Toward understanding the progenitor channels to SNe Ibn/Icn: X-ray modeling of their SN-CSM interaction

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Kyoto University

1. Introduction of SNe Ibn/Icn

2. X-ray light curve(LC) modeling

3. Parameter dependence of the X-ray LC

4. Application to Individual object (SN2006jc)

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The progenitor System of Type Ibn/Icn SuperNovae

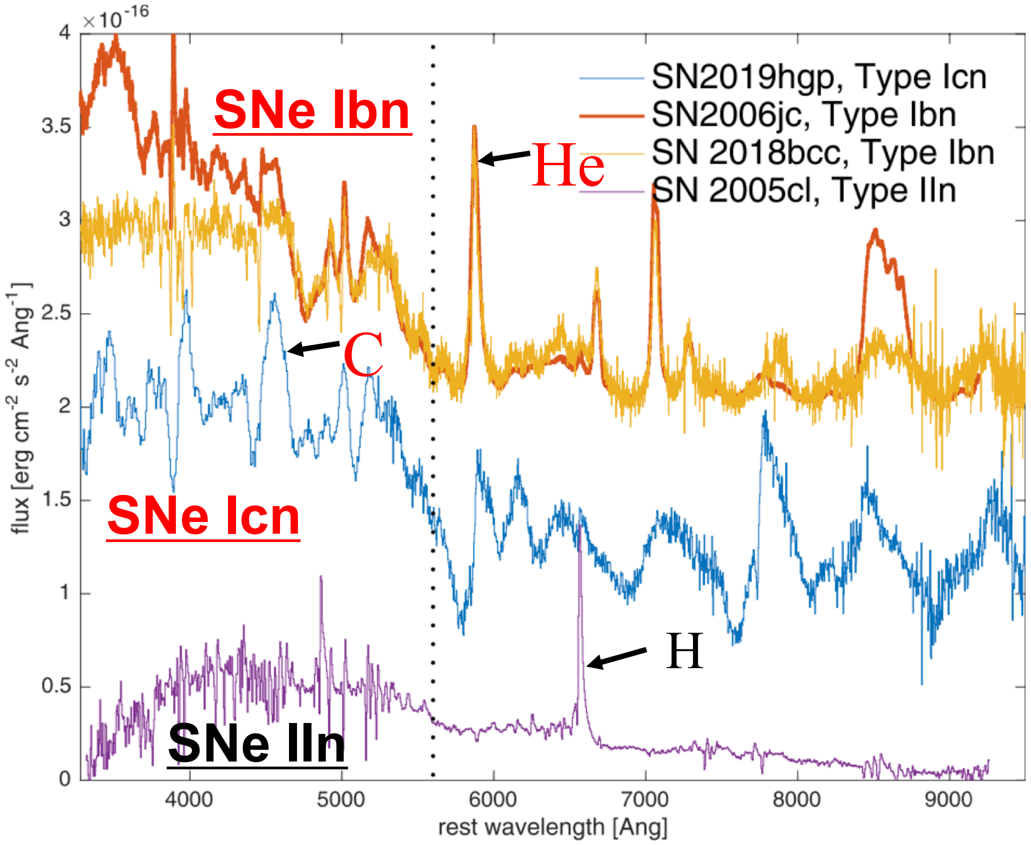
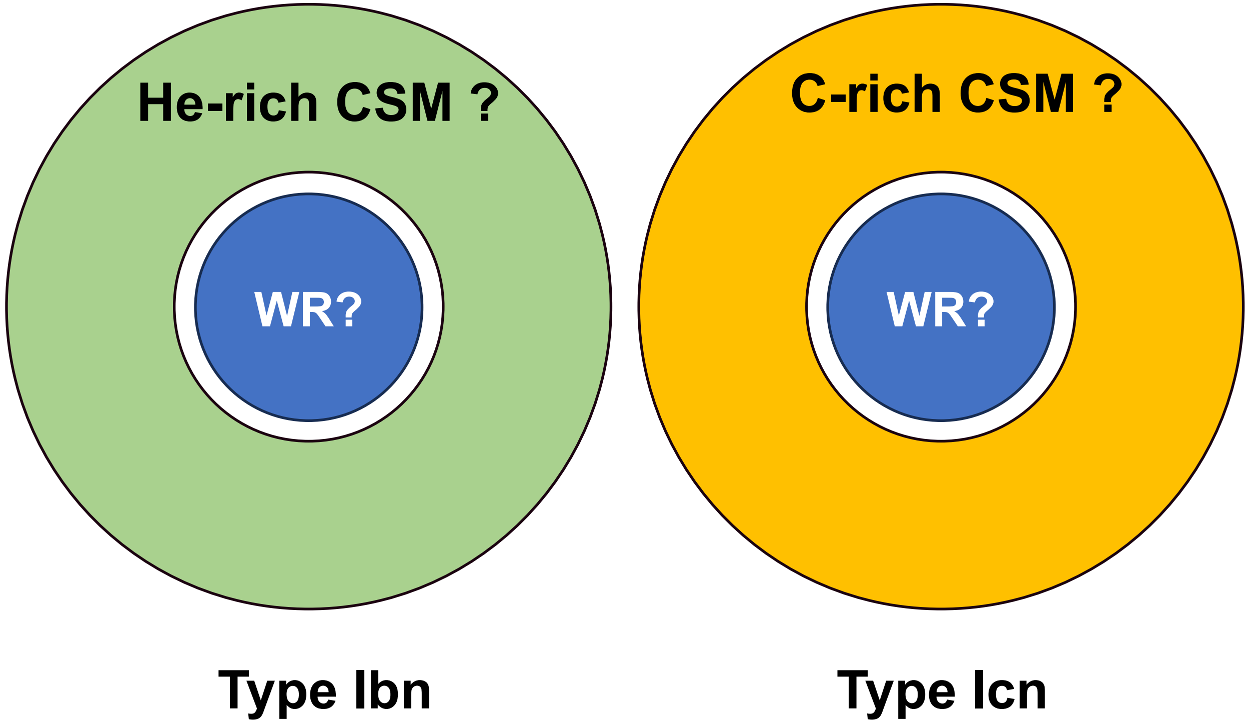


Fig. Optical Spectra of interacting SNe (Gal-Yam+22)

width of narrow line ≒ CSM velocity
(1000～3000 km/s)

Image of Progenitor System



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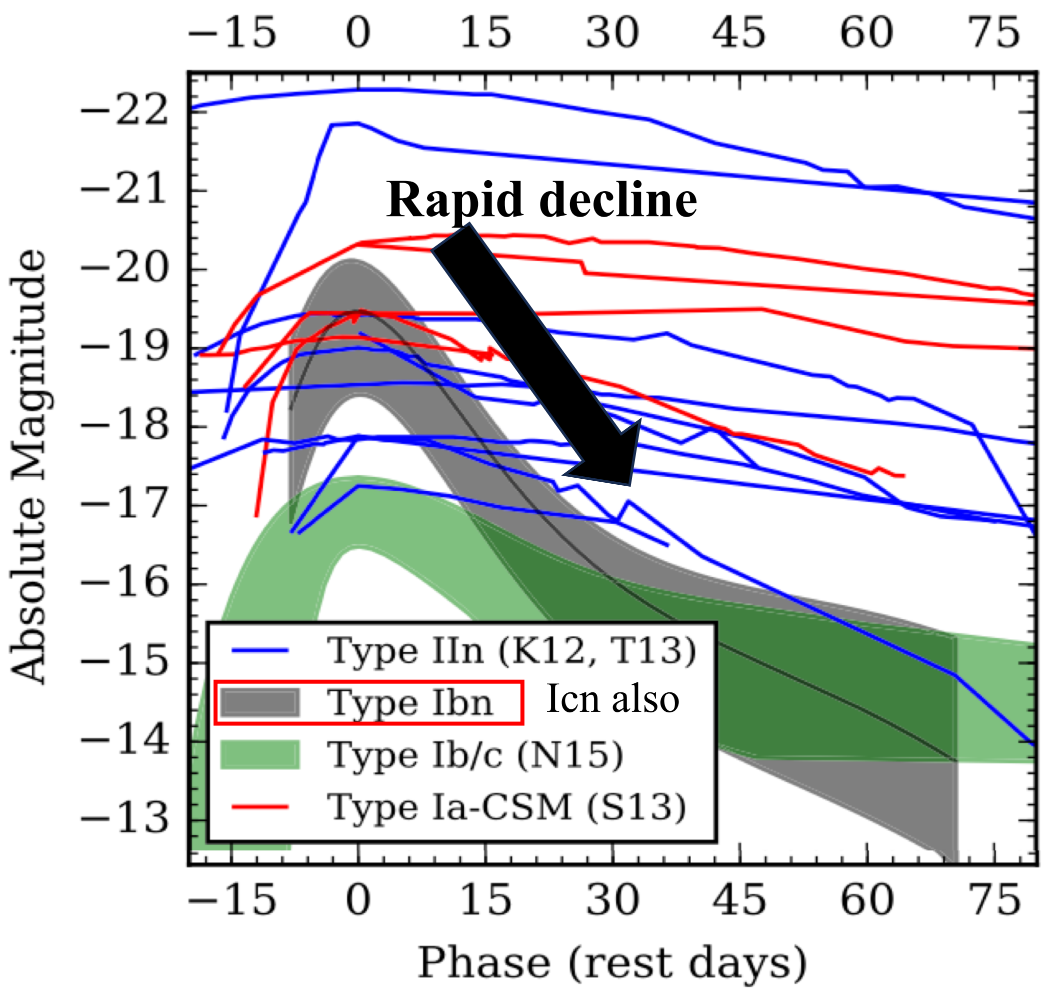

fig. Optical Light curve (Pellegrino et al. 2022)

