Composition and Origin of Dust Probed by IR Spectra of SNRs

(超新星残骸の赤外分光観測から探るダストの組成と起源)

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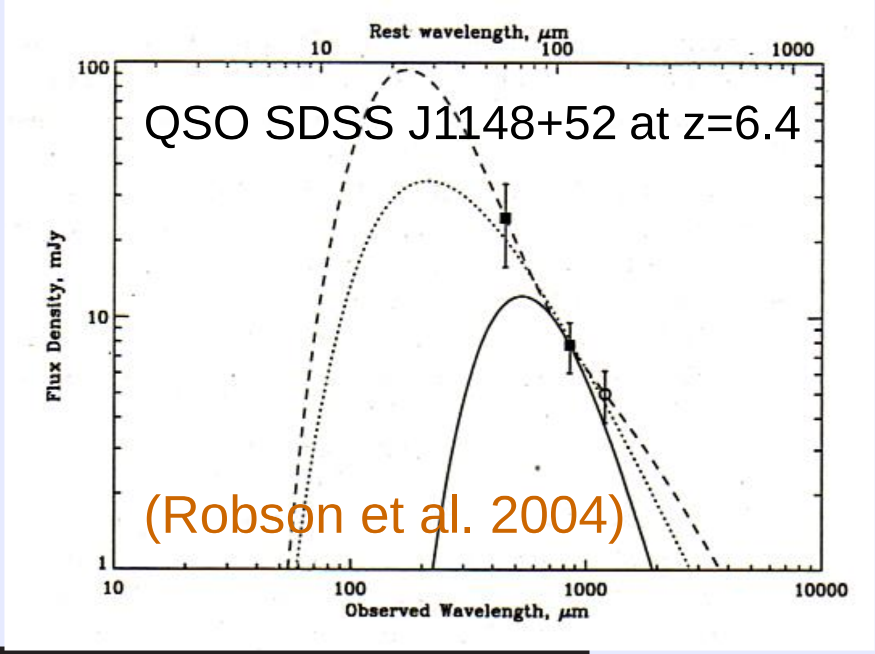
1-1. Introduction

Supernovae are the important sources of dust?

- theoretical studies ➔ M_{dust} = **0.1-1 M_{sun}** by **SNe II**
  (Bianchi & Schneider 2007; Nozawa et al. 2007)
- large amounts of dust (10^8-10^9 M_{sun}) for QSOs at z > 5
  (Bertoldi et al. 2003; Priddy et al. 2003; Robson et al. 2004)



0.1-1 M_{sun} of dust per SN II are required to form
(Morgan & Edmunds 2003; Maiolino et al. 2006; Dwek et al. 2007)

SNe are dust factory!

1-2. Introduction

○ IR observaitons of dust-forming SNe (~10 SNe)

M_{dust} = 10^{-5}-10^{-3} M_{sun}

SN 1987A ➔ 10^{-4}-10^{-3} M_{sun} (Elcolano et al. 2007)

SN 2003gd ➔ 0.02 M_{sun} (Sugerman et al. 2006)

➔ $4x10^{-5}$ M_{sun} (Miekle et al. 2007)

SN 2006jc ➔ ~$7x10^{-5}$ M_{sun} (Sakon et al. 2008)

➔ $6x10^{-6}$ M_{sun} (Smith et al. 2008) , $3x10^{-4}$ M_{sun} (Mattila et al 2008)

○ IR observaitons of nearby young SNRs

M_{dust} = 10^{-4}-10^{-2} M_{sun}

(e.g., Hines et al. 2004, Temim et al. 2006; Morton et al. 2007)

Theoretical predictions overestimate dust mass?
Observations are seeing only hot dust (＞100K)?

1-3. Aim of our study

How much and what kind of dust are supplied by SNe?

↓

It is necessary to combine theoretical models with IR observational results

- Observations of

  ongoing formation of dust in SNe (see Sakon's poster)

  nearby young SNRs

- Theoretical studies of

  dust formation in the SN ejecta

  ➔ mass, size, and temperature of dust

  dust evolution in the shocked gas within SNRs

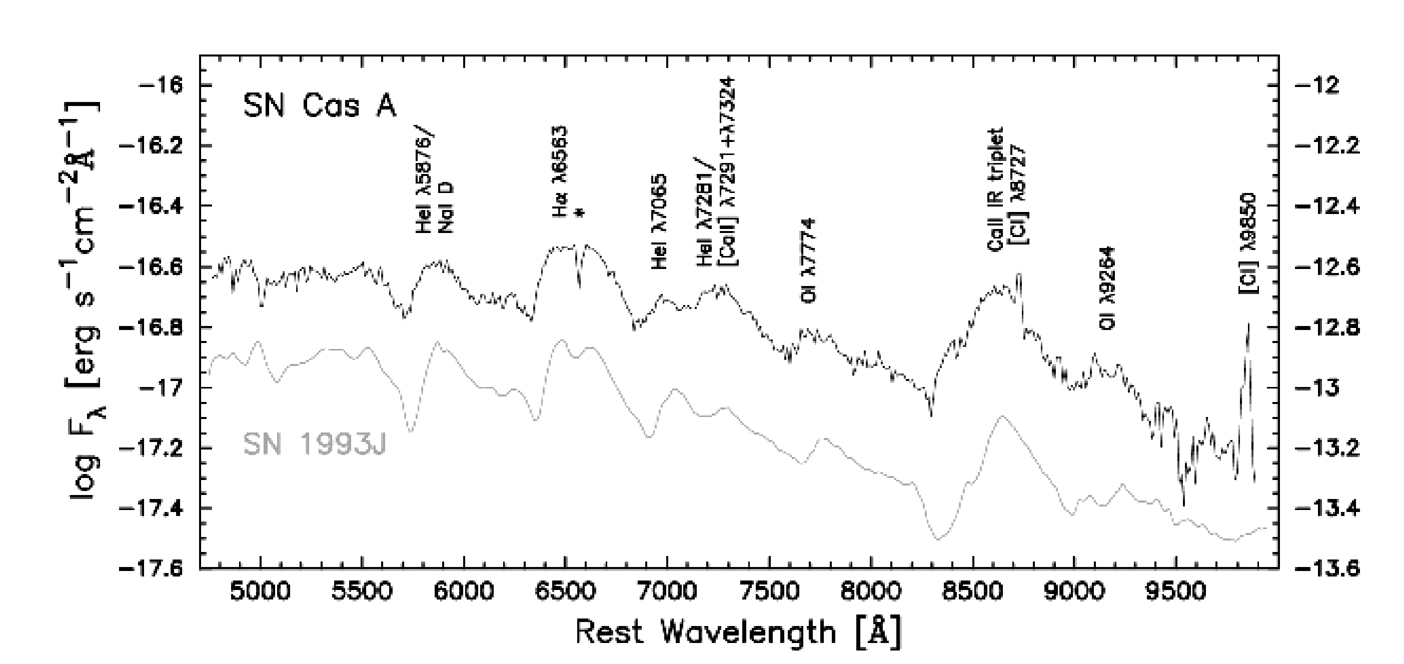
  ➔ destruction by sputtering, dynamics, heating

➔ Cas A SNR

2-1. Cassiopeia A SNR

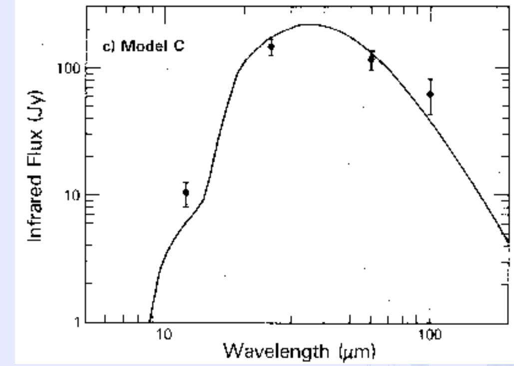
○ Cas A SNR (SN 1671)

age: 337yr (Thorstensen et al. 2001)
distance: d=3.4 kpc (Reed et al. 1995)
radius: ~150” (~2.5 pc)
SN type : **Type IIb** (M_{pr}=15-25 M_{sun})

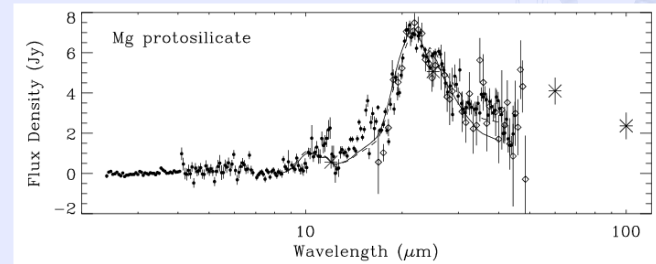


Krause et al. (2008)

