Revealing the mass of dust formed in the ejecta of SNe with ALMA

ALMAで探る超新星爆発時におけるダスト形成量

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2011/1/31

1-1. SNe are important sources of dust?

・Theoretical studies

— at dust formation : **~0.1-1 M_{sun}** in CCSNe (SNe II-P)
(Nozawa+03; Todini & Ferrara 2001; Cherchneff & Dwek 2010)

— after destruction of dust by reverse shock :
~0.01-0.5 M_{sun} (Nozawa+07; Bianchi & Schneider 2007)

dust amount needed to explain massive dust at high-z!

・Observational works

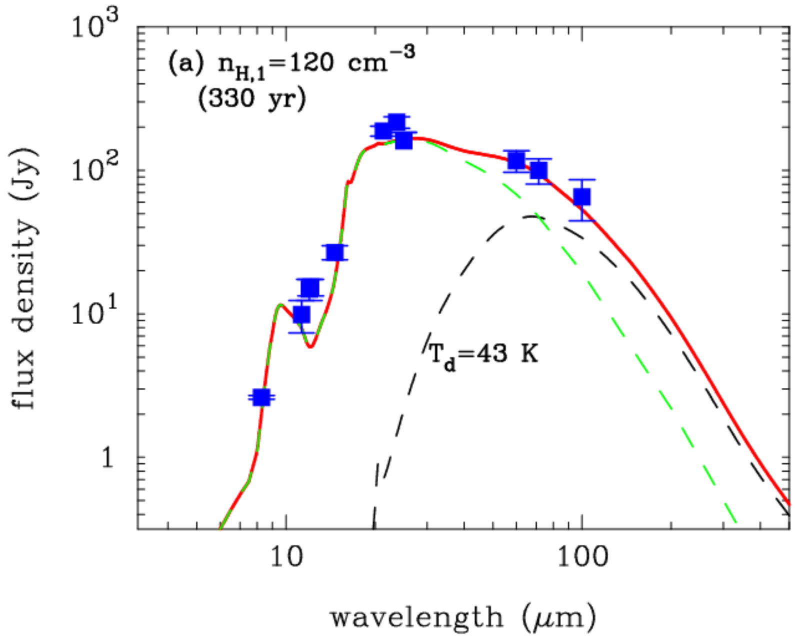
— MIR observations of dust-forming SNe : **< 10^{-3} M_{sun}**
(e.g., Ercolano+07; Sakon+09; Kotak+09)

— submm observations of SNRs : **>1 M_{sun}**
(Dunne+03; Morgan+03; Dunne+09; Krause+05)

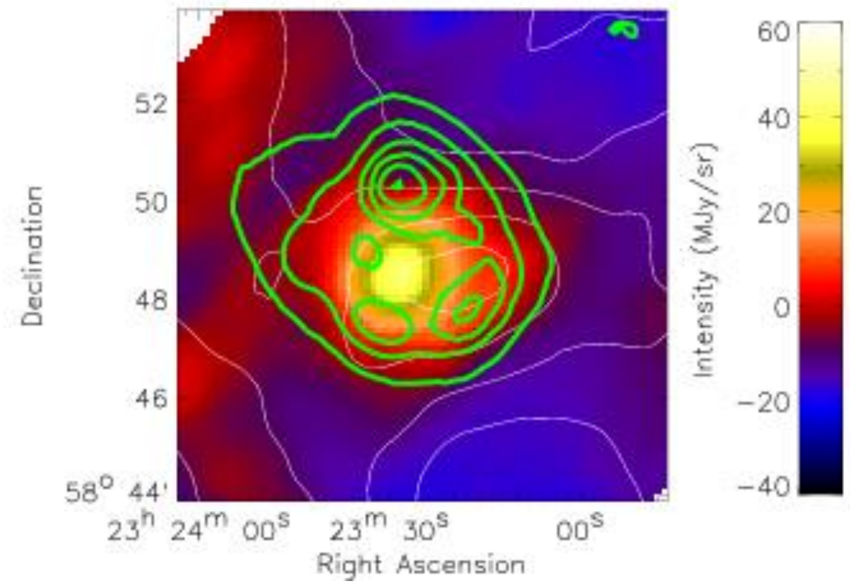
— MIR-FIR observation of Cas A SNR : **0.02-0.075 M_{sun}**
(Rho+08; Sibthorpe+09; Barlow+10)

1-2. Dust in Cassiopeia A

Nozawa+10, ApJ, 713, 356



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

AKARI observation

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

T_{dust} = 33-41 K

(Sibthorpe+10)

