

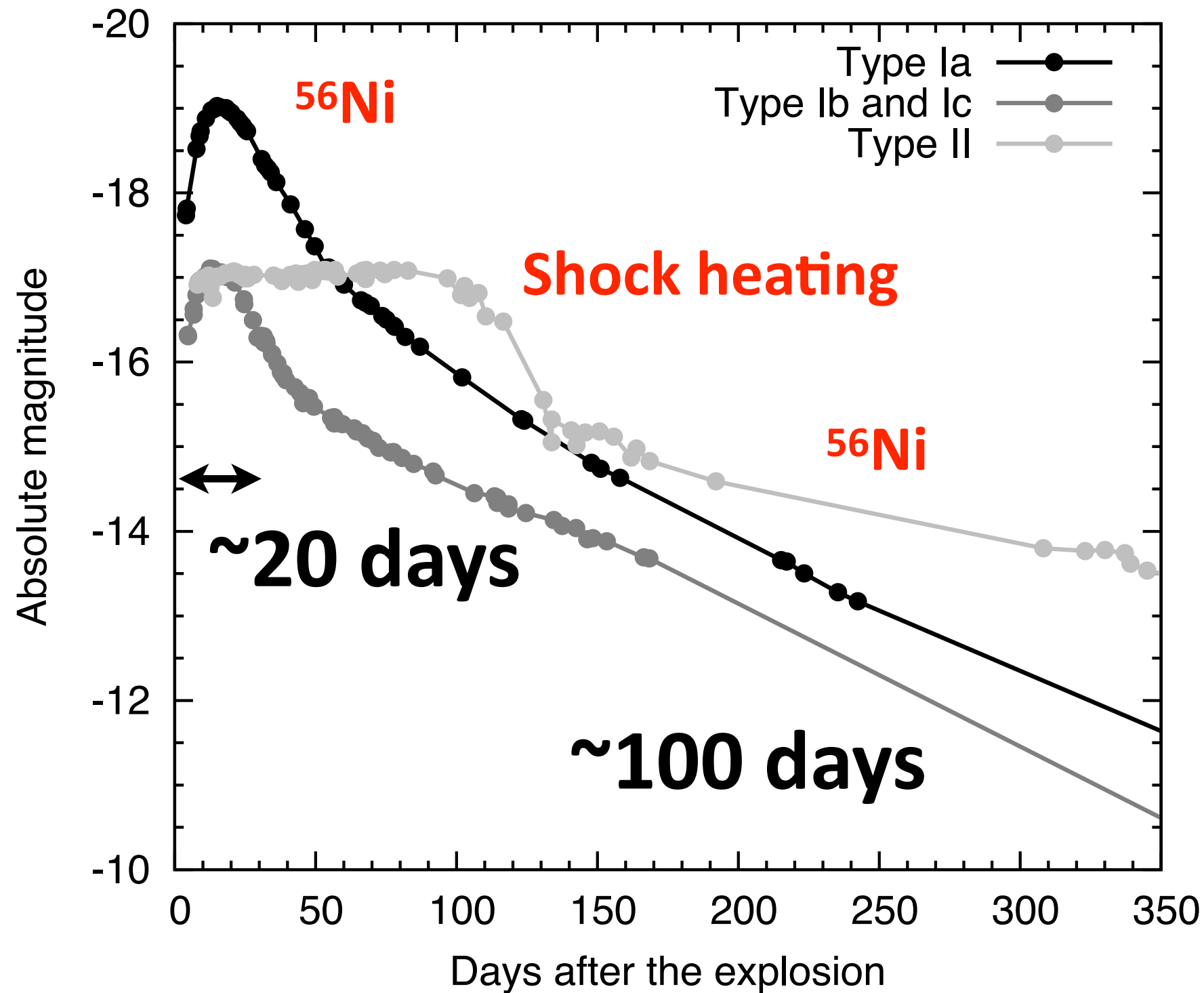
Section 9.

Radiation from supernovae (II)

9.1 Timescale of supernovae

9.2 Application to neutron star mergers

Light curves



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

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

**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

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

4. Magnetar?

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



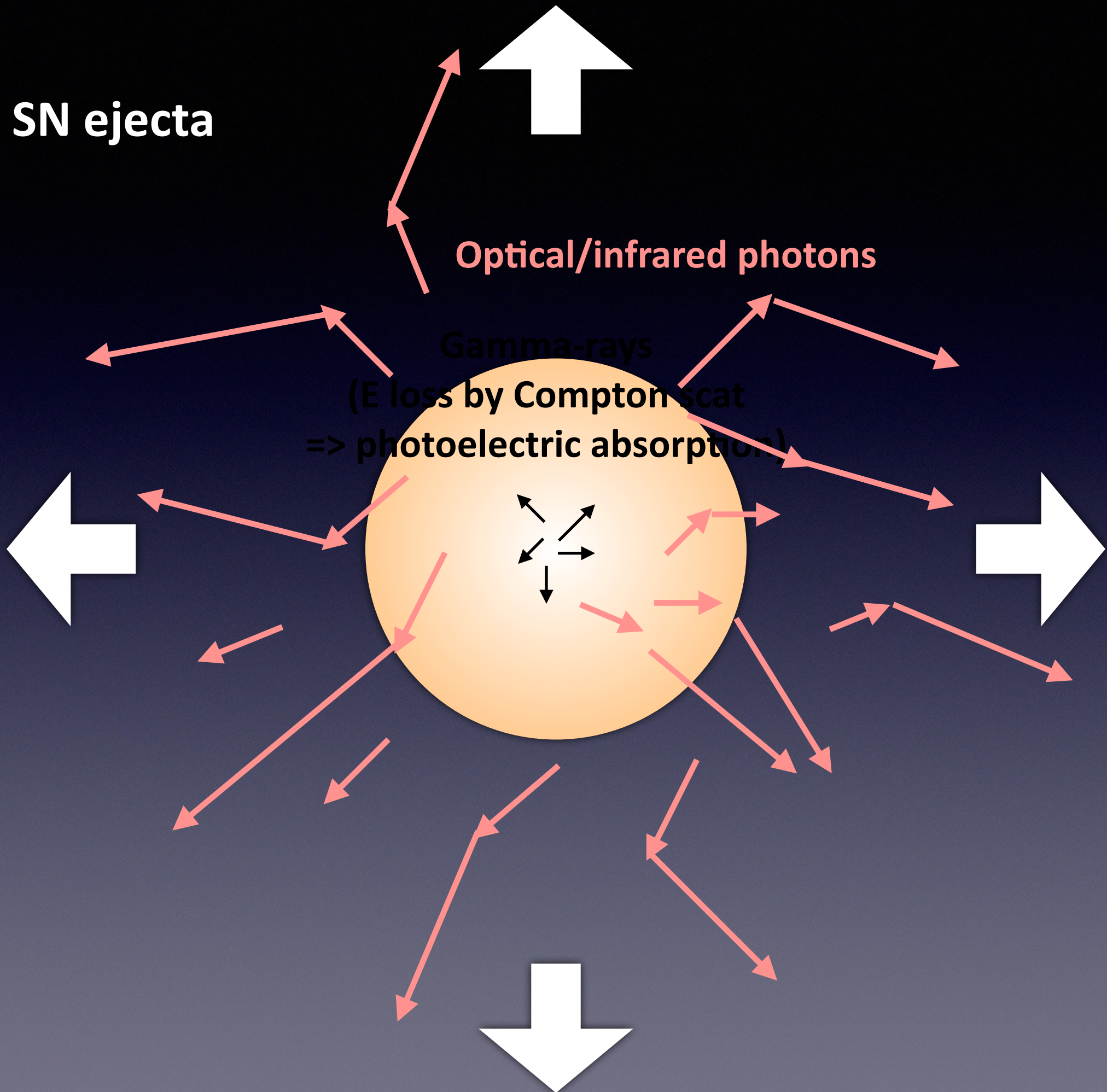
What determines the timescale of supernovae?

