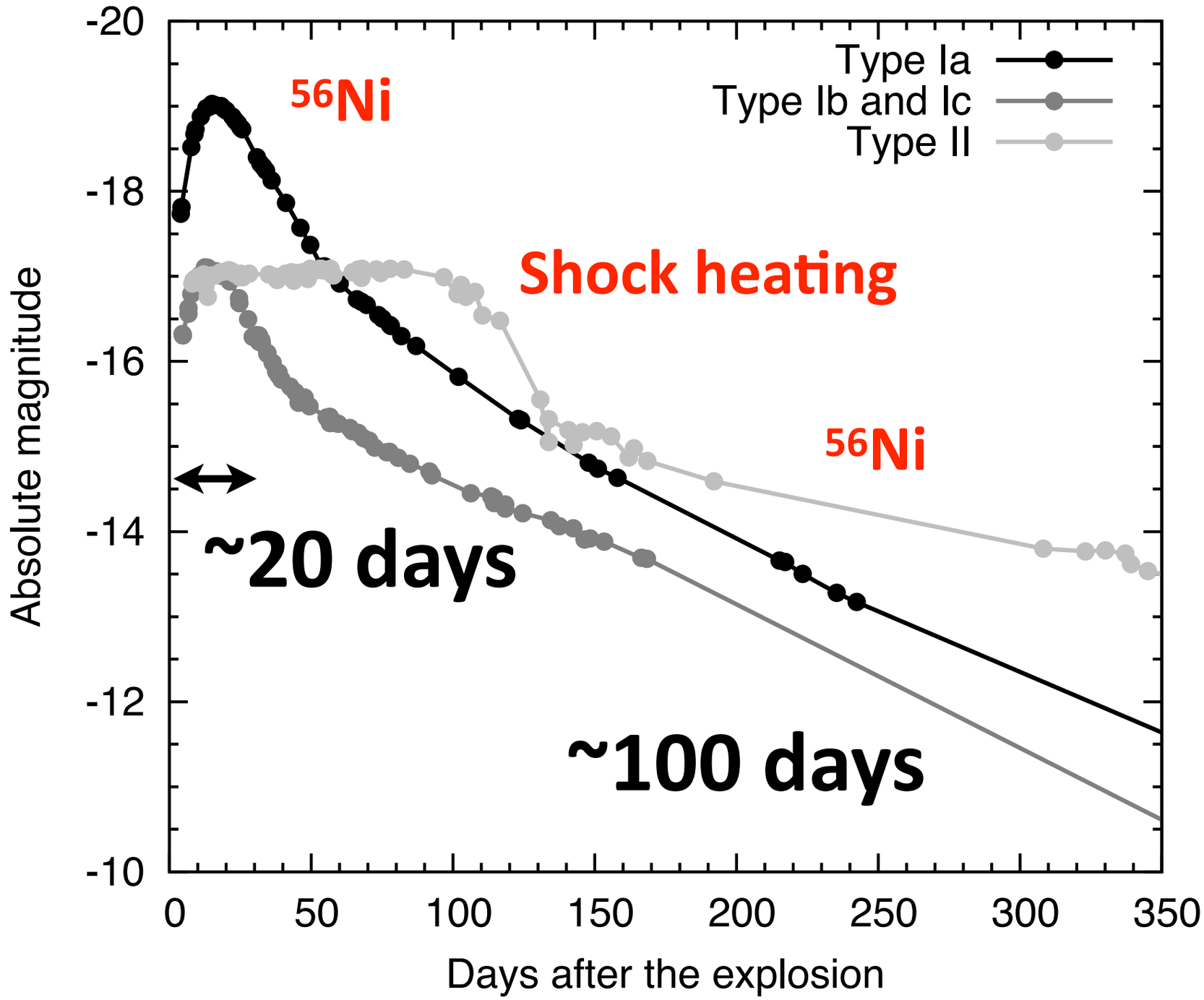
Section 9.
Radiation from supernovae (II)

9.1 Timescale of supernovae

9.2 Application to neutron star mergers

Light curves



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

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

Type Ia SNe eject more ^{56}Ni

Heating source of supernovae

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

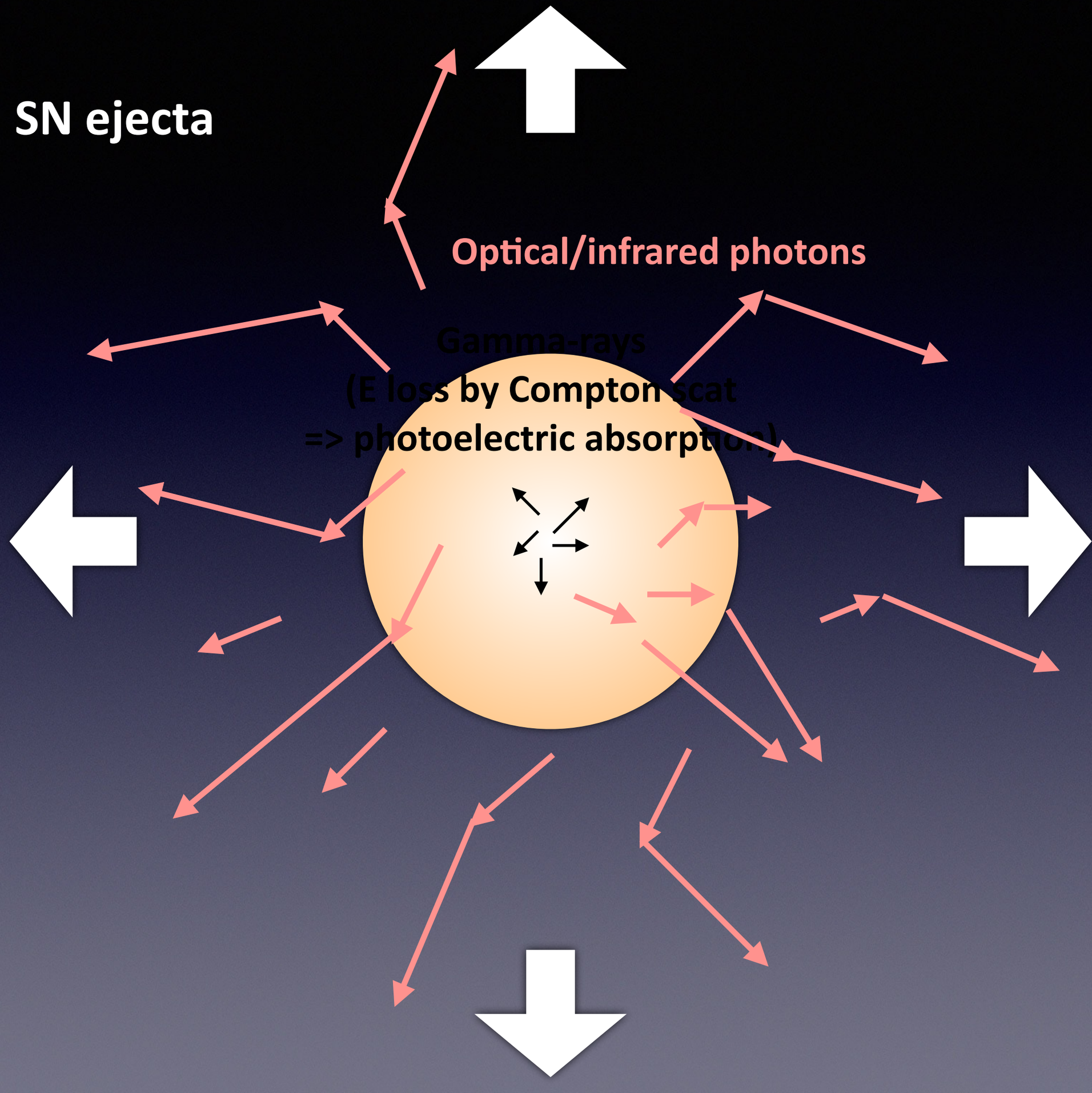
2. **Shock heating**
   Important for large-radius star (Type II)

