

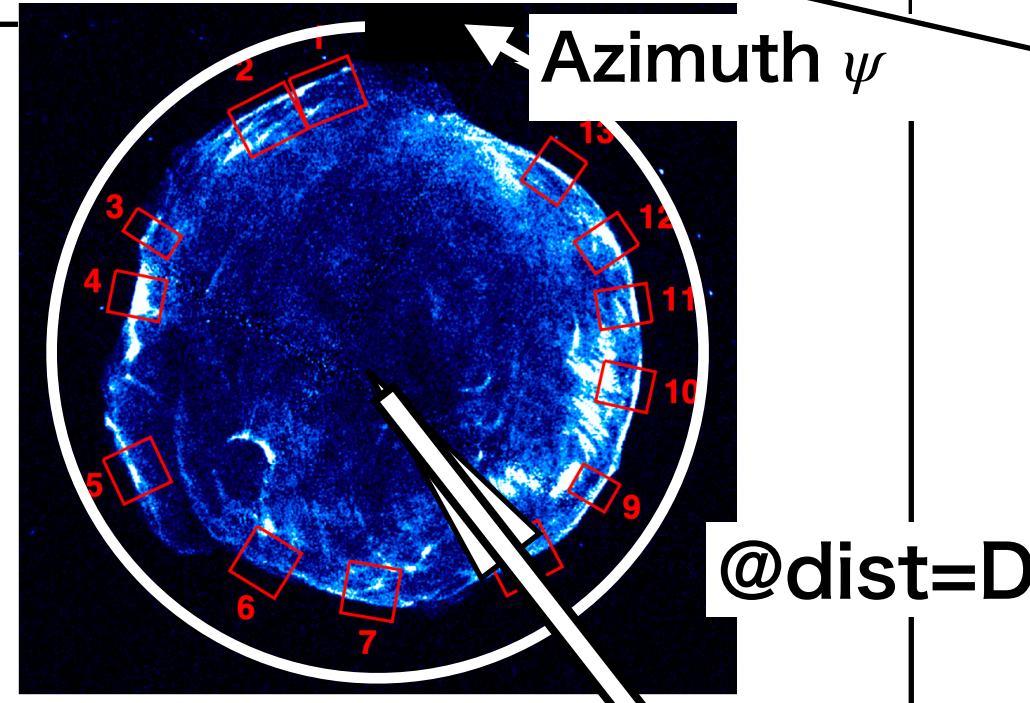
# Exploring the Pre-supernova environment of Tycho's SNR from shock-dynamics and spectrum

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Kobashi et al. (2024, ApJ, 961, 32); Kobashi et al. (2025, ApJ, 979, 81)

## 1. Background

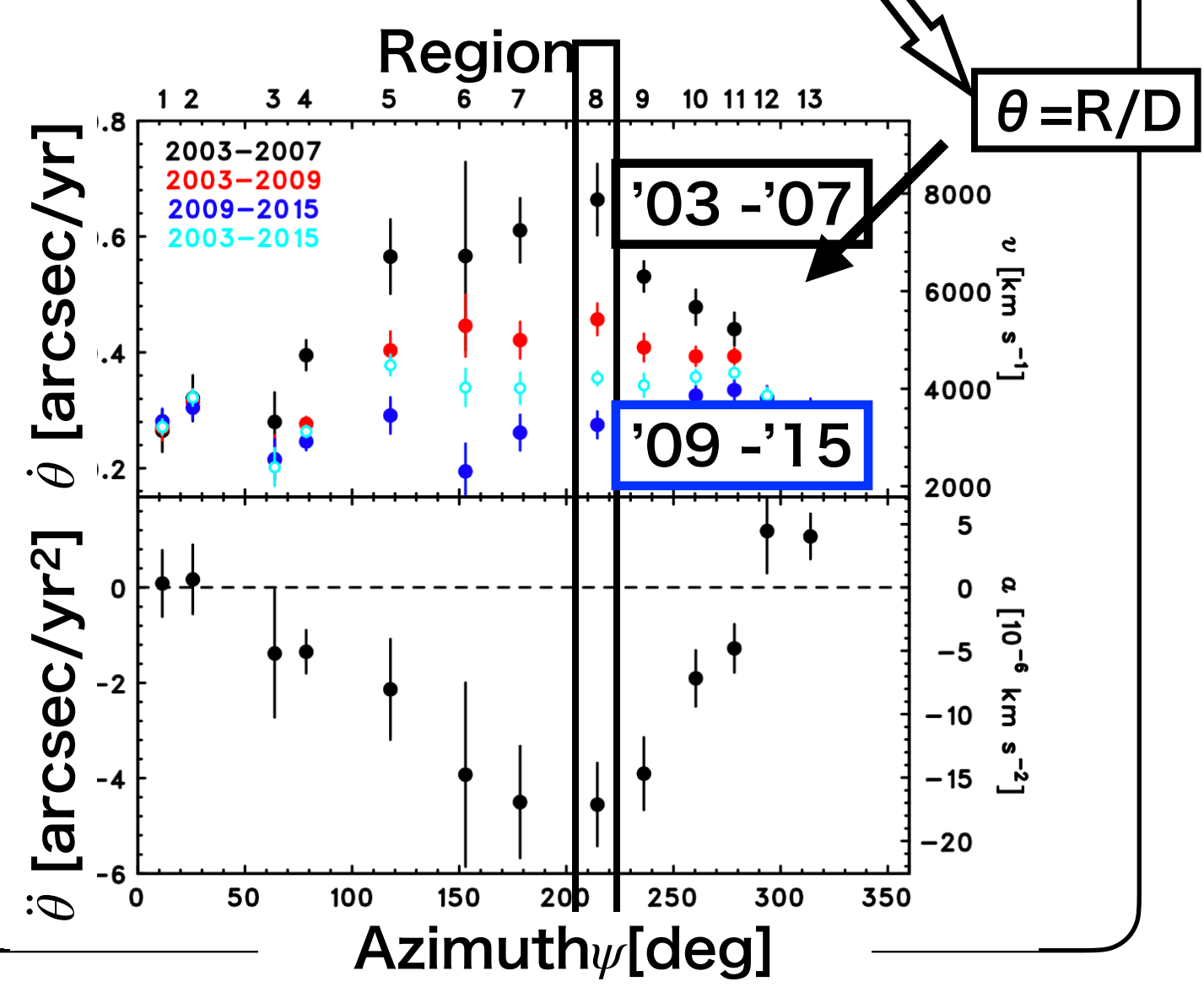
Rapid deceleration of expansion of Tycho's size

