Cas A 超新星残骸中の
ダストの一生

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Nozawa et al. (2010), ApJ, 713, 356
(arXiv: 0909.4145)

1-1. Introduction

○ Cassiopeia A SNR

– distance : d=3.4 kpc (Reed et al. 1995)

– age : t=330 yr (Thorstensen et al. 2001)

– ejecta mass : M_{eje}=2-4 M_{sun} (e.g. Willingale et al. 2002)

– SN type : Type IIb (Krause et al. 2008)
(generated from a supergiant that had lost most of H-envelope)

– thermal emission from ejecta-dust (mainly silicates)
→ M_{dust} = 0.02-0.054 M_{sun} (Rho et al. 2008)

- formation process of dust in the ejecta
- physical processes of dust in the shocked gas
  → erosion by sputtering and collisional heating
- CCSNe are important sources of dust?

1-2. Aim of our study

- **Birth of dust in the ejecta of Cas A**

  dust formation calculation based on SN II model

  ➔ **composition, size, and mass of newly formed dust**
  ➔ **dependence of dust formation process on types of SNe (on the mass of H-envelope)**

- **Brightening of dust in the shocked hot gas**

  dust evolution calculation in the SNR

  ➔ **IR emission from the shock-heated dust**
  ➔ **comparison with IR observations of Cas A**

- **Fate of dust in Cas A SNR**

  ➔ **How much mass of the dust grains in Cas A can survive and can be injected into the ISM?**

2-1. Dust formation calculation in the ejecta

○ Dust formation calculation

– non-steady nucleation and grain growth theory

(Nozawa et al. 2003)

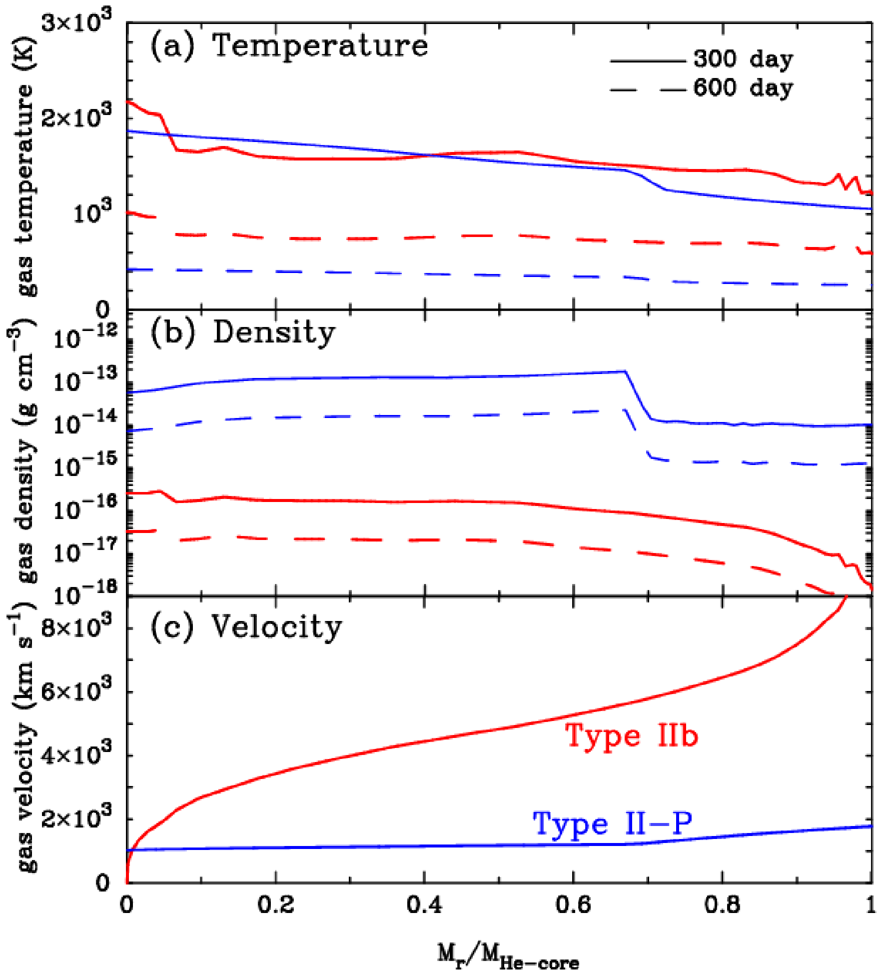
○ SN IIb model

(SN1993J-like model)

– $M_{H\text{-}env} = 0.08\ M_{sun}$
$M_{ZAMS} = 18\ M_{sun}$
$M_{eje} = 2.94\ M_{sun}$