Rapid decline → Not ^{56}Ni decay

→ SN-CSM interaction.
(steep CSM density distribution)

Optical light curve modeling (Previous studies)

H The parameter range of SNe Ibn by optical Light curve modeling

(※ SNe Icn is similar)

$E_{ej}[10^{51}$ erg]	$M_{ej}[M_\odot]$	**s**	D'
~1	2-6	**3**	0.5-5.0

$$※\rho_{CSM} = 10^{-14} D' \left(\frac{r}{5\times10^{14}}\right)^{-s}$$

CSM velocity 1000 km/s

$\dot{M}_{loss}$~0.01-0.1 $M_\odot$/year (1 yr before SN)

(Maeda & Moriya. 2022, Nagao et al. 2023)

The mystery of SNe Ibn/Icn

- Pre SN-activity for the dense CSM
- The progenitor

SNe Ibn/Icn?

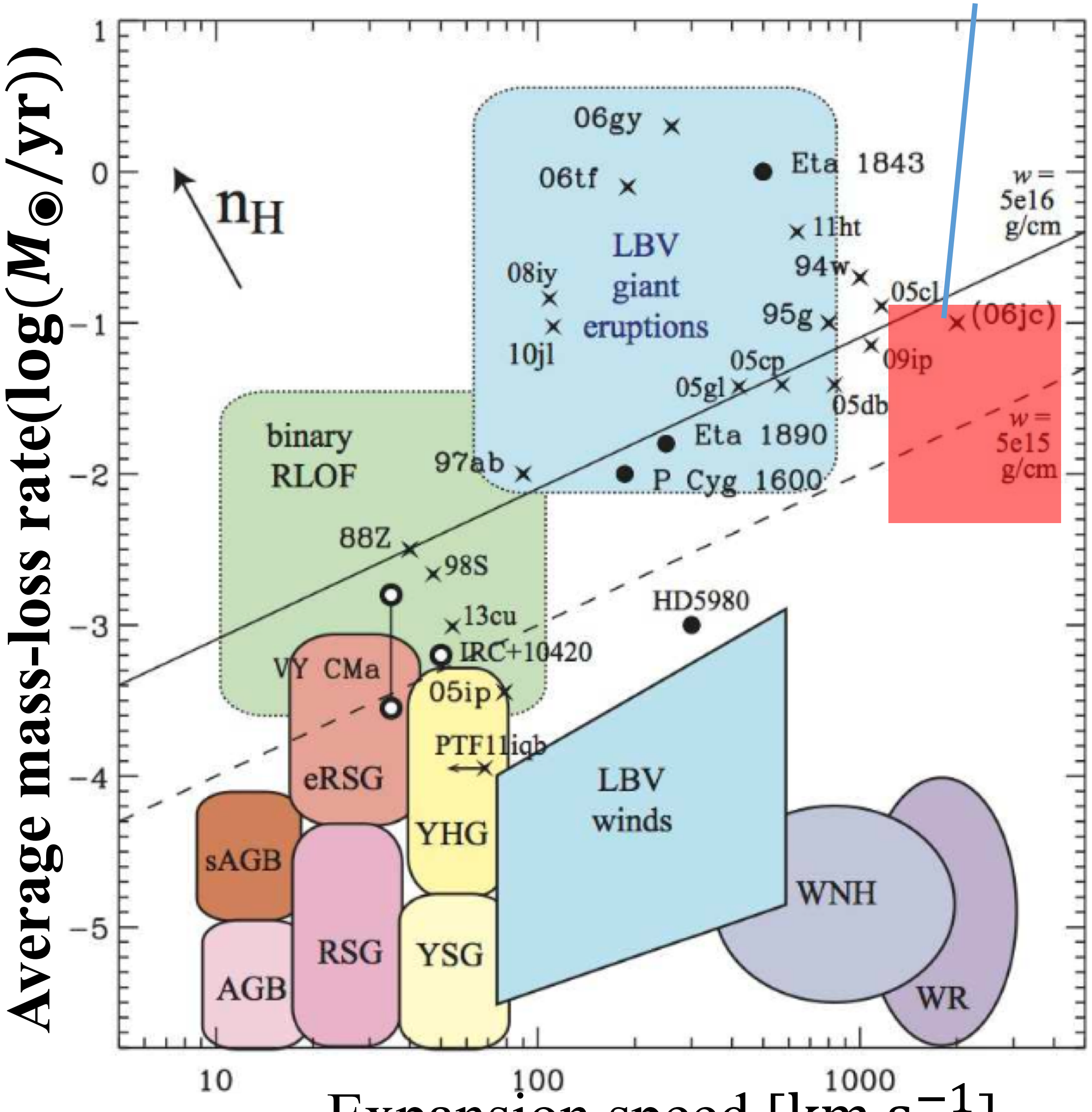

fig. Progenitors and mass-loss rate (Smith 2017 for review)

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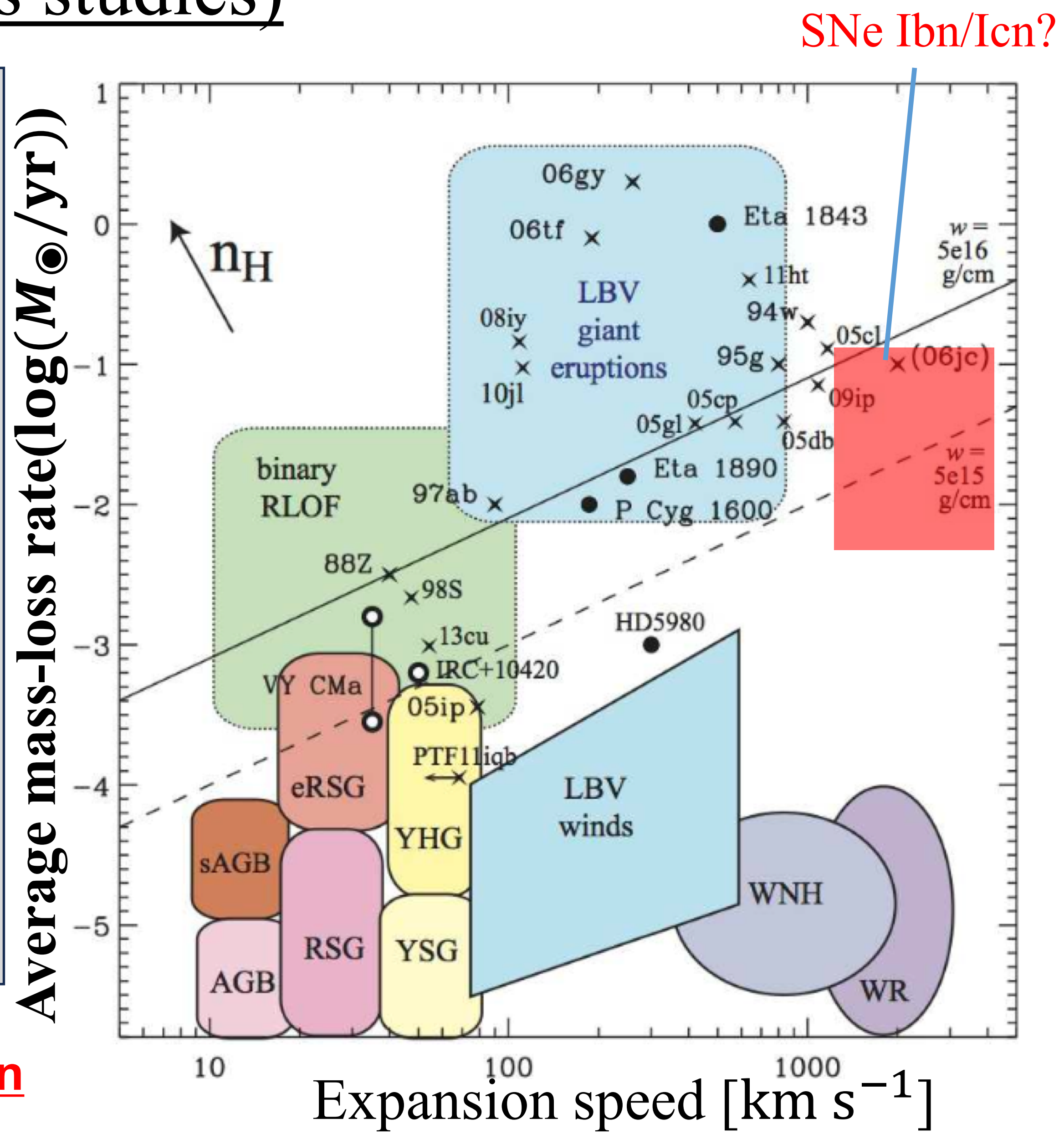
Toward understanding the progenitor of SNe Ibn/Icn

