Dust in supernovae

Takaya Nozawa

Kavli IPMU (Kavli Institute for the Physics and Mathematics of the Universe)

Collaborators:
 T. Kozasa, A. Habe (Hokkaido University)
 K. Maeda, K. Nomoto (K-IPMU)
 H. Umeda (U.T.), N. Tominaga (Konan Univ.)

東京大学 THE UNIVERSITY OF TOKYO

TODIAS 東京大学国際高等研究所 TODAI INSTITUTES FOR ADVANCED STUDY

WPI World Premier International Research Center Initiative

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

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)**
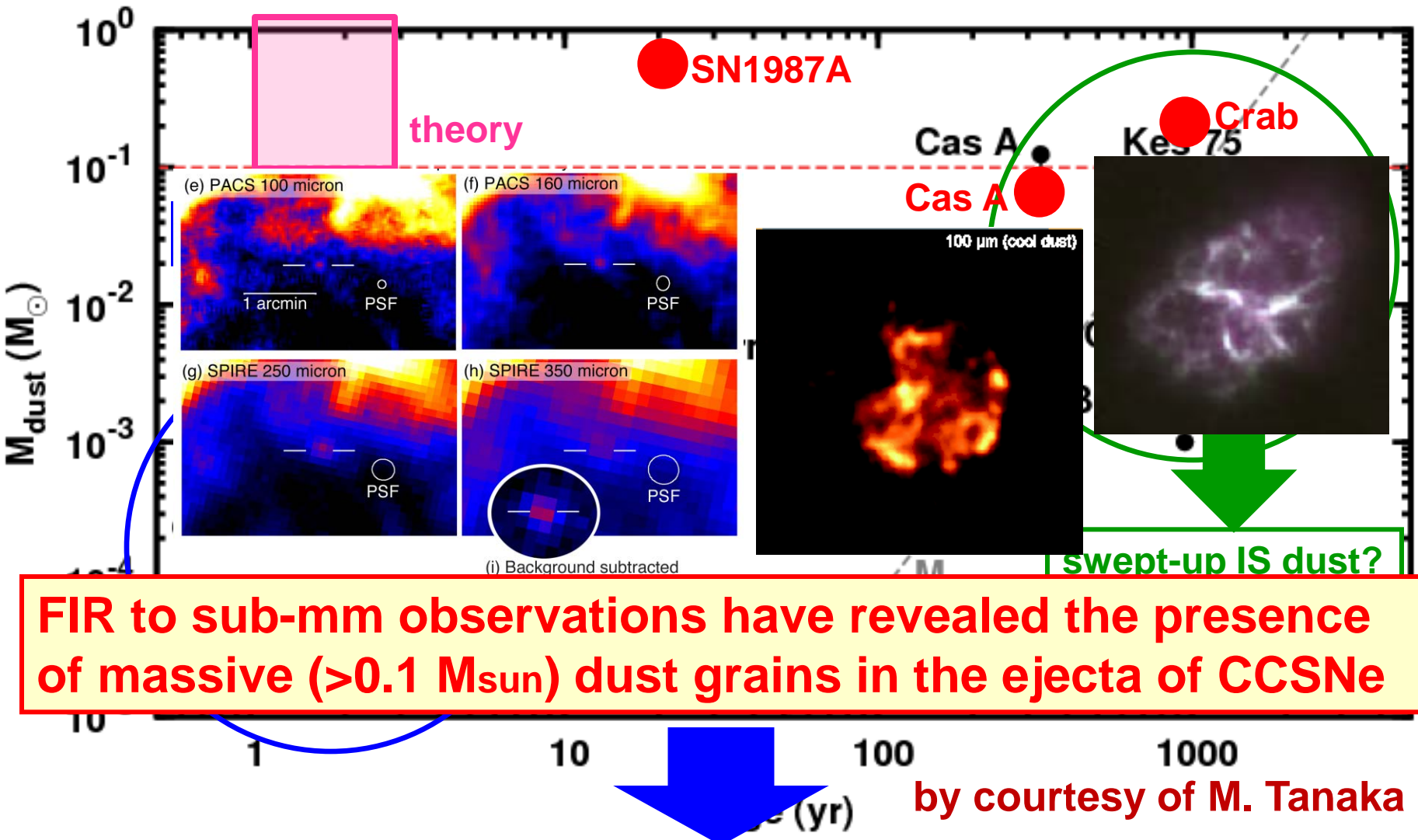
– **contribution of dust mass from AGB stars and SNe**

  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?

theory

**SN1987A**

Crab

Cas A

KeS 75

Cas A

swept-up IS dust?

FIR to sub-mm observations have revealed the presence of massive (>0.1 M$_{sun}$) 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**

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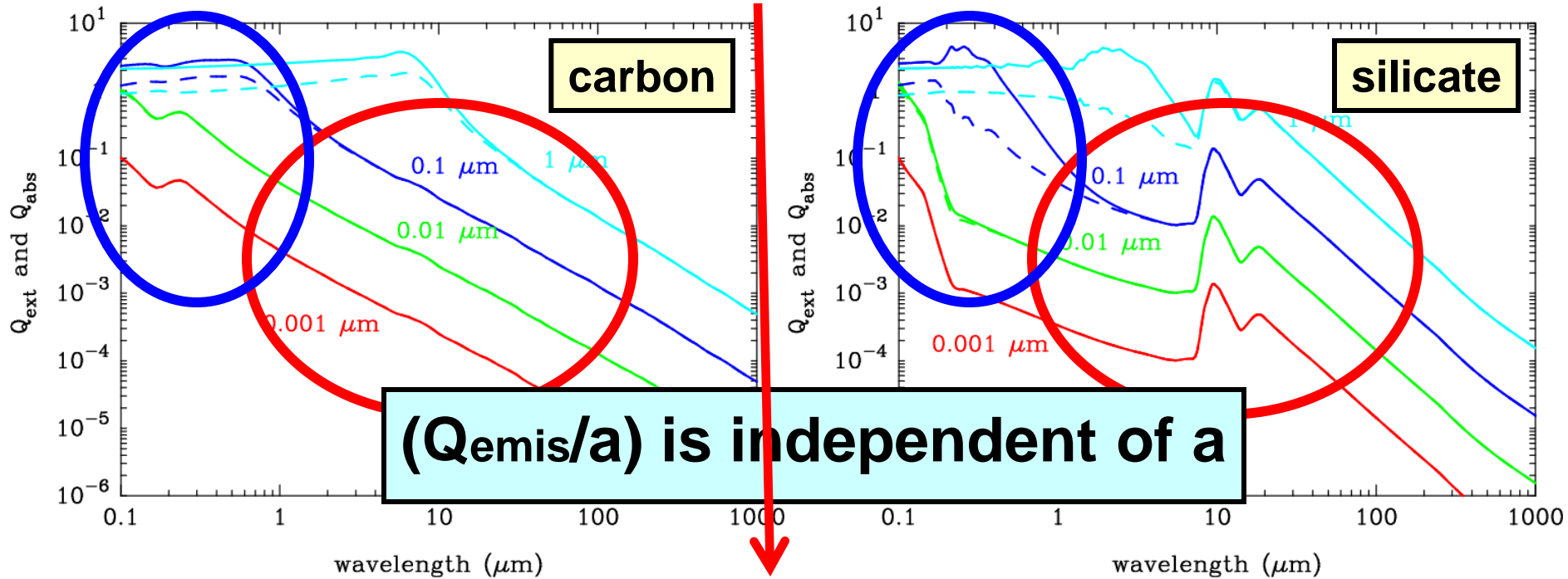
carbon

