

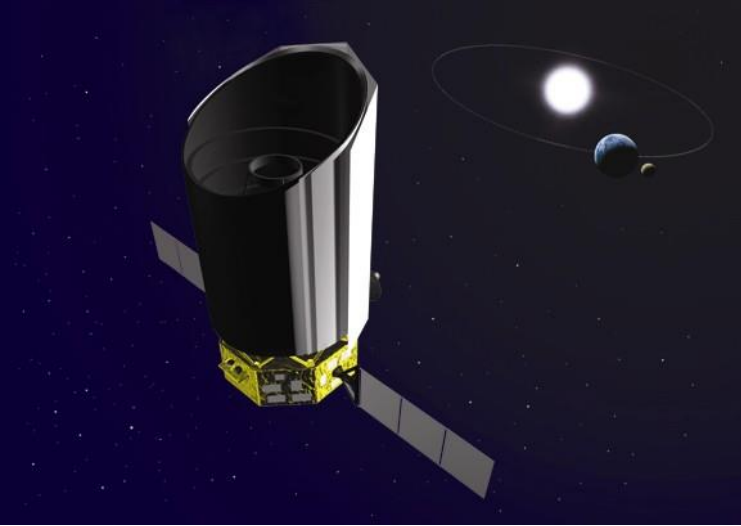
IIb型超新星爆発時のダスト形成と その放出過程

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Collaborators;

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SPICA

2017年打ち上げ予定

Observatory型

口径：3.5 m

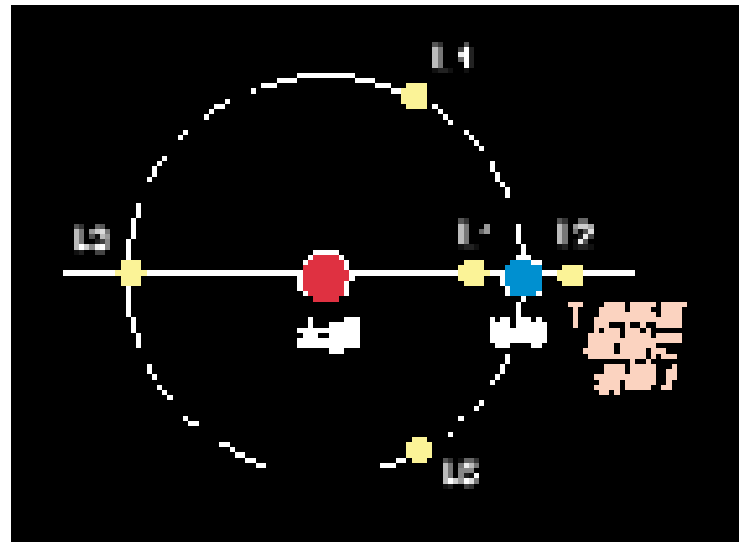
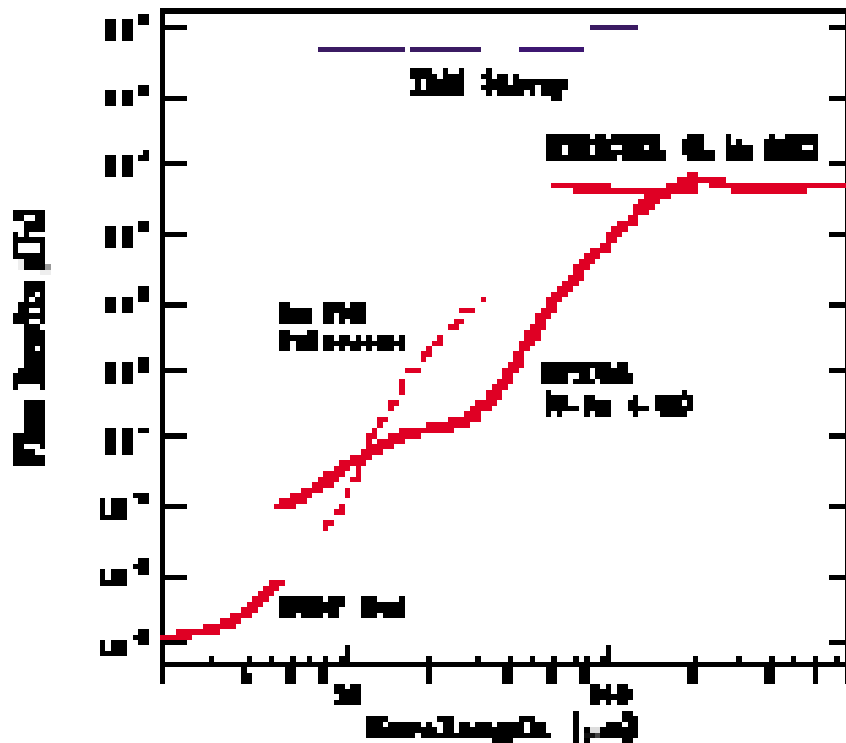
空間分解能：0.2''

視野：0.6'x0.6'

観測波長：5-200 μm

絶対温度：4.5 K

分光：5-38 μm , $R \sim 30000$



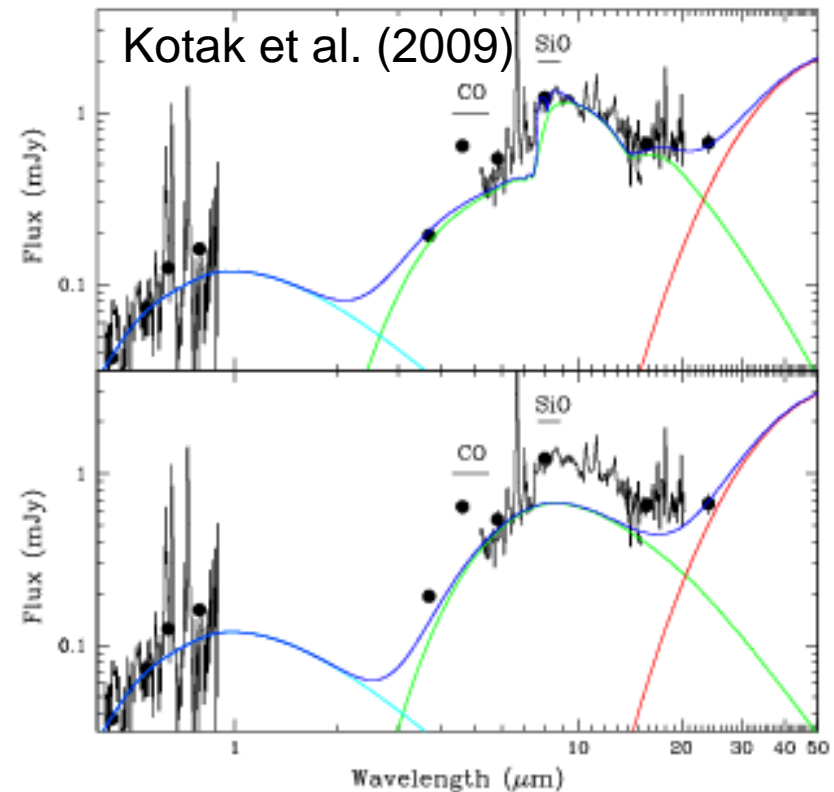
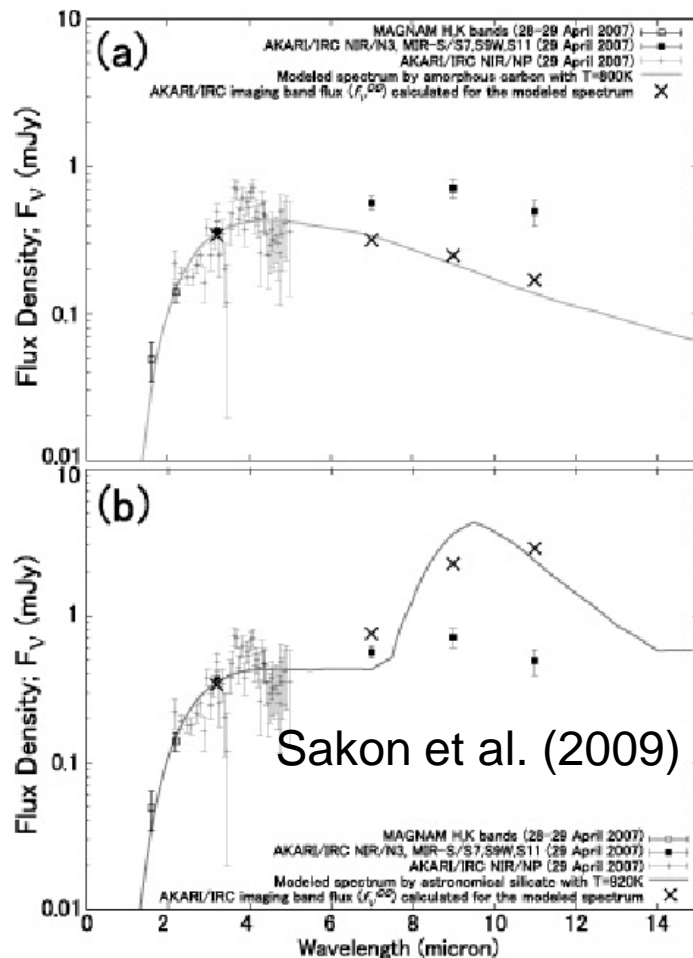
中間一周年外線観測で観測できる感度を表現

1. Introduction

1-1. Background

CCSNe are main sources of interstellar dust?

- formation of dust in the ejecta of SNe
- destruction of dust in the shocked gas of SNRs



Schmeider 2007, Nozawa et al. 2007)

1-2. Aim of our study

- Comparison of models with IR observations of SNRs
 - erosion by sputtering and collisional heating
 - properties of dust and density structure in CSM

What size and how much amount of dust are injected from CCSNe into the ISM?

- Dust formation and evolution in SN with no envelope
 - 30-40% of CCSNe explode as SNe Ib/c and SN IIb
(Prieto et al. 2009; Smartt et al. 2008; Boissier & Prantzos 2009)

How do formation and destruction processes of dust depend on the type of CCSNe?

