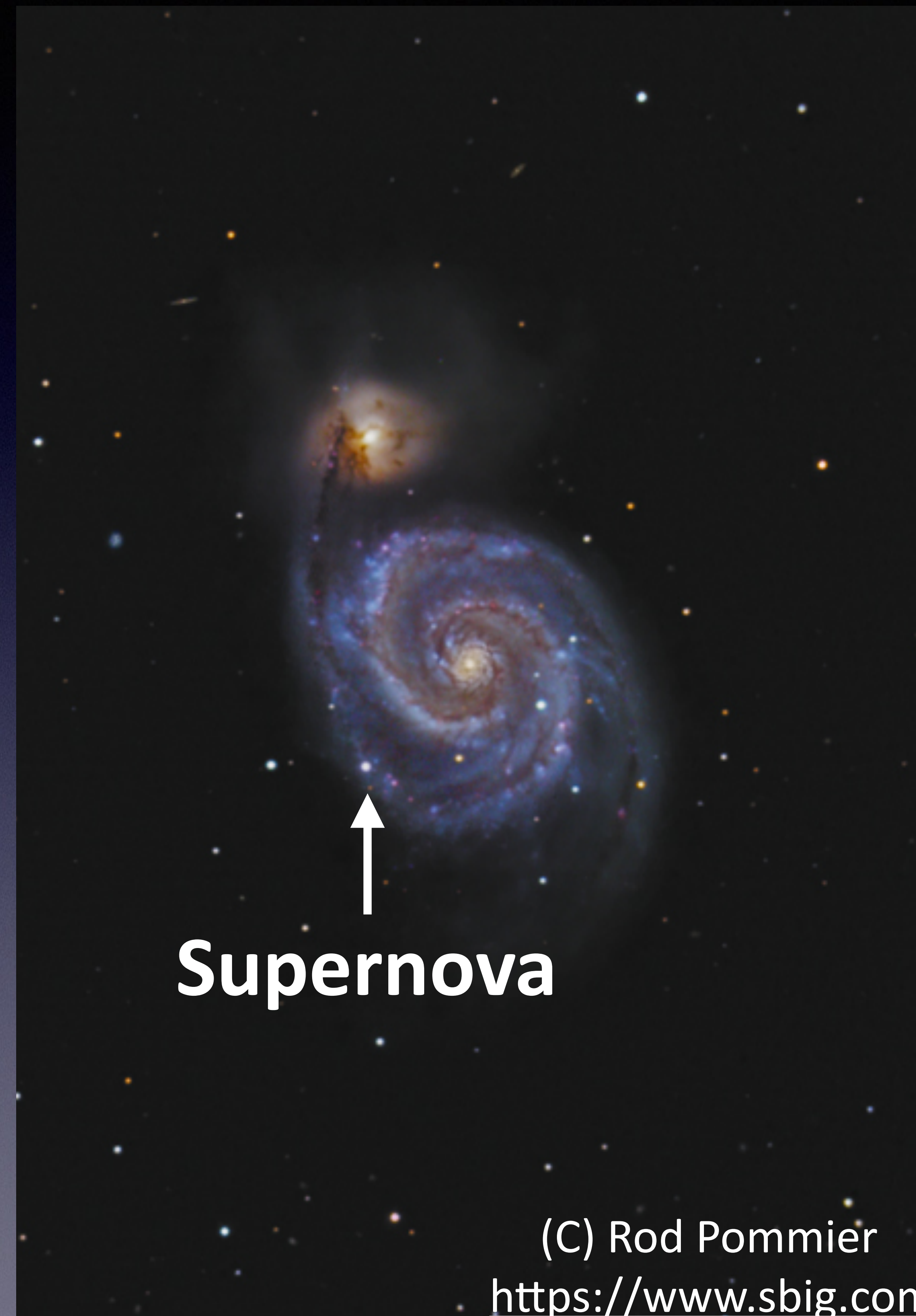
Spot the difference!!

Answer

Spot the difference!
(level **)