silicate

(Q_{emis}/a) **is independent of a**

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

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

→ **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

CO   SiO

silicate

SiO
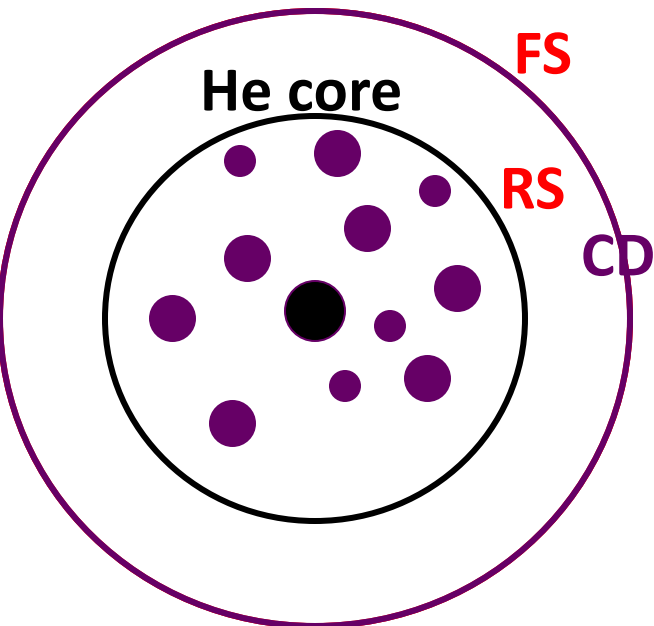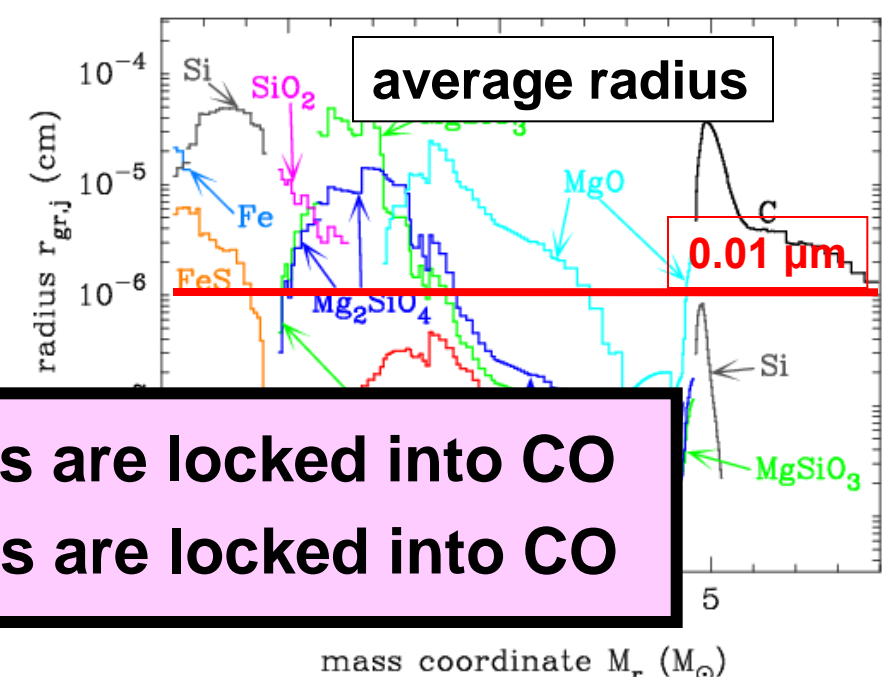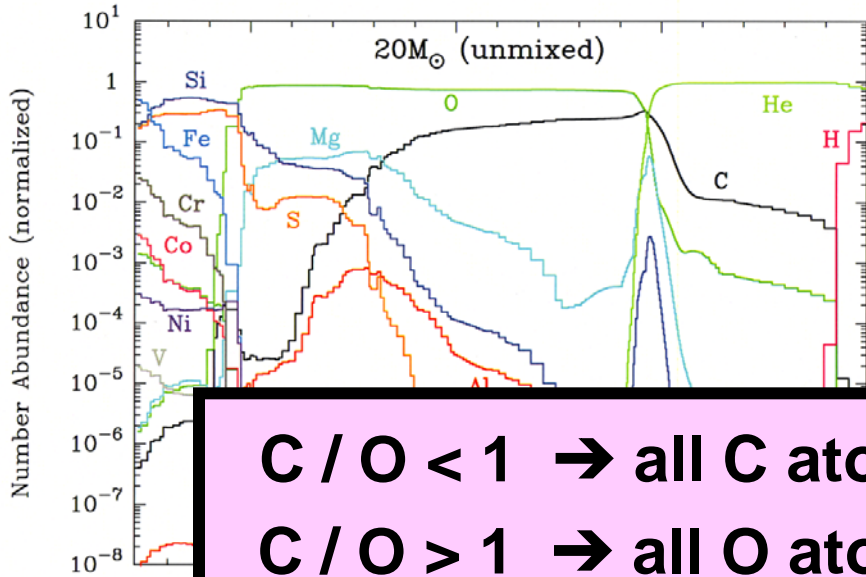
CO