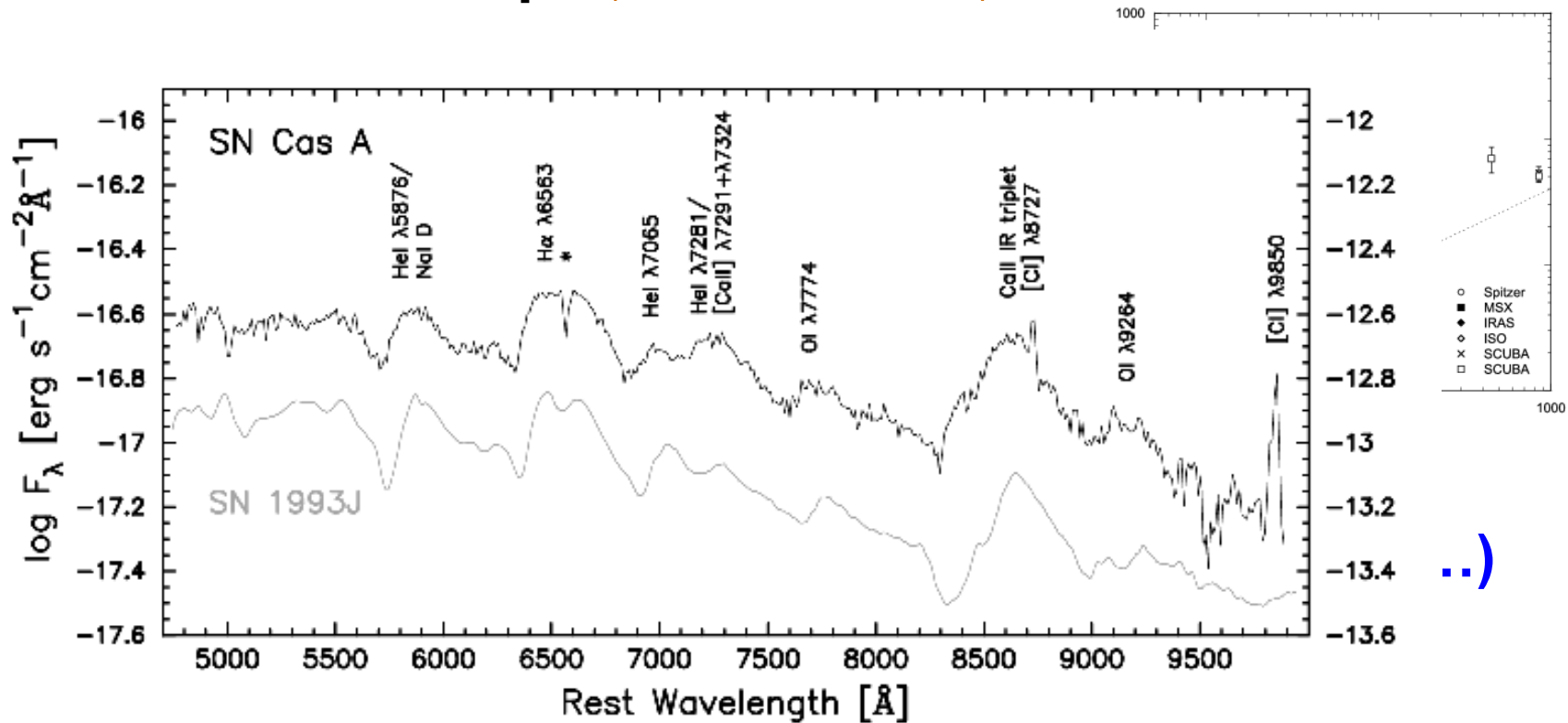
1-3. Outline

- Formation of dust in the ejecta of **Type IIb SN**
 - composition, size, and mass of newly formed dust
- Destruction of dust in the hot gas of the SNR
 - What fraction of dust grains in the SN ejecta can survive and is injected into the ISM?
- Thermal emission from shock-heated dust
 - comparison with IR observations of **Cas A SNR**
 - constraint to gas density in the ambient medium

1-4. Cassiopeia A SNR

Cas A SNR

- age: ~330 yr (Thorstensen et al. 2001)
- distance: $d=3.4$ kpc (Reed et al. 1995)



- SN type : **Type IIb** (Krause et al. 2008)

2. Formation of dust in Type IIb SN

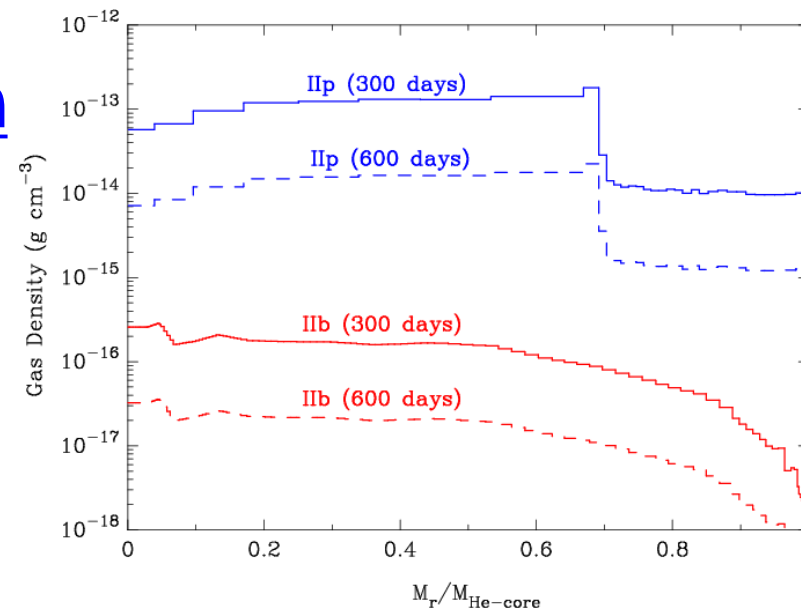
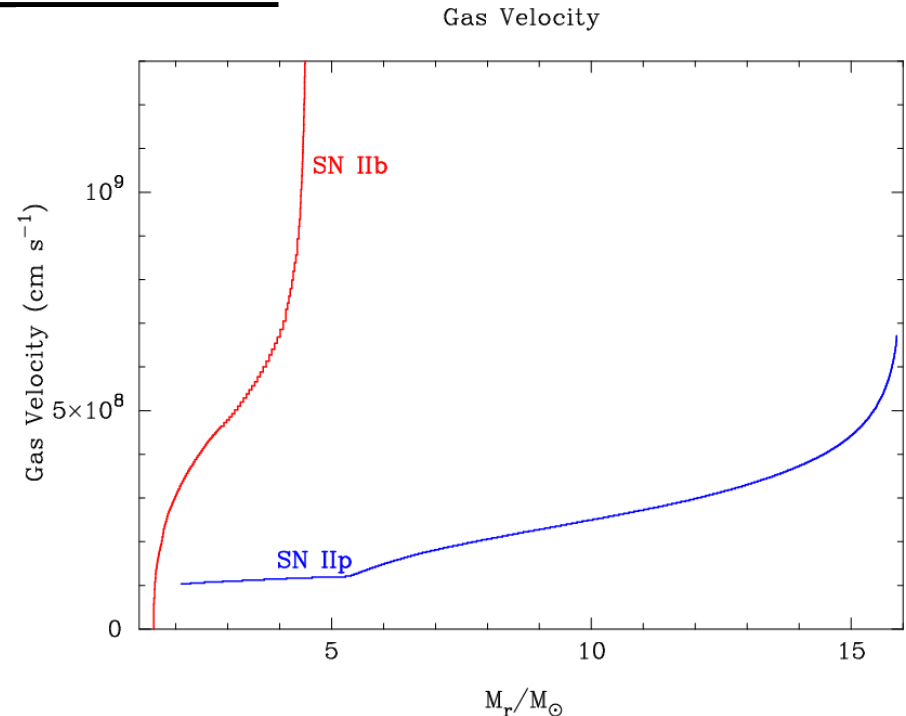
2-1. Dust formation calculation

Type IIb SN model (SN1993J-like model)

- $M_{\text{eje}} = 2.94 M_{\text{sun}}$
 $M_{\text{H-env}} = 0.08 M_{\text{sun}}$
 $M_{\text{star}} = 18 M_{\text{sun}}$
- $E_{51} = 1$
- $M(^{56}\text{Ni}) = 0.07 M_{\text{sun}}$

Dust formation calculation

- non-steady nucleation and grain growth theory
(Nozawa et al. 2003)
- onion-like composition



2-2. Composition and mass of dust formed

Mass of dust formed

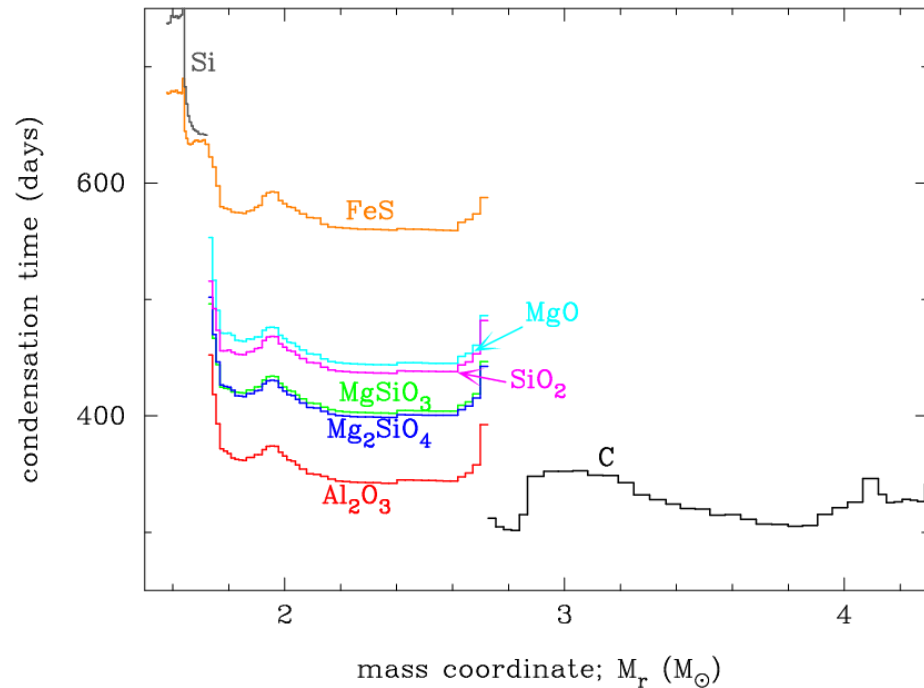
dust species	$M_{d,j} (M_{\odot})$	$M_{d,j}/M_{d,total}$
C	7.08×10^{-2}	0.423
Al_2O_3	6.19×10^{-5}	3.7×10^{-4}
Mg_2SiO_4	1.74×10^{-2}	0.104
MgSiO_3	5.46×10^{-2}	0.326
SiO_2	1.57×10^{-2}	0.094
MgO	2.36×10^{-3}	0.014
FeS	1.47×10^{-3}	0.009
Si	5.07×10^{-3}	0.030
total	0.167	1

