2013/10/24

# Dust emission in SNR 1987A and high-z dust observations

Takaya Nozawa (Kavli IPMU)

**○ Contents of this talk**

- Introduction
- Our ALMA proposals for SNR 1987A
- Infrared Emission of Dust Grains
- Extinction Curves in high-z Galaxies
- Summary

# 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)**

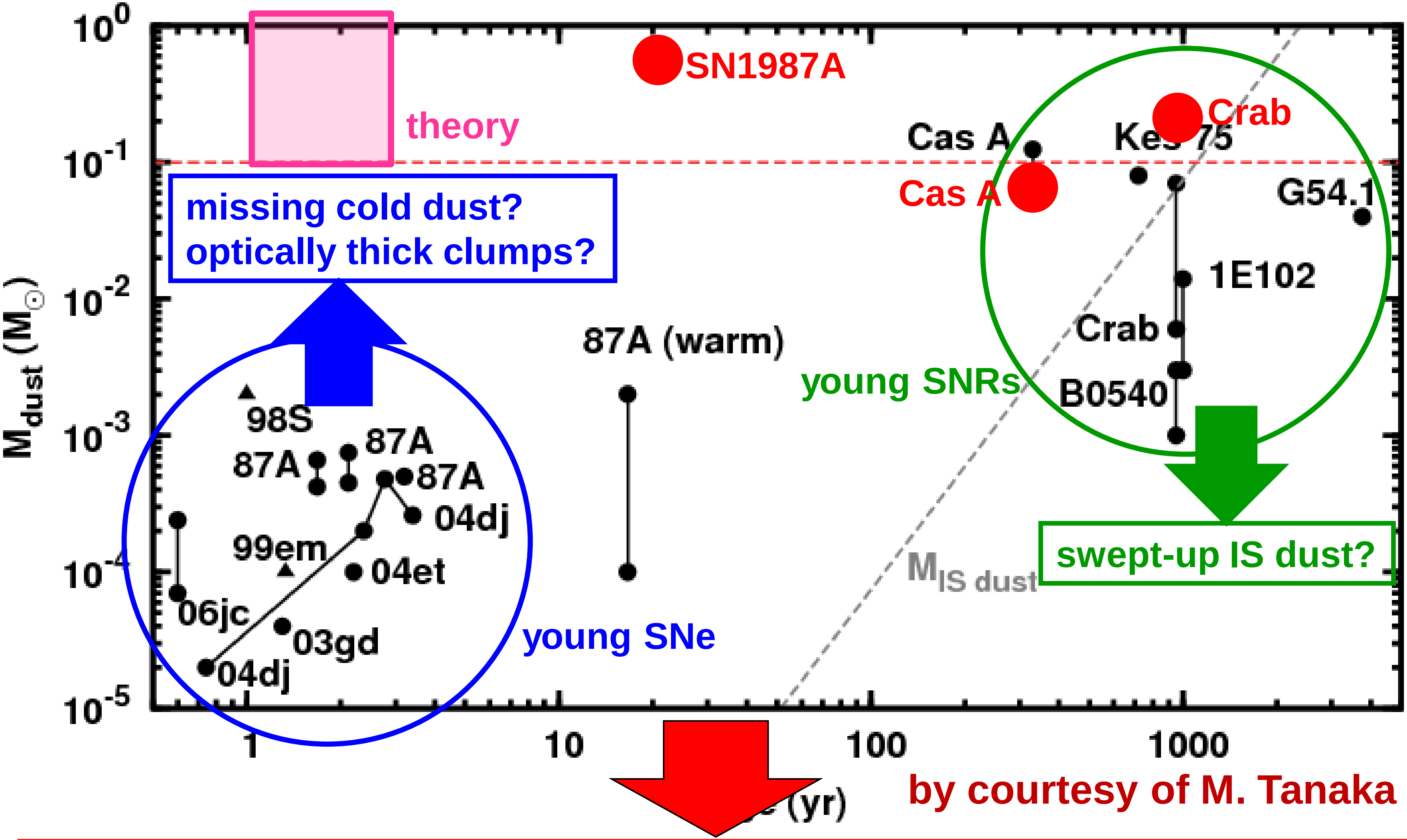
- **contribution of dust mass from AGB stars and SNe**

**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?**

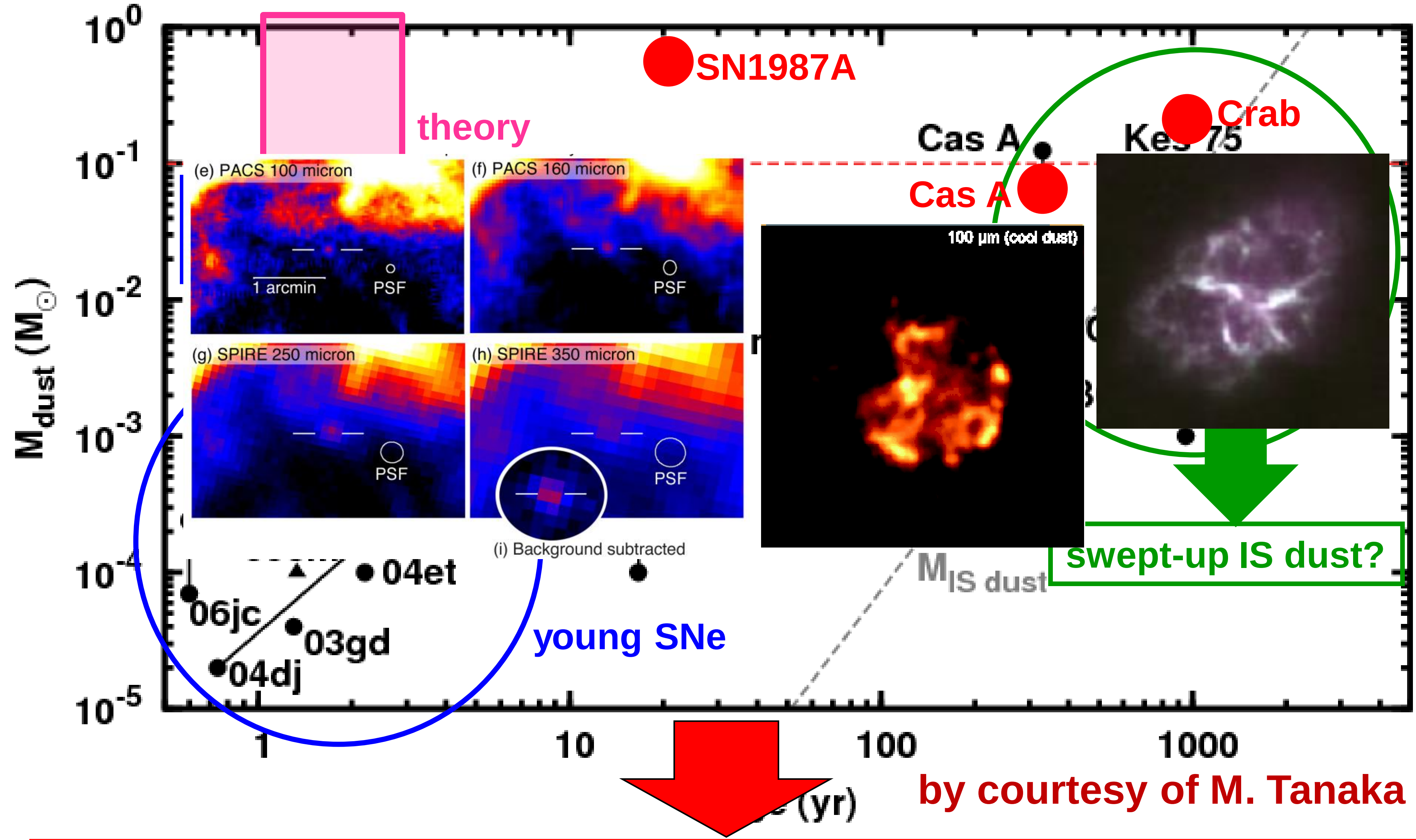
# 1-2. Summary of observed dust mass in CCSNe