What can we learn from observations?

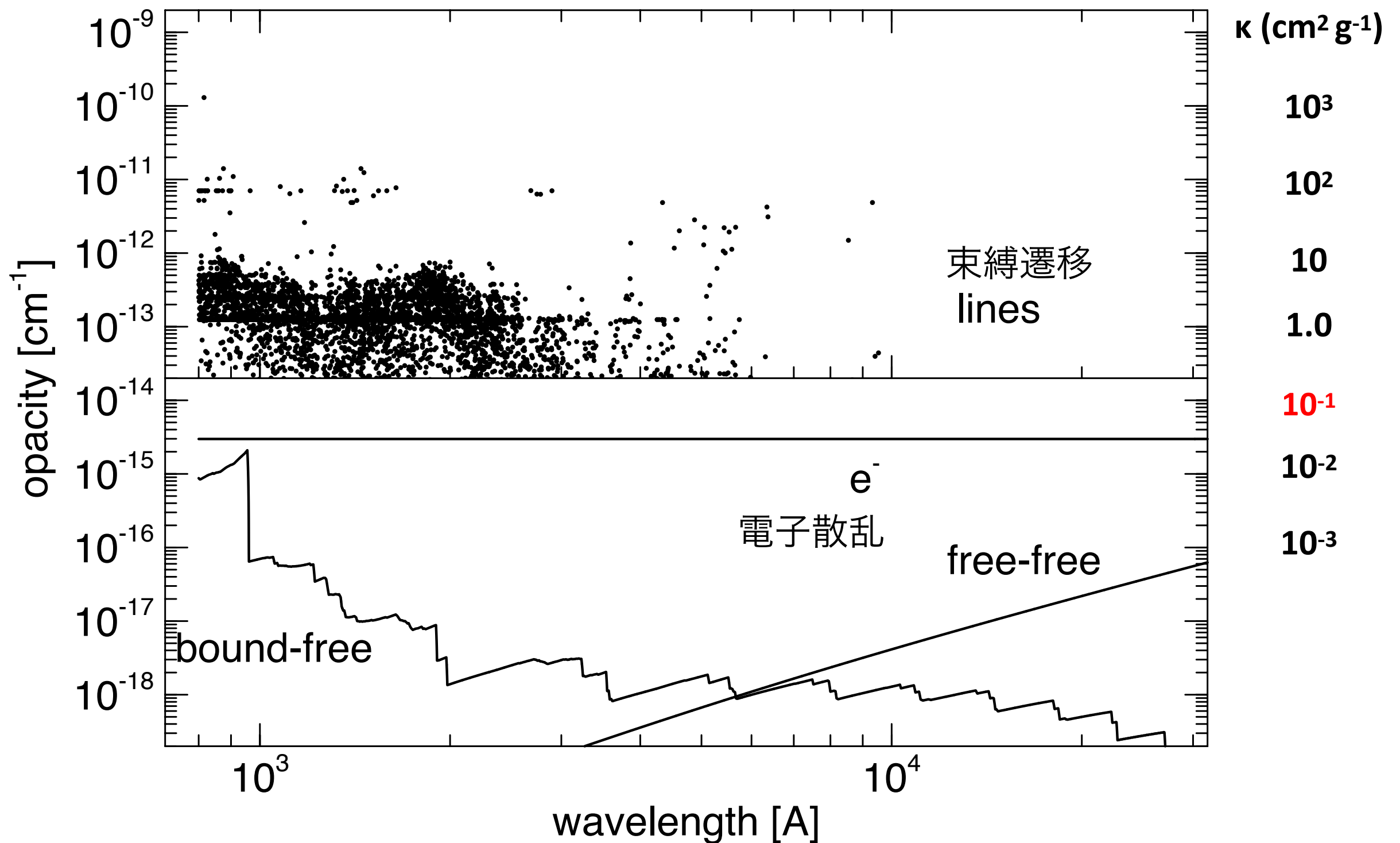
SN ejecta

Optical/infrared photons

Gamma-rays
(E loss by Compton scat
=> photoelectric absorption)

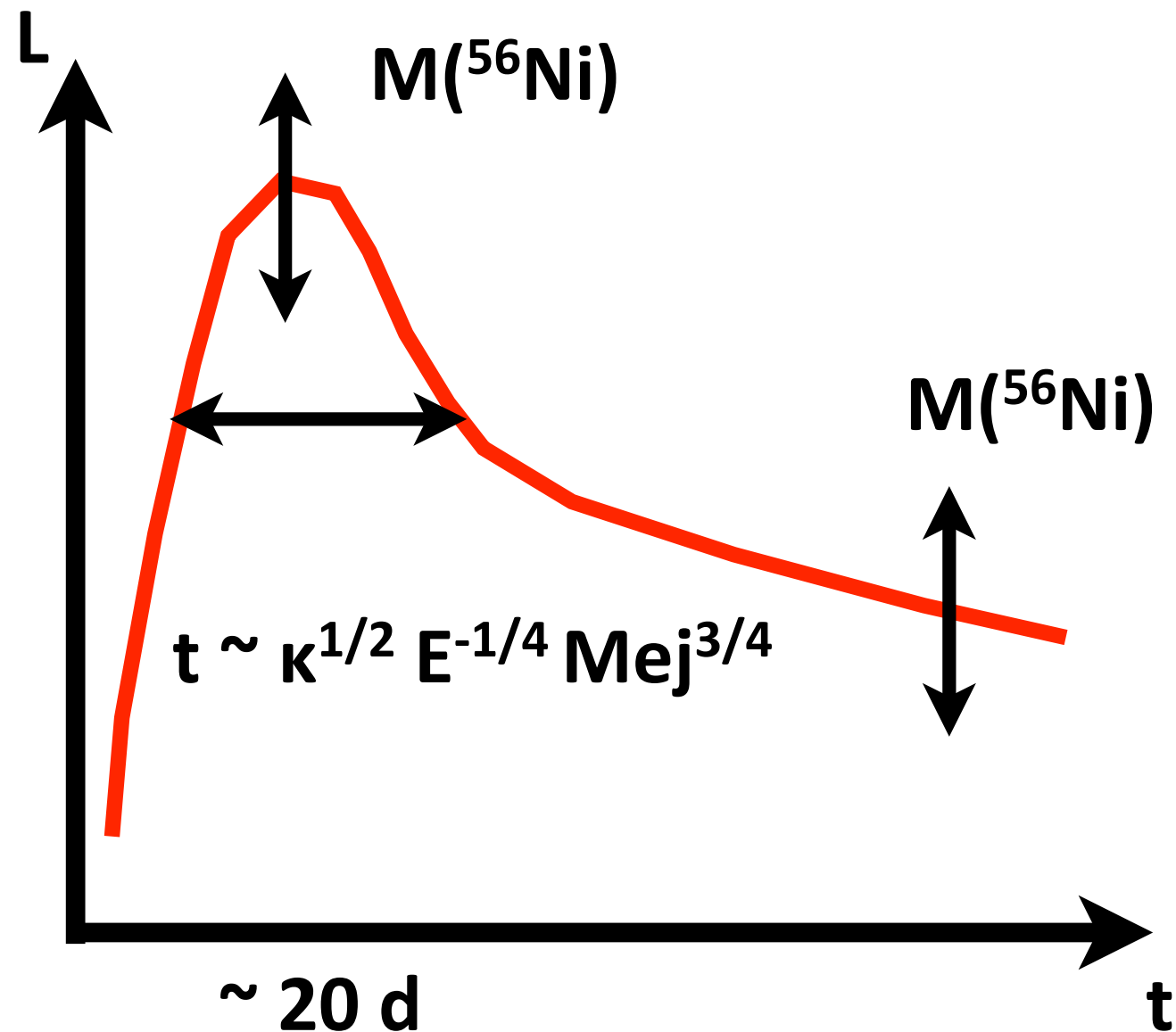


Opacity in supernova ejecta (Type Ia SN, $\rho = 10^{-13} \text{ g cm}^{-3}$)