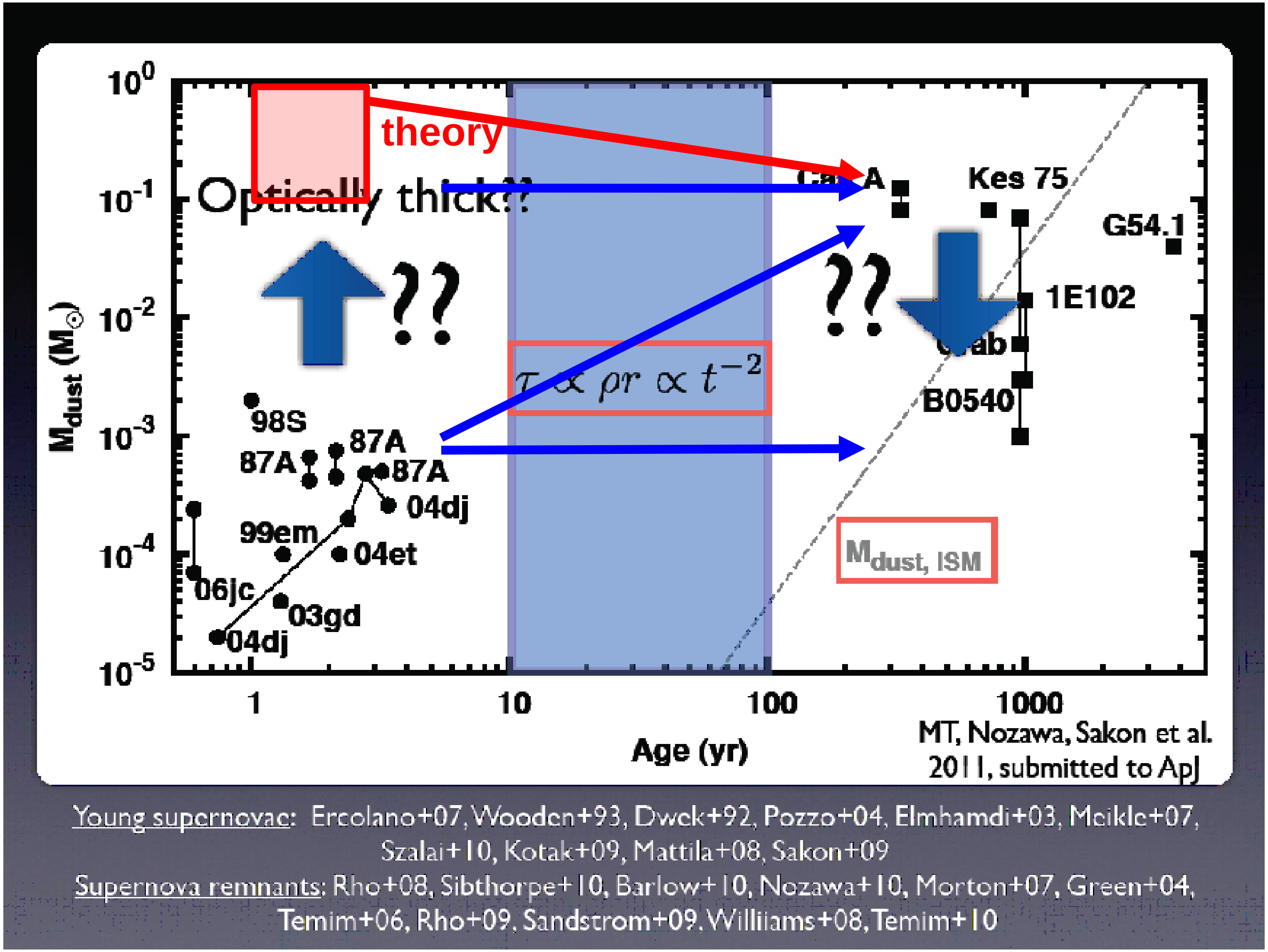
Herschel observation

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

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

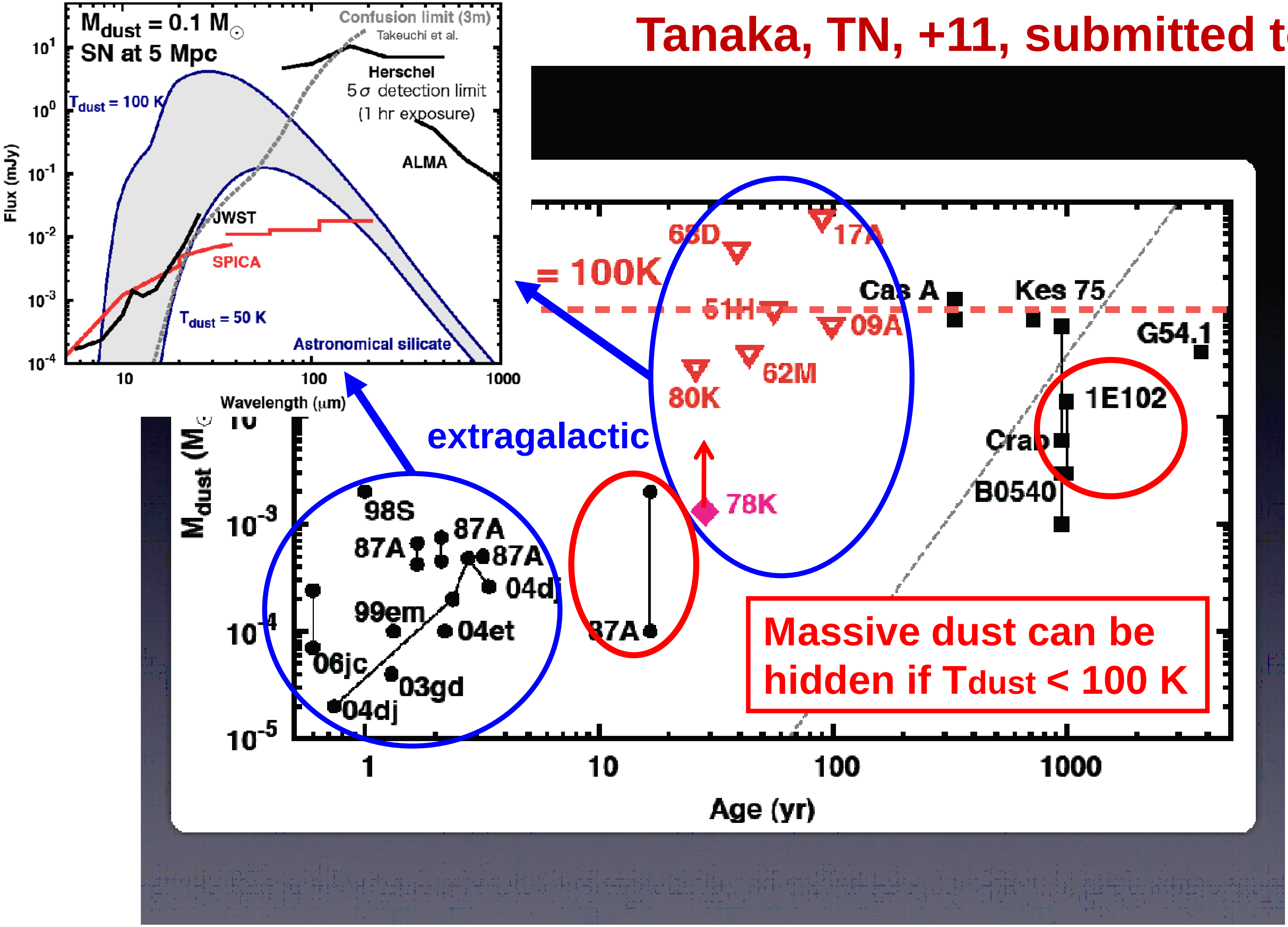
1-3. Missing-dust problem in CCSNe

