2026/2/19
YITP long-term workshop
@Panasonic hall, YITP

Dust formation in confined circumstellar material and its impact on kilonova surveys

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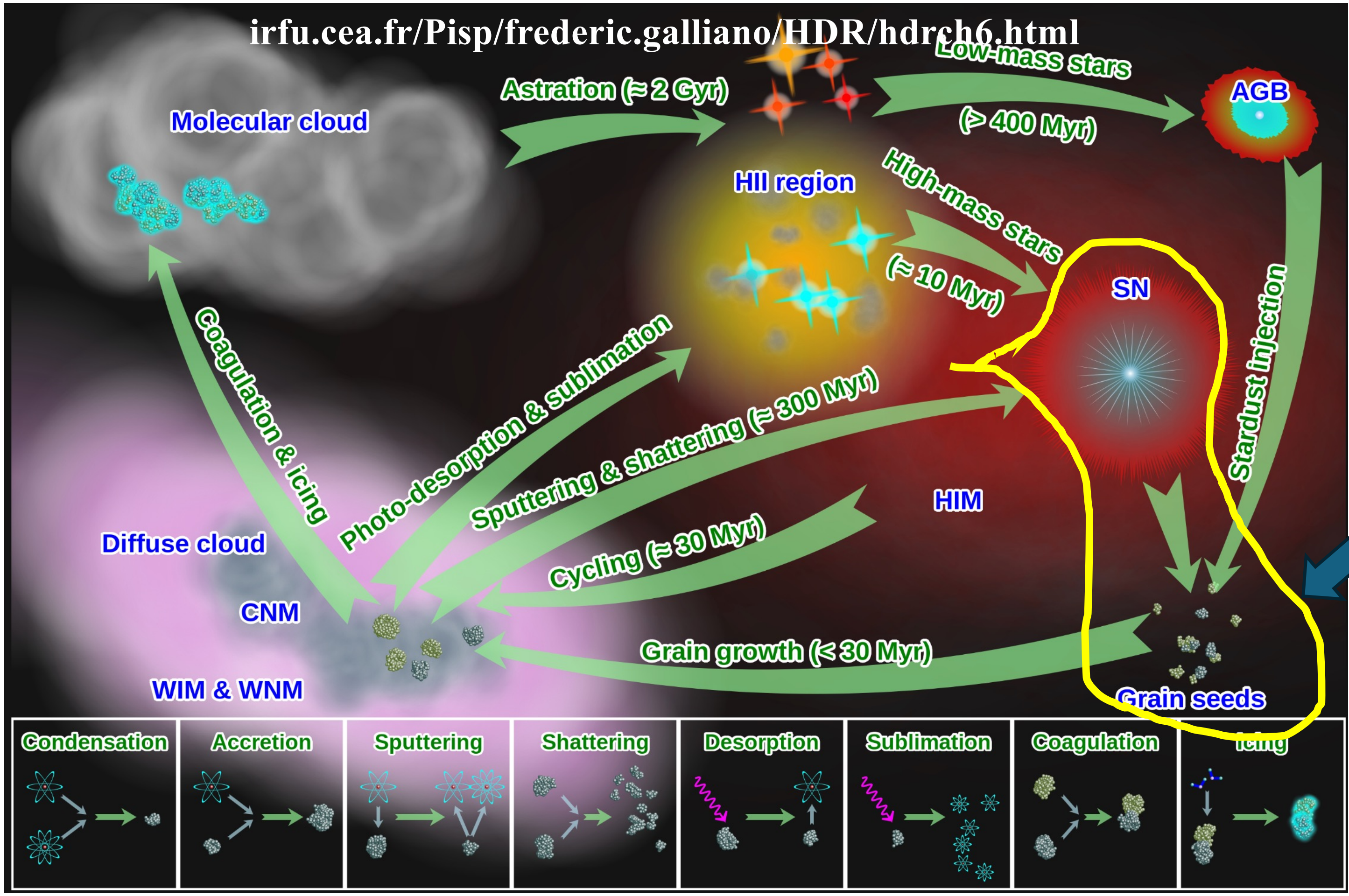
ApJ, 992, 137, arXiv: 2507.22763

