Dust Enrichment by Supernova Explosions

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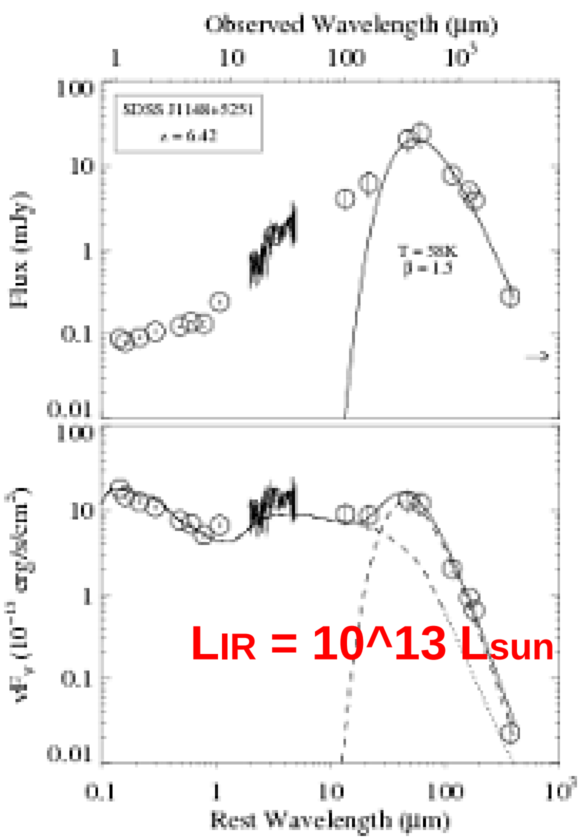
How does the cosmic dust evolve throughout the cosmic age?

When and how did the universe begin to be enriched with dust?

1-1. Discovery of huge amounts of dust at z > 5

There has been clear evidence for the presence of a large amount of dust (>10^8 Msun) in quasars at z > 5 (t < 1.2 Gyr)

SED of QSO at z=6.4



Leipski+'10, A&A, 518, L34

What is the origin of massive dust?

- **core-collapse SNe (Type II SNe)**

  ➔ ~0.1-1 Msun per SN is needed

  (Maiolino+'06; Dwek+'07; Gall+'11)

- **AGB stars + SNe**

  (Valiante+'09; Dwek & Cherchneff'11)

  ➔ 0.01-0.05 Msun per AGB stars

- **Grain growth in ISM + AGB stars + SNe**

  (Draine'09; Michalowski+'10; Pipino+'11; Asano-san' talk)

1-2. Dust formation and destruction in SNe

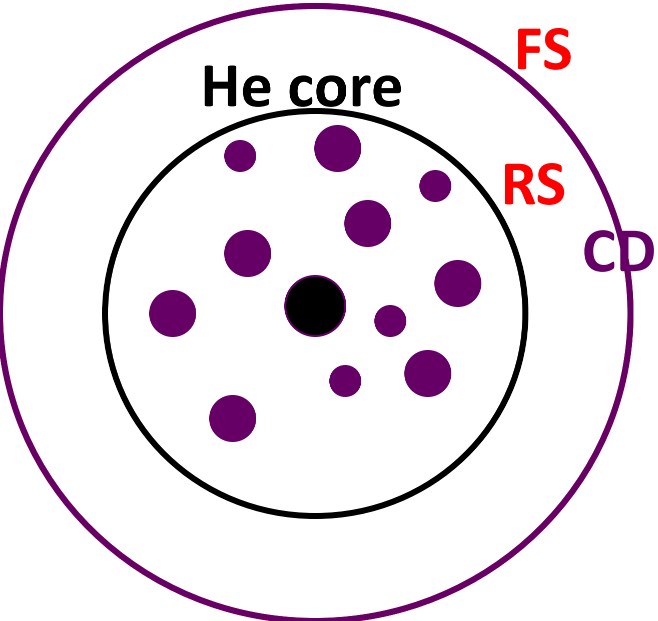
Supernovae may be sources of the first dust

・ **Theoretical studies on dust formation in the SN ejecta**

(Todini & Ferrara'01; Nozawa+'03; Schneider+'04; Bianchi & Schneider+'07; Cherchneff & Dwek'09, '10)

— M_{dust}=0.1-1 M_{sun} in (primordial) Type II-P SNe (SNe II-P)

its presence has not been proved observationally



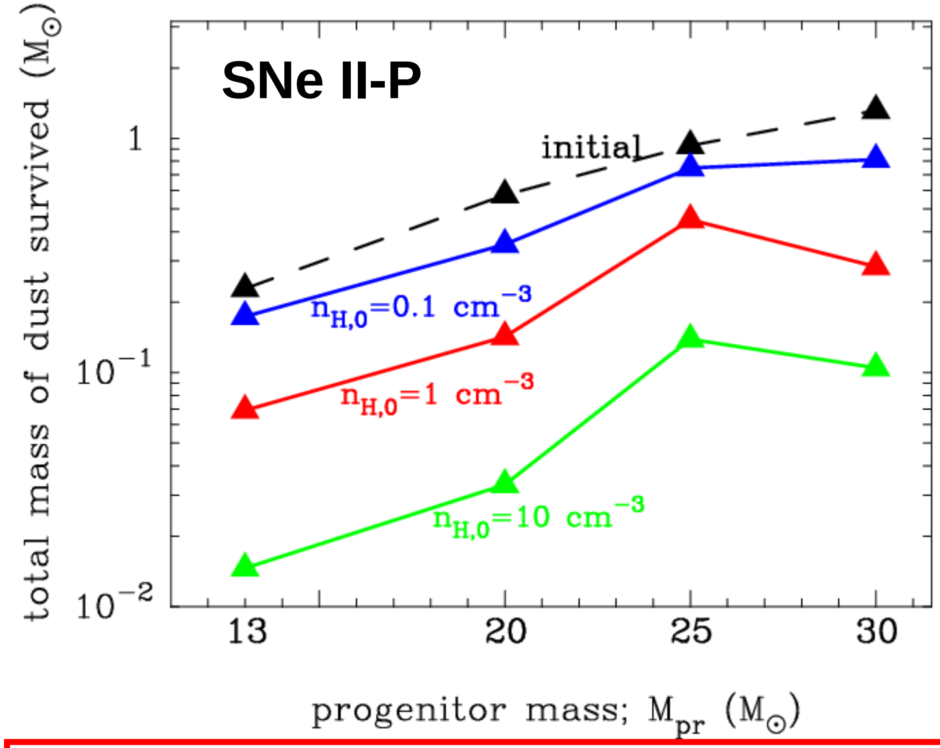
・ a part of dust grains formed in SNe are destroyed due to sputtering in the hot gas swept up by the shocks

