超新星残骸中での
ダストの物理進化過程

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1-1. Introduction

○ Dust in SNRs

・ CCSNe are main sources of interstellar dust?

— formation of dust in the ejecta of SNe

— destruction of dust by the reverse shock

➔ What kind and how much amount of dust are supplied by CCSNe?

・ physical processes of dust in the shocked gas

— erosion by sputtering and collisional heating

・ IR thermal emission from shock-heated dust

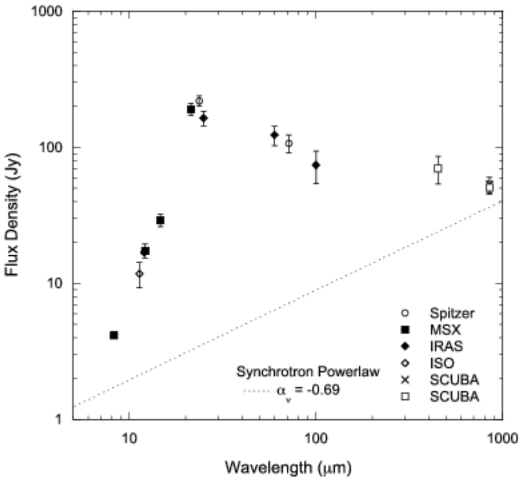
➔ structure of circumstellar medium and mass-loss history of progenitor star

➡ young remnants of CCSNe!

1-2. Cassiopeia A SNR

○ Cas A SNR

- age: ~340 yr (Thorstensen et al. 2001)
- distance: d=3.4 kpc
  (Reed et al. 1995)
- shock radius
  forward shock : ~150” (~2.5 pc)
  reverse shock : ~100” (~1.7 pc)



- oxygen-rich SNR
  dense O-rich fast-moving knots (O, Ar, S, Si, Fe …)
  thermal emission from ejecta-dust
  ➔ M_{dust} = 0.02-0.054 M_{sun} (Rho et al. 2008)
- **SN type : Type IIb** (M_{star}=15-20 M_{sun})
  (Krause et al. 2008)

1-3. Aim of our study

・ Formation of dust in the ejecta of Type IIb SN

➔ composition, size, and mass of newly formed dust

・ Evolution of dust in the hot plasma in the SNR

➔ dynamics and destruction of dust

➔ What fraction of newly formed dust can survive and is injected into the ISM?

・ Thermal emission from shock-heated dust

➔ comparison with IR observations of Cas A

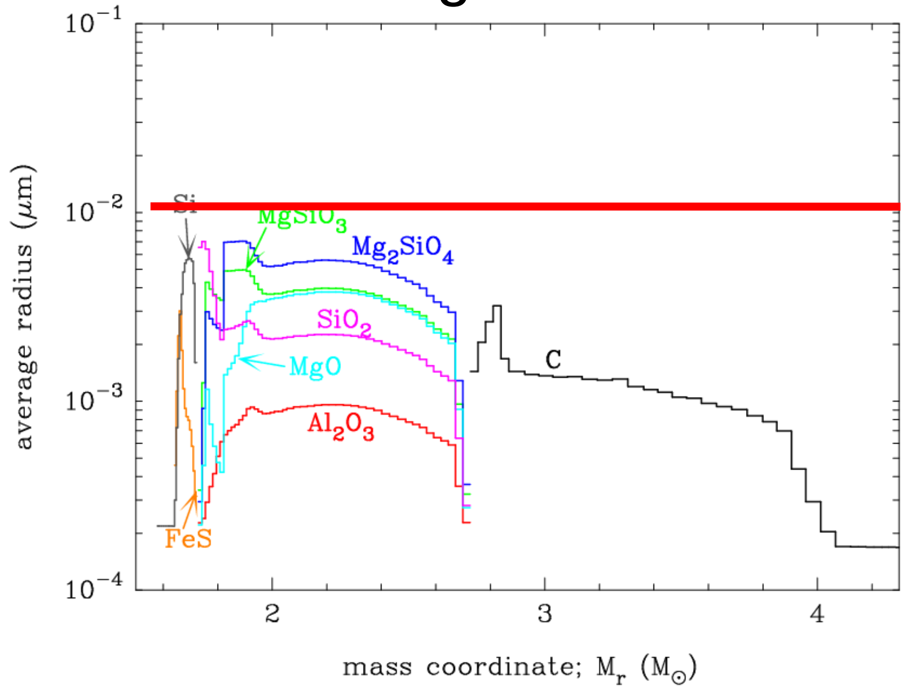
➔ dependence of thermal emission from dust on the ambient density

