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Dust in supernovae

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1-1. Introduction

・SNe are important sources of interstellar dust?

— huge amounts of dust grains (>10^8 M_{sun}) are detected in host galaxies of quasars at redshift z > 5

➔ 0.1 M_{sun} of dust per SN is needed to be ejected to explain such massive dust at high-z (Dwek et al. 2007)

— contribution of dust mass from AGB stars and SNe

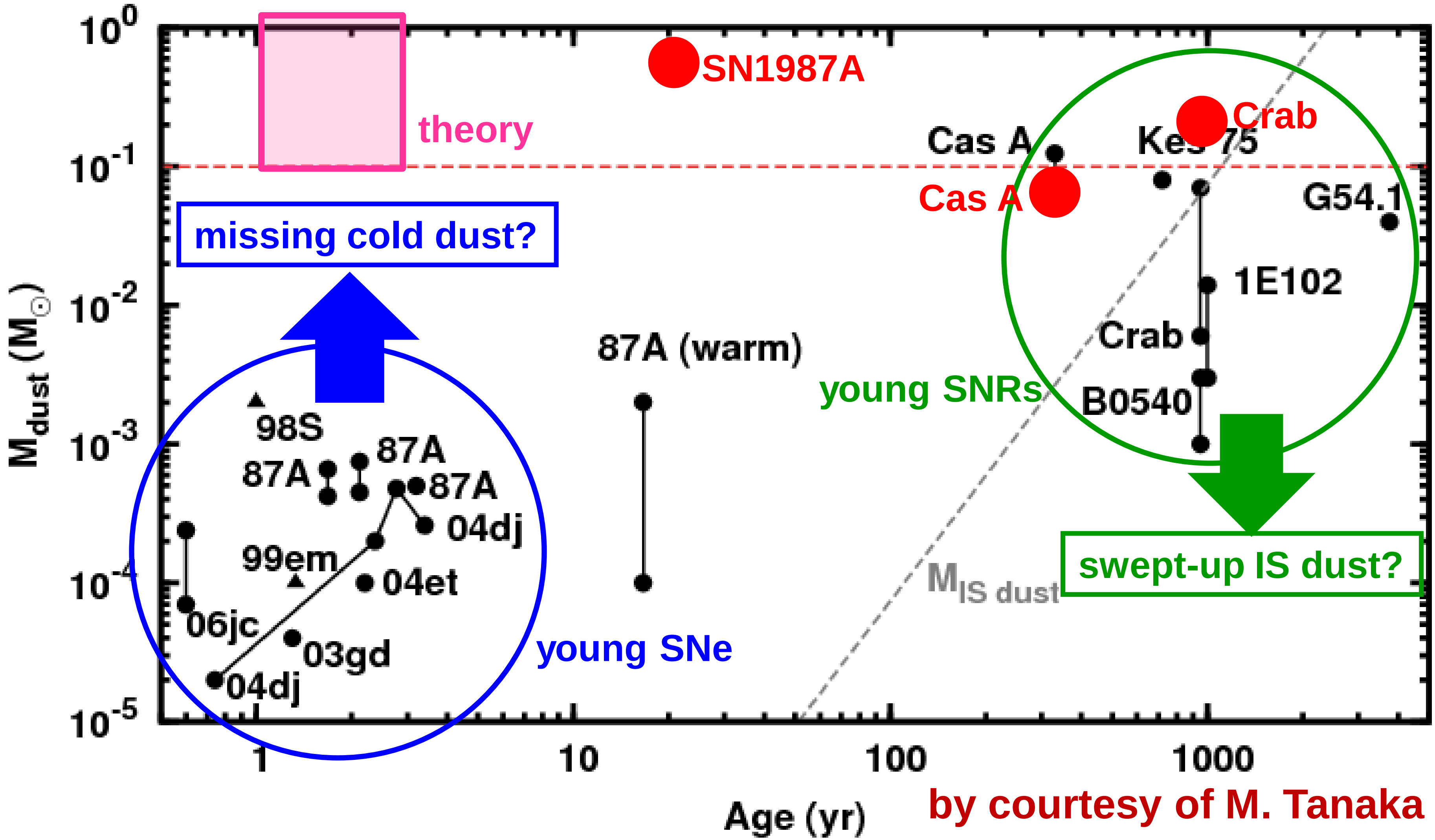
n(AGB stars) / n(SNe) ~ 10-20

M_{dust} = 0.01-0.05 M_{sun} per AGB (Zhukovska & Gail 2008)

M_{dust} = 0.1-1.0 M_{sun} per SN (Nozawa et al. 2003; 2007)

What composition, size, and mass of dust can be formed in SNe?

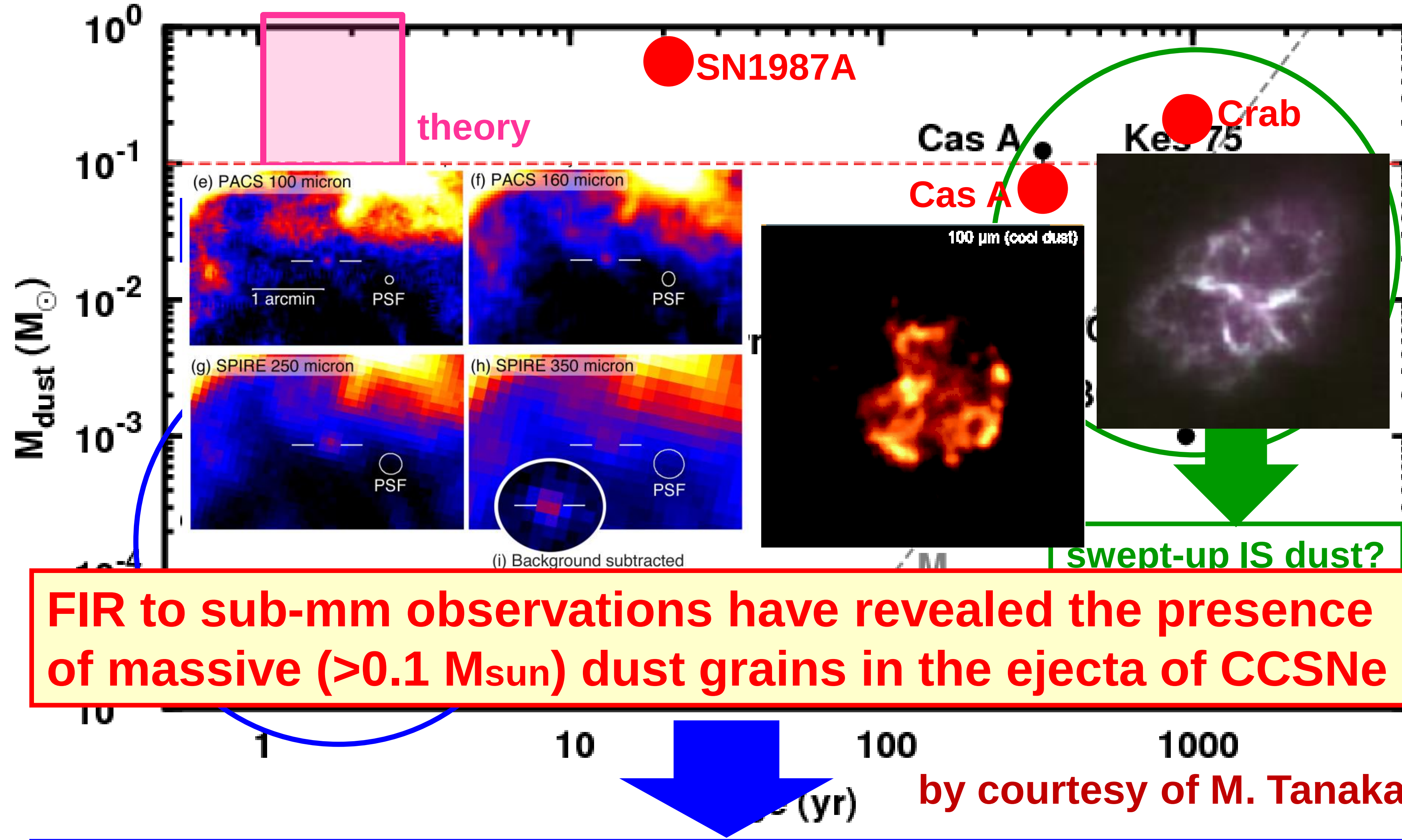
1-2. Summary of observed dust mass in CCSNe



by courtesy of M. Tanaka

FIR to sub-mm observations have revealed the presence of massive (>0.1 Msun) dust grains in the ejecta of CCSNe

