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Properties of interstellar and circumstellar dust as probed by mid-IR spectroscopy of supernova remnants
(超新星残骸の中間赤外分光から探る星間・星周ダスト)

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1-1. Motivation : unsolved problems

・ How has the cosmic dust evolved in galaxies?

- origin of dust : SNe, AGB stars, any other sources
- destruction of dust : SN blast wave

・ Galactic dust model

MRN model (Mathis et al. 1977, Draine & Lee 1984)

- carbonaceous : graphite or amorphous?
- silicate : astronomical silicate?
- size distribution : $f(a) \propto a^{-3.5}$ ($0.005\ \mu m < a_{dust} < 0.25\ \mu m$)

・ SMC and LMC dust model

- only silicate grains (Pei 1992)
- small grains are abundant (Weingartner & Draine 2001)

1-2. Why dust in SNRs?

- interstellar dust in diffuse medium

  T_{dust} ~ 15-30 K ➔ far-IR emission (> 50 μm)

  poor information on composition and size of dust

- interstellar dust swept up by SNRs

  T_{dust} ~ 50-200 K ➔ mid-IR emission (5-50 μm)

  – 9.8 μm and 18 μm features of silicate
  – 30 μm broad feature of graphite

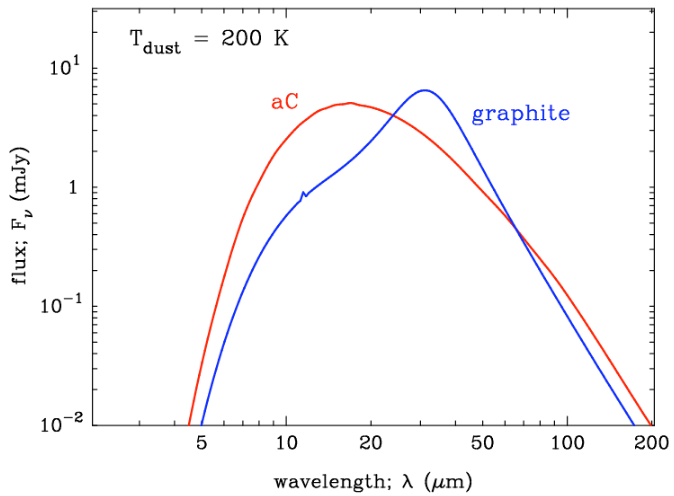
  ➔ dust composition

  # shocked dust is destroyed by sputtering in the hot plasma

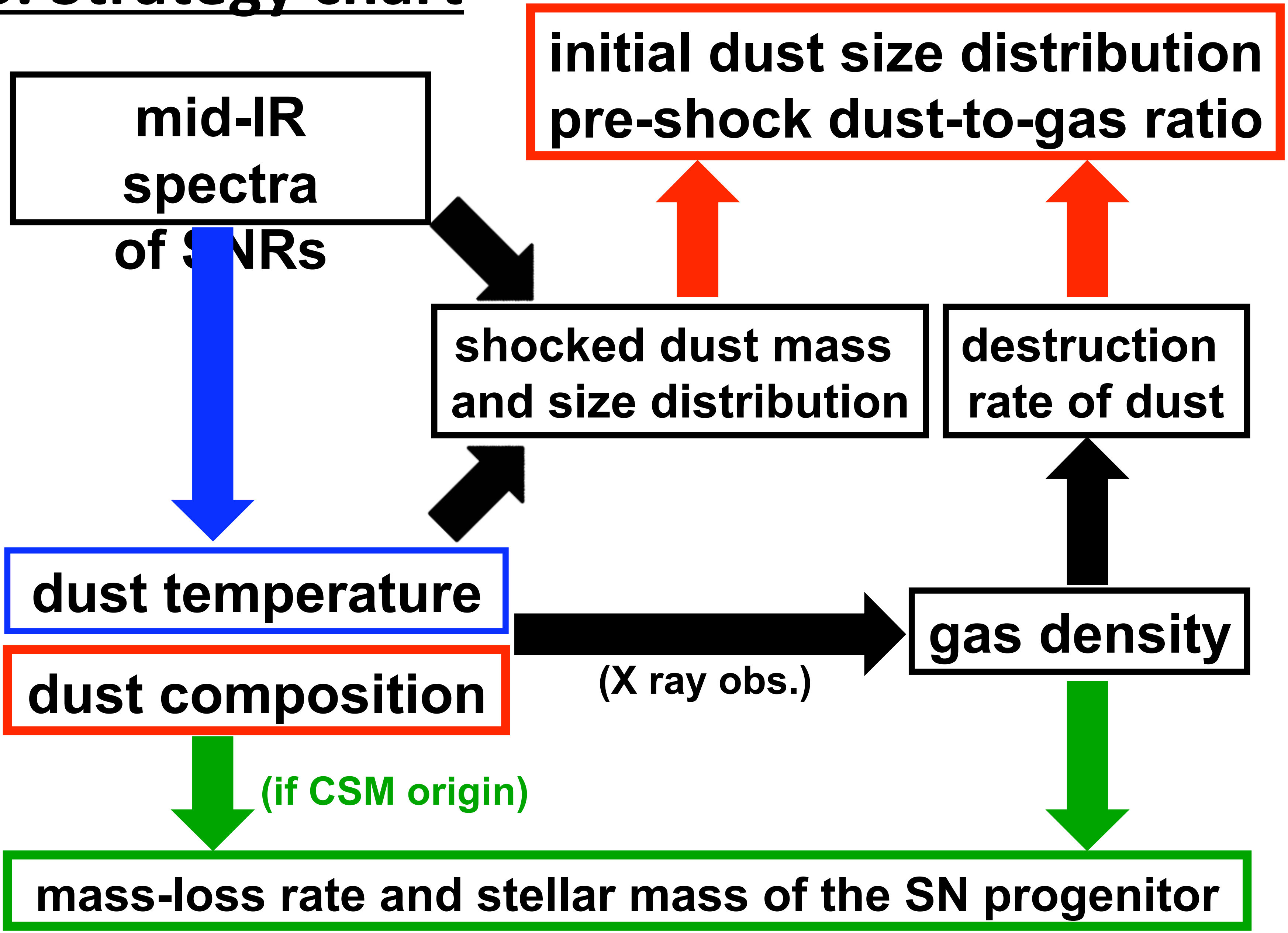
  – dust temperature

  ➔ gas density ➔ dust radius

  ➔ dust destruction efficiency



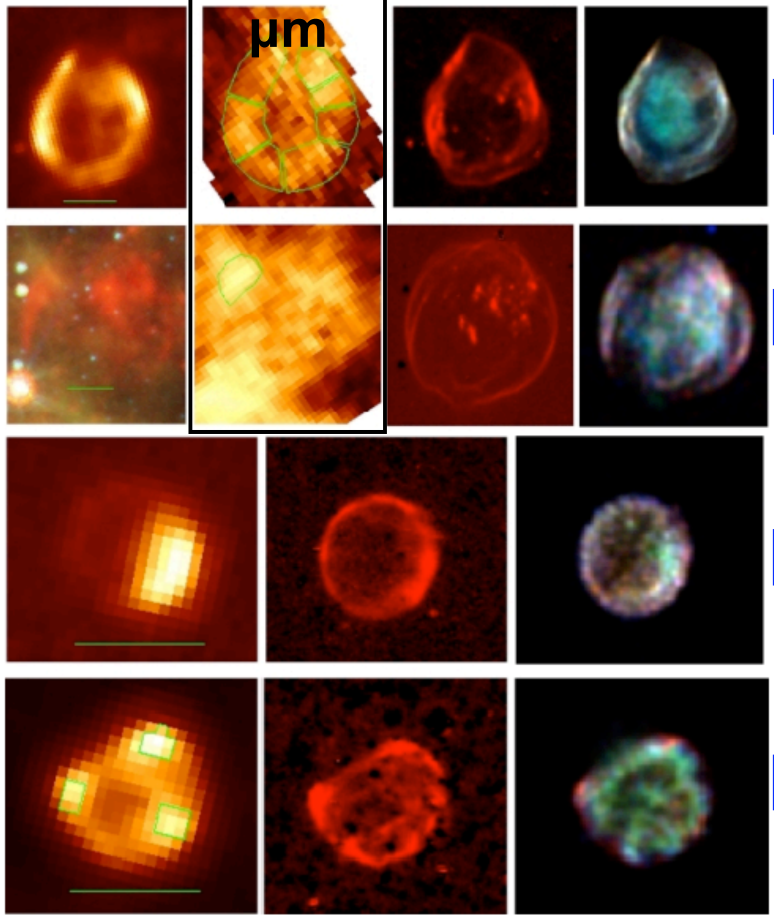
1-3. Strategy chart



2-1. Spitzer observations of SNRs in LMC

Type Ia | 24 µm | 70 µm | Hα | X-ray

Borkowski et al. (2006)