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

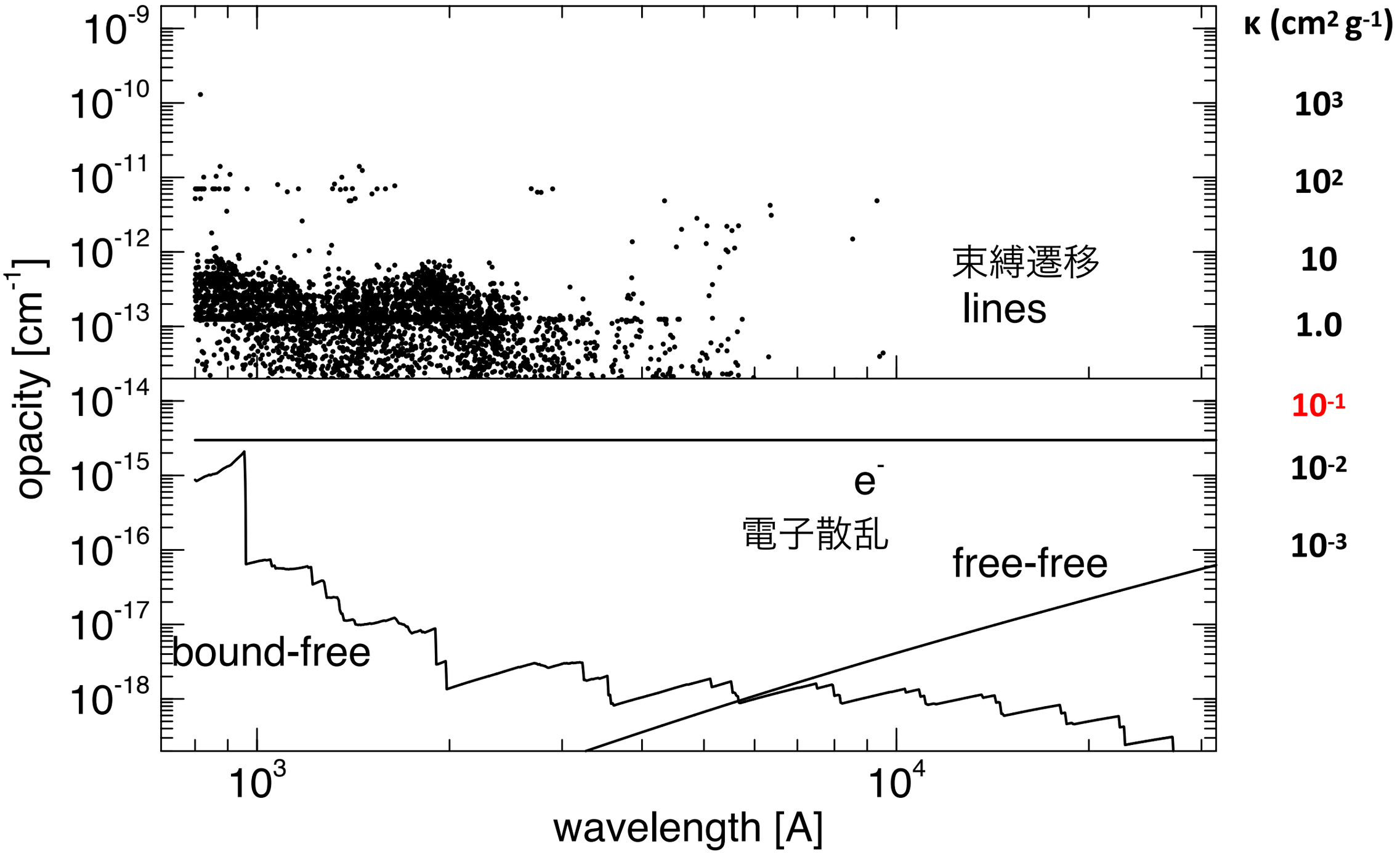
4. **Magnetar?**
   Erot => energy loss by spin down

What determines the timescale of supernovae?

What can we learn from observations?