carbon

SN 2006jc

silicate ➔ 1750 K

carbon ➔ 1660 K
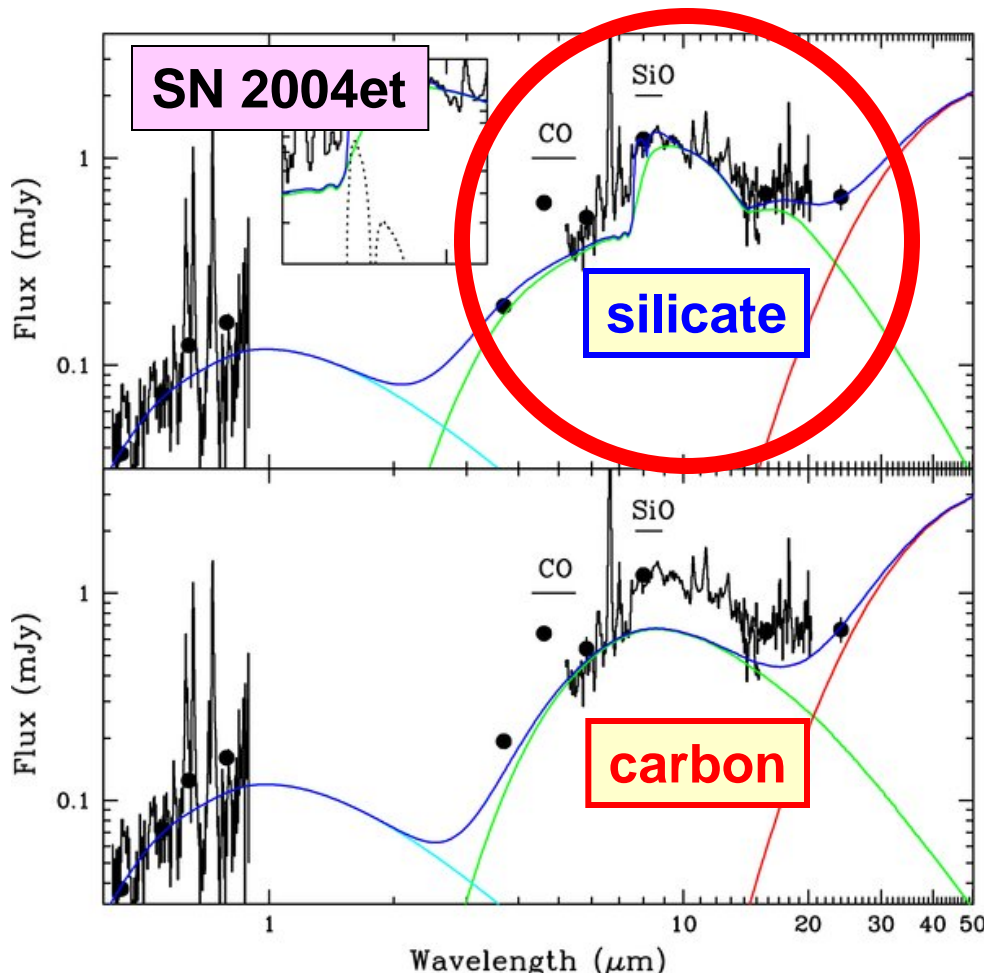
SN 2004et, Kotak+09
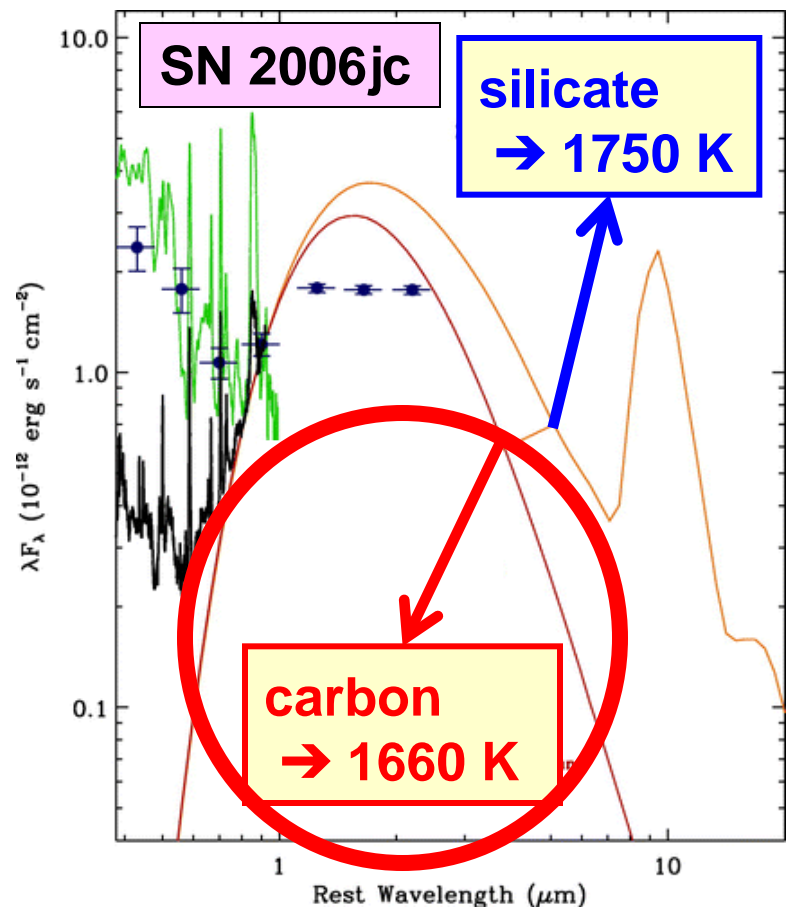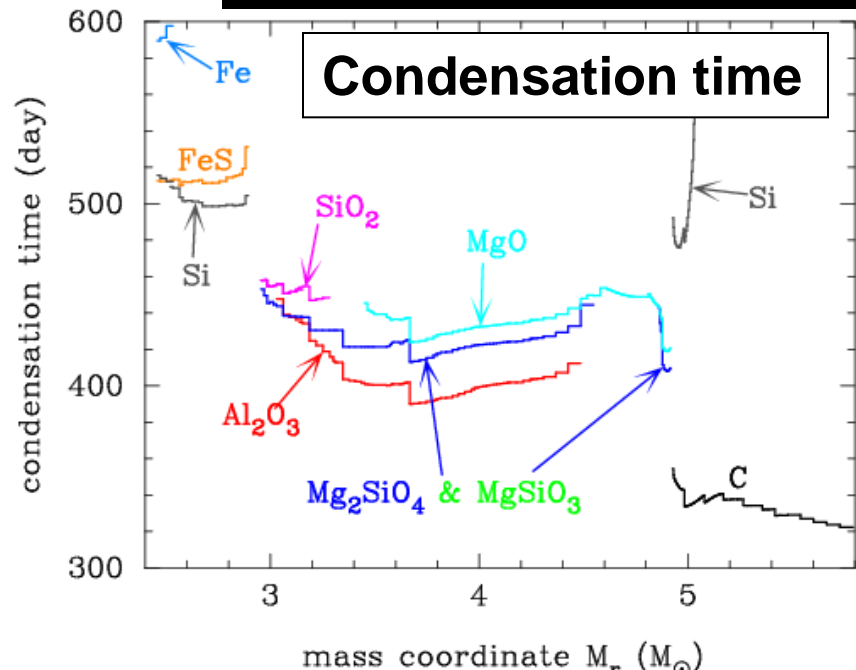
SN 2006jc, Smith+08
SN 2010jl, Keiichi's talk

2. Formation and evolution of dust in supernovae

FS

He core

RS

CD

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

20M☉ (unmixed)

average radius

0.01 μm

C / O < 1 ➔ all C atoms are locked into CO
C / O > 1 ➔ all O atoms are locked into CO

Condensation time

— **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
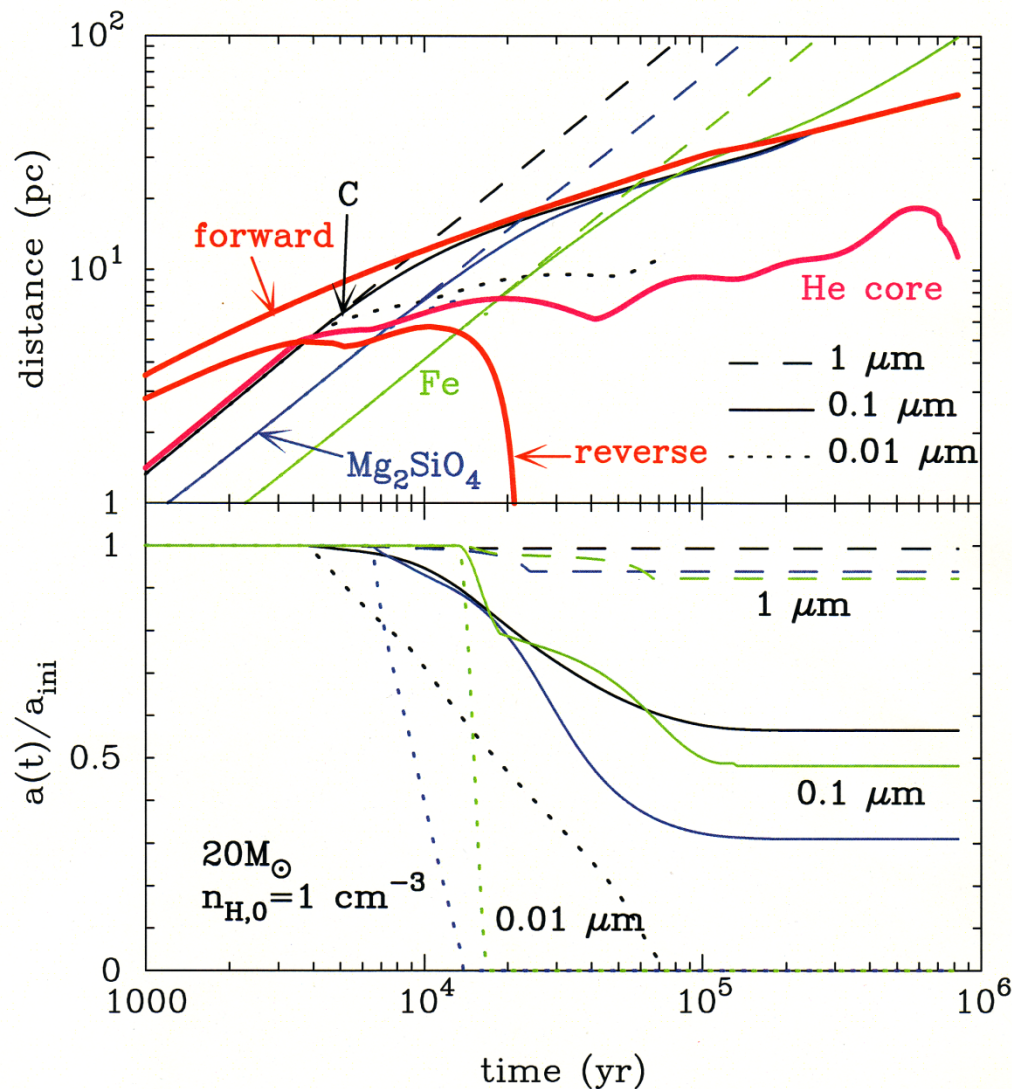
Model : Type II-P