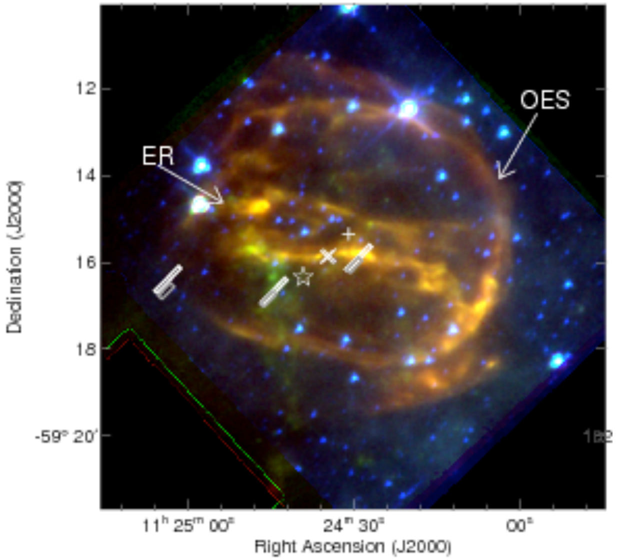


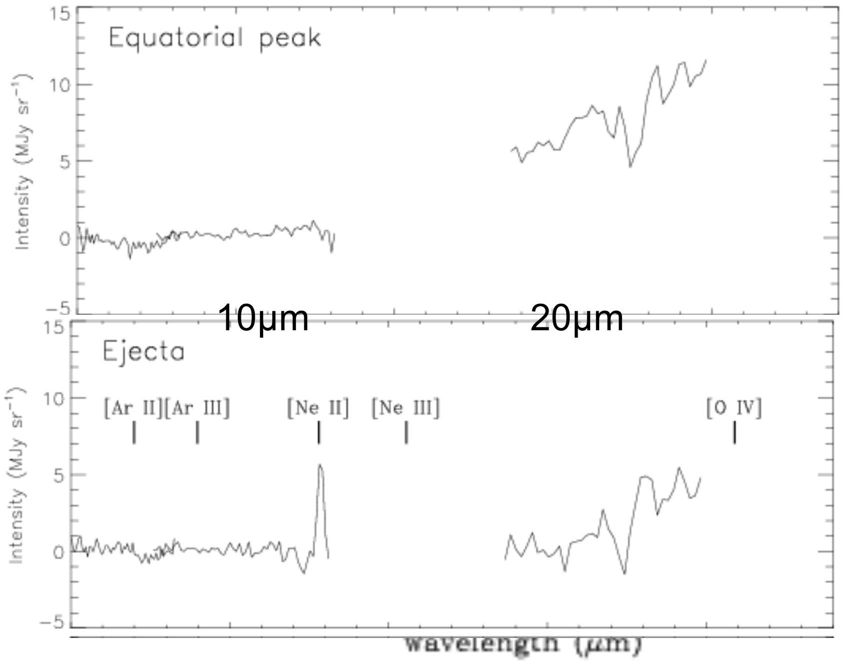
DEM L71	4400 yr	Tdust = 55-65 K	Mdust = 0.034 Msun	ne = 2.7 cm^{-3}
0548-70.4	7100 yr	Tdust = 53-62 K	Mdust = 0.0018 Msun	ne = 2.0 cm^{-3}
0509-67.5	400 yr	Tdust = 66-70 K	Mdust < 0.0011 Msun	ne > 1.6 cm^{-3}
0519-69.0	600 yr	Tdust = 72-86 K	Mdust < 0.0033 Msun	ne > 3.4 cm^{-3}

24µm / 70µm flux ratio, LMC dust model
➔ dust-to-gas mass ratio is less than 0.3 %

see also Williams et al. (2006) for CCSN remnants in LMC

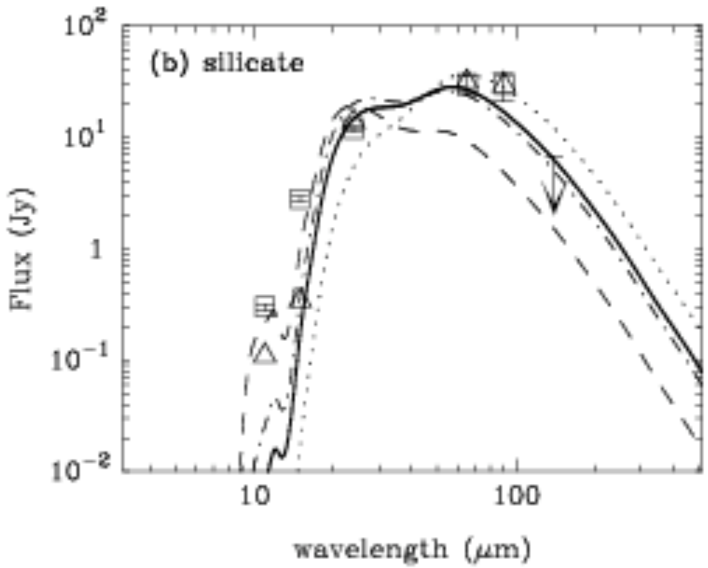
2-2. AKARI observations of G292.0+1.8





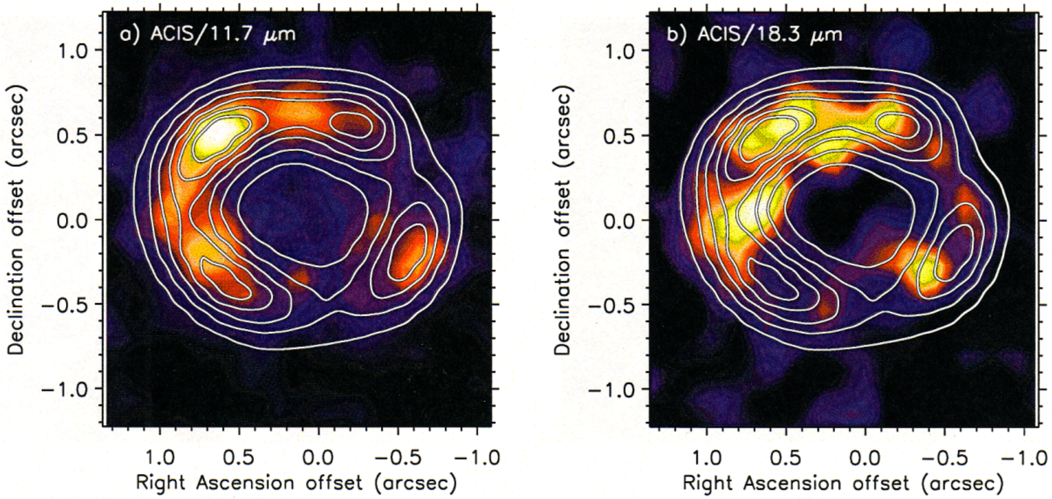
Lee, ..,TN, .. et al. (2009)