1-4. Composition and mass of dust formed

Mass of dust formed

dust species	$M_{d,j}$ ($M_\odot$)	$M_{d,j}/M_{d,total}$
C	7.08×10^{-2}	0.423
Al_2O_3	6.19×10^{-5}	3.7×10^{-4}
Mg_2SiO_4	1.74×10^{-2}	0.104
$MgSiO_3$	5.46×10^{-2}	0.326
SiO_2	1.57×10^{-2}	0.094
MgO	2.36×10^{-3}	0.014
FeS	1.47×10^{-3}	0.009
Si	5.07×10^{-3}	0.030
total	0.167	1

average radius

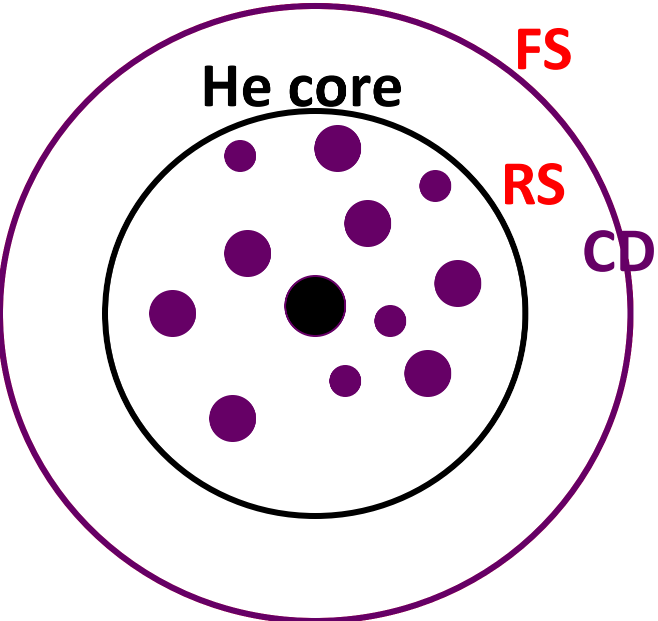


- various kinds of dust can condense in each layer
- Total dust mass : 0.167 Msun

Because of the low gas density in SN IIb, the radius of newly fomred dust grains is small (< 0.01μm)

Dust Evolution in SNRs

$T = (1\text{-}2) \times 10^4$ K
$n_{H,0} = 0.1\text{-}1\ cm^{-3}$

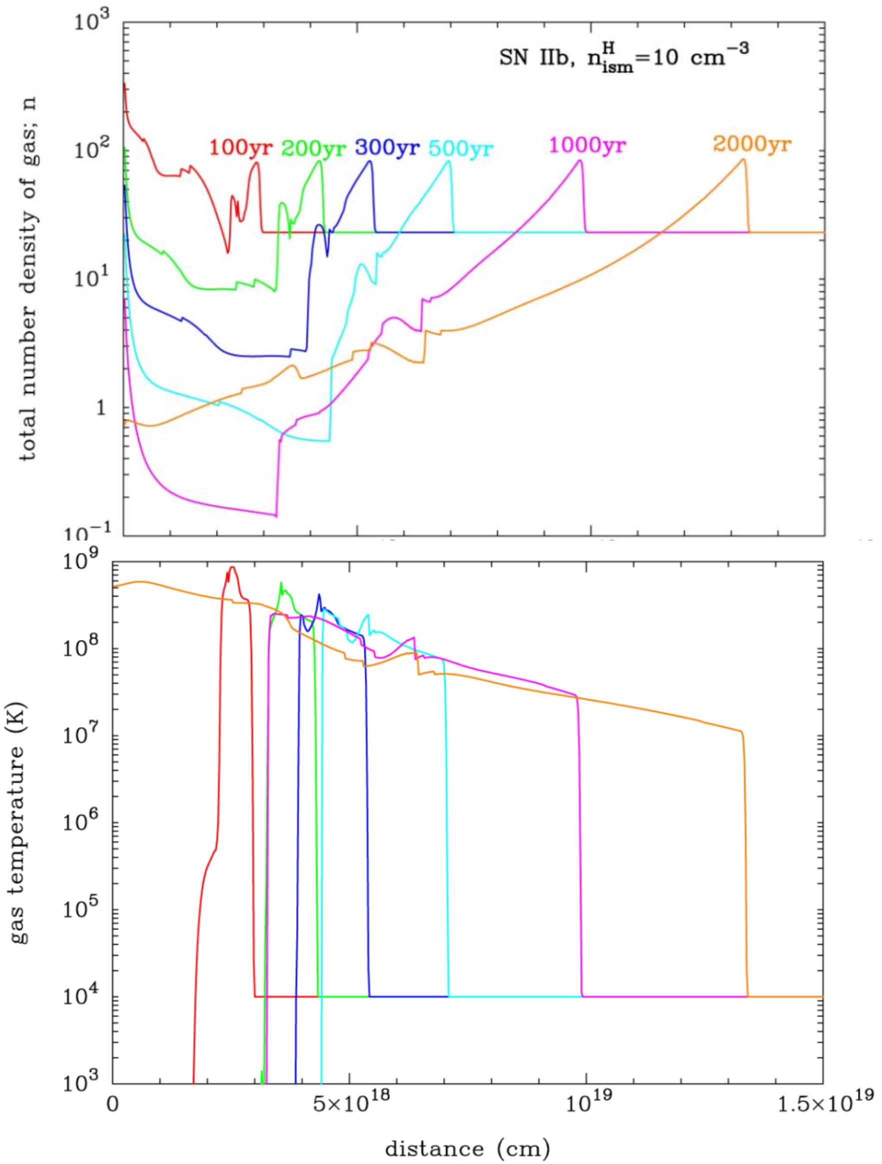


2-1. Calculation of dust evolution in SNR

○ Model of calculations

(Nozawa et al. 2006, 2007)