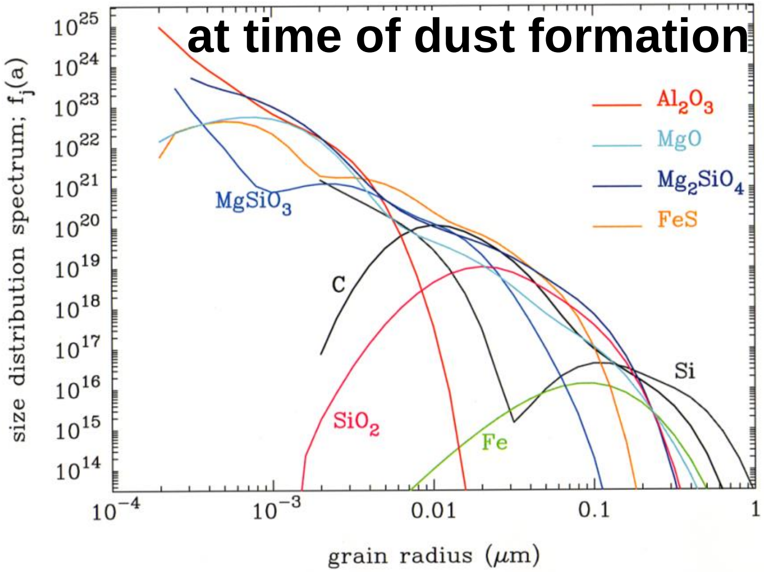
(Bianchi & Schneider'07; Nozawa+'07, '10)

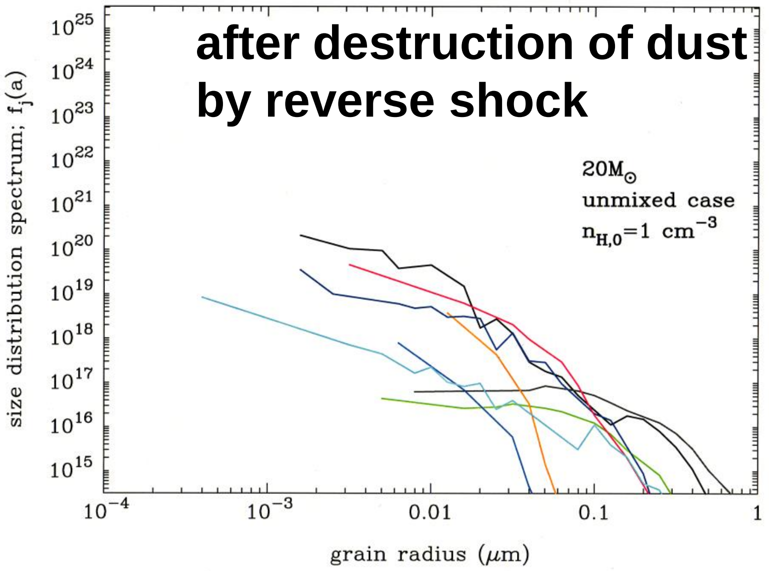
➔ the destruction efficiency of dust depends on the size distribution

1-3. Mass and size of dust ejected from SN II-P

Nozawa+2007, ApJ, 666, 955



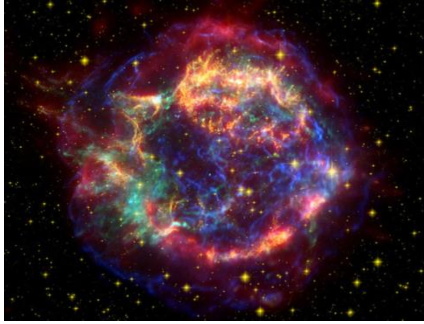




total dust mass surviving the destruction in Type II-P SNRs; 0.07-0.8 M_{sun} ($n_{H,0}$ = 0.1-1 cm^{-3})

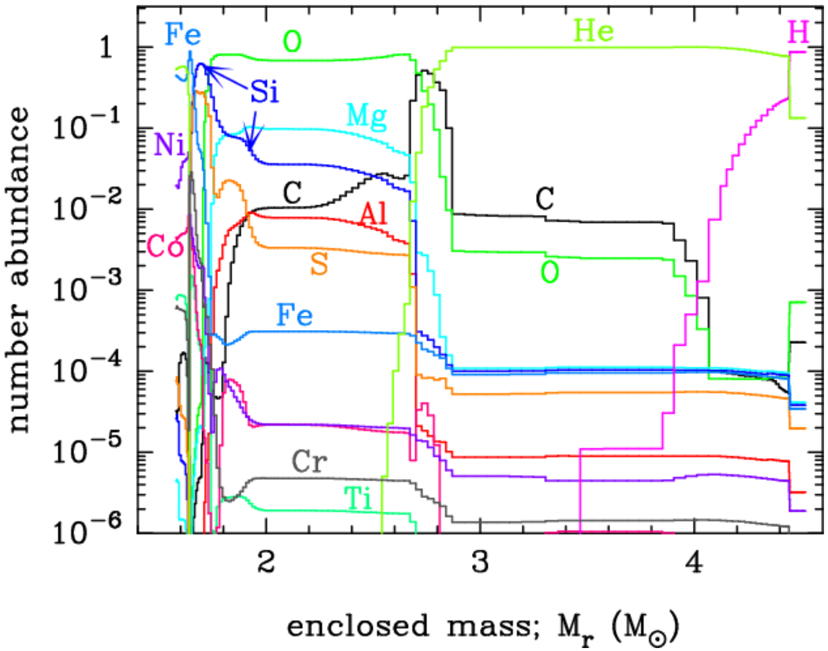
size distribution of dust after RS destruction is domimated by large grains (> 0.01 μm)