by courtesy of M. Tanaka

**FIR to sub-mm observations have revealed the presence of massive (>0.1 $M_{sun}$) dust grains in the ejecta of CCSNe**

# 1-2. Summary of observed dust mass in CCSNe

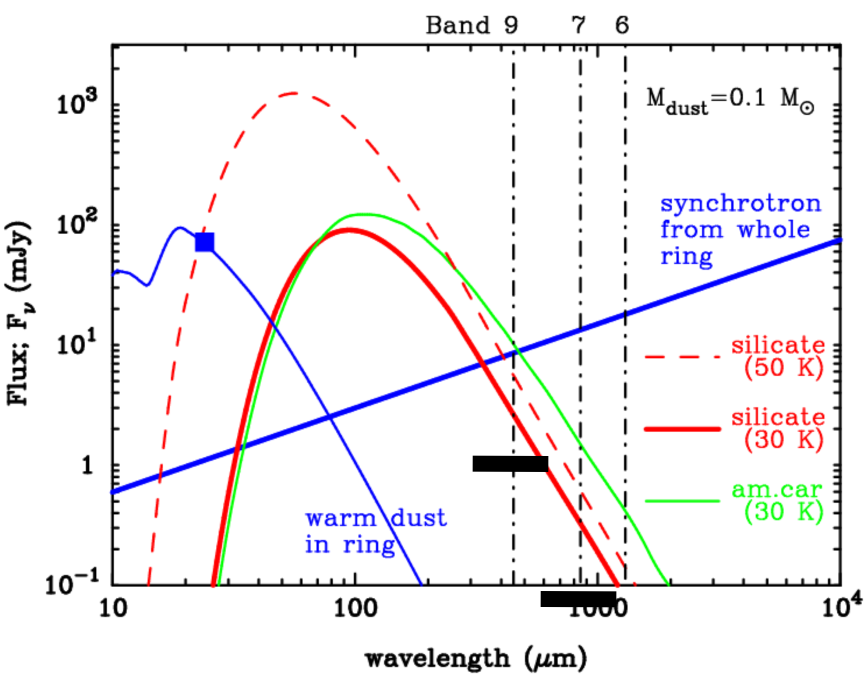



by courtesy of M. Tanaka

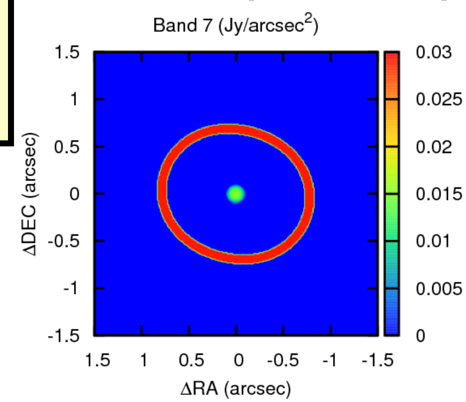
**FIR to sub-mm observations have revealed the presence of massive (>0.1 Msun) dust grains in the ejecta of CCSNe**

# 2-1. Resolving cool dust in SN 87A with ALMA

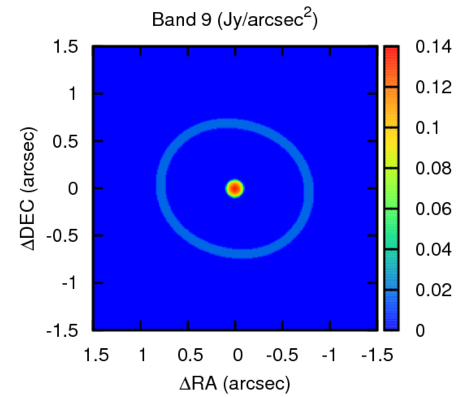
**ALMA Cycle 0 Proposal**
**'Detecting cool dust in SN1987A'**
**(TN, Tanaka, et al.)**