Total mass of dust formed :

0.167 M_{sun} in SN IIb

0.1-1 M_{sun} in SN II-P

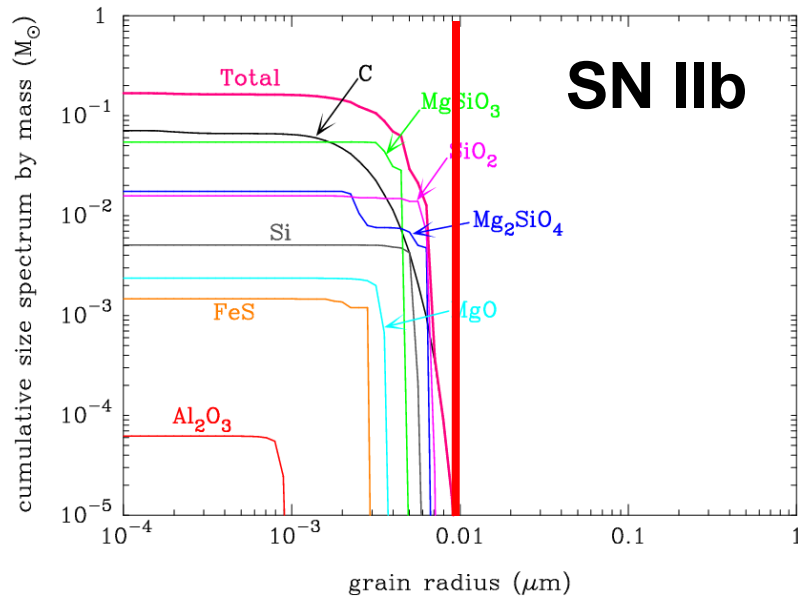
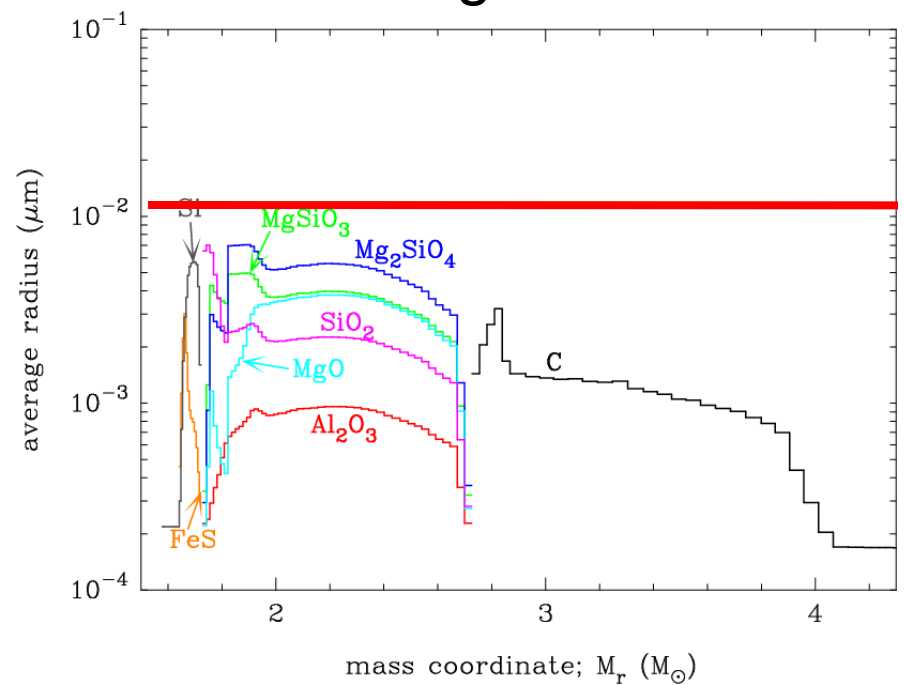
condensation time



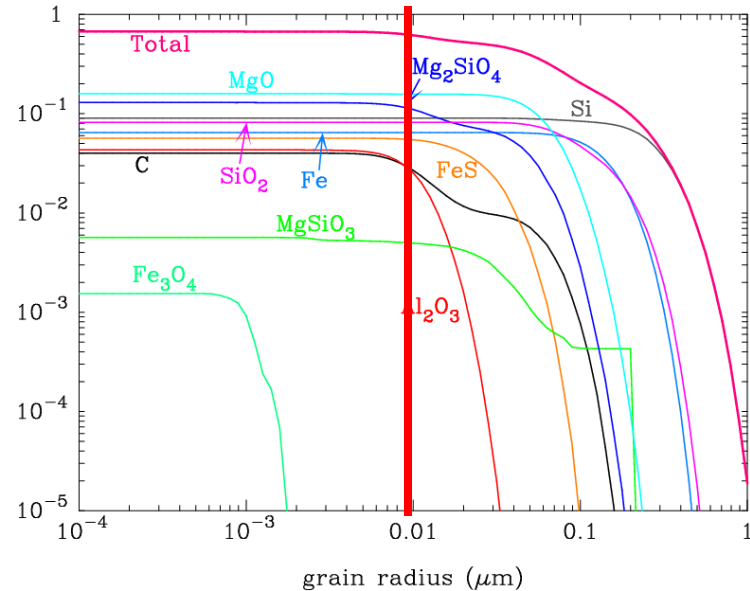
- different species of dust can condense in different layers
- condensation time: 300-700 days

2-3. Radius of dust formed in the ejecta

average radius



SN II-P (Mstar=20 Msun)



Grain radius

→ **> 0.01 μm for SN IIP**

→ **< 0.01 μm for SN IIb**

Dust grains formed in H-deficient SNe are small

3. Evolution of dust in Type IIb SNR

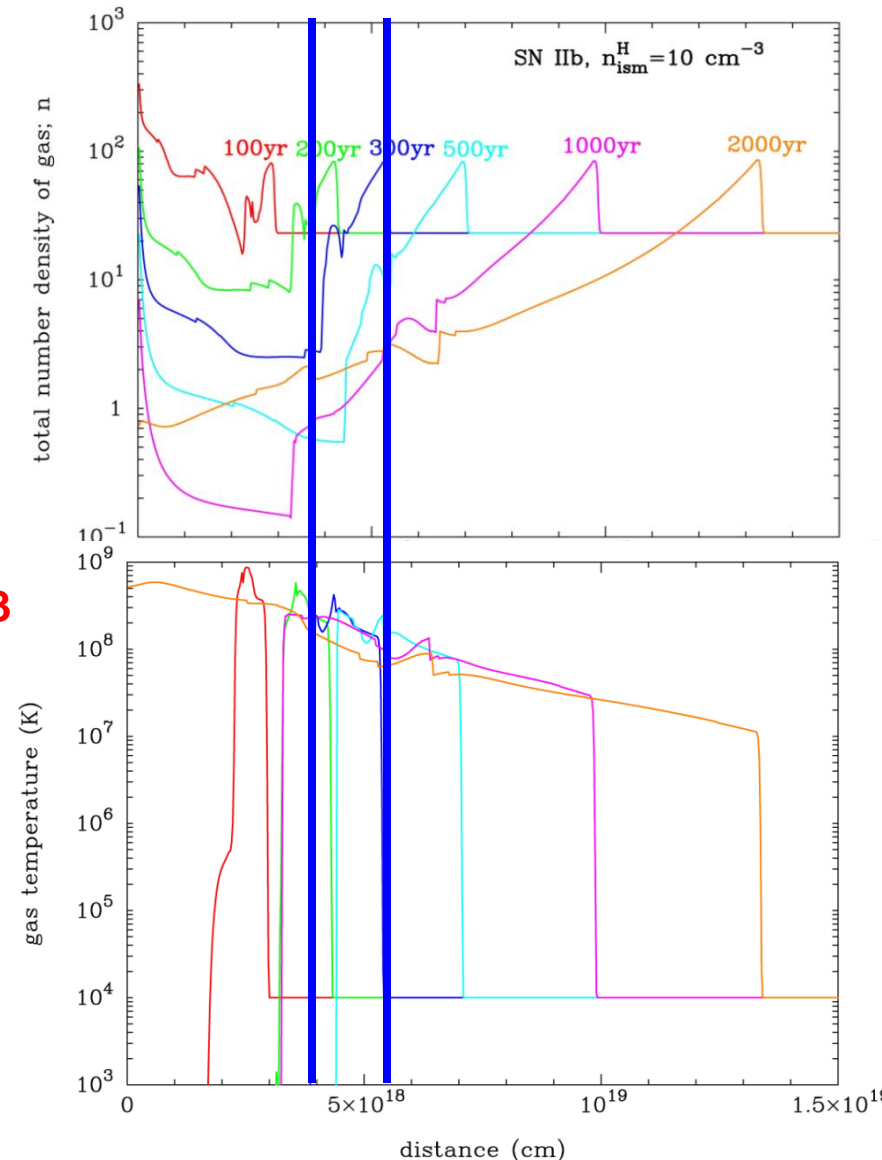
3-1. Calculation of dust evolution in SNRs