- O-rich SNR (Type II-P)
- SNR age : ~3000 yr
- **Galactic size distribution**
  - $n_{H,0}$ = 0.5 cm^{-3}
  - silicate (CSM origin)
  - T_{dust} ~ 45-65 K
  - dust-to-gas ratio ~ 0.1%

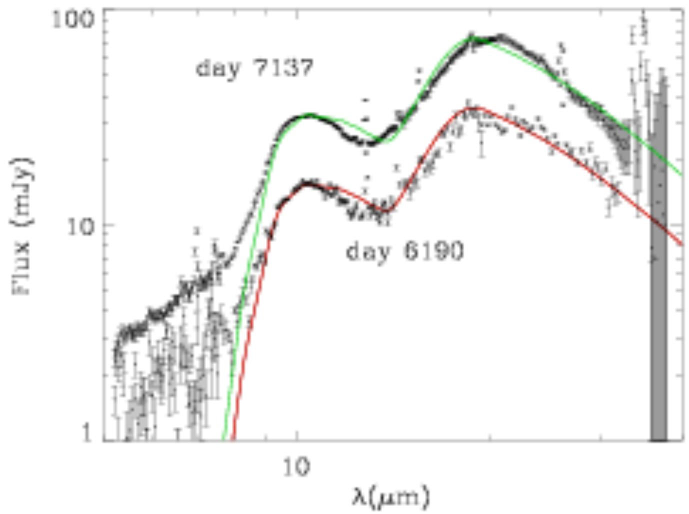


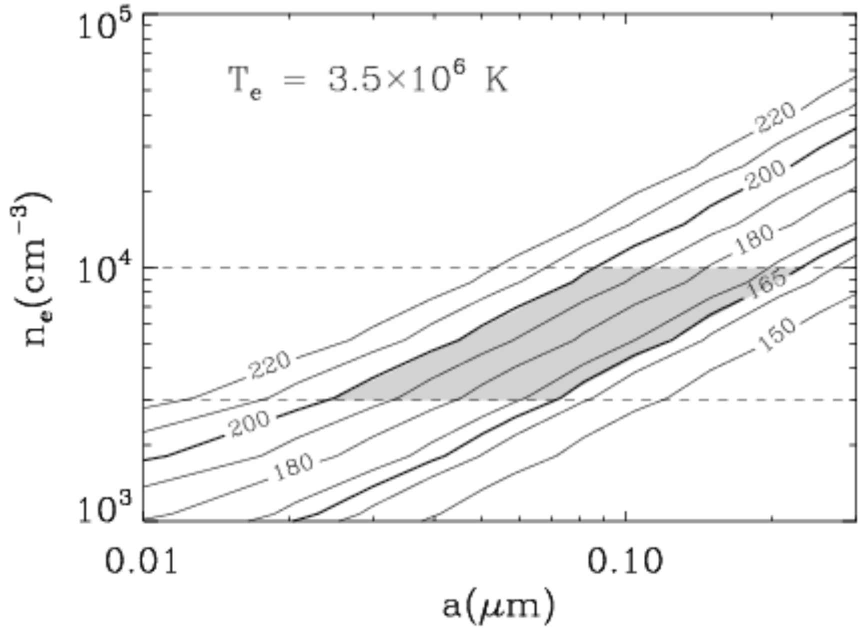
2-3. IR observations of middle-aged SN 1987A

Dwek et al. (2008)



Bouchet et al. (2006)