- **Rapid deceleration** of forward shock in  $\sim 10$ yr (2003–2015) **discovered** using Chandra archive data (Tanaka+21)



Lower velocity  
...Means High density

- Existence of CSM is inferred
- → **Stellar Companion (SD)**



## 2. Motivation: Tycho among Ia SNe

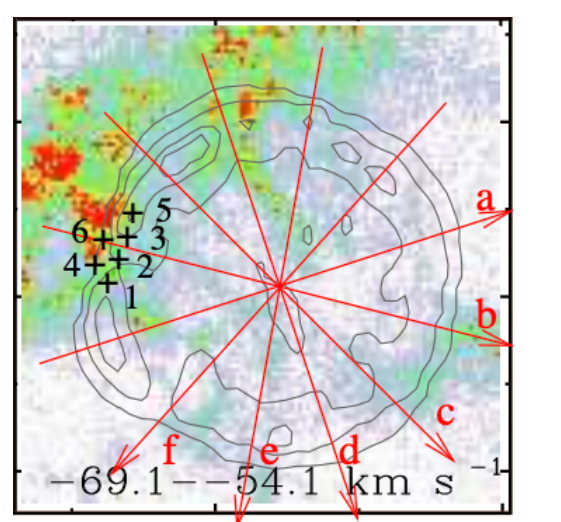
- Progenitor&Environment of Ia Supernovae (SNe)

	Progenitor system	Environment
SD	RG/MS/He WD	Some models • Hachisu wind: <b>WD+RG/WD+MS</b> • AGB wind: WD+ <b>AGB</b> star etc.
DD	WD WD	Maybe uniform (due to binary evolution)

- Environment of Tycho

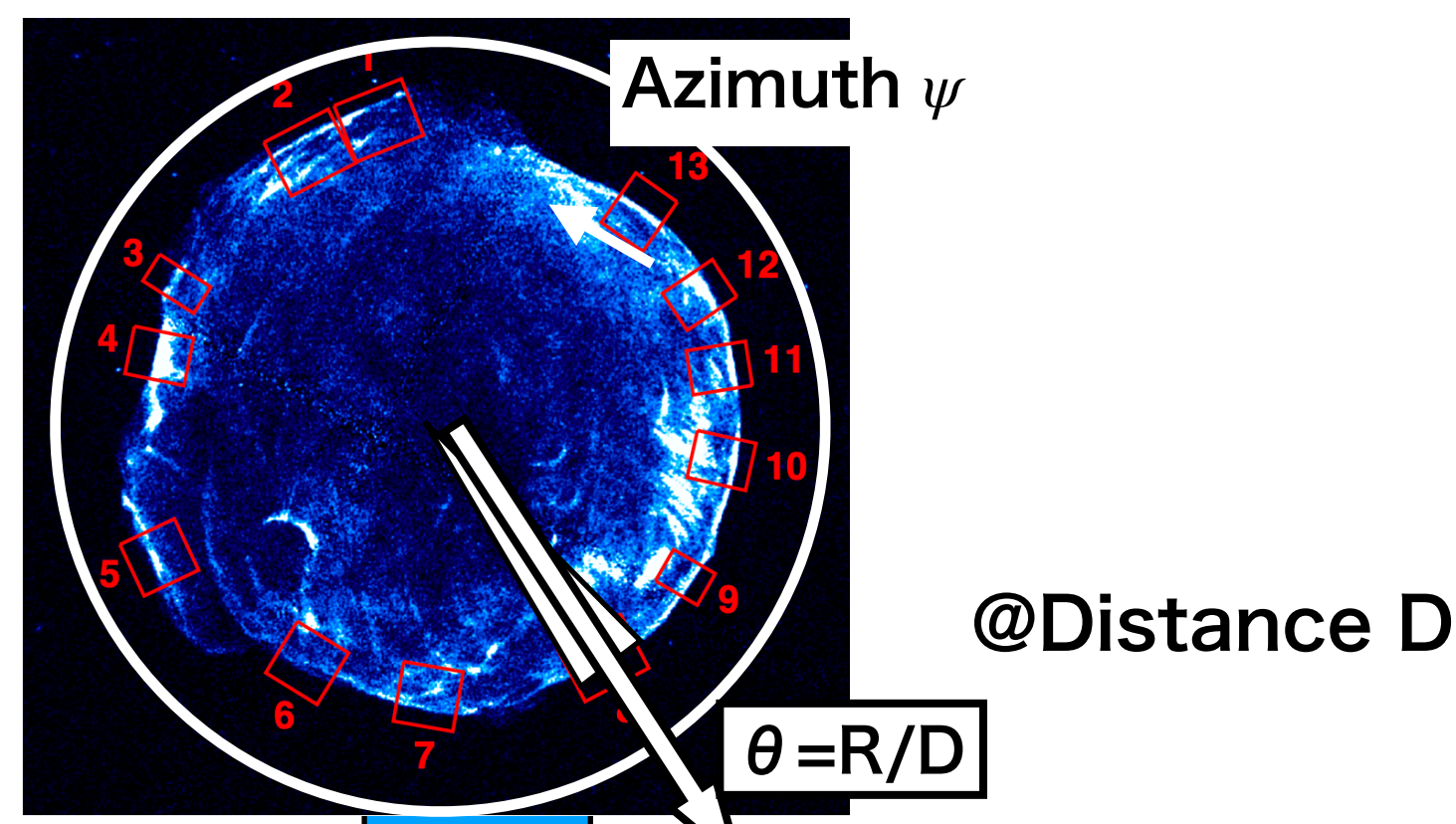
- Models used so far:  
Have been explained using 1-D hydro simulation **with uniform medium** (e.g., Slane+14, Yasuda+19)
- Tanaka+21 (after discovery of rapid deceleration):  
Tycho **first evolves in a cavity**, and then high-density  
→ **Support SD scenario**

- CO obs(Zhou et al.16)  
← Hachisu wind?