– $E_{51} = 1$

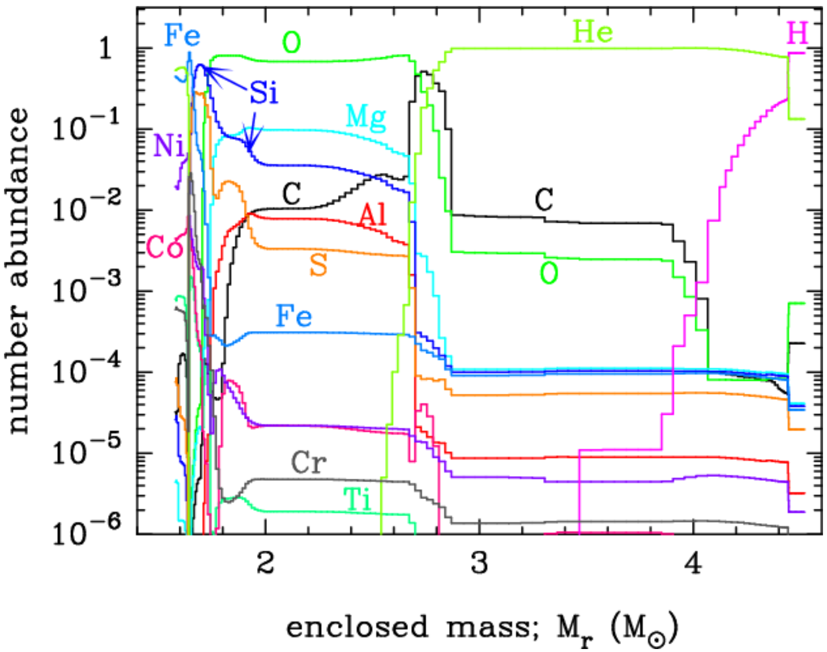
– $M(^{56}Ni) = 0.07\ M_{sun}$

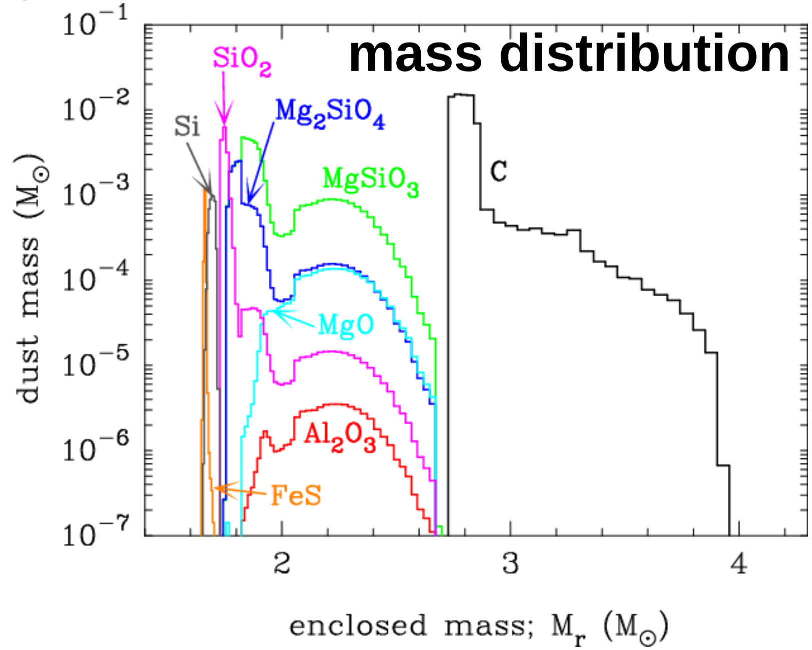


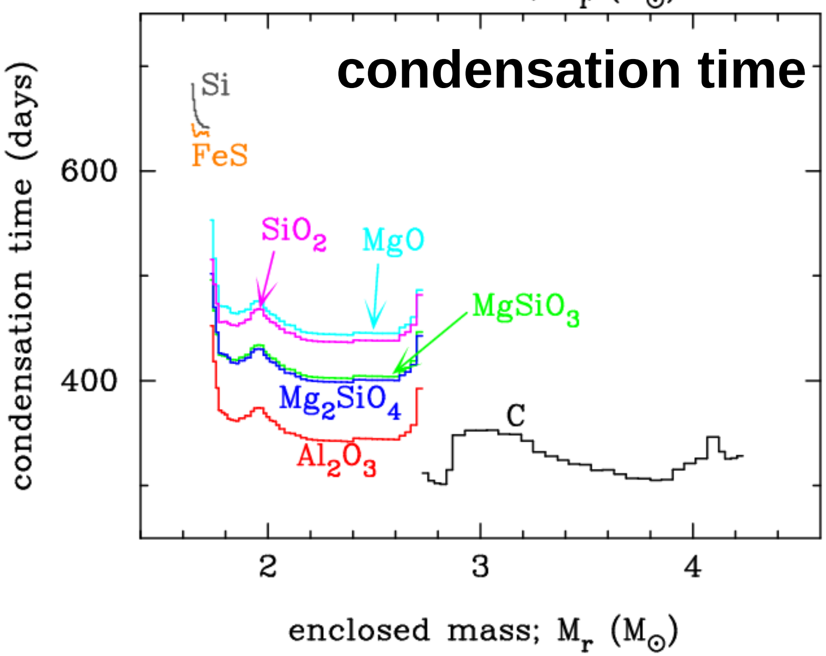
○ **SN II-P model : $M_{H\text{-}env} = 13\ M_{sun}$, $M_{ZAMS} = 20\ M_{sun}$, $E_{51} = 1$**

(Umeda & Nomoto 2002)