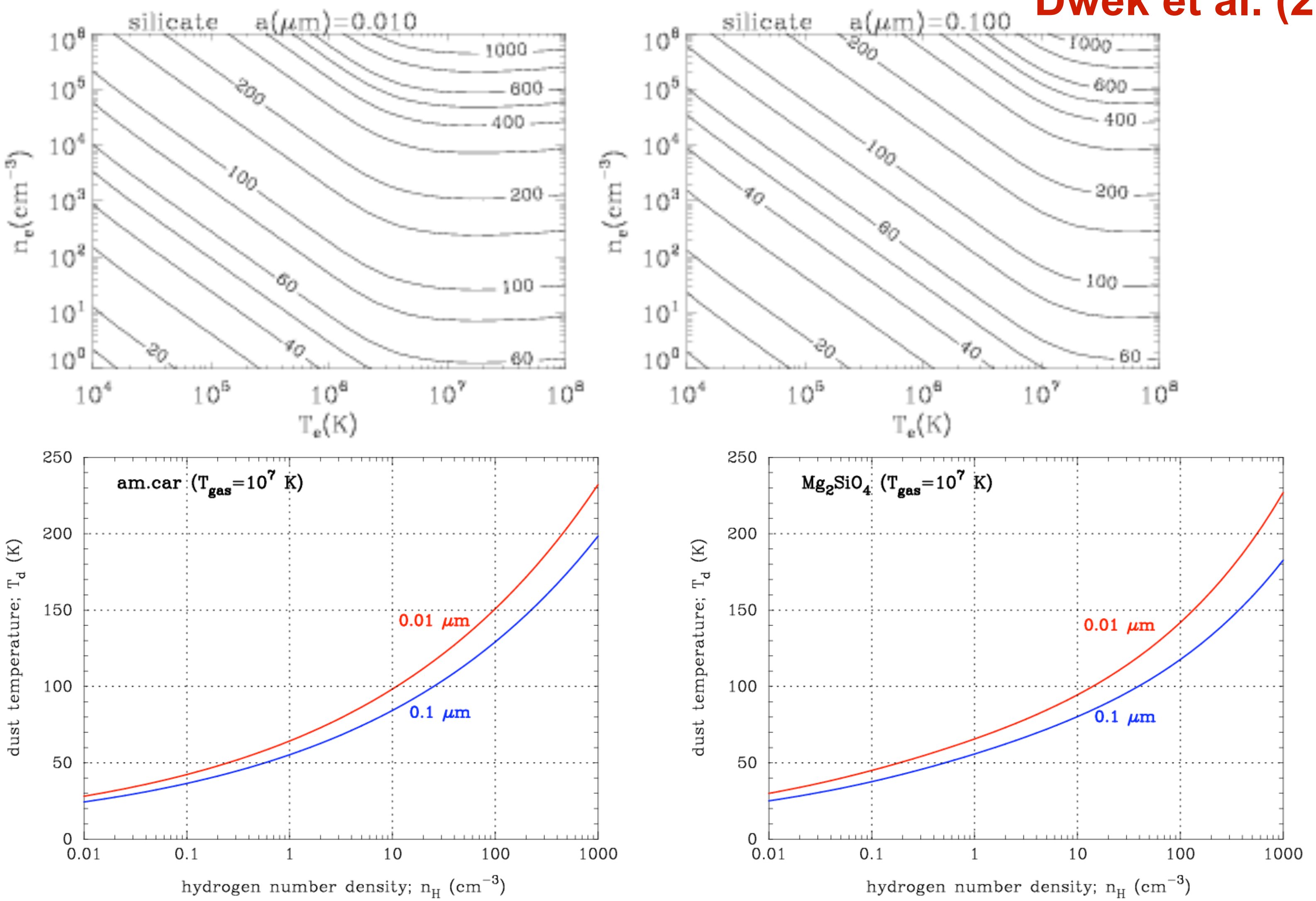


- O-rich SNR (Type II-P)
- SNR age : ~20 yr
- n_e = (0.3-1)x10^4 cm^{-3}
- T_{dust} ~ 180 K
- silicate (CSM origin)
- 0.02 μm < a_{dust} < 0.2 μm
- dust-to-gas ratio ~ 0.3%

see also Dwek et al. (2010)

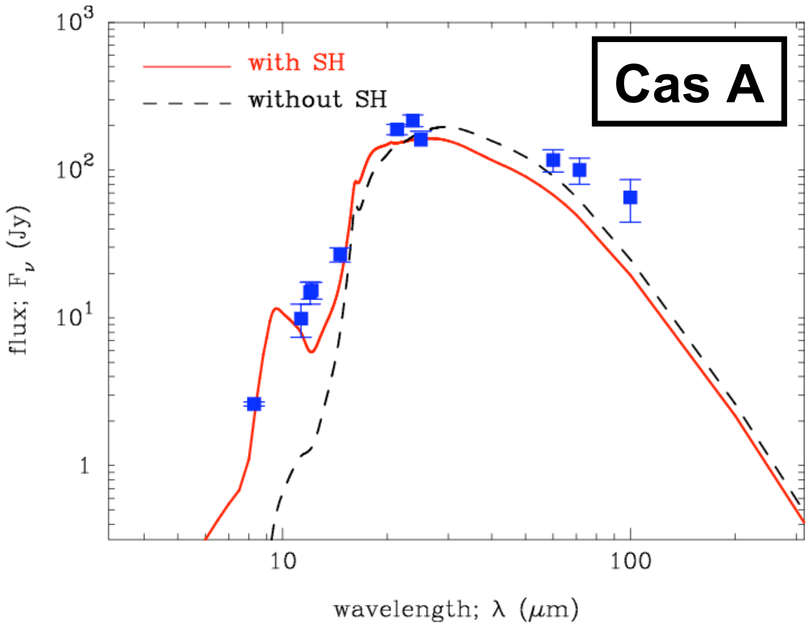
3-1. Temperature of dust in the hot plasma

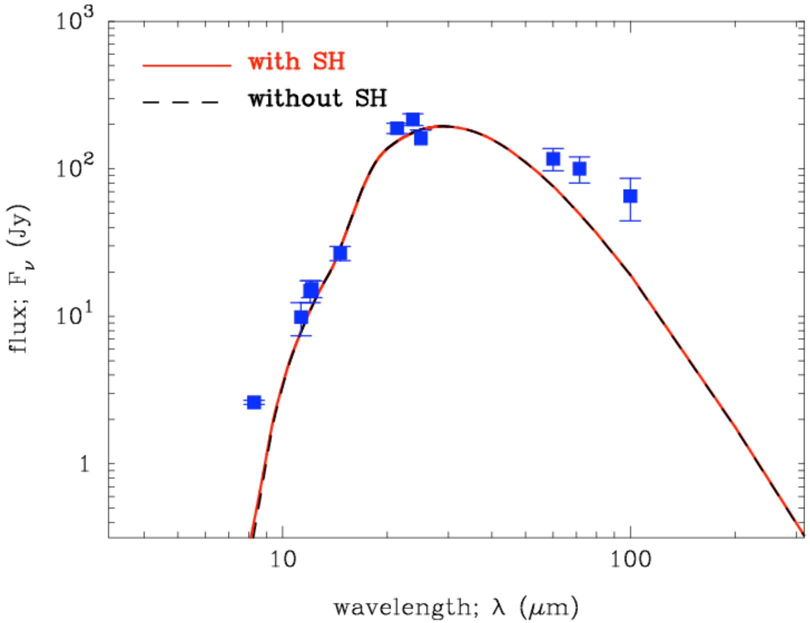
Dwek et al. (2008)