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

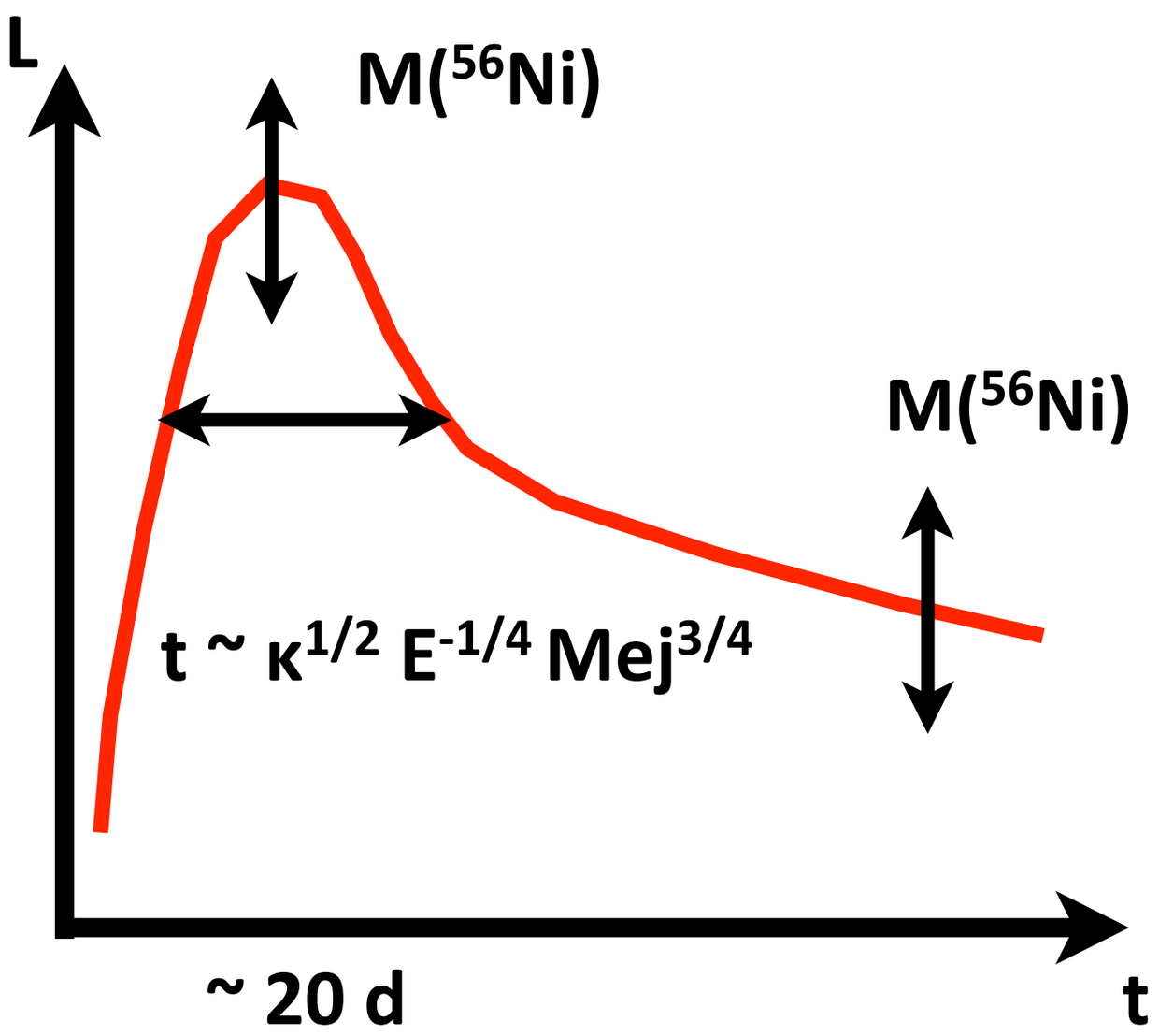
Opacity in supernova ejecta (Type Ia SN, ρ = 10^{-13} g cm^{-3})



Pinto & Eastman 2000

Observations <=> physical quantities

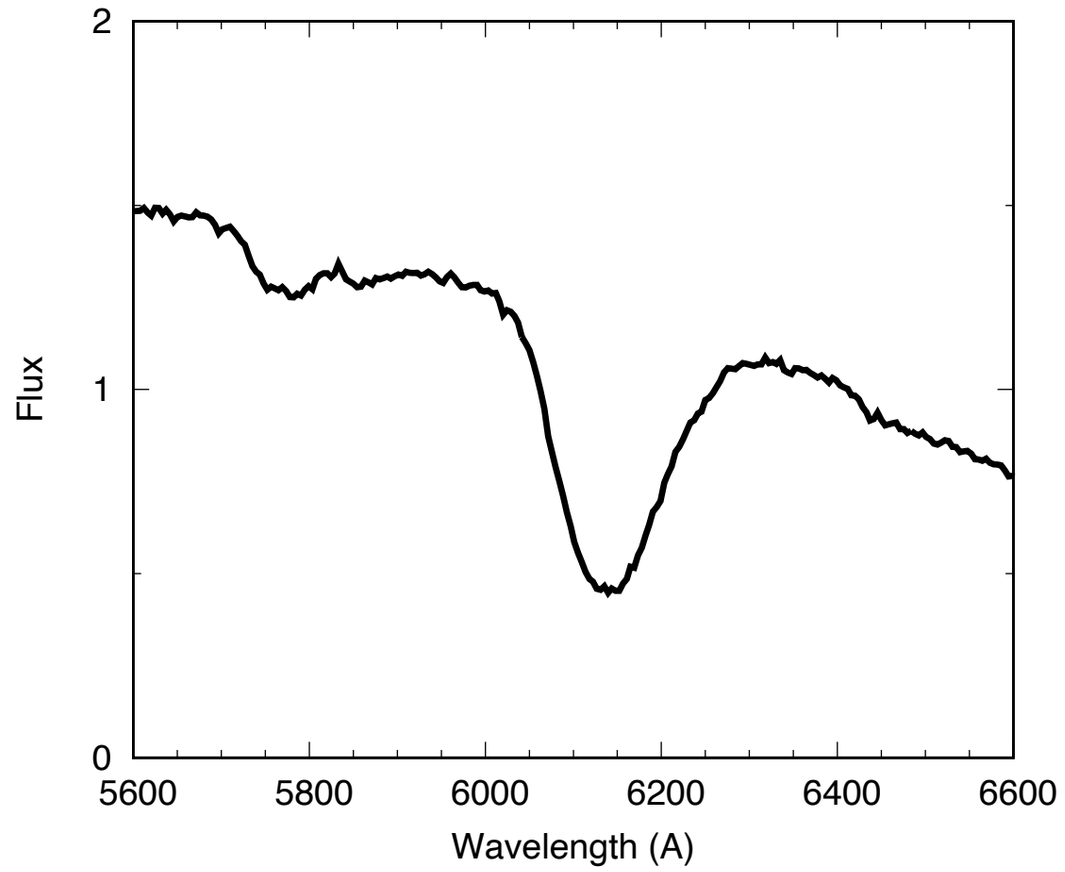
Light curves



Spectra

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

+ chemical composition



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

Section 9.
Radiation from supernovae (II)