(Massive-low mass) star as a dust supplier

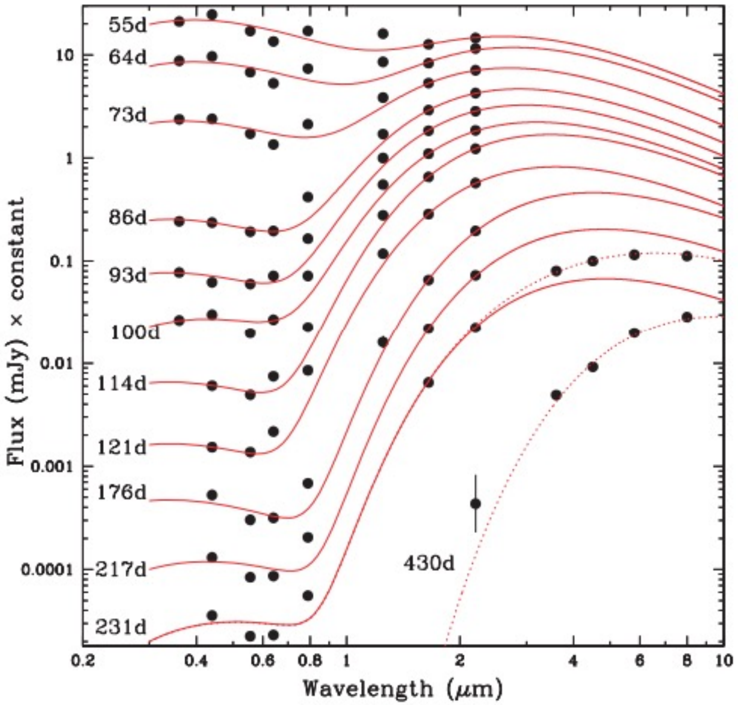


Today's topic

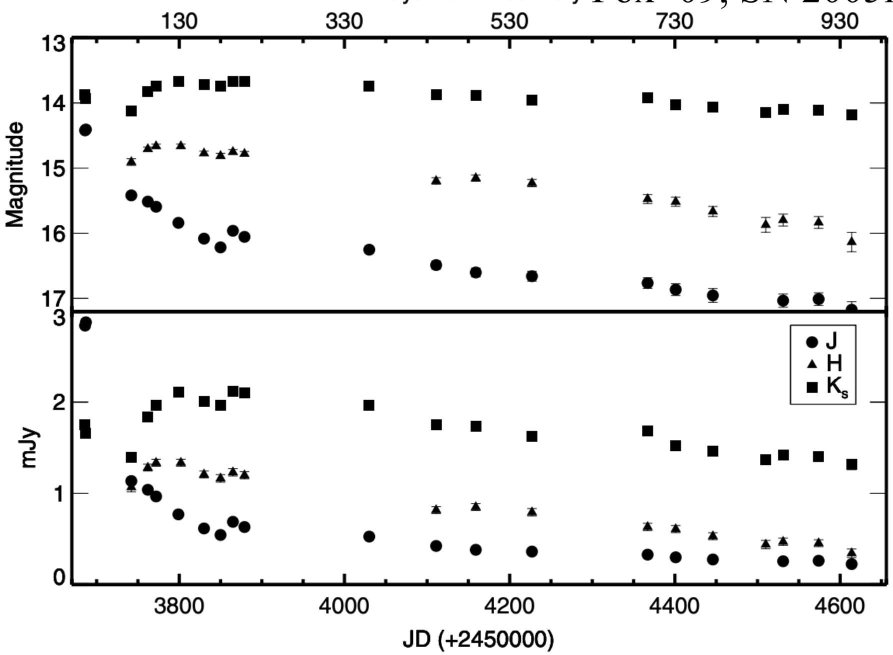
Dust formed in SNe IIn/Ibn

- IR excess is observed in some SNe IIn/Ibn
  - ➢IR excess indicates newly formed dust

Mattila+08, SN 2006jc (Ibn)



Fox+09, SN 2005ip (IIn)



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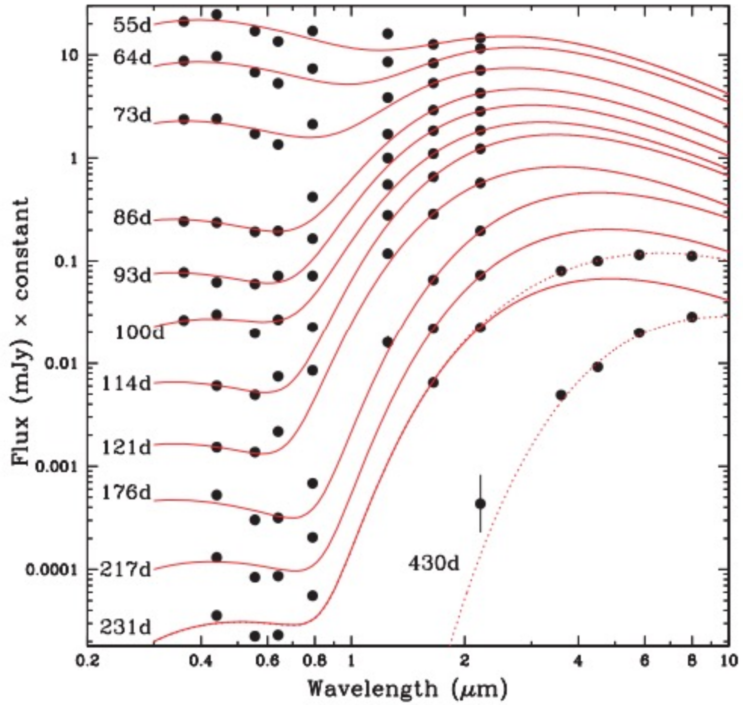
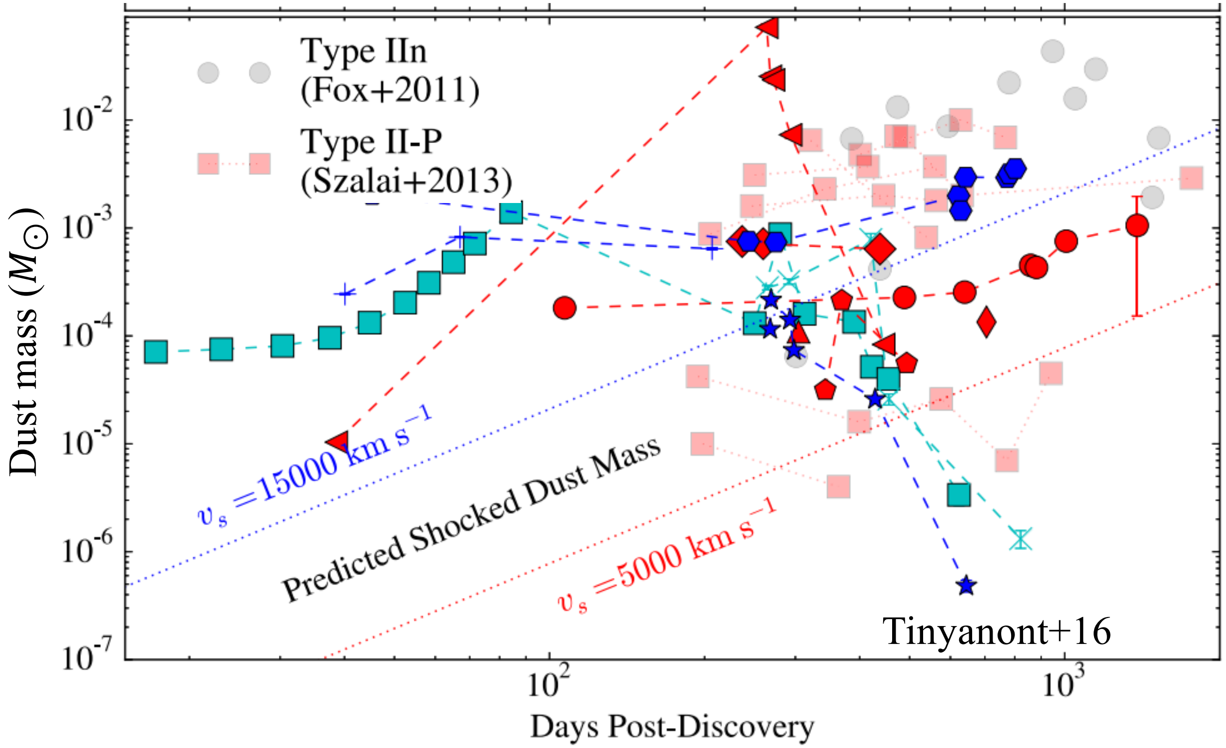


Does the presence of CSM make dust formation more likely?