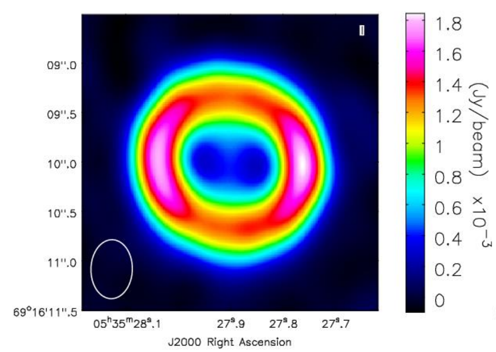

**Band 7 (850 μm)**

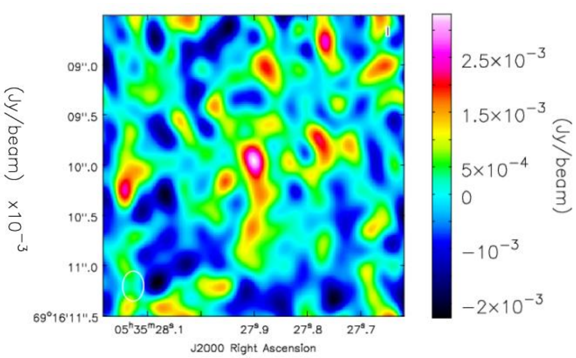



**Band 9 (450 μm)**




**CASA simulation with extended config. (4 hrs)**




**0.1 Msun of silicate**
**➔ 5σ detection at Band 9 !!**

# 2-2. Successful ALMA proposals for SN 1987A

| 2011.0.00221.S | | | |
|---|---|---|---|
| **PI** | **Exec** | **Country** | **Institute** |
| Nozawa, Takaya | EA | Japan | The University of Tokyo |
| **COI** | | | |
| Tanaka, Masaomi | EA | Japan | The University of Tokyo |
| Moriya, Takashi | EA | Japan | University of Tokyo |
| Minamidani, Tetsuhiro | EA | Japan | Hokkaido University |
| Kozasa, Takashi | EA | Japan | Hokkaido University |

**This proposal was ranked in the highest priority !!**

| 2011.0.00273.S | | | |
|---|---|---|---|
| **PI** | **Exec** | **Country** | **Institute** |
| Indebetouw, Remy | NA | United States | Virginia, University of |
| **COI** | | | |
| McCray, Richard | NA | United States | Colorado at Boulder, Univ of |
| Matsuura, Mikako | EU | United Kingdom | London, University of |
| Andjelic, Milica | OTHER | Serbia | Belgrade, University of |
| Arbutina, Bojan | OTHER | Serbia | Belgrade, University of |
| Baes, Maarten | EU | Belgium | Ghent University |
| Bolatto, Alberto | NA | United States | Maryland, University of |
| Burrows, David | NA | United States | Pennsylvania State University |
| Chevalier, Roger | NA | United States | Virginia, University of |
| Gaensler, Bryan | OTHER | Australia | Sydney, University of |
| Long, Knox | NA | United States | Space Telescope Science Institute |
| Lundqvist, Peter | EU | Sweden | Stockholm University |
| Meixner, Margaret | NA | United States | Space Telescope Science Institute |
| Marcaide, Jon | EU | Spain | Valencia, University of |
| Marti-Vidal, Ivan | EU | Germany | Max-Planck-Institute for Radio Astronomy |
| OTSUKA, Masaaki | EA/NA | Taiwan | Academia Sinica |
| Sandstrom, Karin | EU | Germany | Max-Planck-Institute for Astronomy |
| Sonneborn, George | NA | United States | National Aeronautics and Space Administration |
| Staveley-Smith, Lister | OTHER | Australia | International Centre for Radio Astronomy Research |
| van Loon, Jacco | EU | United Kingdom | Keele University |
| Urosevic, Dejan | OTHER | Serbia | Belgrade, University of |
| Vlahakis, Catherine | CL | Chile | Chile, University of |
| Zekovic, Vladimir | OTHER | Serbia | Belgrade, University of |
| Zanardo, Giovanna | OTHER | Australia | International Centre for Radio Astronomy Research |
| Ng, Chi-Yung | NA | Canada | McGill University |
| Park, Sangwook | NA | United States | Texas at Arlington, University of |
| Barlow, Michael | EU | United Kingdom | London, University of |
| Clayton, Geoffrey | NA | United States | Louisiana State University |
| Wesson, Roger | EU | United Kingdom | London, University of |
| Dwek, Eli | NA | United States | National Aeronautics and Space Administration |
| Bouchet, Patrice | EU | France | CEA Saclay |
| Lakicevic, Masa | EU | Germany | European Southern Observatory |
| Potter, Toby | OTHER | Australia | International Centre for Radio Astronomy Research |

# 2-2. Successful ALMA proposals for SN 1987A

2011.0.00221.S

| PI | Exec | Country | Institute |
|---|---|---|---|
| Nozawa, Takaya | EA | Japan | The University of Tokyo |
| COI | | | |
| Tanaka, Masa[illegible]i | EA | Japan | The University of Tokyo |
| Moriya, Takashi | EA | Japan | University of Tokyo |
| Minamidani, Tetsuhiro | EA | Japan | Hokkaido University |
| Kozasa, Takashi | EA | Japan | Hokkaido University |