9.1 Timescale of supernovae

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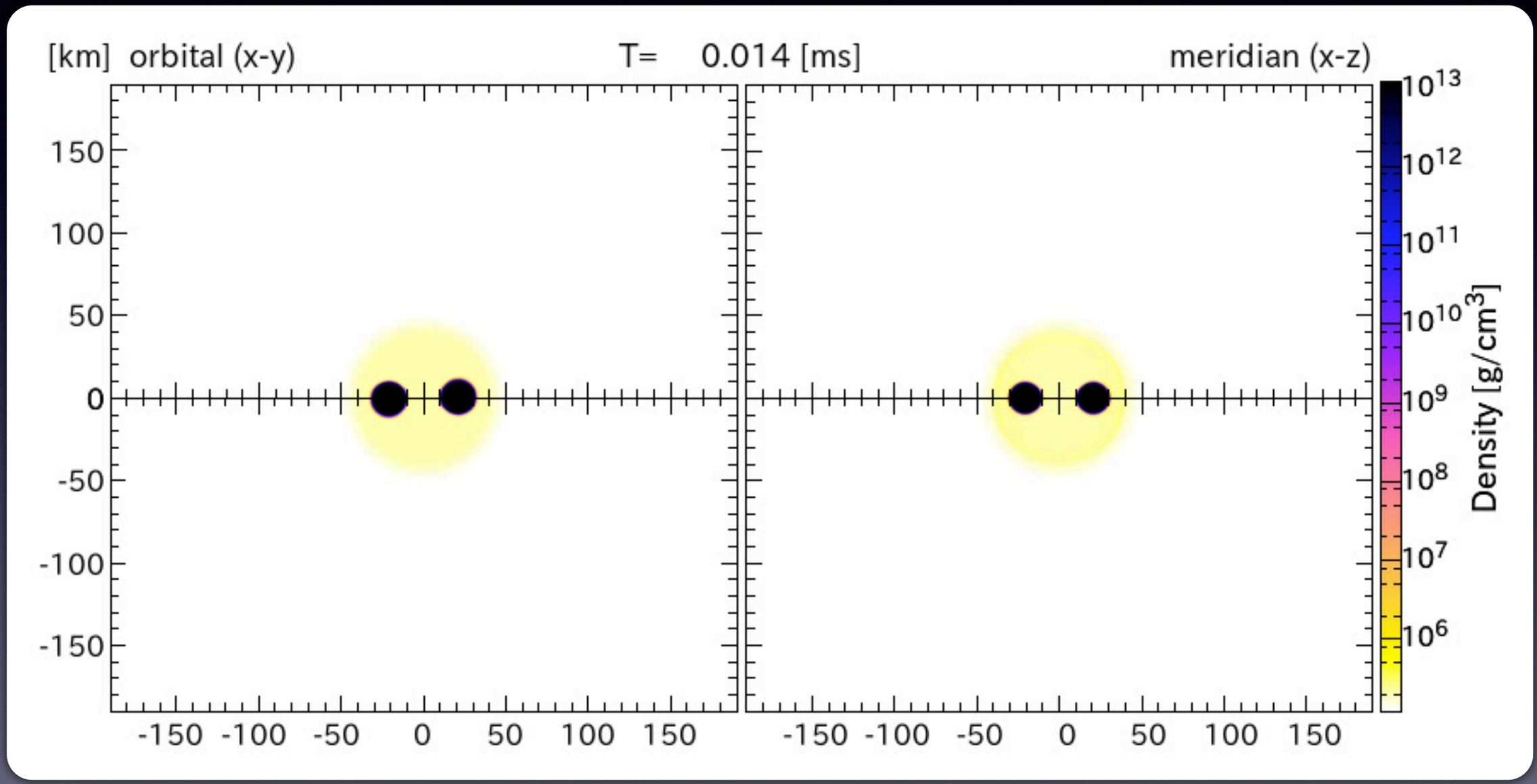
Neutron star merger