$M_{pr}= 20\ M_{sun}\ (E_{51}=1)$

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

Dust grains in the He core collide with reverse shock at $(3\text{-}13)\times10^3$ yr

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

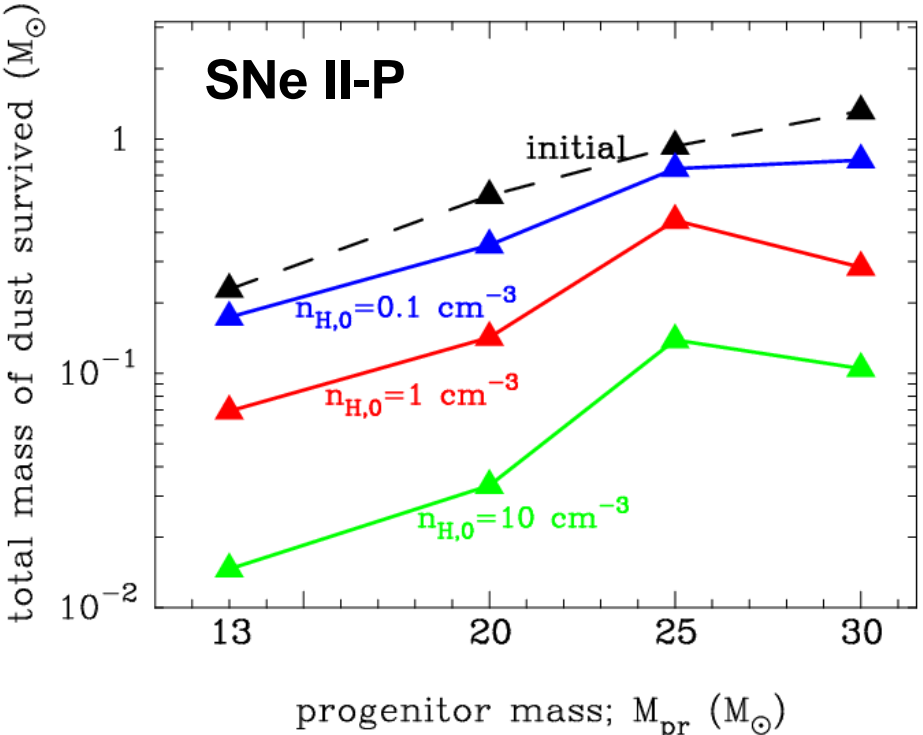$a_{ini} = 0.01\ \mu m$ (dotted lines)
  ➔ **completely destroyed**
$a_{ini} = 0.1\ \mu m$ (solid lines)
  ➔ **trapped in the shell**
$a_{ini} = 1\ \mu m$ (dashed lines)
  ➔ **injected into the ISM**

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

SNe II-P

initial

$n_{H,0}=0.1$ cm^{-3}

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

$n_{H,0}=10$ cm^{-3}

total mass of dust survived ($M_\odot$)

progenitor mass; M_{pr} ($M_\odot$)

at time of dust formation

size distribution spectrum; $f_j(a)$

grain radius (μm)

Al$_2$O$_3$
MgO
Mg$_2$SiO$_4$
FeS

MgSiO$_3$

C

SiO$_2$

Fe

Si

after destruction of dust by reverse shock

20M$_\odot$
unmixed case
$n_{H,0}=1$ cm^{-3}

size distribution spectrum; $f_j(a)$

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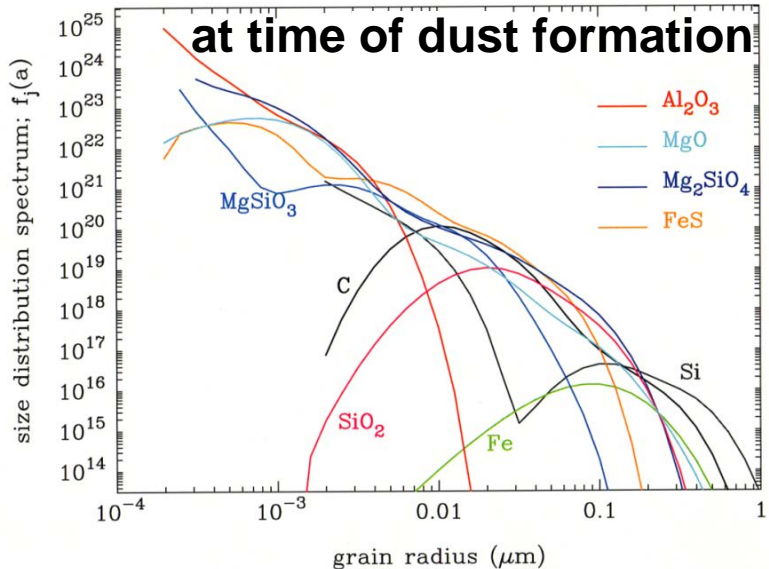
total dust mass surviving the destruction in Type II-P SNRs; 0.07-0.8 M$_{sun}$ ($n_{H,0}$ = 0.1-1 cm^{-3})