Comparison of observed dust

- Compared with other SNe (such as Type IIP), the observed dust mass seems larger (e.g., Fox+11; Szalai+13)



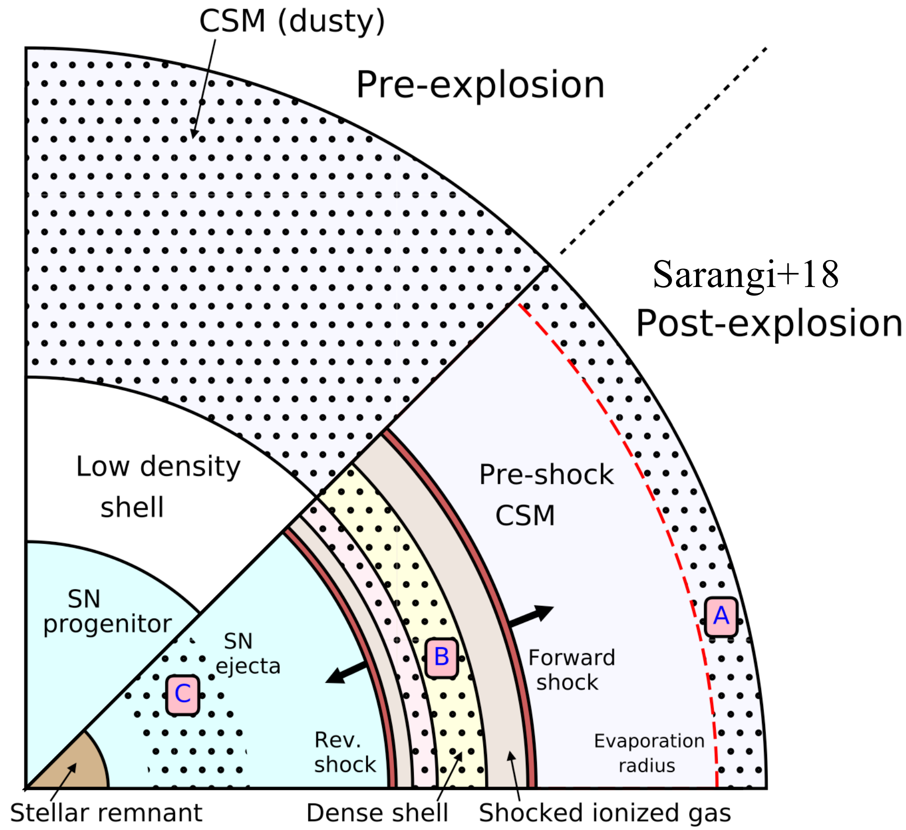
Dust formation site in SNe

- (A) Pre-existing dust in the stellar wind (e.g., Bode & Evans 80)

- (B) Dust formation in cold dense shell (CDS) formed in the shocked region between SN and CSM (e.g., Pozzo+04)

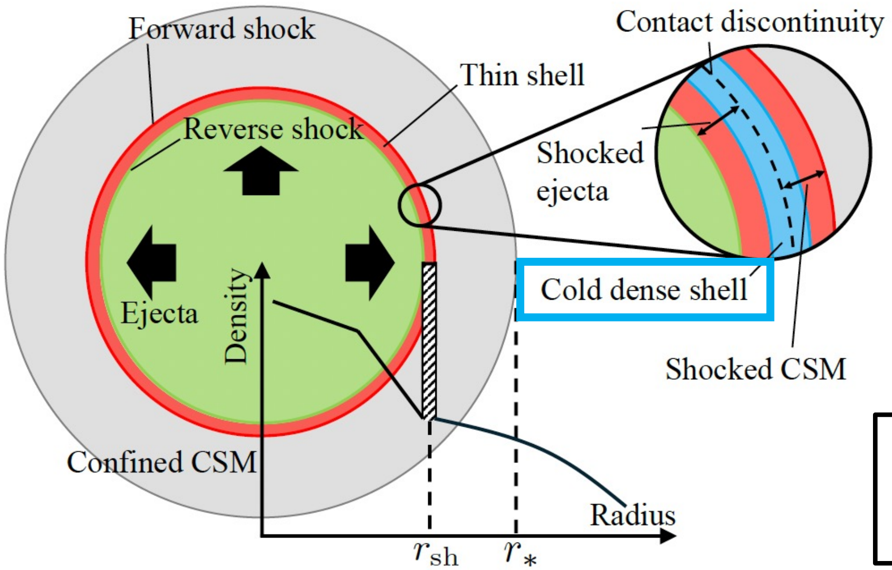
Very important!!

- (C) Dust formation in SN ejecta (e.g., Todini & Ferrara 2000)



Dust formation site in confined CSM

- Inspired by the dust formation in SNe IIn, we model the interaction between SN ejecta and confined CSM, and dust formation
- We do not solve the dust formation itself, but evaluate the density of the CDS at the temperature below which atoms can condense into dust



We need ejecta and CSM profiles
We simulate CSM formation

CHIPS code

YT, Tsuna, Kuriyama, Ko, Shigeyama 2022
YT, Tsuna, Ko, Shigeyama 2024
https://github.com/DTsuna/CHIPS

Open-source code aimed to unveil the
Complete History of Interaction-Powered Supernovae

Key parameters

- f_{inj}: Energy injected at the base of the stellar envelope, scaled with the envelope's binding energy (order of 0.1-1)
- t_{inj} [yr]: Time from energy injection to core-collapse