Need more CSM and Ejecta properties of SNe Ibn/Icn



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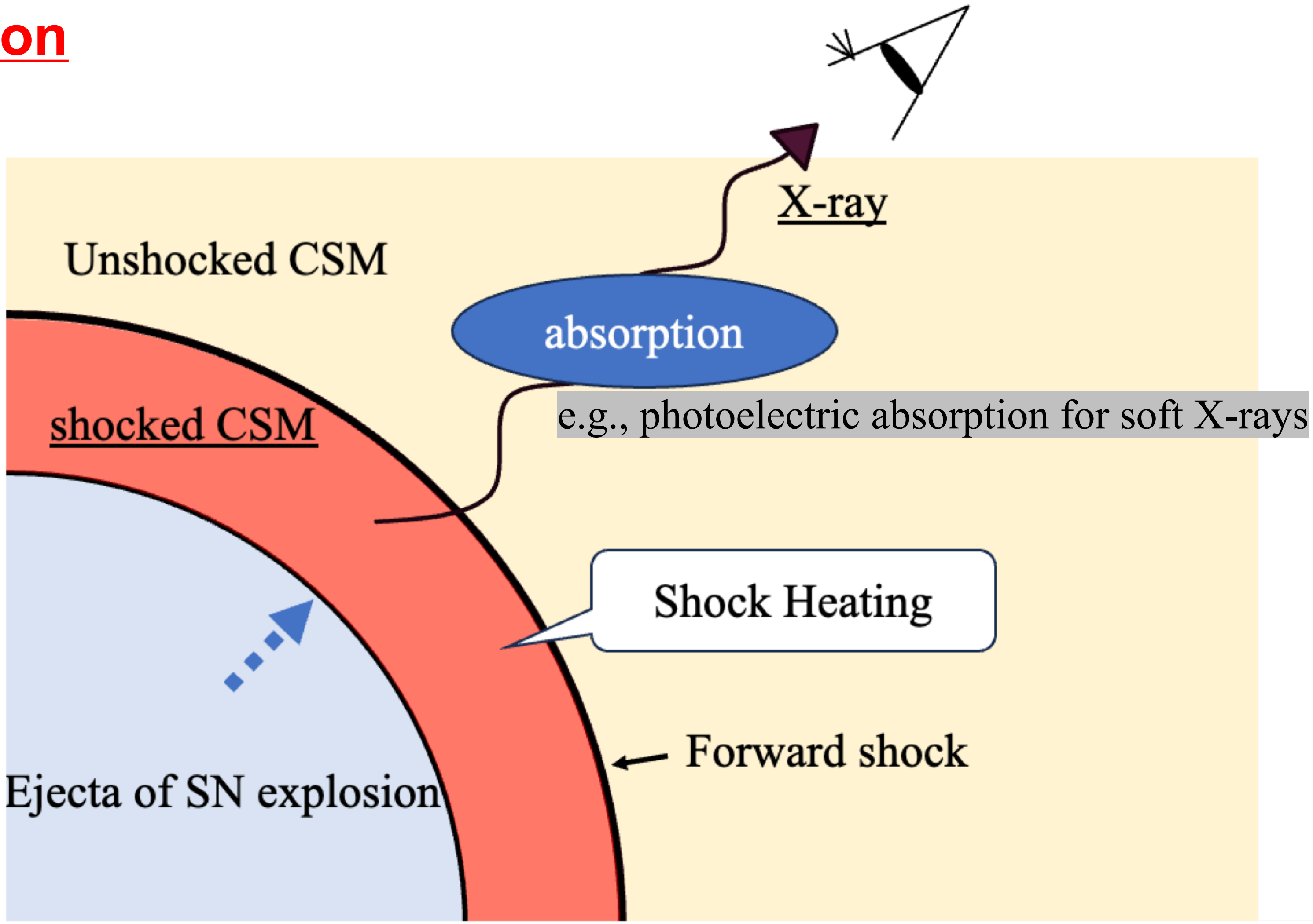
Why X-ray?

Our Study

We focused on X-ray emission from SNe Ibn/Icn.

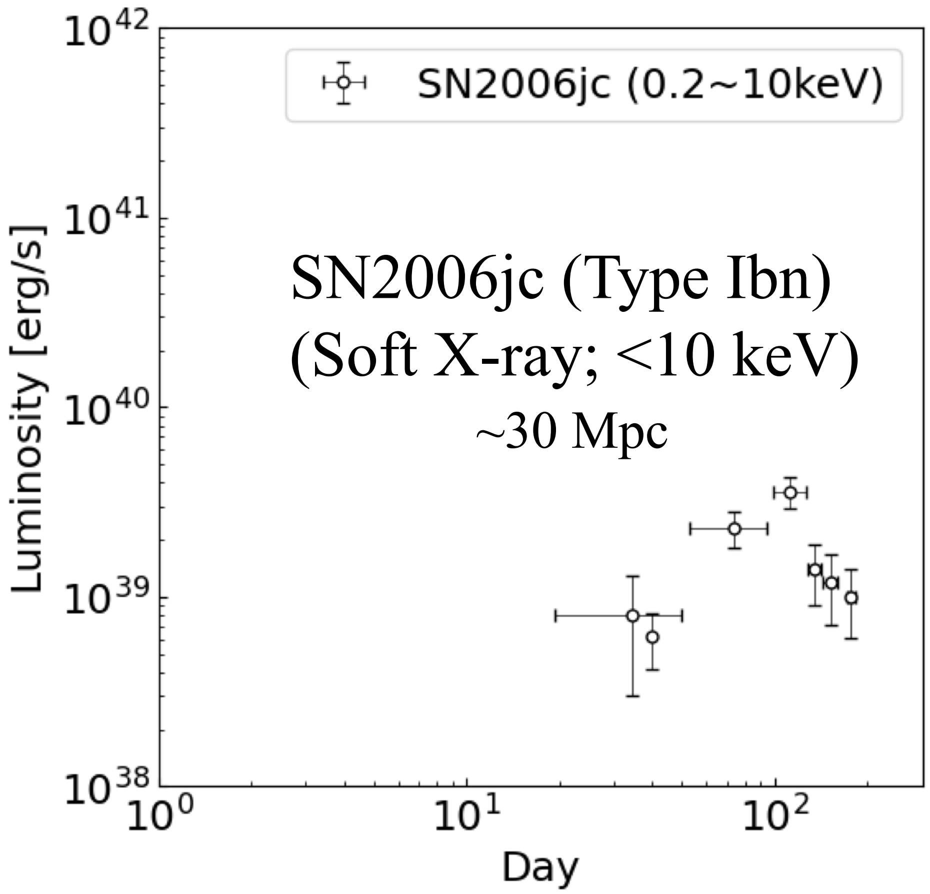
X-ray emission



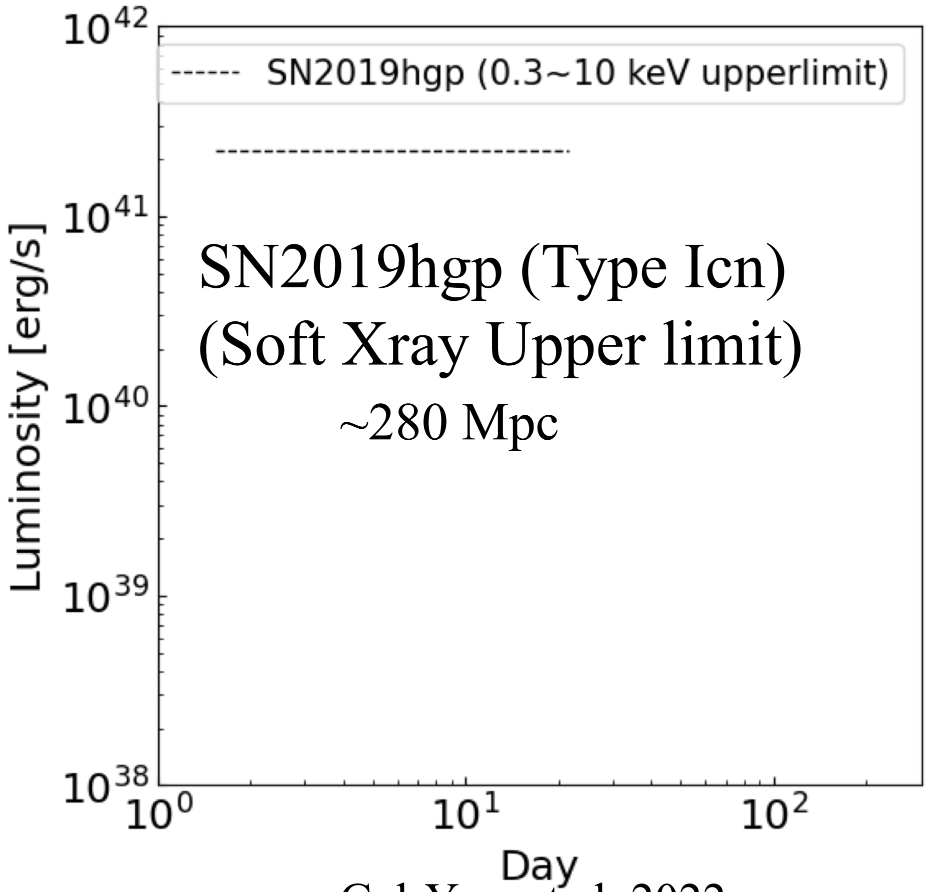
High temperature & High density → X-ray (free-free emission)

Why X-ray?