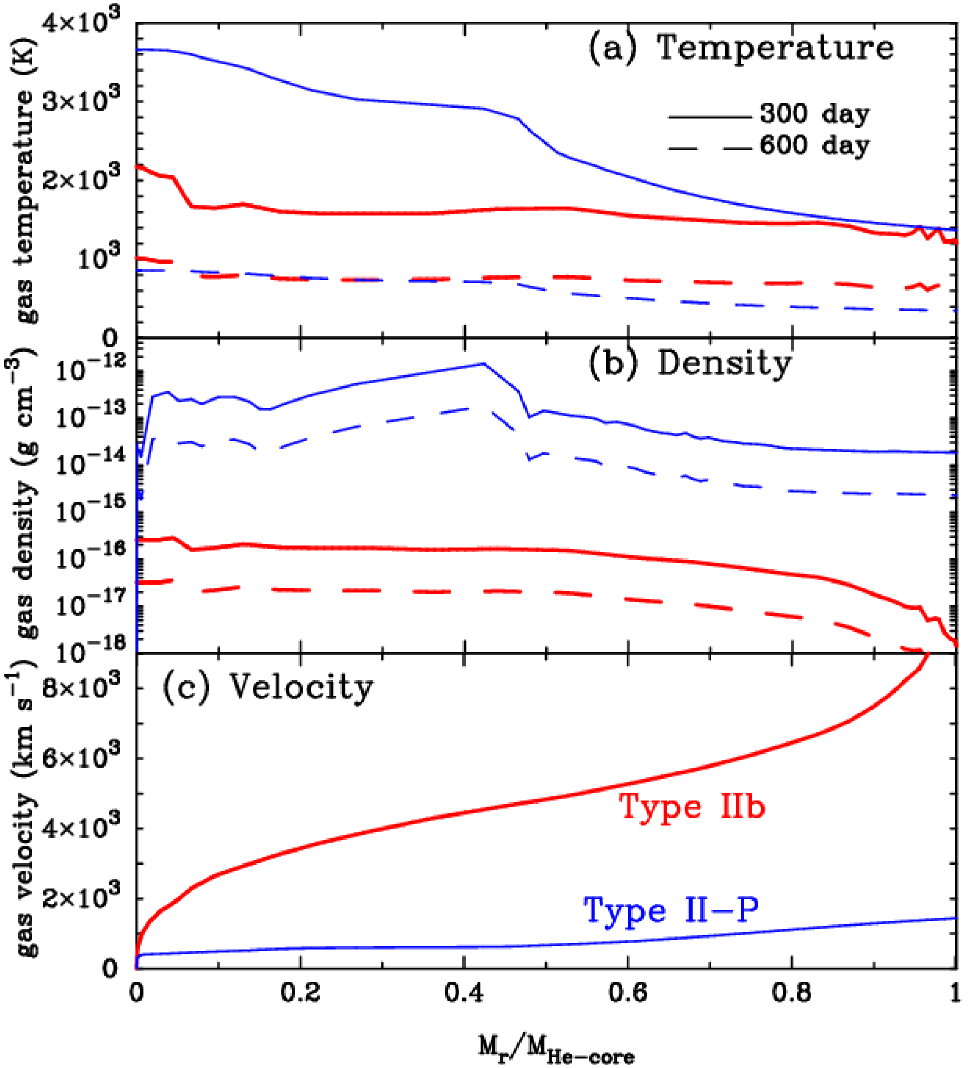
2-1. Dust formation in Type IIb SN



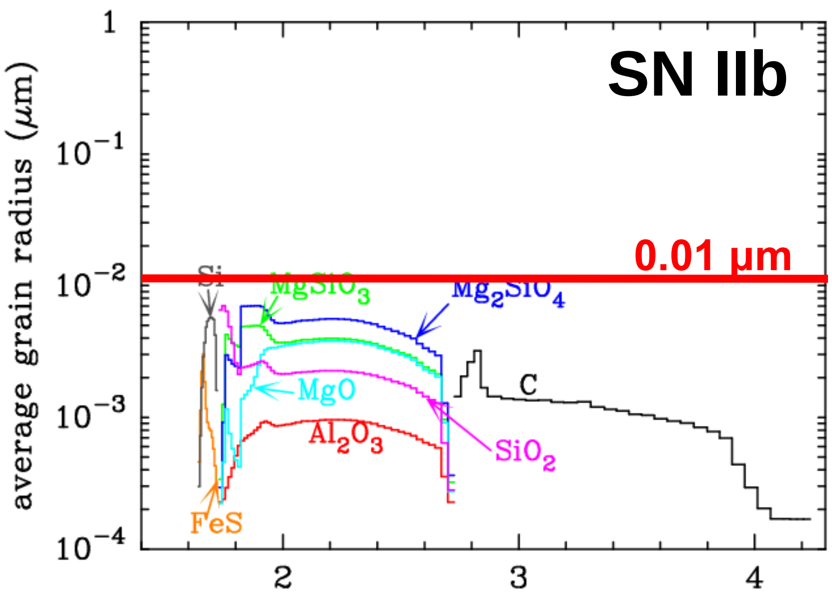
○ SN IIb model (SN1993J-like model)