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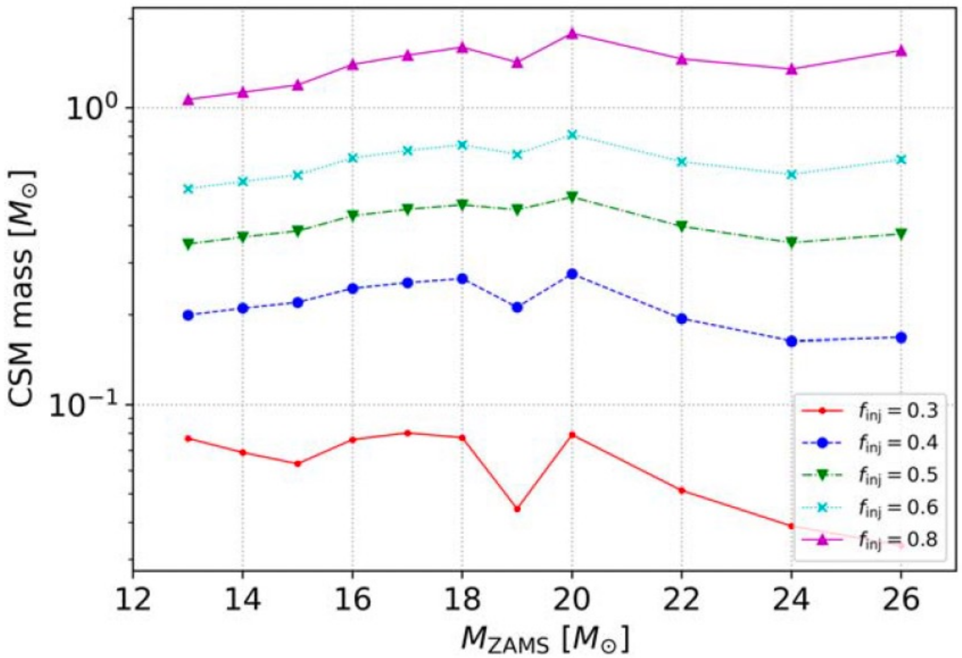
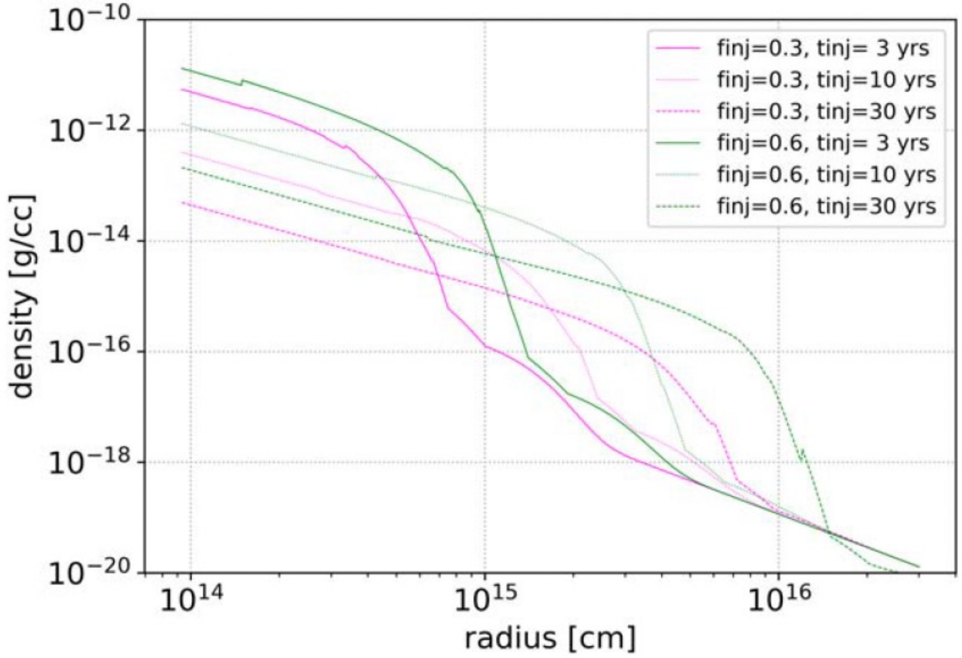