- ejecta model
  - hydrodynamic model for dust formation calculation
- ISM
  - homogeneous, $T_{gas}=10^4$ K
  - **n_H = 1.0 and 10.0 cm^{-3}**
  - solar composition of gas
- treating dust as a test particle
  - erosion by sputtering
  - deceleration by gas drag
  - collsiional heating



2-2. Dynamics of dust

- dust model : results of dust formation calculations
- treating (spherical) dust grains as test particles
- neglecting the effects of charge of dust

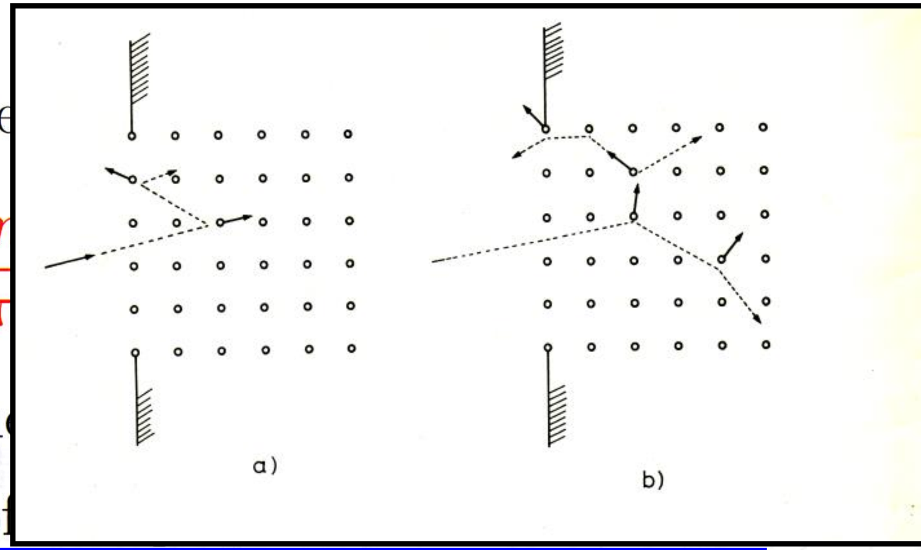
- deceleration of dust due to drag force (Baines et al. 1965)

$$\frac{dw_{\mathrm{d}}}{dt} = \frac{F_{\mathrm{drag}}}{m_{\mathrm{d}}} = -\frac{3n_{\mathrm{H}}kT}{2a\rho_{\mathrm{d}}}\sum_i A_i G_i(s_i)$$ (w_{d} : relative velocity)

$$\begin{aligned}
F_{\mathrm{drag}} &= m_{\mathrm{d}}\frac{dw_{\mathrm{d}}}{dt} = -\pi a^2 \sum n_i \left\langle v_i m_i v_i \cos\theta \right\rangle \\
\frac{dw_{\mathrm{d}}}{dt} &= -\frac{\pi a^2}{\frac{4}{3}\pi a^3 \rho_d} n_{\mathrm{H}} \sum A_i \left\langle v_i m_i v_i \cos\theta \right\rangle \\
&= -\frac{3n_{\mathrm{H}}}{4a\rho_d} kT \sum A_i G_i
\end{aligned}$$

2-3. Erosion rate of dust by sputtering

• dust destruction by sputte… 96)



$Y_i(E) = 2Y_i^0(E)$; th…

$m_{\rm sp}$; average mass o…

· rate equ… gas taken account… 78)

$$\frac{dV_{\rm d}}{dt} = 4\pi a^2 \frac{da}{dt} = -\pi a^2 \frac{4\pi a_0^3}{3} \sum n_i \langle v_i Y_i \rangle$$

$$\frac{da}{dt} = -\frac{1}{4} \Omega n_{\rm H} \sum A_i \langle v_i Y_i \rangle$$