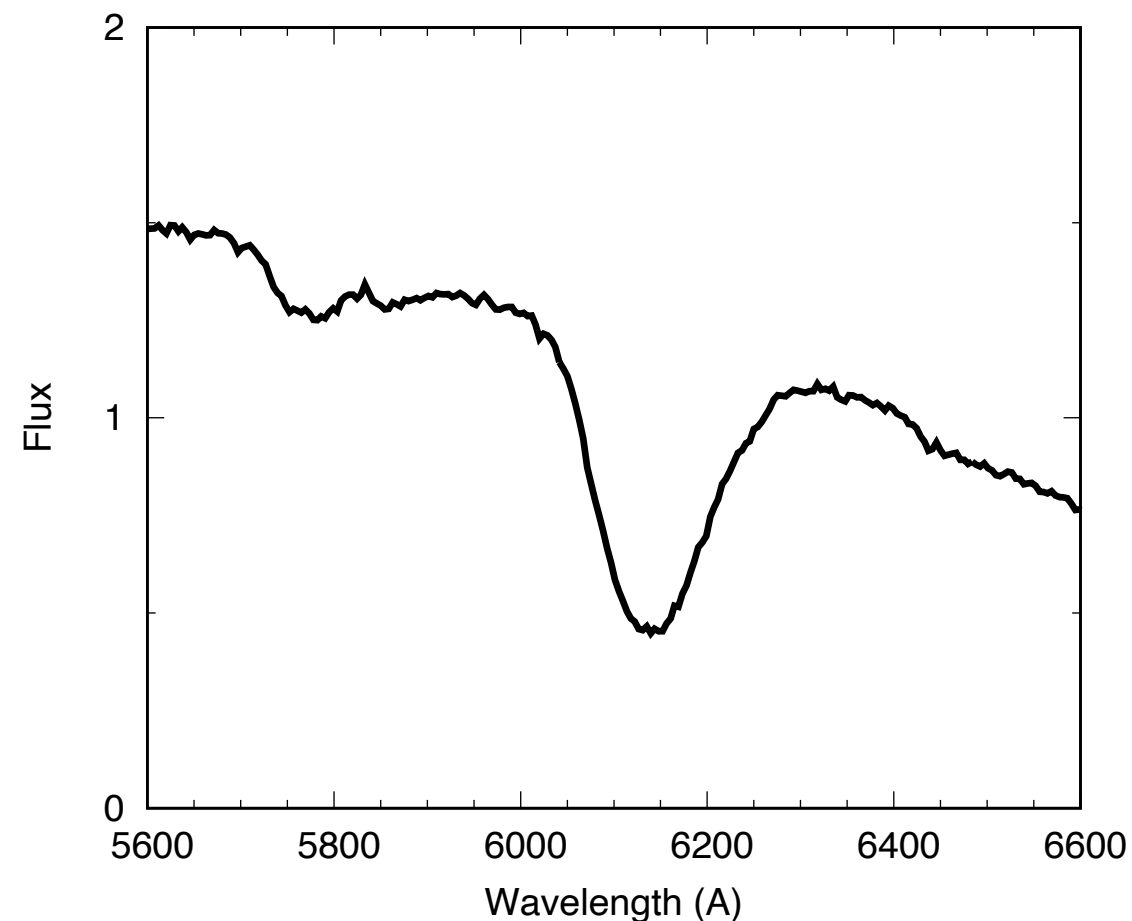
Observations $\Leftrightarrow$ physical quantities

Light curves



Spectra

$v \sim E^{1/2} \text{Mej}^{-1/2}$
+ chemical composition



$E, \text{Mej}, M(^{56}\text{Ni}), X \text{ (element)}$

Section 9.

Radiation from supernovae (II)