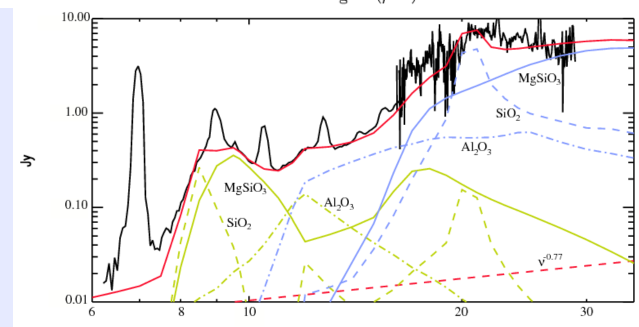
2-2. Dust in Cas A SNR



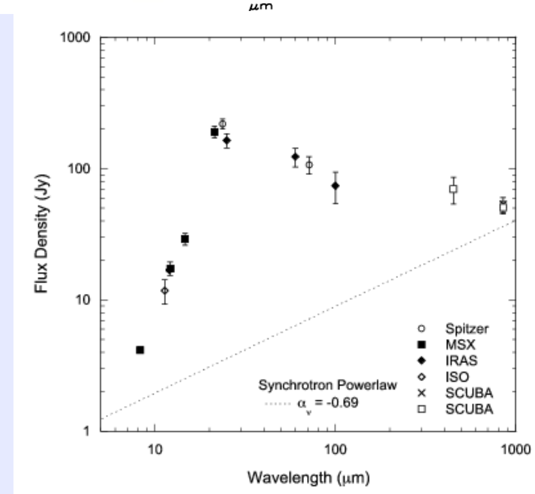
○ Estimated mass of dust in Cas A

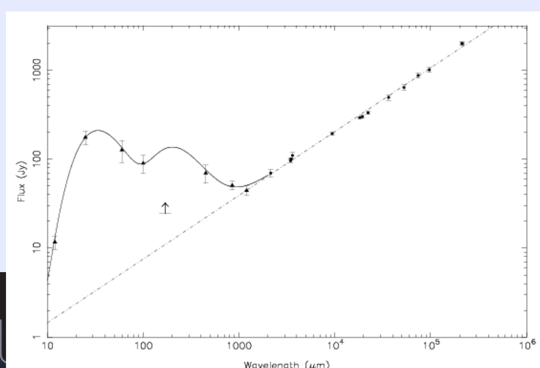


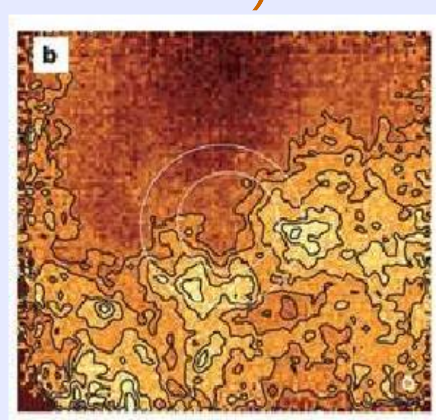
- warm/hot dust (50-300K)
  (3-7)x10^{-3} Msun (*IRAS*, Dwek et al. 1987)
  ~7.7x10^{-5} Msun (*ISO*, Arendt et al. 1999)
  ~6x10^{-4} Msun (*ISO*, Douvion et al. 2001)
  ~3x10^{-3} Msun (*Spitzer*, Hines et al. 2004)



- cold dust (~18K)
  2.2-26 Msun (*SCUBA*, Dunne et al. 2003)
  no cold dust (Krause et al. 2004)
  ＜1.5 Msun (Wilson & Batrla 2005)

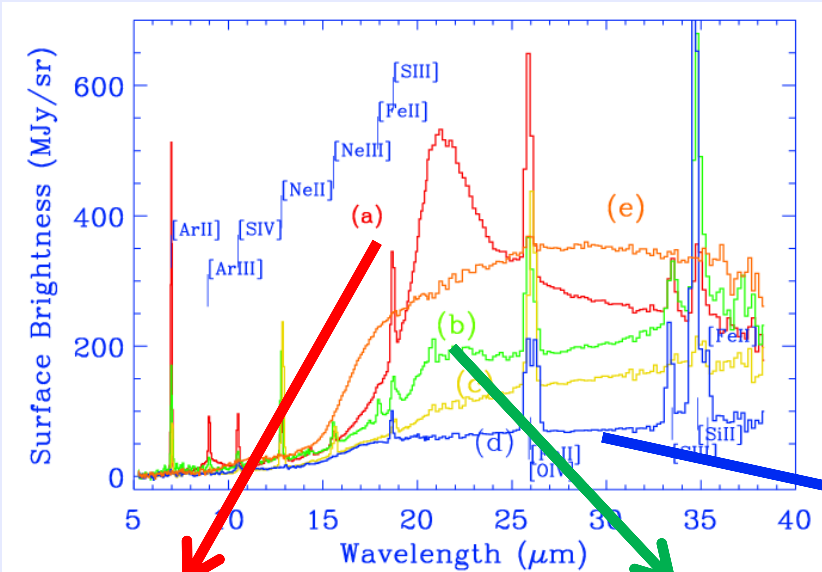


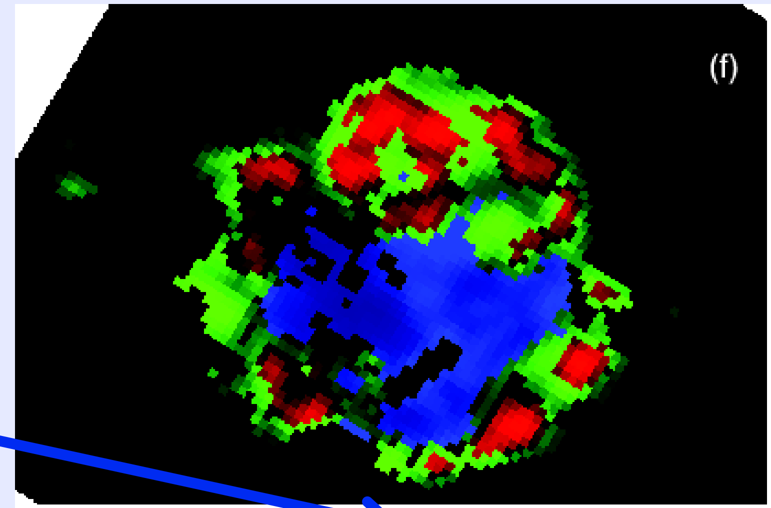


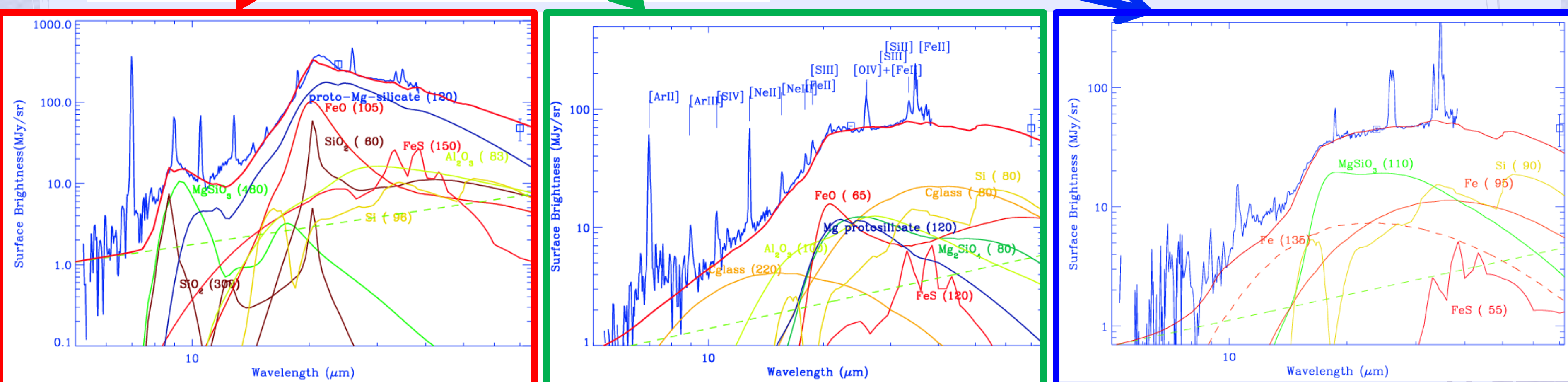


2-3. Latest estimate of dust mass in Cas A

(Rho et al. 2008)