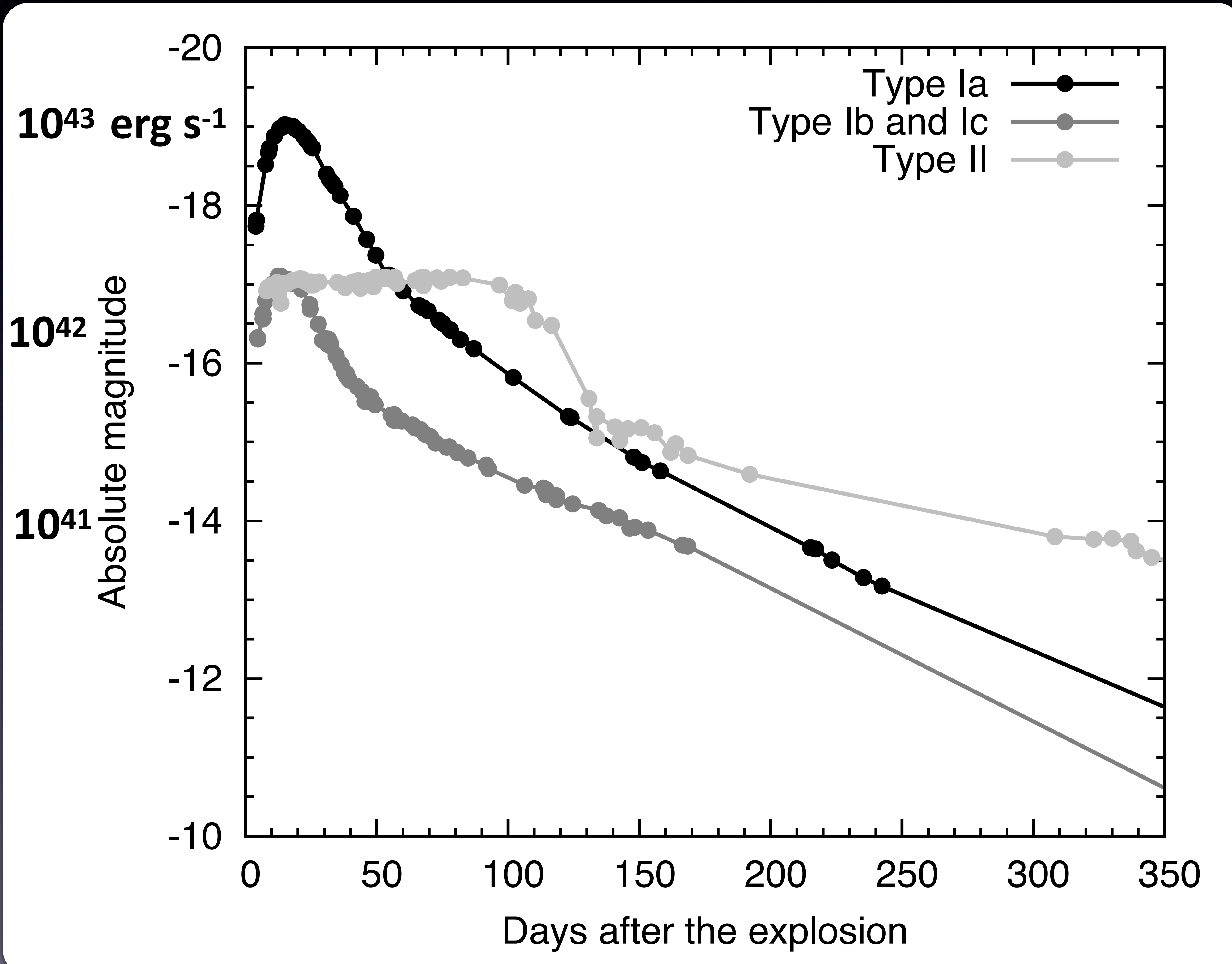
Answer



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



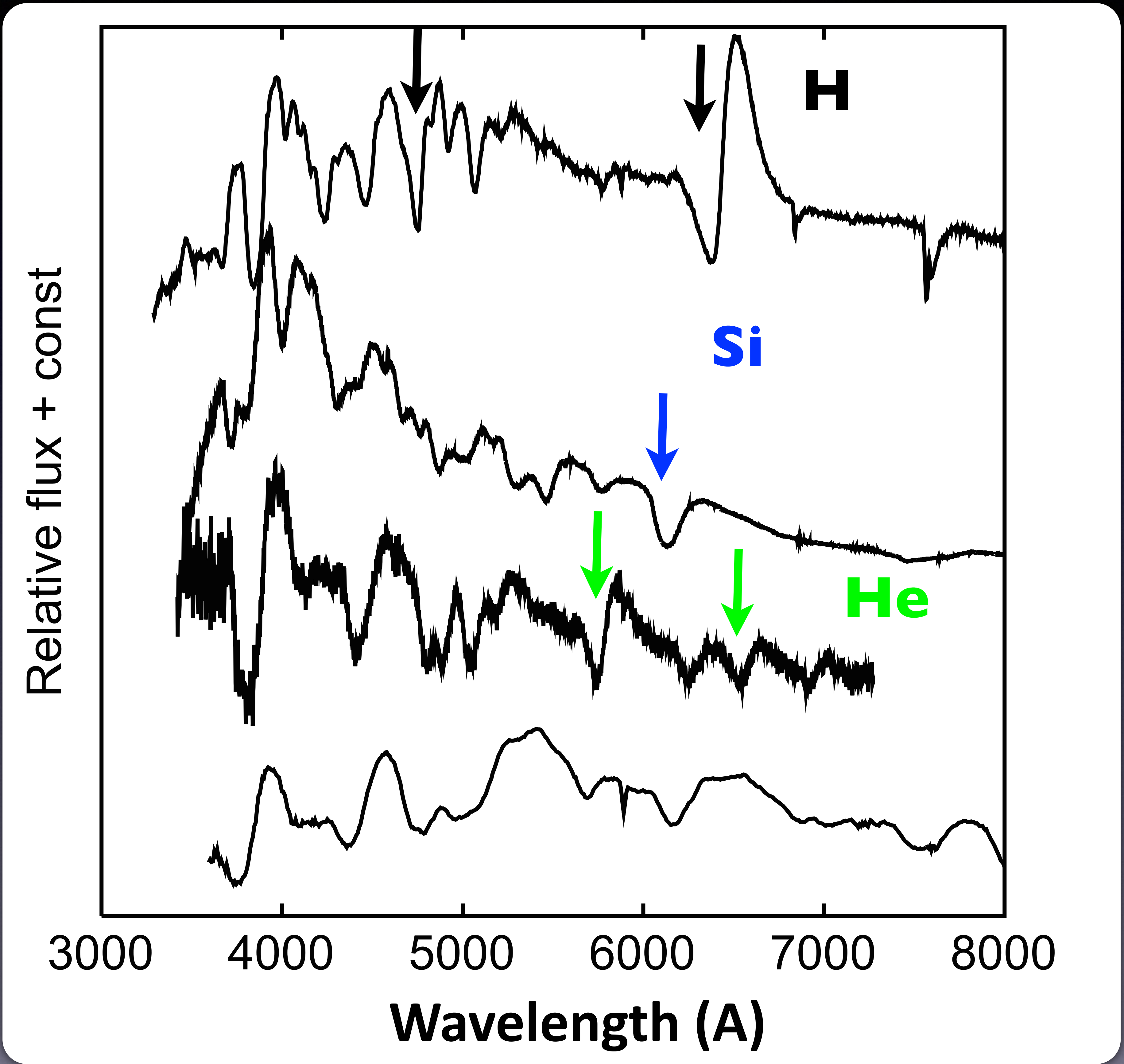
Type I

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

Type II

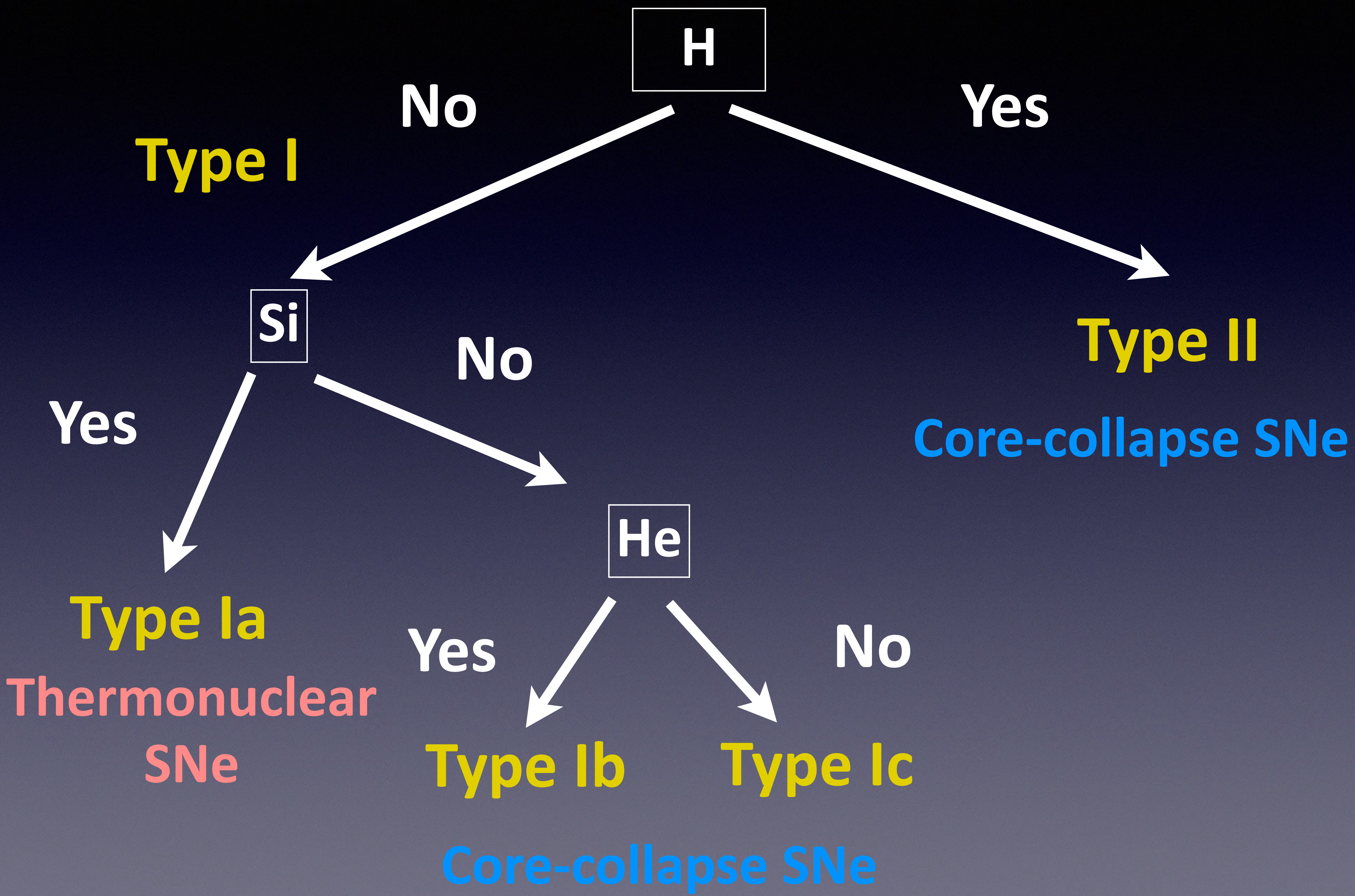
- plateau
- L(Ia) > L(II)