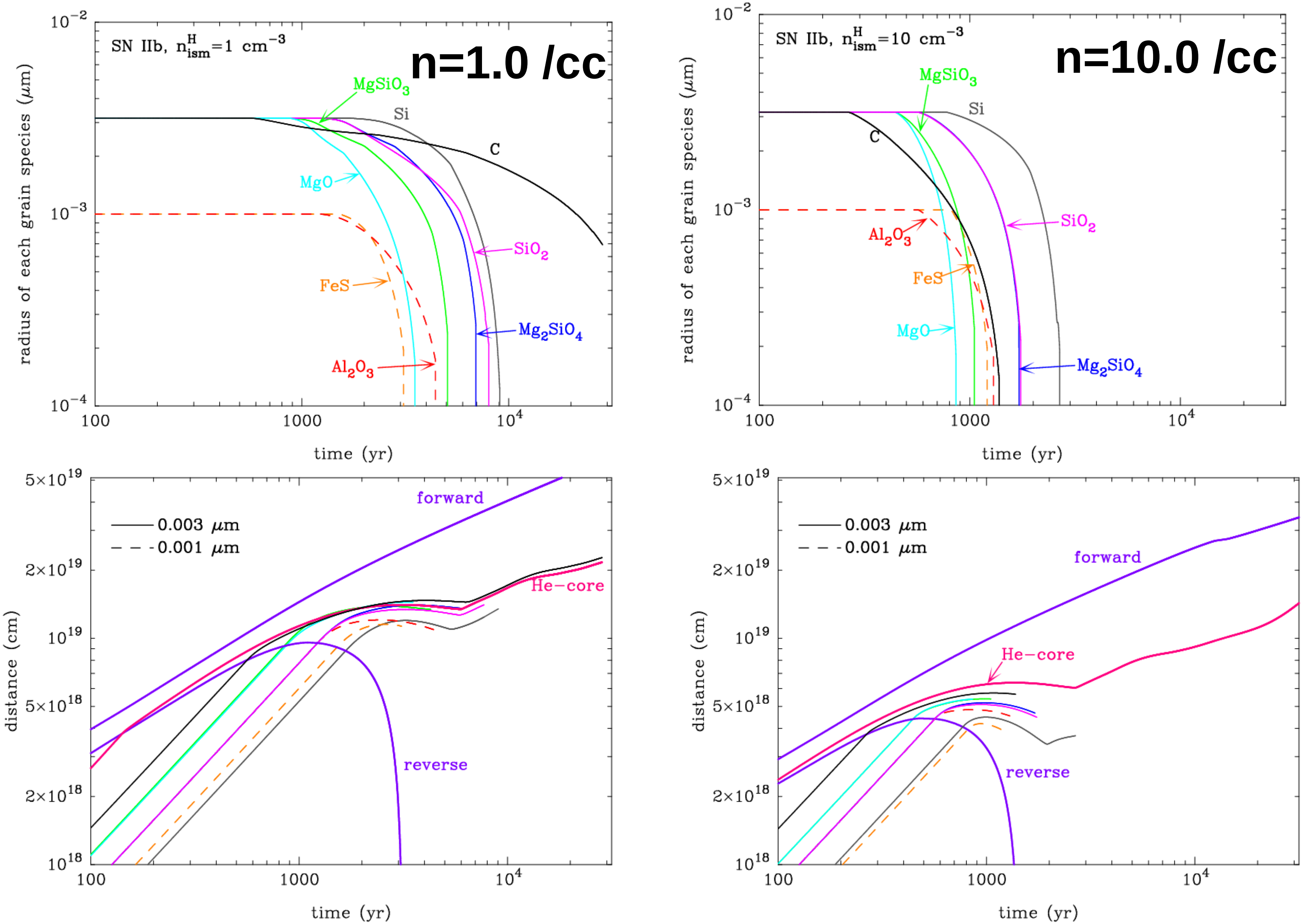
$\mathcal{R}(X_i($ … $\sqrt{\epsilon})X_i(\epsilon)d\epsilon$