Our proposal was not executed

Band 9
extended configuration

2011.0.00273.S

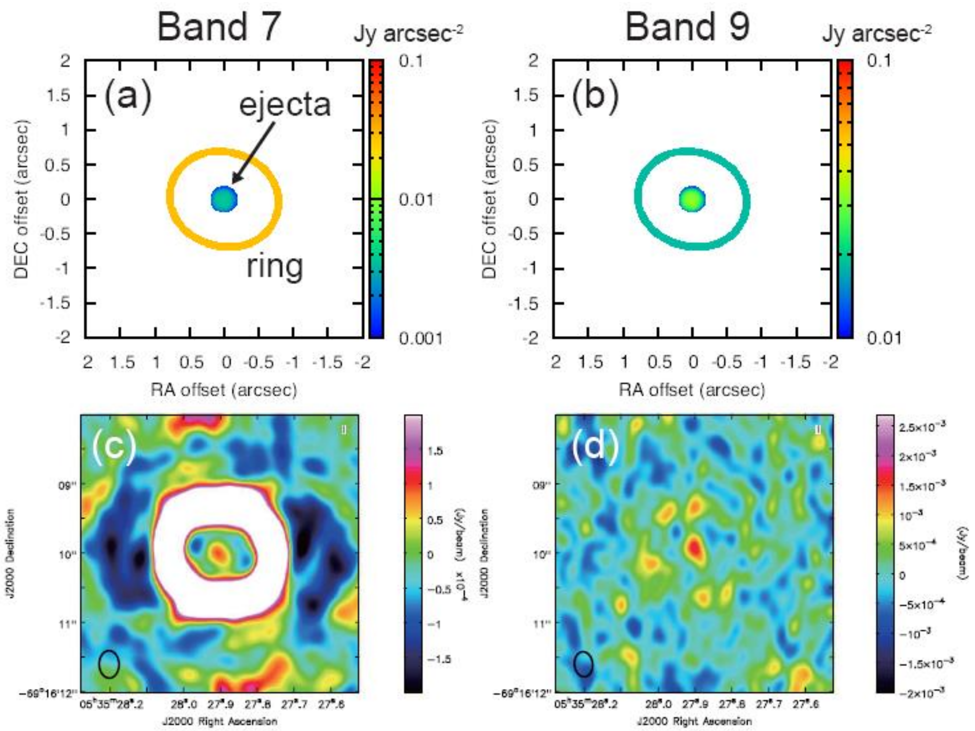
| PI | Exec | Country | Institute |
|---|---|---|---|
| Indebetouw, Remy | NA | United States | Virginia, University of |
| COI | | | |
| McCray, Richard | NA | United States | Colorado at Boulder, Univ of |
| Matsuura, Mikako | EU | United Kingdom | London, University of |
| Andjelic, Milica | OTHER | Serbia | Belgrade, University of |
| Arbutina, Bojan | OTHER | Serbia | Belgrade, University of |
| Baes, Maarten | EU | Belgium | Ghent University |
| Urosevic, Dejan | OTHER | Serbia | Belgrade, University of |
| Vlahakis, Catherine | CL | Chile | Chile, University of |
| Za | | | |
| Za | | | |
| Ng | | | |
| Pa | | | |
| Ba | | | |
| Cl | | | |
| Wesson, Roger | EU | United Kingdom | London, University of |
| Dwek, Eli | NA | United States | National Aeronautics and Space Administration |
| Bouchet, Patrice | EU | France | CEA Saclay |
| Lakicevic, Masa | EU | Germany | European Southern Observatory |
| Potter, Toby | OTHER | Australia | International Centre for Radio Astronomy Research |