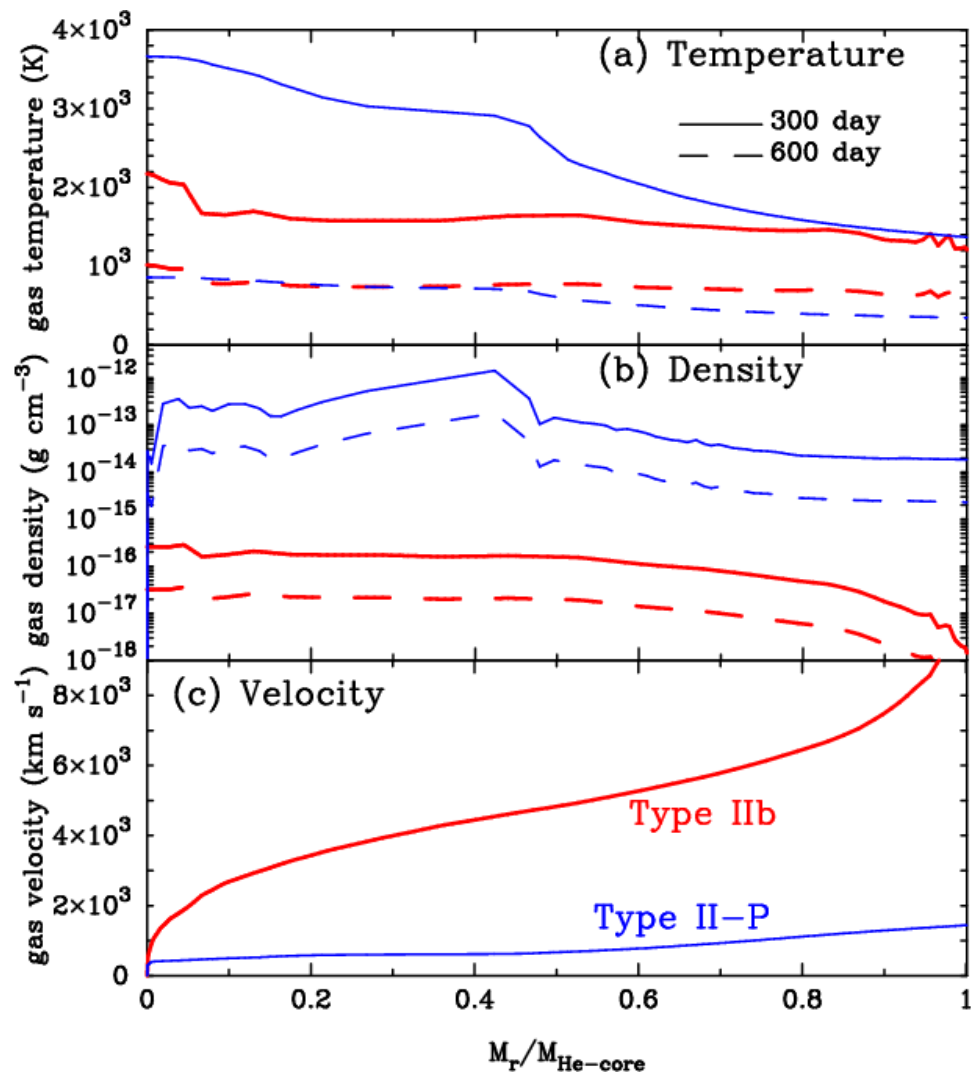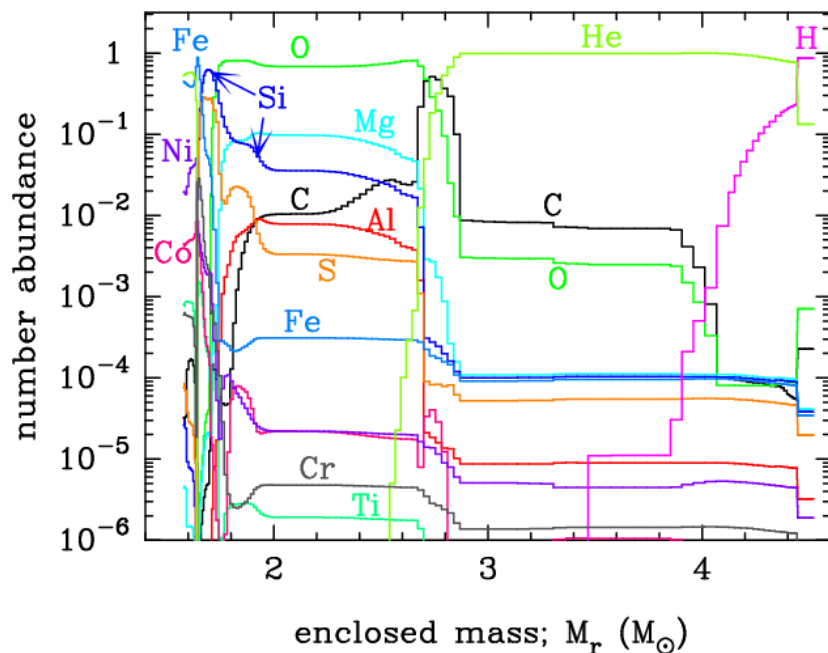**size distribution of dust after RS destruction is <u>domimated by large grains</u> (> 0.01 μm)**
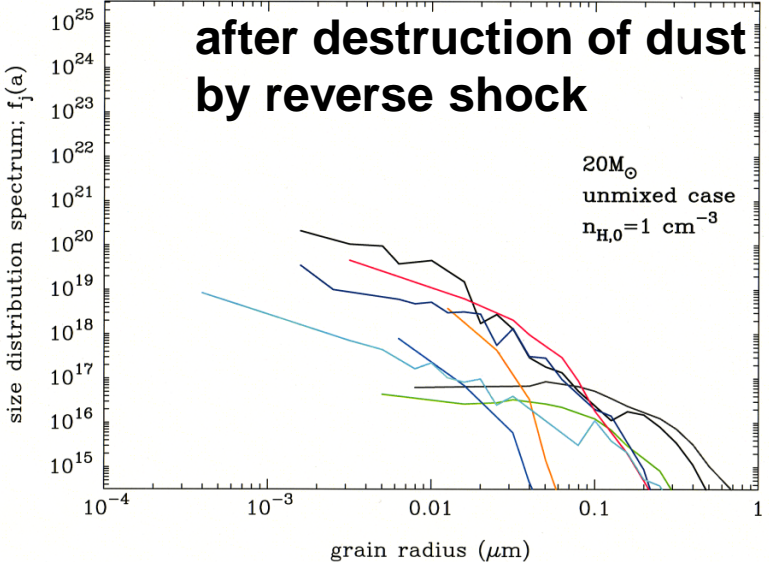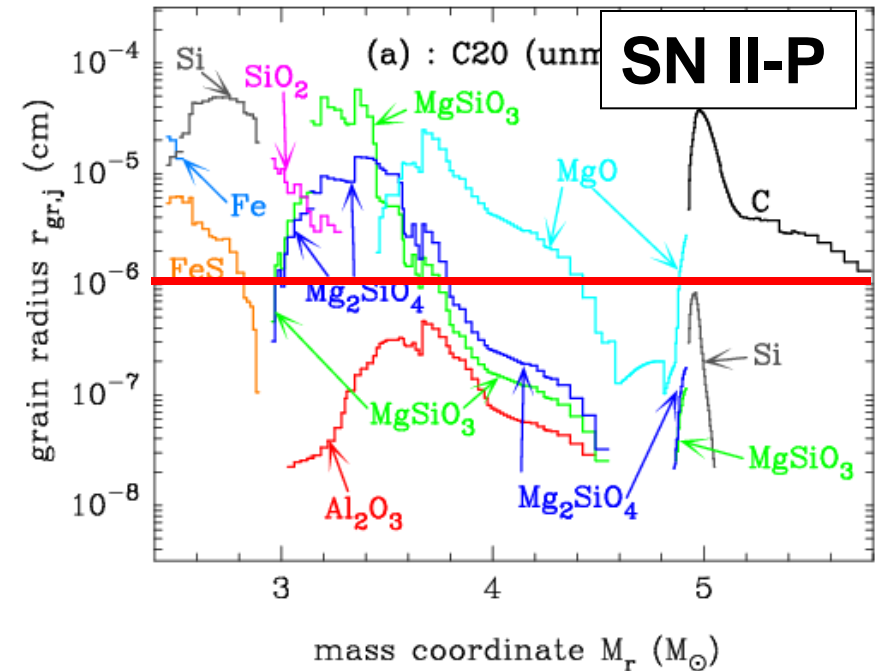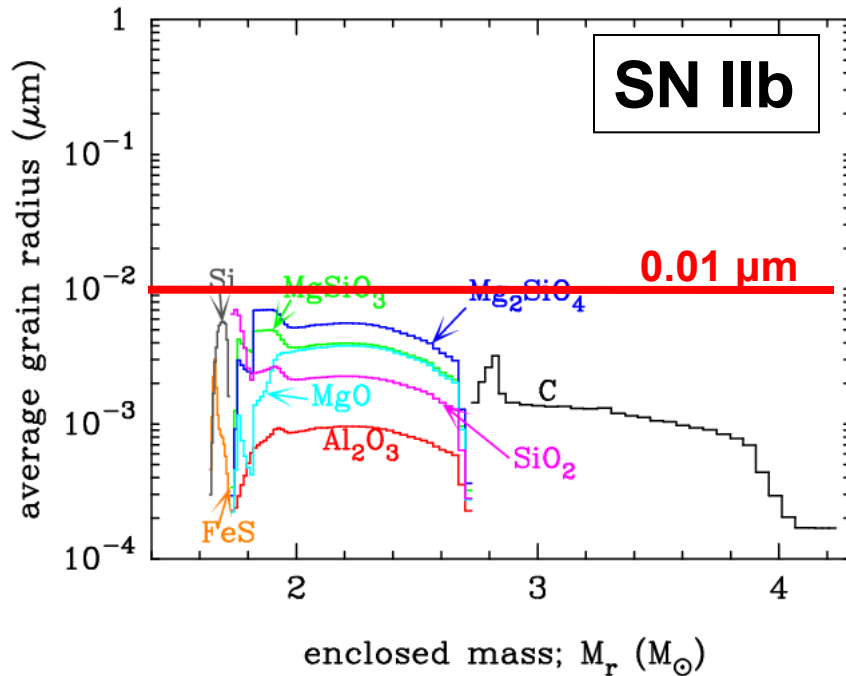
3-1. Dust formation in Type IIb SN