(C) NASA

NS merger => mass ejection

Top view

Side view

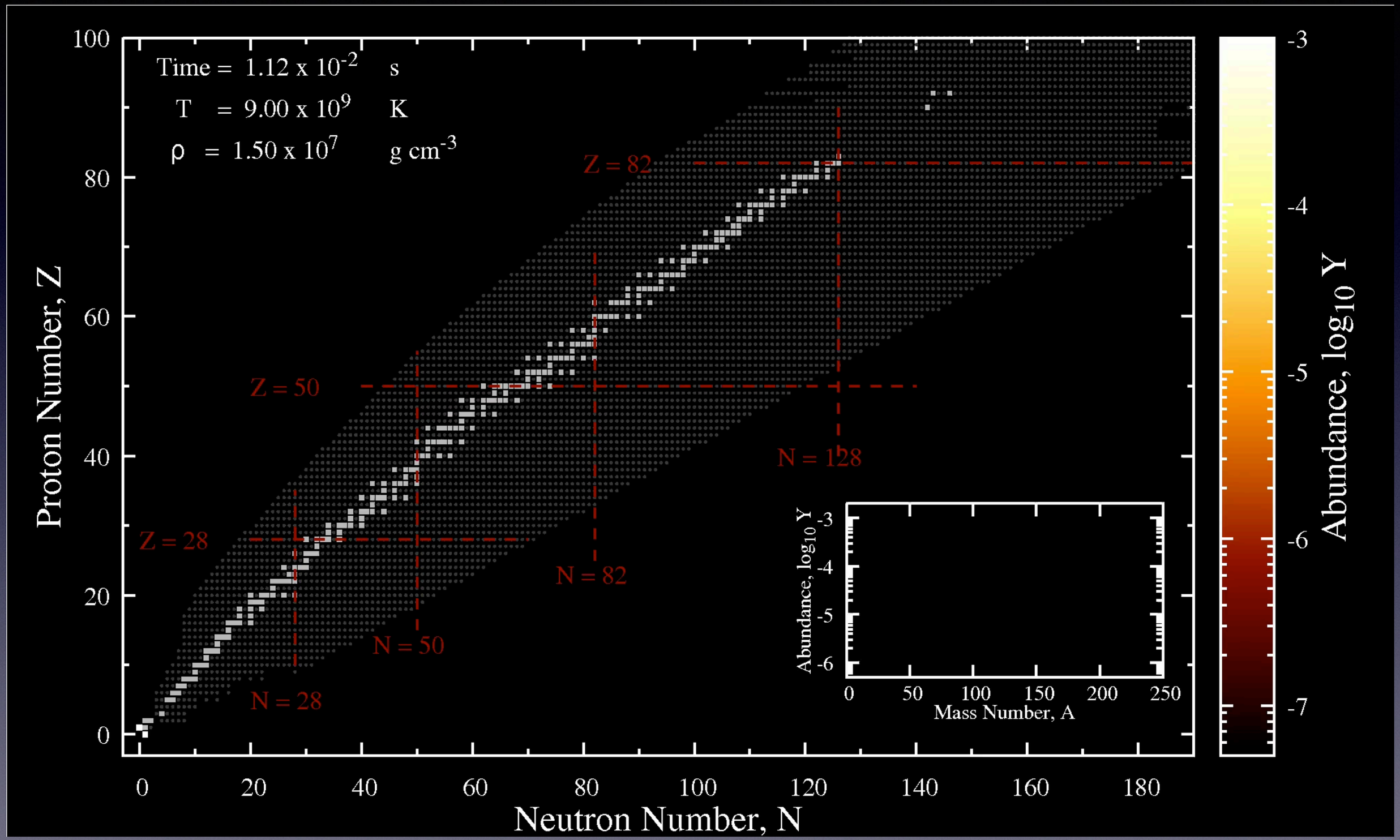


Sekiguchi+15, 16

M ~ 10^{-3} - 10^{-2} Msun

v ~ 0.1 - 0.2 c

r-process nucleosynthesis in NS merger

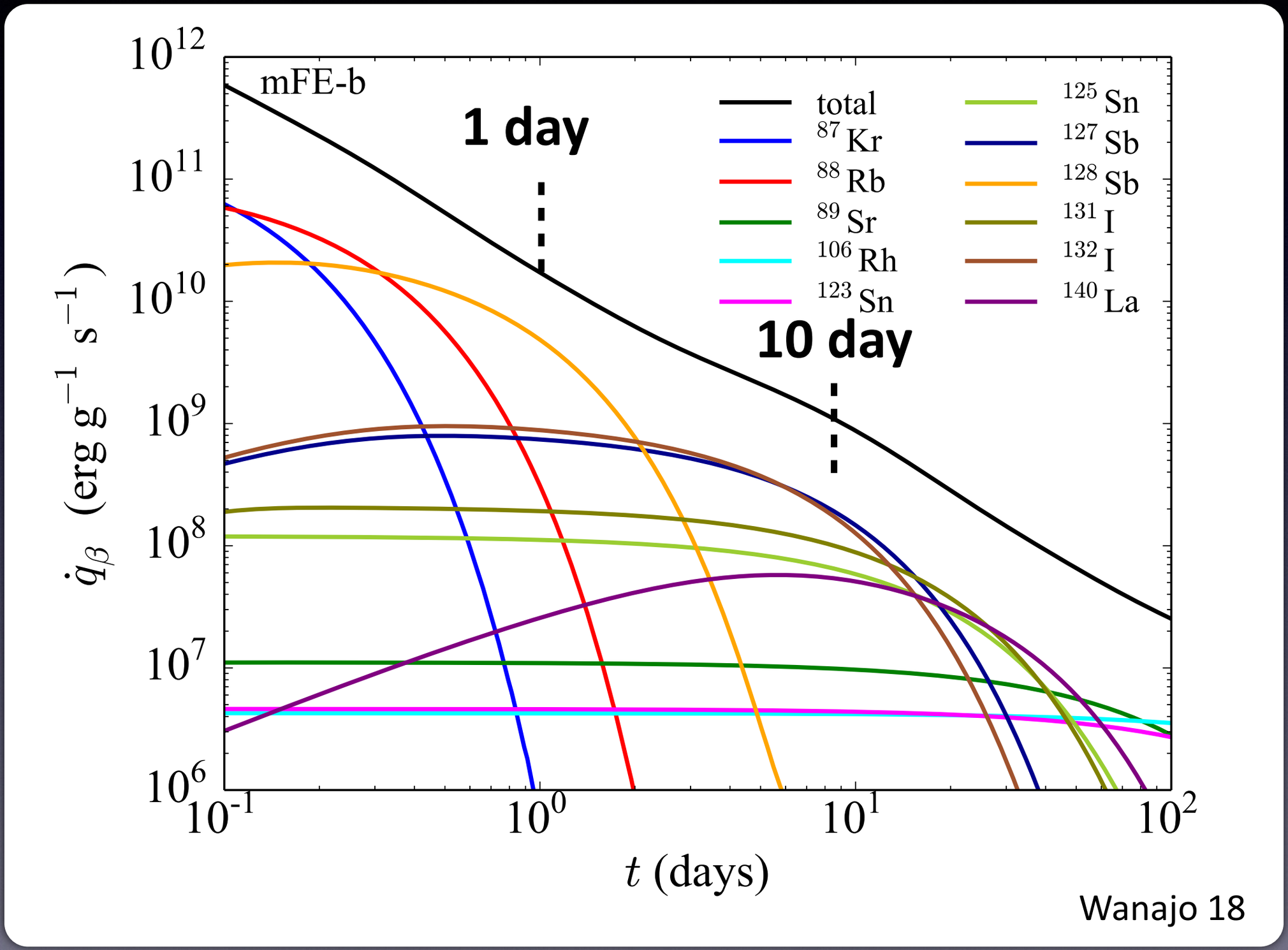


(C) Nobuya Nishimura

Supernova vs NS merger

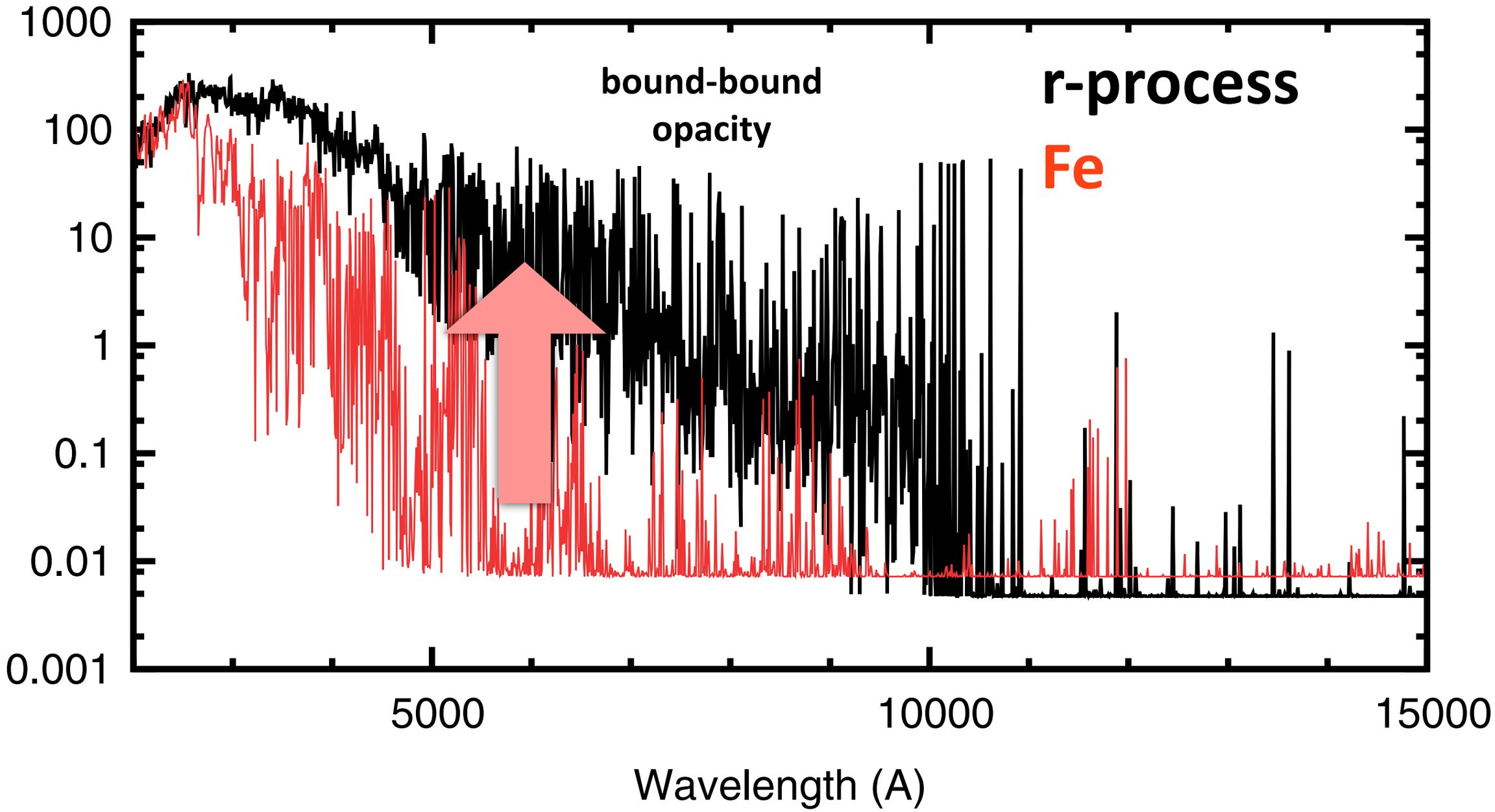
	Supernova	NS merger
Power source	^{56}Ni	r-process elements
Ejecta mass	1-10 Msun	0.01 Msun
Ejecta velocity	5,000-10,000 km/s	30,000-60,000 km/s (0.1c-0.2c)
Kinetic energy	10^{51} erg	1-5 x 10^{50} erg
Composition	H, He, C, O, Ca, Fe-group	r-process elements