1-2. Summary of observed dust mass in CCSNe



FIR to sub-mm observations have revealed the presence of massive (>0.1 Msun) dust grains in the ejecta of CCSNe

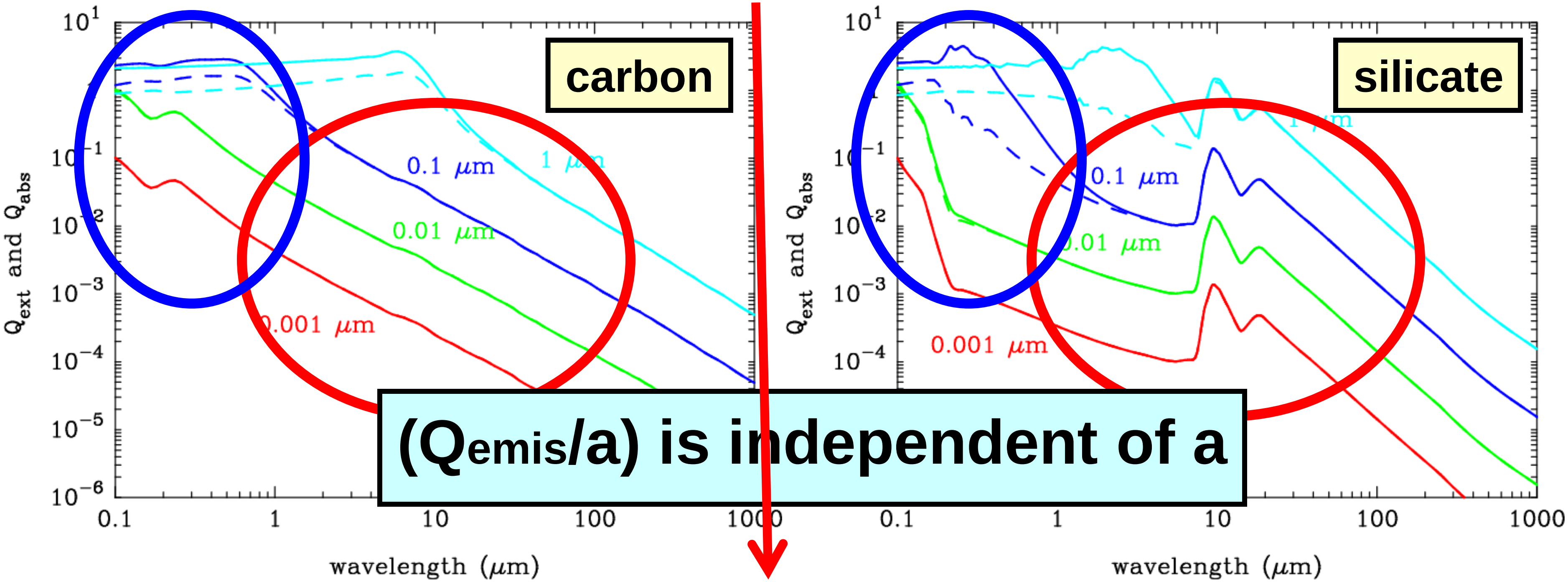
by courtesy of M. Tanaka

What mass of the newly formed grains can survive to be injected into the interstellar space?

1-3. Emission and absorption efficiency of dust

○ Thermal radiation from dust grains

$F_\lambda \propto 4\pi a^2\, Q_{emis}(a,\lambda)\, \pi B_\lambda(T_{dust})$ # $Q_{emis} = Q_{abs}$



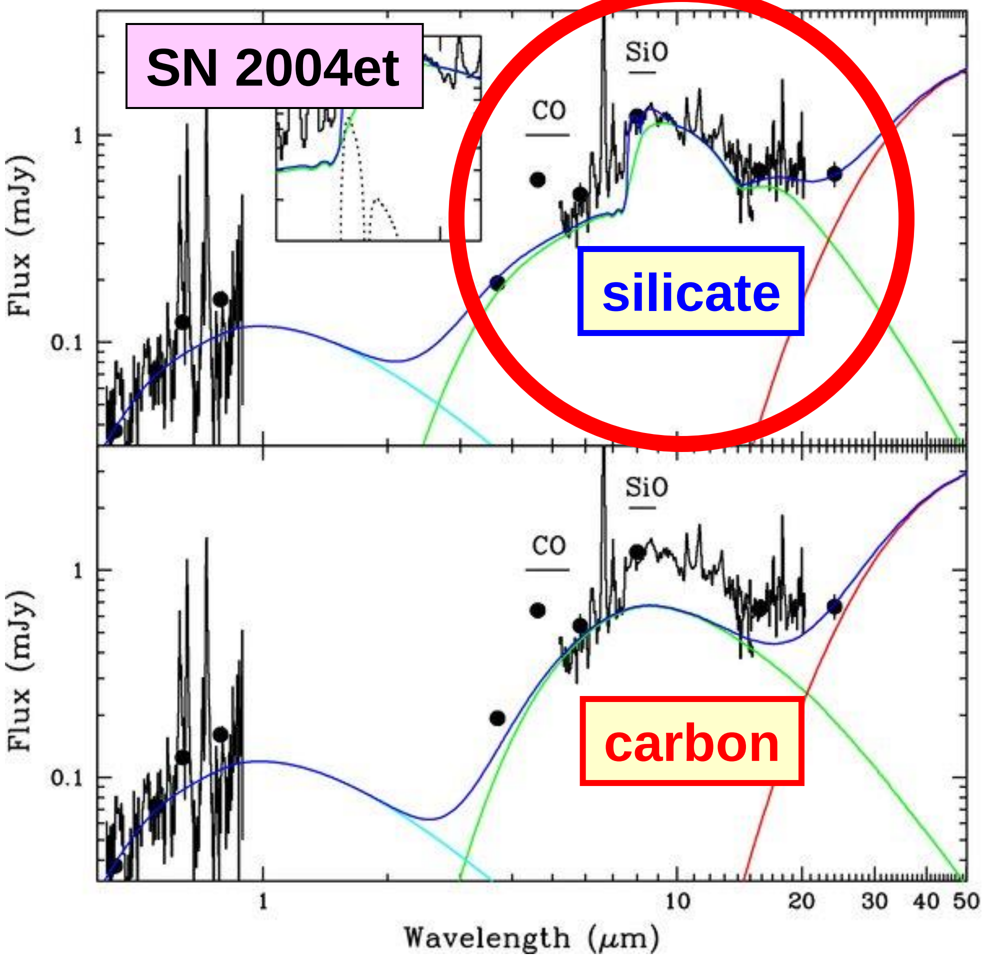
$F_\lambda \propto 4\pi a^3\, (Q_{emis}[a,\lambda]/a)\, \pi B_\lambda(T_{dust})$

$\propto 4\, M_{dust}\, \kappa_{emis}(\lambda)\, \pi B_\lambda(T_{dust})$

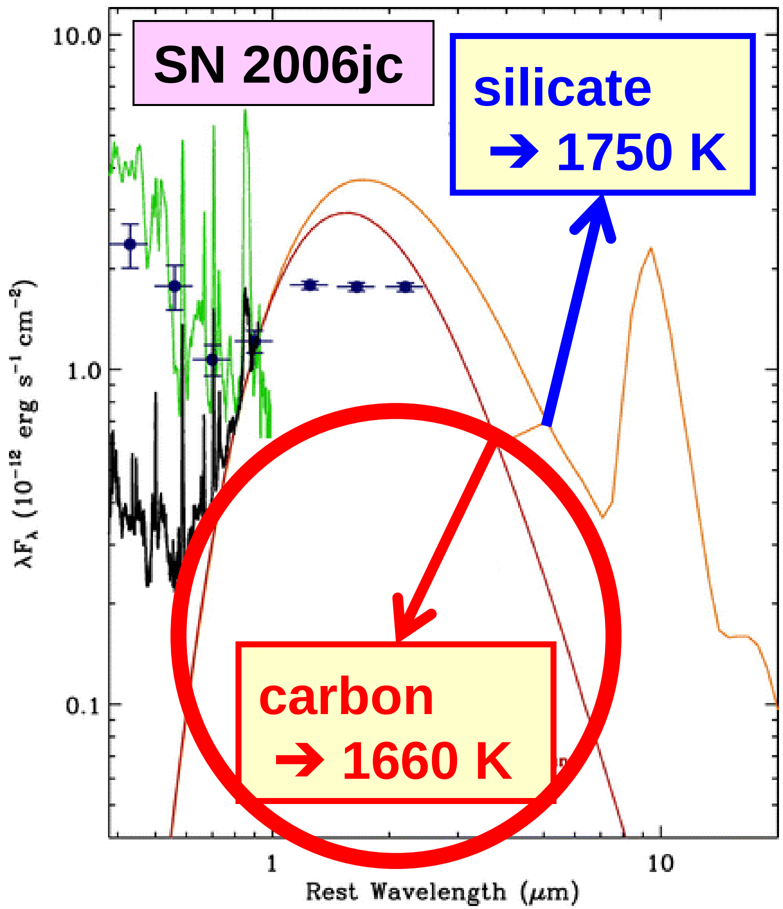
➔ IR emission is derived given M_{dust}, κ_{abs}, and T_{dust}