O SN IIb model (SN1993J-like model)

- M_{eje} = 2.94 M_{sun}

  M_{ZAMS} = 18 M_{sun}

  M_{H-env} = 0.08 M_{sun}

- E_{51} = 1

- $M(^{56}Ni)$ = 0.07 M_{sun}

3-2. Dependence of dust radii on SN type

SN IIb

0.01 μm

SN II-P

(a) : C20 (unm...

- ― 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

- ― condensation time of dust **300-700d** after explosion
- ― total mass of dust formed
  - · **0.167 M$_{sun}$ in SN IIb**
  - · **0.1-1 M$_{sun}$ in SN II-P**

Nozawa+10, ApJ, 713, 356

3-3. Evolution of dust in Type IIb SNR

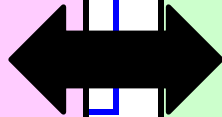**Time evolution of dust mass**
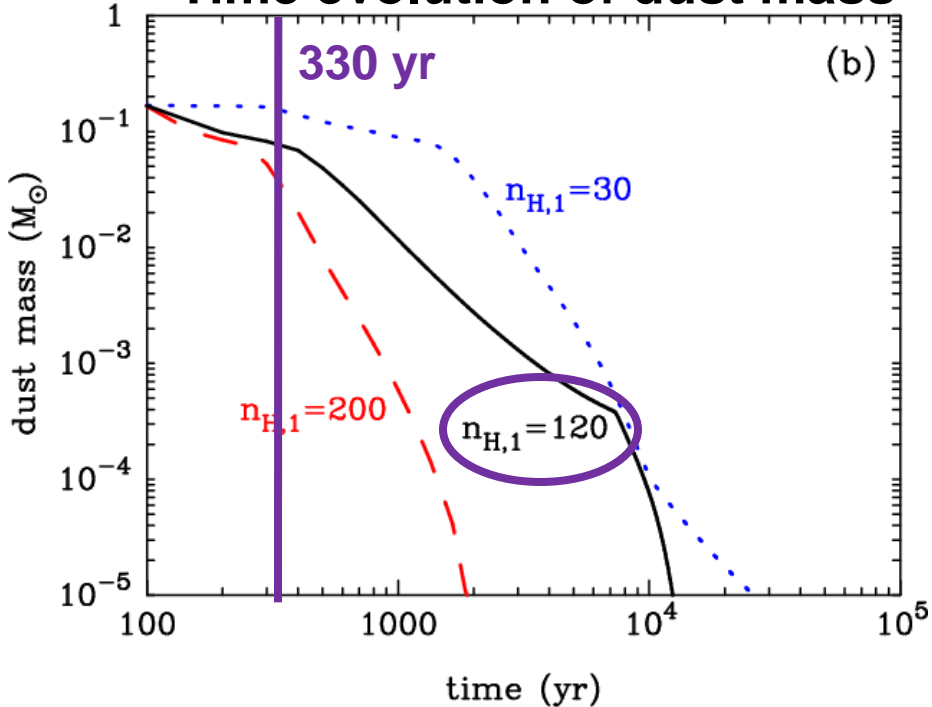
predicted IR SED at 330 yr
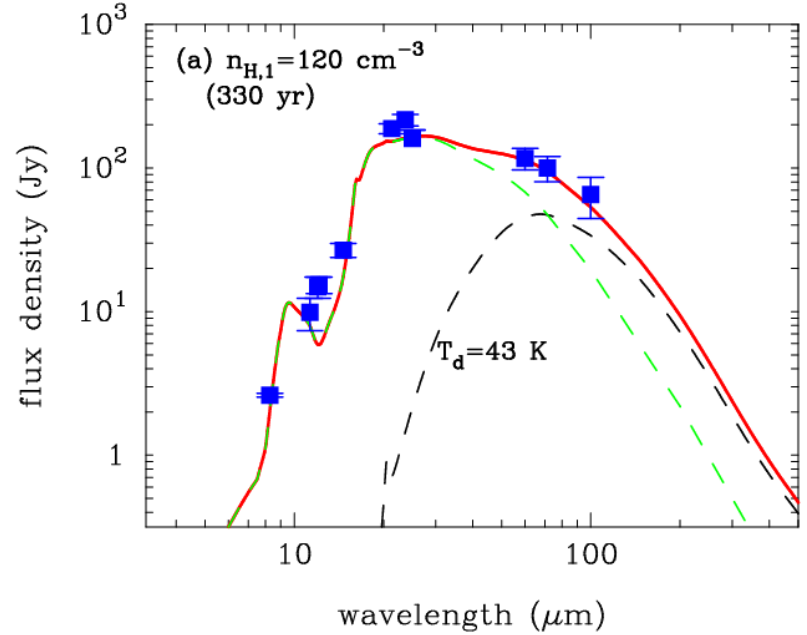
Almost all newly formed grains are destroyed in shocked gas in the SNR
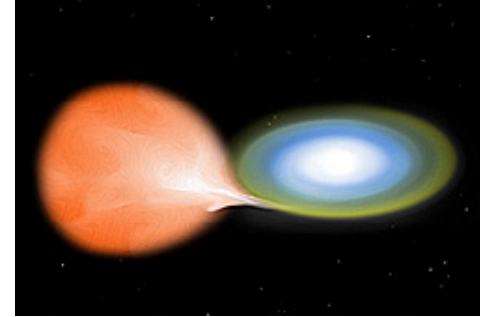
Herschel observation
$M_{d,cool}$ = 0.075 M_{sun}
T_{dust} ~ 35 K (Barlow+10)