Radioactive decay luminosity



Wanajo 18

Opacity



Higher opacity by factor of 100

(Kasen+13, Tanaka & Hotokezaka 13)

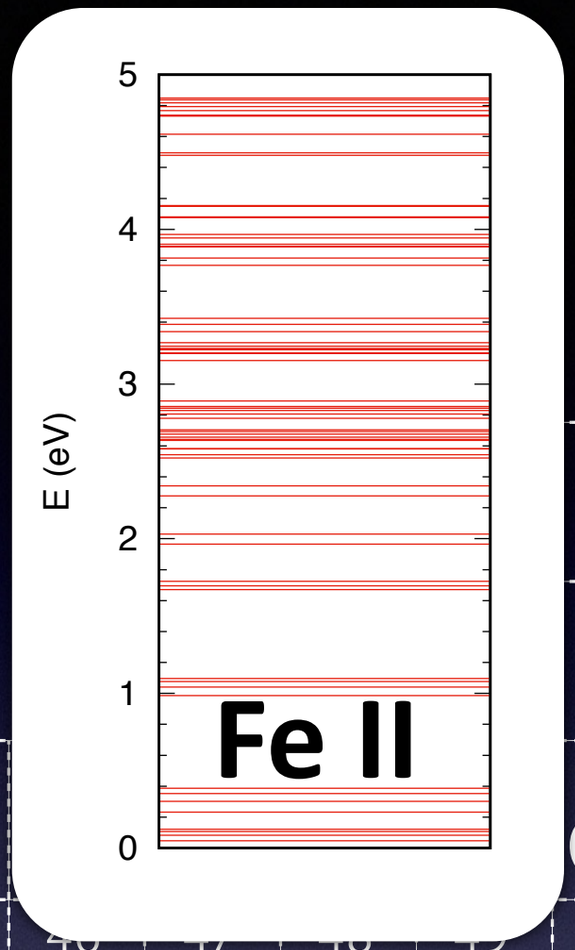
$$\lambda = \frac{hc}{\Delta E}$$

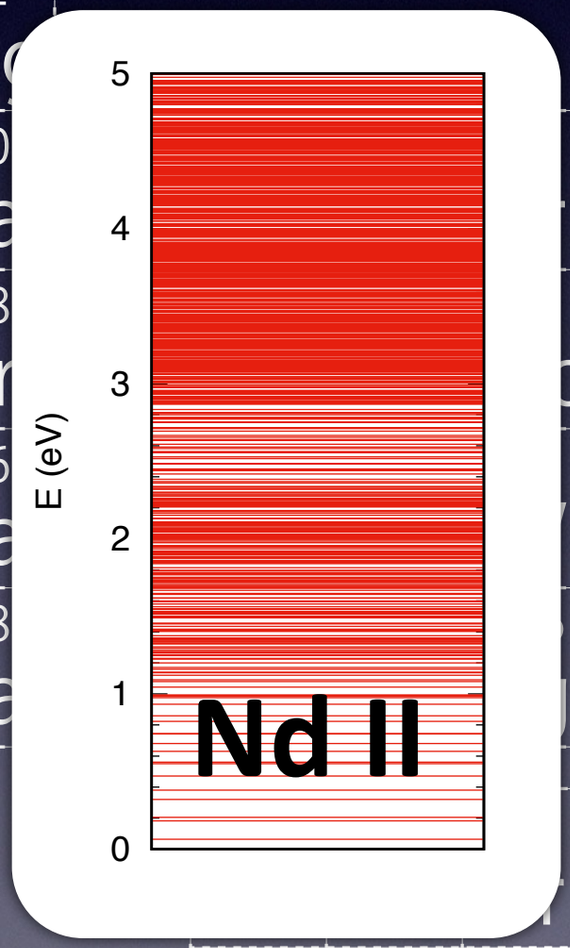
open s shell

open p-shell

open d-shell

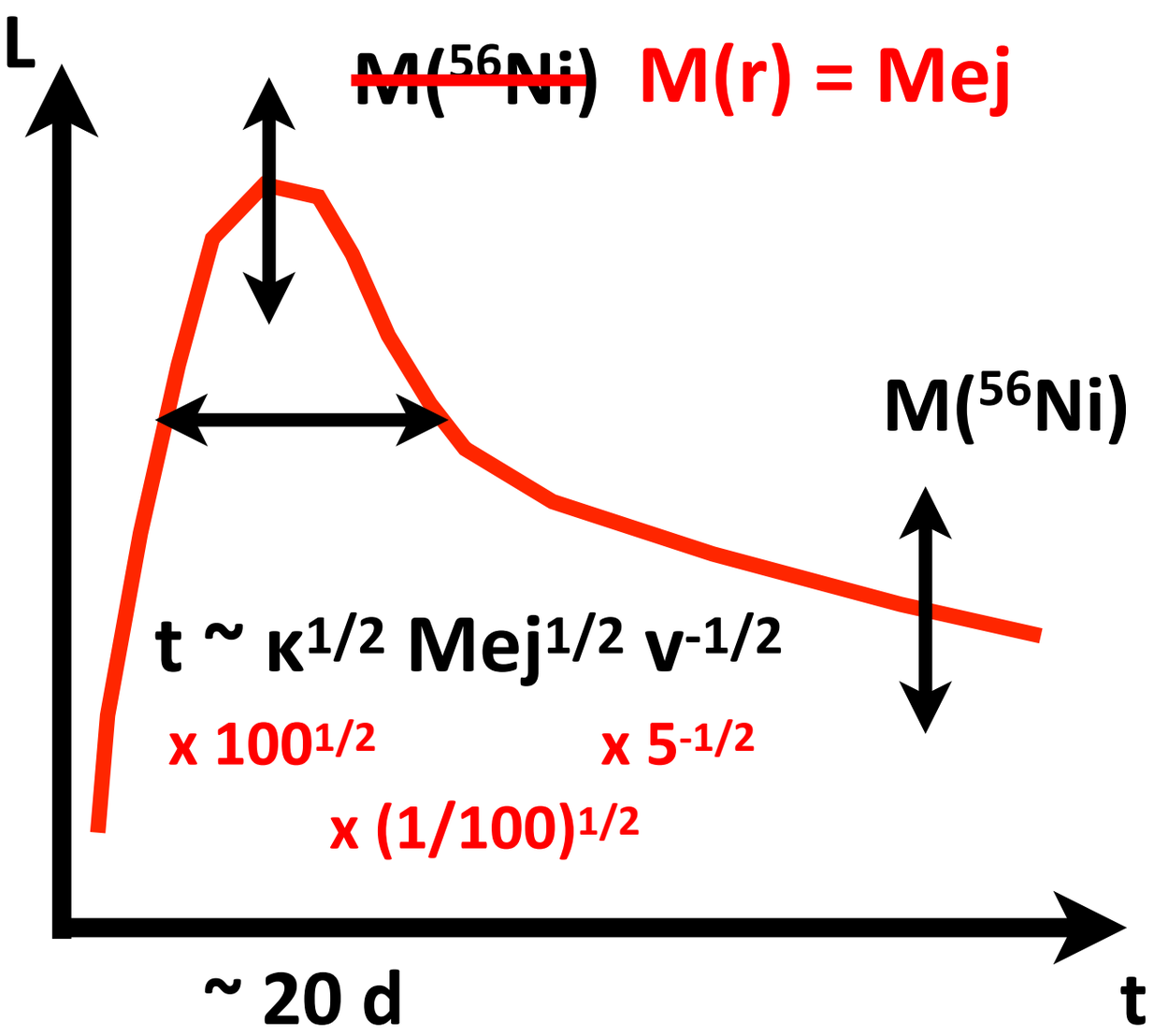
open f shell





Radiation from NS merger

Light curves

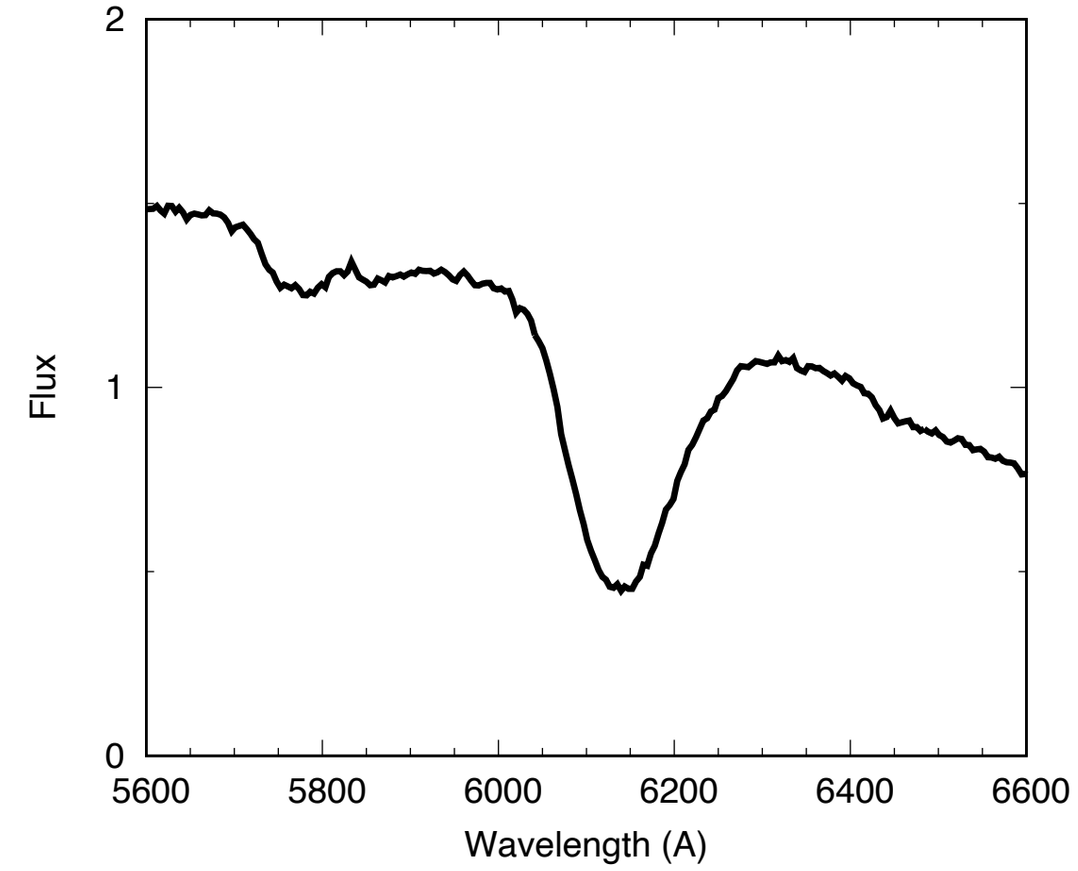