Tanaka, TN, +11, submitted to ApJ

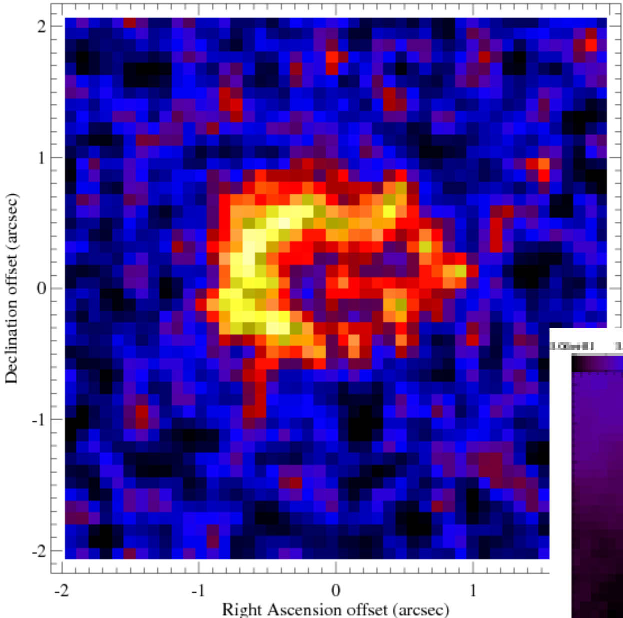


1-4. Possible targets : SNRs in LMC and SMC

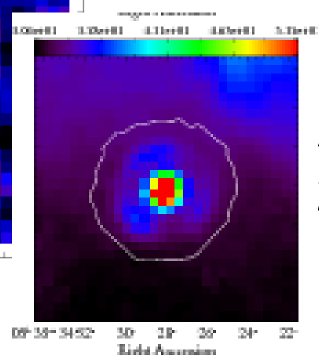
Tanaka, TN, +11, submitted to ApJ



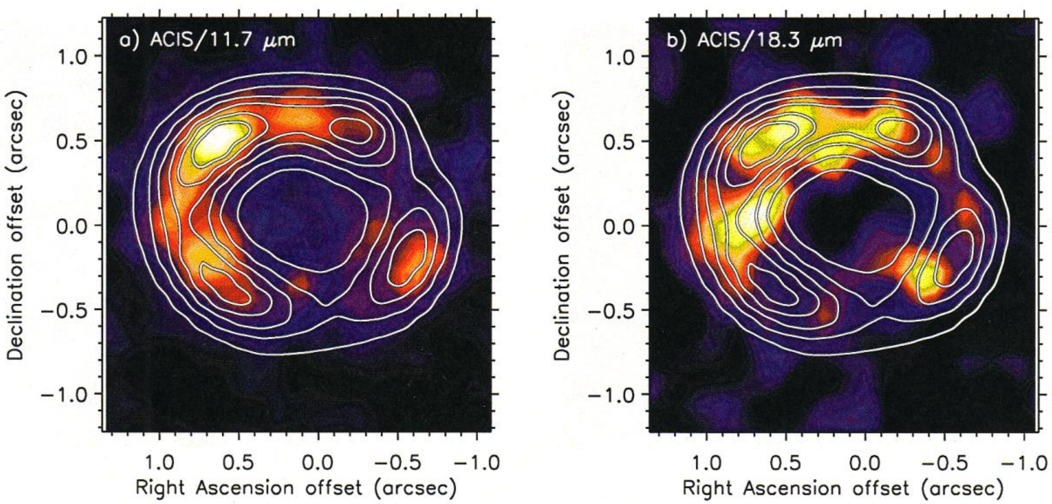