Spectra of supernovae

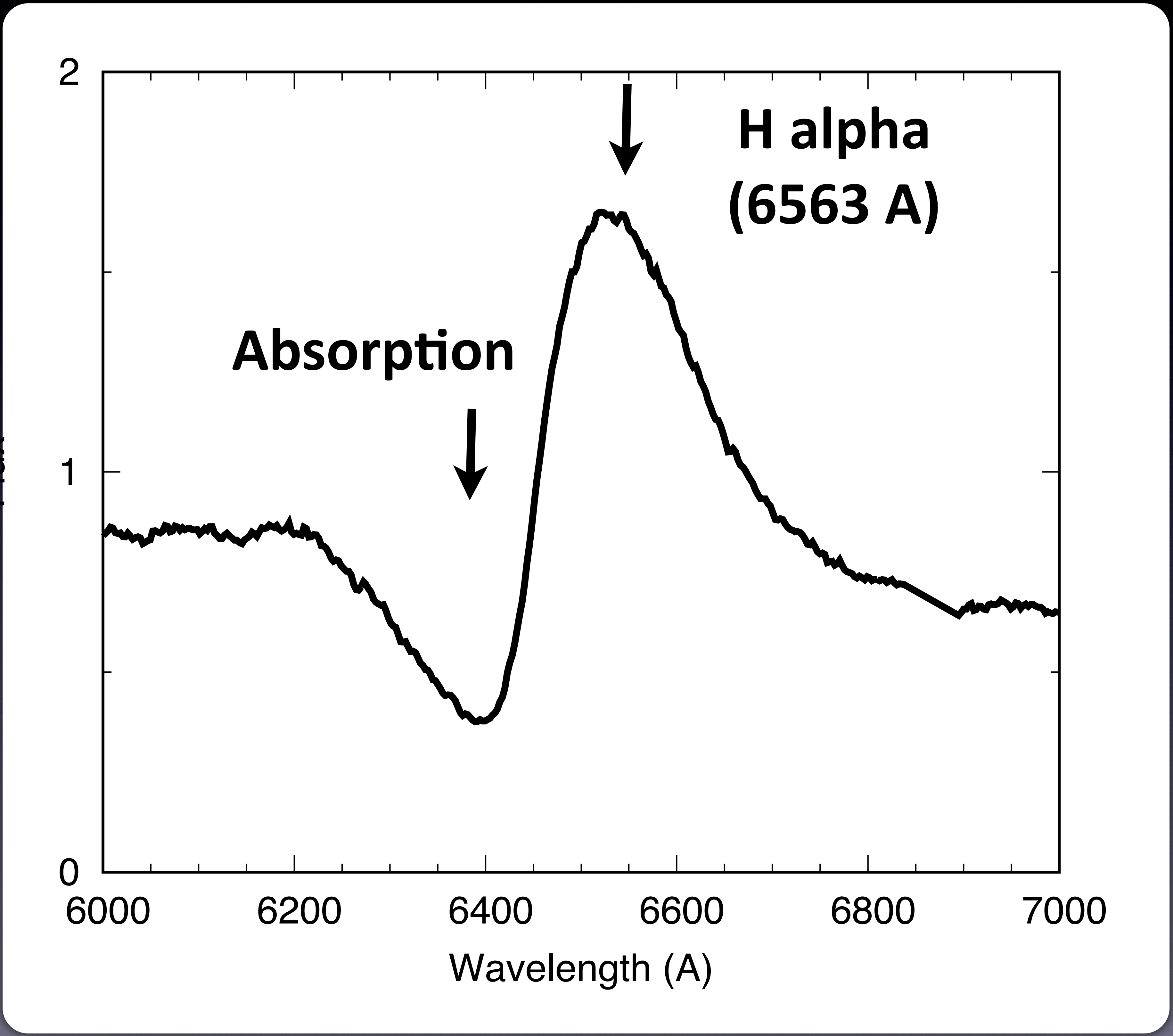


- Thermal continuum
- Broad absorption
- Doppler shift
- Associated with emission component