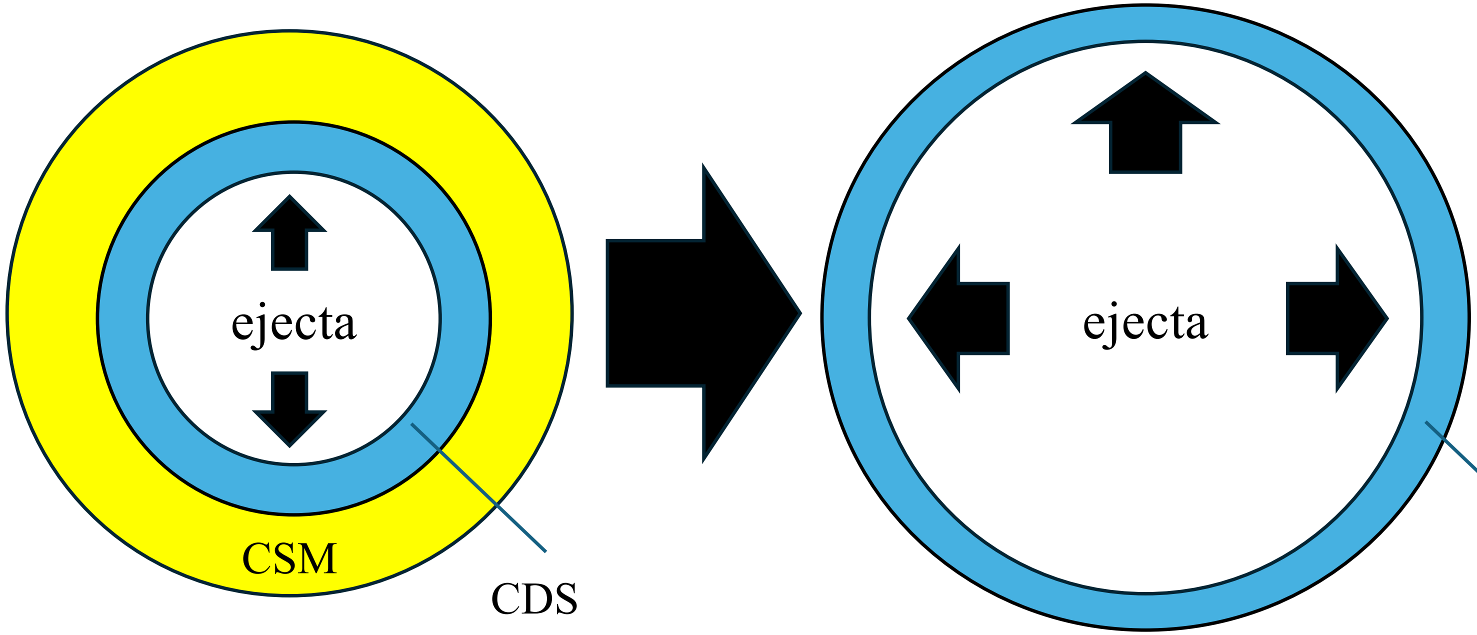
f_{inj} dependence

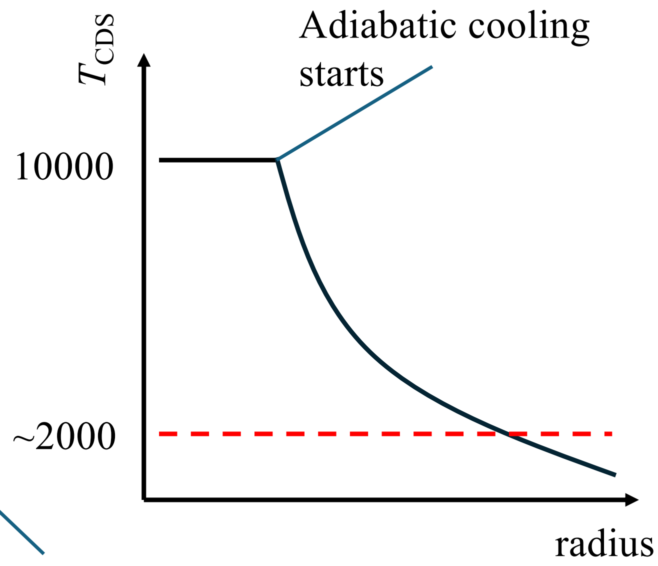


t_{inj} dependence

Evolution of temperature/density of CDS

- During the interaction between the ejecta and the CSM, T_{CDS} rapidly drops to ~10^4K, following the cooling function (assumption)
- Adiabatic cooling starts after the shock passes through the CSM





Location and mass of CDS

- Determine the position by thin-shell approximation (e.g., Moriya+13)

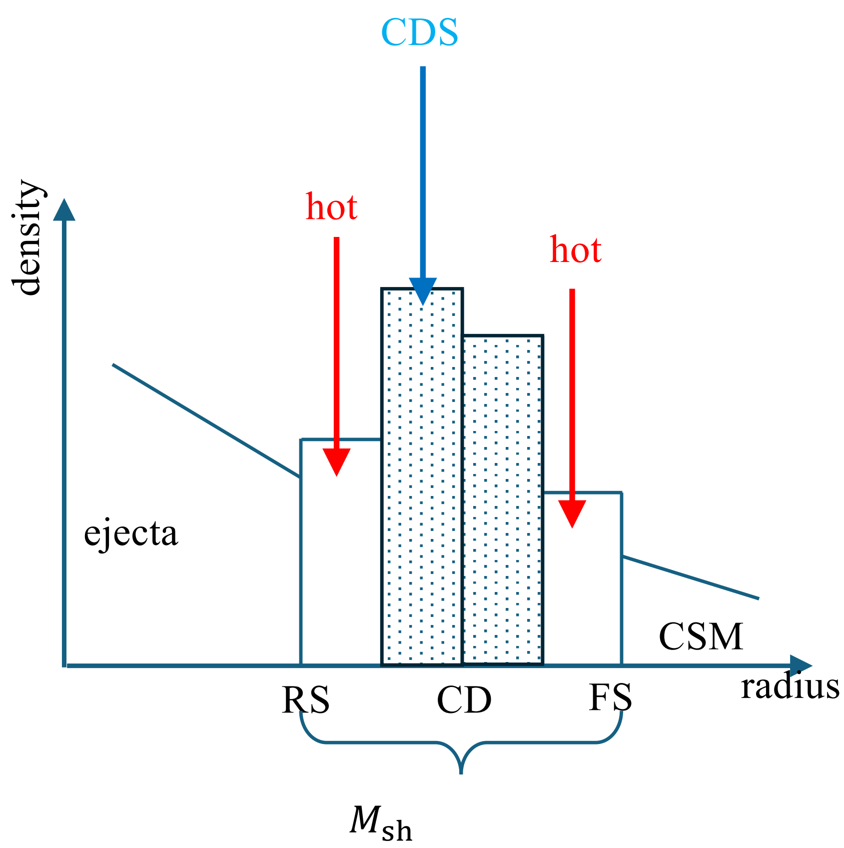
$$\frac{dM_{\rm sh}}{dt} = 4\pi r_{\rm sh}^2 \left[\rho_{\rm ej}(u_{\rm sh} - v_{\rm ej}) + \rho_{\rm CSM}(u_{\rm sh} - v_{\rm CSM})\right], \quad (6)$$

$$M_{\rm sh}\frac{du_{\rm sh}}{dt} = 4\pi r_{\rm sh}^2 \left[\rho_{\rm ej}(u_{\rm sh} - v_{\rm ej})^2 - \rho_{\rm CSM}(u_{\rm sh} - v_{\rm CSM})^2\right] \quad (7)$$

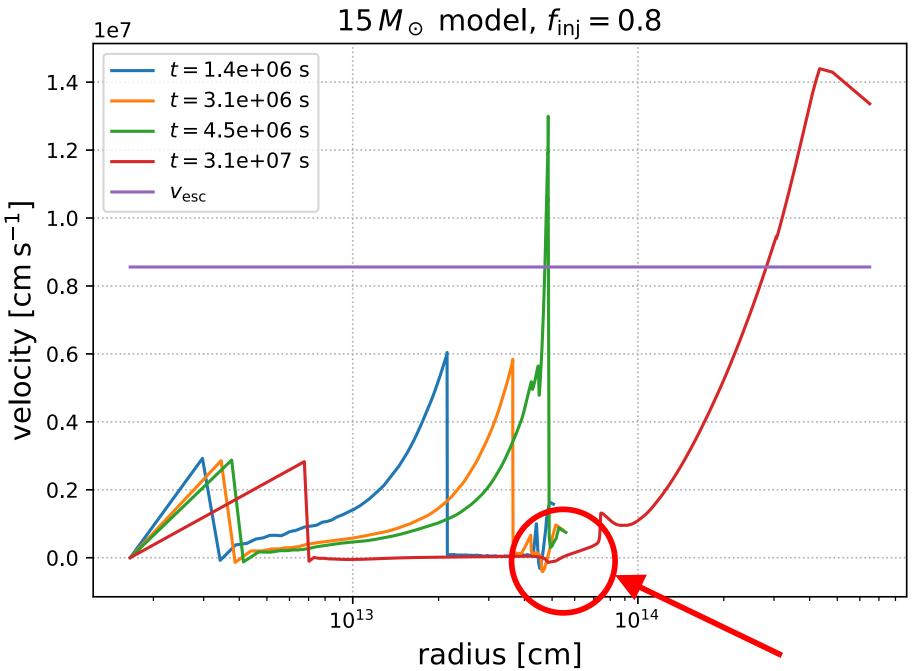
- We consider that the shock-heated shell settles into the CDS on the cooling timescale $\tau_{\rm cool}$

