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Mid-infrared Observations of Aged Dusty Supernovae

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special thanks: Tanaka, M., Arimatsu, K., Ohsawa, R., Sakon, I.

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
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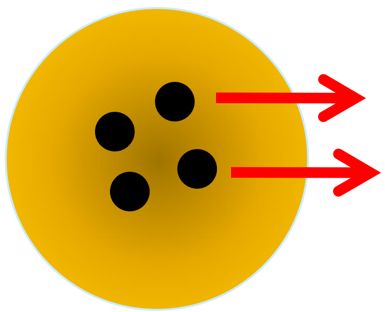
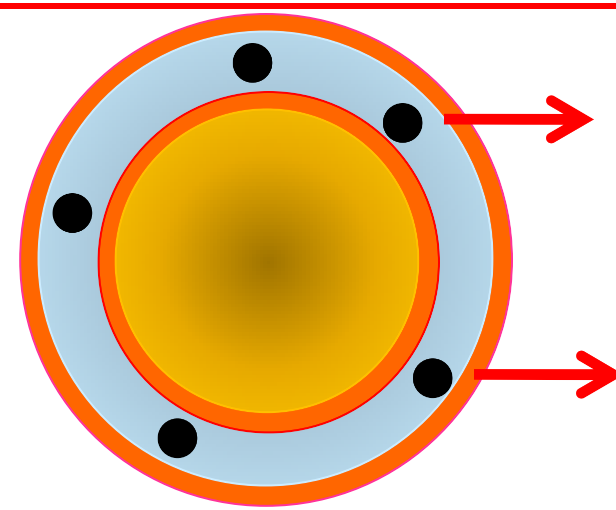
1-1. Origin of IR emission from SNe