- dust temperature well reflects the plasma density

3-2. Stochastic heating of small grains





Nozawa et al. (2010)

dust formation calculations

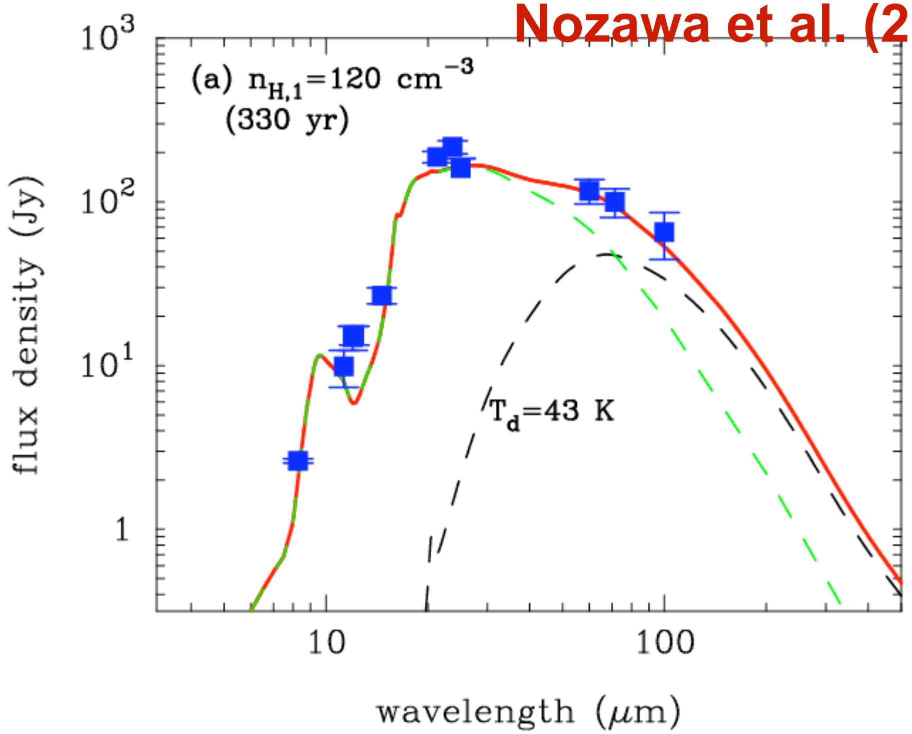
- **silicate dominated**
- **a_{dust} < ~0.01 μm**

emission spectra at shorter mid-IR are good probes of abundance of small grains!

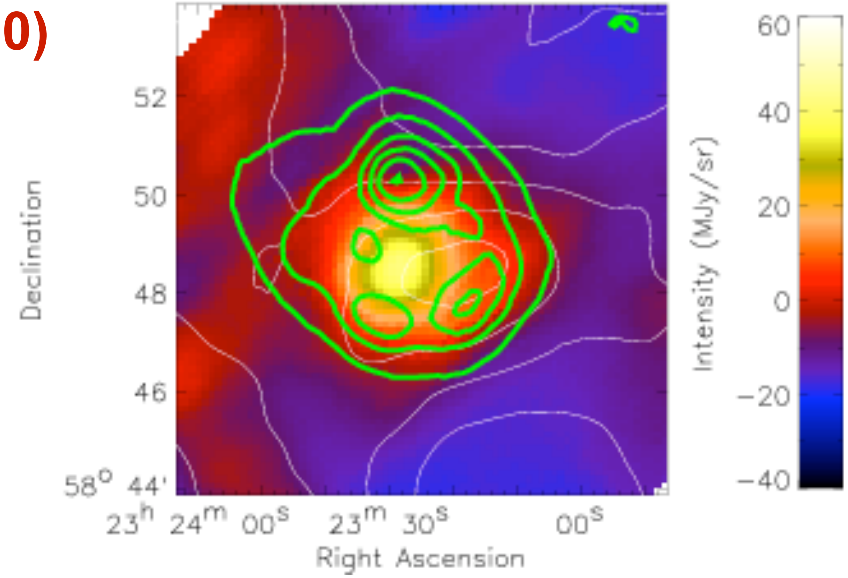
- **aC and silicate (Mg_2SiO_4)**
- **dust size distribution**
  - **f(a) ∝ a^-3.5**
  - **a_{min} = 0.001 μm**
  - **a_{max} = 0.5 μm**
- **dust-gas ratio: parameter**

3-3. Dust in Cas A

Nozawa et al. (2010)



AKARI corrected 90 μm image



- $M_{d,warm}$ ~ 0.008 M_{sun}
- $M_{d,cool}$ ~ 0.072 M_{sun} with T_{dust} ~ 40 K
- mass-loss rate $dM/dt = 8\times10^{-5}$ M_{sun}/yr