- 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}
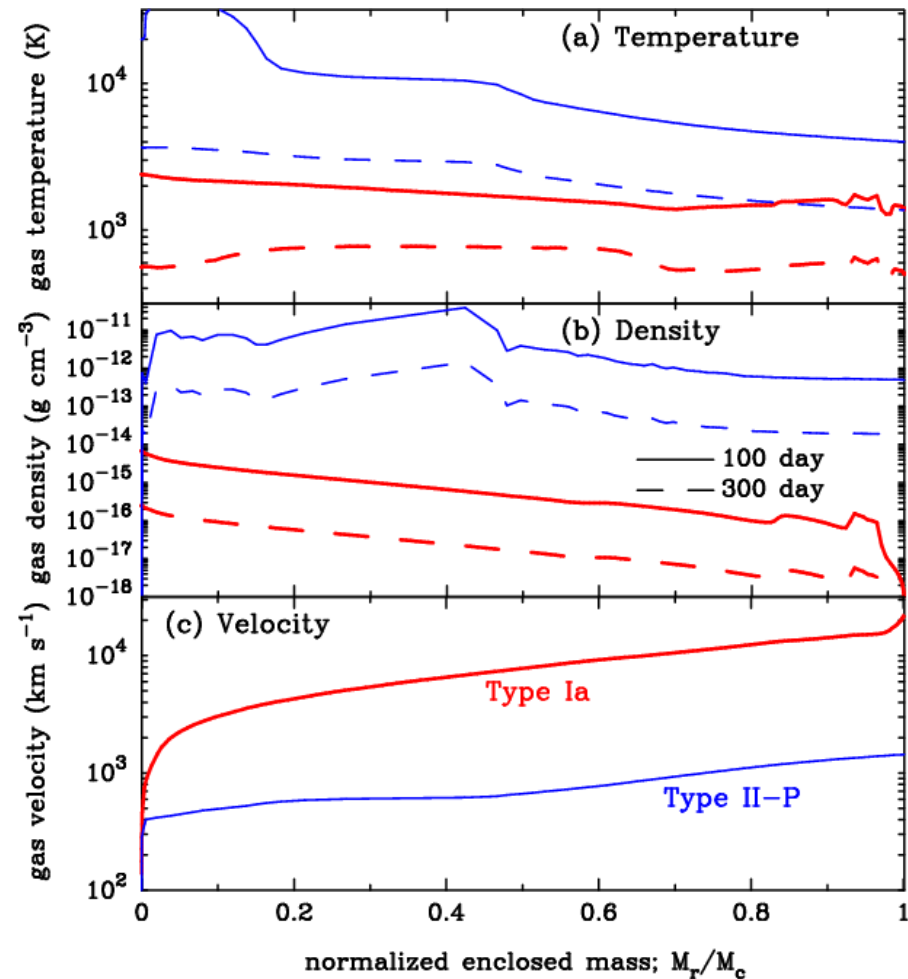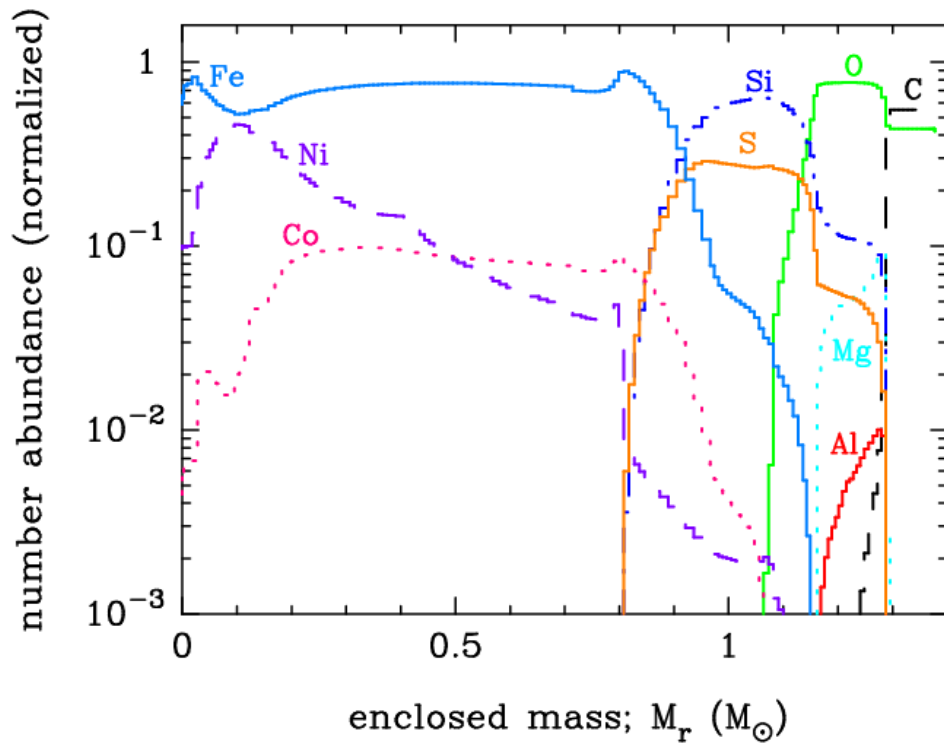 with T_{dust} ~ 40 K

4-1. Dust formation in Type Ia SN

○ Type Ia SN model

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

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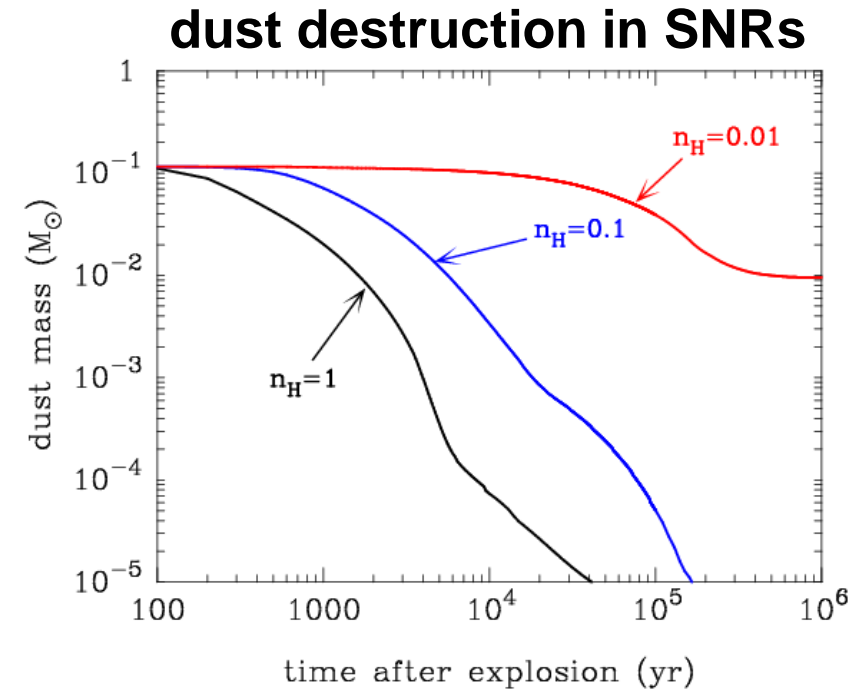- $E_{51} = 1.3$
- $M(^{56}Ni) = 0.6 \ M_{sun}$

4-2. Dust formation and evolution in SNe Ia

average radius

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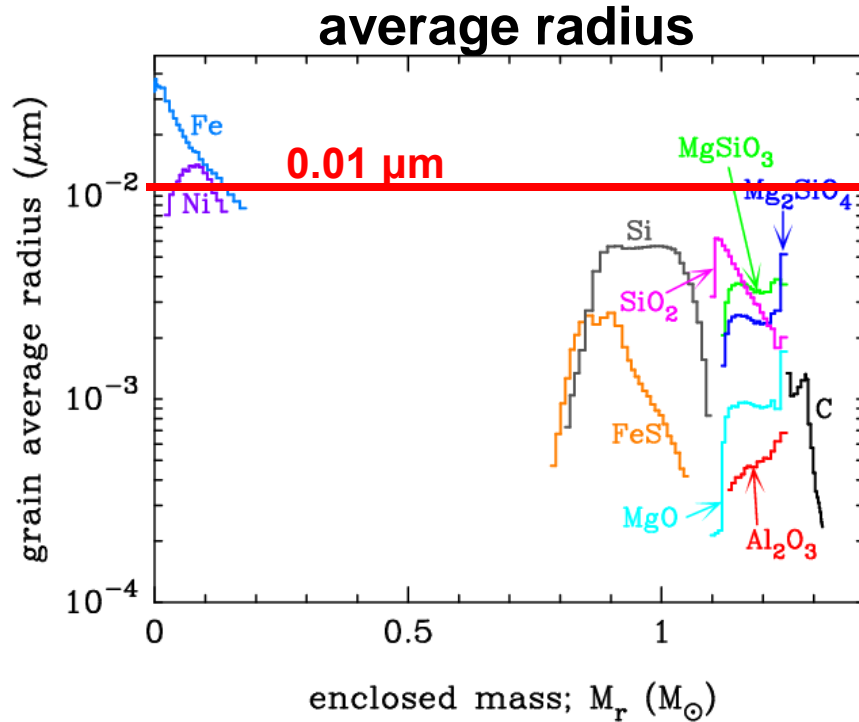
- **condensation time :**
  100-300 days
- **average radius of dust :**
  a_{ave} <~ 0.01 μm
- **total dust mass :**
  M_{dust} ~ 0.1 M_{sun}