2-2. Birth of dust in the ejecta of Cas A





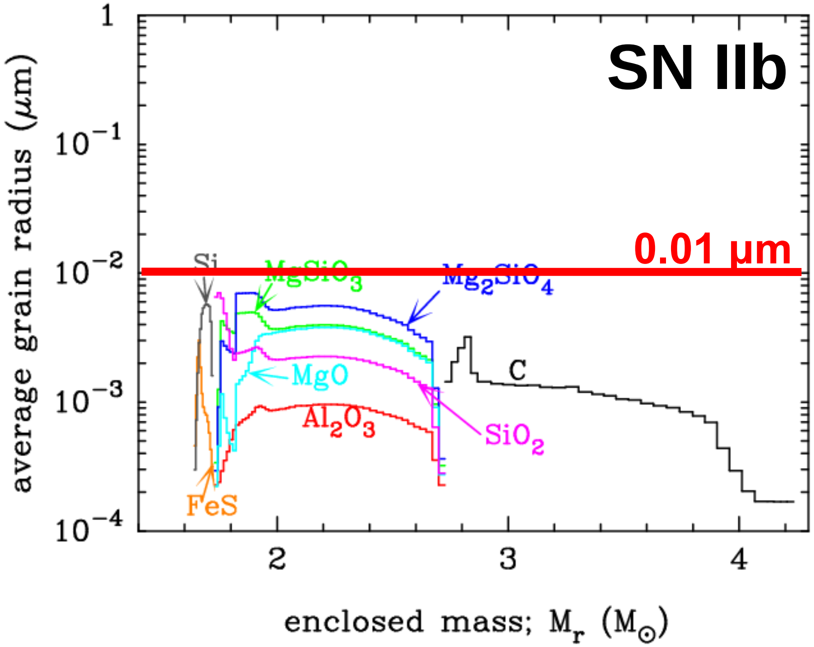


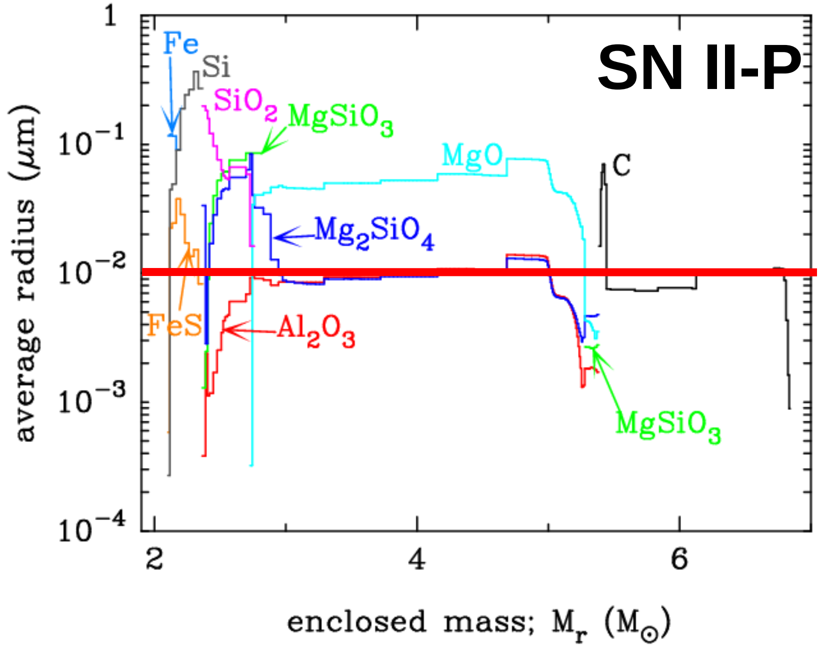
— condensation time of dust
300-700 d after explosion

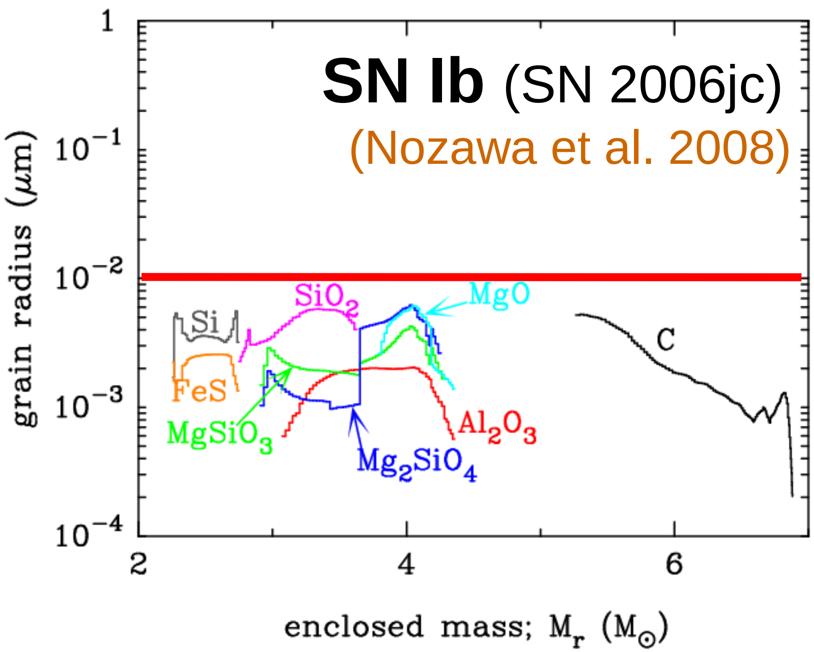
— total mass of dust formed

- 0.167 Msun in SN IIb
  - M_c=0.07 Msun
  - $M_{silcate}$=0.08 Msun
- 0.1-1 Msun in SN II-P