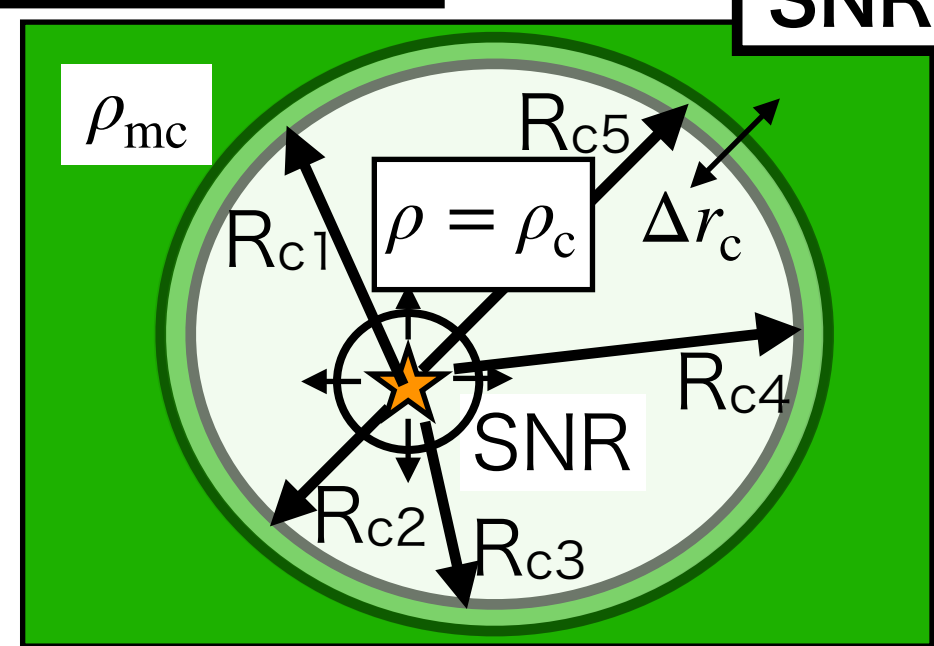


## 3. Models

Data of SNR:  
Tanaka+21

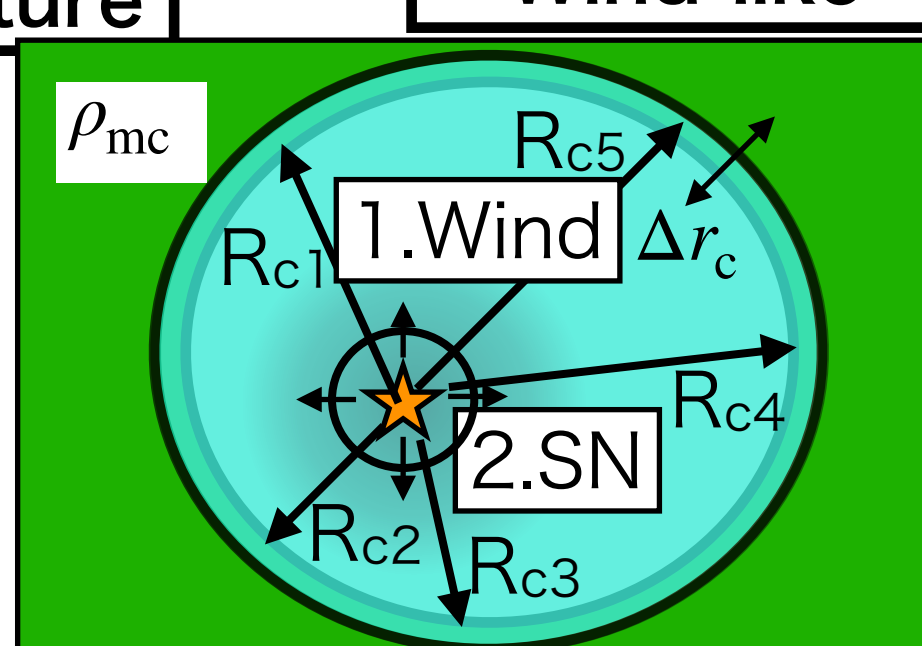


- Uniform



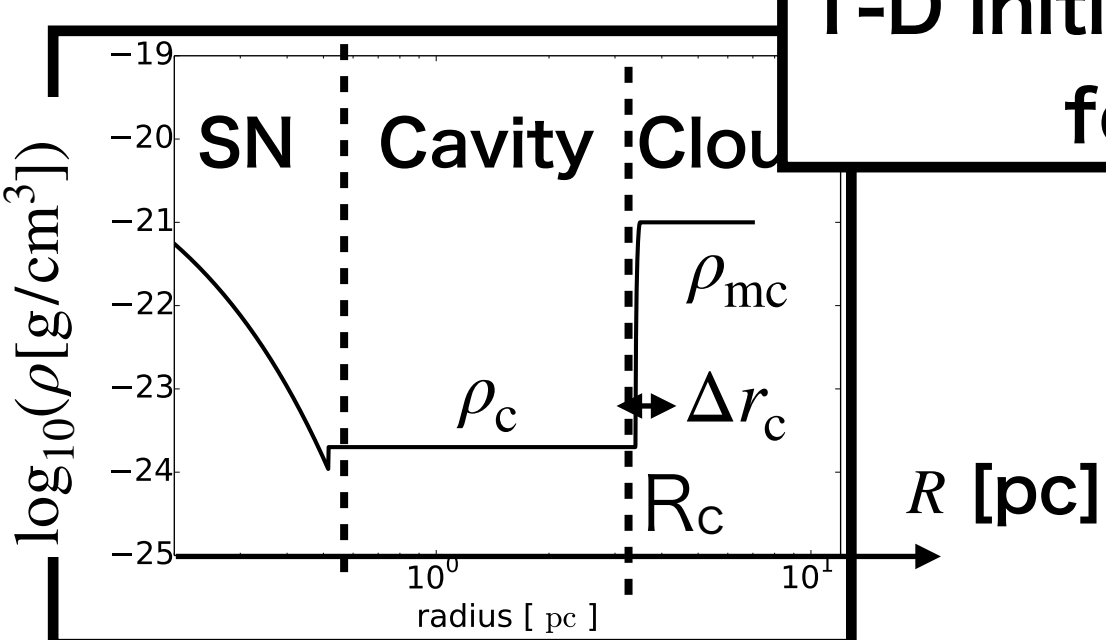
( $R_c$  differs over azimuth)