○ Model of calculations

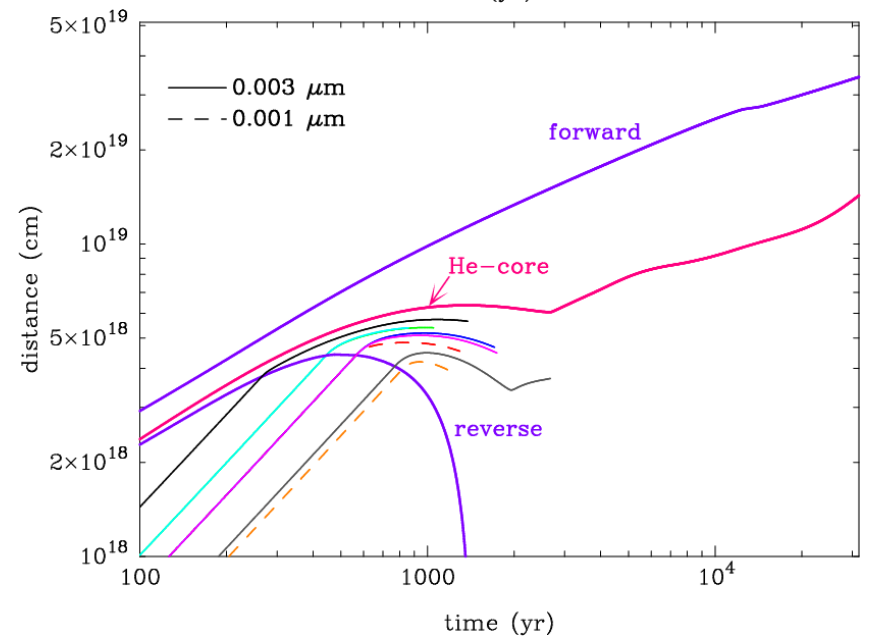
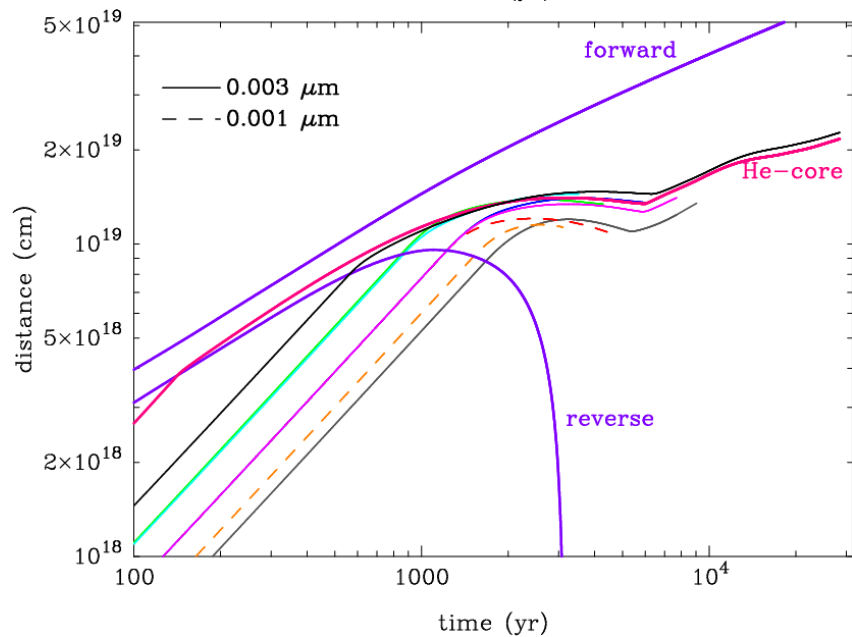
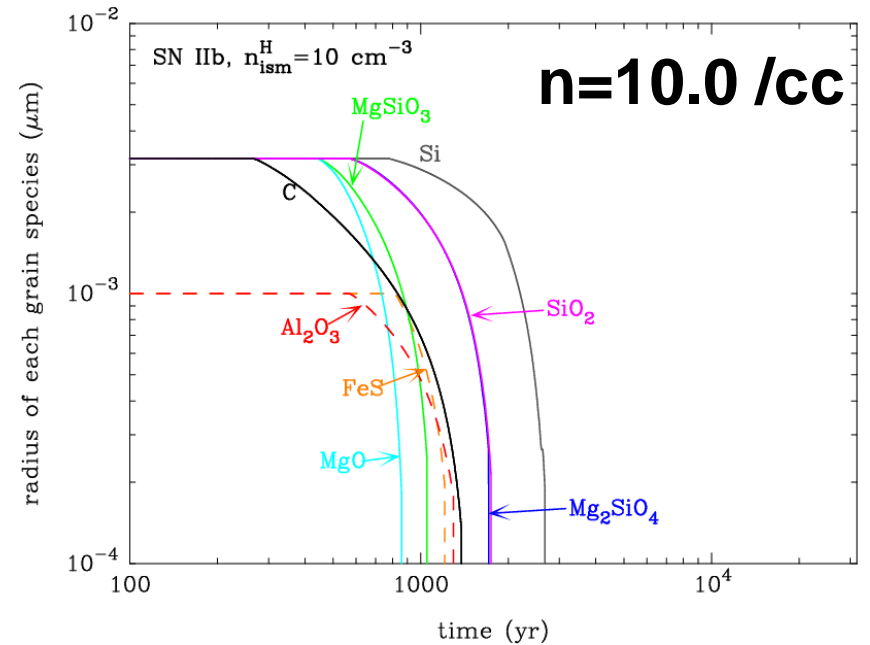
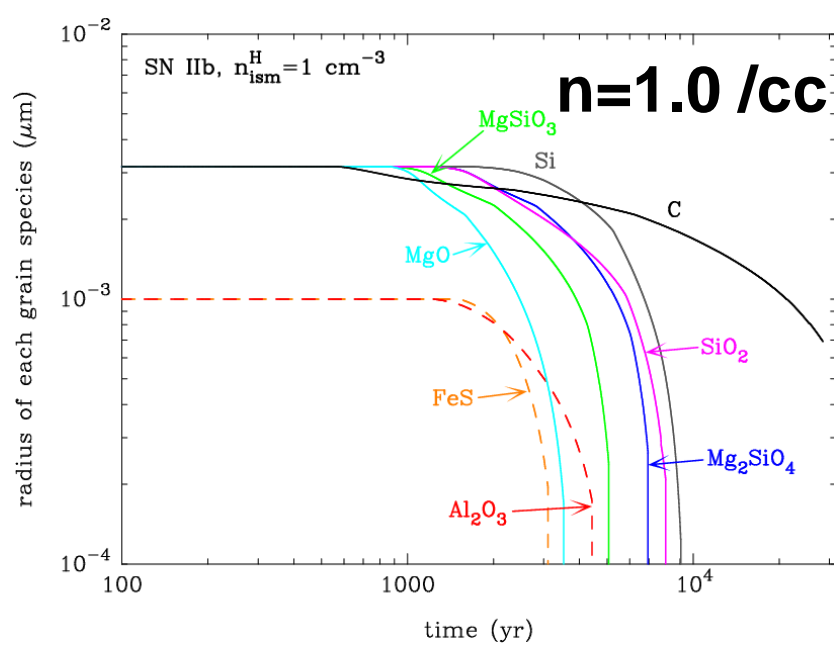
(Nozawa et al. 2006, 2007)

- ejecta model
 - hydrodynamic model for dust formation calculation
- CSM gas density
 - $n_H = 1.0$ and 10.0 cm^{-3}
 - $n_H(r) \propto M / (4\pi r^2 v_w) \text{ g/cm}^{-3}$
($M = 2 \times 10^{-5} M_{\text{sun/yr}}$)
- treating dust as a test particle
 - erosion by sputtering
 - deceleration by gas drag
 - collisional heating

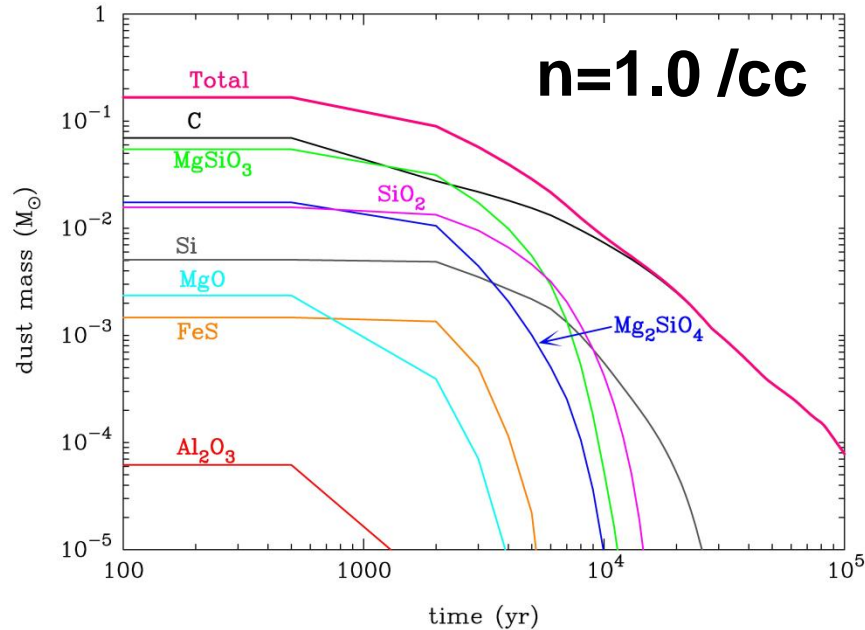
→ stochastic heating



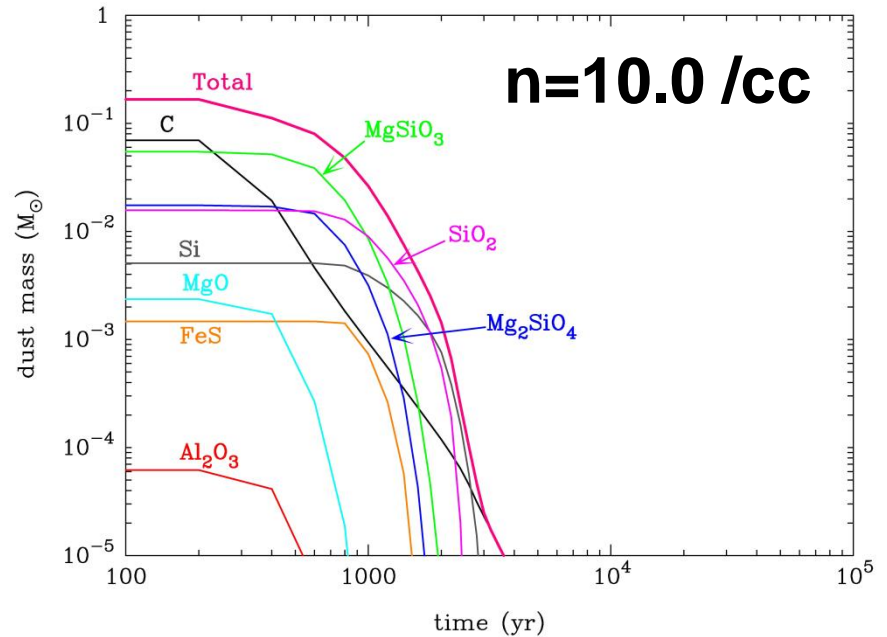
3-2. Evolution of dust in Type IIb SNR



3-3. Time evolution of dust mass



$M_{\text{dust}} \sim 10^{-4} M_{\text{sun}}$ at 10^5 yr



$M_{\text{dust}} = 0 M_{\text{sun}}$ at 10^5 yr

Newly formed dust grains in the ejecta are completely destroyed in the shocked gas within the SNR