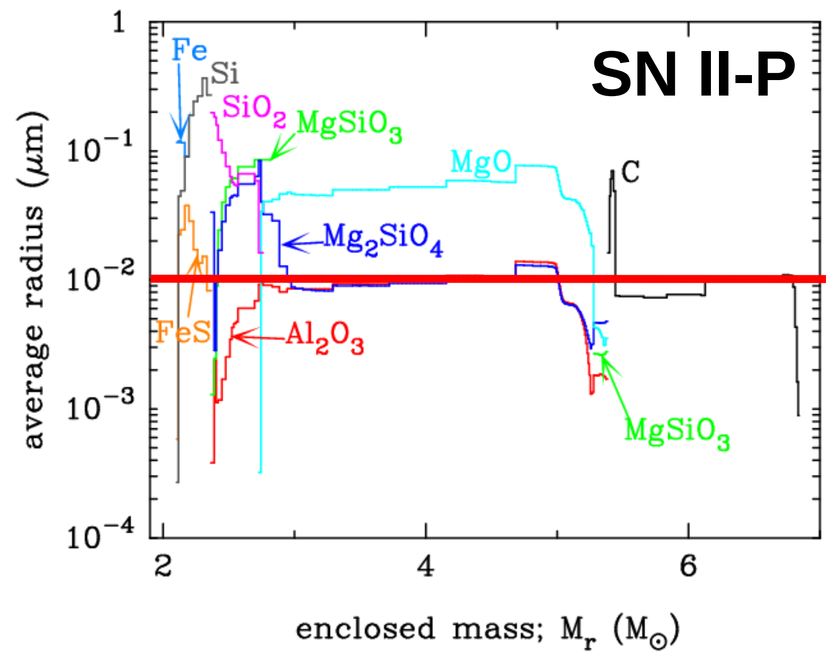
- M_{eje} = 2.94 M_{sun}
  M_{ZAMS} = 18 M_{sun}
  $M_{H\text{-}env}$ = 0.08 M_{sun}
- E_{51} = 1.0
- $M(^{56}Ni)$ = 0.07 M_{sun}

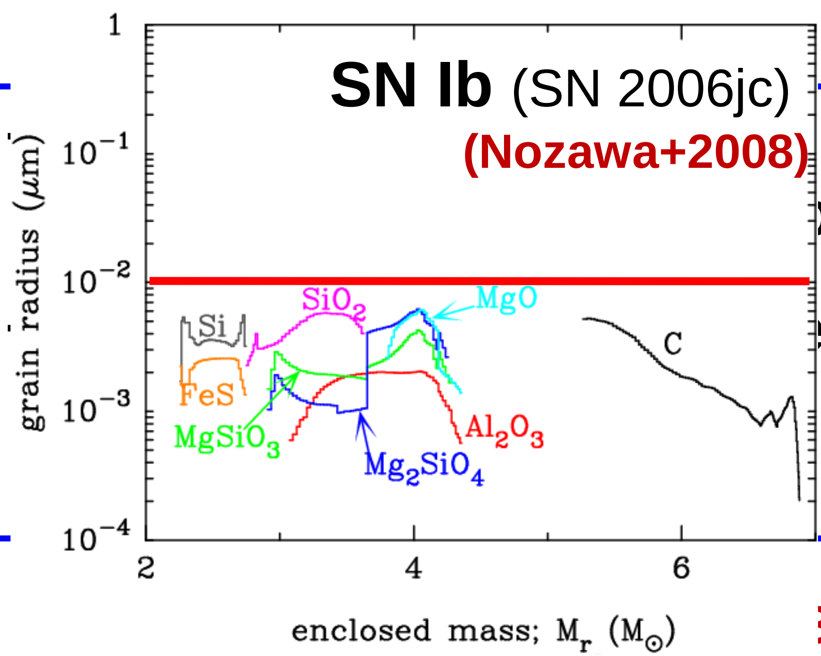




2-2. Dependence of dust radii on SN type







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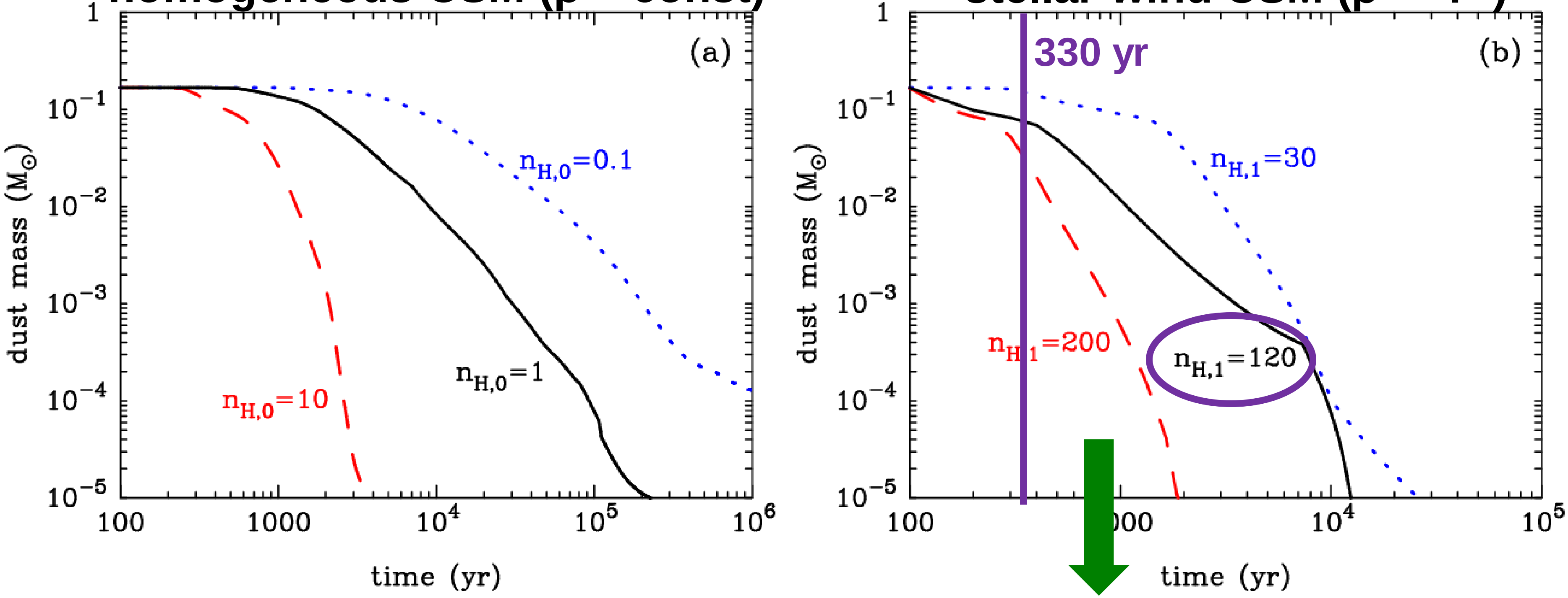
— the radius of dust formed in H-stripped SNe is small