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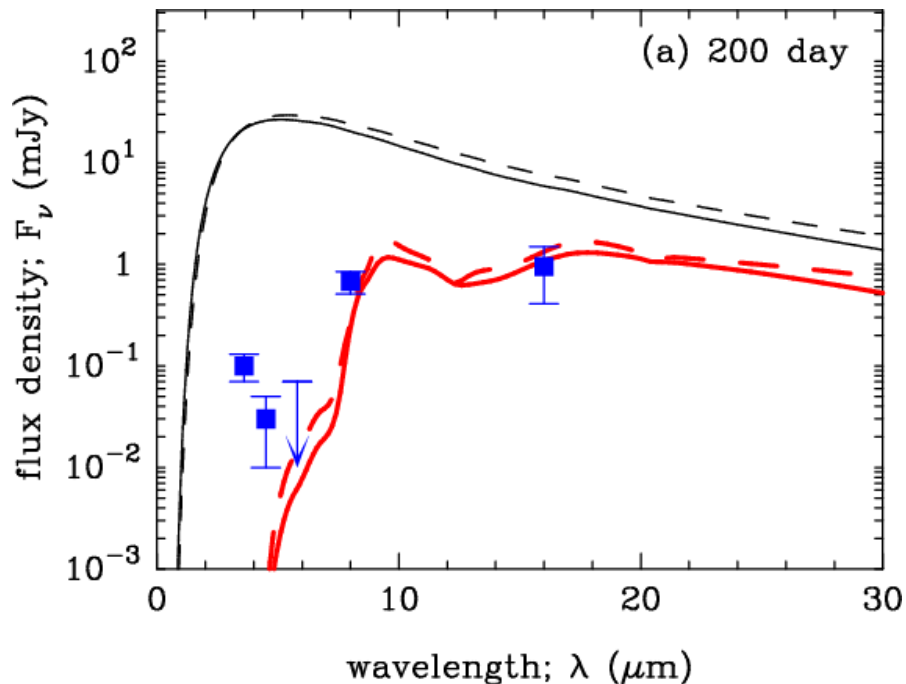
Observational data: SN 2005df at day 200 and 400 (Gerardy+07)

— **C dust mass: ~0.001 M$_{sun}$**
— **massive unburned carbon (~0.05 M$_{sun}$) in deflagration**

observationally estimated carbon mass in SNe Ia :
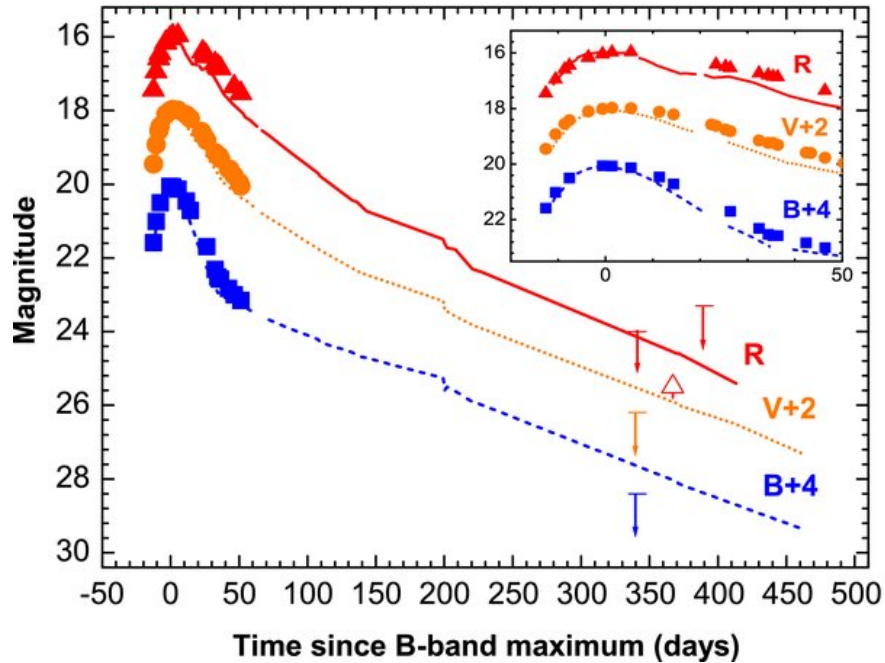**Mc < 0.01 M$_{sun}$**
(Marion+06; Tanaka+08)

The presence of unburned carbon-rich layer always involve formation of C dust
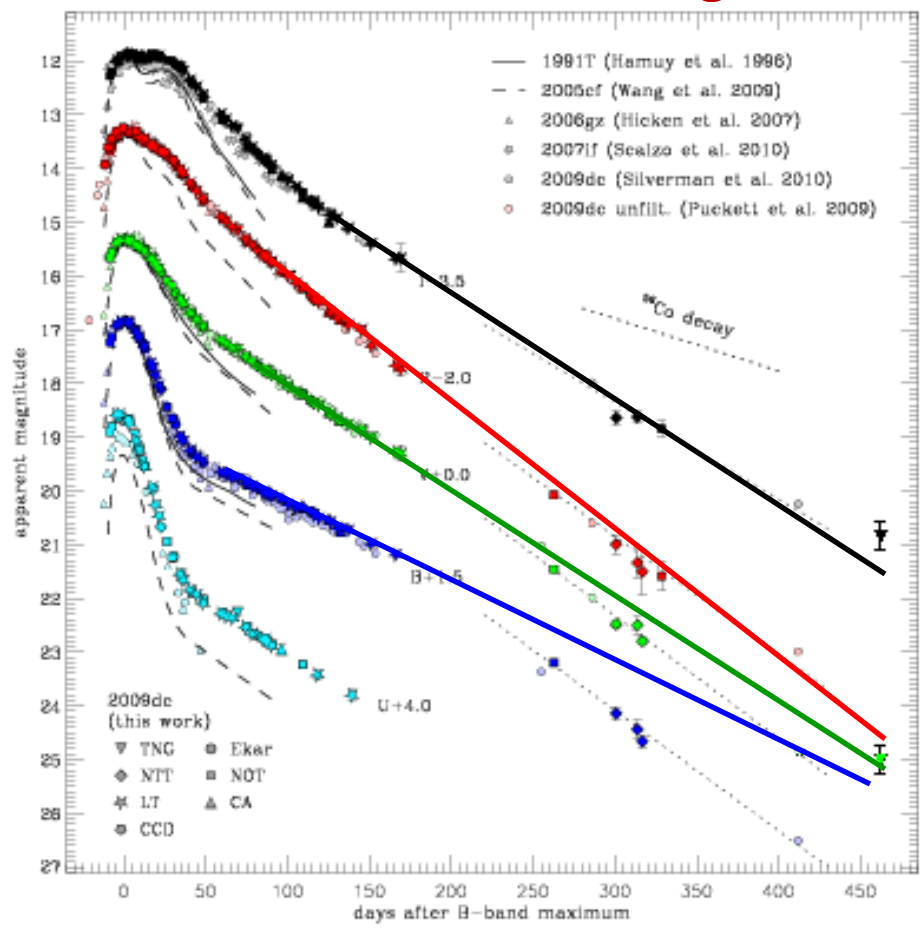
4-4. Dust formation in super-Chandra SNe?

— **super-Chandra SNe :**
  M_{eje} ~ 2.0 M_{sun}

detection of CII line
  ➔ presence of massive unburned carbon

SN 2009dc, Tarbenberger+10

SN 2006gz, Maeda+09

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**