Observational Data of X-ray



Immler et al. 2008



Gal-Yam et al. 2022

We provide our X-ray light curve(LC) modeling, after that the model apply SN2006jc

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Method of X-ray light curve simulation for Type Ibn/Icn SNe

Model in this study

① Calculate SN-CSM interaction in adiabatic hydrodynamics.
(SNEC : 1D hydro code (Morozova et al. 2015))

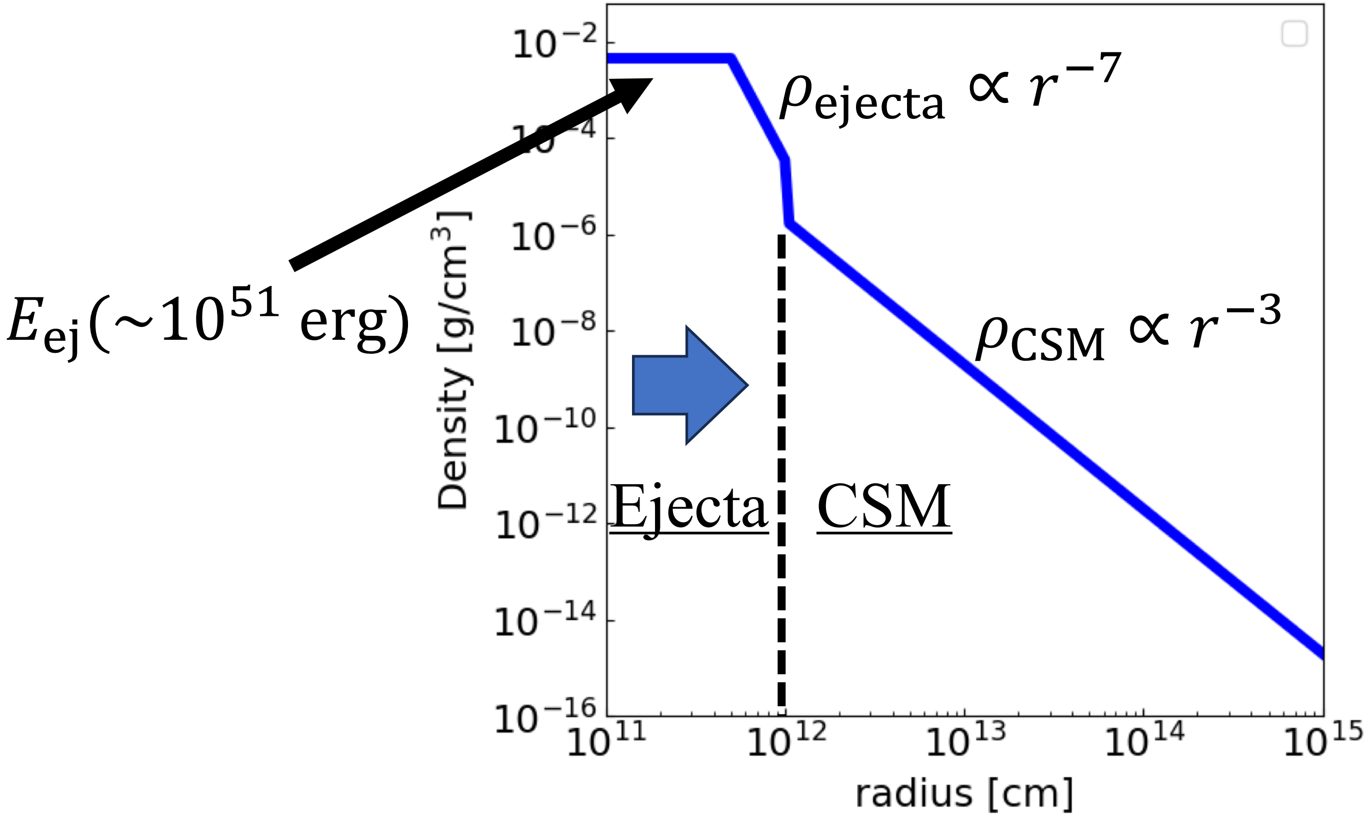

fig. Initial density profile (Example)

Parameters are referenced from
(Maeda & Moriya. 2022, Nagao et al. 2023)

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② For each mass grid, re-solve the time evolution of the internal energy as follows

$$\frac{\mathrm{d}E_{th}}{\mathrm{d}t} = \frac{\mathrm{d}E_{\mathrm{ad},th}}{\mathrm{d}t} - L_X$$

Radiative cooling

Adiabatic Expansion , Shock Heating (from ①)

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Radiative cooling

Adiabatic Expansion , Shock Heating (from ①)

③ Calculate X-ray emission (from ①&②)

$L_X \propto \int \rho^2 T^{0.5} \mathrm{d}V$ (free-free emission)

$L_{X,\mathrm{obs}} = L_X \exp(-\tau)$ (photoelectric abs.; Compton scat.)

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Hard & soft X-ray light curve(LC)

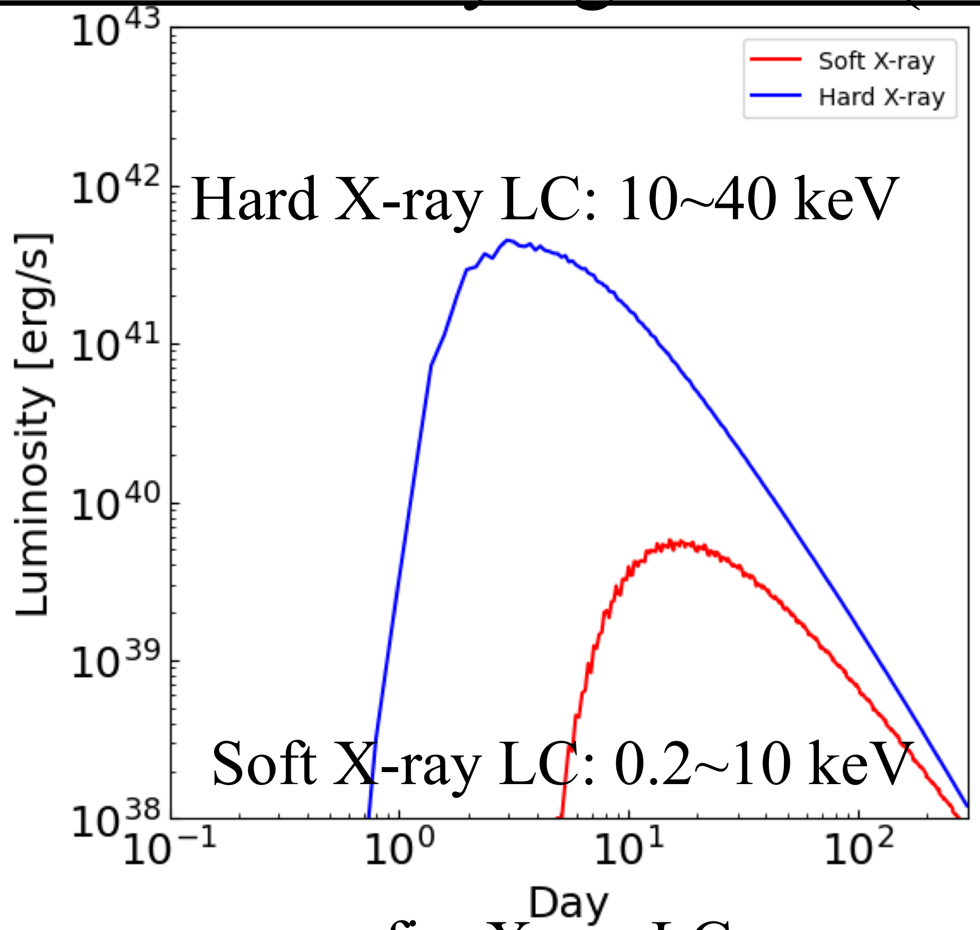


fig. X-ray LC

(X(He), X(C), X(O))=(0.5, 0.25, 0.25)