Core-collapse SNe with low-mass outer envelope cannot be main sources of dust

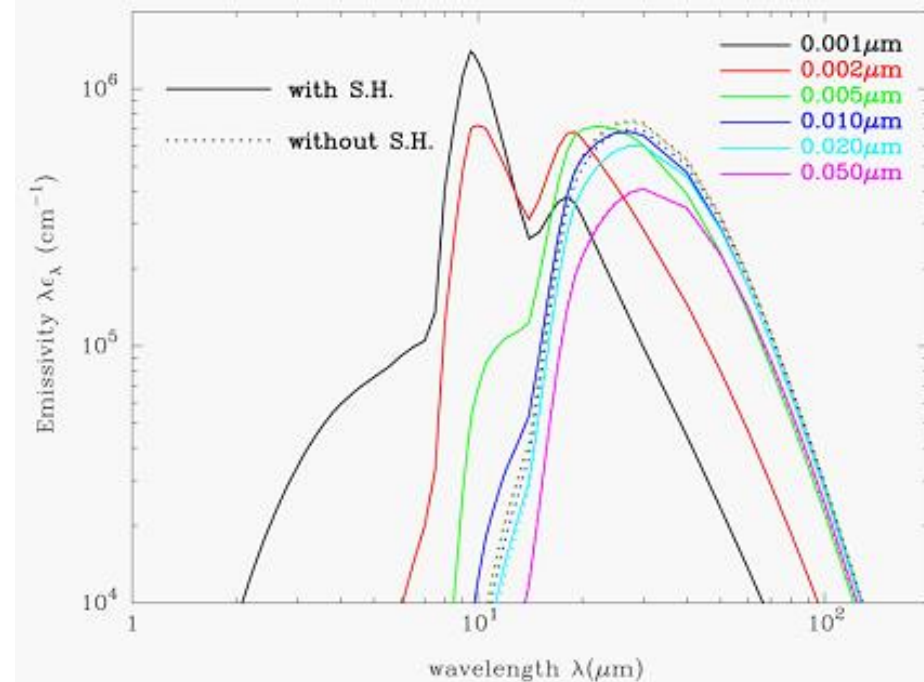
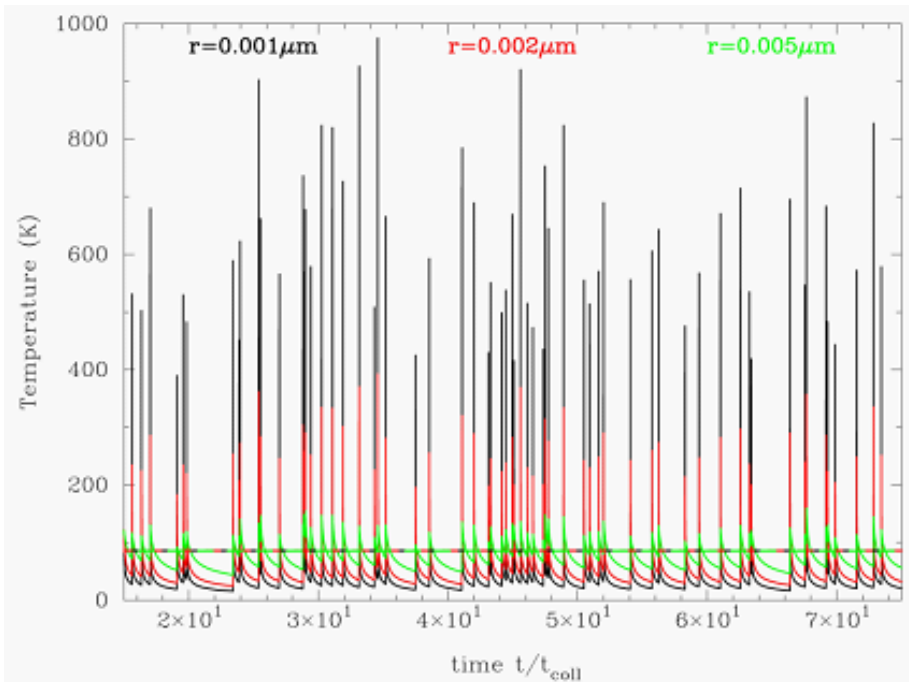
4. Thermal emission of dust in SNRs

4-1. Thermal emission from dust in the SNR

- thermal radiation from dust ← temperature of dust
- equilibrium temperature of dust in SNR is determined by collisional heating with gas and radiative cooling

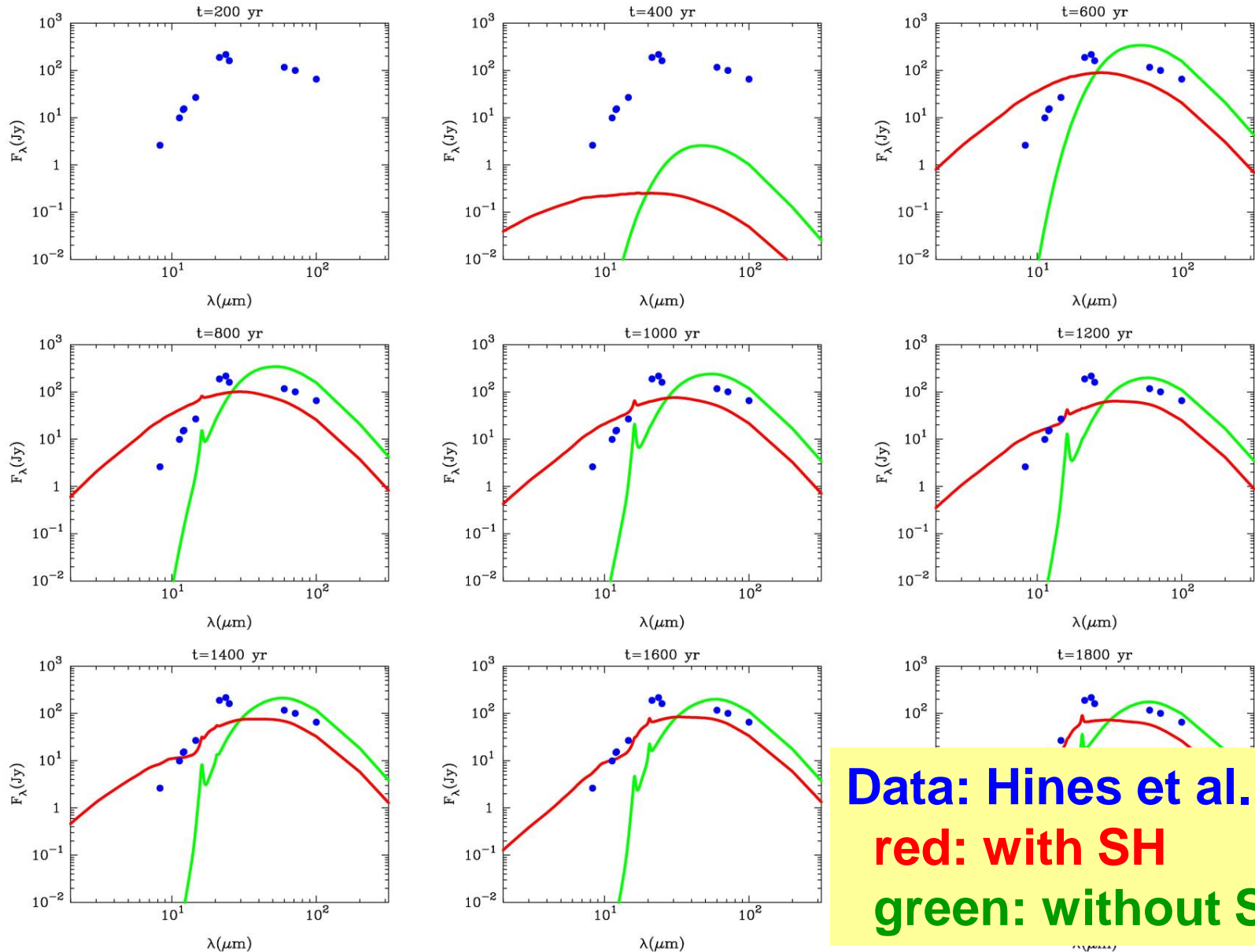
$$H(\mathbf{a}, n, T_g) = \Lambda(\mathbf{a}, Q_{\text{abs}}, T_d) \rightarrow \text{thermal emission}$$

- small-sized dust grains ($< 0.01 \mu\text{m}$) → stochastic heating



4-2. Time evolution of IR thermal emission (1)