AKARI observation

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

T_{dust} = 33-41 K

(Sibthorpe et al. 2010)

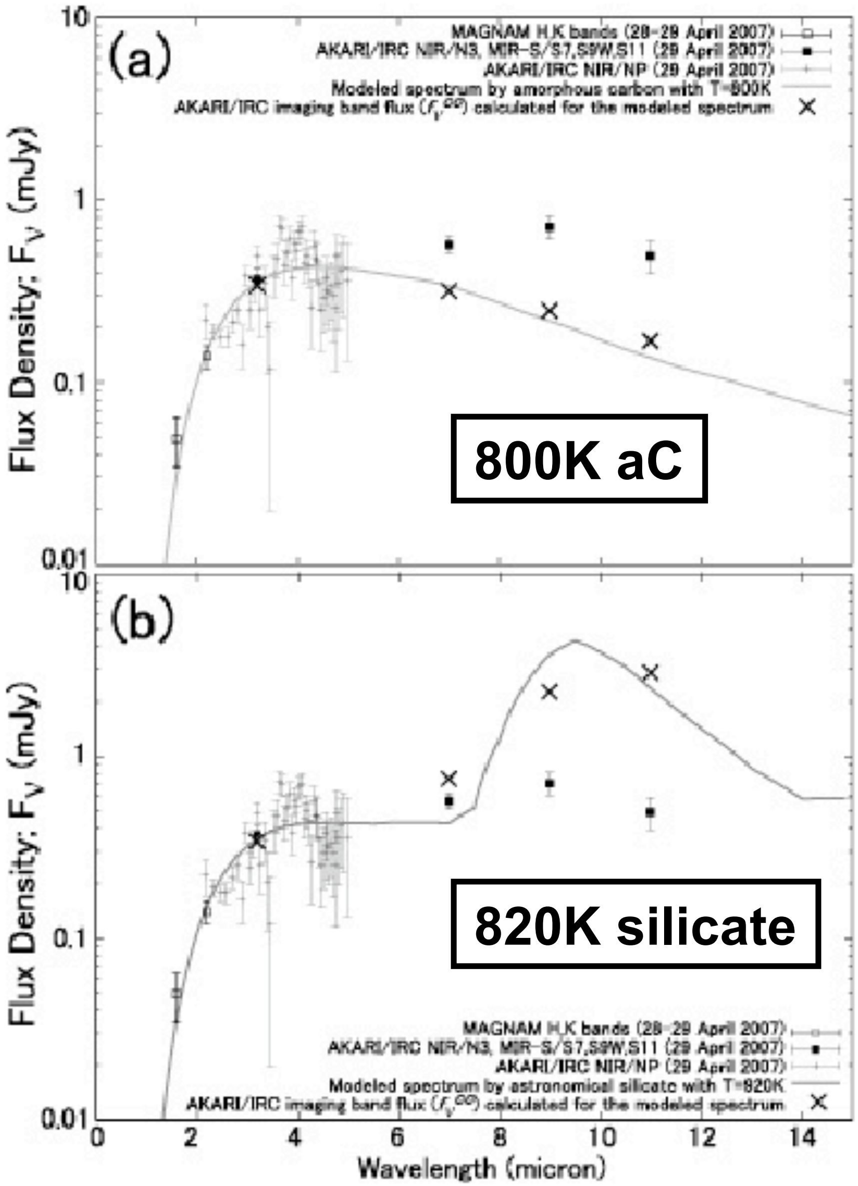
Herschel observation

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

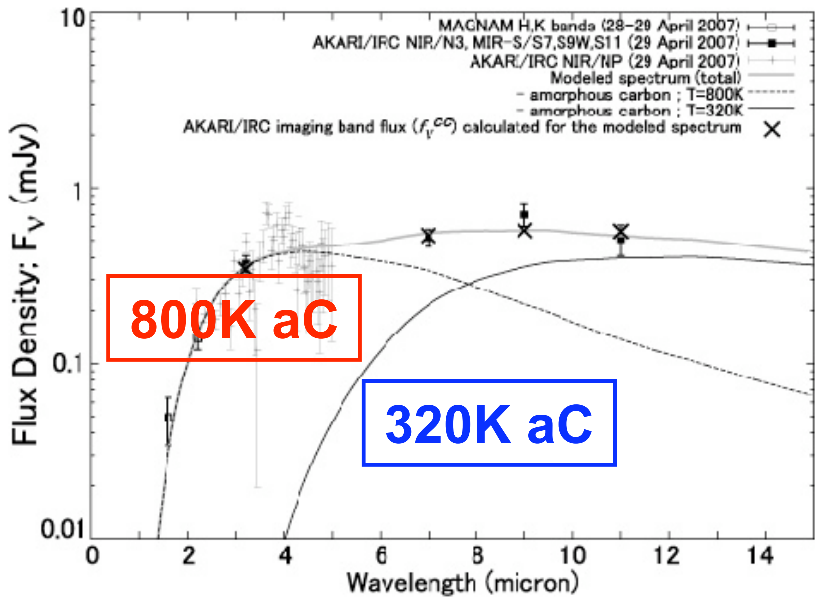
T_{dust} ~ 35 K

(Barlow et al. 2010)