・da / dt ∼ 10^{-6} n_H μm yr^{-1} cm^3 at T > 10^6 K

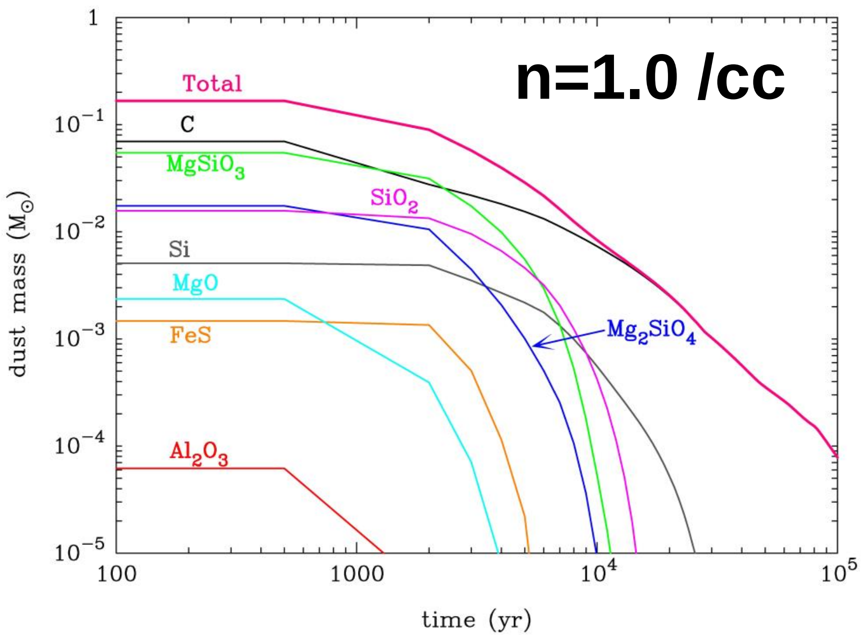
whe…

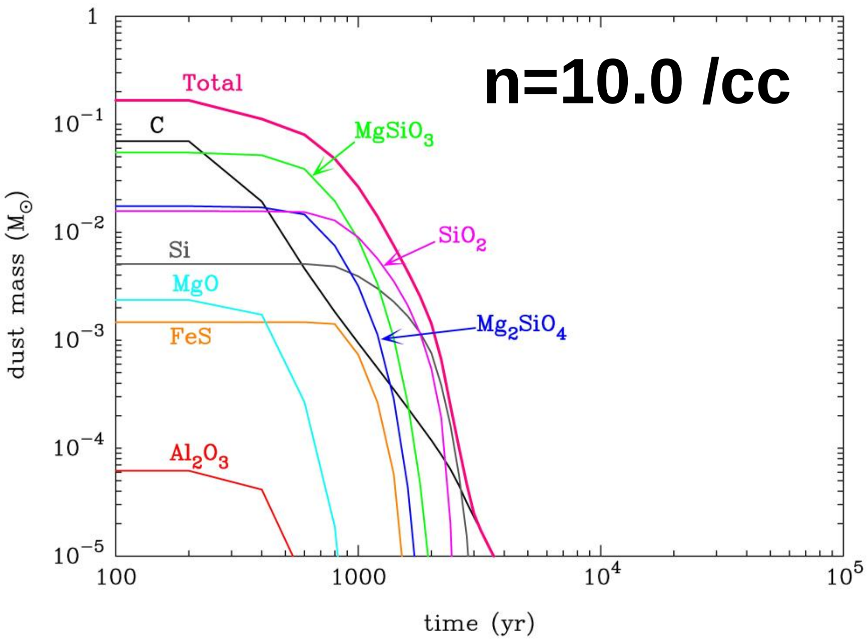
$$\times \int \epsilon^{\frac{1}{2}} e^{-\epsilon_i} \sinh(2 s_i \epsilon_i^{\frac{1}{2}}) Y_i^0(\epsilon_i) d\epsilon_i$$

2-4. Evolution of dust in Cas A SNR



2-5. Time evolution of dust mass





M_{dust} ~ **10^{-4} M_{sun}** at 10^5 yr

M_{dust} = **0 M_{sun}** at 10^5 yr

Core-collapse SNe with thin H-envelope cannot be the main sources of dust

3-4. Thermal emission from dust

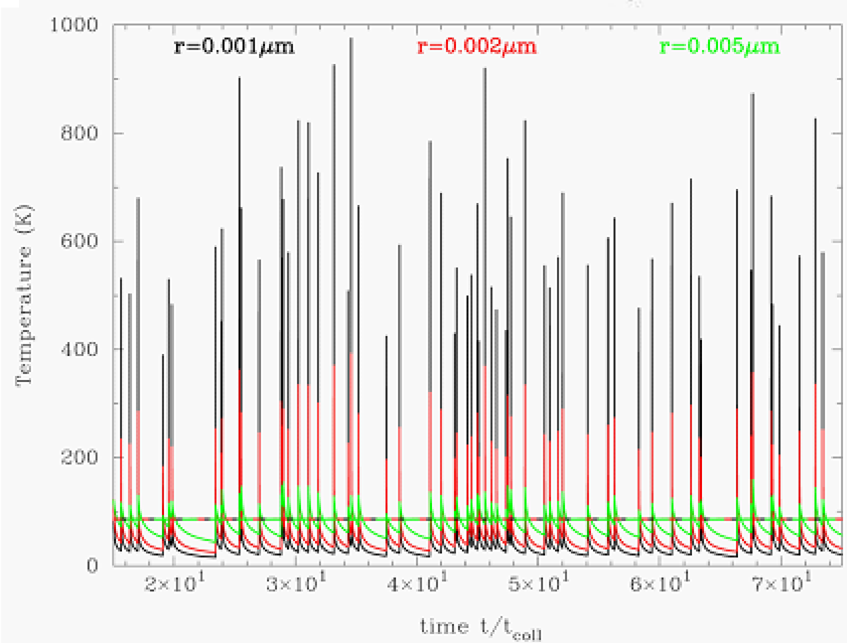
- heating of dust grains (e.g., Dwek & Arendt 1992)