- Wind-like

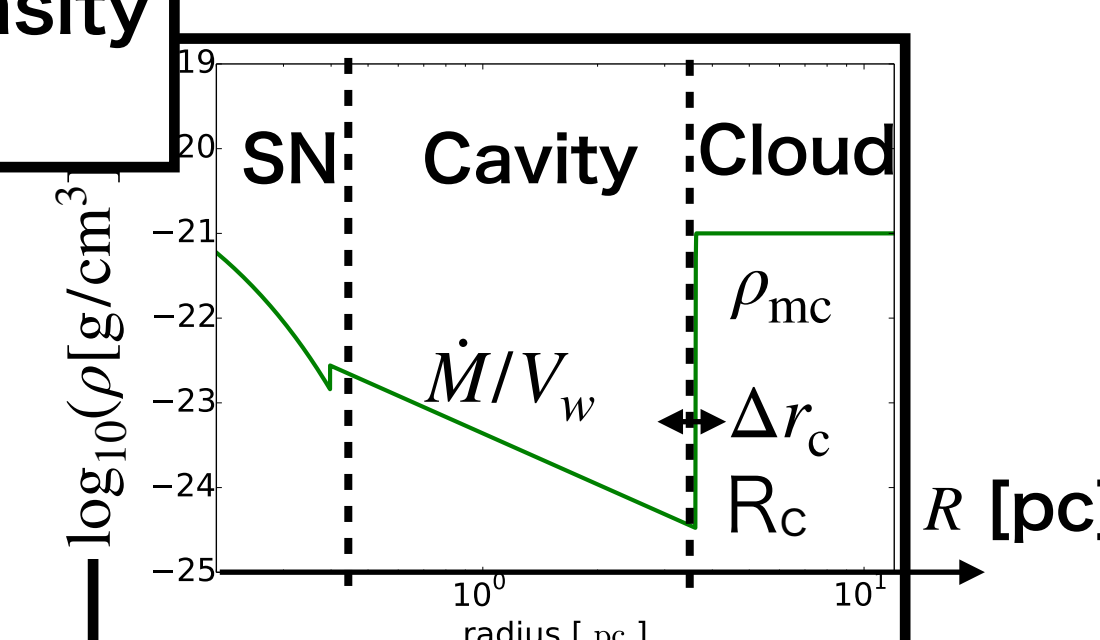


$R_c$  wind parameter differs

1-D initial profile of density  
for simulation



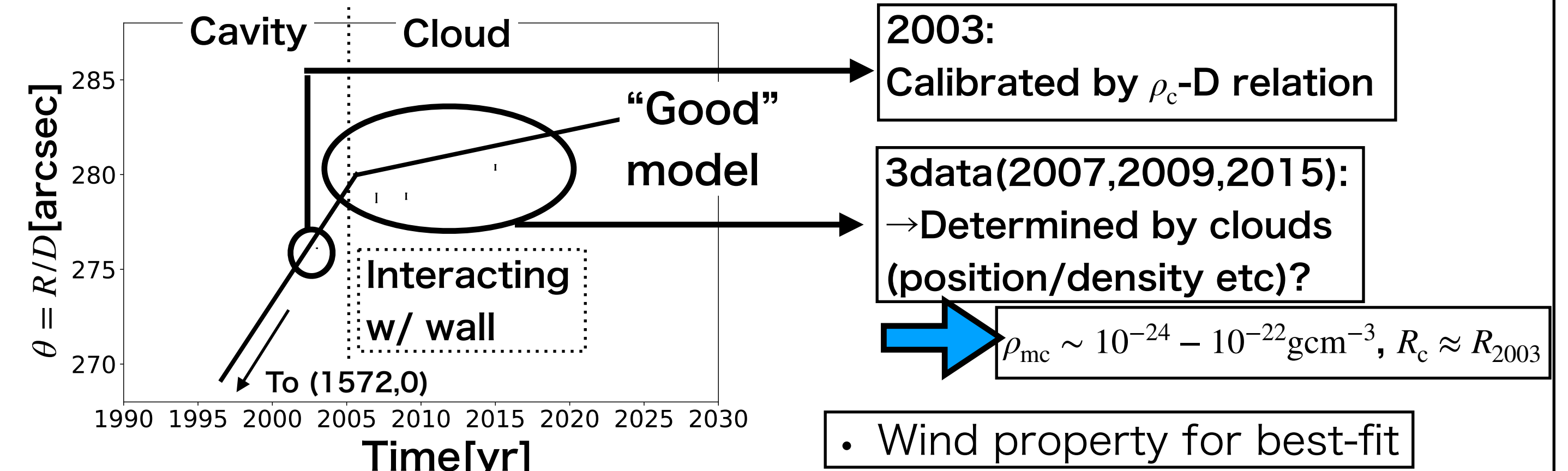
- parameters:  $\rho_c$ ,  $\rho_{mc}$ ,  $R_c$ ,  $\Delta r_c$



- parameters:  $\dot{M}/V_w$ ,  $\rho_{mc}$ ,  $R_c$ ,  $\Delta r_c$

## 4. Radius evolution and estimated CSM

- Schematic picture of radius evolution



- Uniform cavity is unlikely

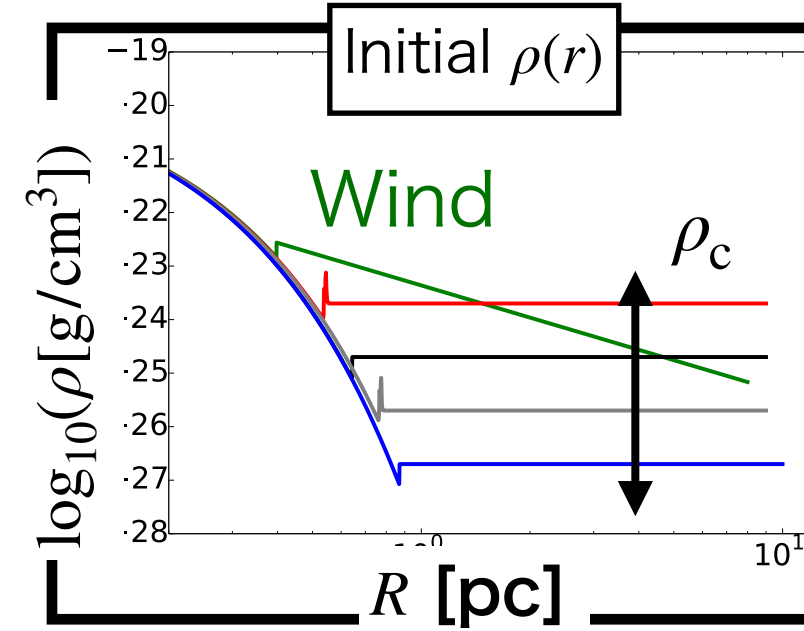
From '03 :