Fainter and faster than supernovae

Spectra

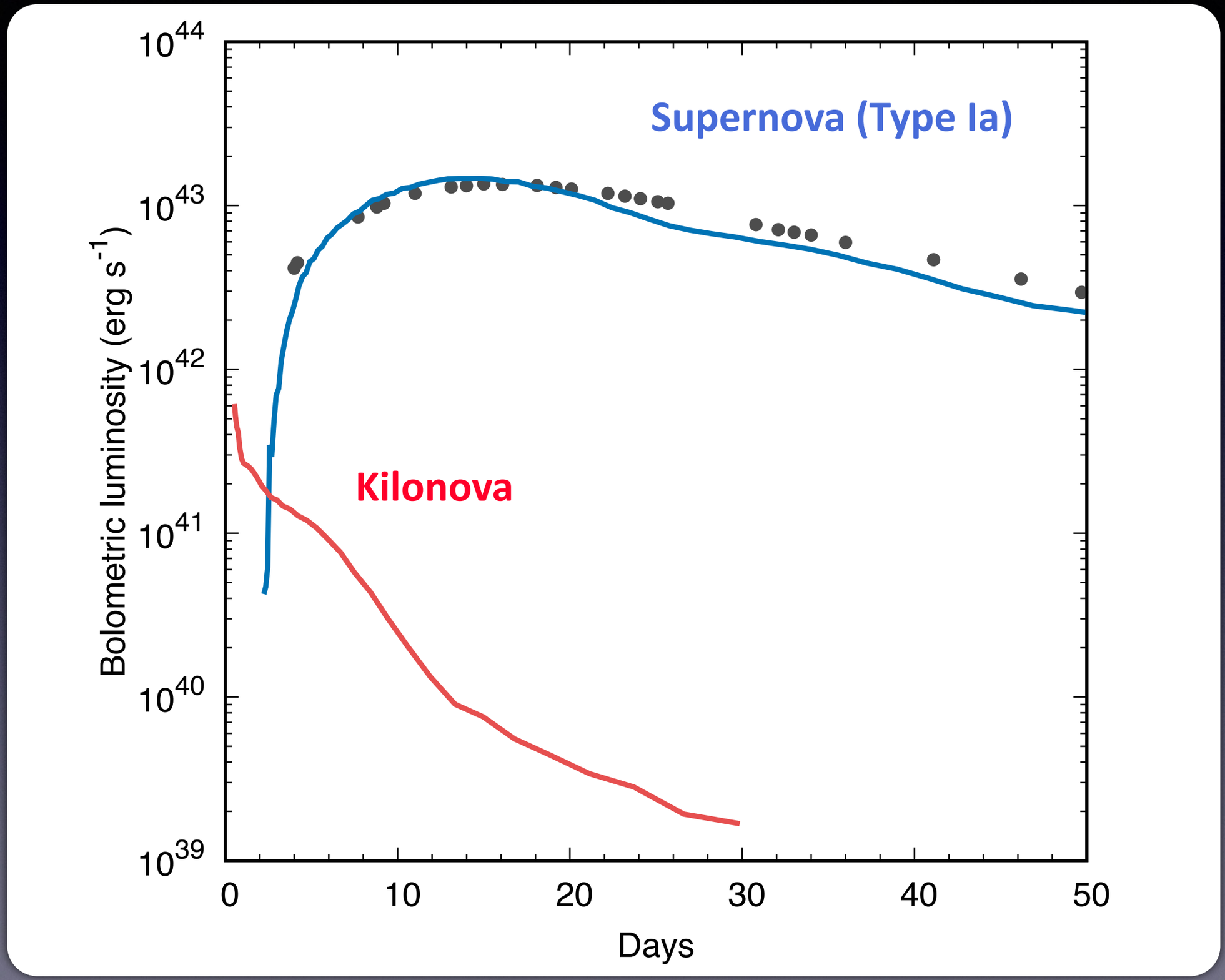
$v \sim E^{1/2} Mej^{-1/2}$

+ Chemical composition

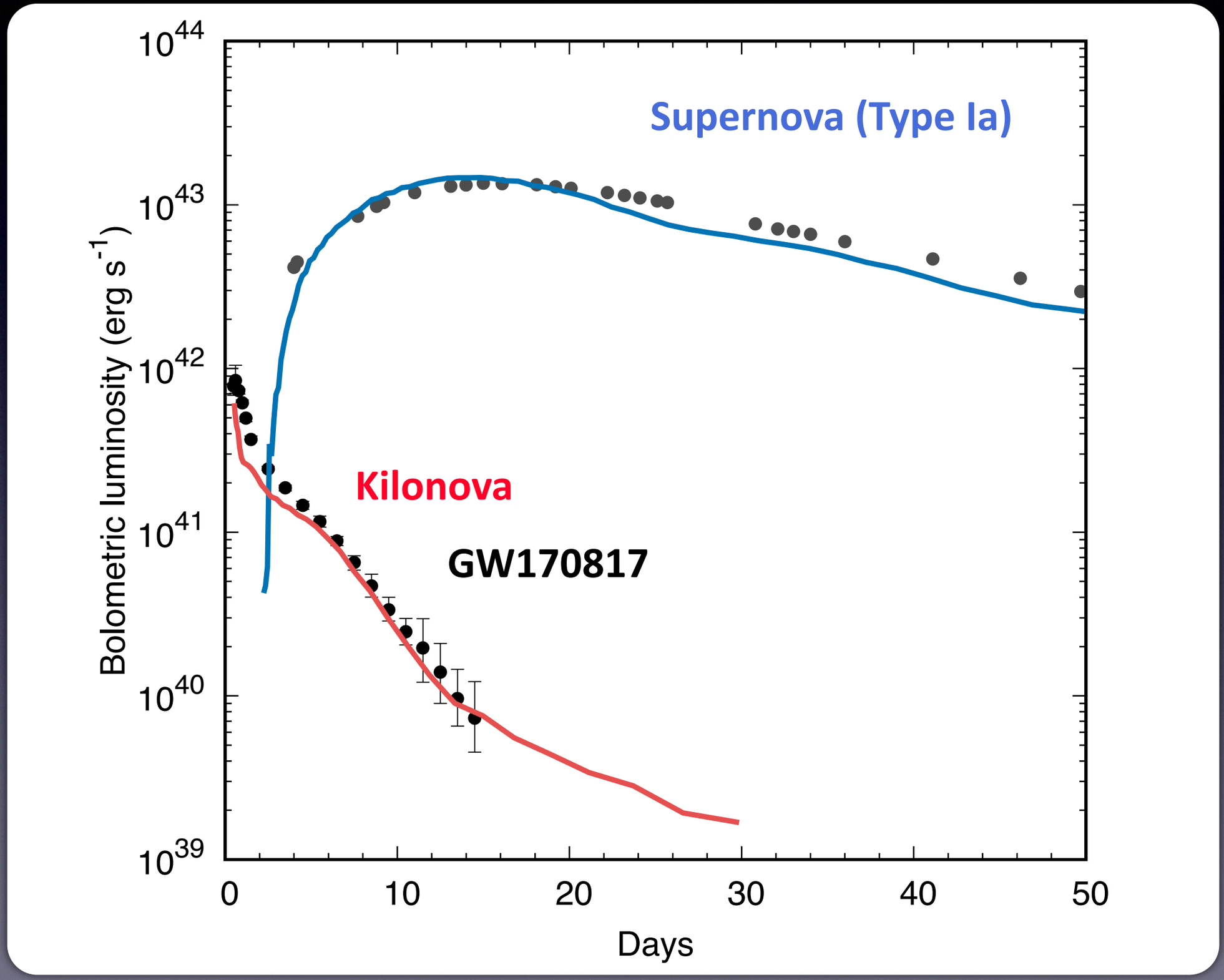


Higher velocities than supernovae

Supernova and kilonova



Supernova and kilonova



Summary: Radiation from supernovae (II)

- **Timescale of emission**
  - Photons diffusion in expanding material (bound-bound transitions and e-scattering)
  - Typical timescale $t \sim \kappa^{1/2} Mej^{3/4} Ek^{-1/4} \sim \kappa^{1/2} Mej^{1/2} v^{-1/2}$
- **Lessons from observations**
  - M (Type II SN) > M (Type Ibc SN) > M (Type Ia SN)
  - E (CC SN) ~ E (Type Ia SN)
- **Applications to Neutron star merger merger**
  - Lower ejecta mass (x 1/100), Faster expansion (x 5), Higher opacity (x 100)
  - Kilonova: Fainter and faster than supernovae