Emission lines allow us to specify the composition of dust

➔ M_{dust} = 0.02-0.054 M_{sun}

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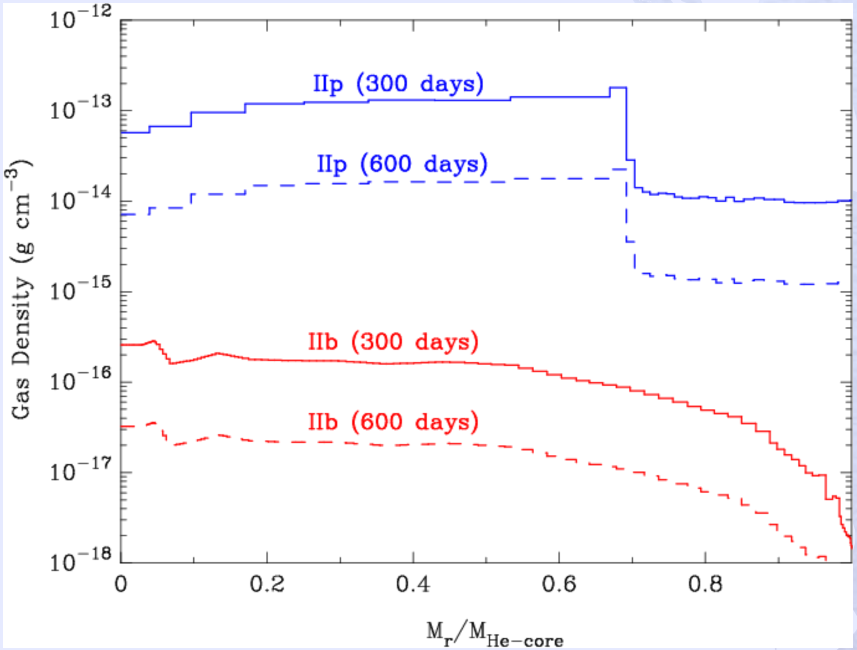
3-1. Dust formation calculation

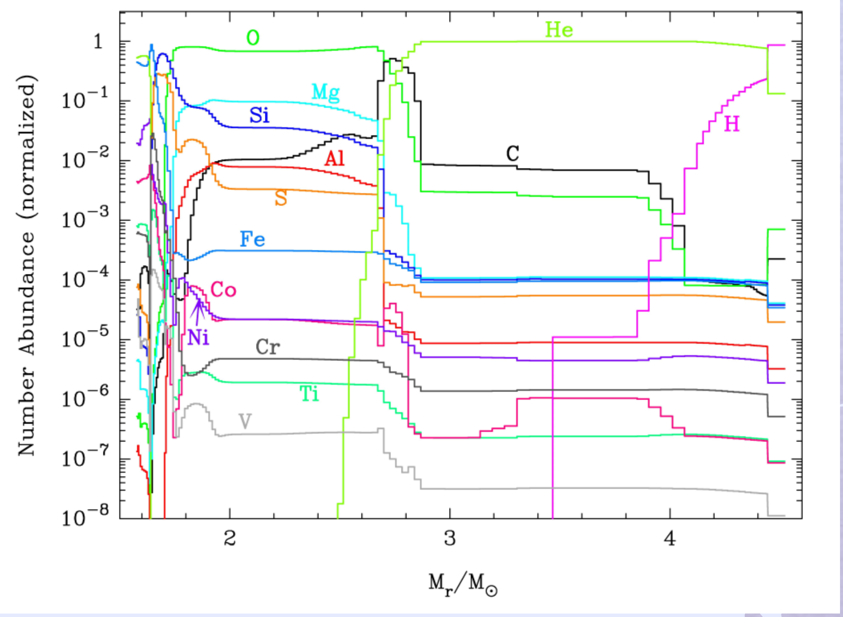
○ Type IIb (1993J) model

- M_{pr} = 18 Msun
  M_{ej} = 2.94 Msun
  $M_{H\text{-}env}$ = 0.08 Msun
- E_{51} = 1
- $M(^{56}Ni)$ = 0.07 Msun



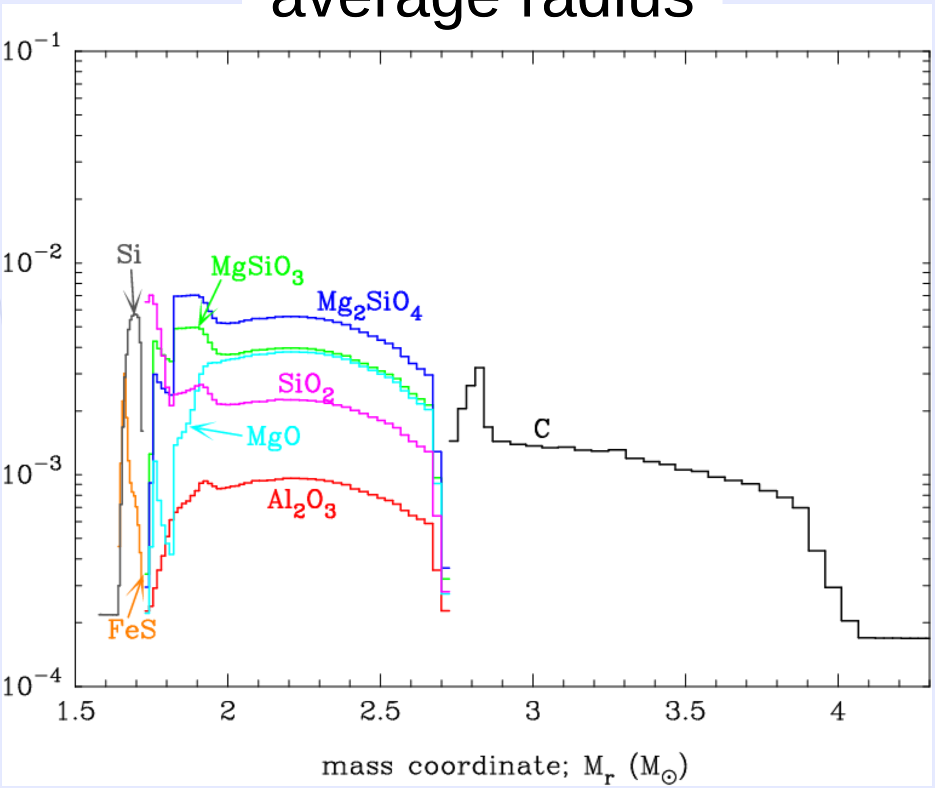
○ Dust formation theory

- non-steady nucleation and grain growth theory
  (Nozawa et al. 2003)
- onion-like composition
- sticking probability; α_s = 1