9.1 Timescale of supernovae

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Neutron star merger

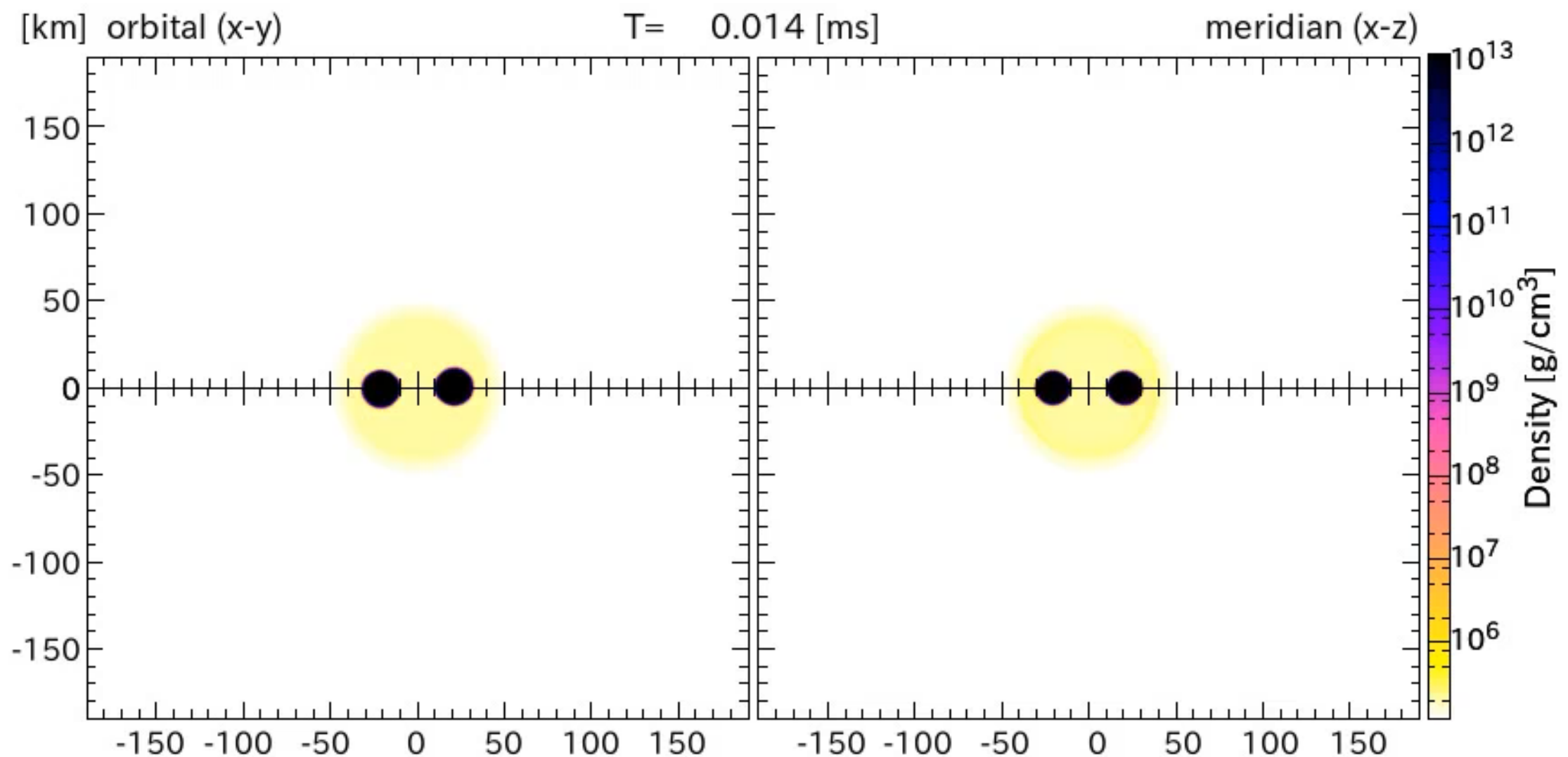


(C) NASA

NS merger => dynamical mass ejection (< 0.1 sec)

Top view

Side view



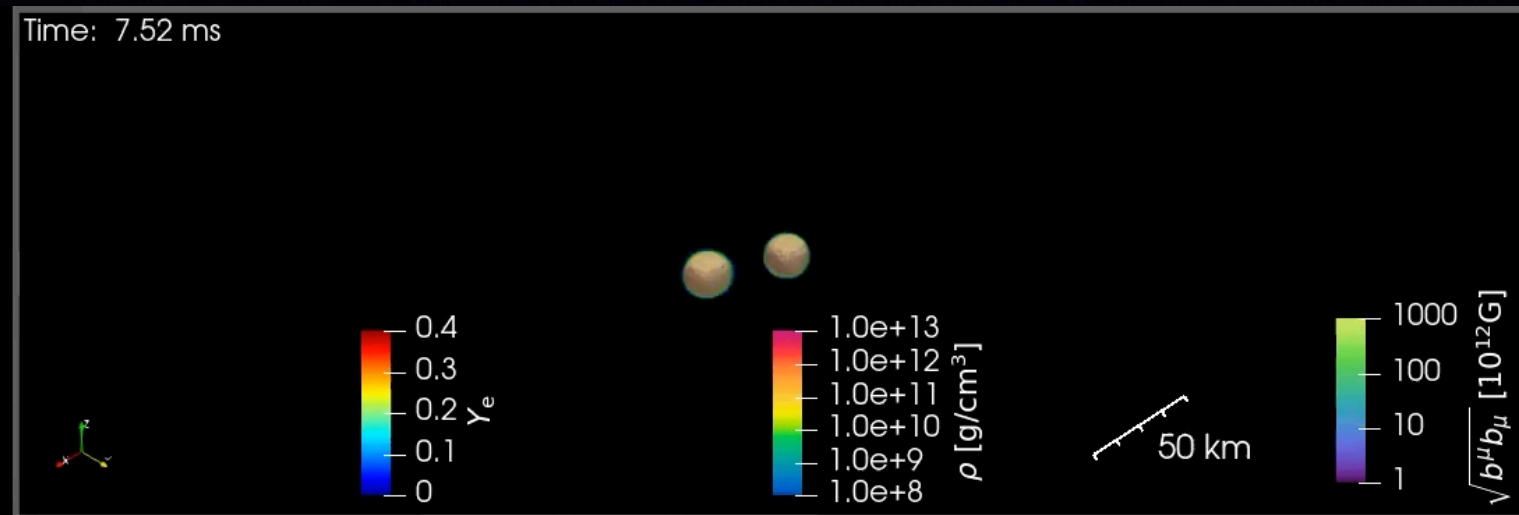
Sekiguchi+15, 16

$M \sim 10^{-3} - 10^{-2} M_{\text{sun}}$

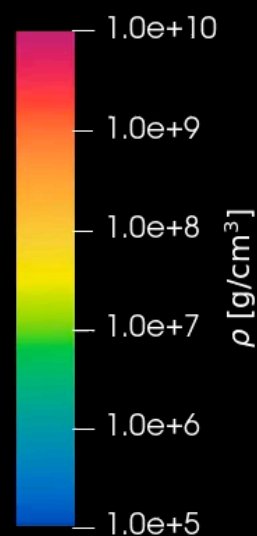
$v \sim 0.1 - 0.2 c$

$\leq \sim$ escape velocity of NS

NS merger => dynamical mass ejection (< 0.1 sec)
=> “wind” from disk (~ 1 sec)