- SN IIb without massive H-env ➔ a_{dust} < 0.01 μm
- SN II-P with massive H-env ➔ a_{dust} > 0.01 μm

2-3. Destruction of dust in Type IIb SNR

homogeneous CSM (ρ = const) stellar-wind CSM ($\rho \propto r^{-2}$)



$n_{H,1}$ = 30, 120, 200 /cc ➔ dM/dt = 2.0, 8.0, 13x10^{-5} M_{sun}/yr for v_W=10 km/s

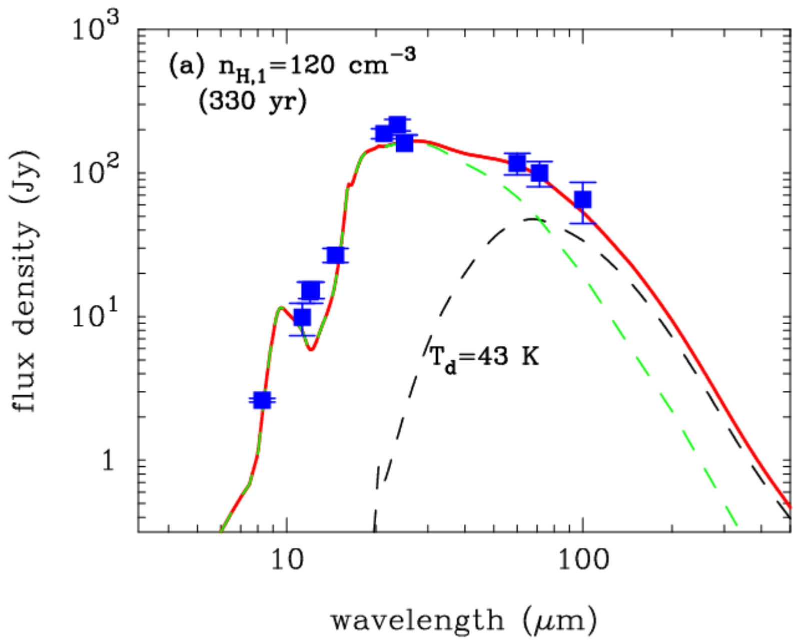
Almost all newly formed grains are destroyed in shocked gas within the SNR for CSM gas density of n_H > 0.1 /cc

➔ **small radius of newly formed dust**

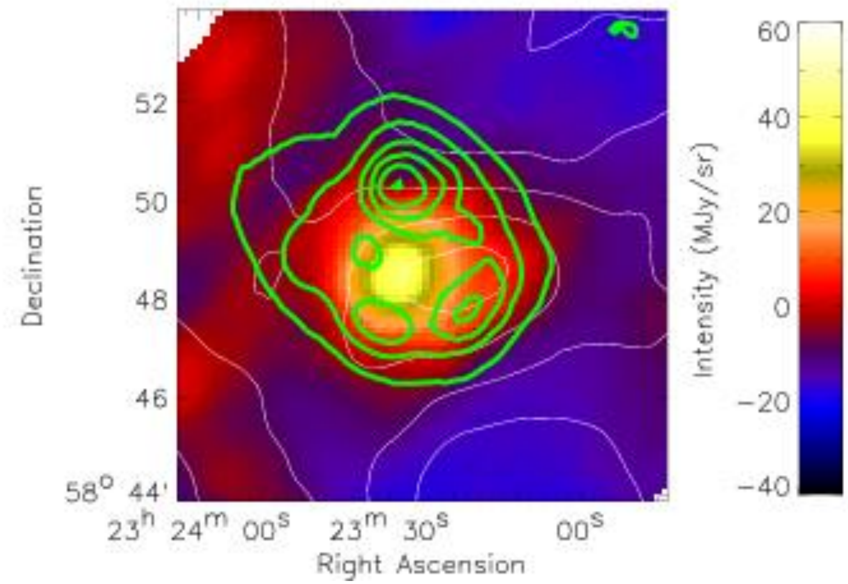
➔ **early arrival of reverse shock at dust-forming region**

Nozawa et al. 2010, ApJ, 713, 356

2-4. IR emission from dust in Cas A SNR



AKARI corrected 90 μm image



- total mass of dust formed
  M_{dust} = 0.167 M_{sun}
- shocked dust : 0.095 M_{sun}
  $M_{d,warm}$ = 0.008 M_{sun}
- unshocked dust :
  $M_{d,cool}$ = 0.072 M_{sun}
  with T_{dust} ~ 40 K