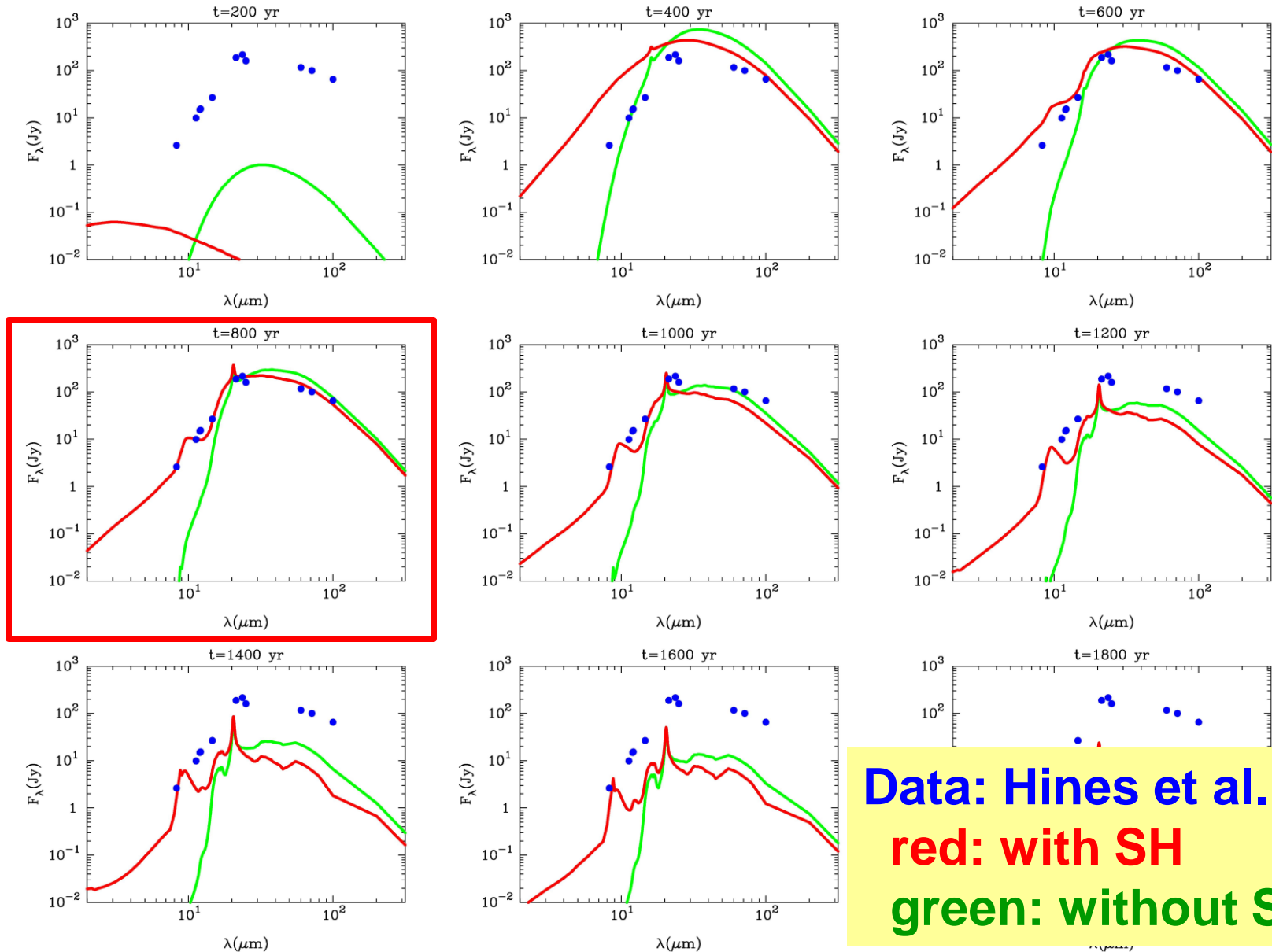
Type IIb ($n=1.0$) with and without stochastic heating



Data: Hines et al. (2004)
red: with SH
green: without SH

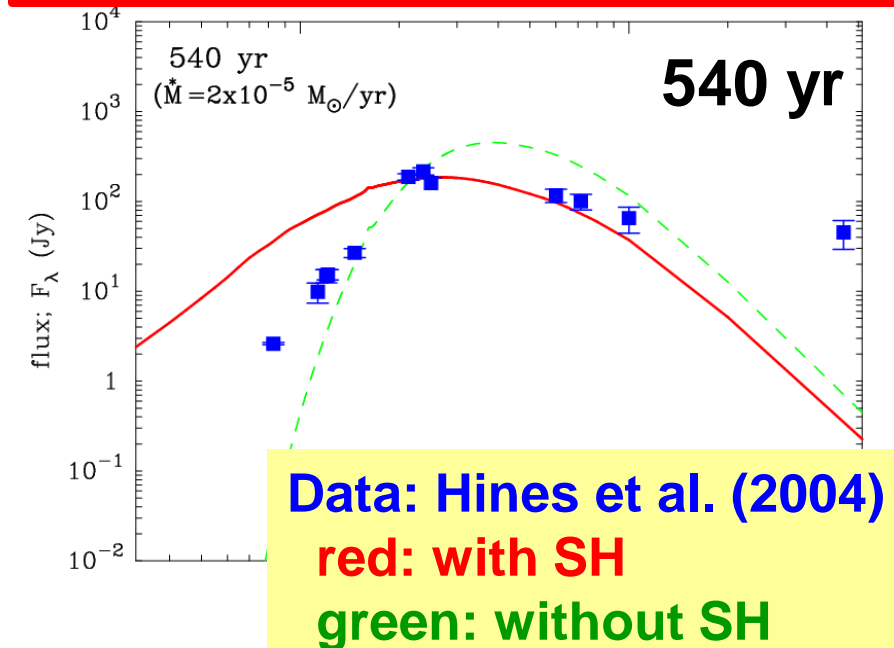
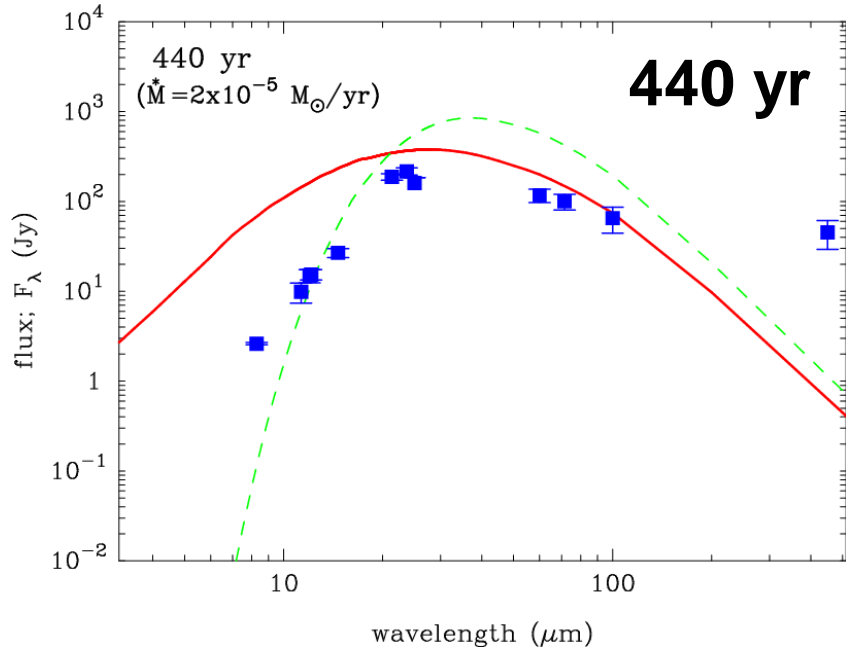
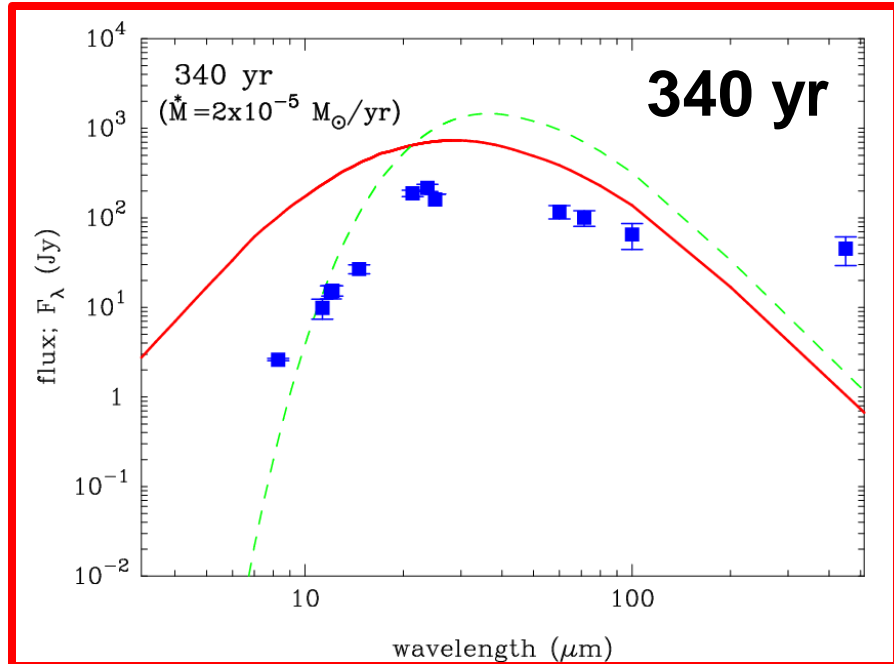
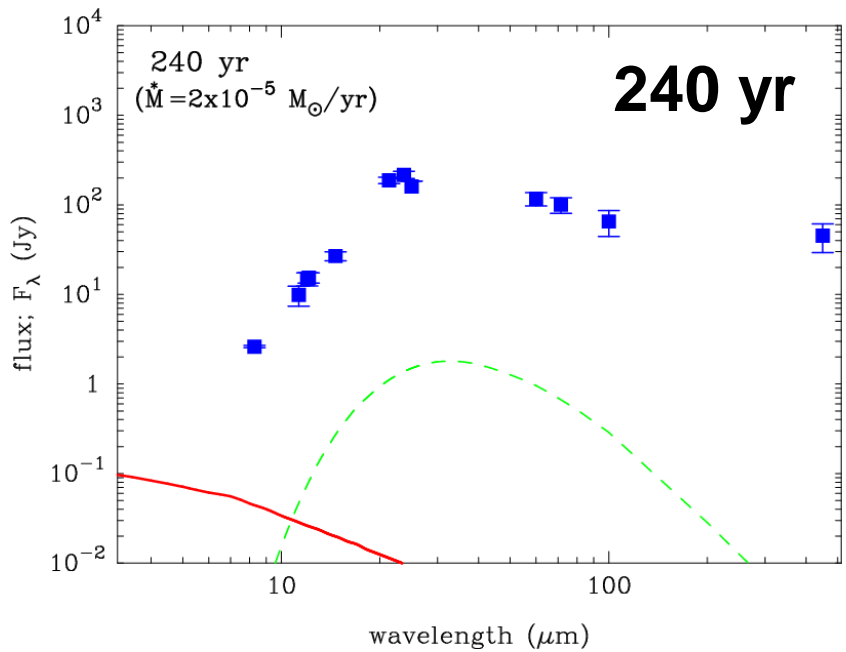
4-3. Time evolution of IR thermal emission (2)