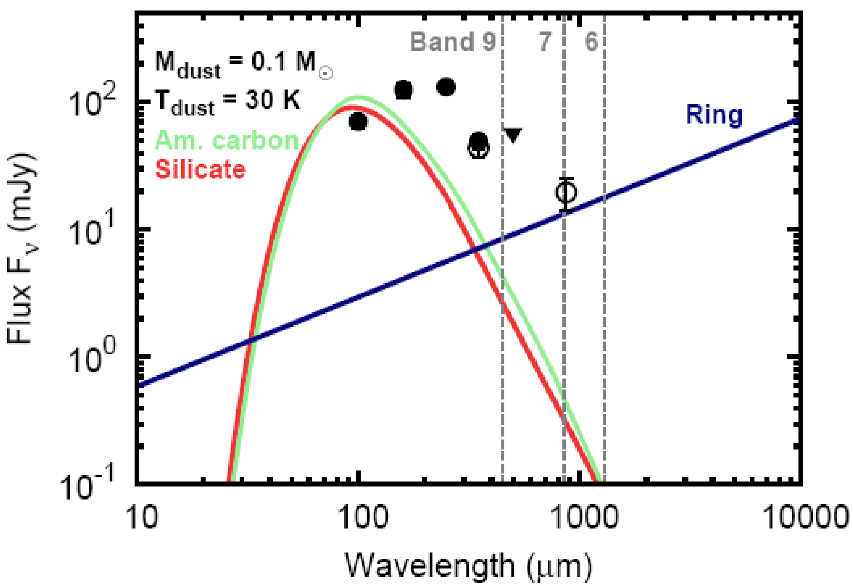
Band 3, 6, 7, 9
compact configuration

# 2-3. Our proposal for ALMA Cycle 1

**ALMA Cycle 1 Proposal**
**'Detecting cool dust in SN1987A'**
**(Tanaka, TN, et al.)**

**This proposal was not ranked as high priority**



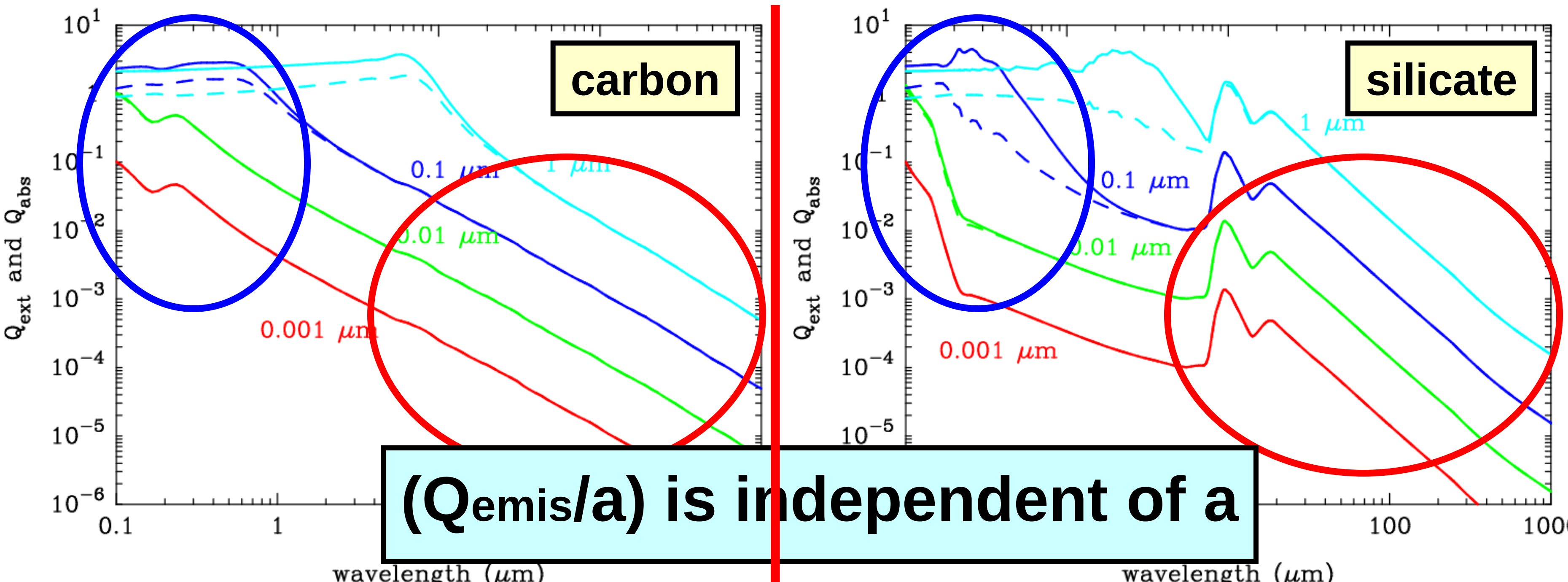




**Observing with the resolution of 0.25" in Bands 7 and 9**
**➔ 10σ detection for silicate of 0.1 Msun and 30 K**

# 3-1. Emission and absorption efficiency of dust

## ○ Thermal radiation from a dust grain

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

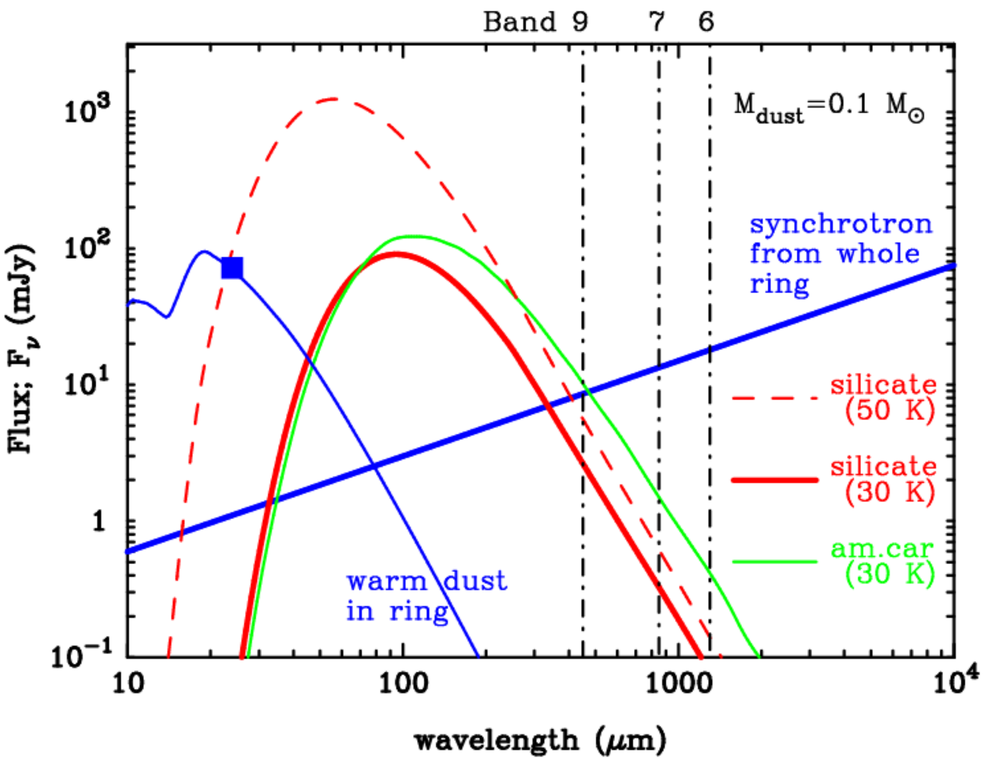



$$F_\lambda \propto 4\pi a^3\, (Q_{emis}[a,\lambda]/a)\, \pi B_\lambda(T_{dust})$$

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

➔ IR emission is derived given $M_{dust}$, $\kappa_{abs}$, and $T_{dust}$

# 3-2. Resolving cool dust in SN 87A with ALMA




**power-law index $Q \propto \nu^{-\beta}$**

- $\beta$ = 1.0-1.5 for carbon
- $\beta$ = ~2.0 for silicate

**flux density**

- Fv ∝ v^-(4.0-4.5) for carbon
- Fv ∝ v^-5.0 for silicate

## ○ Thermal radiation from a dust grain

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

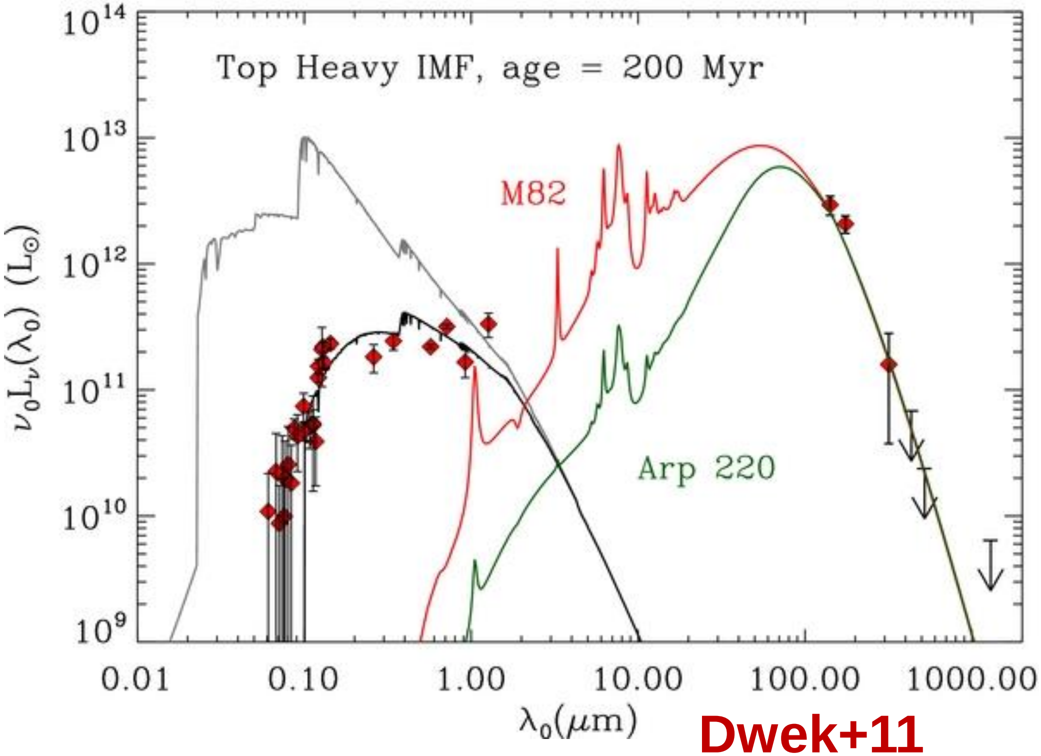
# 3-3. ALMA observations of high-z galazies