1-4. Composition of dust formed in SNe

IS dust : carbonaceous grain and silicate ($MgSiO_3$, $MgFeSiO_4$, …)

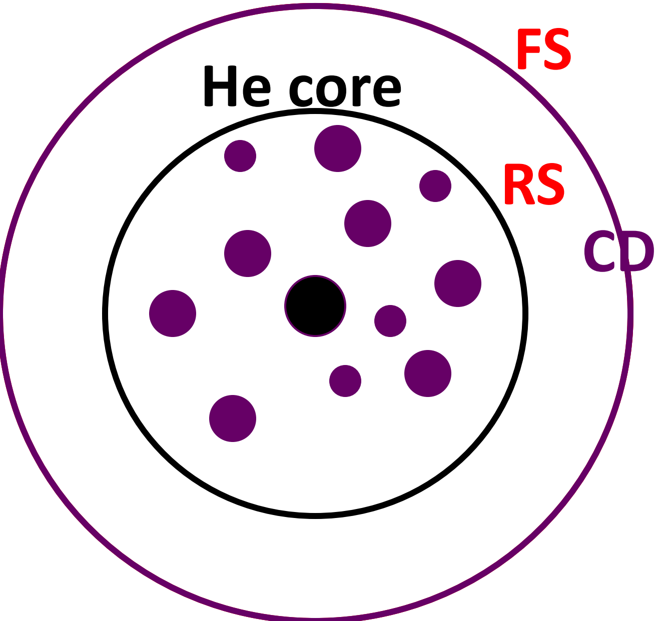


SN 2004et, Kotak+09

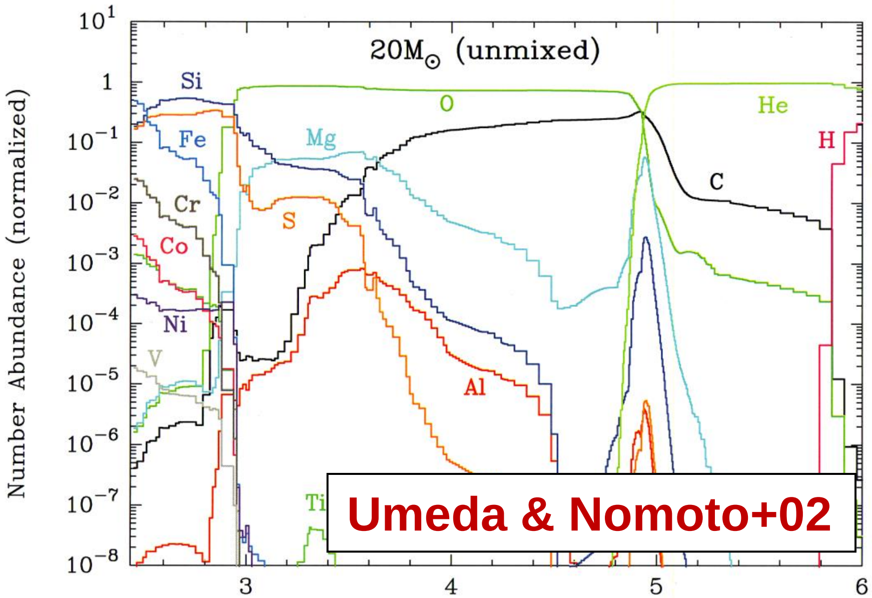


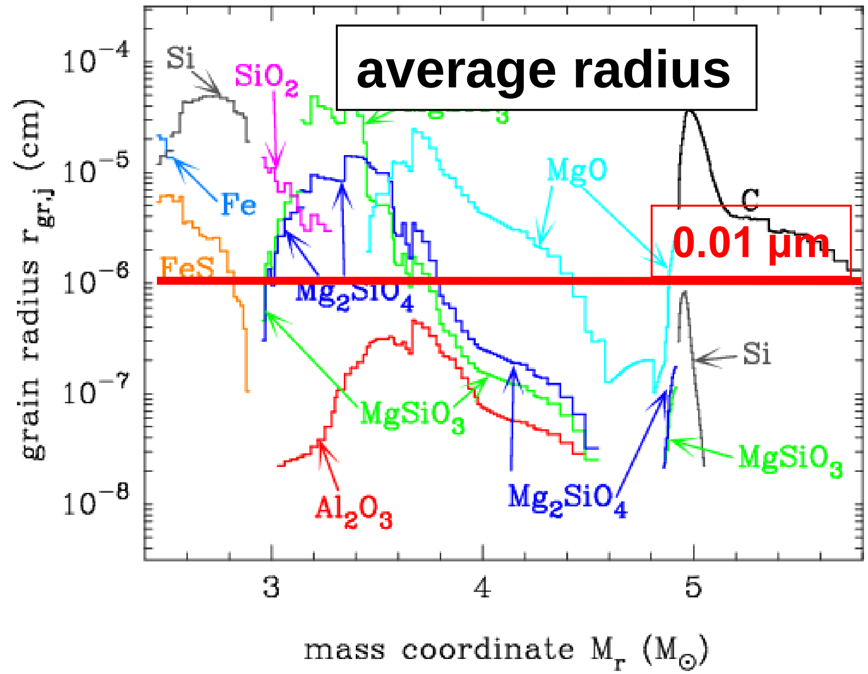
SN 2006jc, Smith+08
SN 2010jl, Keiichi's talk

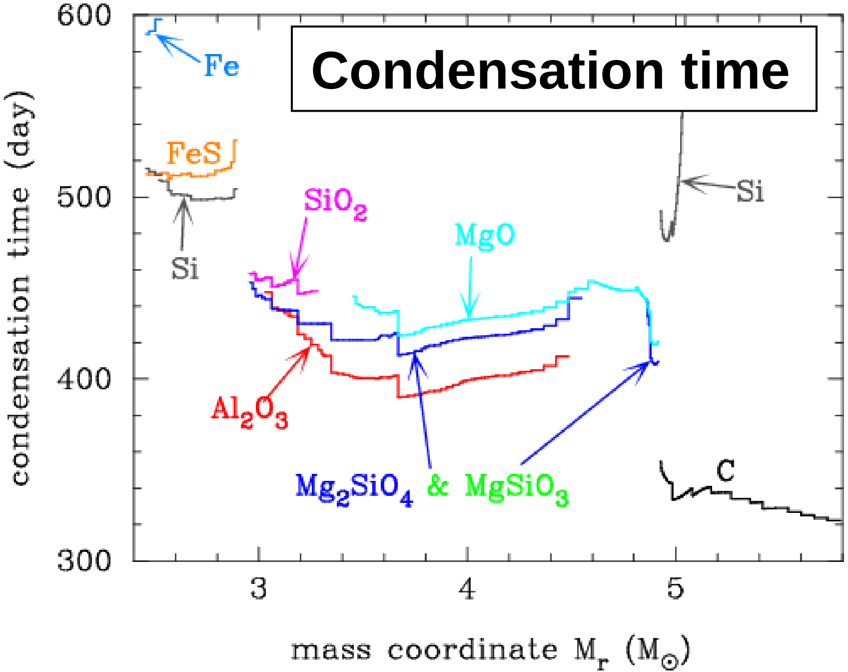
2. Formation and evolution of dust in supernovae