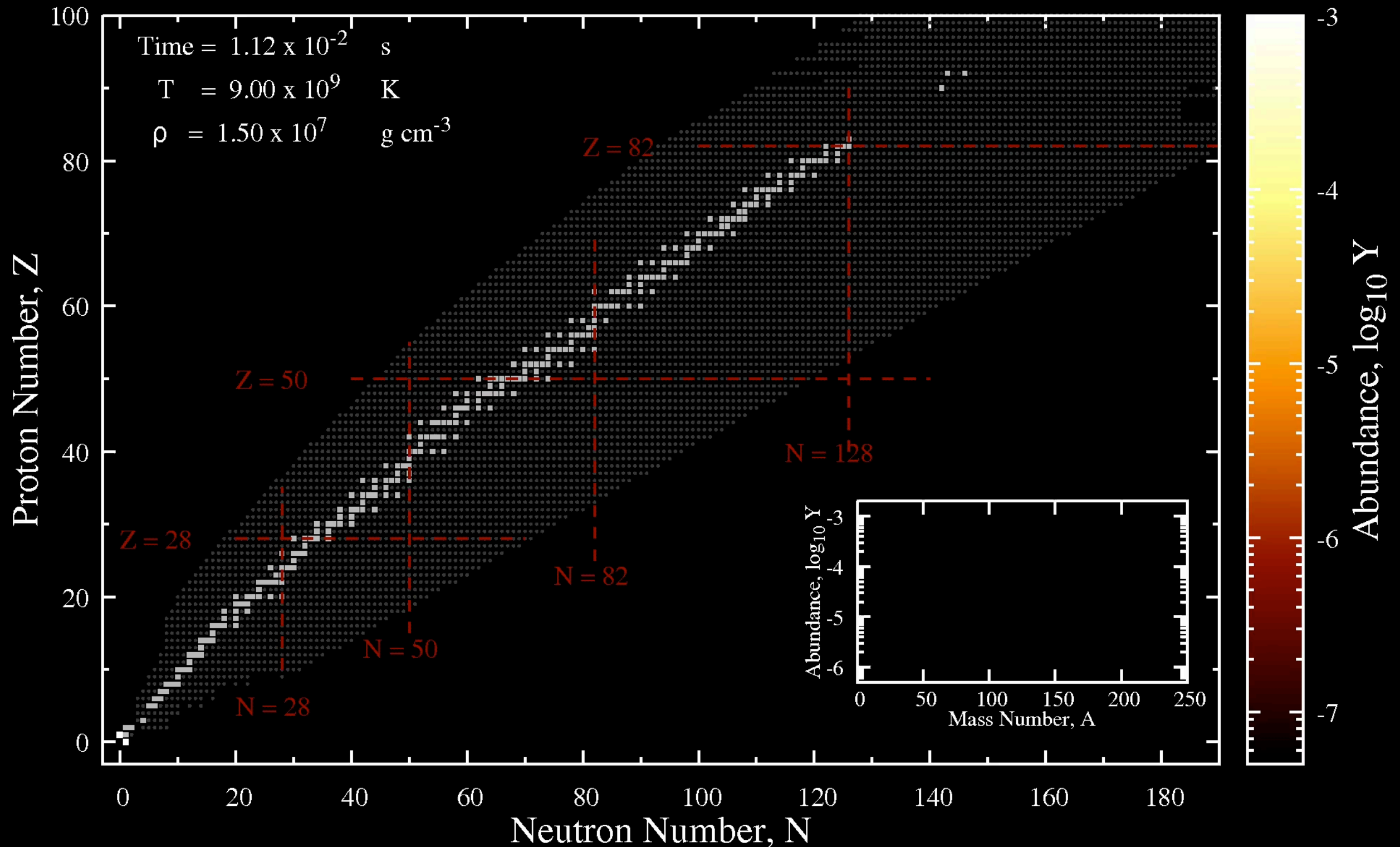
Density



B field



r-process nucleosynthesis in NS merger

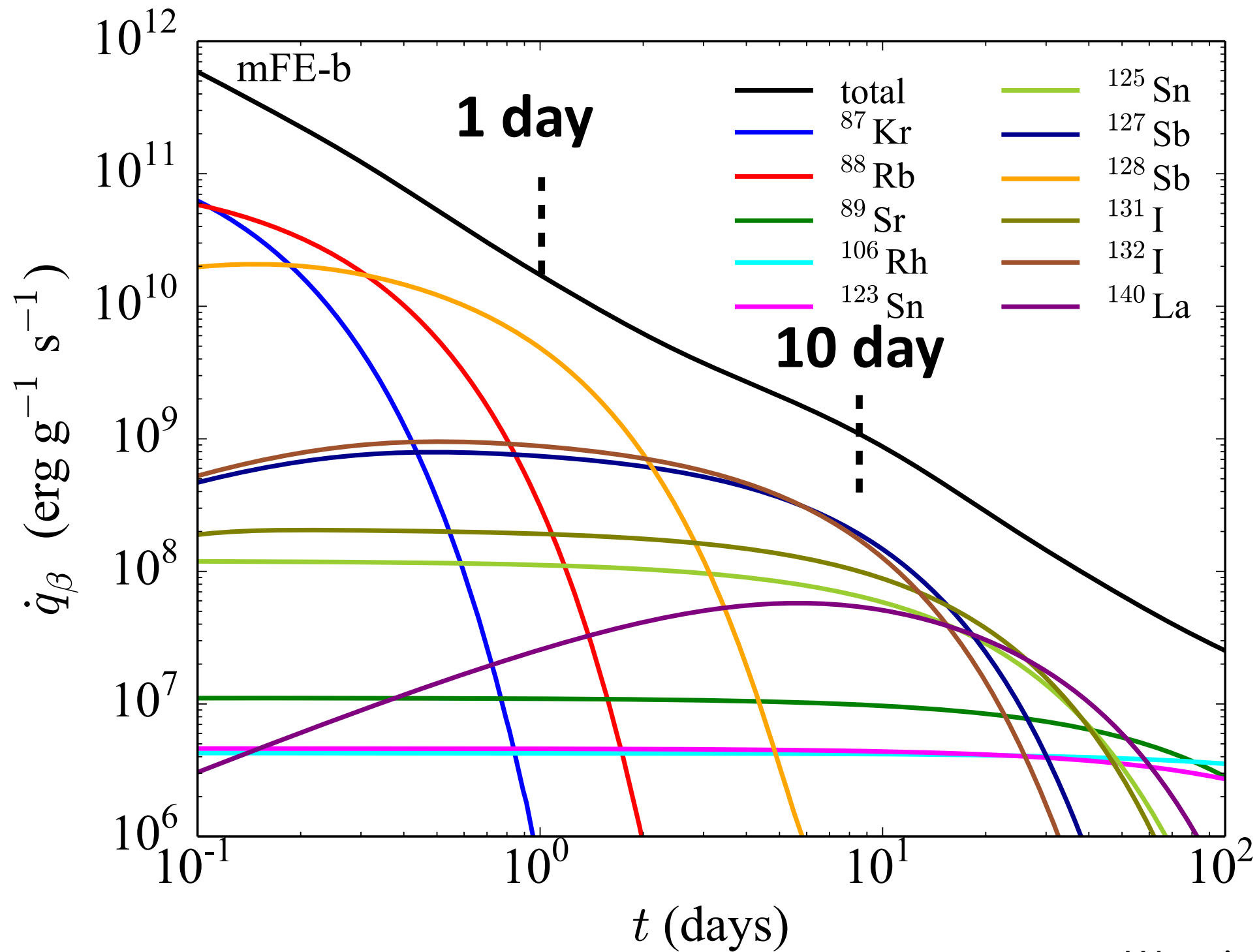


(C) Nobuya Nishimura

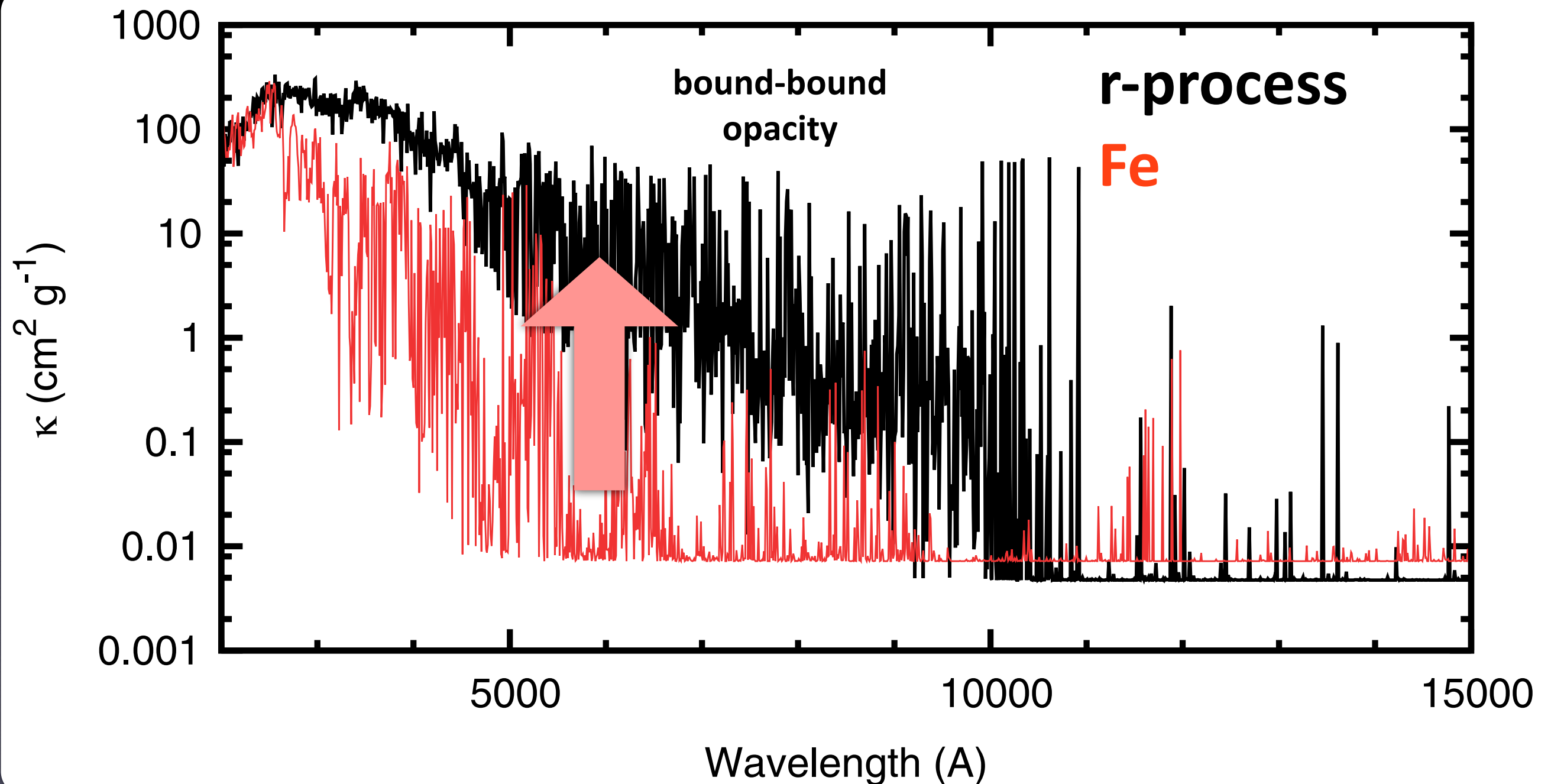