$\rho_c \sim 1 \times 10^{-24} \text{ g cm}^{-3}$

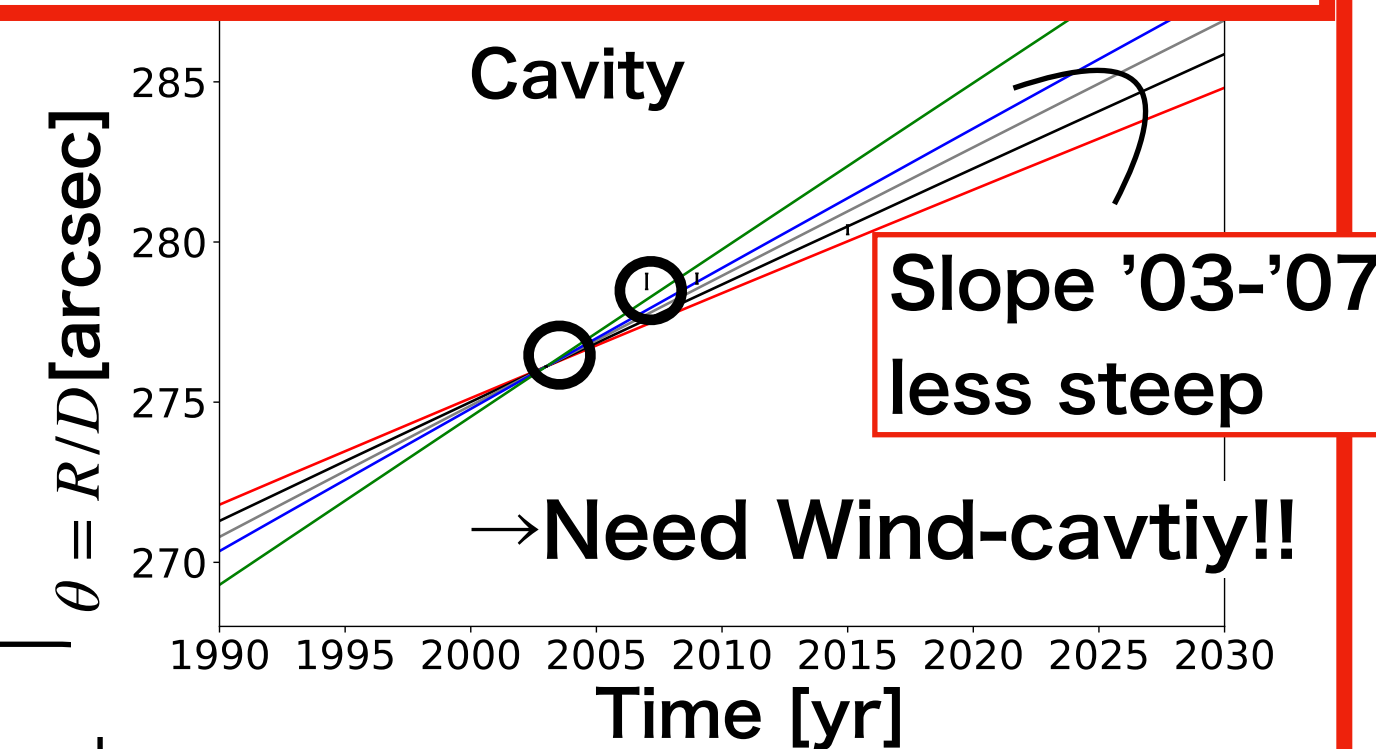
$D \sim 3 \text{ kpc}$

Estimate of D

→ **Red**

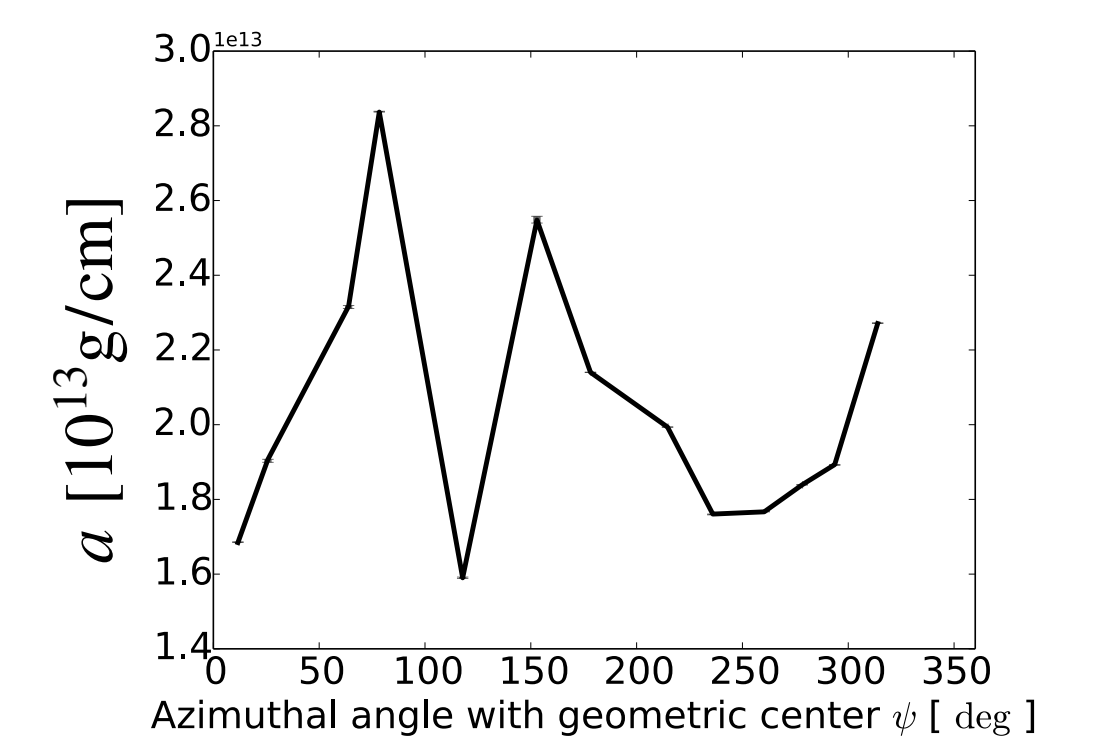


- Radius evolution uniform VS wind



- Wind property for best-fit

- Estimated wind density  $a$  over  $\psi$



- $a \equiv \dot{M}/4\pi V_w \sim 10^{13} \text{ g cm}^{-1}$ ,  $R \sim 4 \text{ pc}$

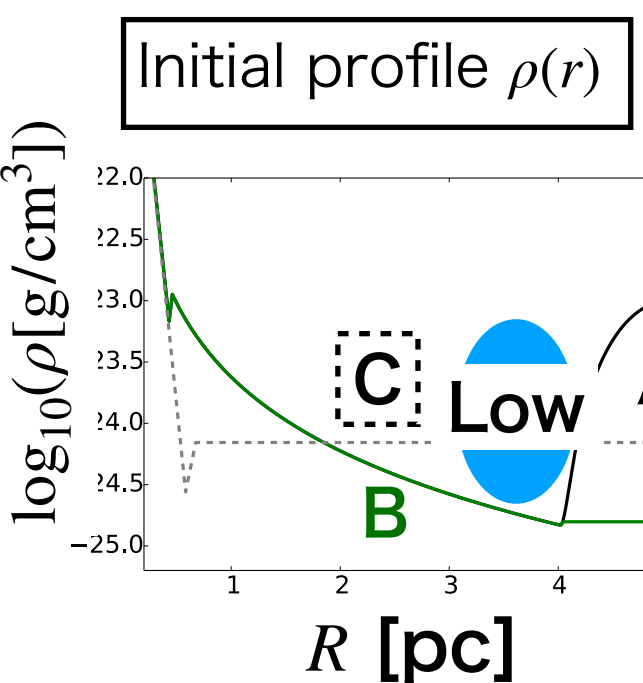