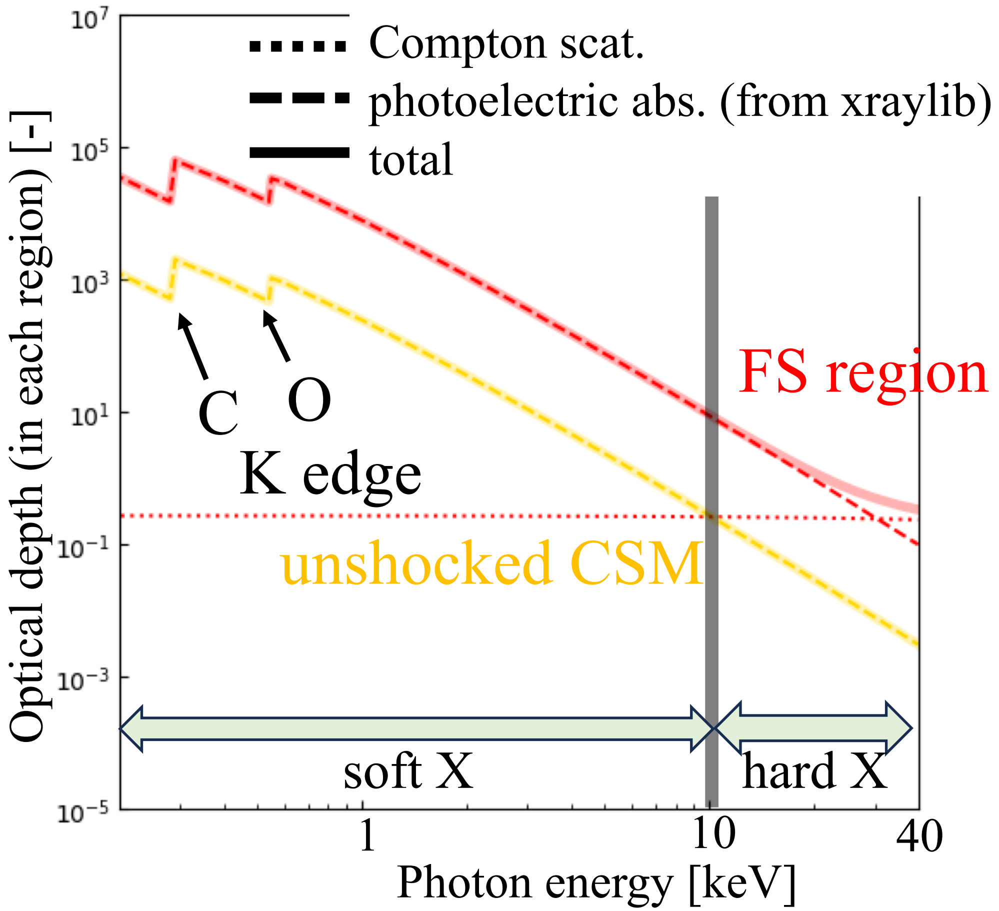


fig. Optical depth for X-ray (20 day)

	Peak day	Peak Luminosity
Hard X-ray	a few days	luminous
Soft X-ray	a few 10 days	faint

CSM abundance

- X(He)=0.85, 0.5, 0.0 (the other; C/O=1) for CSM abundance

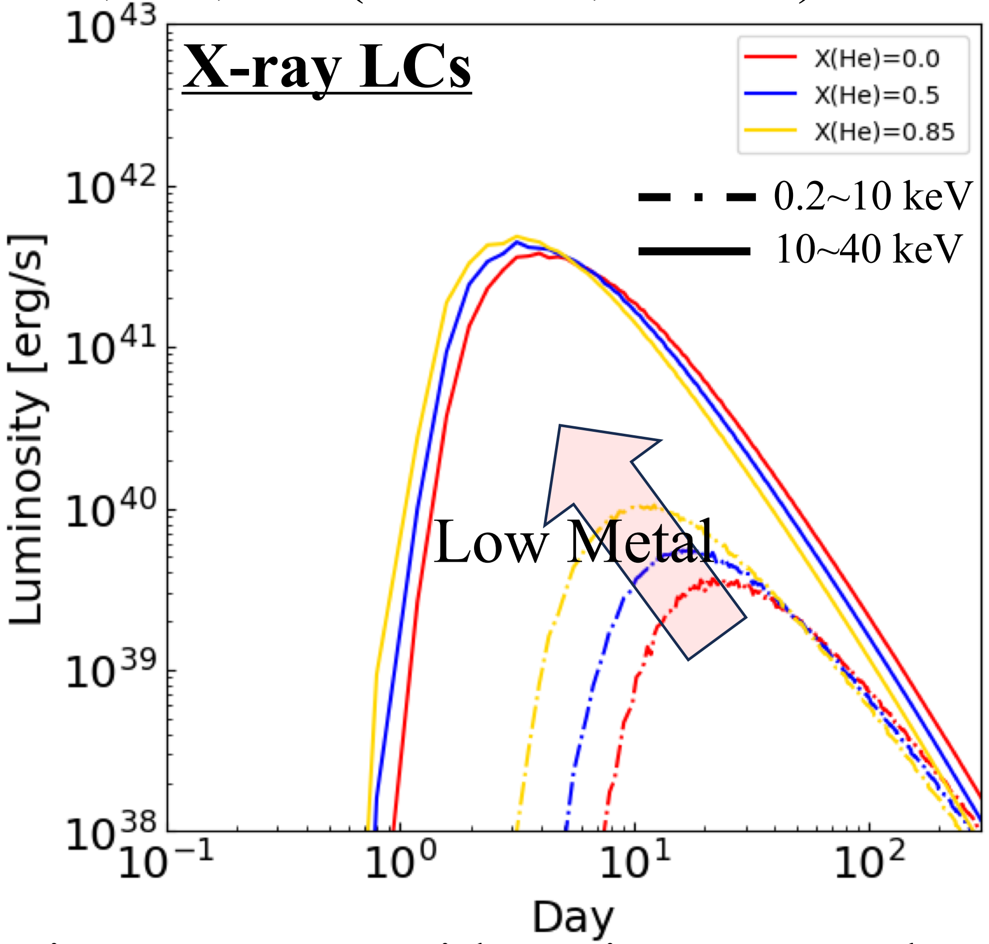
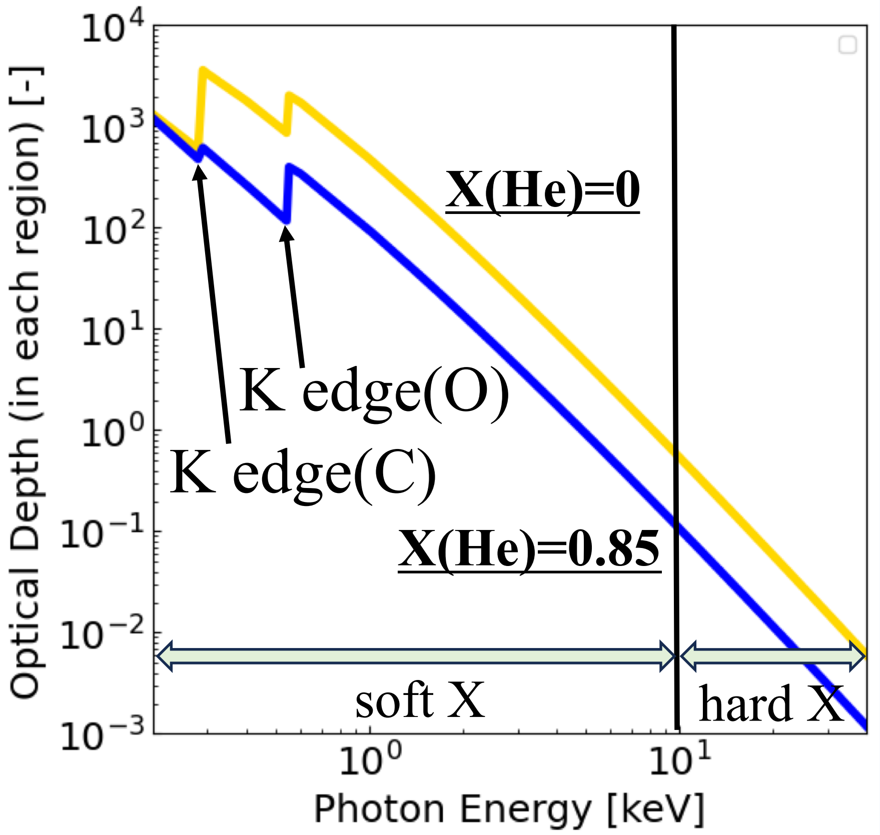


Fig. X-ray LC with various CSM abundance

Optical depth in unshocked CSM (20 day)



- Low metal CSM → early peak day

($\tau_{photoele} \propto Z^4 E_{photon}^{-3.5}$(for K shell))