Supernova vs NS merger

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

Radioactive decay luminosity



Opacity



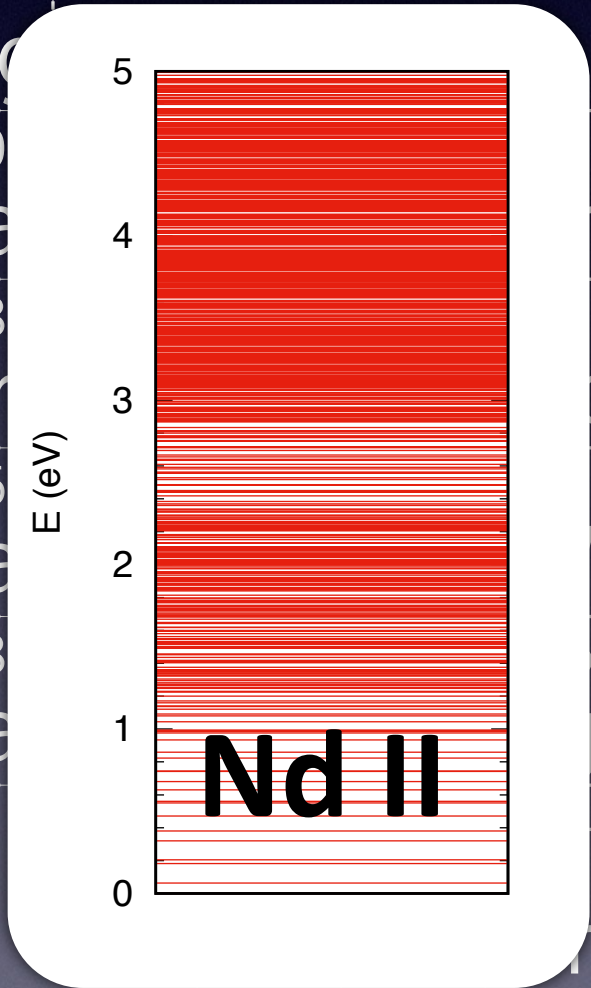
Higher opacity by factor of 100

(Kasen+13, Tanaka & Hotokezaka 13)