4 types of supernovae

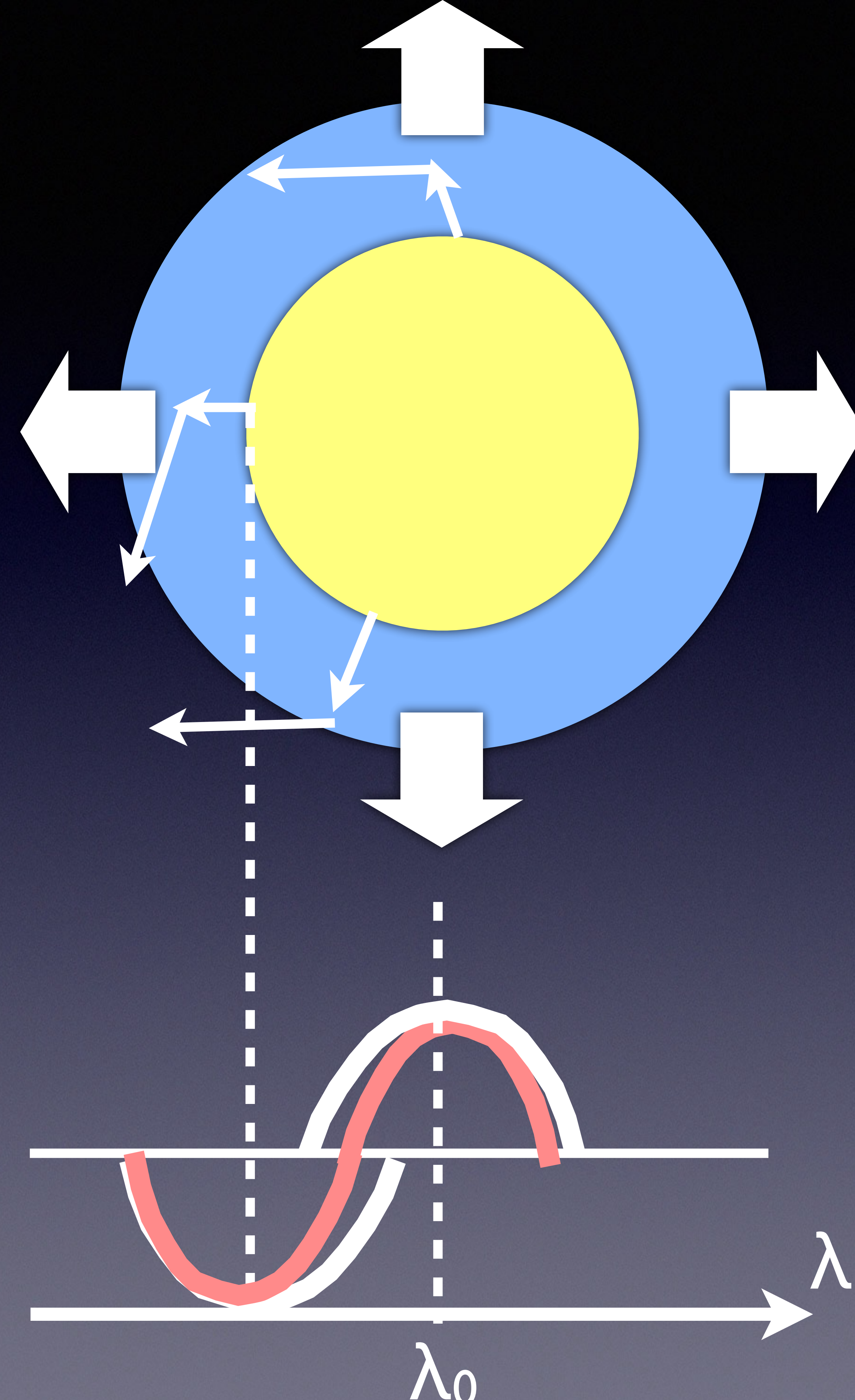


Line profile



"P-Cygni" Profile

Observer

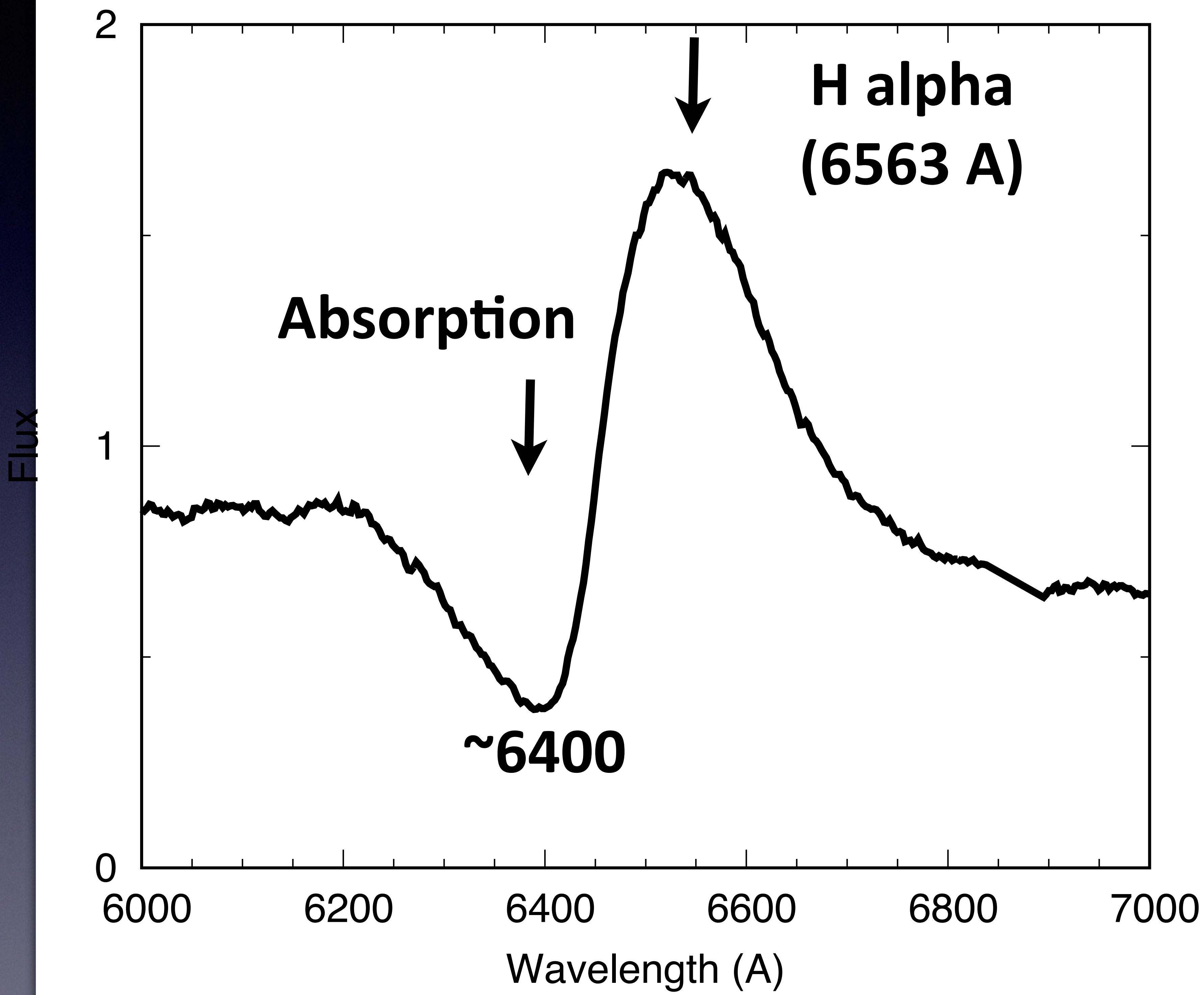


Doppler effects

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

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

Line profile



v/c = 163/6563

=>

v = 0.025 x c

~ 7,000 km/s

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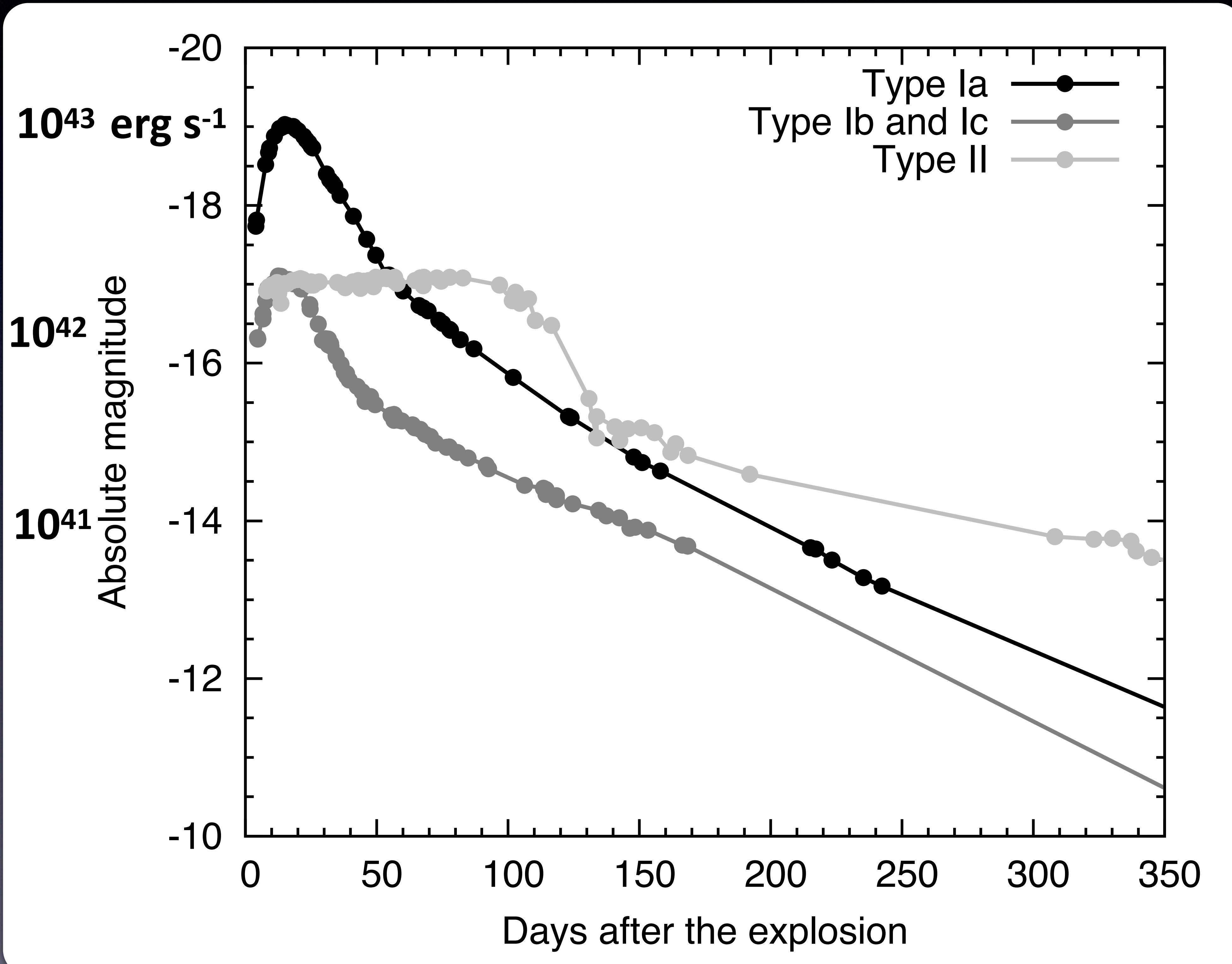
Light curves



Type I

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

Type II

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

What determines the luminosity and timescale of radiation?