CSM abundance

- X(He)=0.85, 0.5, 0.0 (the other; C/O=1) for CSM abundance

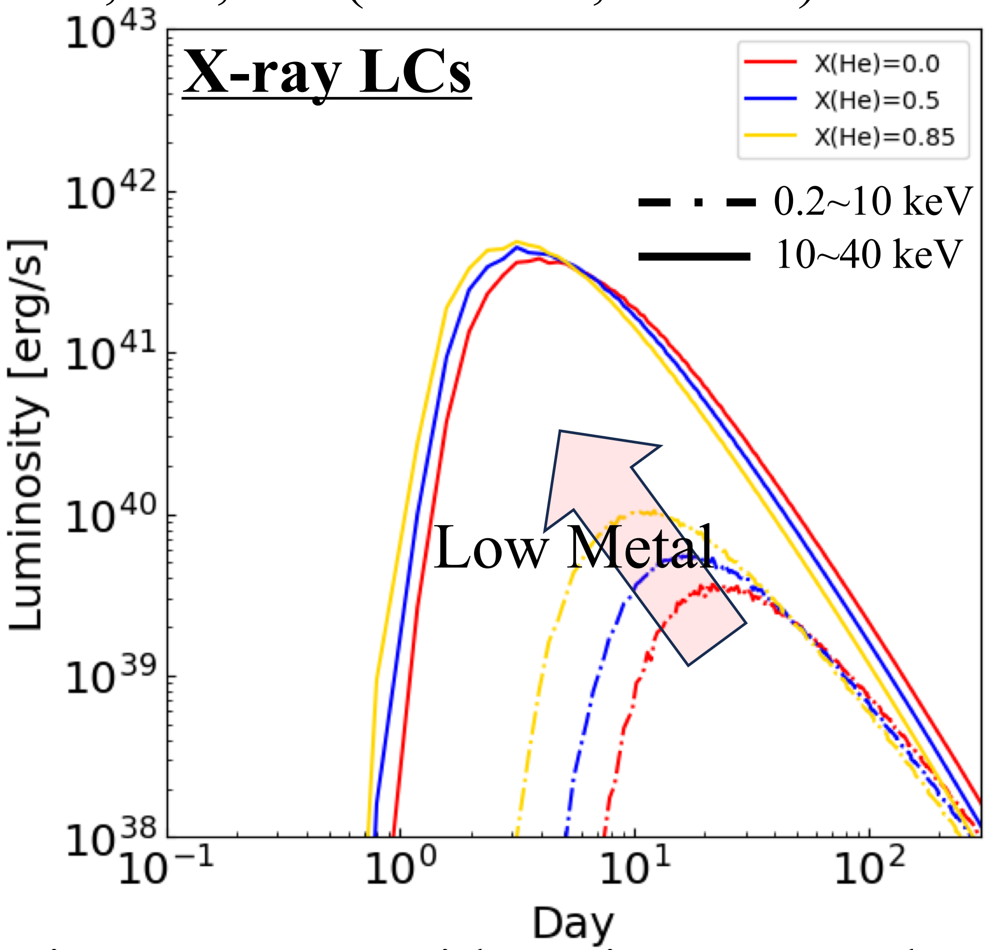
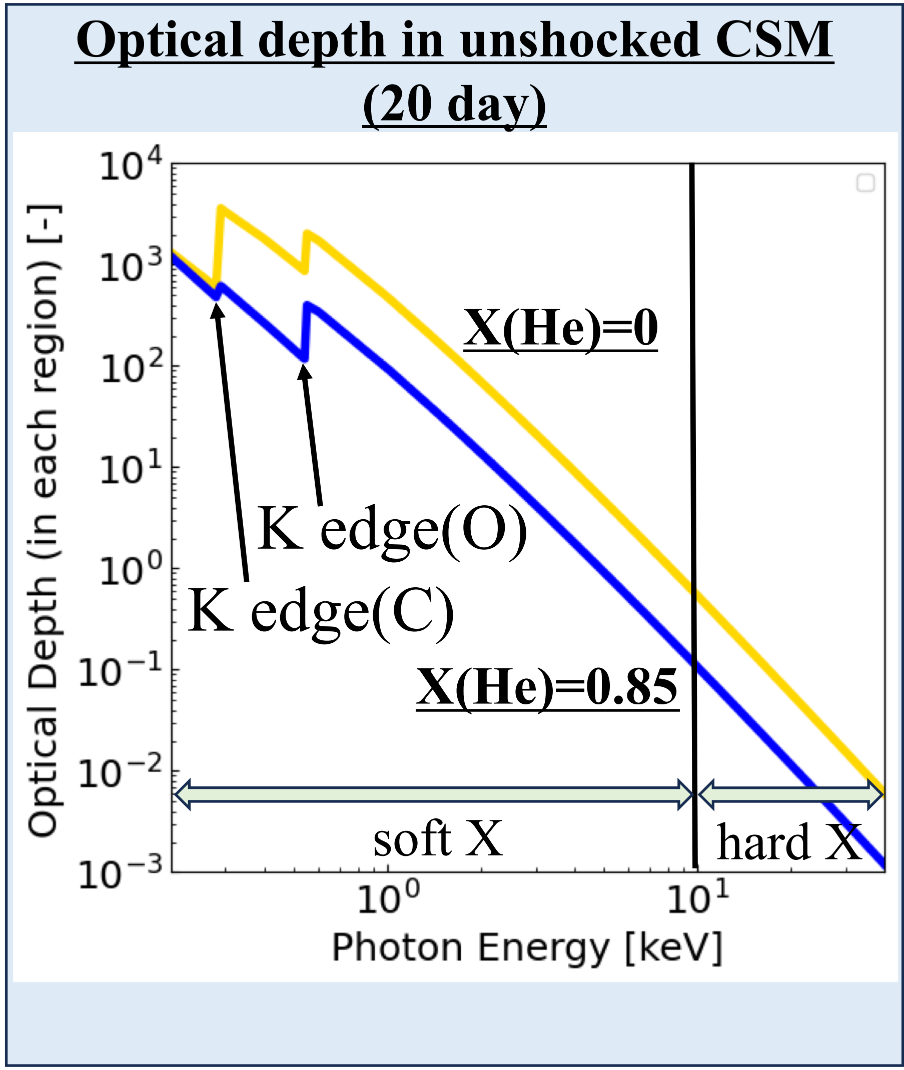


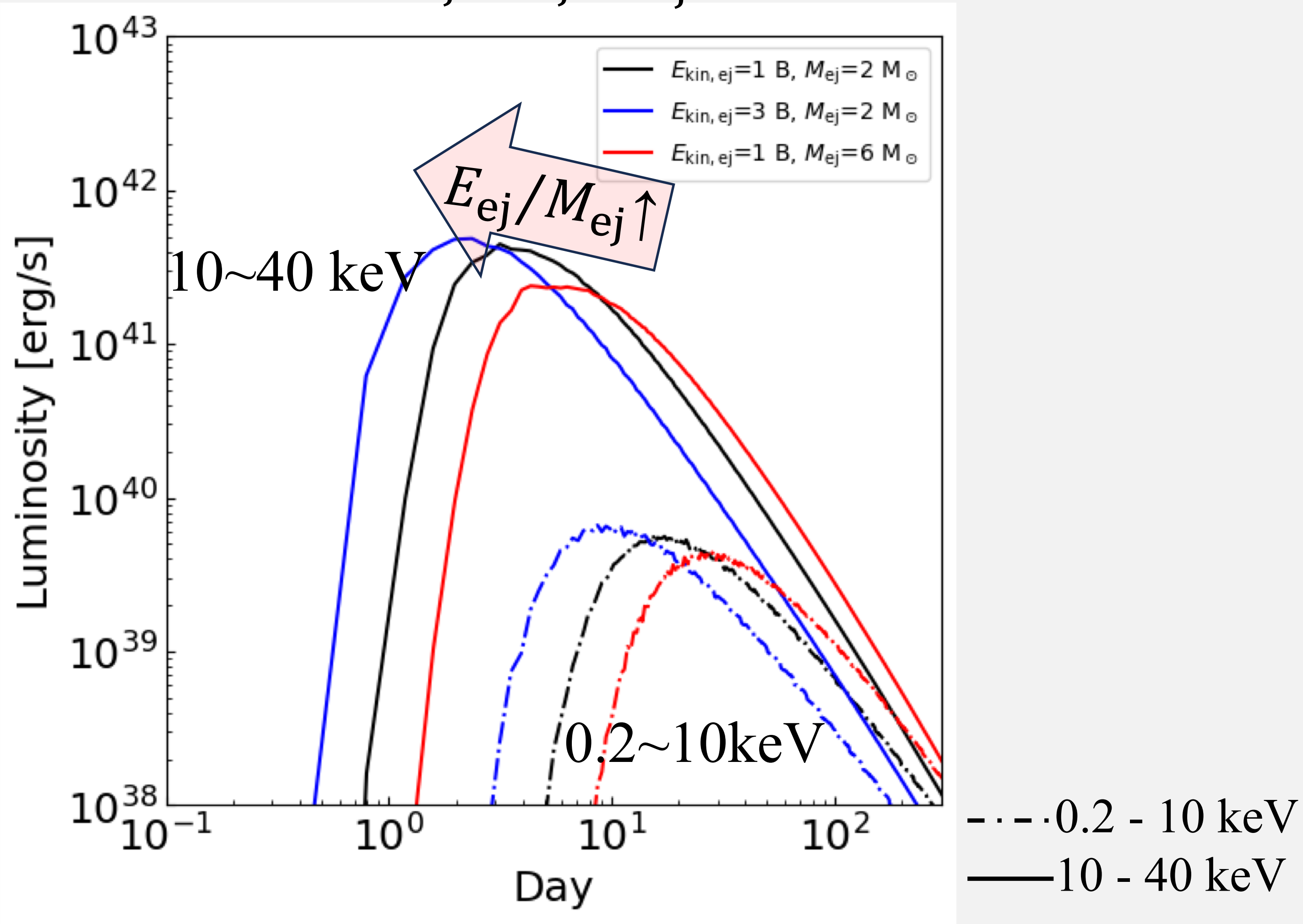
Fig. X-ray LC with various CSM abundance