2-3. Dependence of dust radii on SN type







The radius of dust formed in H-stripped SNe is small

– **SN IIb and SN Ib/Ic without massive H-env**
  ➔ **a_{dust} < 0.01 μm**

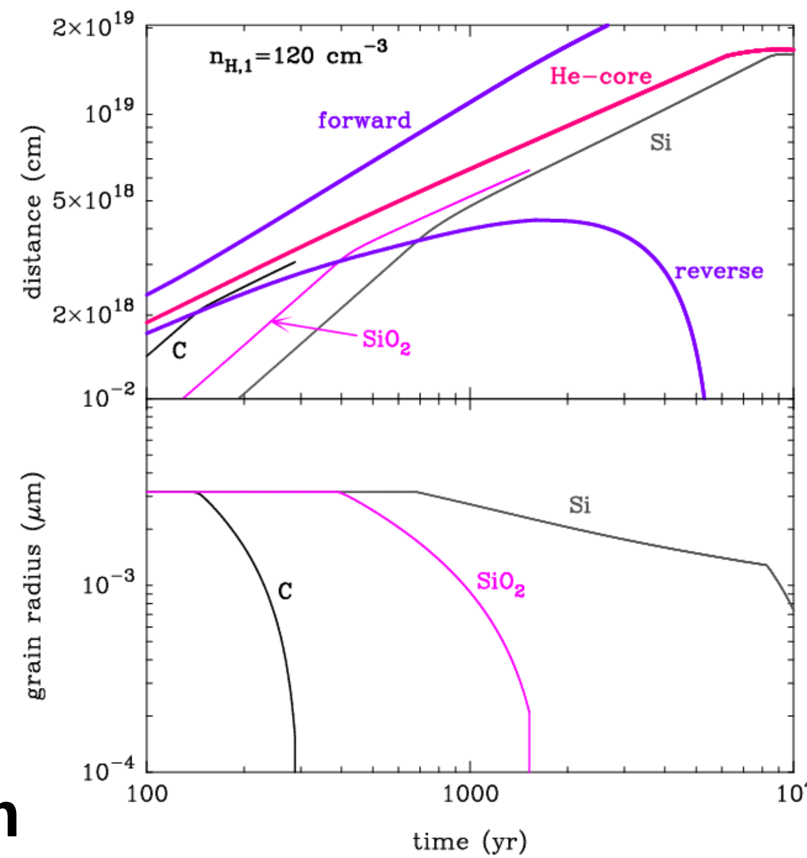
– **SN II-P with massive H-env**
  ➔ **a_{dust} > 0.01 μm**

3-1. Calculation of dust evolution in SNRs

○ Dust evolution calculations (Nozawa et al. 2006, 2007)

– spherical symmetric hydrodynamic calculation based on the ejecta model of the SN IIb

– treating dust as a test particle
  - erosion by sputtering
  - deceleration by gas drag
  - collsional stochastic heating



– **density profile of CSM**

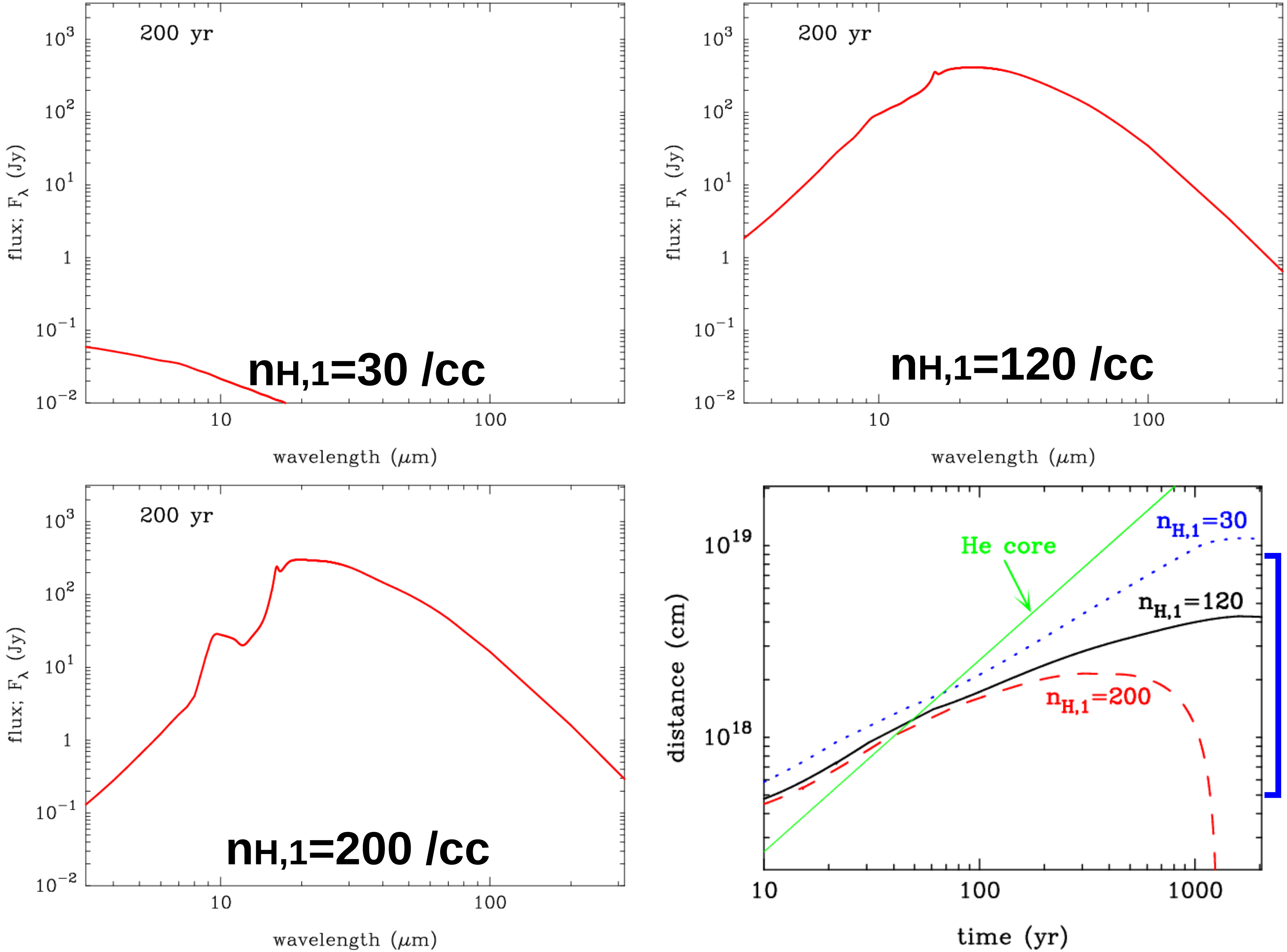
$$n_H(r) = n_{H,1}\,(r / r_1)^{-2}\ /cc$$
$$= 1\ /cc \quad \text{for } n_H < 1\ /cc$$