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

^{56}Ni

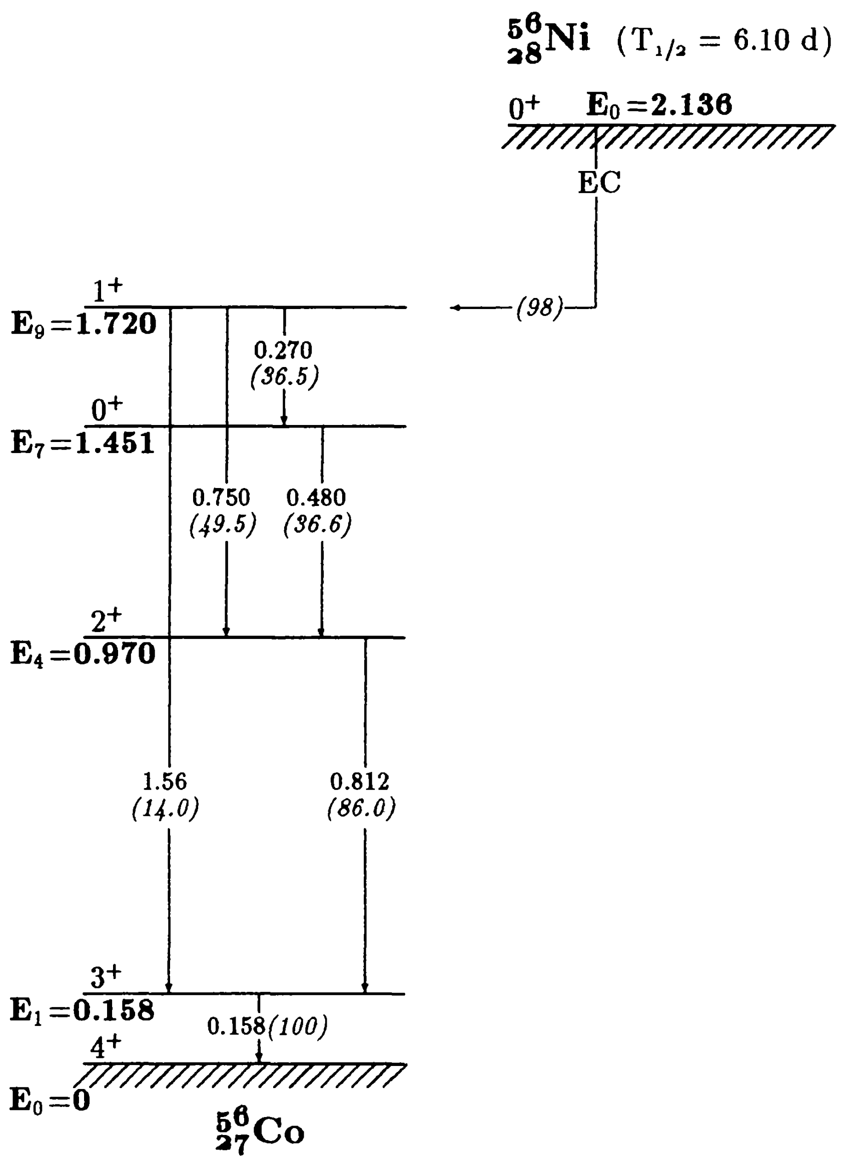
^{56}Co

Nadyozhin 94

e capture

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

τ = 8.8 days

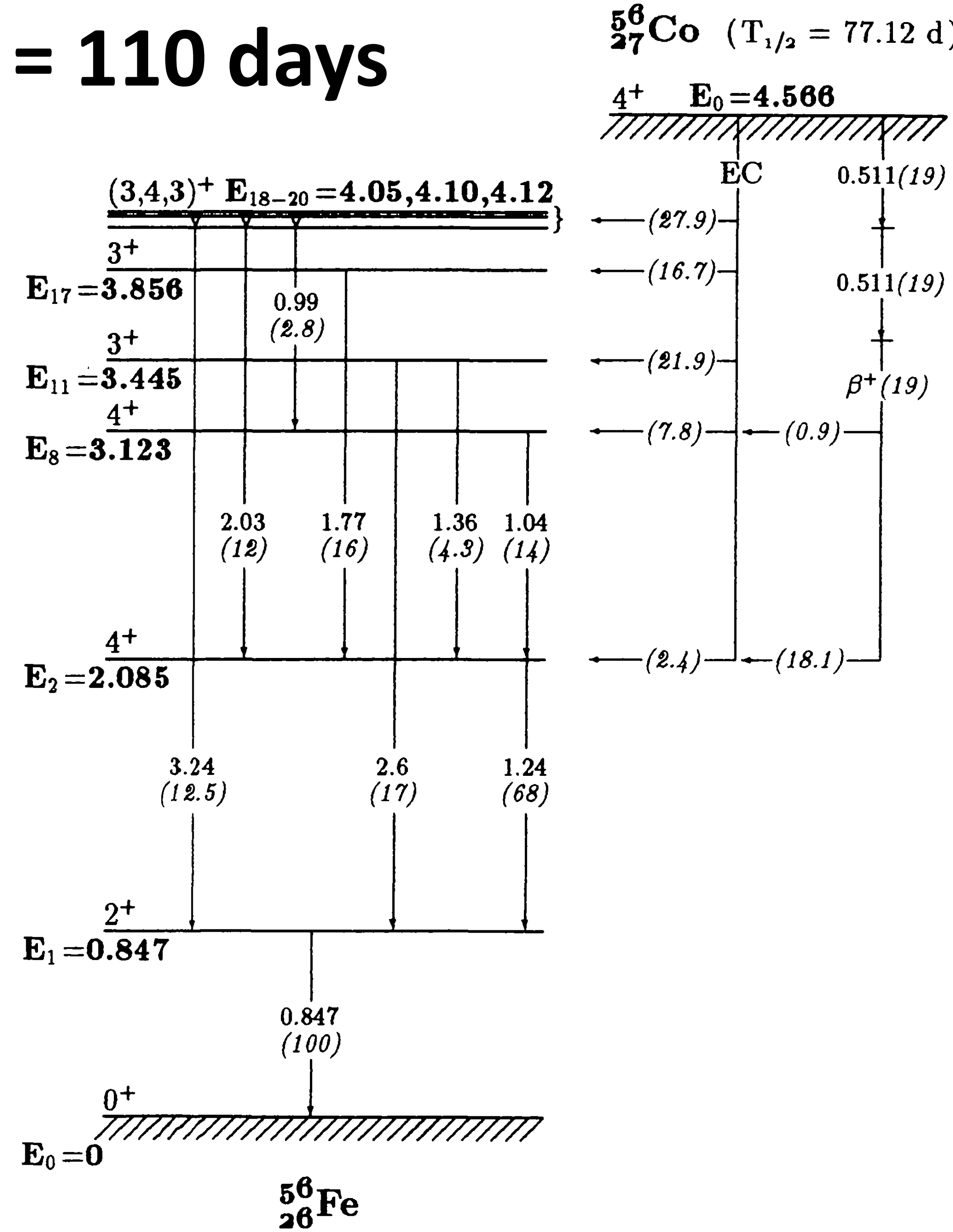


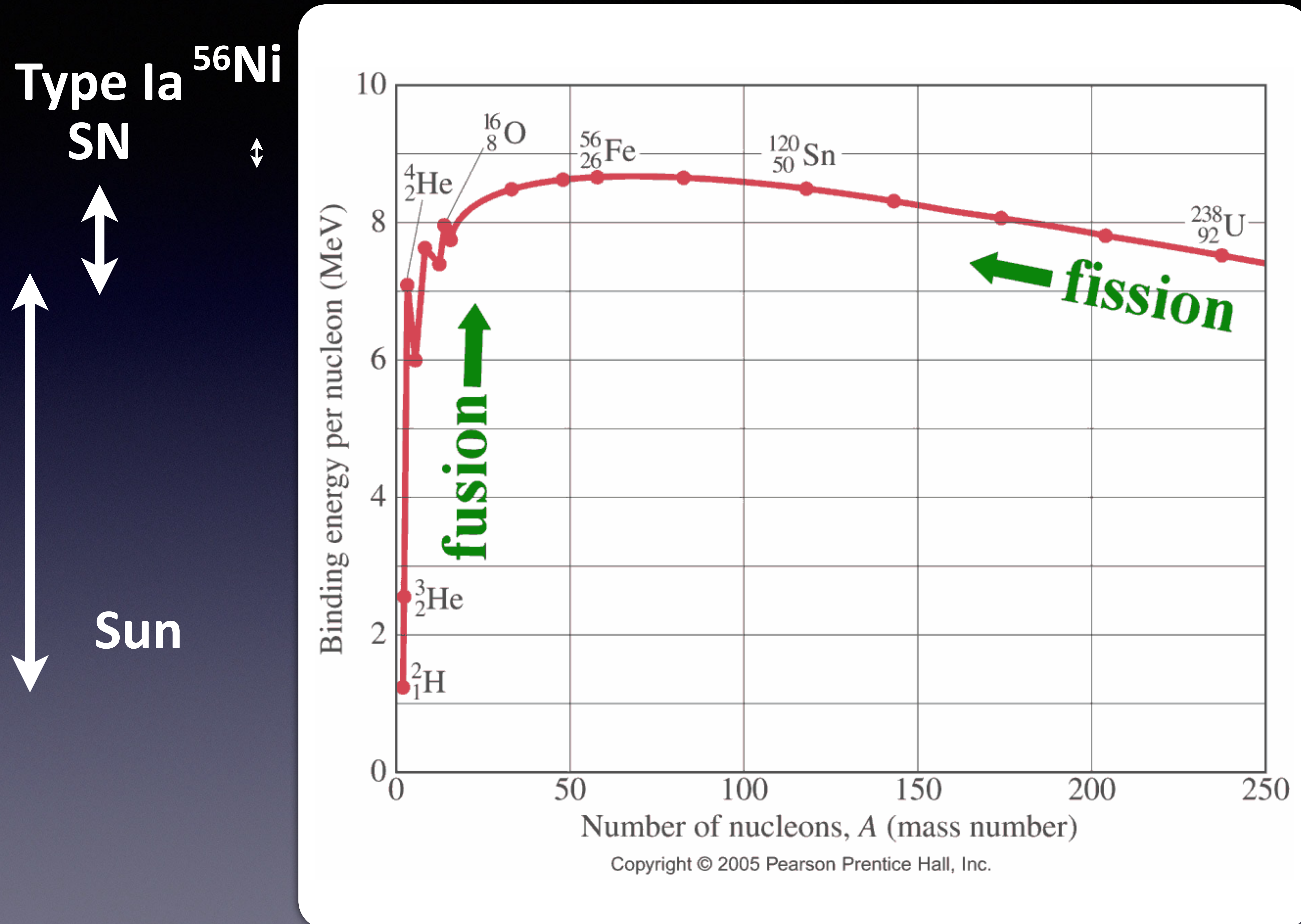
e capture

pos decay

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

τ = 110 days