3-2. Results of dust formation calculation

average radius



Low gas density in SN IIb prevents dust grains from growing up to large radius

dust mass

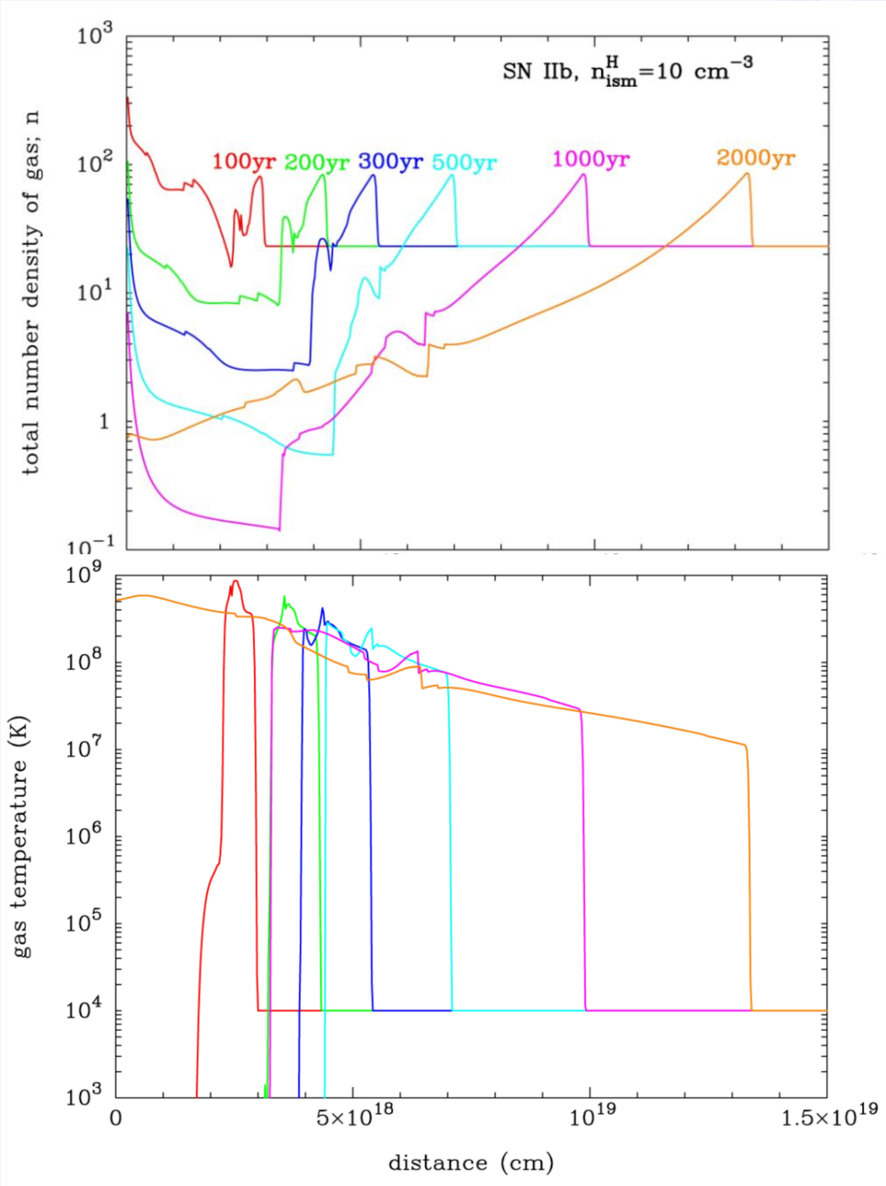
C	7.08×10^{-2}
Al_2O_3	6.19×10^{-5}
Mg_2SiO_4	1.74×10^{-2}
$MgSiO_3$	5.46×10^{-2}
MgO	2.36×10^{-3}
SiO_2	1.57×10^{-2}
Fe_3O_4	
FeS	1.47×10^{-3}
Si	5.07×10^{-3}
Fe	
total	0.167
M_d/M_{metal}	0.129

3-3. Calculation of dust evolution in SNRs

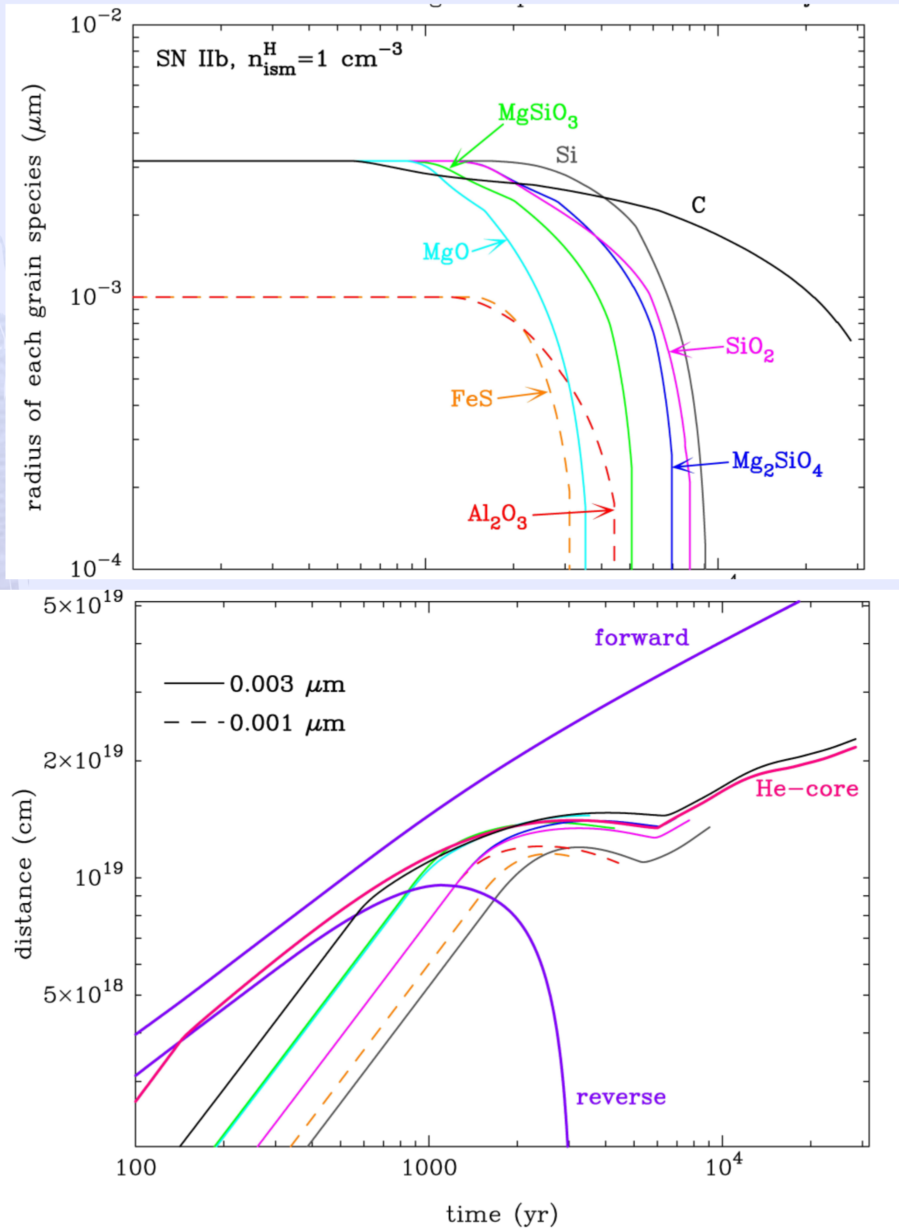
○ Model of calculations

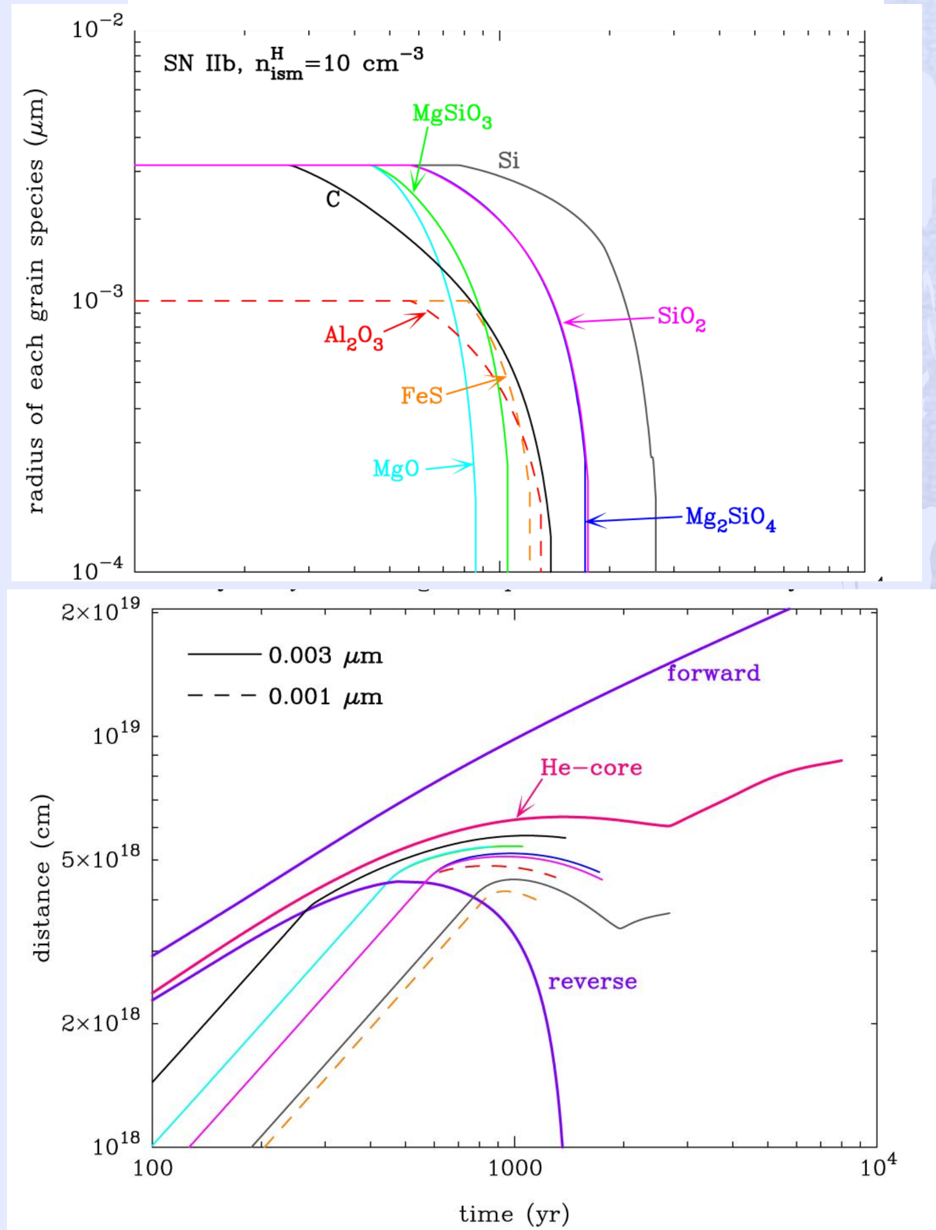
Nozawa et al. (2007)