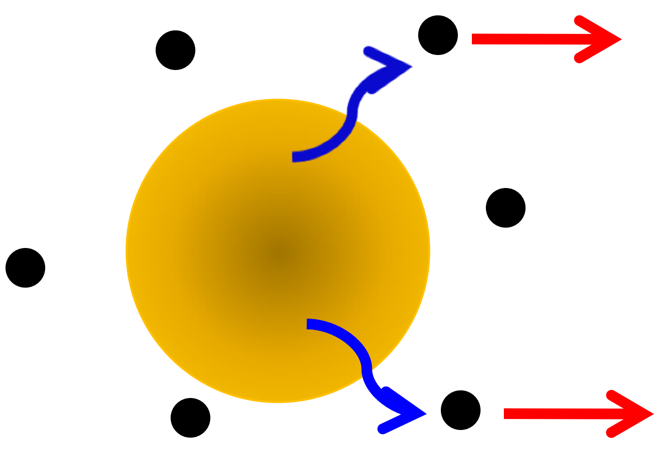
Dust formation in the ejecta



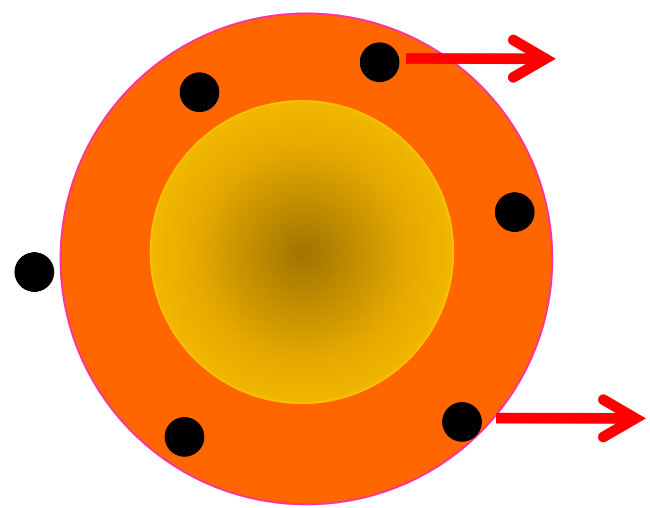
Dust formation in dense shell



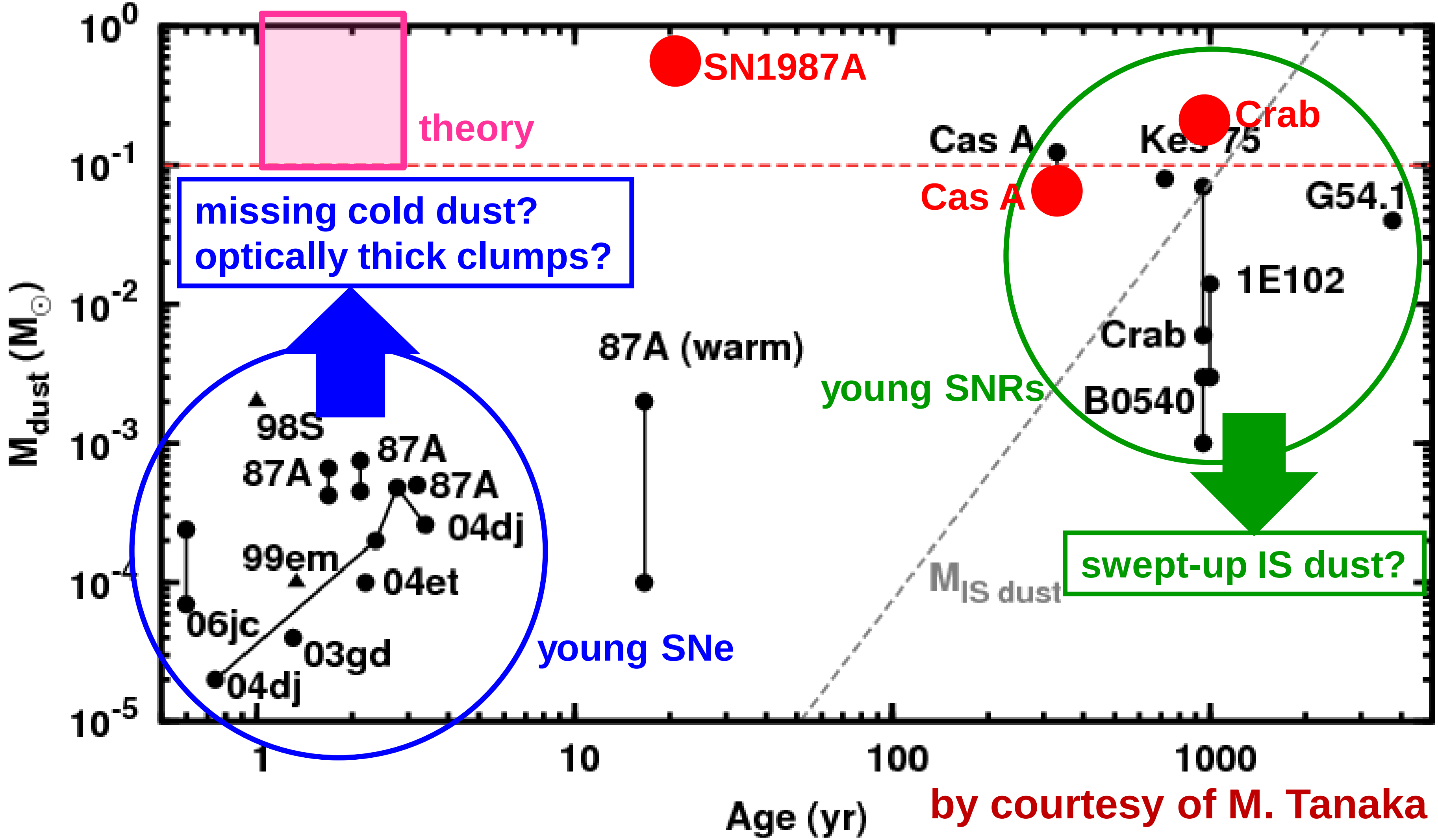
IR light echo by CS dust



Shock heating of CS dust



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

1-3. Observing SNe in nearby galaxies

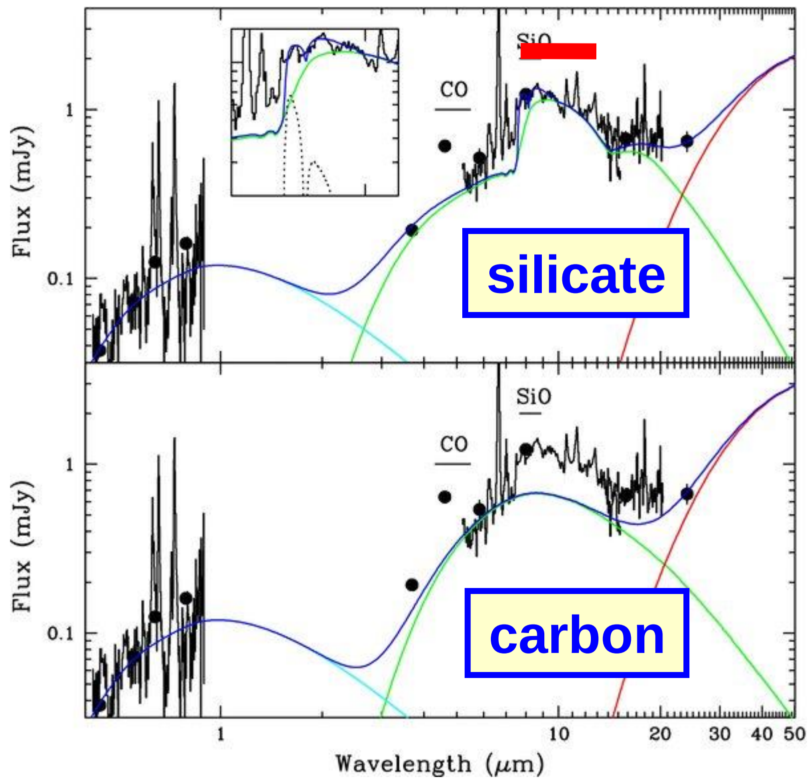
SNe are important sources of interstellar dust?

○ Unresolved problems of dust formation in SNe

- what is the cause of difference in dust mass observed in MIR/FIR?
- when does dust start to form?
- what is the main composition of newly formed dust?
- what is a typical size of dust?
- what fraction of SNe forms dust?

- recent unobserved SNe in MIR
  - SN 2011dh (M51, d = 8.1 Mpc)
  - SN 2011fe (M101, d = 6.7 Mpc)