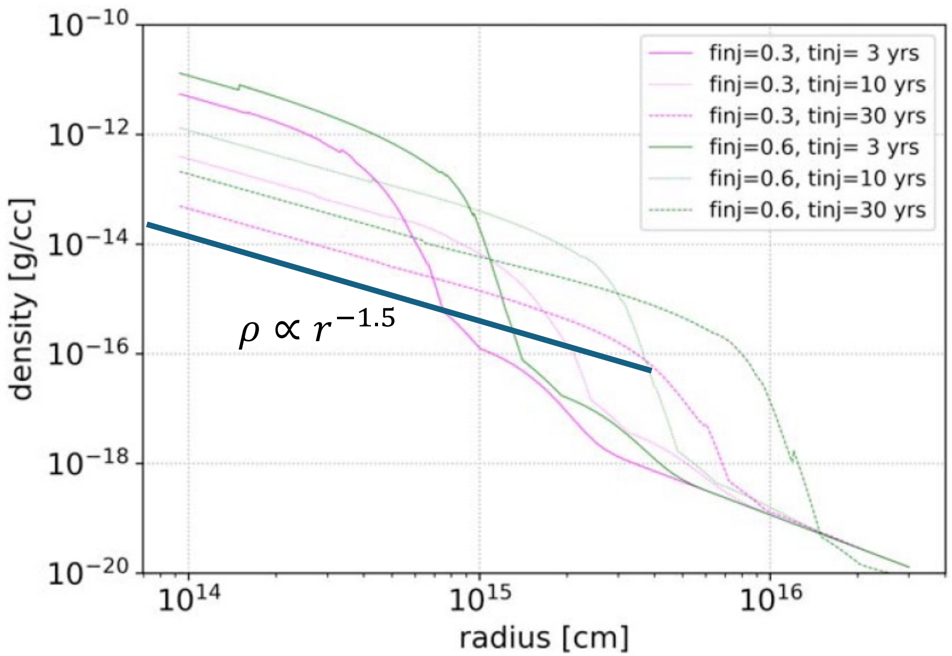
$$\frac{dM_{\rm CDS}}{dt} \sim \frac{M_{\rm hot}}{\tau_{\rm cool}},$$