2-1. Dust formed in Type II-P SNe





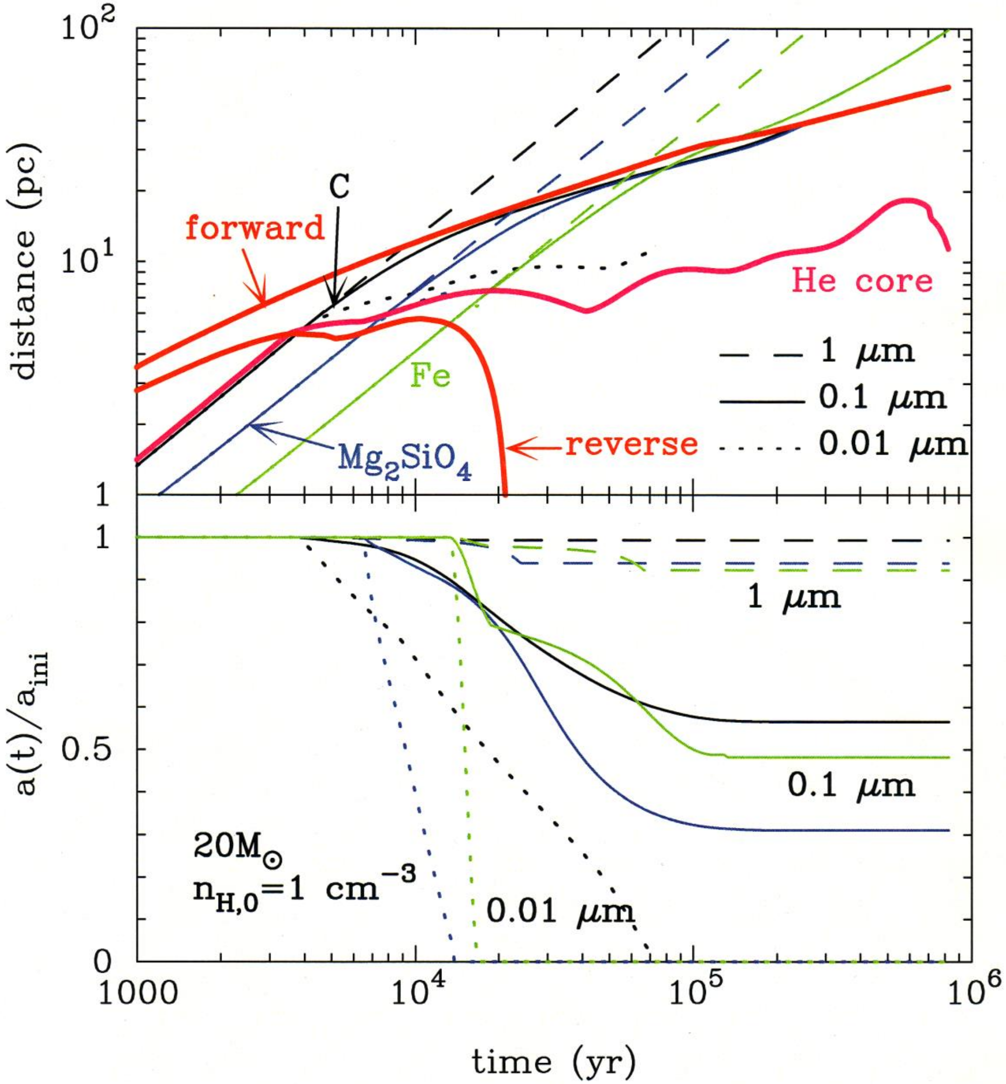


- various dust species form according to composition of gas in each layer
- condensation time: **300-600d** after explosion
- average radii: **>~0.01 μm**

Nozawa+03, ApJ, 598, 785

2-2. Evolution of dust in SNRs

Nozawa+07, ApJ, 666, 955



Model : Type II-P

M_{pr}= 20 Msun (E_{51}=1)

$n_{H,0}$ = 1 cm^{-3}

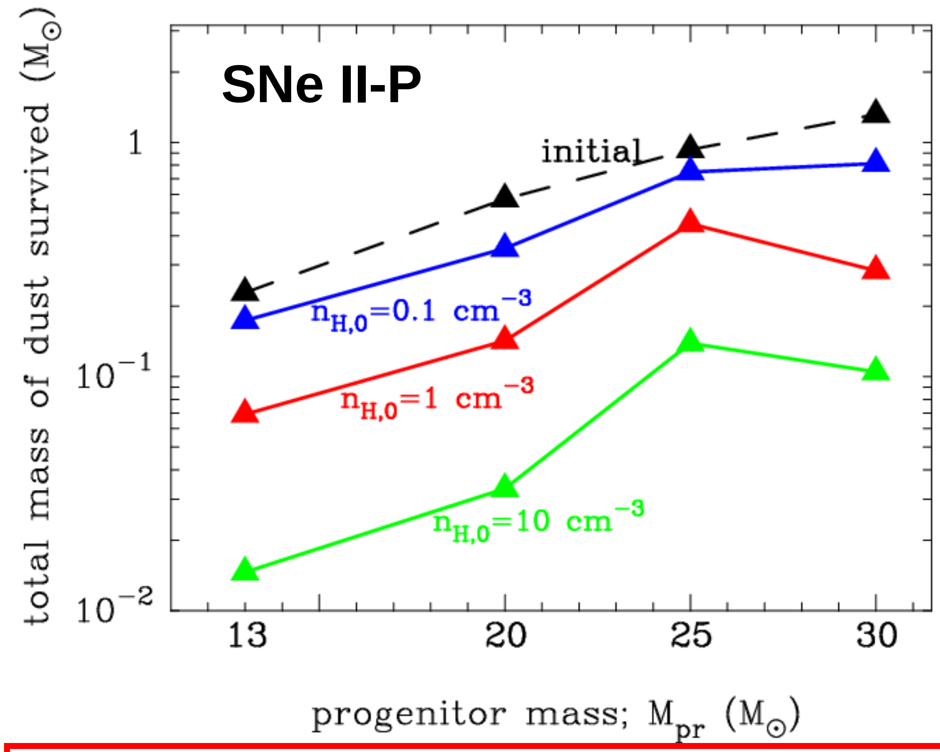
Dust grains in the He core collide with reverse shock at (3-13)x10^3 yr

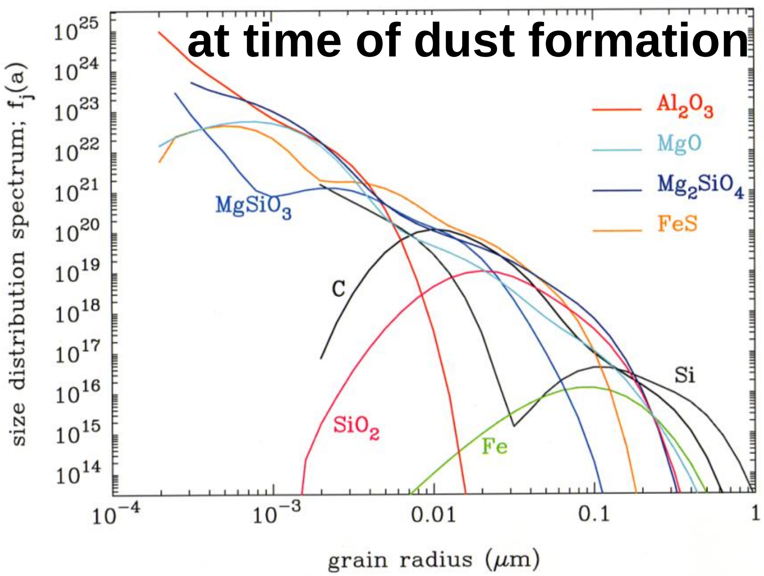
The evolution of dust heavily depends on the initial radius and composition