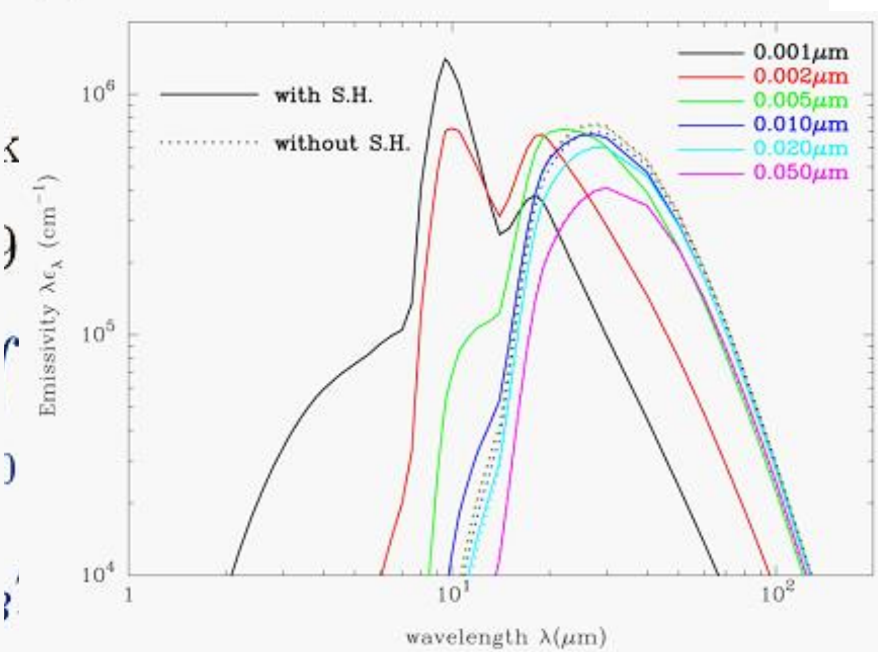
$$H(a,T) = \sum_i \mathcal{R}(\eta_i(a,E)E) \quad (\eta_i : \text{deposition fraction})$$

$$= n_{\rm H}\pi a^2 kT \sum_i A_i \left(\frac{8kT}{\pi m_i}\right)^{\frac{1}{2}} \frac{e^{-s_i^2}}{2s_i} \int \epsilon^{\frac{3}{2}} e^{-\epsilon} \sinh(2s_i\sqrt{\epsilon})\eta_i(a,\epsilon)d\epsilon$$

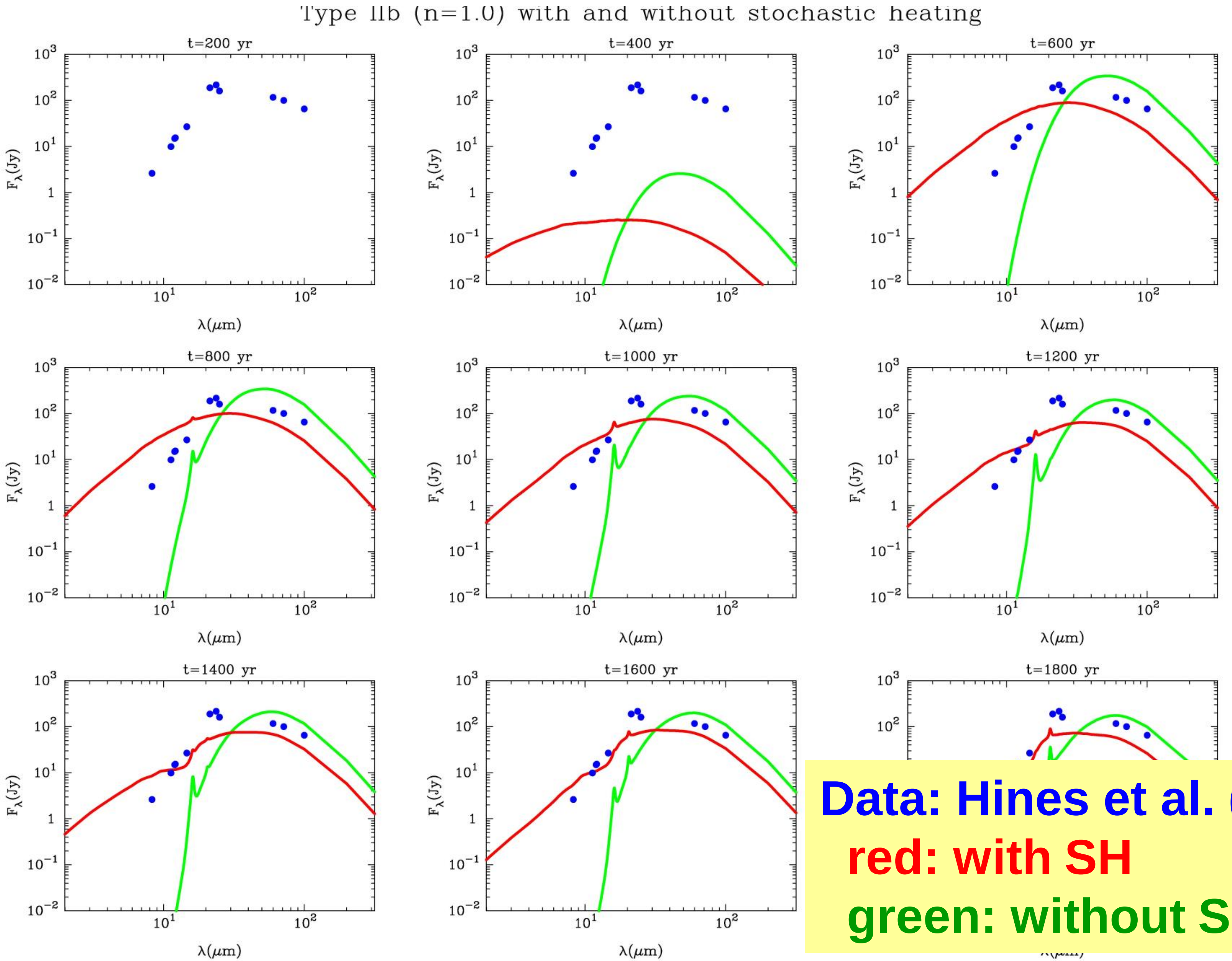
$$\eta_i(a,E) \sim 1 \qquad \text{for } R < R^*$$