$$M_{\rm CDS} = M_{\rm sh} - M_{\rm hot},$$



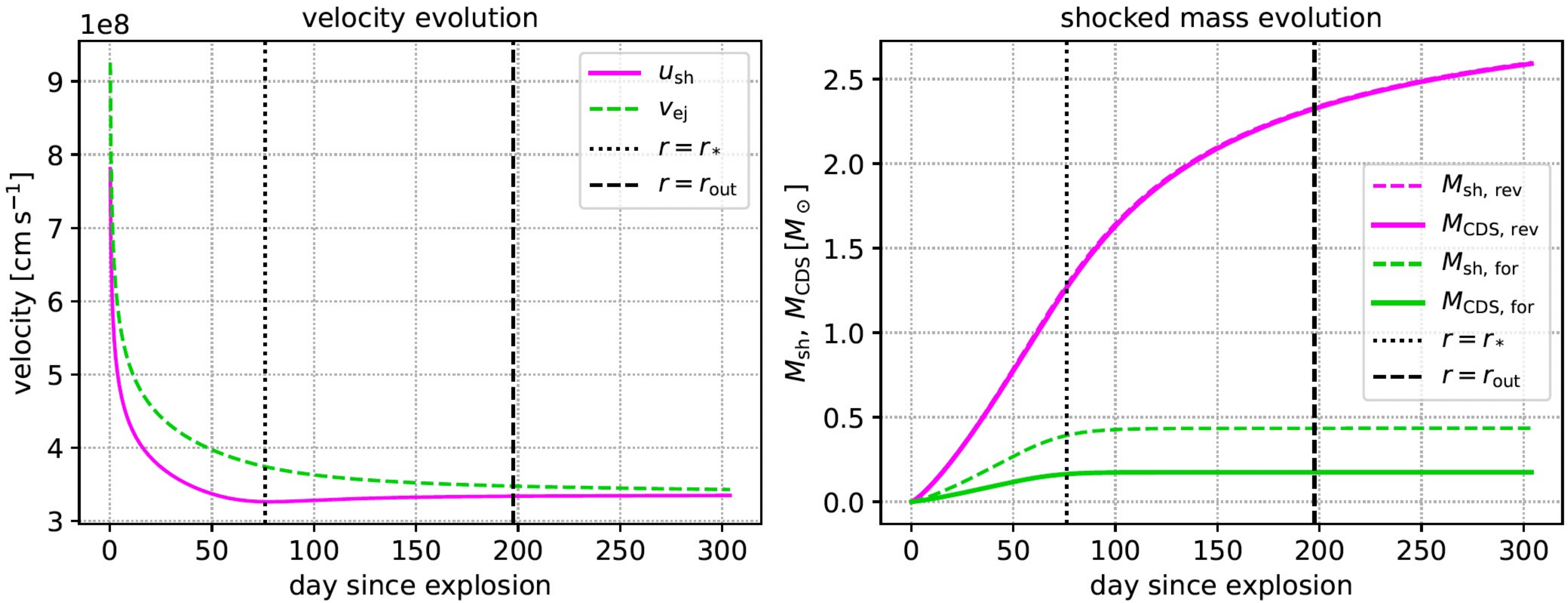
Simulation: Mass Eruption





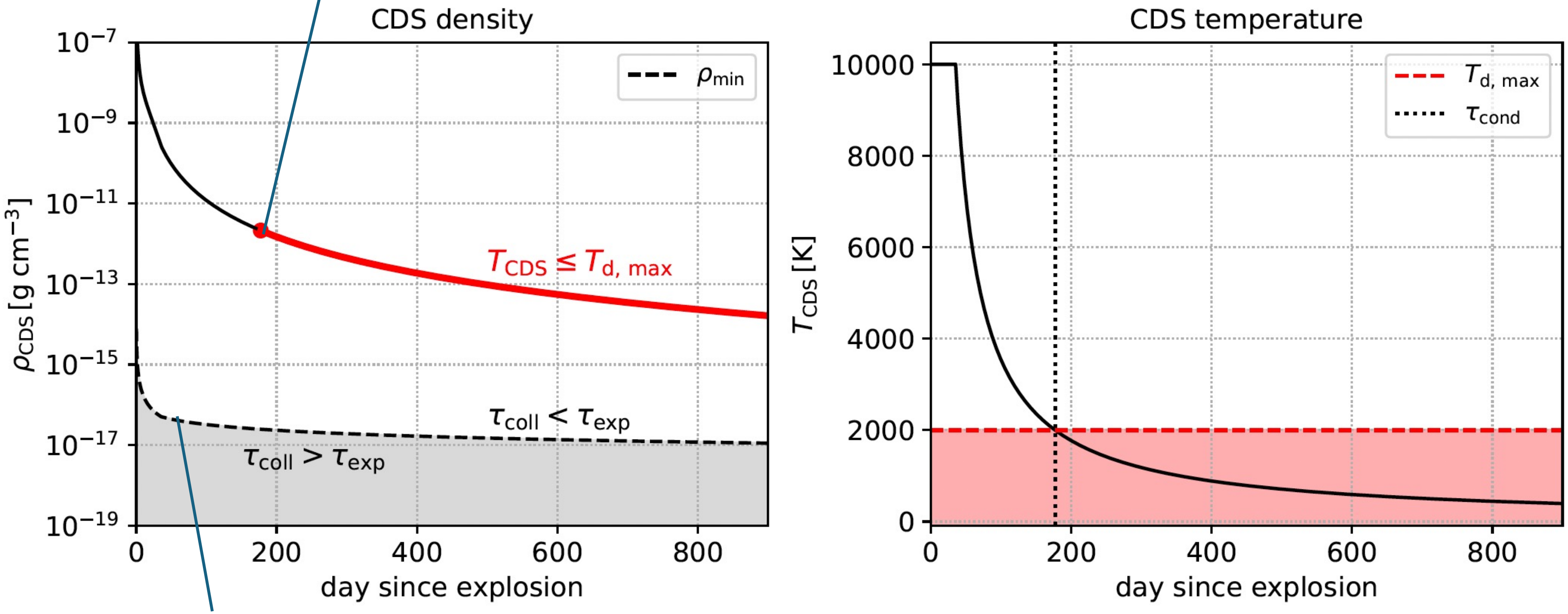
Partial ejection of the envelope results in the fallback of the inner CSM, which makes **the inner profile of $\boldsymbol{\rho \propto r^{-1.5}}$** (shallower profile compared to stellar wind, $\boldsymbol{\rho \propto r^{-2}}$) (Kuriyama & Shigeyama 20; Tsuna, YT+21)