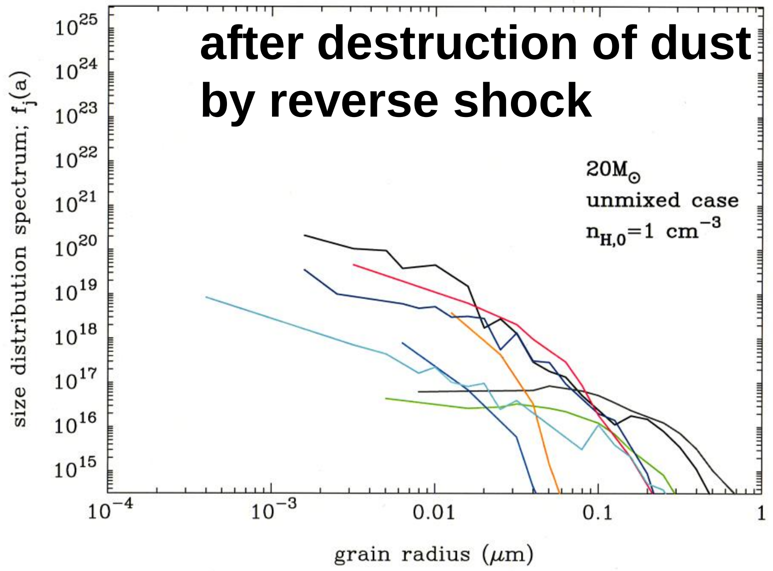
a_{ini} = 0.01 μm (dotted lines)
➔ completely destroyed
a_{ini} = 0.1 μm (solid lines)
➔ trapped in the shell
a_{ini} = 1 μm (dashed lines)
➔ injected into the ISM

2-3. Mass and size of dust ejected from SN II-P

Nozawa+2007, ApJ, 666, 955



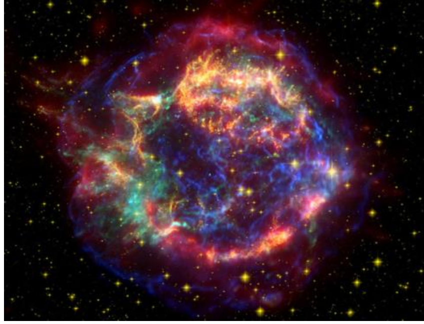




total dust mass surviving the destruction in Type II-P SNRs;
0.07-0.8 Msun ($n_{H,0}$ = 0.1-1 cm^{-3})

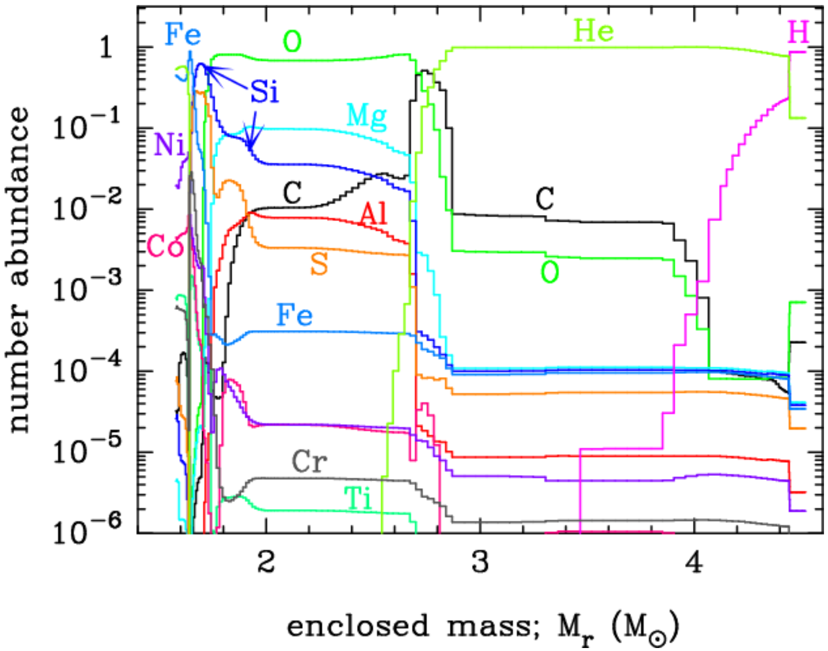
size distribution of dust after RS destruction is domimated by large grains (> 0.01 μm)

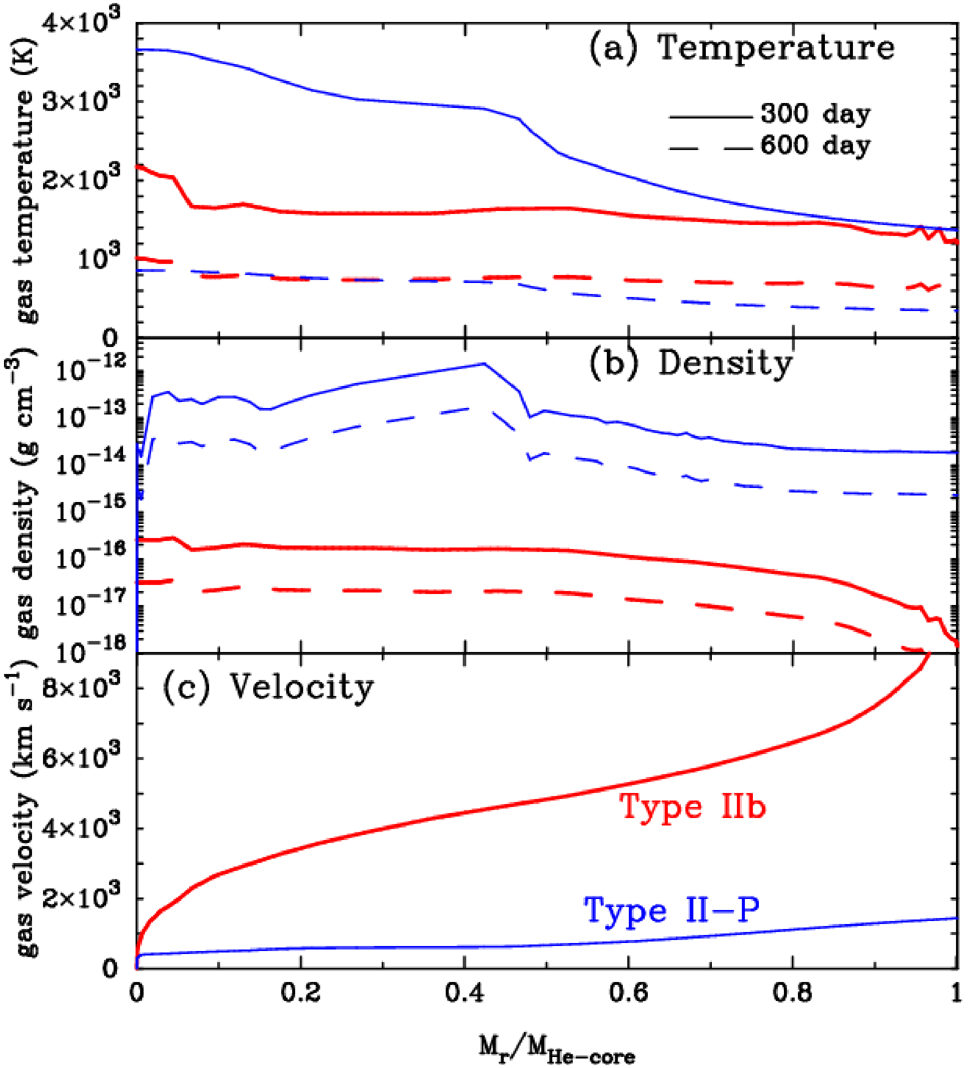
3-1. Dust formation in Type IIb SN



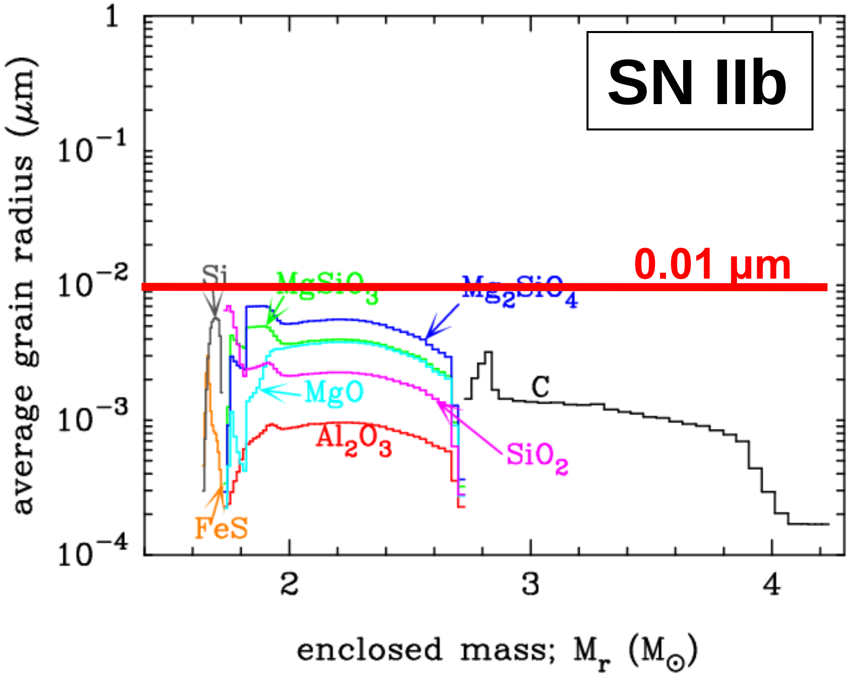
○ SN IIb model (SN1993J-like model)