r_1 = r(at 10 yr) = 1.2x10^{18}cm

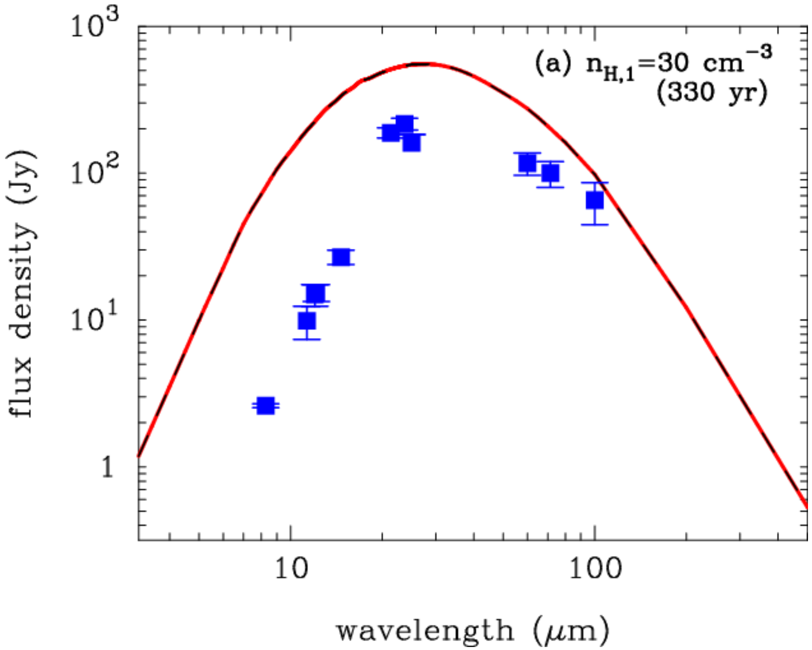
$n_{H,1}$ = 30, 120, 200 /cc

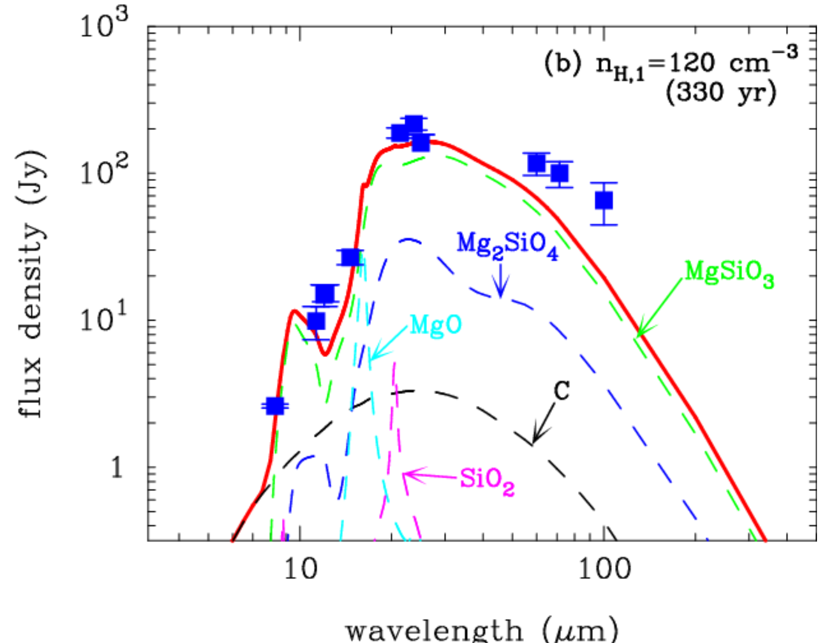
(➔ dM/dt = 2.0, 8.0, 13x10^{-5} M_{sun}/yr for v_w=10 km/s)