Nozawa et al. 2010, ApJ, 713, 356

AKARI observation

$M_{d,cool}$ = 0.03-0.06 M_{sun}

T_{dust} = 33-41 K

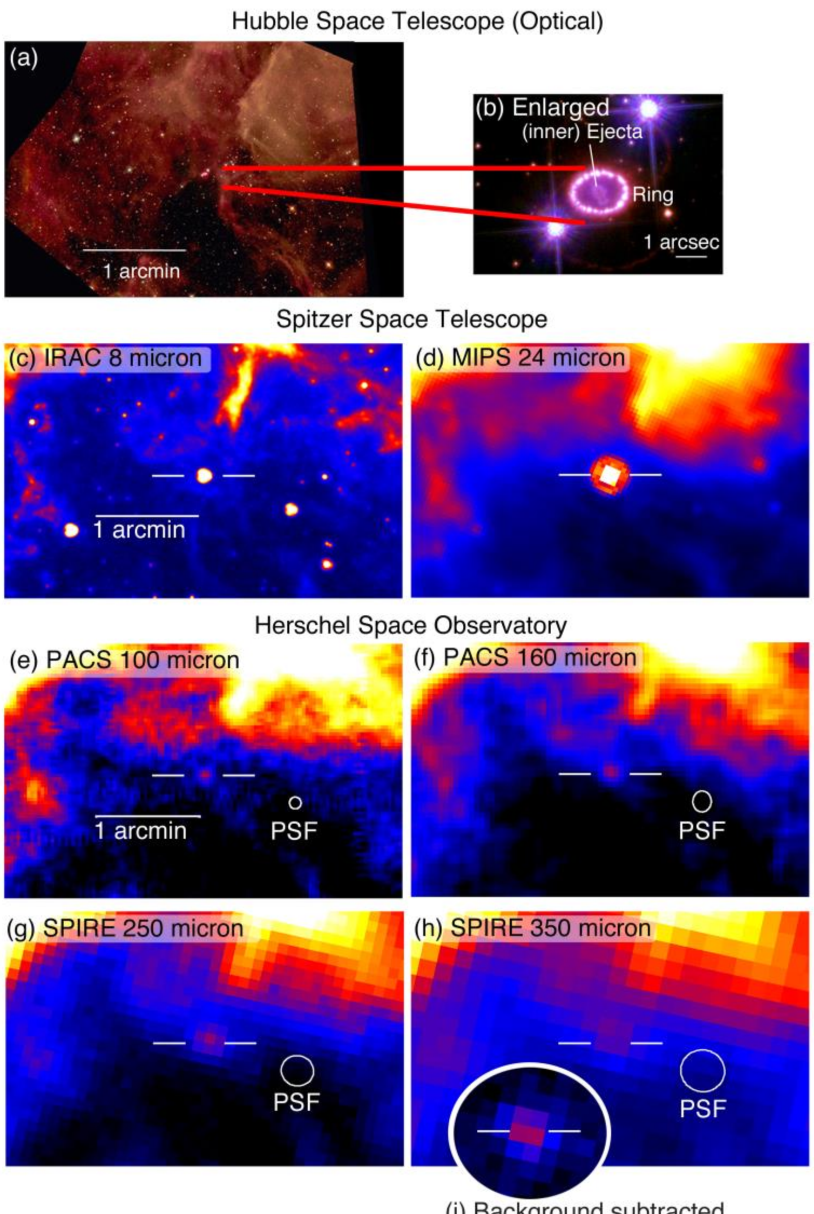
(Sibthorpe+'10)

Herschel observation

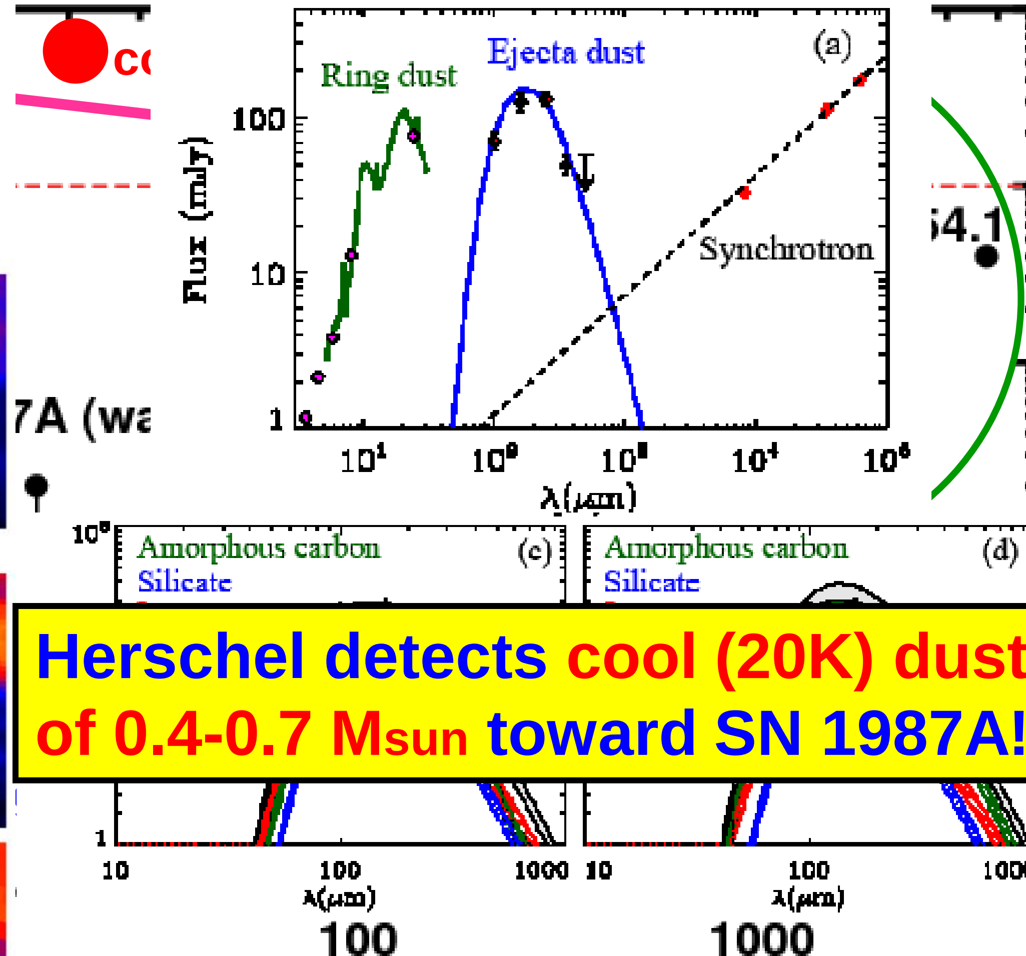
$M_{d,cool}$ = 0.075 M_{sun}

T_{dust} ~ 35 K (Barlow+'10)