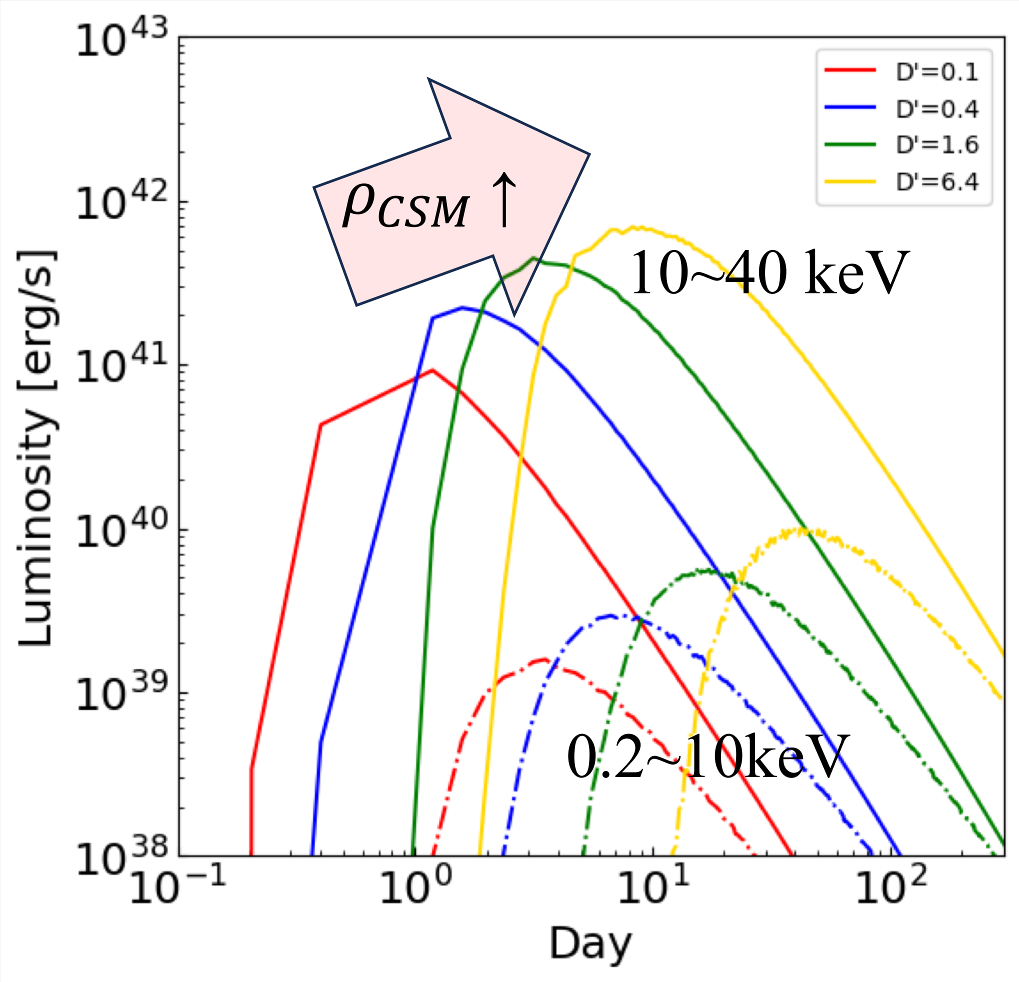
- $\tau_{photoele} \propto Z^4 E_{photon}^{-3.5}$ (for K shell).
- Soft X-ray LC tell us CSM abundance.

Physical properties ($E_{ej}, M_{ej}, \rho_{CSM}$)

Ejecta property($E_{ej}/M_{ej} \sim V_{ej}^2$) dependence



CSM density (ρ_{CSM}) dependence

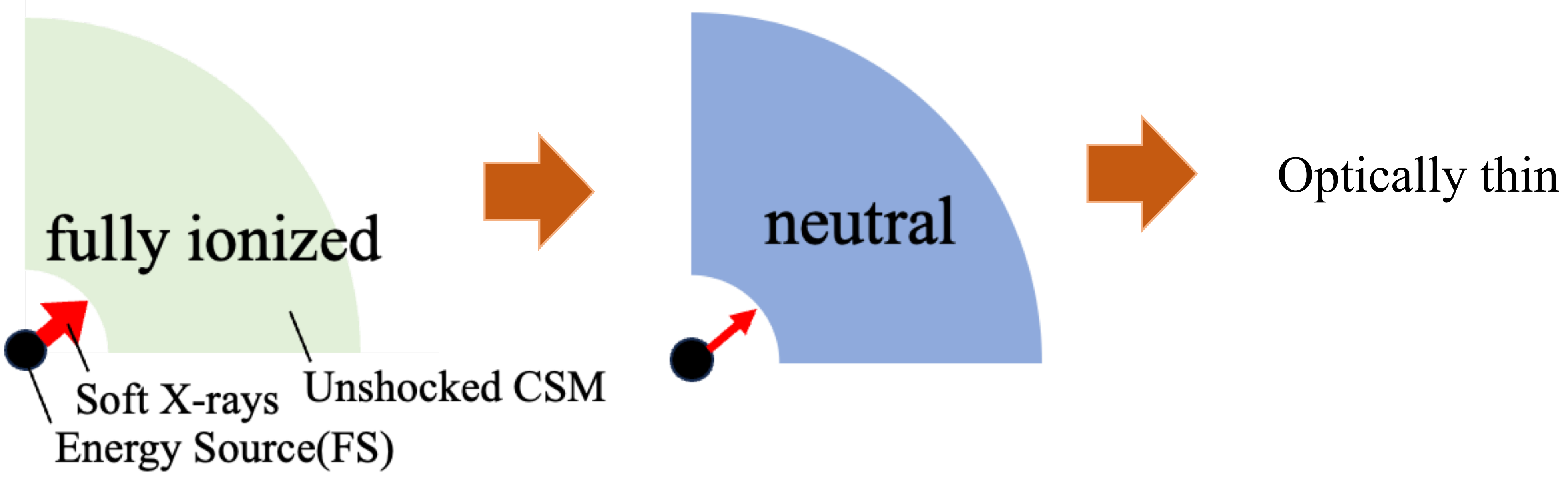


- The combination of Hard & Soft X-ray LC is useful to determine the CSM and Ejecta properties.
  - Hard X-ray LC could determine the physical properties even during the rising phase of soft X-ray LC.

Absorption processes ~Photoionization Changing~

Photoionization Parameter (for K shell of C, O)

$$\xi = \frac{L_{\rm softX}}{nr^2}$$



(~1 days)

(~10 days)

Dominant Process (for soft X-rays <10 keV)

Compton Scat.

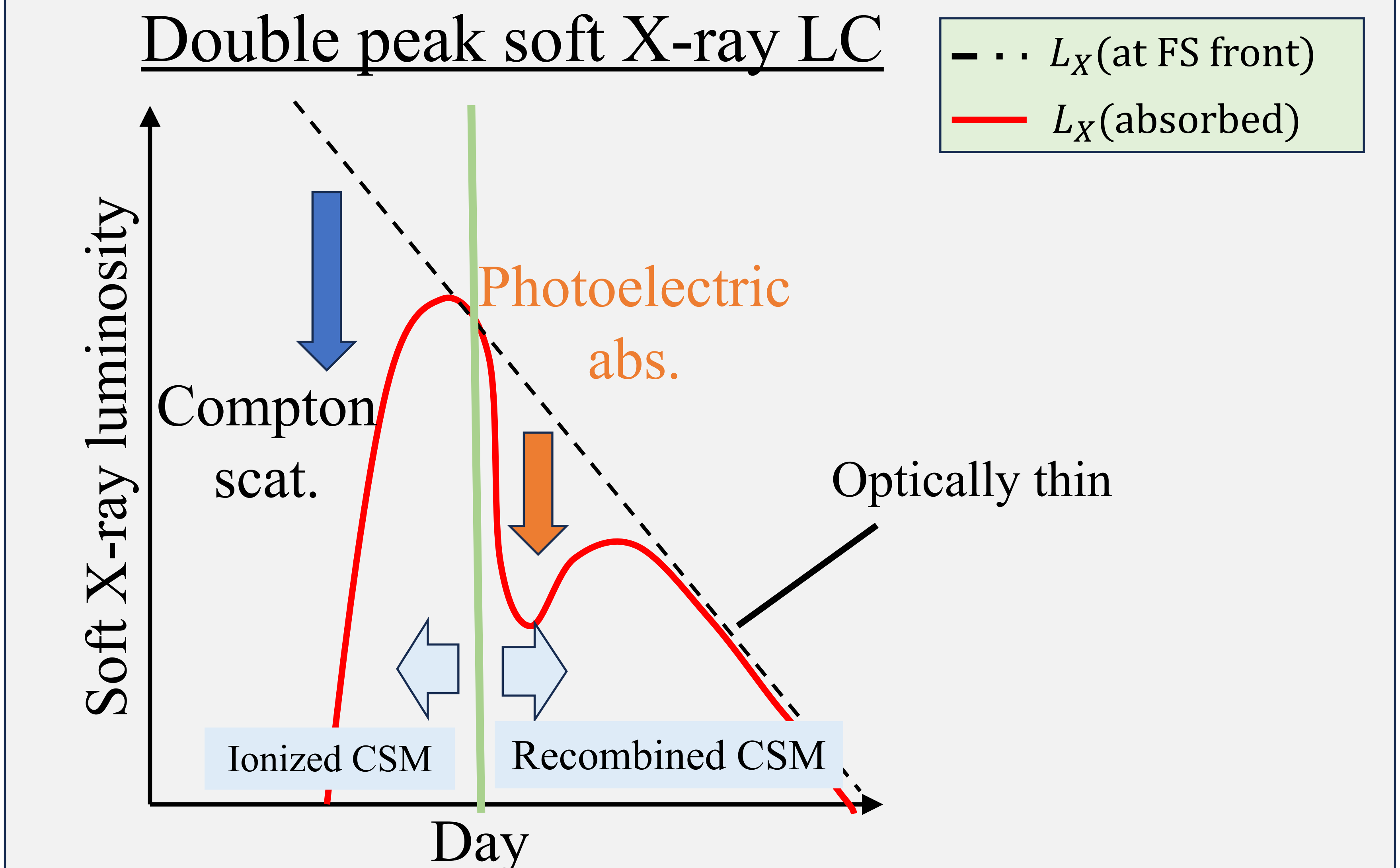
Photoelectric Abs.