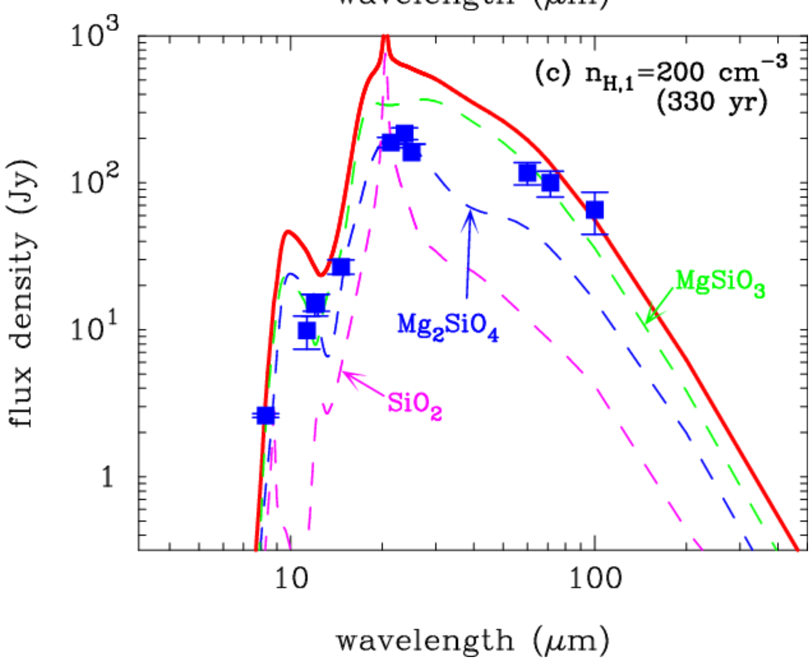
3-2. Time evolution of IR SEDs in Cas A SNR



3-3. Comparison with observations of Cas A







— $M_{IR,\,d}$ = 0.008 M_{sun}

($M_{shocked,\,d}$ ~ 0.1 M_{sun})

— dM/dt = 8x10^{-5} M_{sun}/yr

➔ dM/dt ~ 2x10^{-5} M_{sun}/yr for Cas A (Chevalier & Oishi 2003)

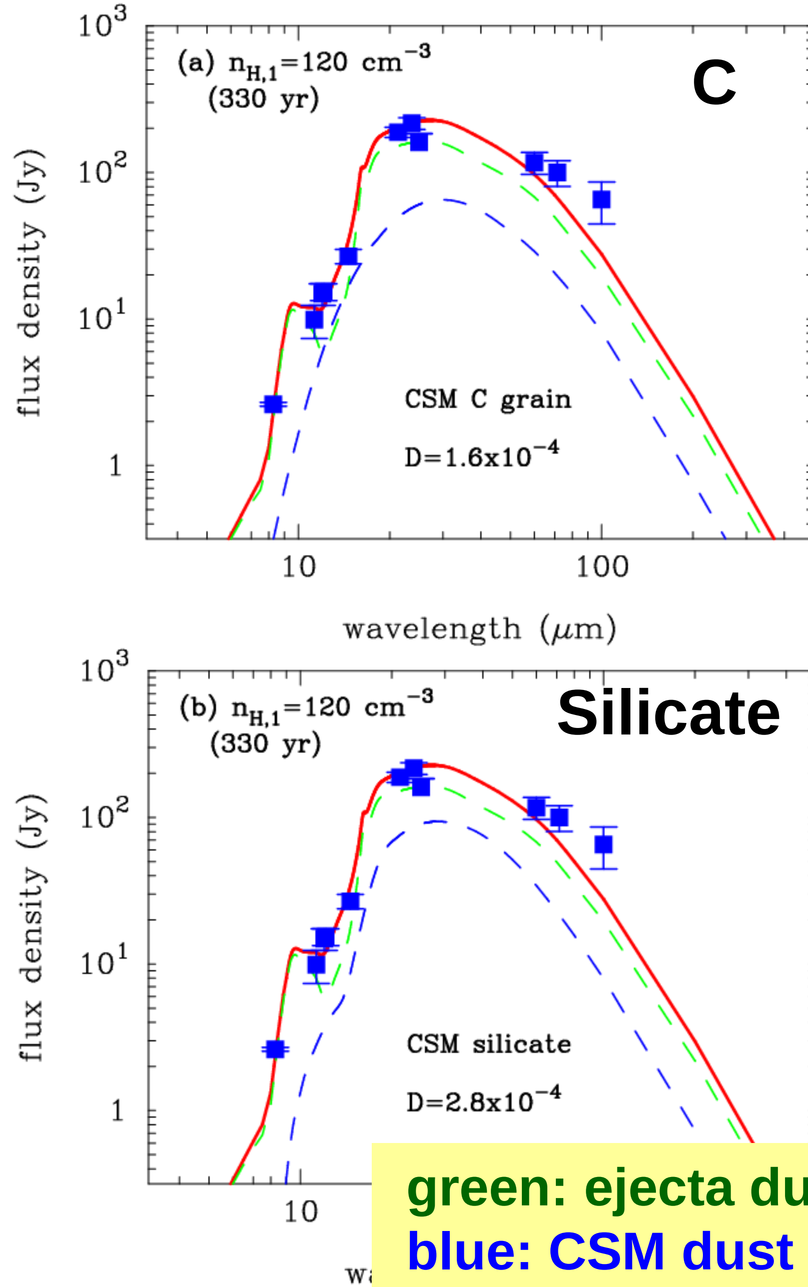
➔ dM/dt = (3-4)x10^{-5} M_{sun}/yr for 93J (Suzuki & Nomoto1995)