3. Missing-dust problem in CCSNe



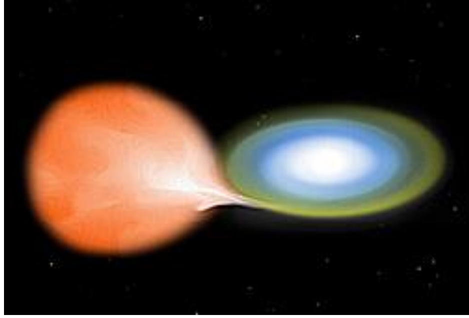
Matsuura, ..., TN, et al. 2011, Science



Herschel detects cool (20K) dust of 0.4-0.7 Msun toward SN 1987A!

nce in the mass of dust between
tes and theoretical predictions!!

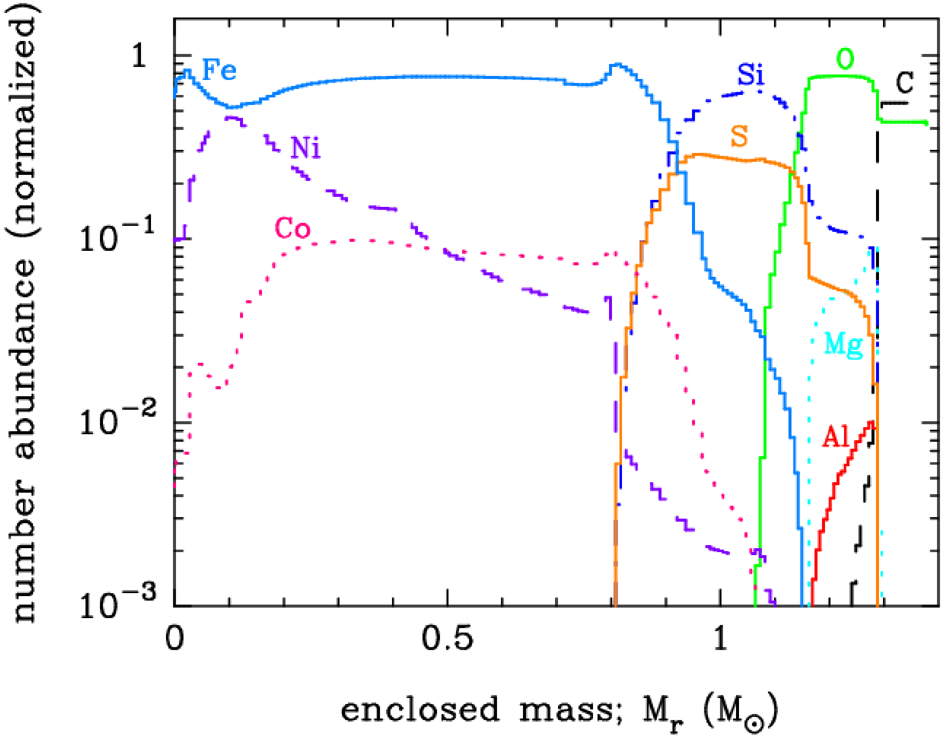
4-1. Dust formation in Type Ia SNe

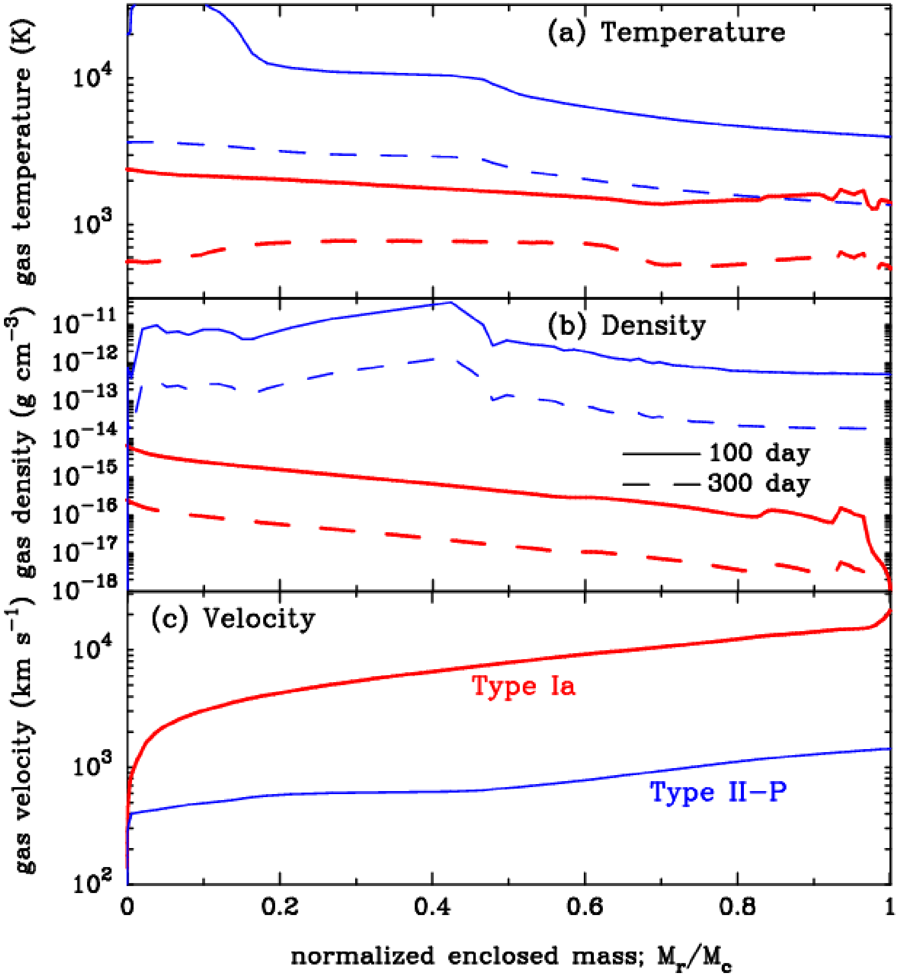


○ Type Ia SN model

W7 model (C-deflagration) **(Nomoto+'84; Thielemann+'86)**

- M_{eje} = 1.38 Msun
- E_{51} = 1.3
- M(^{56}Ni) = 0.6 Msun

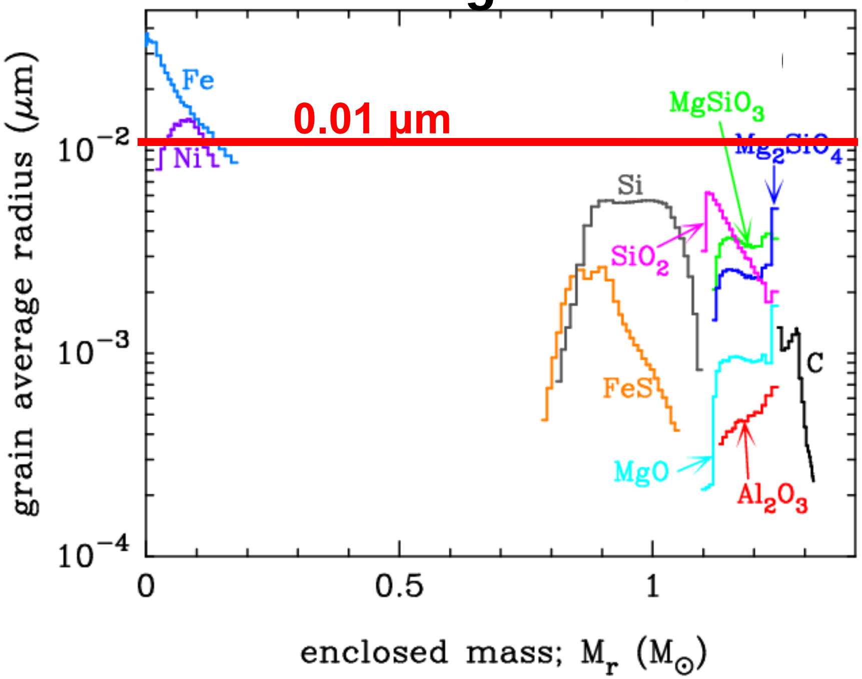




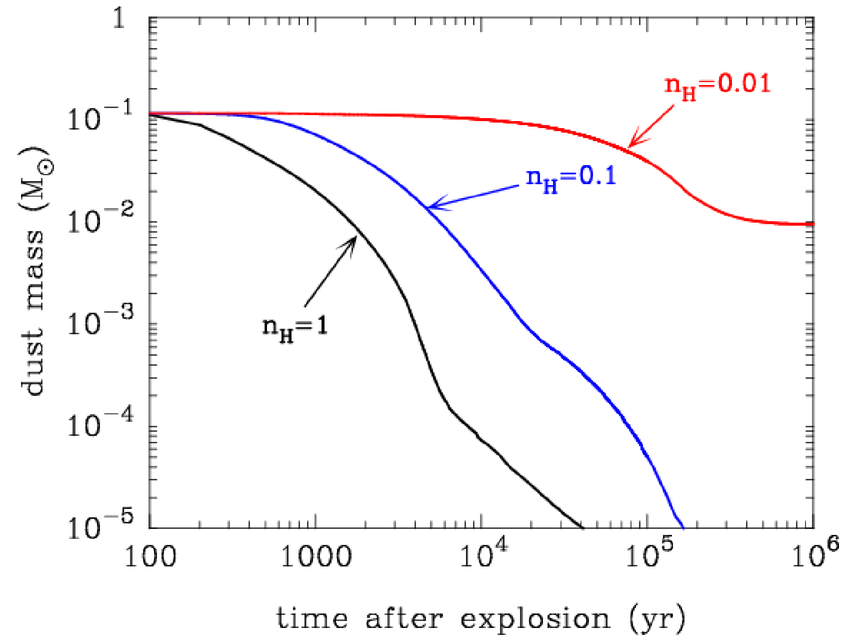
4-2. Dust formation and evolution in SNe Ia

Nozawa et al. 2011, ApJ, 736, 45

average radius



dust destruction in SNRs



- **condensation time :**
  100-300 days
- **average radius of dust :**
  a_{ave} <~ 0.01 μm
- **total dust mass :**
  M_{dust} ~ 0.1 M_{sun}

newly formed grains are completely destroyed for ISM density of n_H > 0.1 cm^{-3}

➔ SNe Ia are poor sources of interstellar dust

5. Summary of this talk

・ Type II SNe with massive H envelopes

— radius of dust formed : a_{ave} > 0.01 μm

➔ H-retaining SNe may be important sources of dust, supplying 0.1-1.0 M_{sun} of dust to the ISM

・ Type IIb/Ib/Ia SNe without massive H envelopes

— grain radius formed : a_{ave} < 0.01 μm

➔ dust is almost completely destroyed in the SNRs

➔ H-stripped SNe are not likely to be sources of dust

∗ Our model treating dust formation and evolution self-consistently can reproduce the IR emission from Cas A SNR

・ Mass of dust in young SNRs are dominated by cool dust

— FIR and submm observations of SNRs are essential

➔ Herschel detected massive cool dust in SN 1987A