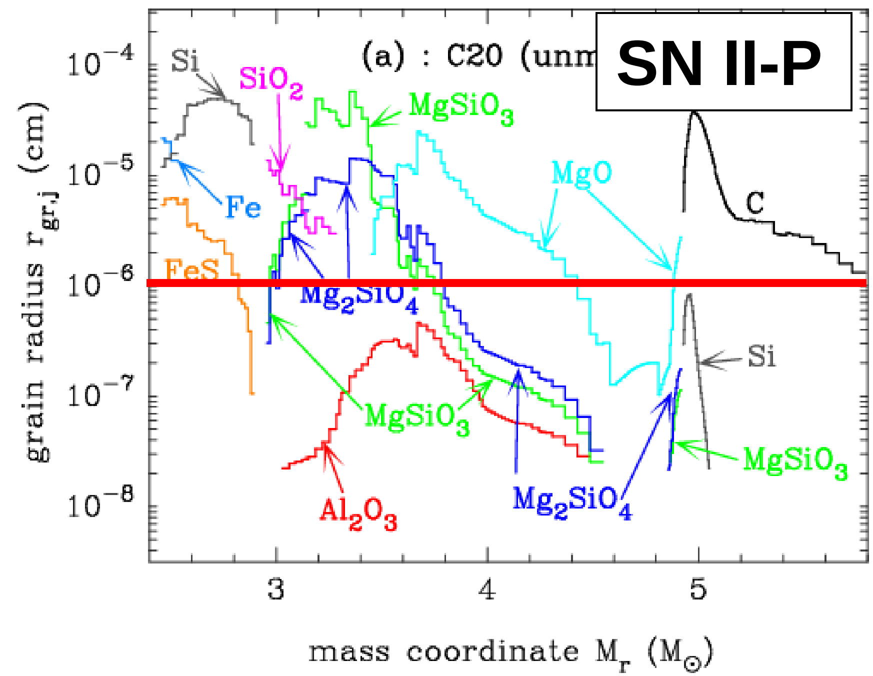
- M_{eje} = 2.94 M_{sun}
  M_{ZAMS} = 18 M_{sun}
  $M_{H\text{-}env}$ = 0.08 M_{sun}
- E_{51} = 1
- $M(^{56}Ni)$ = 0.07 M_{sun}





3-2. Dependence of dust radii on SN type





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

- SN IIb without massive H-env ➔ adust < 0.01 μm
- SN II-P with massive H-env ➔ adust > 0.01 μm

— condensation time of dust 300-700d after explosion

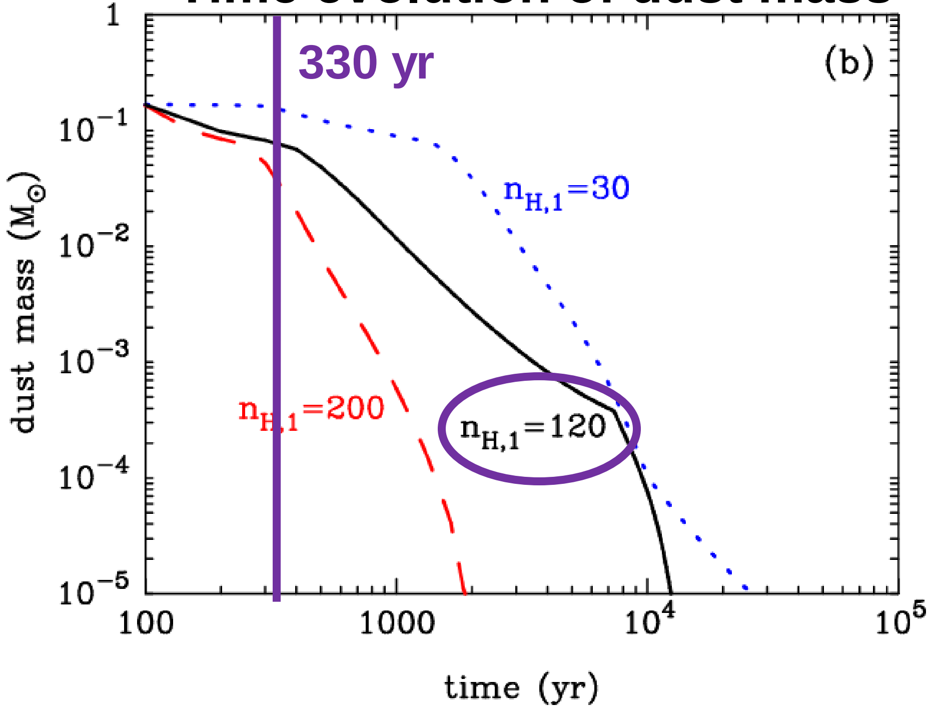
— total mass of dust formed

- 0.167 Msun in SN IIb
- 0.1-1 Msun in SN II-P

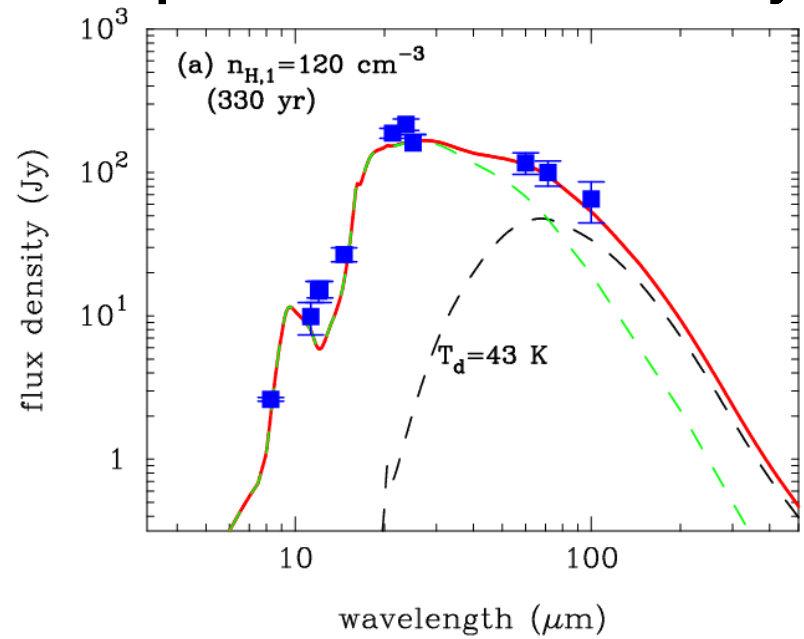
Nozawa+10, ApJ, 713, 356

3-3. Evolution of dust in Type IIb SNR

Time evolution of dust mass



predicted IR SED at 330 yr

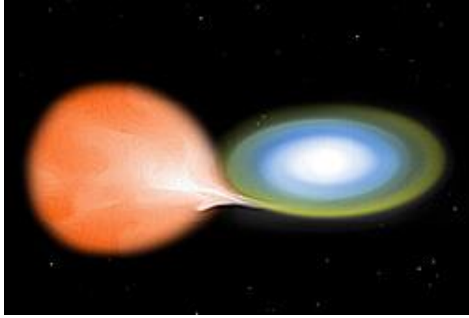


Almost all newly formed grains are destroyed in shocked gas in the SNR

Herschel observation
$M_{d,cool}$ = 0.075 Msun
T_{dust} ~ 35 K (Barlow+10)