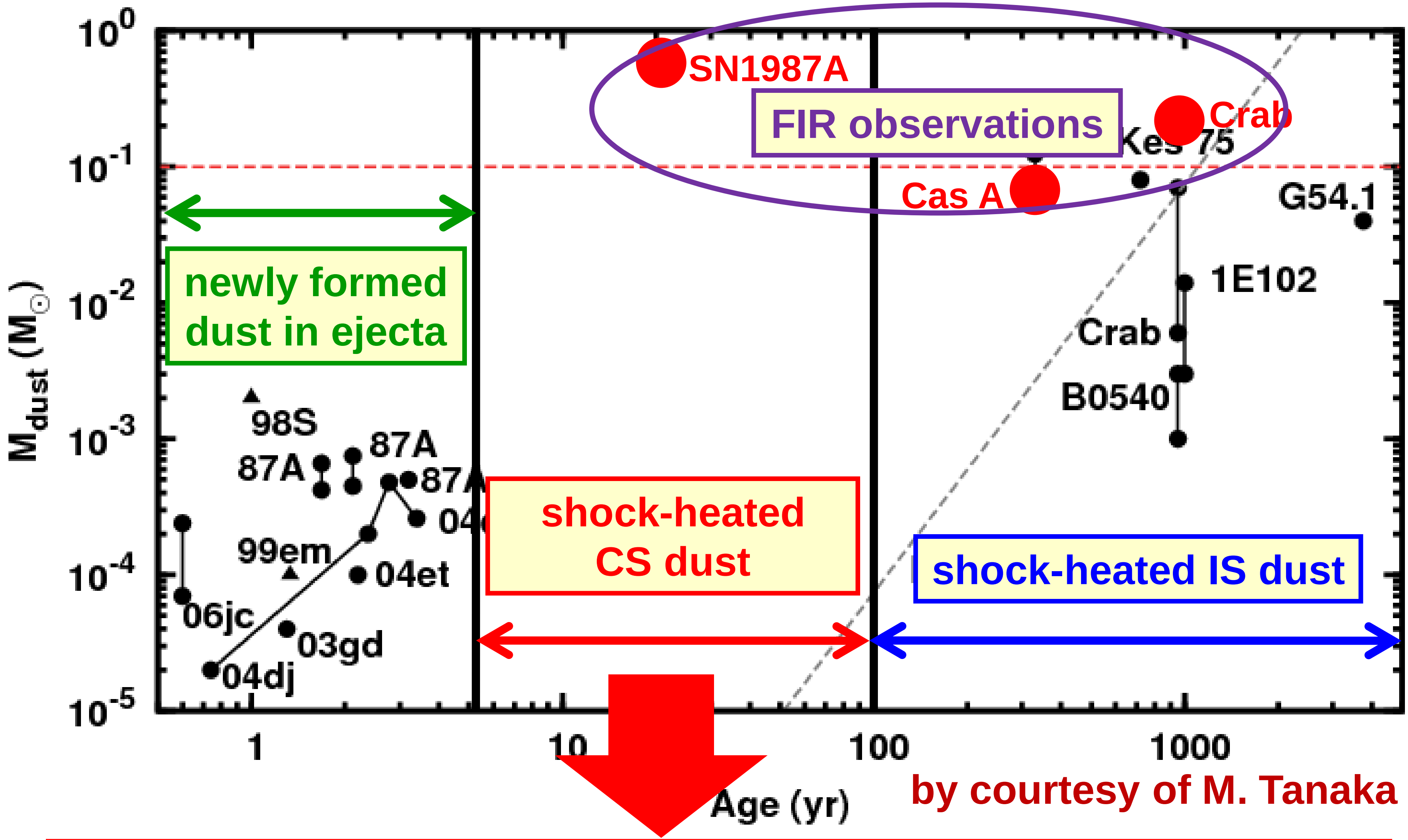
MIMIZUKU imaging, 10^4sec, 5σ



SN 2004et (d=5.6 Mpc, Kotak+09)

$M_{dust} \sim 10^{-4} M_{sun}$, $T_{dust} \sim 650K$

2. Observing CS dust in aged dusty SNe



by courtesy of M. Tanaka

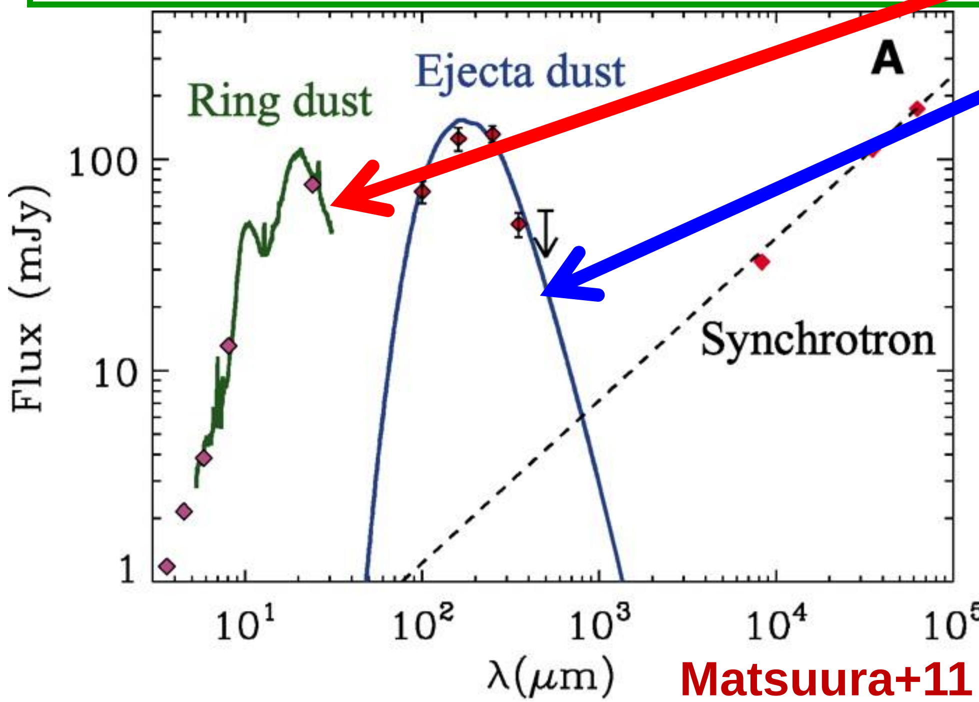
Exploring the evolution of CS dust by MIR observations of SNe 5-100 yr after explosions with MIMIZUKU