- $\dot{M} = 10^{-4} M_\odot \text{ yr}^{-1}$  @  $V_w = 250 \text{ km/s}$   
 $10^{-6} M_\odot \text{ yr}^{-1} R/V \sim 0.01 M_\odot$   
→ near-Mch will not occur

- $\dot{M} = 10^{-5} M_\odot \text{ yr}^{-1}$  @  $V_w = 25 \text{ km/s}$   
 $10^{-6} M_\odot \text{ yr}^{-1} R/V \sim 0.1 M_\odot$   
→ faint companion star survive

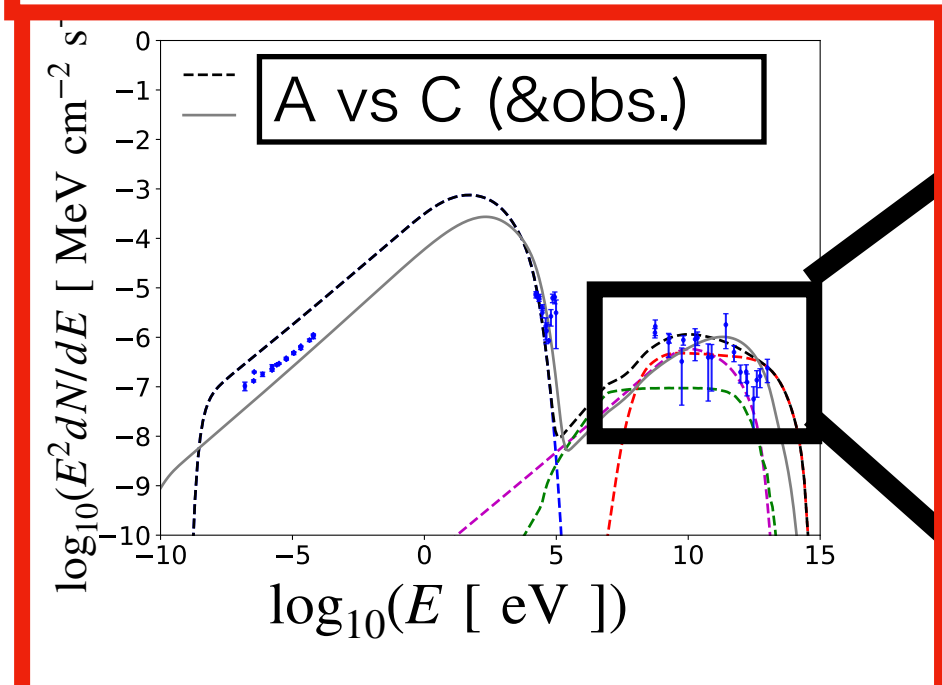
- Our work can explain in **SD**.