The evolution of velocity and mass of CDS



Density/temperature evolution

Assume that atoms condense into dust instantaneously here

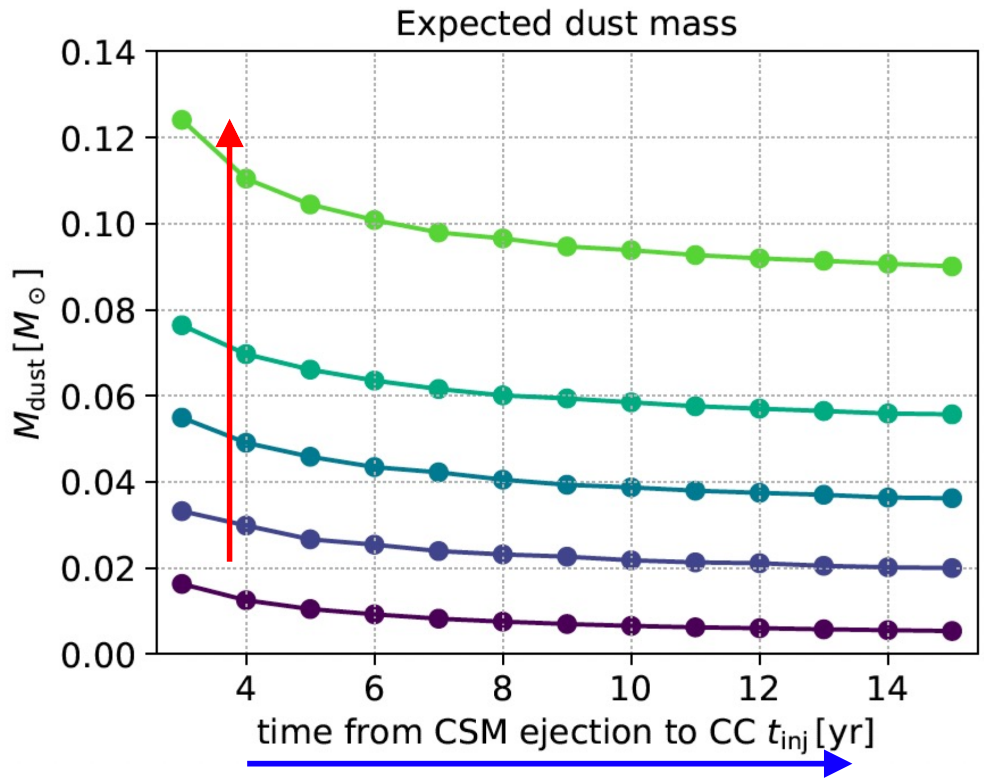


The line where the expansion timescale equals to the atomic collision timescale

→If collisions occur on a short timescale, dust formation becomes possible

Expected dust mass

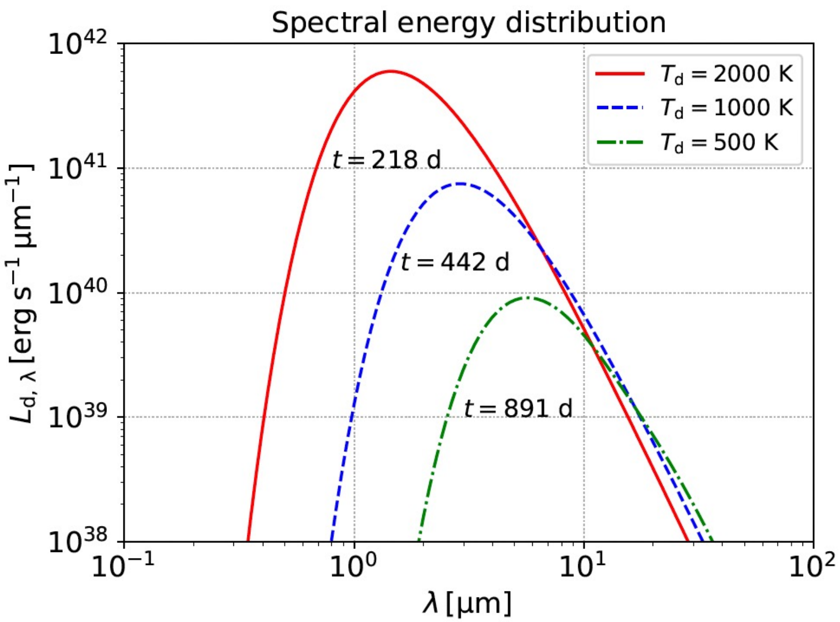
Larger CSM mass results in larger dust mass (larger $f_{\rm inj}$)

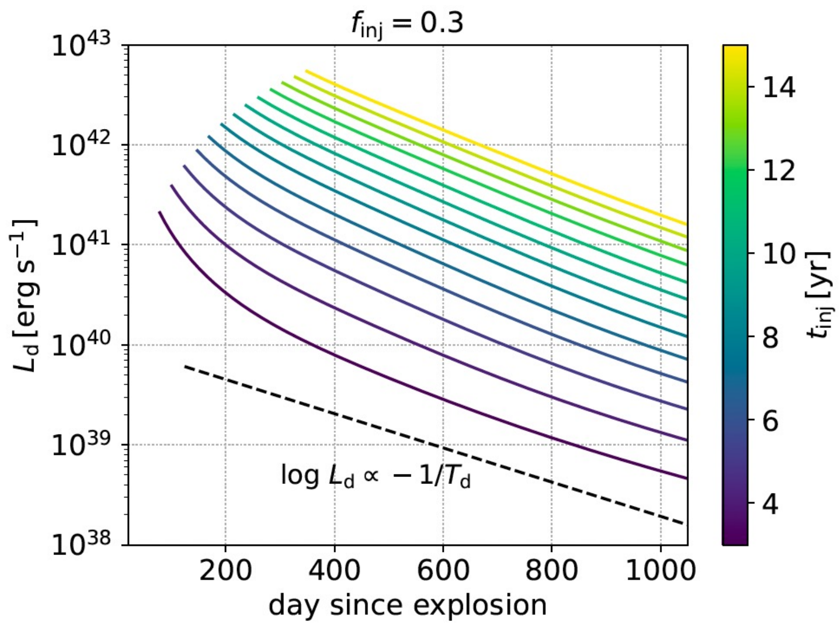


Longer $t_{\rm inj}$ → The reverse shock cannot sweep up larger ejecta mass before the interaction terminates

Light curves of dust emission

- Dust emission at IR bands
- Assuming $T_{\mathrm{dust}} = T_{\mathrm{CDS}}$, we calculate the dust light curves



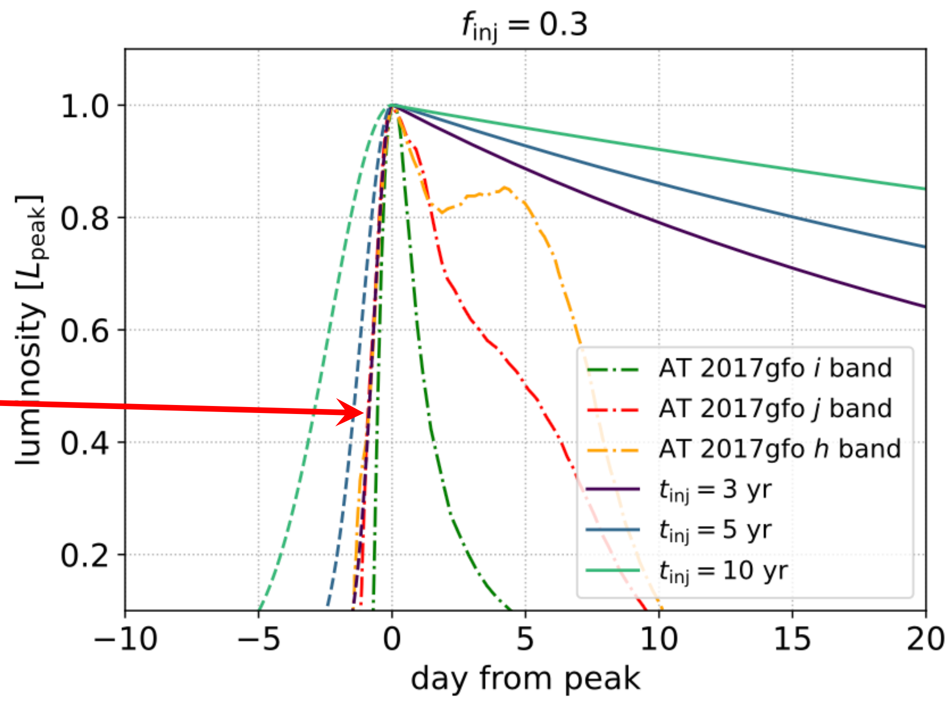


Implications for kilonova surveys

- The light curve of a kilonova (KN) exhibits a rapid rise within a timescale of a few days (e.g., Kasen+13, 17)

Dust emission light curves can mimic early KNe due to light-travel-time effects

$$t_{\rm rise} \sim \frac{r_{\rm sh}}{c}$$



Rise phase alone is insufficient; decay must also be examined.

Summary

- Interaction of the SN ejecta with CSM can promote the dust formation
- A new model that describes the temporal evolution of the density and temperature in the CDS is proposed
- Up to $\sim 0.1 M_{\odot}$ of dust can be newly formed in the CDS formed between the SN ejecta and confined CSM
- We should take into account the contamination by dust formed in the confined CSM for kilonova surveys