- 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

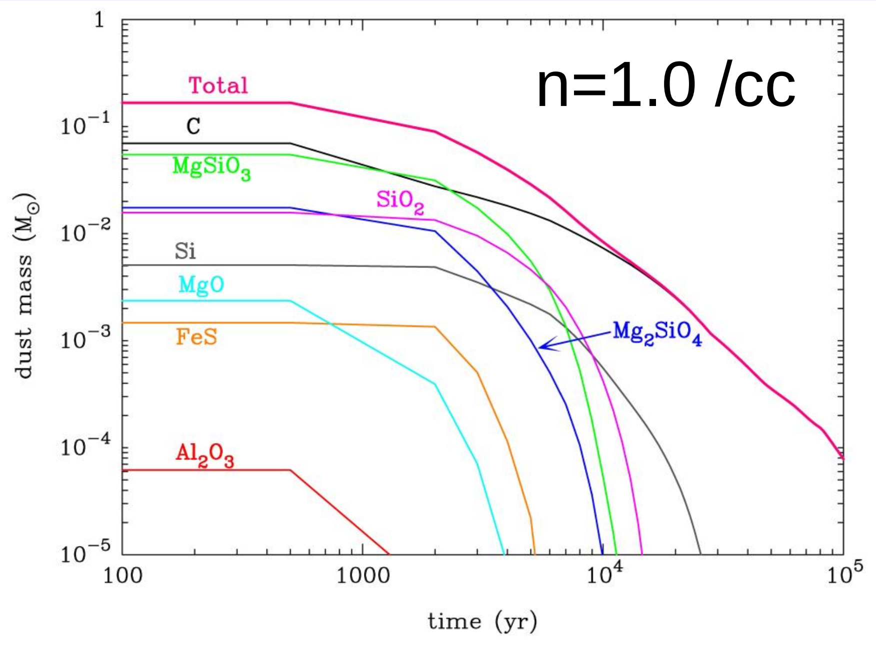


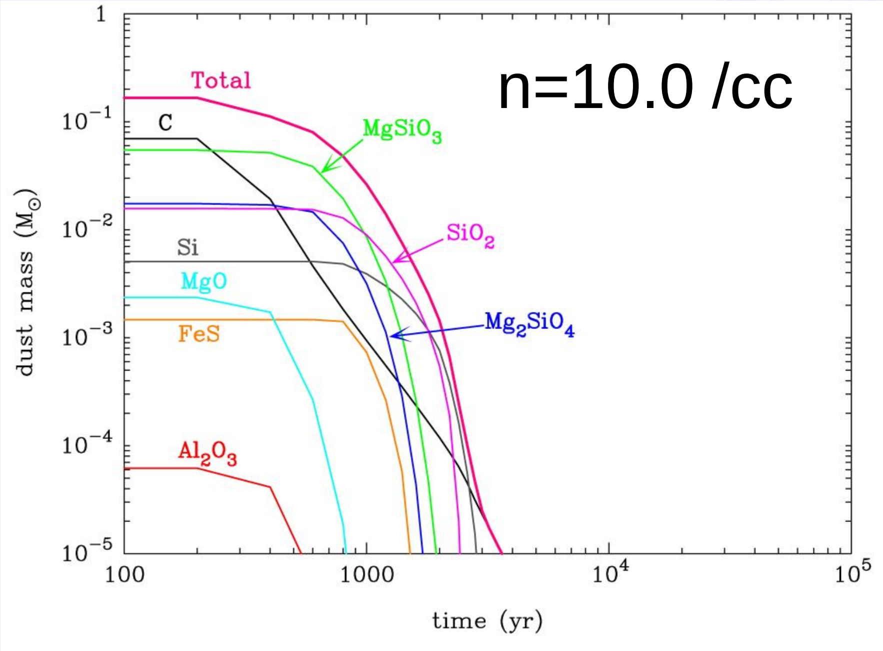
3-4. Evolution of dust in Cas A SNR





3-5. Time evolution of dust mass





Mdust ~ **10^{-4} Msun** at 10^5 yr

Mdust = **0 Msun** at 10^5 yr

This type of SNe (Type IIb) cannot be the main sources of dust

※ In Type IIp SNe, dust grains of ＞0.02 μm are formed and can survive the destruction in SNRs (Nozawa et al. 2007)

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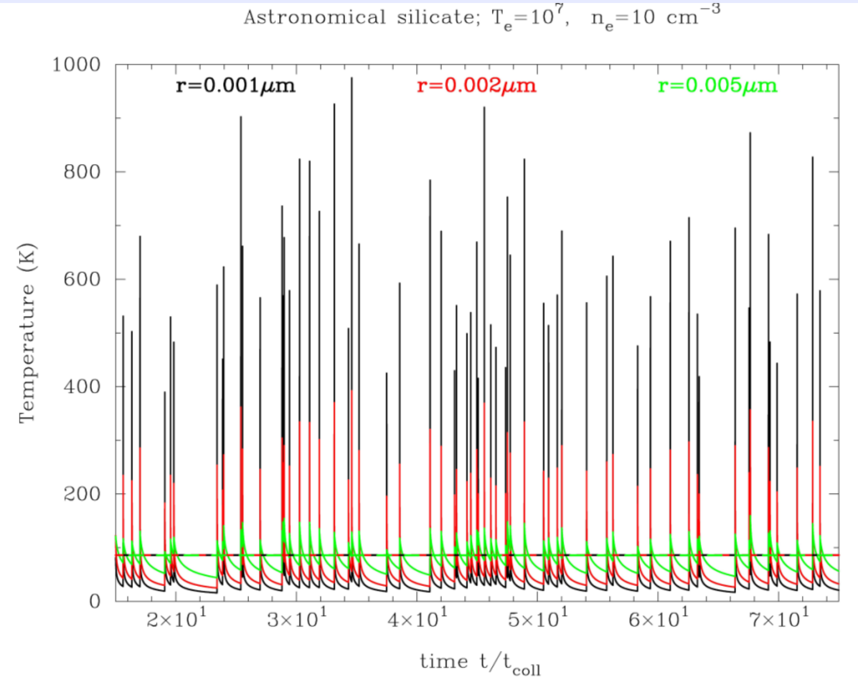
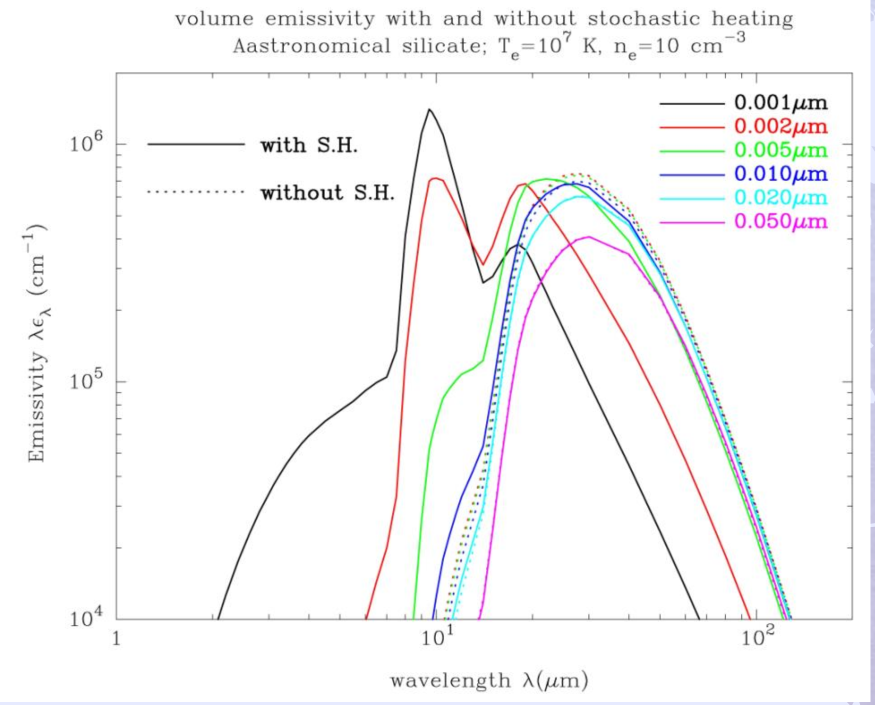
3-6. Thermal emission from dust in the SNR