Type IIb ($n=10.0$) with and without stochastic heating



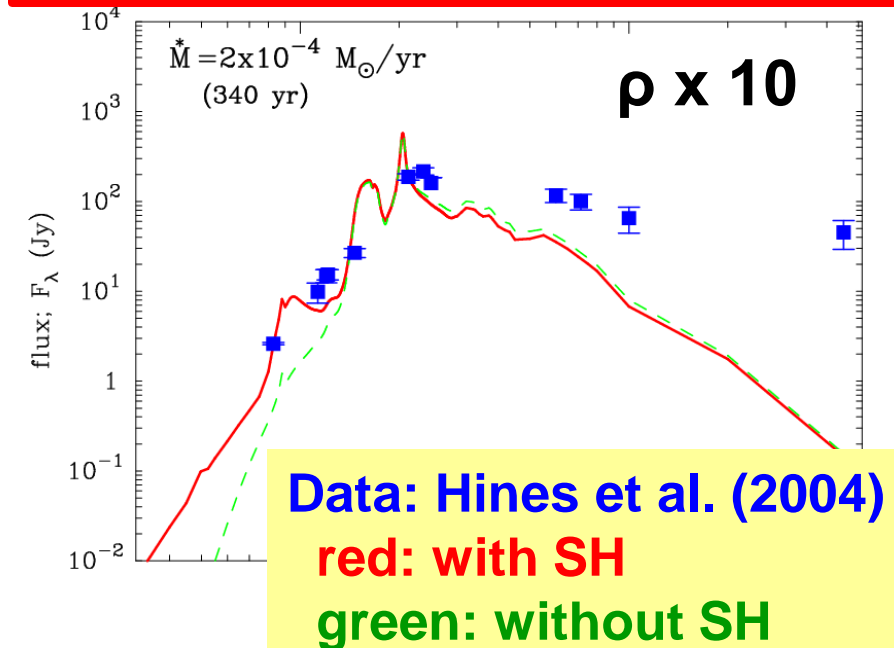
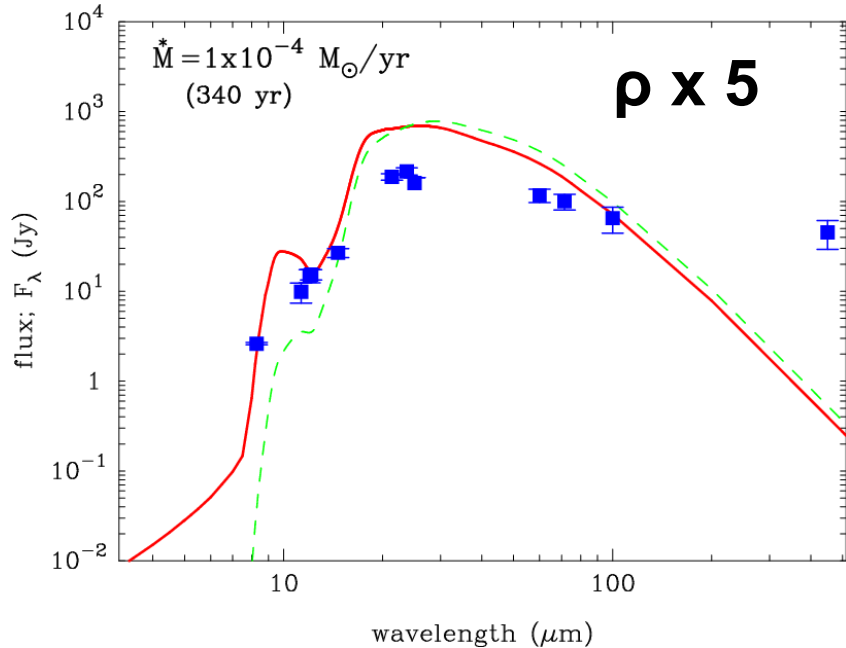
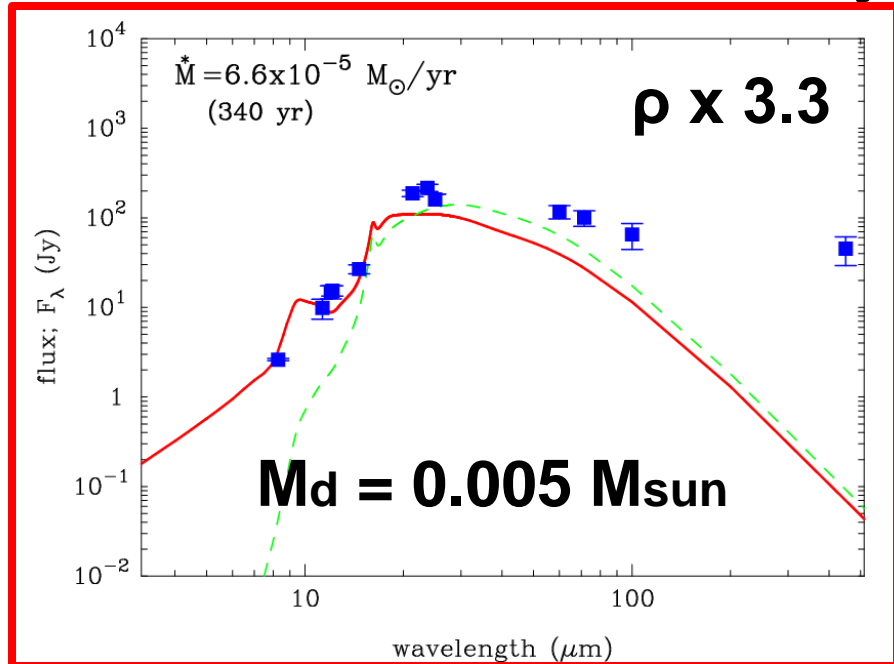
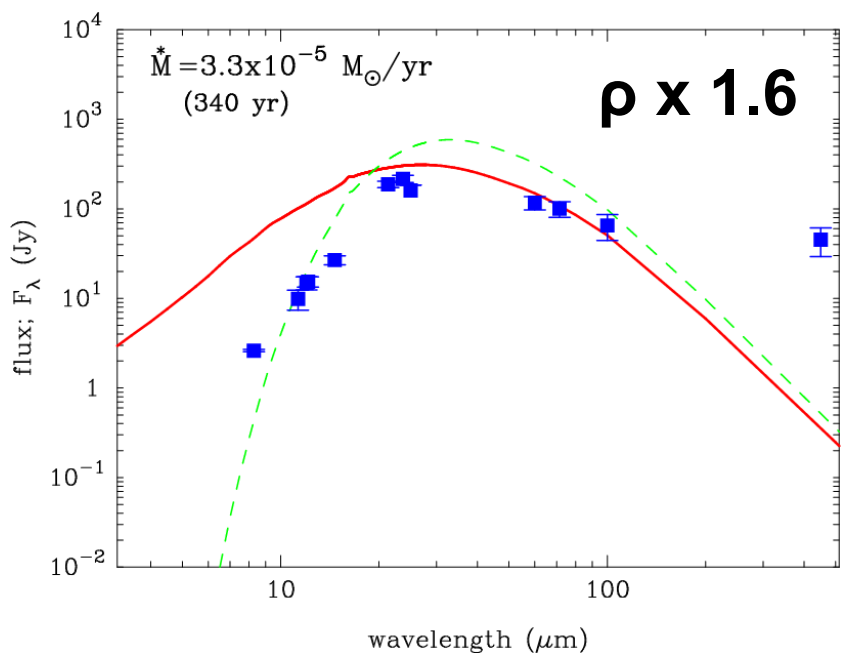
Data: Hines et al. (2004)
red: with SH
green: without SH