2-1. Possible target (1): SN 1987A



on 4 Oct 2003
Gemini T-ReCS
(λ = 10.36 μm)
2 pixels : 0.18"
(Bouchet+04)



AKARI
24 μm
(Seok+08)



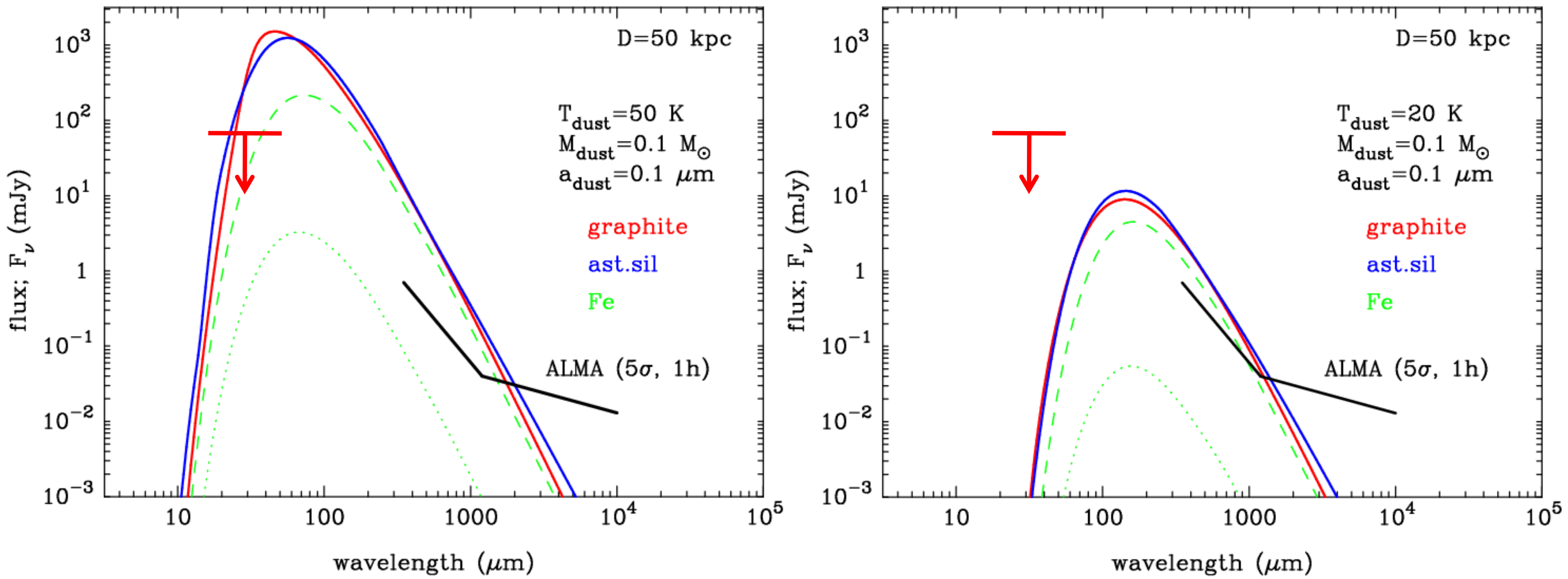
On 6 Jan and 1 Feb 2005 (Bouchet+06)