$$\sim E^*/E \quad \text{for } R \geq R^*$$





3-5. Comparison with Cas A observation (1)

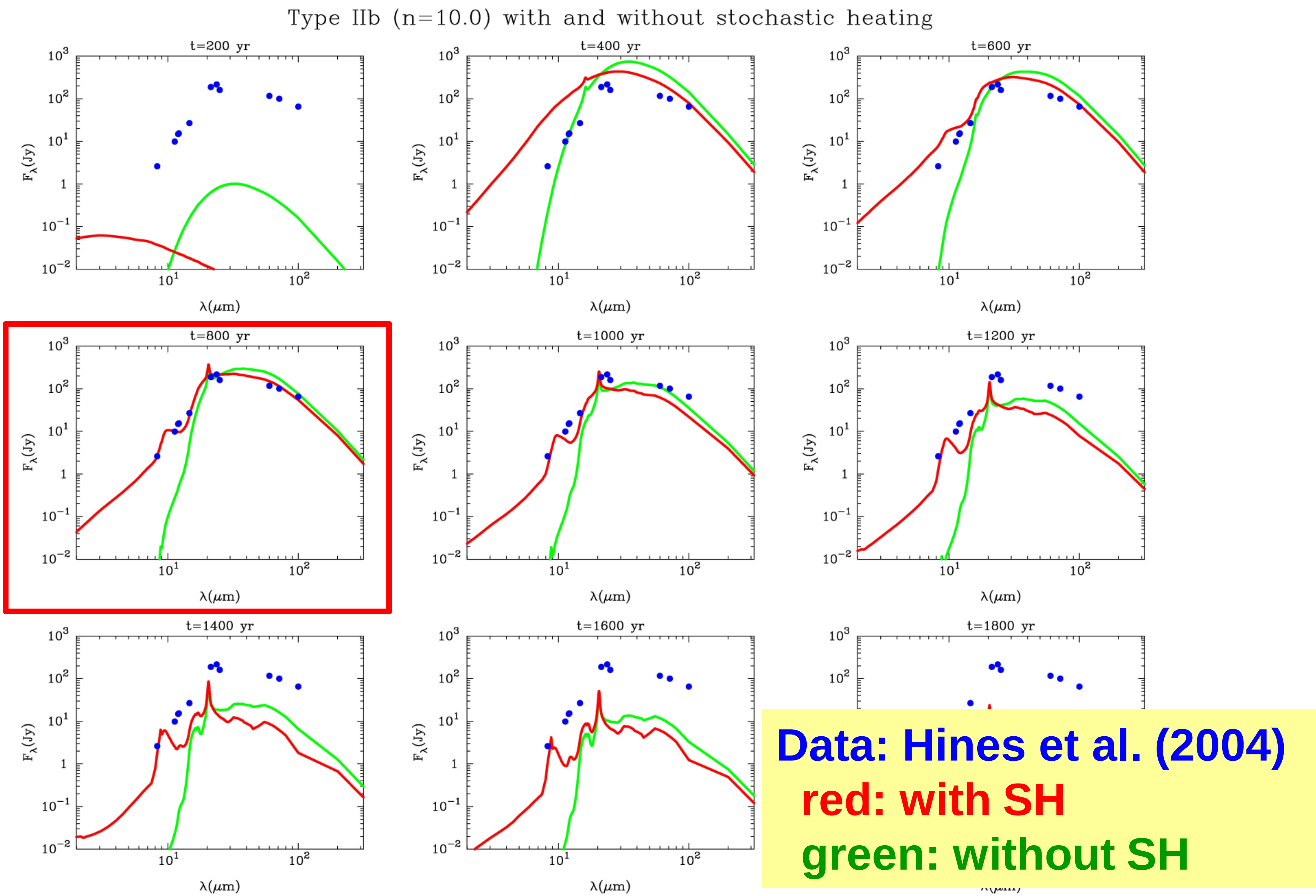


Data: Hines et al. (2004)

red: with SH

green: without SH

3-6. Comparison with Cas A observation (2)