**what can we learn from FIR observations of galaxies?**

- power-law index of emission coefficients
  - ➔ implication of dust composition
- mass of cool dust (which dominates dust mass in galaxies)
  - ➔ dust evolution history
  - ➔ depletion of carbon by combining [C II] or CO observations
- temperature of cool dust
  - ➔ clues to star-formation activity and compactness of galaxies
- FIR luminosity (reflecting star formation rate)
  - ➔ corresponds UV-optical luminosity processed by interstellar dust

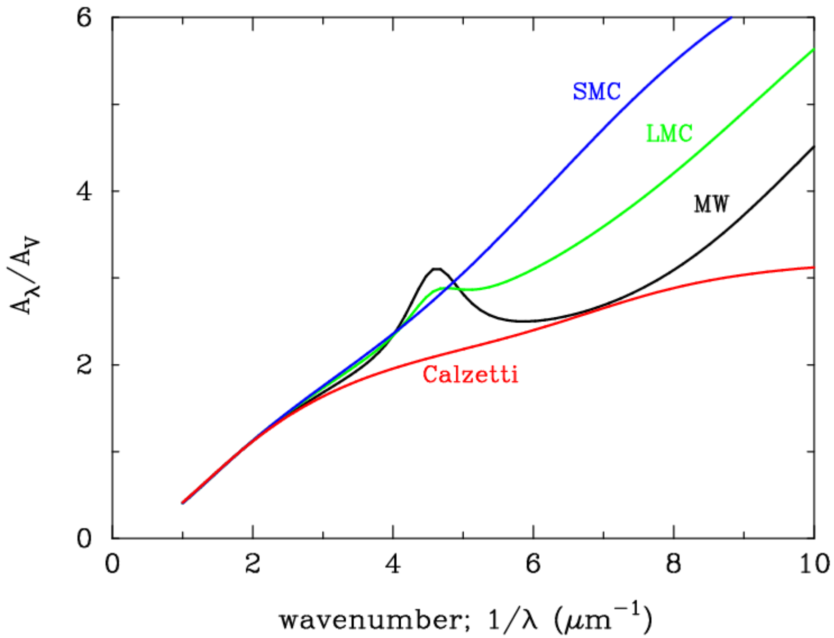
# 4-1. What are the extinction curves at high-z?

**example of SED of high-z galaxies**




Dwek+11

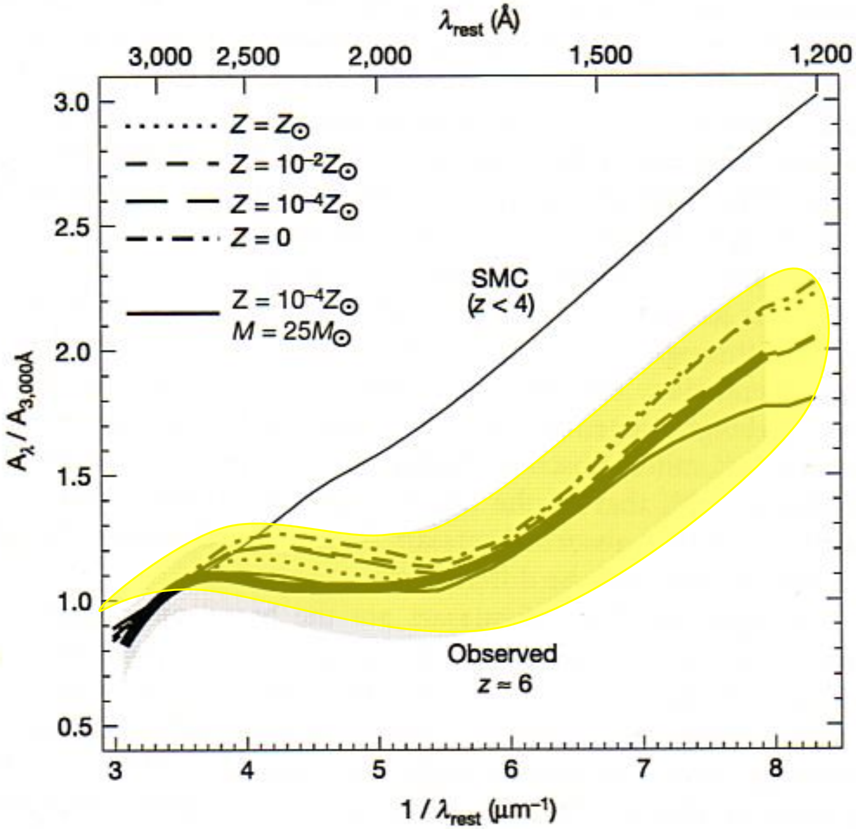
**example of extinction curves**




- **We need to know the extinction properties to extract the intrinsic stellar emission in galaxies**