Optically thin

Photoionization Changing in unshocked CSM

Photoionization Parameter (for K shell of C, O)

$$\xi = \frac{L_{\rm softX}}{nr^2}$$



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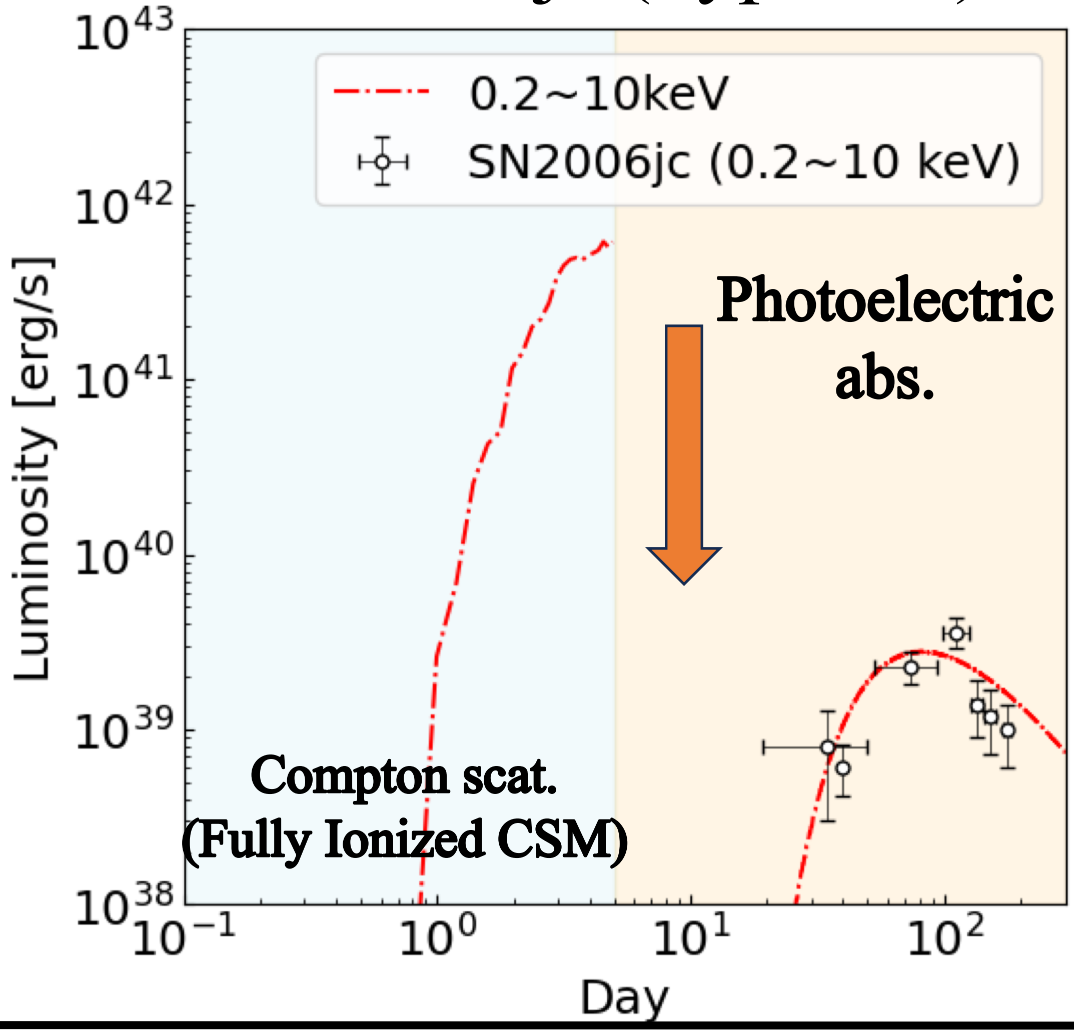
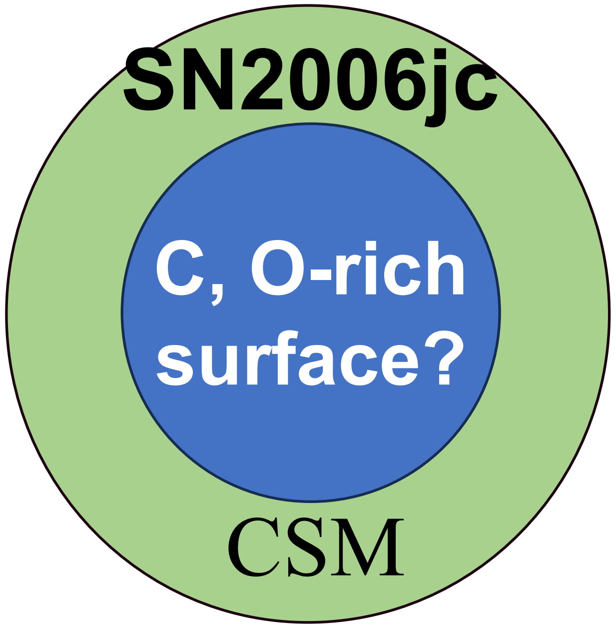
Application to SN2006jc (Type Ibn)



CSM abundance of SN2006jc;
(X(He) : X(C) : X(O))=(0.2 : 0.4 : 0.4)
by mass fraction



C.S., Chugai 2009

Other Parameters (the result of optical LC model)

※$\rho_{CSM} = 10^{-14} D' (\frac{r}{5\times10^{14}})^{-s}$

	$E_{ej}[10^{51}$ erg]	$M_{ej}[M_\odot]$	s	D'	V_{CSM}[km/s]
SN2006jc(Type Ibn)	0.8	4	3	2.0	3000 km/s

Summary

X-ray LC model

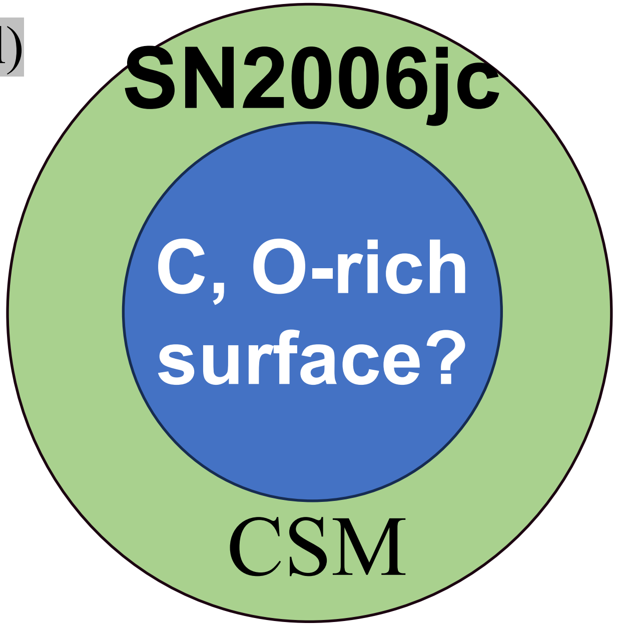
fig. X-ray LC properties

	Optically thin phase for photoE. abs.	$E_{ej}, M_{ej}, \rho_{CSM}$	CSM abundance
Hard X-ray LC	>~1 days	○	×
Soft X-ray LC	>~10 days	×	○

・Broad band X-ray observation is needed for revealing SNe Ibn/Icn

Application

(with optical LC model)



CSM abundance of SN2006jc

(X(He) : X(C) : X(O))=(0.2 : 0.4 : 0.4)
by mass fraction

※(He : C : O) ~ (0.5 : 0.3 : 0.2) by number fractio

Thank you for listening!