4. AKARI observations of SN 2006jc



Sakon, .., TN, .., et al. (2009)

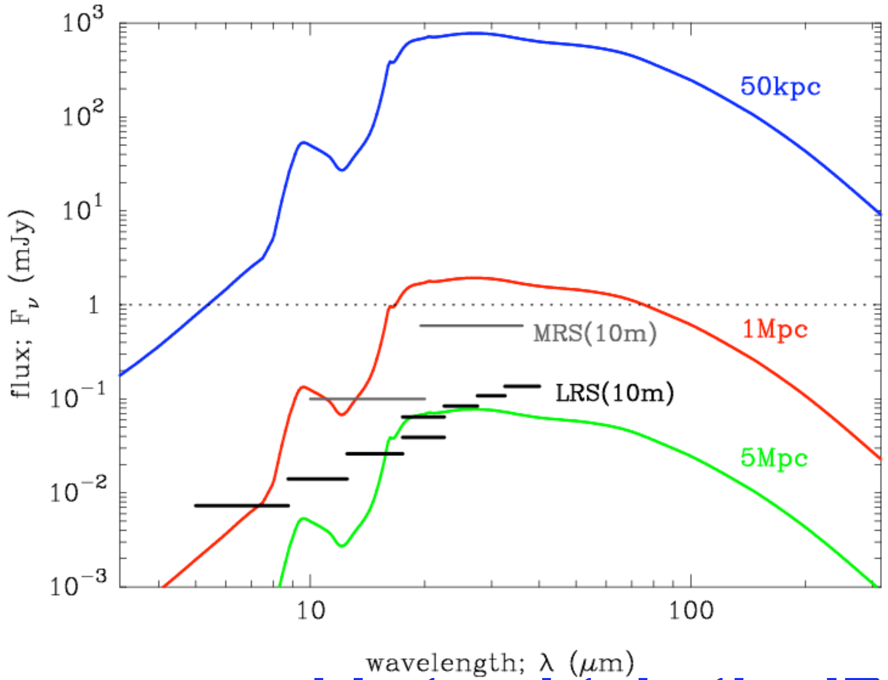


- dust species
  - newly formed hot aC
  - CSM origin cool aC
- progenitor : WR star

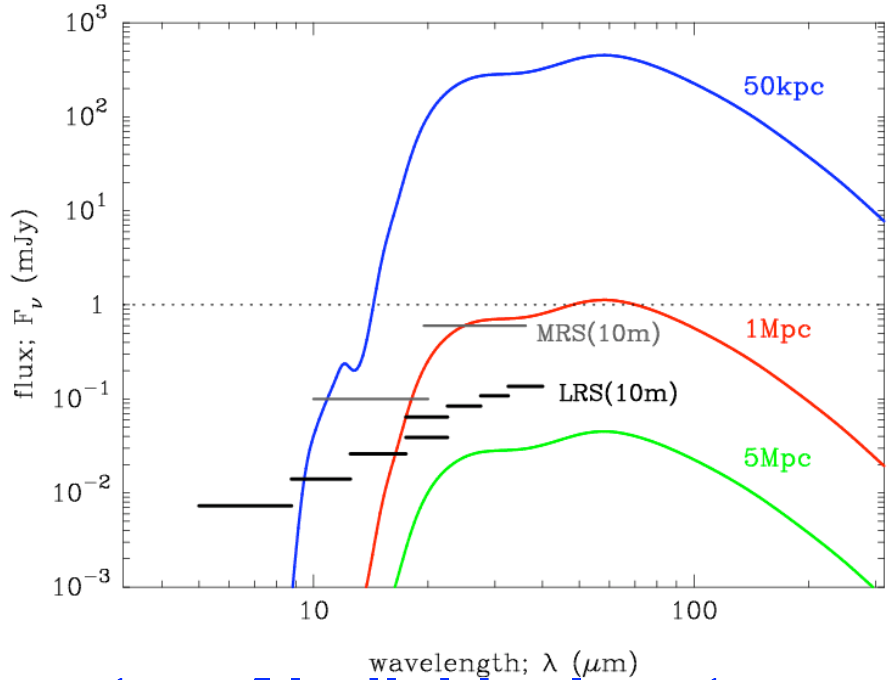
simultaneous observations
at 5-40 μm are necessary!

5. Detectability of IR emission from SNRs

IR SED of Cas A-like SNR
(SNR age = 330 yr, Tdust ~ 100 K)



IR SED of G292-like SNR
(SNR age = 3000 yr, Tdust ~ 50 K)



- **enable to obtain the IR spectra of individual parts of SNRs in LMC and SMC**
- **possible to detect the mid-IR emission from shocked dust in very nearby (~a few Mpc) extragalactic SNRs**

Summary on IR spectroscopy of SNRs

- **Targets for accomplishing this science**
  - SNR age: up to ~10000 yr
  - SN type : both SNe Ia and CCSNe
  - SNRs in MW, LMC, SMC, nearby galaxies
- **What we learn from IR spectroscopy of SNRs**
  - composition and size distribution of ISM/CSM dust
  - dust-to-gas mass ratio, dust destruction efficiency
  - gas density around SNe ➔ mass-loss rate of progenitor
- **Instrument for accomplishing this science**
  - mid-IR spectroscopy at 5-40 μm is essential
  - low/mid-resolution, simultaneous observations