- **What extinction curve is appropriate for high-redshift galaxies?**

# 4-2. Observed extinction curves at high-z

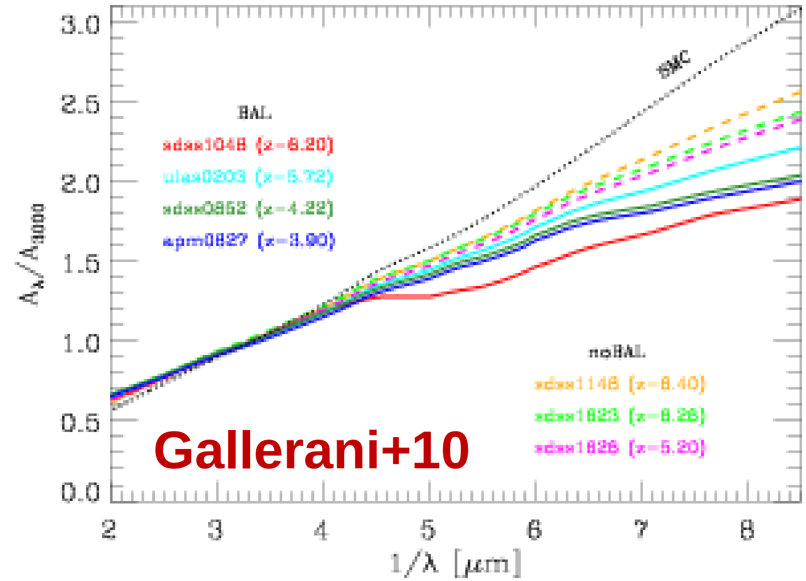


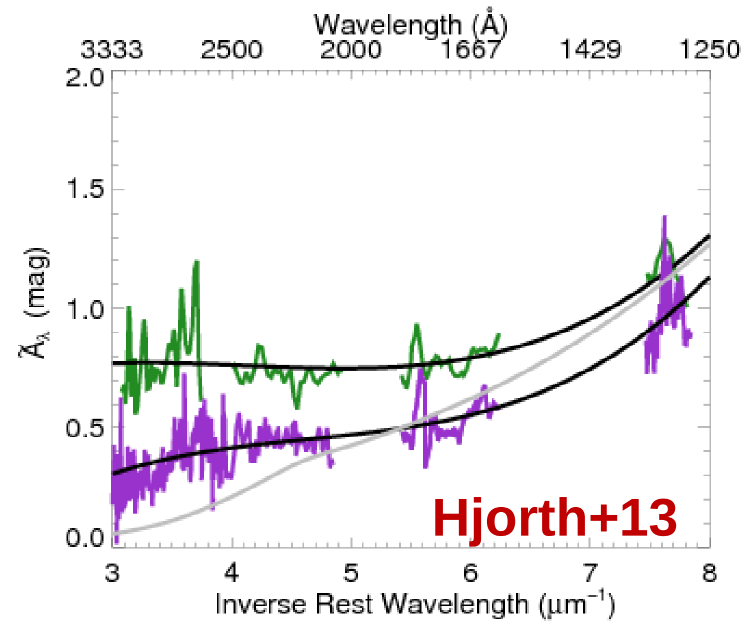

**SDSS J1048+4637 at z=6.2**

Broad absorption line (BAL) quasars

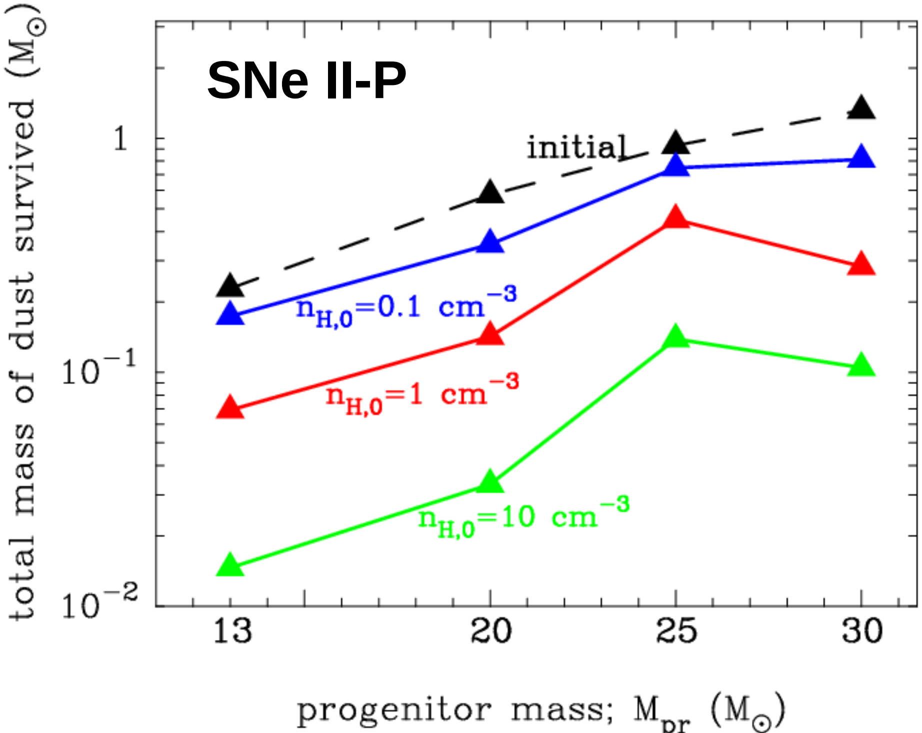
**Maiolino+04, Nature, 431, 533**

**different dust properties from those at low redshift**

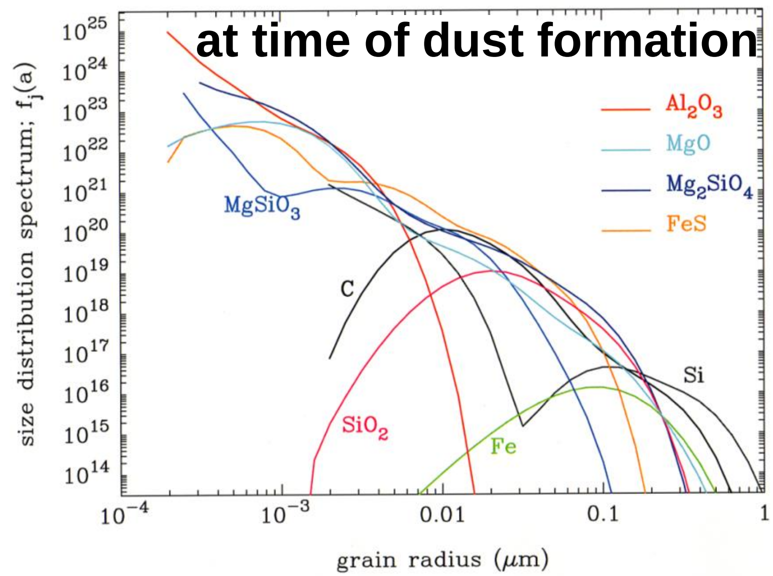


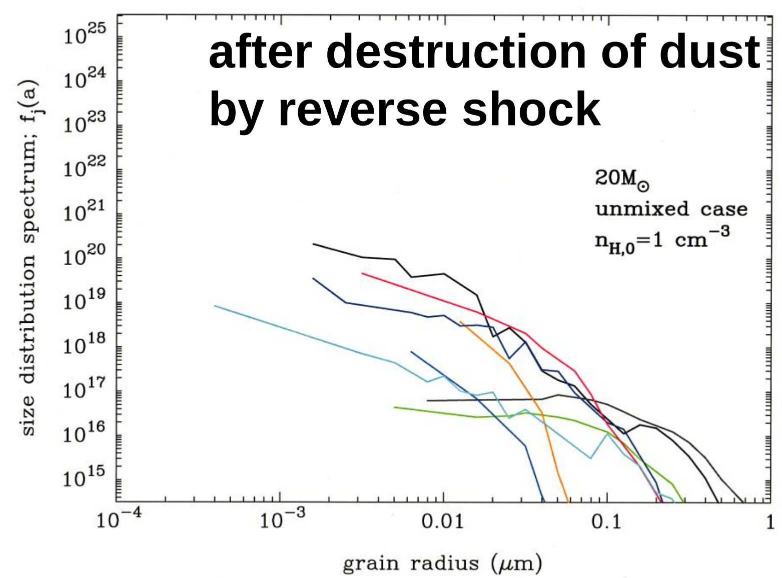



# 4-3. Mass and size of dust ejected from SN II-P




**Nozawa+07**



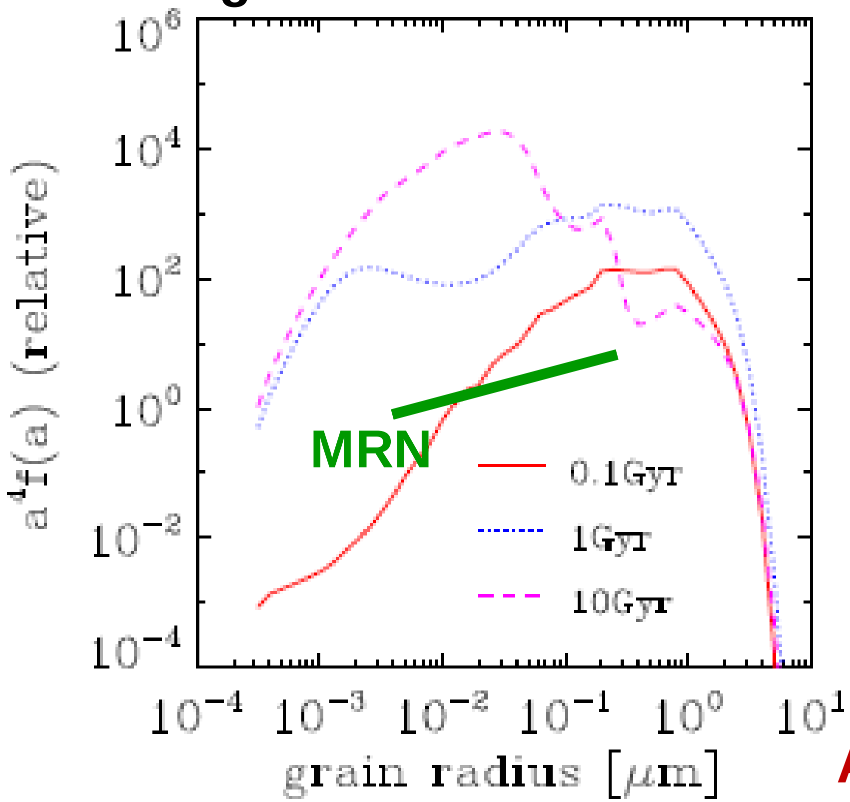




**total dust mass surviving the destruction in Type II-P SNRs; 0.07-0.8 $M_{sun}$ ($n_{H,0}$ = 0.1-1 cm$^{-3}$)**

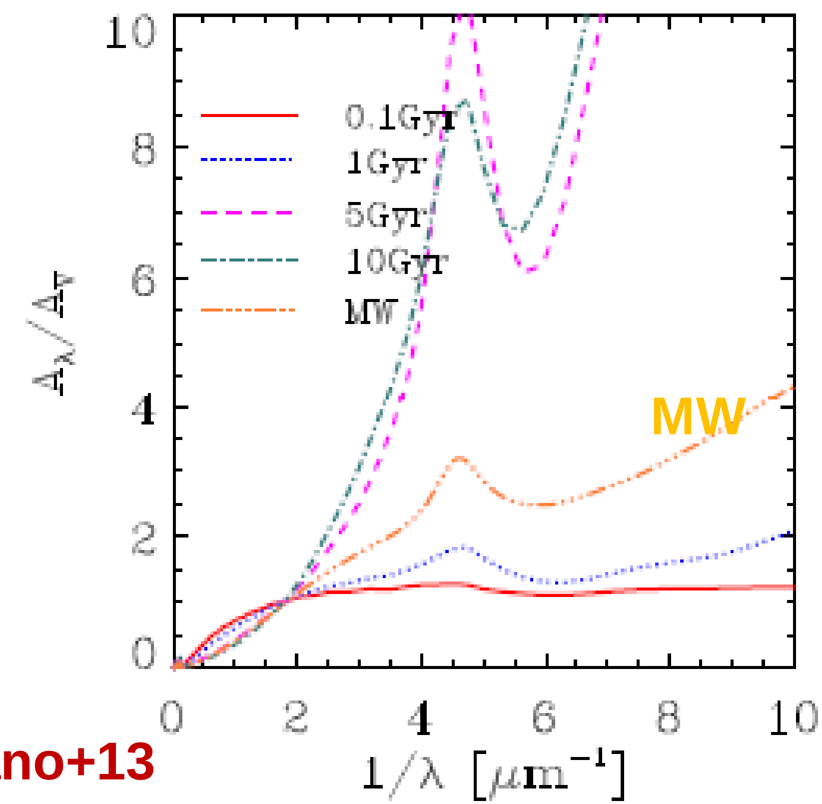
**size distribution of dust after RS destruction is domimated by large grains (> 0.01 μm)**

# 4-4. Evolution of extinction curves

**grain size distribution**




**extinction curve**




Asano+13

- **Large grains from SNe and AGB stars at earlier times**
  ➔ **flat extinction curve**
- **Small grains from shattering and growth at later times**
  ➔ **steep extinction curve**

# 5. Summary

**・ FIR dust emission from high-z galaxies**

- **mass, temperature (and composition) of dust and FIR luminosity**

  **➔ relation between carbon dust mass and gas phase carbon ([C II] or CO)**

**・ Synergy with optical-to-NIR observations**

- **extinction curves from both theoretical models and observations**

  **➔ information on the size of interstellar dust**

**Disclosing the evolution history of galaxies from the origin and evolution of dust grains**