3-4. Contribution from circumstellar dust

○ CSM dust model

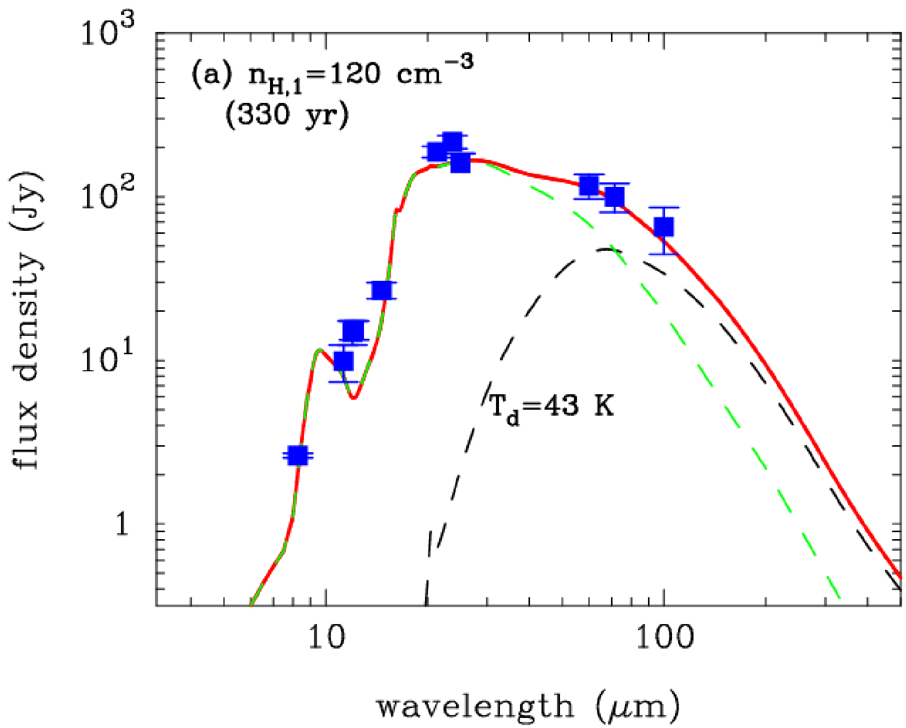
- dust species
  C and silicate
- dust size distribution
  f(a) ∝ a^-3.5
  a_{min} = 0.001 μm
  a_{max} = 0.5 μm
- dust-gas ratio: parameter

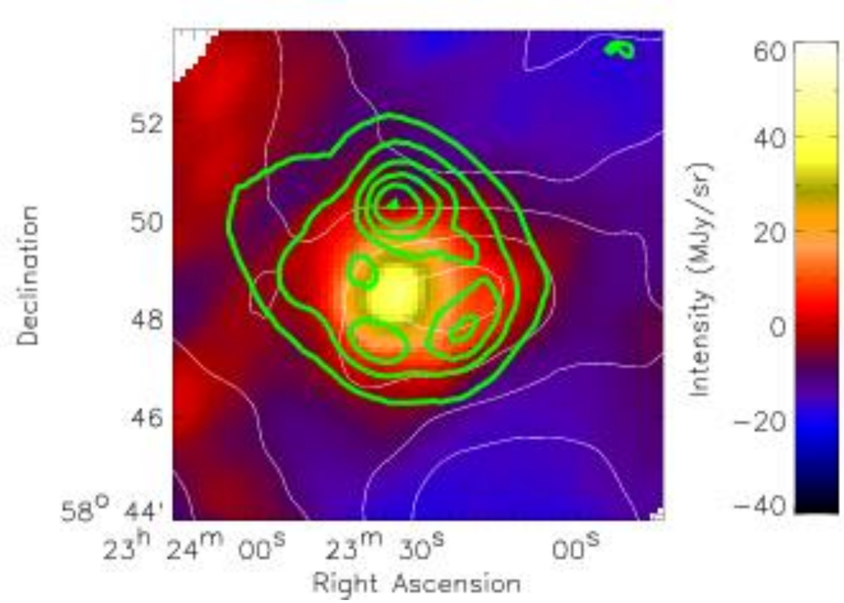
- CSM dust cannot compensate the flux densities at λ > 50 μm



green: ejecta dust
blue: CSM dust

3-5. Contribution from unshocked dust





Sibthorpe et al. 2009

observed IR SED can be well reproduced !