- **SN1987A in LMC**
  - **Type-II peculiar**
  - **age : 24 yr**
  - **diameter : 2"**
    (= 0.5 pc @ 50 kpc)

- **dust mass in ejecta**
  - **Mdust > 1×10^{-4} Msun**
    (Wooden+93)
  - **Mdust = 0.23 Msun**
    (Kozasa+91)
  - **Mdust > 10^{-4} Msun**
    (Bouchet+04)

- **dust mass in ER**
  - **Mdust=10^{-6}-10^{-5} Msun**
    (Seok+08, Dwek+08)

2-2. Expected detectability of SN 1987A



- **Case of T_{dust} = 50 K**
  5.0 mJy @ 450 μm (B9)
  0.5 mJy @ 850 μm (B7)
  0.1 mJy @ 1.3 mm (B6)

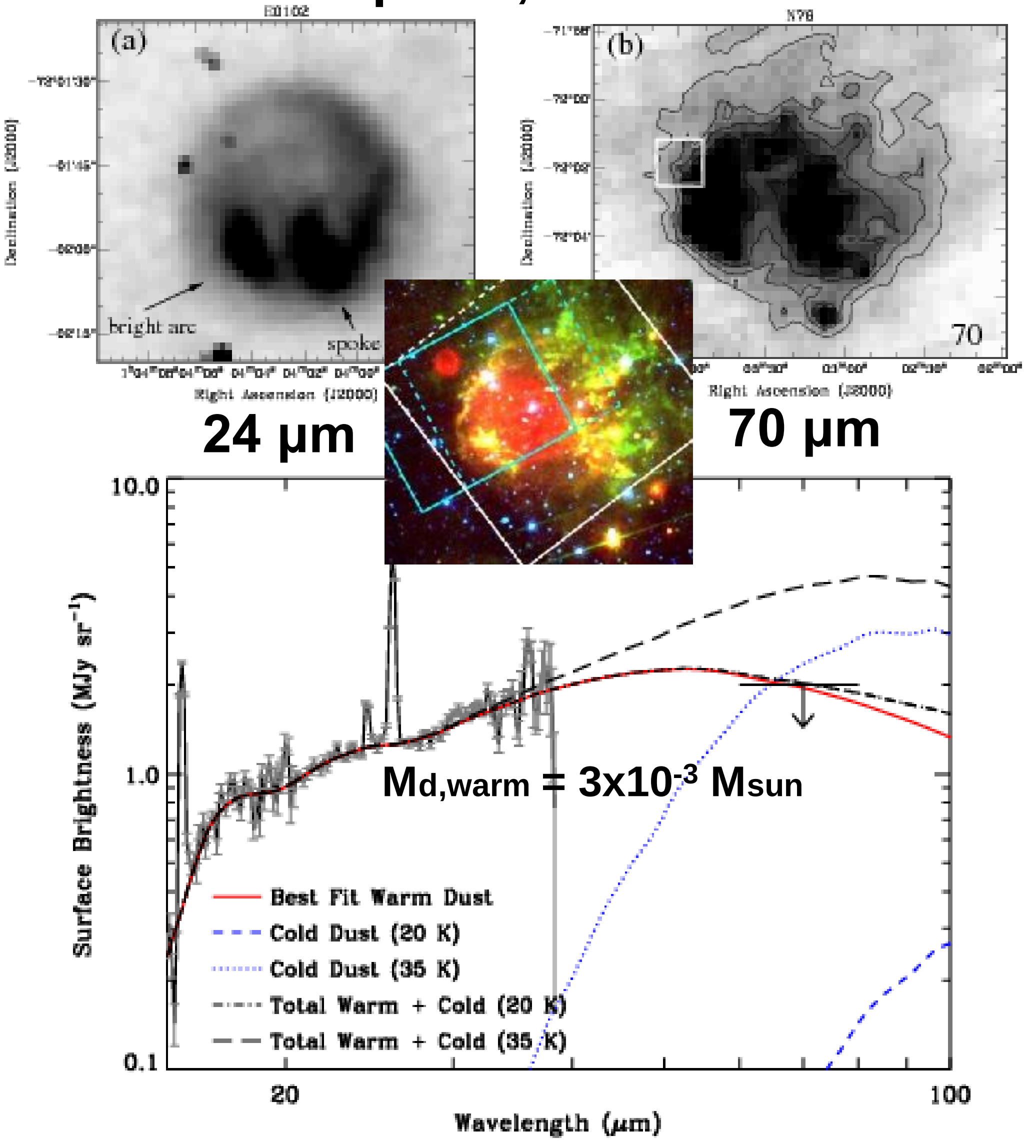
- **Case of T_{dust} = 20 K**
  1.23 mJy @ 450 μm (B9)
  0.16 mJy @ 850 μm (B7)
  0.04 mJy @ 1.3 mm (B6)