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

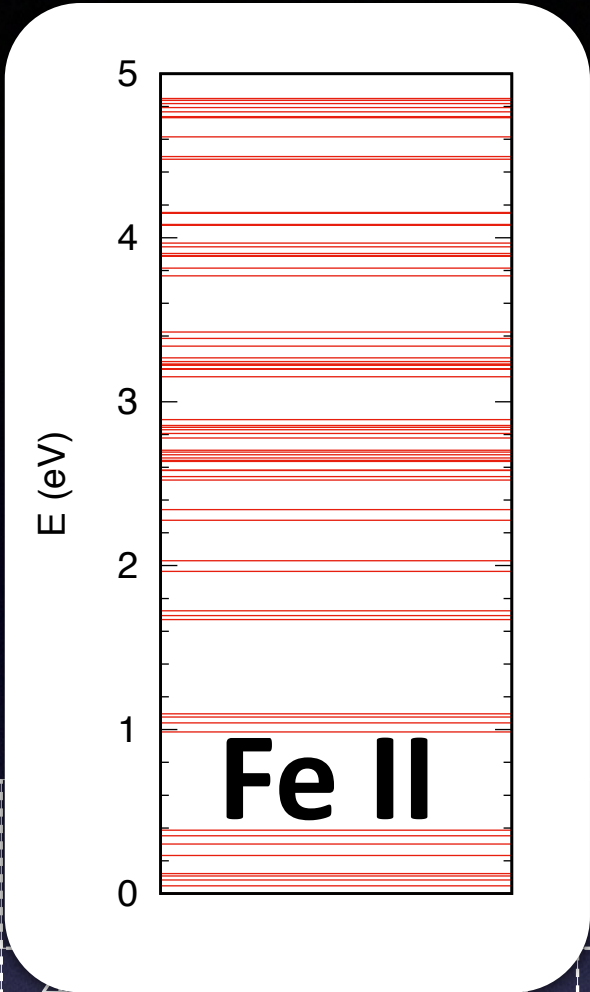
open s shell

1	H
3	Li
4	Be
11	Na
12	Mg
19	K
20	Ca
37	Rb
38	Sr
55	Cs
56	Ba
87	Fr
88	Ra



open d-shell

25	Mn	26	Fe	27	Co
43	Tc	44	Ru	45	Rh
75	Re	76	Os	77	Ir
107	Bh	108	Hs	109	Mt



open p-shell

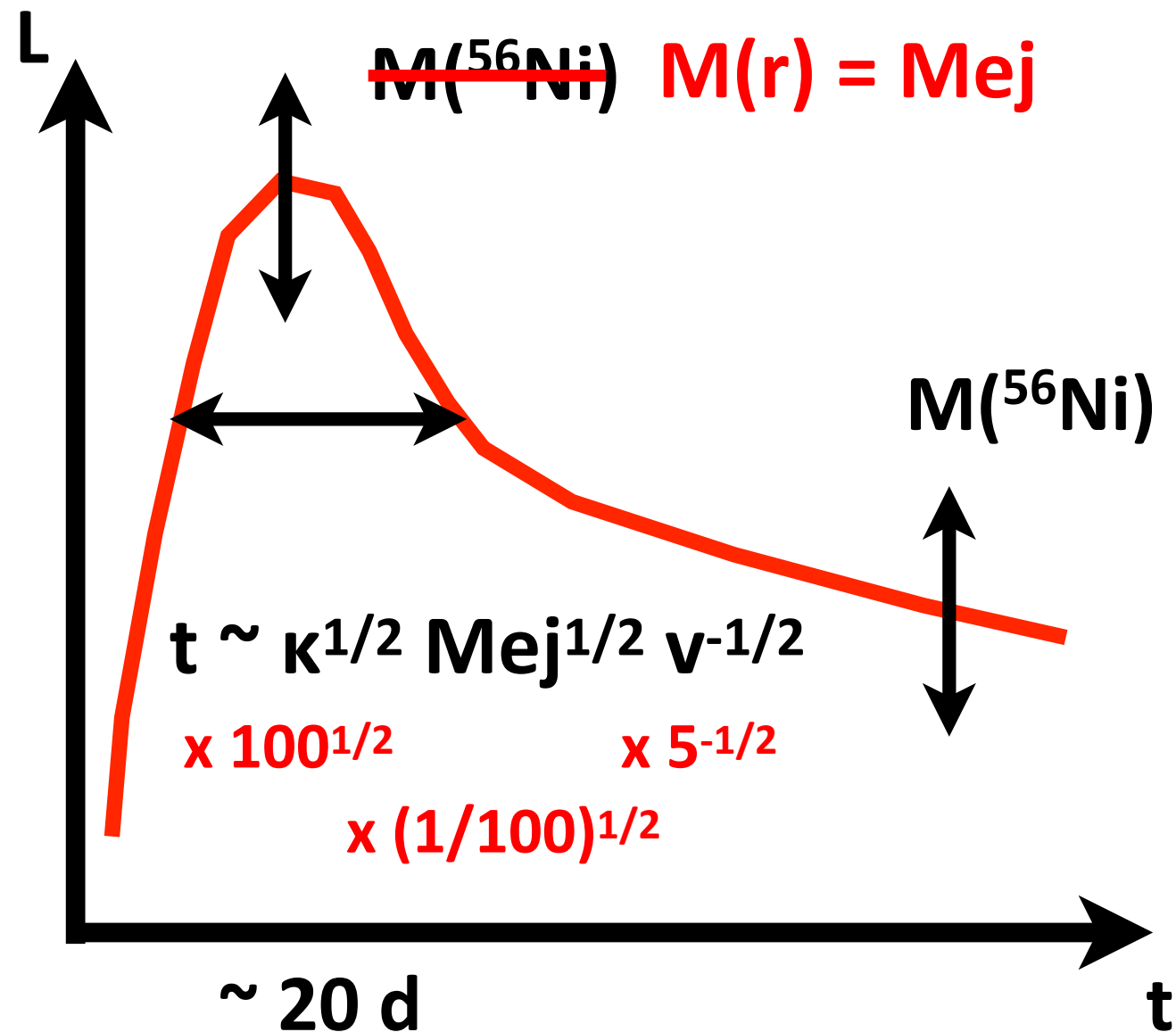
6	C	7	N	8	O	9	F	10	Ne
14	Si	15	P	16	S	17	Cl	18	Ar
32	Ge	33	As	34	Se	35	Br	36	Kr
50	Sn	51	Sb	52	Te	53	I	54	Xe
82	Pb	83	Bi	84	Po	85	At	86	Rn