Type Ia SN
^{56}Ni
Sun
10
8
6
4
2
0
Binding energy per nucleon (MeV)
$^{16}_{8}$O
$^{56}_{26}$Fe
$^{120}_{50}$Sn
$^{4}_{2}$He
$^{238}_{92}$U
fission
fusion
$^{3}_{2}$He
$^{2}_{1}$H
0
50
100
150
200
250
Number of nucleons, A (mass number)
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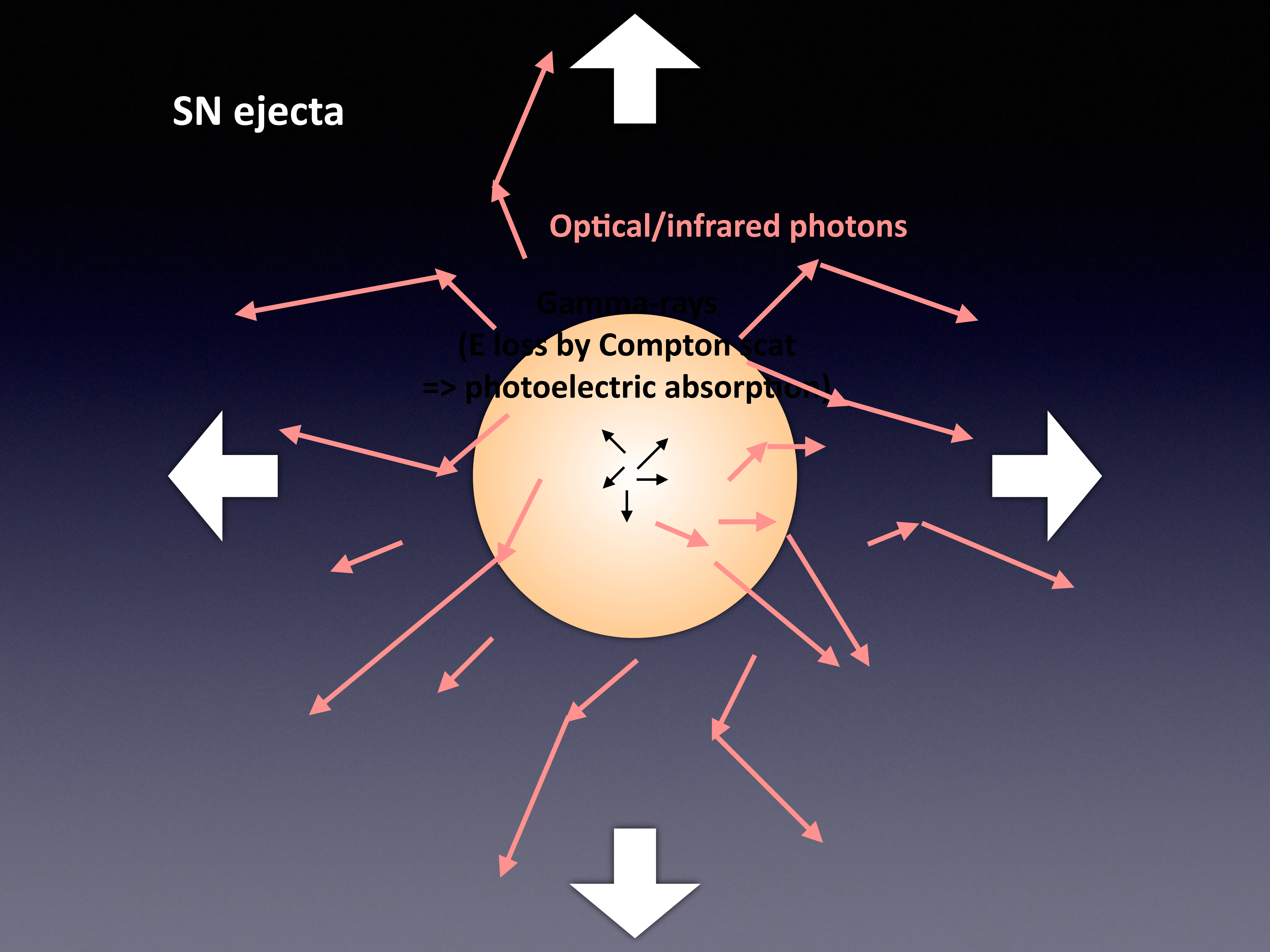
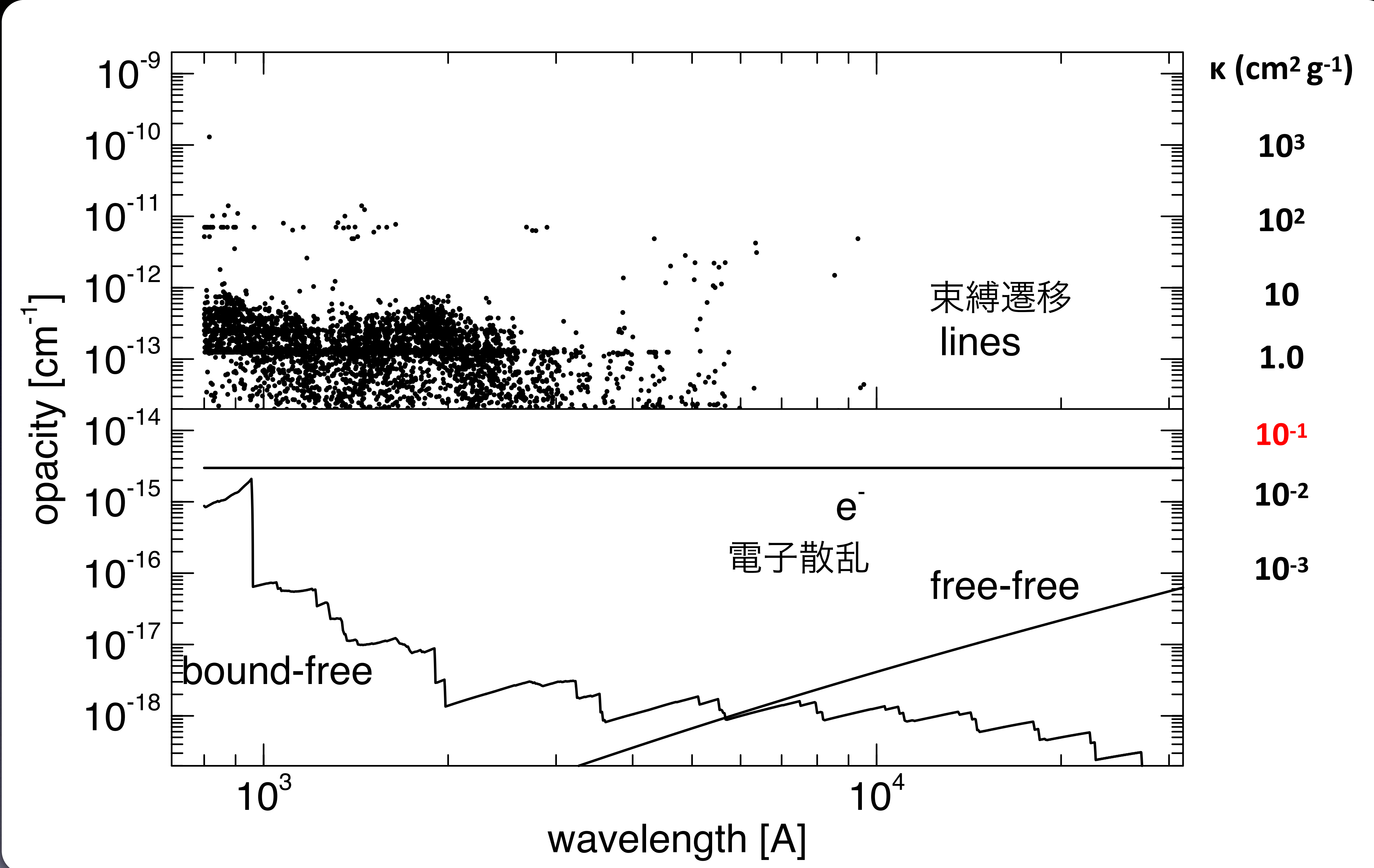