Rayleigh-Jeans law : $B_\nu(T) = 2 \nu^2 k T / c^2$

$M_{dust} = 0.1 M_{sun} \rightarrow F_\nu(T) \propto M_{dust}$

3-1. Possible target (2) : SNR 1E0102.2-7219

Spitzer; Stanimirovic+05



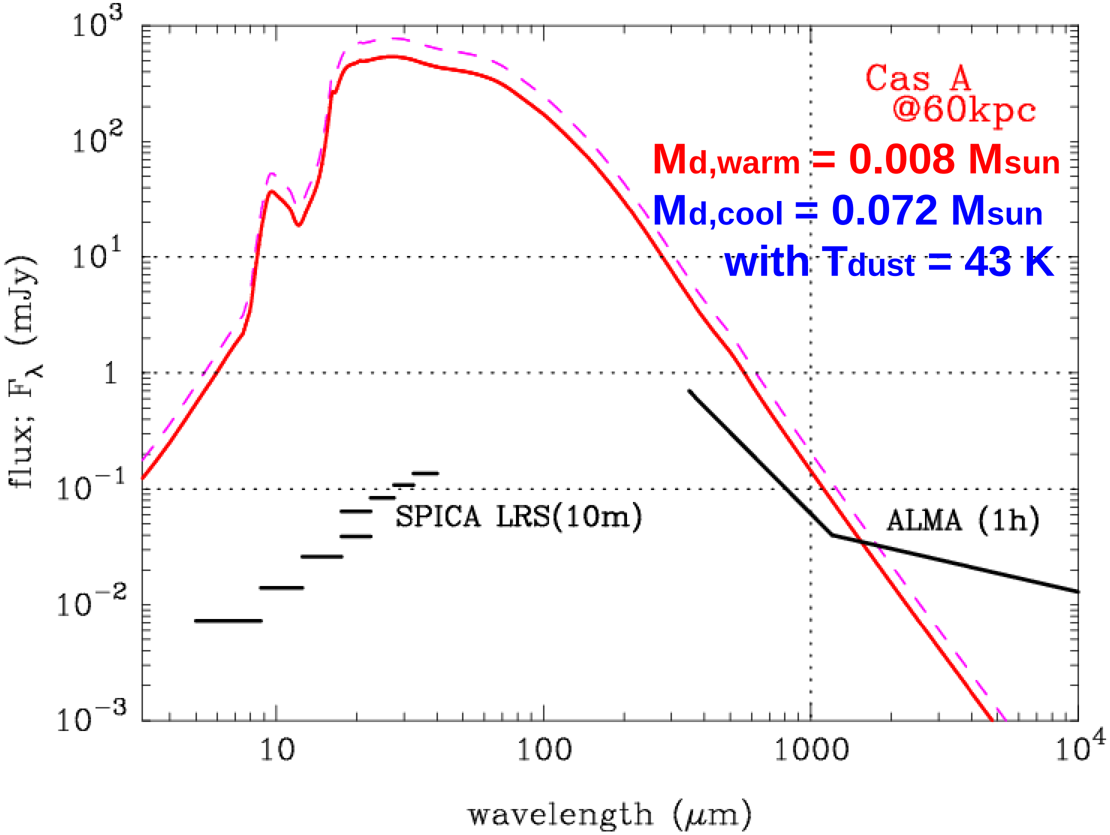
Sandstrom+09

- SNR 1E0102.2 in SMC
  - O-rich (Type Ib?)
  - age : ~1000 yr
  - diameter : ~40”
    (= 12 pc @ 60 kpc)
  - similar to Cas A

- hot dust mass
  - $M_{dust} = 8 \times 10^{-4}\ M_{sun}$
    (Stanimirovic+05)
  - $M_{dust} = 0.014\ M_{sun}$
    (Rho+09)