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

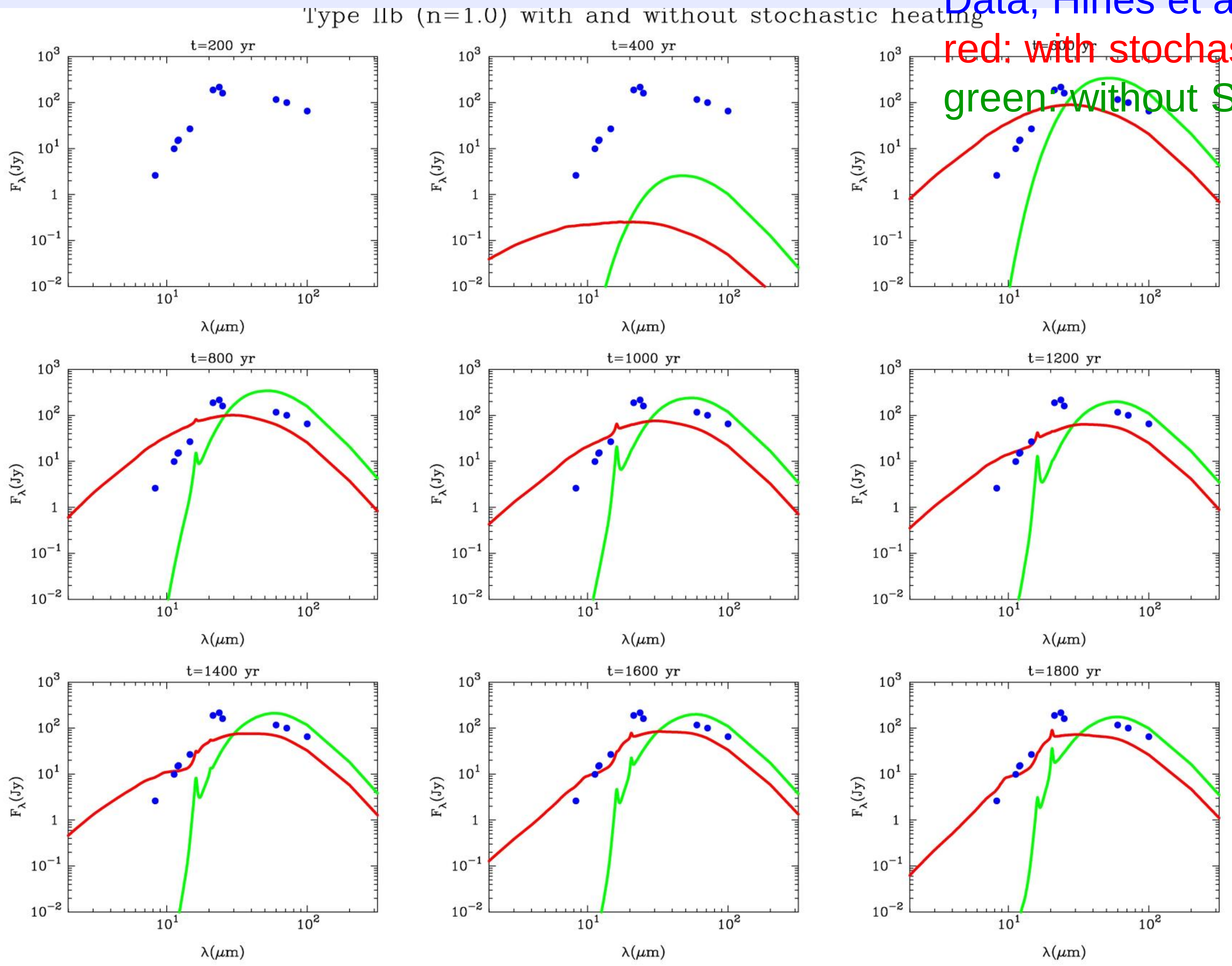
  $H(a, n, T_g) = \Lambda(a, Q_{abs}, T_d)$ ➔ thermal emission
- small-sized dust grains (＜0.01 μm) ➔ stochastic heating



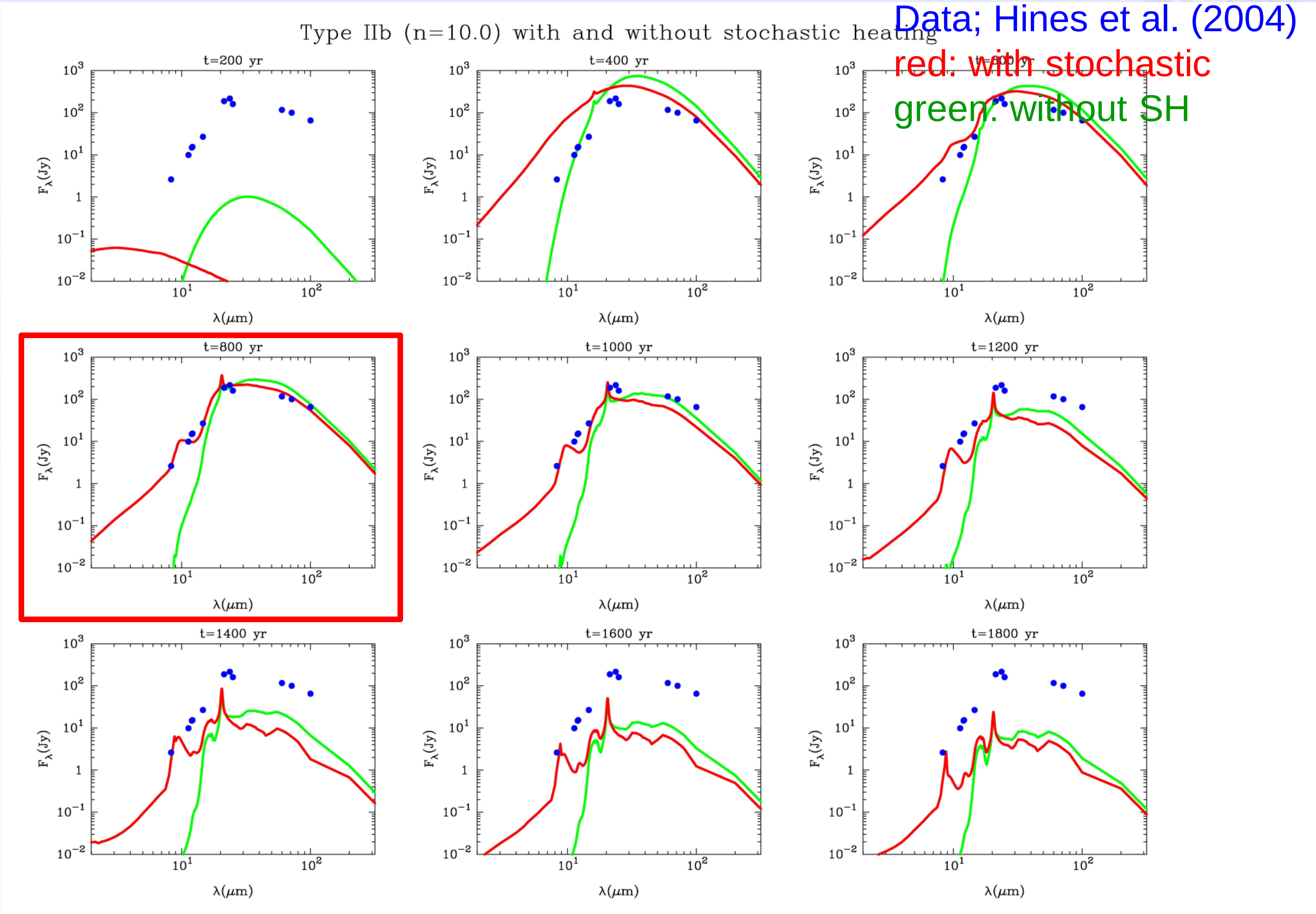


3-7. Comparison with Cas A observation (1)

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



3-8. Comparison with Cas A observation (2)