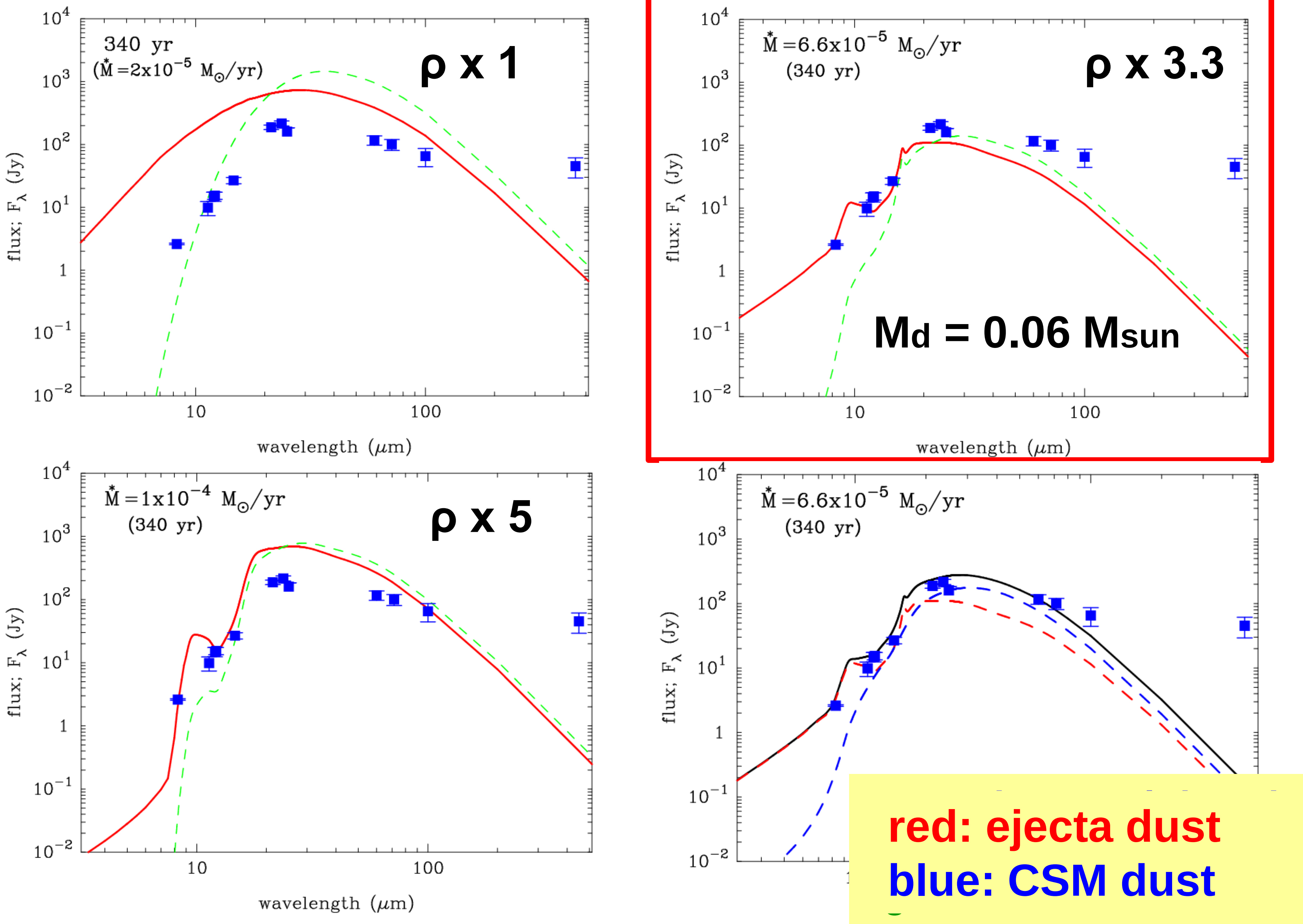


Data: Hines et al. (2004)

red: with SH

green: without SH

4-2. Dependence of IR SED on ambient density



Summary

1) **Small dust grains formed in Type IIb SN cannot survive destruction by the reverse shock**

2) **IR SED well reflects physical processes of destruction and stochastic heating of dust**

   ➔ **properties (size and composition) of dust**

   ➔ **density structure of circumstellar medium**

3) **Model of dust destruction and heating in Type IIb SNR to reproduce the observed SED of Cas A is**

   $M_{d,eje} = 0.06\ M_{sun}$, $M_{d,ism} = 0.03\text{-}0.07\ M_{sun}$

   $dM/dt = 6.6 \times 10^{-5}$ Msun/yr

   ➔ **ejecta-dust in denser clump?**