- cold dust mass
  - $M_{d,cold} < 0.6\ M_{sun}$
    with $T_{dust} = 20$ K
    (Sandstrom+09)

3-2. Expected detectability of 1E0102.2-7219



- for the whole SNR
  2.0 mJy @ 450 μm
  0.24 mJy @ 850 μm
  0.06 mJy @ 1.3 mm

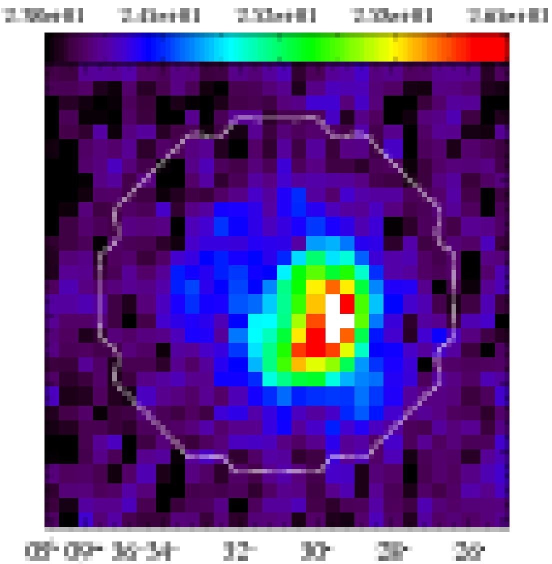
- one pixel resolution
  R ~ 0.84”x(250m/L) x(345GHz/v)

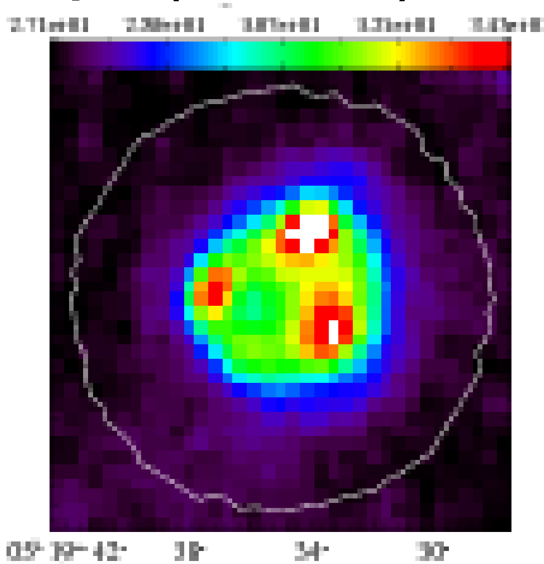
- field of view
  ~ 17” x (345GHz/v)

- L = 25 m, diameter : ~40”
  - 450μm(675GHz) ➔ R=4” ➔ (0.02mJy/pixel) ➔ t = 78 d
  - 850μm(345GHz) ➔ R=8” ➔ (0.01mJy/pixel) ➔ t = 22 d
  - 1.3mm(230GHz) ➔ R=12” ➔ (0.005mJy/pixel) ➔ t = 25 d

4-1. Possible target (3) : Type Ia SNRs in LMC

AKARI, 24 μm (Seok+08)





0509-67.5 (400 yr)	0519-69.0 (600 yr)

↓ Spitzer, 24μm 70μm ↓

Mdust < 1x10^{-3} Msun	Mdust < 3x10^{-3} Msun

(Borkowski+06)

- shock-heated interstellar dust
  ➔ dust destruction by SNe

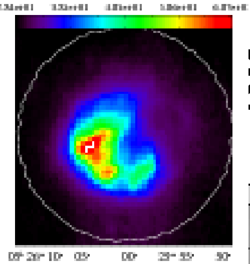
- SNRs 0509-67.5 and 0519-69.0 in LMC
  - Type Ia SNRs
  - age : ~500 yr
  - diameter : ~40”