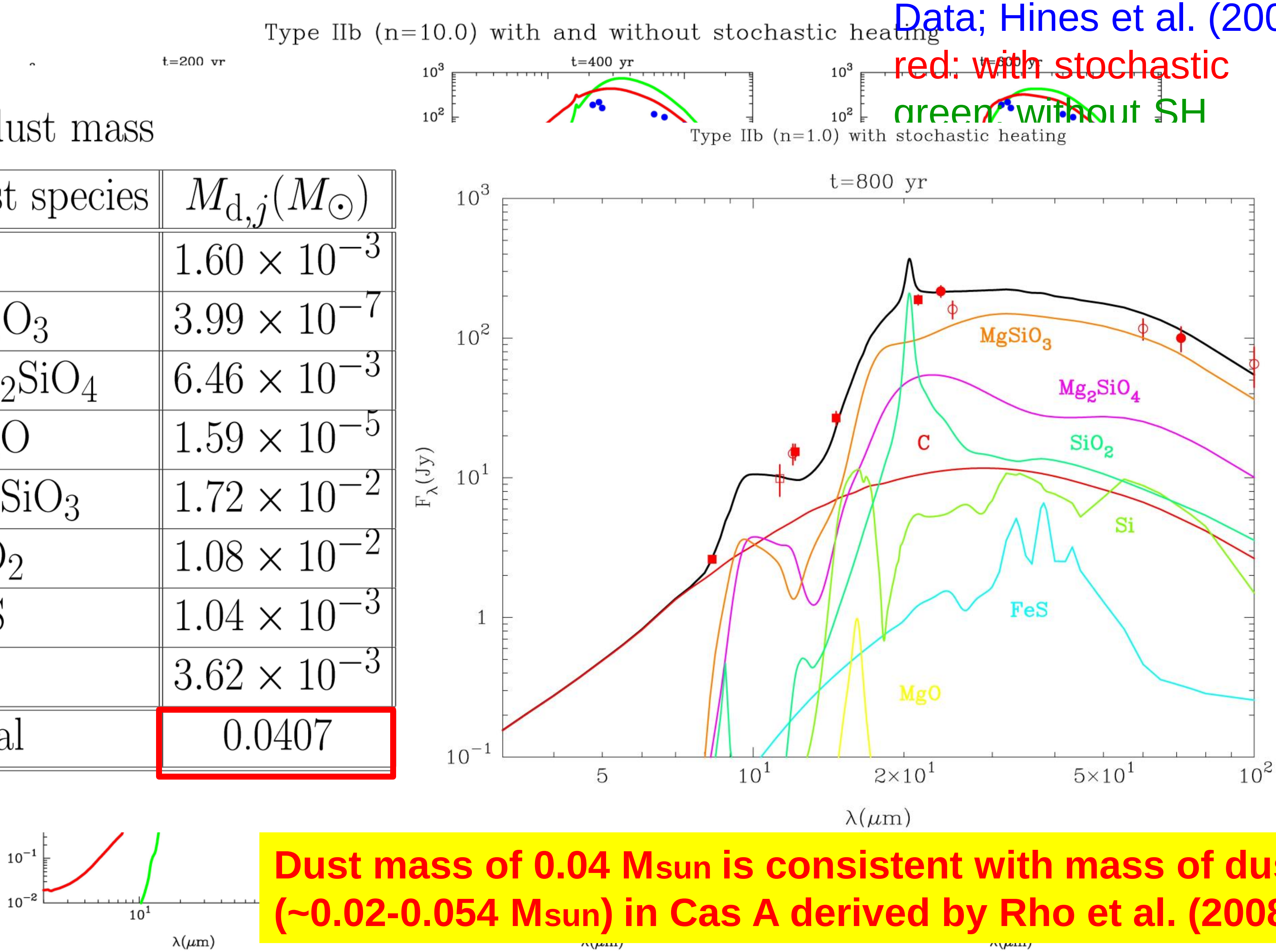


3-8. Comparison with Cas A observation (2)

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

dust mass

dust species	$M_{d,j}(M_\odot)$
C	1.60×10^{-3}
Al_2O_3	3.99×10^{-7}
Mg_2SiO_4	6.46×10^{-3}
MgO	1.59×10^{-5}
$MgSiO_3$	1.72×10^{-2}
SiO_2	1.08×10^{-2}
FeS	1.04×10^{-3}
Si	3.62×10^{-3}
total	0.0407



Dust mass of 0.04 Msun is consistent with mass of dust (~0.02-0.054 Msun) in Cas A derived by Rho et al. (2008)

3-7. Summary

1) The size of dust formed in the ejecta of H-deficient Type IIb is relatively small because of low gas density of the ejecta

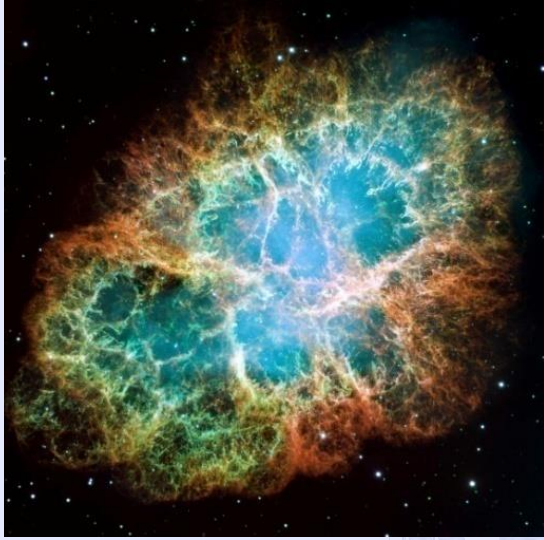
2) Newly formed dust grains cannot survive the reverse shock since their radii are small (< 0.01 μm)

3) Thermal radiation from dust well reflects the size of dust in SNR through the effect of stochastic heating

4) Model of dust formation and destruction of Type IIb SN for n_H=10.0 cm^{-3} reproduces the observed SED of Cas A

   ➔ circumstellar / interstellar dust
   ➔ density structure of circumstellar medium
   ➔ thermal emission from dust at various positions

4-1. Crab SNR



○ Crab nebula (SN 1054)

age: 954 yr

distance: d=2.1 kpc (Reed et al. 1995)

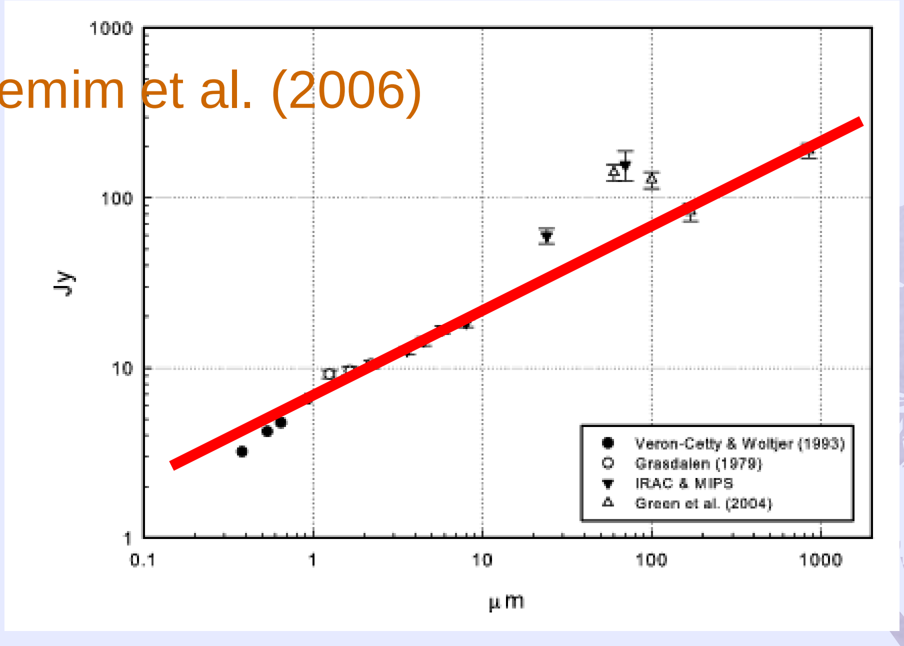
SN type: **Type IIp or IIn?**

O-Ne-Mg core, M_{ms}=8-10 M_{sun} (Nomoto et al. 1982)

dust mass: **M_{dust} = 0.003-0.07 M_{sun}** (Green et al. 2004)

M_{dust} = 0.001-0.015 M_{sun} (Temim et al. 2006)