3-1. Promising targets (1): SN 1987A

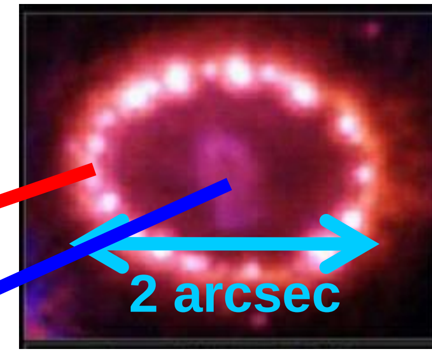
○ SN 1987A (Type II-pec)

- host galaxy: LMC (d = 50 kpc, southern sky)
- interacting equatorial ring
- ring diameter : 2” (= 0.5 pc @ 50 kpc)

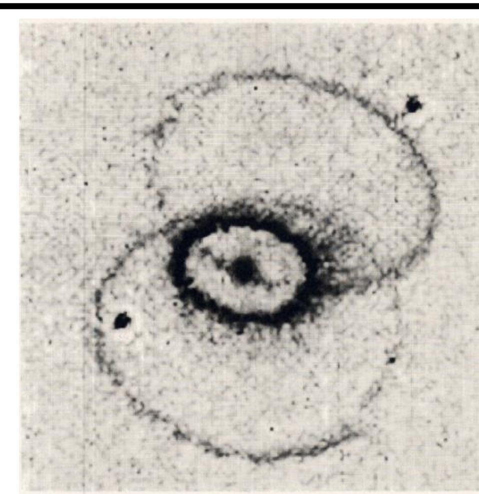
IR-mm SED of 23-years old SN 1987A



Matsuura+11



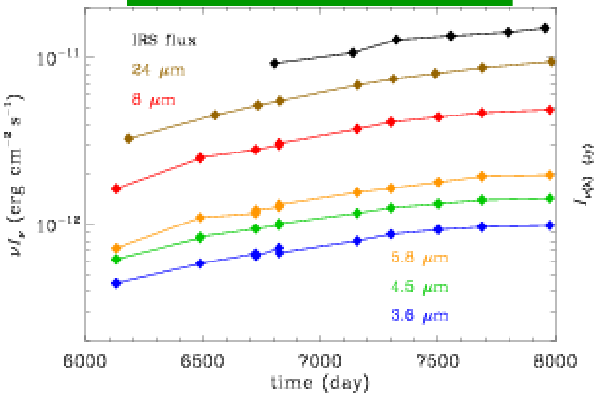
on 2009 Apr (Larsson+11)



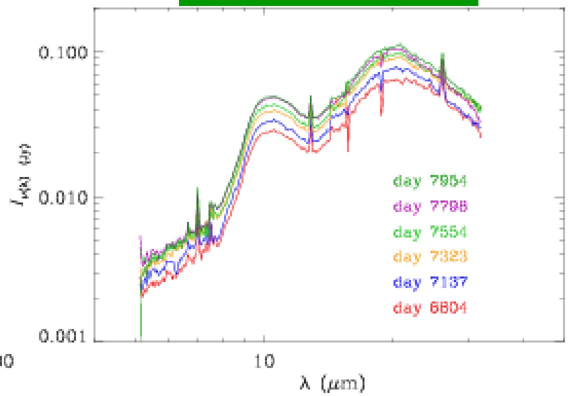
on 1994 Feb (Burrow+95)