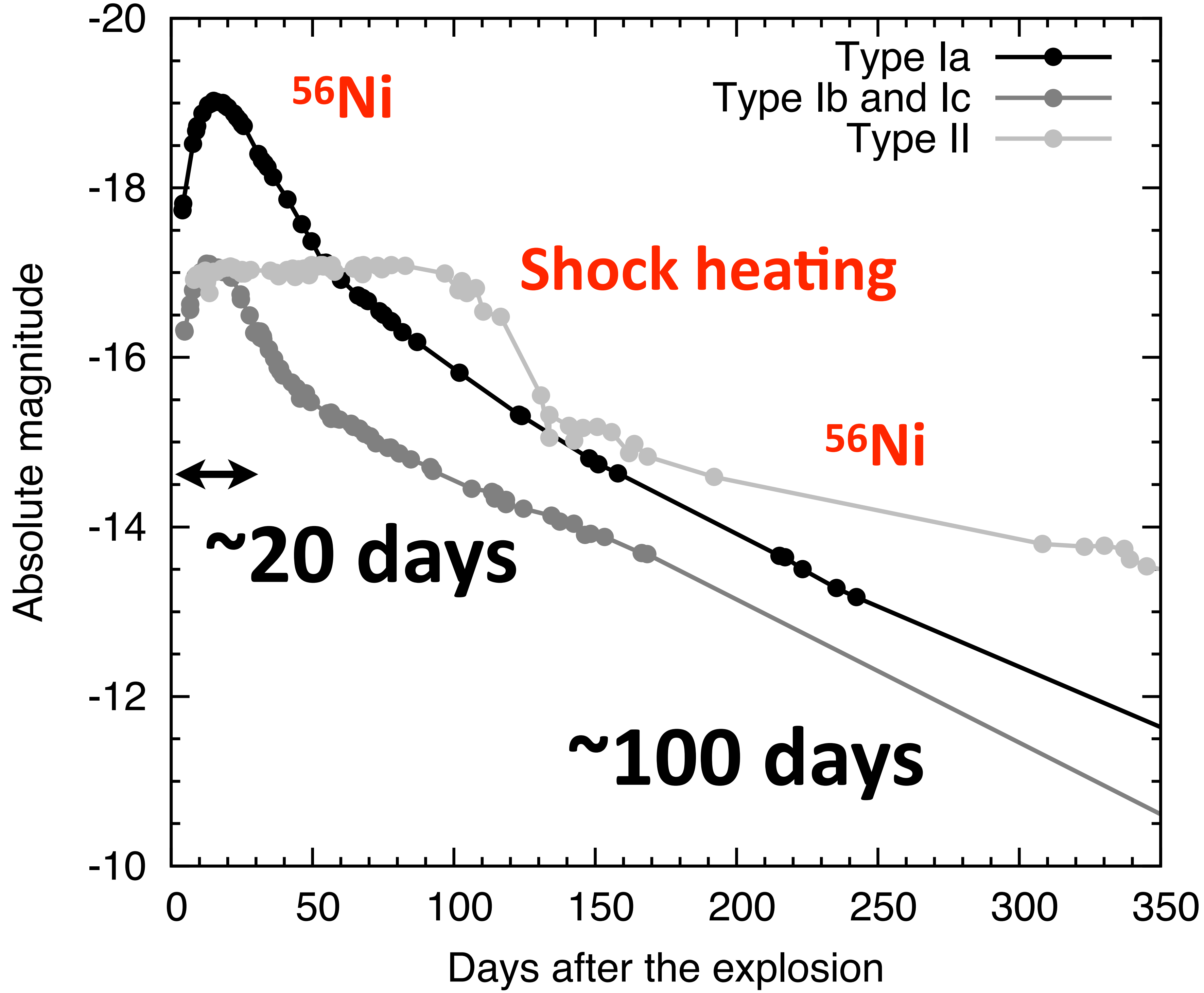
SN ejecta
Optical/infrared photons
Gamma-rays
(E loss by Compton scat
=> photoelectric absorption)

Opacity in supernova ejecta (Type Ia SN, $\rho = 10^{-13}$ g cm^{-3})