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

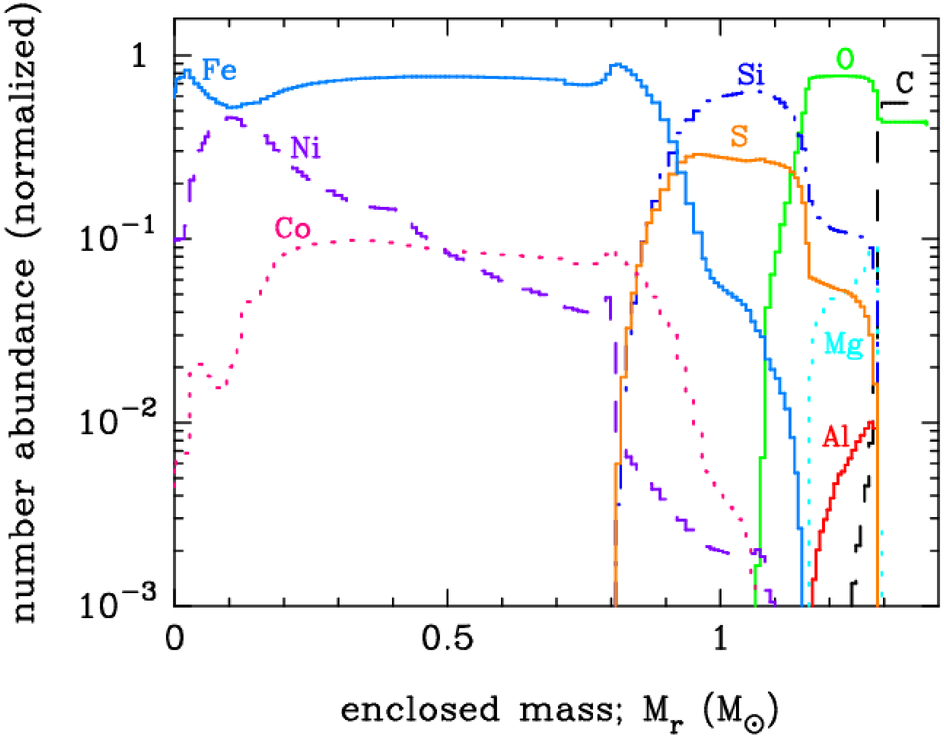
4-1. Dust formation in Type Ia SN

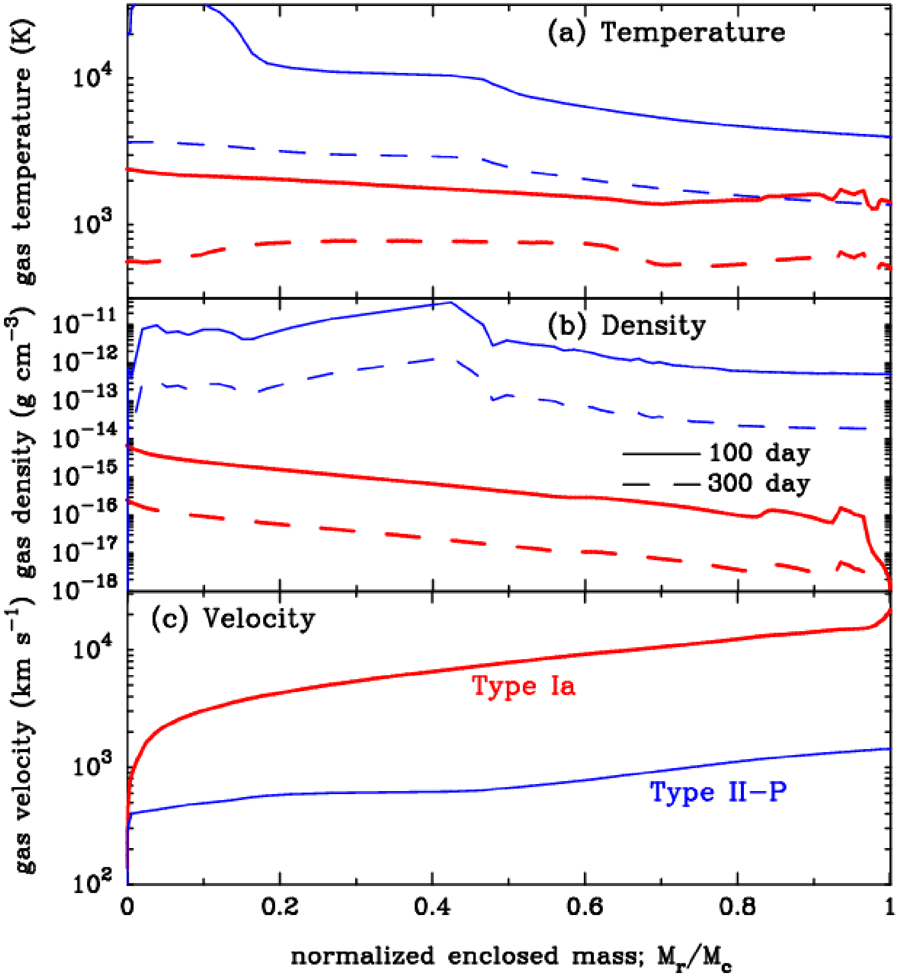


○ Type Ia SN model

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

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

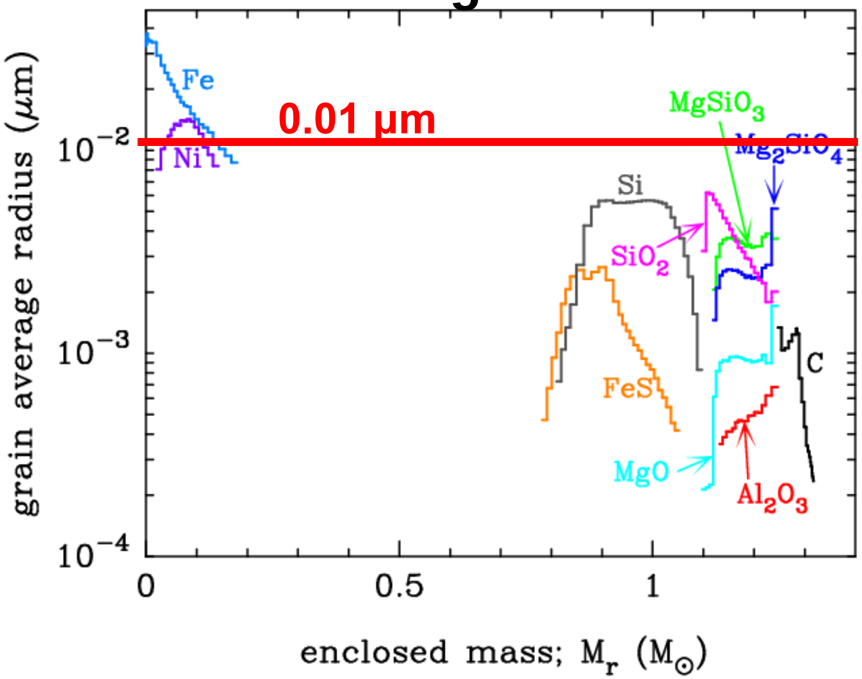




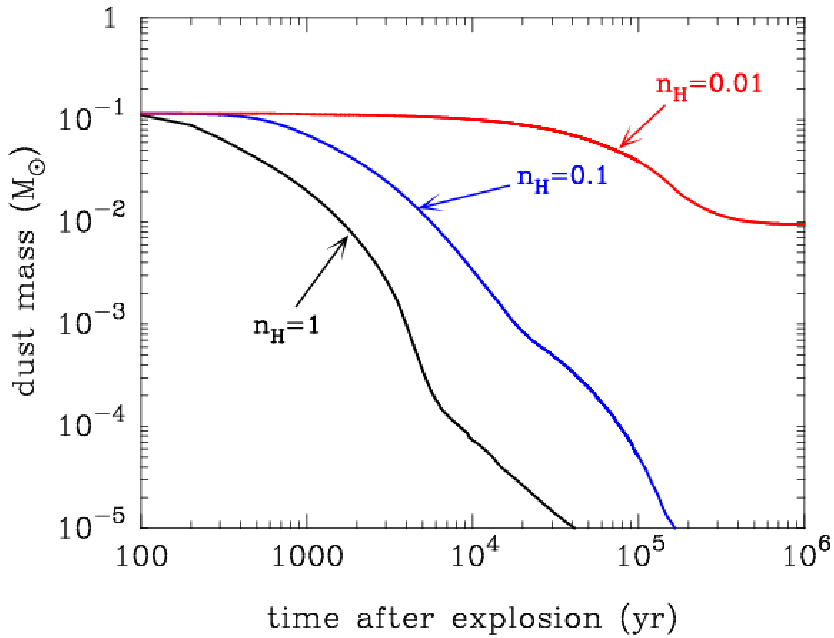
4-2. Dust formation and evolution in SNe Ia