## 5. Nonthermal spectrum and particle acceleration

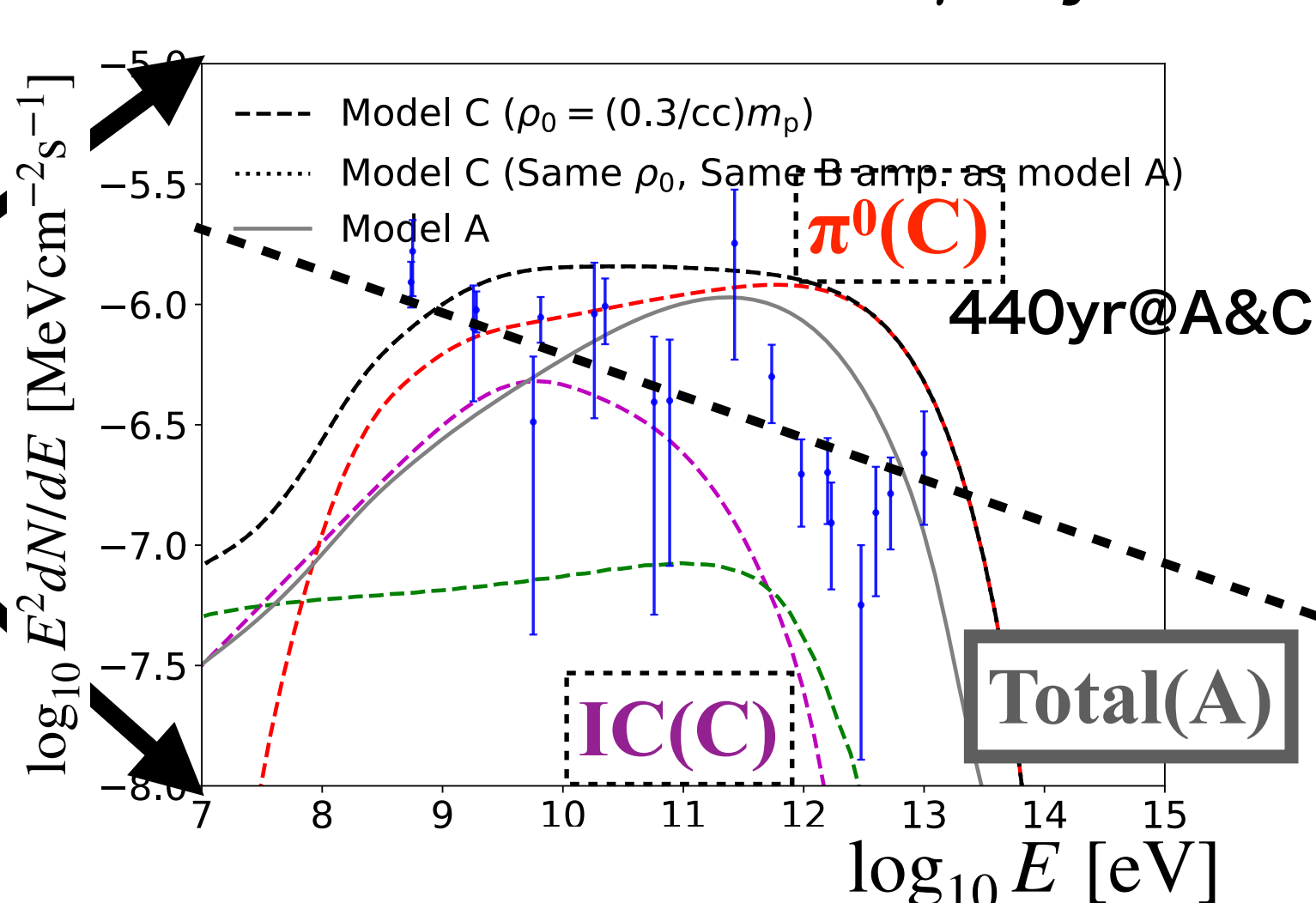
~Impact of different environment~



Spectra among models(2010s)