Pinto & Eastman 2000

Light curves



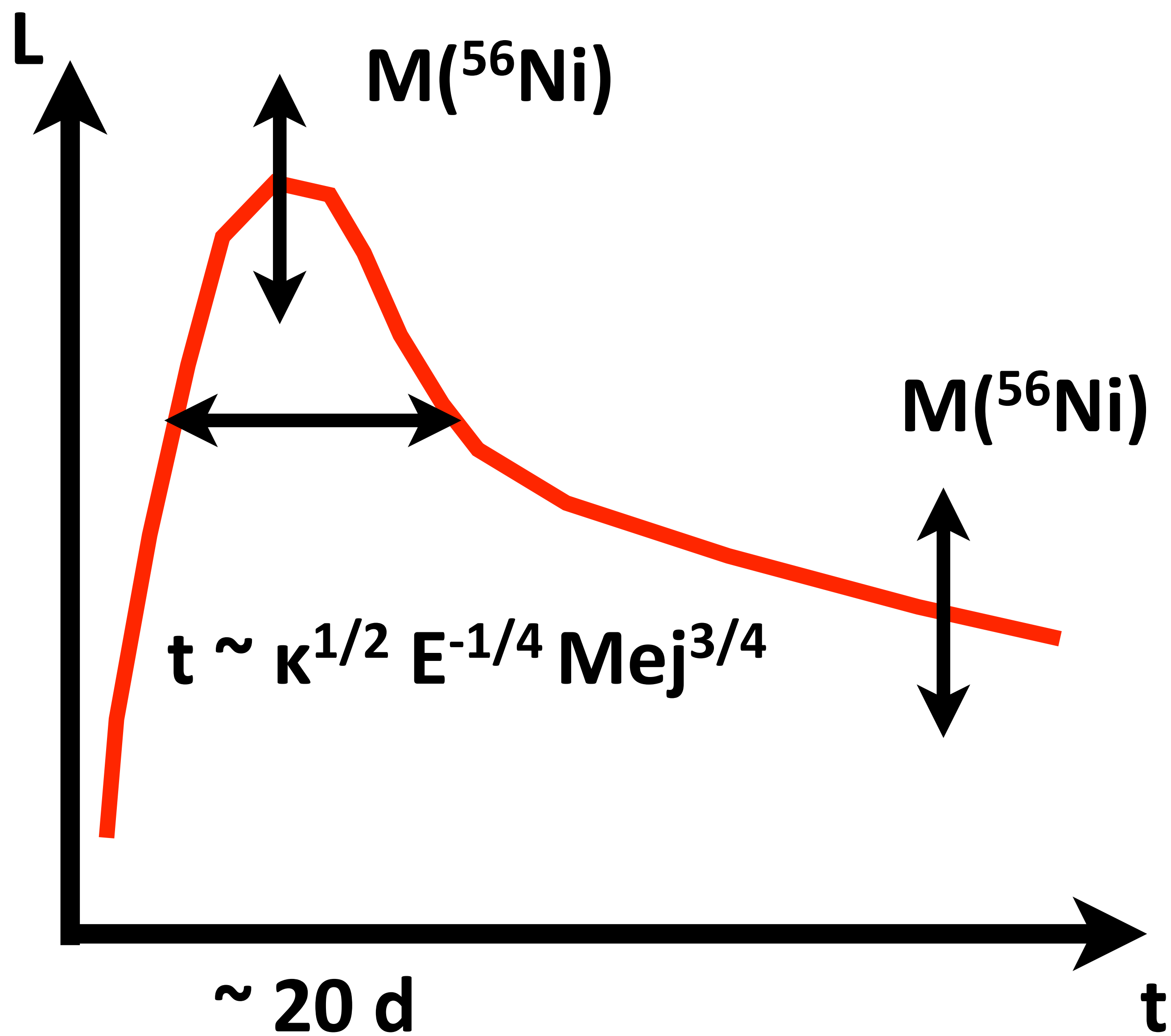
10^{43} erg s^{-1}

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

Type Ia SNe eject more ^{56}Ni

Observations <=> physical quantities

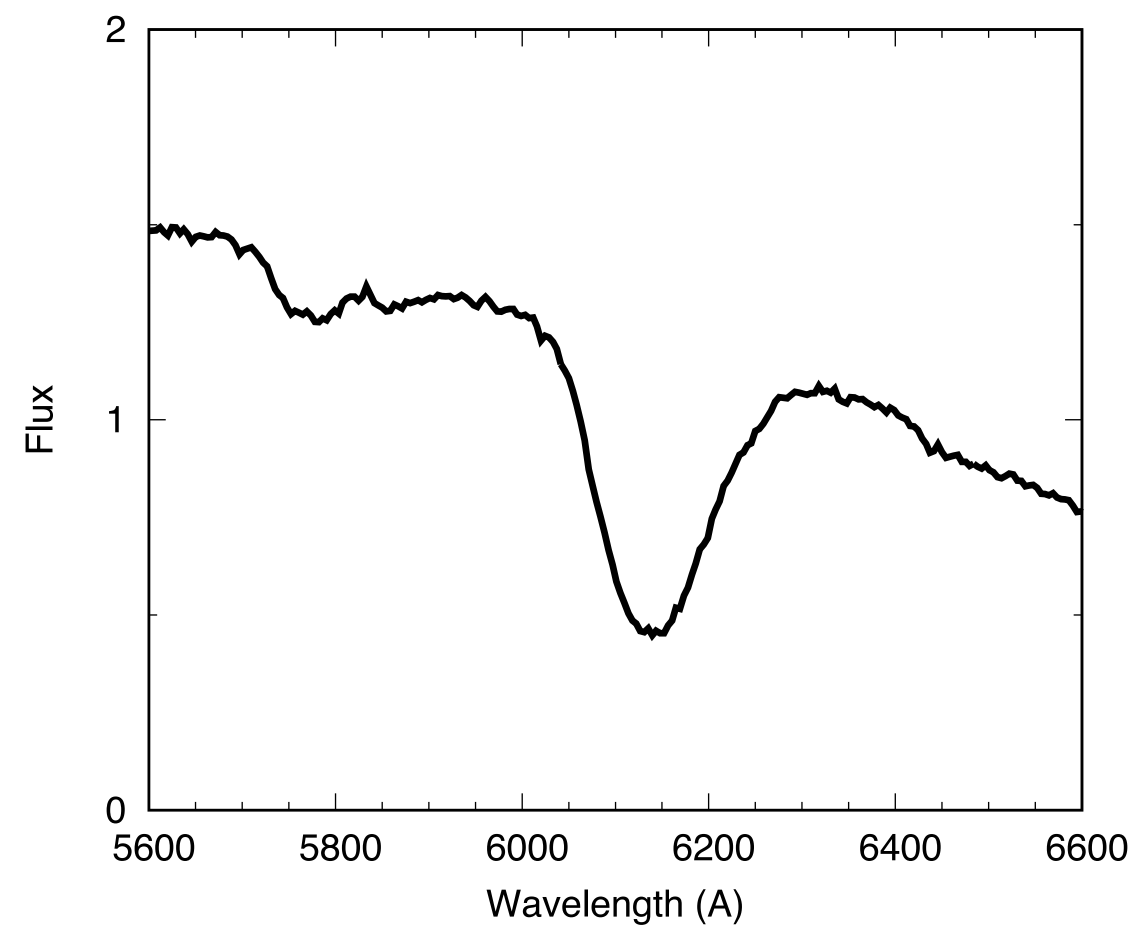
Light curves



Spectra

$v \sim E^{1/2}\,Mej^{-1/2}$

+ chemical composition



E, Mej, M(56Ni), X (element)

Summary: Radiation from supernovae

- **Erad ~ 10^{49} erg**
  << Ekin (10^{51} erg) << Egrav (10^{53} erg)
- **Power source**
  - Radioactivity (^{56}Ni)
  - Shock heating, interaction with CSM, magnetar, …
- **Timescale of emission**
  - Photons diffuse out from SN ejecta
  - bound-bound transitions and e-scattering
  - Typical timescale $t \sim \kappa^{1/2}\ M_{ej}^{3/4}\ E_k^{-1/4}$
    $\sim \kappa^{1/2}\ M_{ej}^{1/2}\ v^{-1/2}$