open f shell

			60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

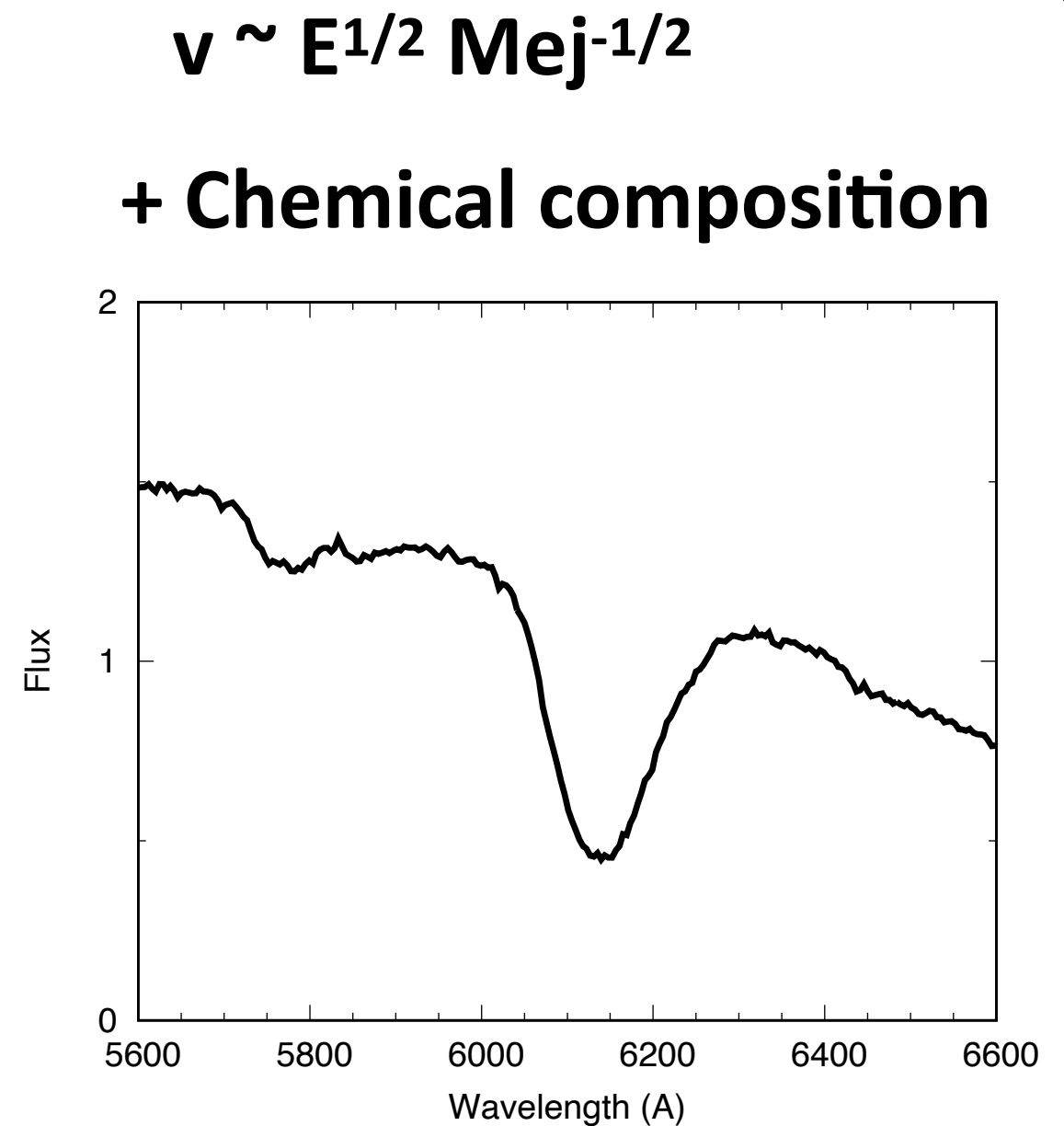
Radiation from NS merger

Light curves



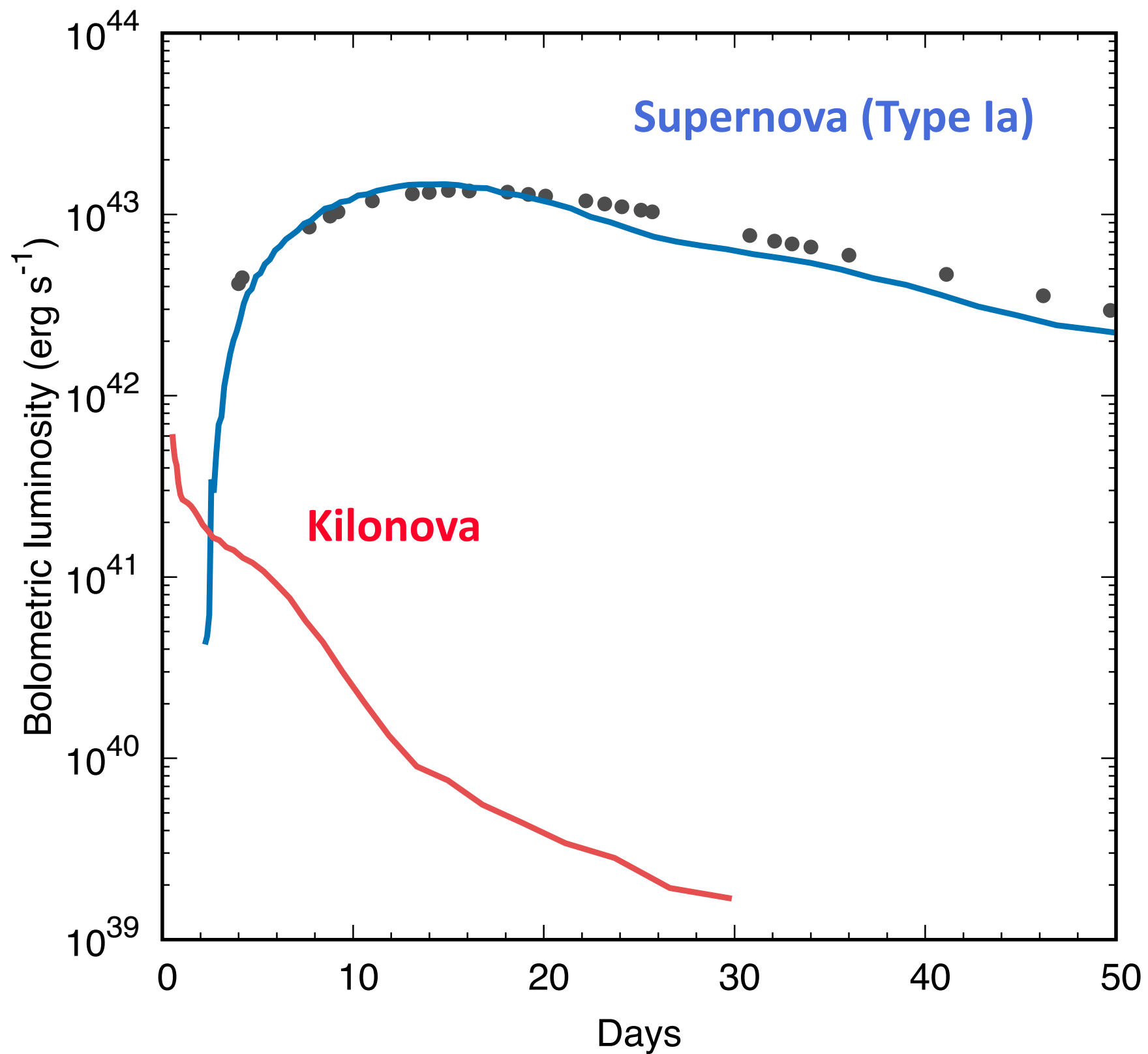
Fainter and faster than supernovae

Spectra

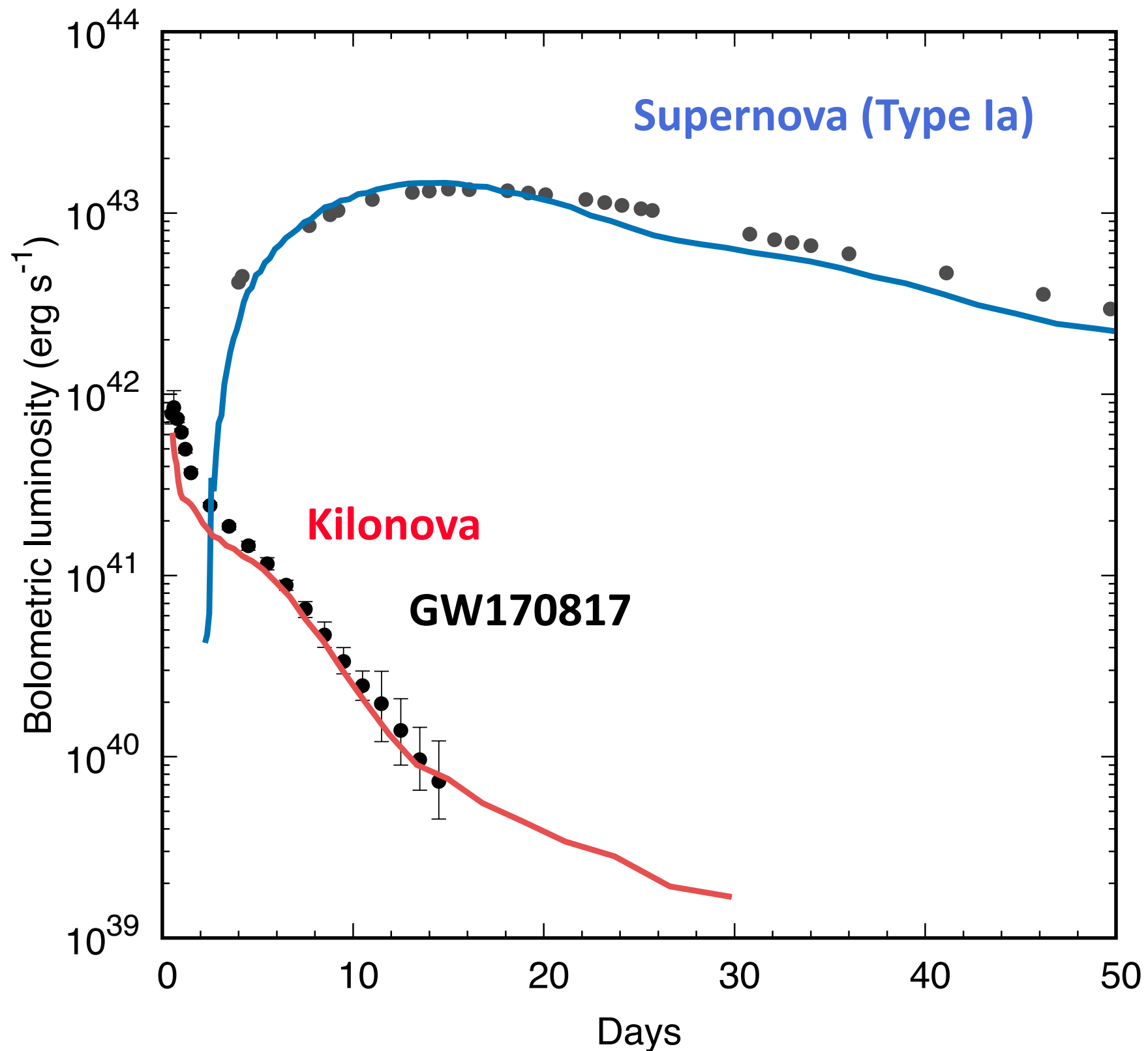


Higher velocities than supernovae

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 $t \sim \kappa^{1/2} M_{ej}^{3/4} E_k^{-1/4} \sim \kappa^{1/2} M_{ej}^{1/2} v^{-1/2}$

- **Lessons from observations**

- $M \text{ (Type II SN)} > M \text{ (Type Ibc SN)} > M \text{ (Type Ia SN)}$
- $E \text{ (CC SN)} \sim E \text{ (Type Ia SN)}$

- **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