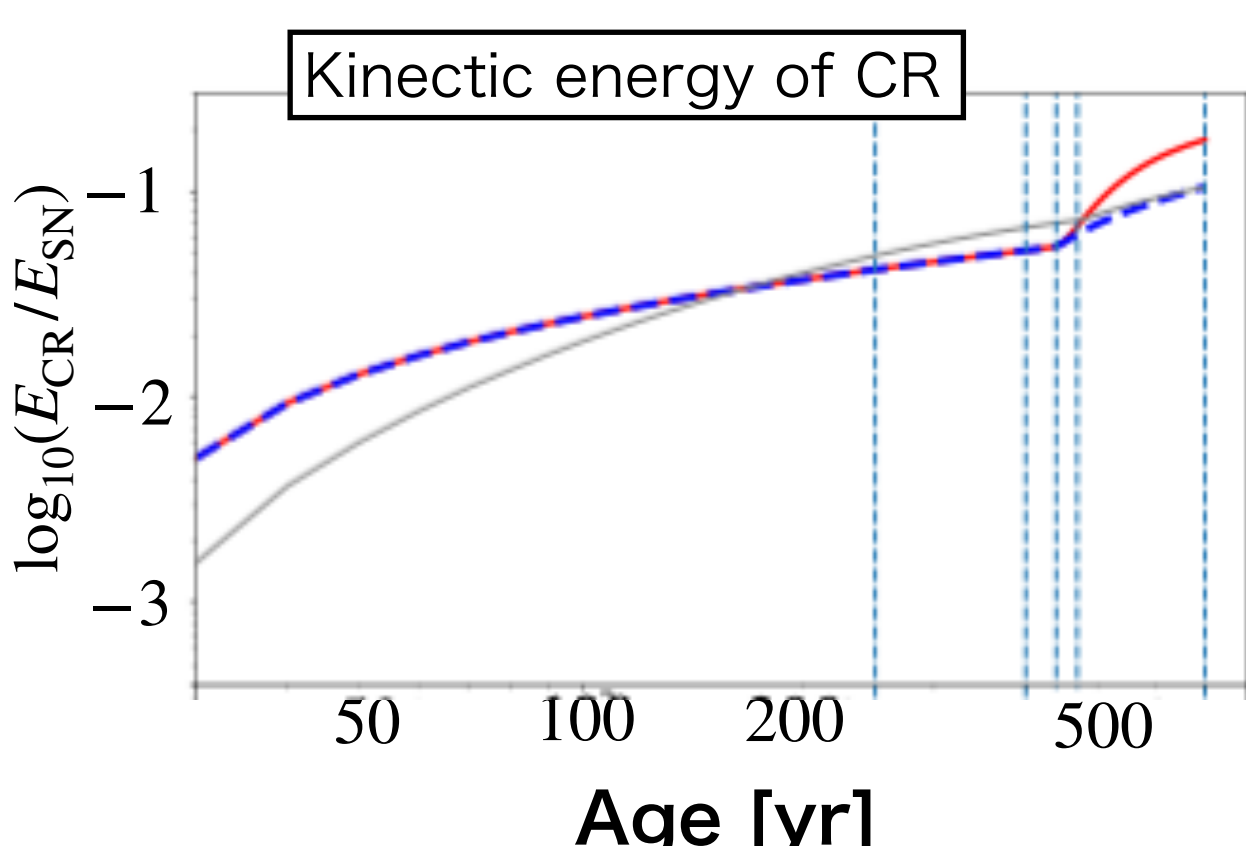


- Not match the obs. in the  $\gamma$ -ray trend



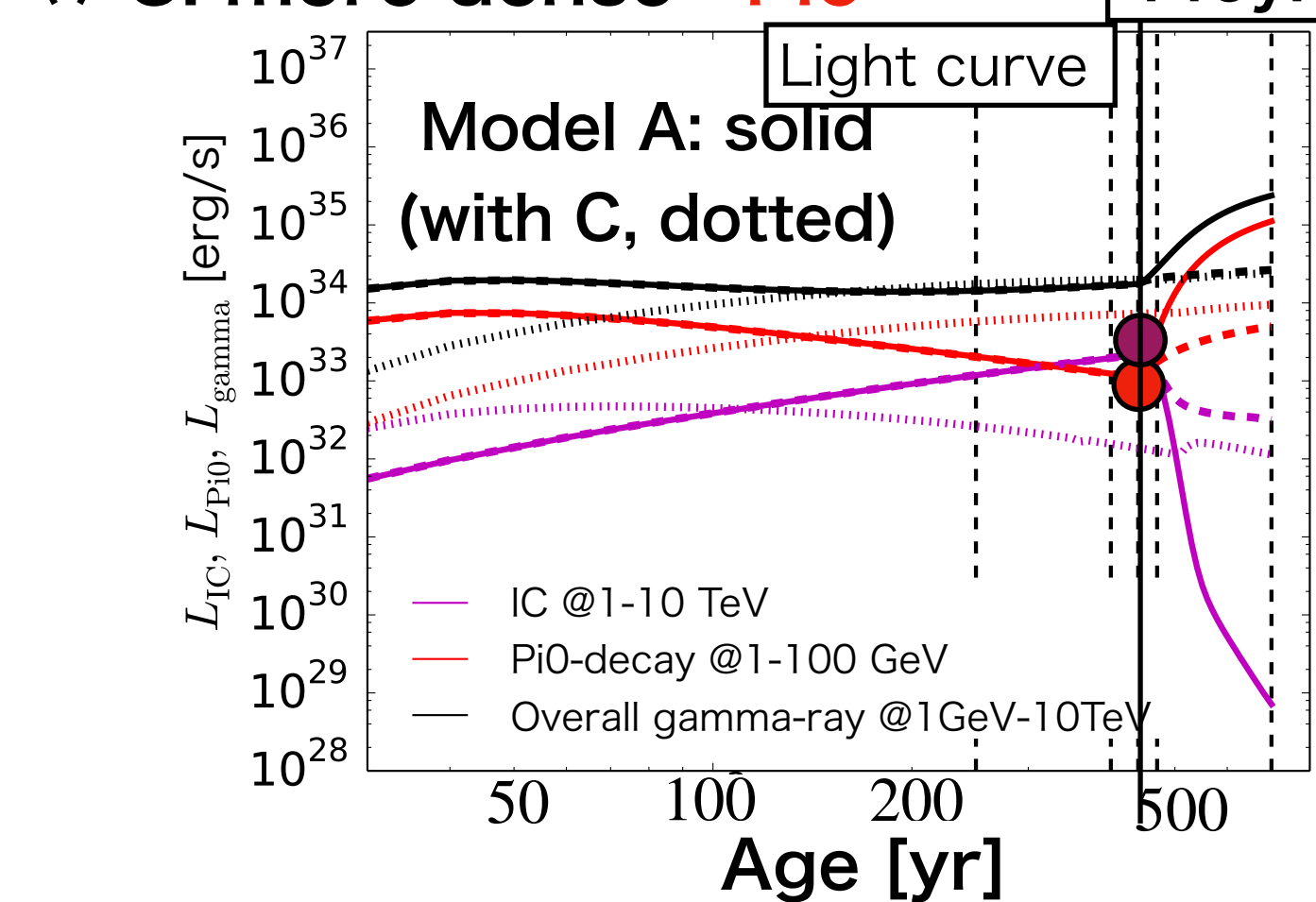
- The effect on CR acc.

CR acc increase soon after cloud interaction



- A/(B): low-density → **IC**

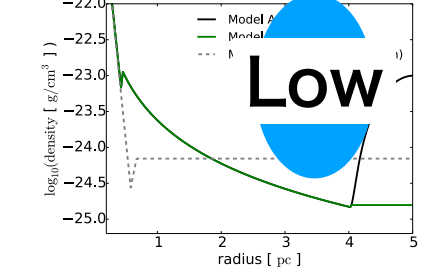
- C: more dense → **Pi0**



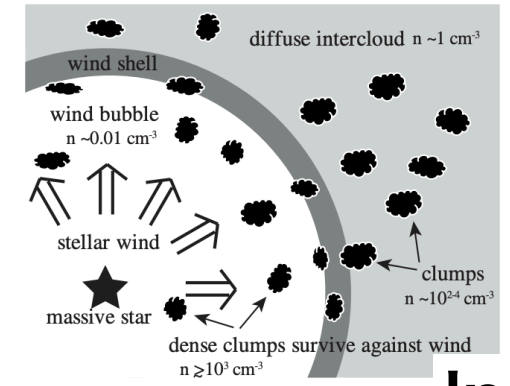
## 6. Future work

- This time wall structure for dense clouds (Upper fig) in 1-D sim
- Realistic picture: **molecular clump** ubiquitously **exist** (Lower fig)?  
← **Pi0** may dominate even with lower density in "avg. density"

- Density averaged in 1-D



- Clumps can enhance acc. & **Pi0**



Inoue+12

## 7. Summary

- Recent observation: rapid deceleration of FS of Tycho  
→ 1D hydro simulation to fit this
- We cannot find uniform cavity model which matches observation  
→ **wind-wall model more likely explain**
- Estimated wind supports **SD scenario**:  
 $D \sim 3.5 \text{ kpc}$ , and  $\dot{M} \sim 10^{-5} M_\odot \text{ yr}^{-1}$  ( $V_w = 25 \text{ km/s}$ )
- The broadband spectrum **matches obs.** (except  $\gamma$ -ray),  
from  $\gamma$ -ray → **existence of clumps?**