4-4. Time evolution of IR SEDs for Cas A SNR

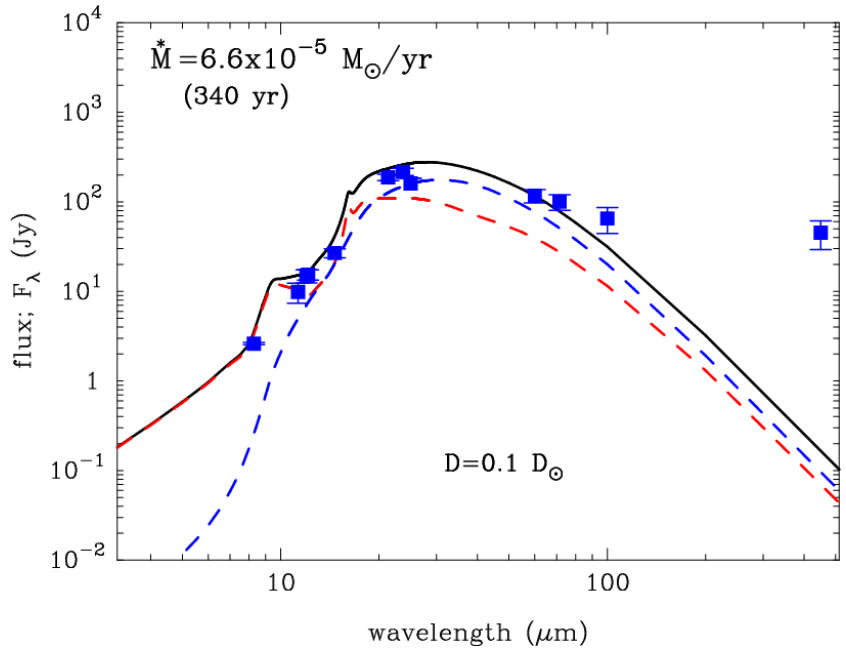


Data: Hines et al. (2004)
red: with SH
green: without SH

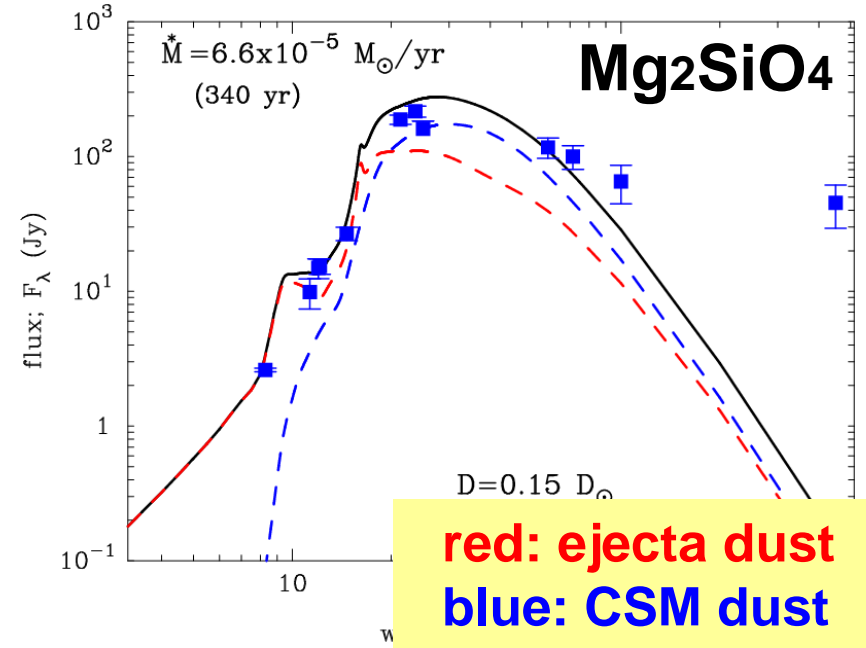
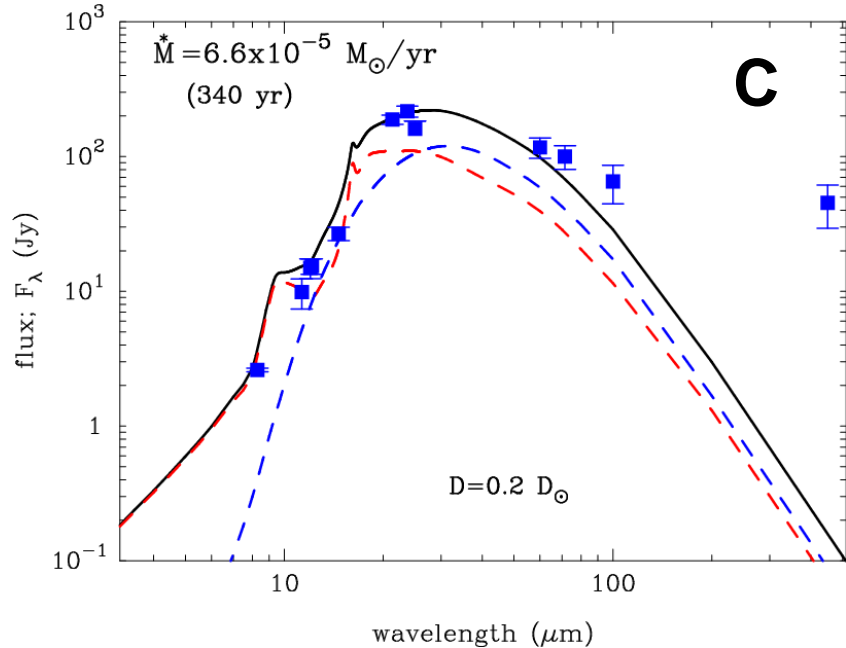
4-5. Dependence of IR SED on ambient density



4-6. Contribution from circumstellar dust

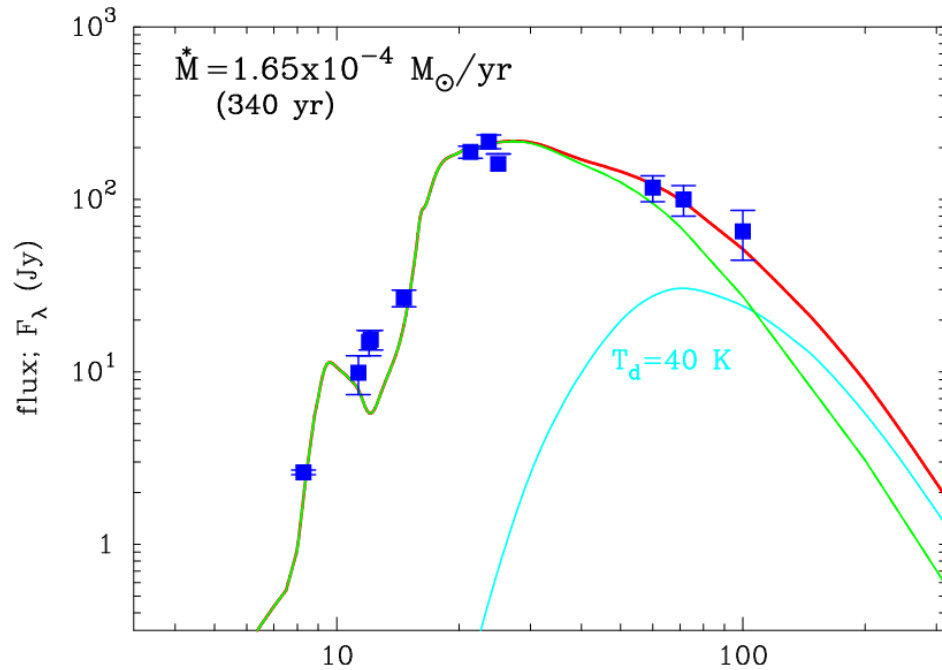


- dust species
C and Mg₂SiO₄
- dust size distribution
 $f(a) \propto a^{-3.5}$
 $a_{min} = 0.001 \mu m$
 $a_{max} = 0.5 \mu m$
- $M_c : M_{sil} = 3 : 7$

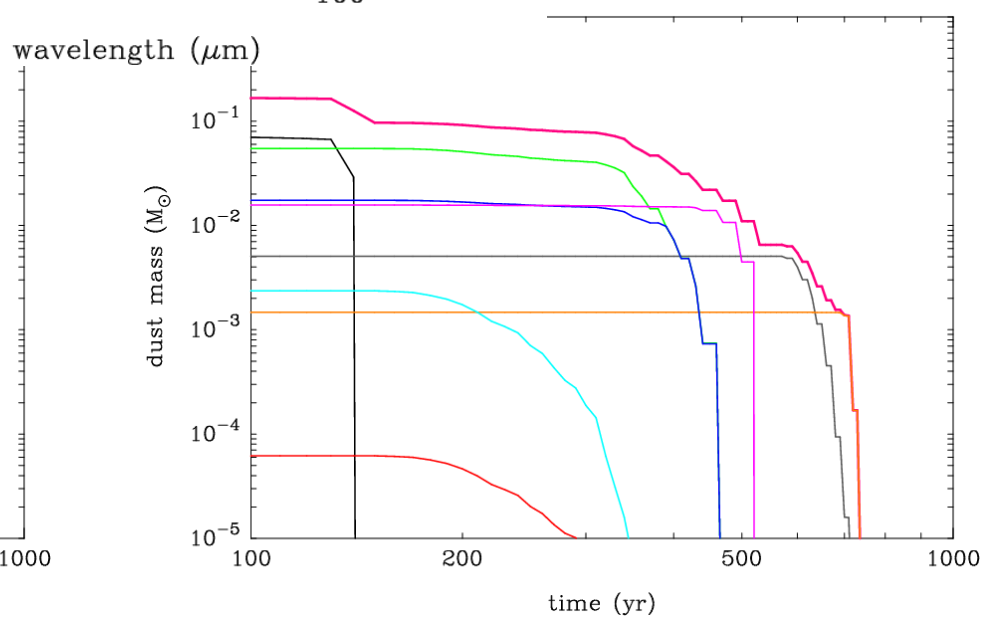
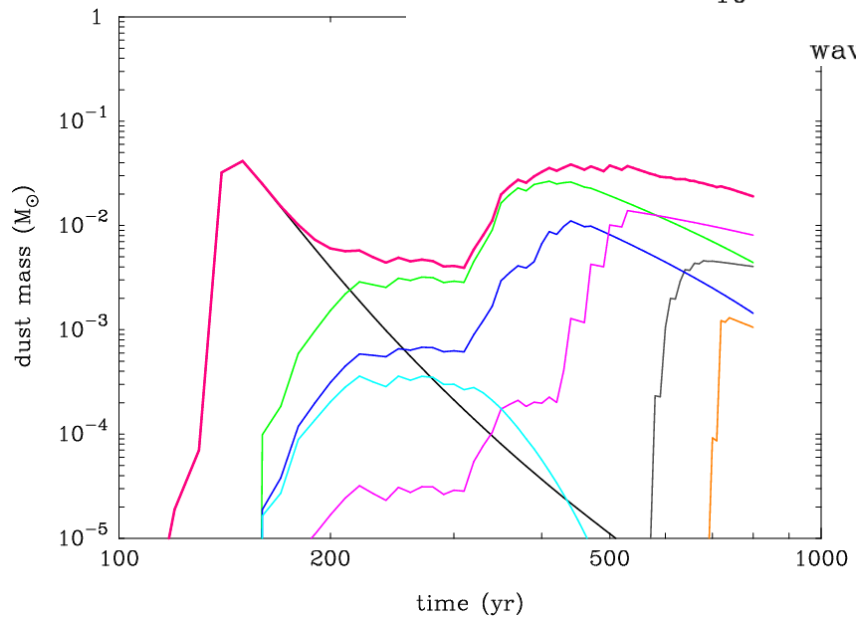


red: ejecta dust
blue: CSM dust

4-7. Contribution from unshocked dust



$\rho \times 4$



Summary

- 1) The radius of dust formed in the ejecta of Type IIb SN is quite small ($< 0.01 \mu\text{m}$) because of low ejecta density
- 2) Small dust grains formed in Type IIb SN cannot survive destruction in the shocked gas within the SNR
- 3) Model of dust destruction and heating in Type IIb SNR to reproduce the observed SED of Cas A is
 $M_{d,warm} = 0.005-0.007 M_{\text{sun}}$, $M_{d,cool} = 0.07-0.09 M_{\text{sun}}$
 $dM/dt = 6-8 \times 10^{-5} M_{\text{sun}}/\text{yr}$
- 4) IR SED reflects the destruction and stochastic heating
→ properties (size and composition) of dust
→ density structure of circumstellar medium