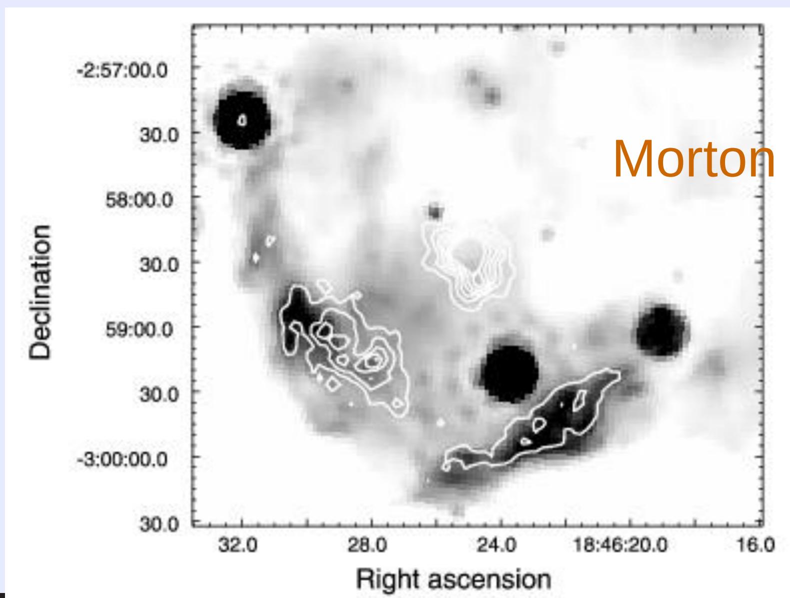
Temim et al. (2006)



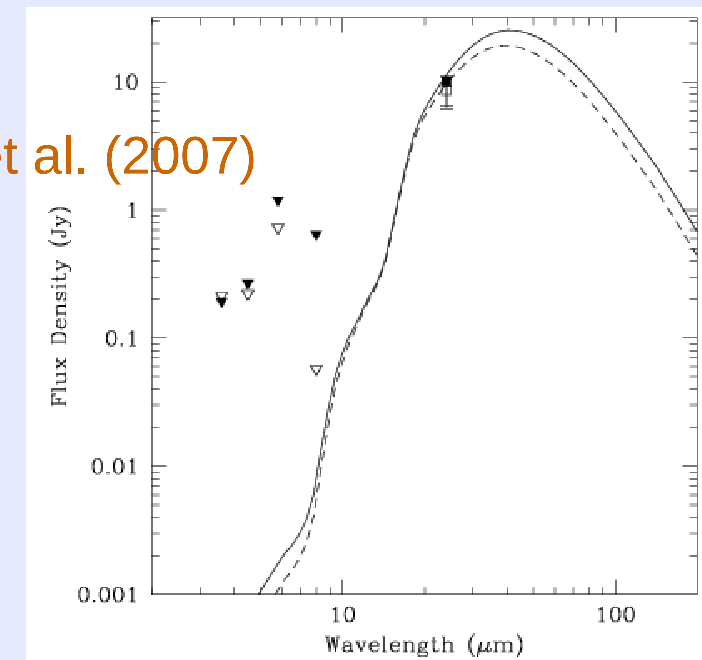
4-2. Kes 75 SNR

○ Kes 75

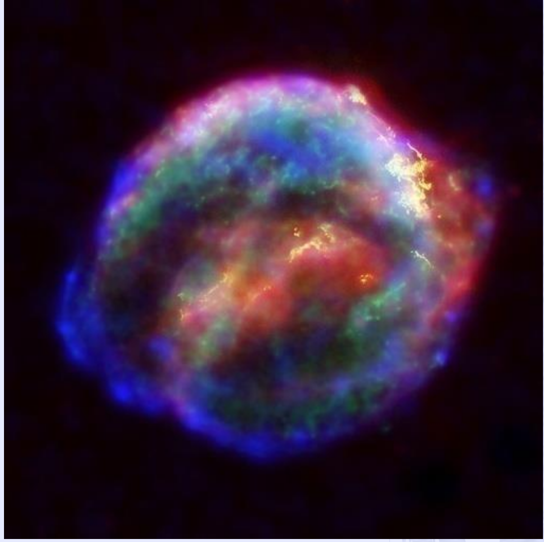
age: ~884 yr (Livngstone et al. 2006)
distance: d=19 kpc (Becker & Helfand 1984)
d=5.1-7.5 kpc (Leahy & Tian 2007)
SN type: **Type Ib or Ic (W-R star, >20 Msun?)** (Chevalier 2005)
dust mass: **M_{dust} = ~0.08 M_{sun}** (Morton et al. 2007)



Morton et al. (2007)

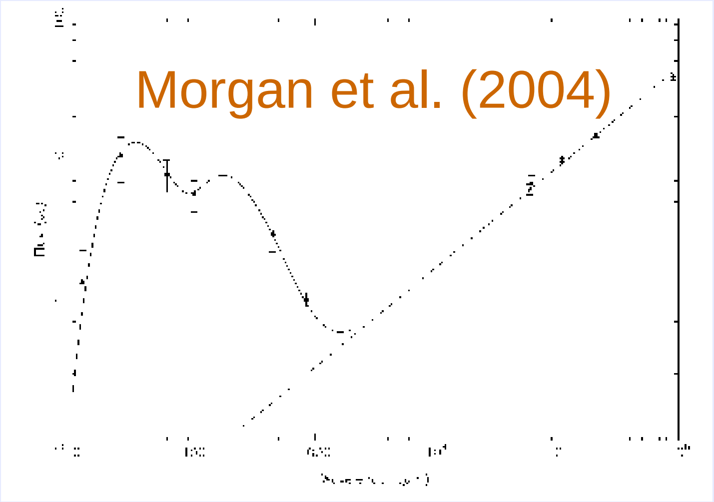


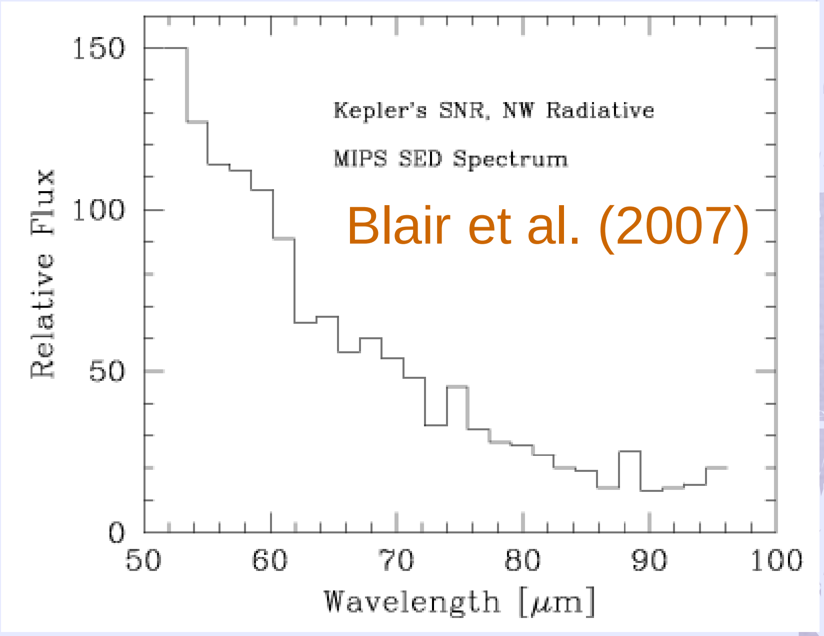
4-3. Kepler SNR



○ Kepler (SN 1604)

age: 404yr (Kepler 1606)
distance: d=2.5-5.8 kpc (Sankrit et al. 2005)
SN type: **Type II or Type Ia?**
dust mass: **$M_{dust} = 10^{-4}$ M_{sun}** (Douvion et al. 2001)
M_{dust} = 0.3-2.7 M_{sun} (17K) (Morgan et al. 2004)
$M_{dust} = 5.4 \times 10^{-4}$ M_{sun} (Blair et al. 2007)





4-4. Prospects

IR spectroscopic observations of dust in SNRs

- newly formed dust? and/or circumstellar/interstellar dust?
- composition of dust ➔ silicate? and/or carbonacious?

⬆

- spectral feature, IR colors
- forbidden emission lines at IR wavelengths
  (by comparing with SN nucleosynthesis results)

- clumpy structure
- size of dust ➔ properties of the SNe (E_{exp} and M_{eje})
- temperature of dust ➔ gas density
  ➔ CSM / ISM structure ➔ mass-loss history

Dust in SNRs can be powerful probes for understanding the properties and evolution history of progenitor stars!