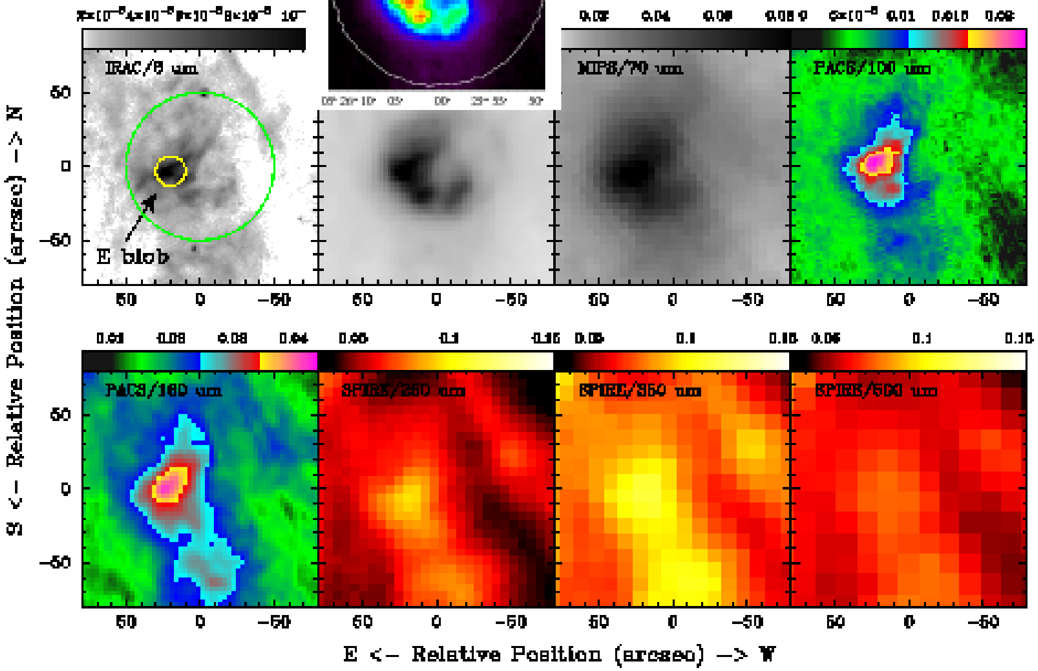
- There is no evidence for dust formation in normal Type Ia SNe

- possible maximum dust mass :
  Mdust = 0.1-0.2 Msun
- conservative upper limit of dust mass :
  Mdust ~ 0.05 Msun

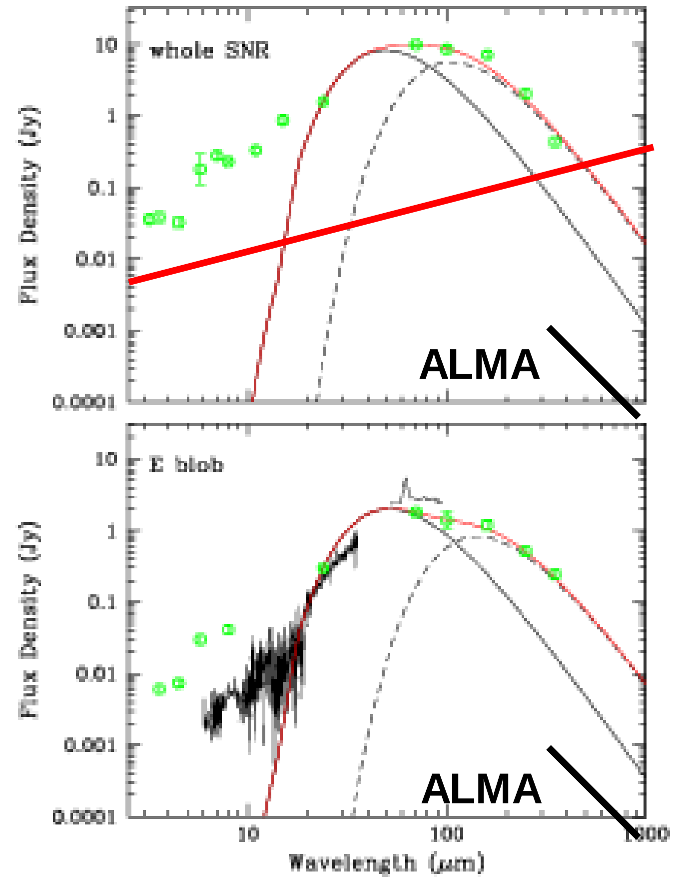
(Nozawa+11 to be submitted)

4-2. Poss arget (4) : SNR N49 in LMC





- SNR N49 in LMC
  - M_{star} ~ 20 M_{sun}
  - age : ~6000 yr
  - diameter : 50”



- SNR interacting with MCs
  - $M_{d,warm}$ = 0.1-0.4 M_{sun}
  - $M_{d,cold}$ ~ 10 M_{sun}

  interacting region (E blob) : 10”

  (Herschel; Otsuka+10)

- synchrotron emission

  ➔ contribution and distribution

5. Summary

Revealing cold dust mass in SNe with ALMA !!

- **Possible targets : young SNRs in LMC and SMC**
  - **SN 1987A in LMC**
    most feasible, but many competitors …
  - **1E0102.2-7219 in SMC**
    too extended ➔ seems to be very hard
  - **Type Ia SNRs 0509-67.5 and 0519.69.0 in LMC**
    if detected, very exciting, but most unfeasible …
  - **N49 in LMC**
    synchrotron emission and/or radiation from interstellar dust may be detectable