Nozawa+11, ApJ, 736, 45

average radius



dust destruction in SNRs



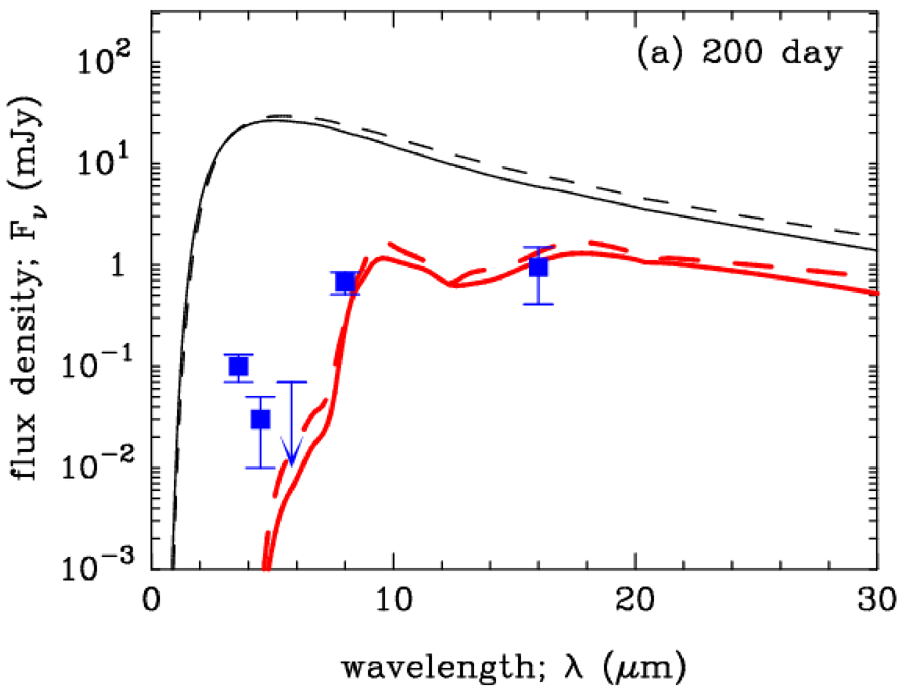
- condensation time :
  100-300 days
- average radius of dust :
  a_{ave} <~ 0.01 μm
- total dust mass :
  M_{dust} ~ 0.1 M_{sun}

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

➔ SNe Ia are unlikely to be major sources of dust

4-3. Carbon dust and outermost layer

- There has been no evidence for dust formation in SNe Ia
  ➔ Formation of massive carbon dust does not match the observations



Observational data: SN 2005df at day 200 and 400 (Gerardy+07)

— C dust mass: ~0.001 Msun

— massive unburned carbon (~0.05 Msun) in deflagration

observationally estimated carbon mass in SNe Ia :
Mc < 0.01 Msun

(Marion+06; Tanaka+08)

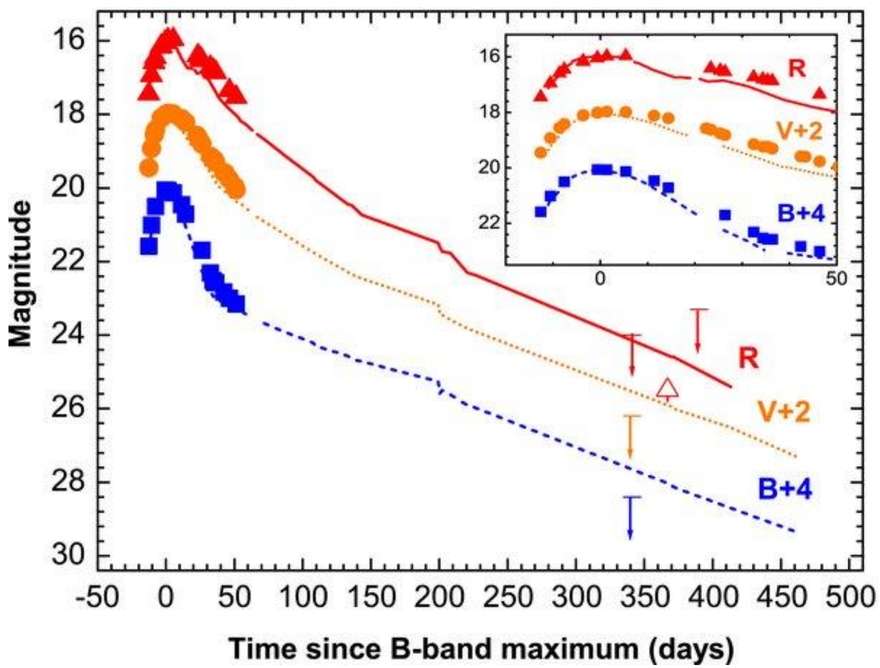
The presence of unburned carbon-rich layer always involve formation of C dust

4-4. Dust formation in super-Chandra SNe?

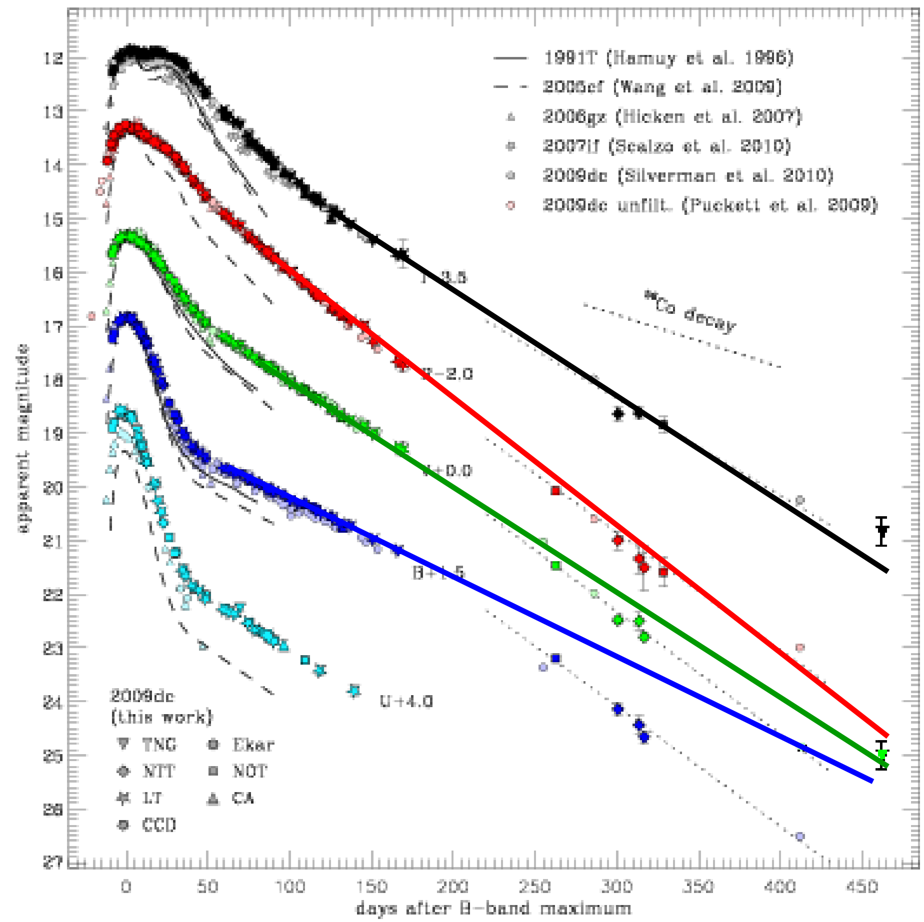
– super-Chandra SNe :
Meje ~ 2.0 Msun

detection of CII line
➔ presence of massive unburned carbon

SN 2006gz, Maeda+09



SN 2009dc, Tarbenberger+10



enhanced fading at ~200 day
➔ formation of carbon dust?

5. Summary of this talk

- **SNe II-P can inject a large amount of dust (>0.1 M_{sun})**
  - **almost all Mg, SI, and Fe atoms are trapped in dust**
  - **FIR observations of SNe support massive dust**

- **Size of newly formed dust depends on types of SNe**
  - **H-retaining SNe (Type II-P) : a_{ave} > 0.01 μm**
  - **H-stripped SNe (Type IIb/Ib/Ic and Ia) : a_{ave} < 0.01 μm**

    ➔ **dust is almost completely destroyed in the SNRs**

    ➔ **H-stripped SNe may be poor producers of dust**

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

- **Formation of C dust in SNe Ia may give some hints on the composition of outermost layers**