↑

- **$M_{d,warm}$ ~ 0.008 M_{sun}**
- **$M_{d,cool}$ ~ 0.07 M_{sun} with T_{dust} ~ 40 K**

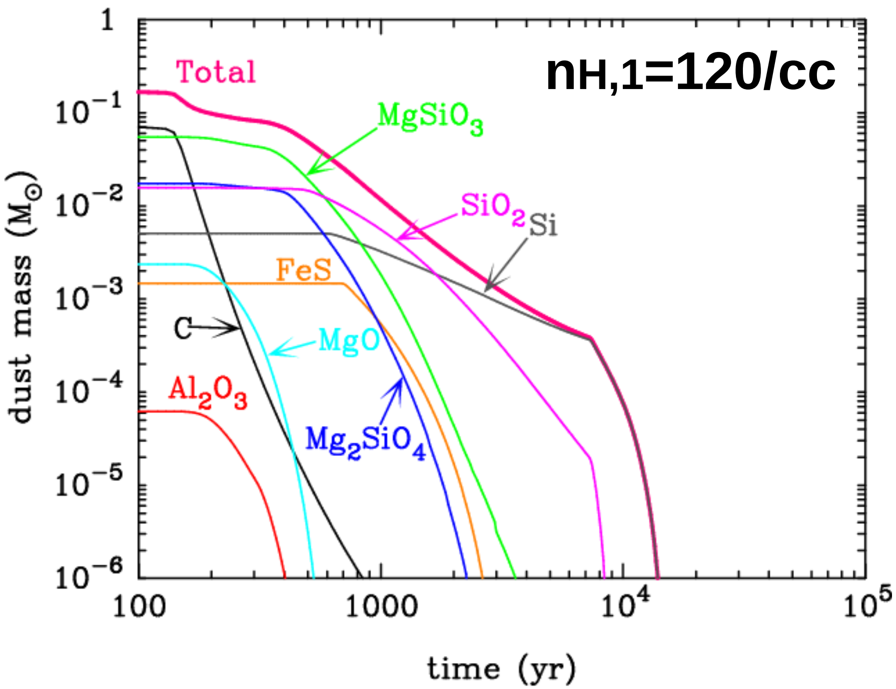
AKARI reduced 90μm image

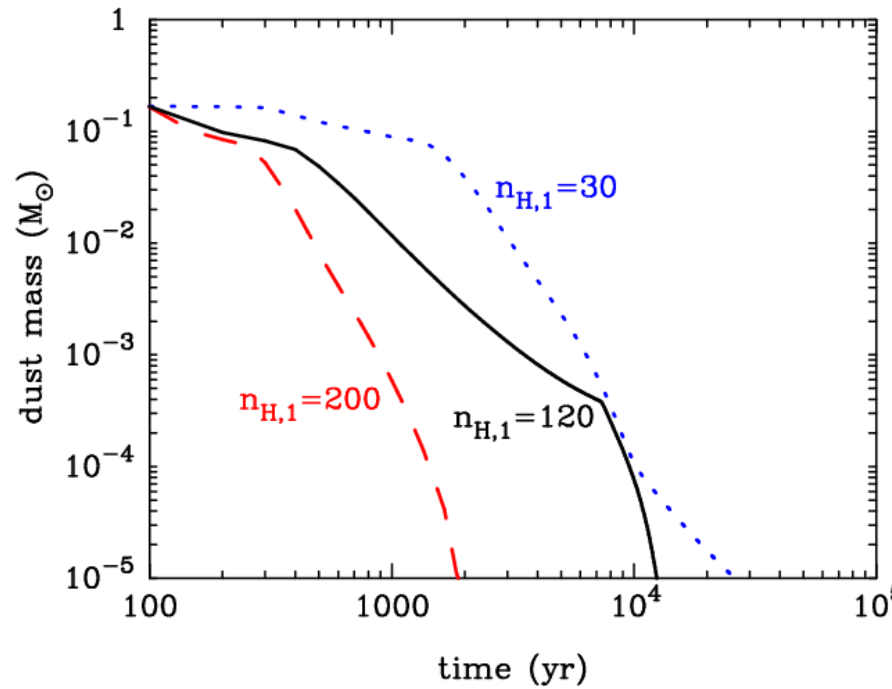
➔ centrally peaked cool dust component

↓

$M_{d,cool}$ = 0.03-0.06 M_{sun} with T_{dust} = 33-41 K

4-1. Fate of dust in Cas A SNR





- **All of the dust grains in Cas A would be destroyed in the shocked gas within the SNR before ~2x10^4 yr**
  - **➔ small grain size of newly formed dust**
  - **➔ early arrival of the reverse shock at the He core**

H-deficient SNe may not be major contributors of dust

- **0.01-0.8 Msun of dust survive for SNe II-P (Nozawa+2007)**

Summary

1) Birth of Dust in the ejecta of Cas A

Dust formed in Cas A was formed at 300-700 days after the explosion with a_{dust} < 0.01 μm and M_{dust} = 0.167 M_{sun}

2) Brightening of dust in the shocked hot gas

Model of dust destruction and heating in Type IIb SNR can reasonably reproduce the observed SED of Cas A;

$M_{d,warm}$ = 0.008 M_{sun}, $M_{d,cool}$ = 0.07 M_{sun}

dM/dt = ~8×10^{-5} M_{sun}/yr

3) Fate of dust in Cas A SNR

Small dust grains in Cas A will be completely destroyed in the shocked gas without being injected into the ISM