3-2. Properties of CS dust around SN 1987A

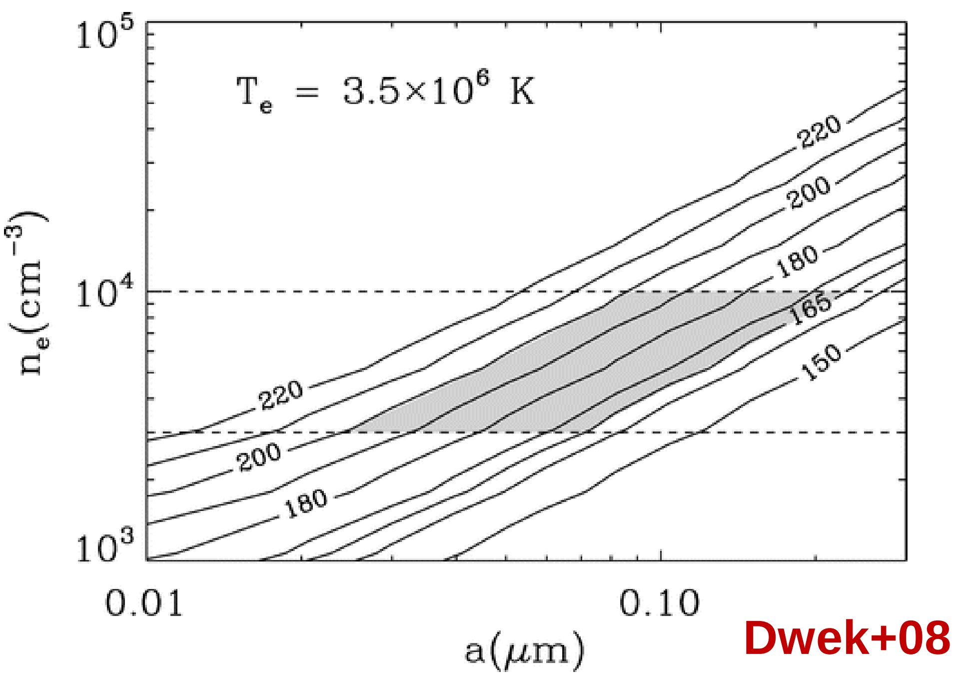
IR light curve



MIR SEDs



Spitzer observation, Dwek+10



Dwek+08

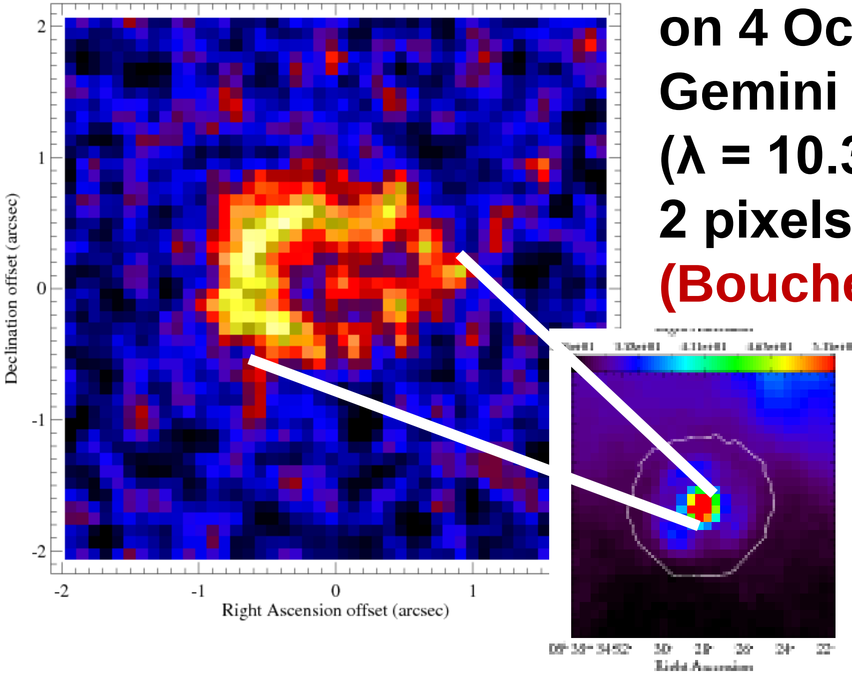
- **IR fluxes increase in all bands by a factor of ~3 between 17 yr and 22 yr**

- **properties of CS dust in ER**

silicate
T_{dust} = 180 K
M_{dust} = 10^{-6}-10^{-5} M_{sun}
L_{IR} = 10^{36}-10^{37} erg/s
(Seok+08, Dwek+08)

- **grain radius: a = 0.02-0.2 μm**
  ➔ relatively large

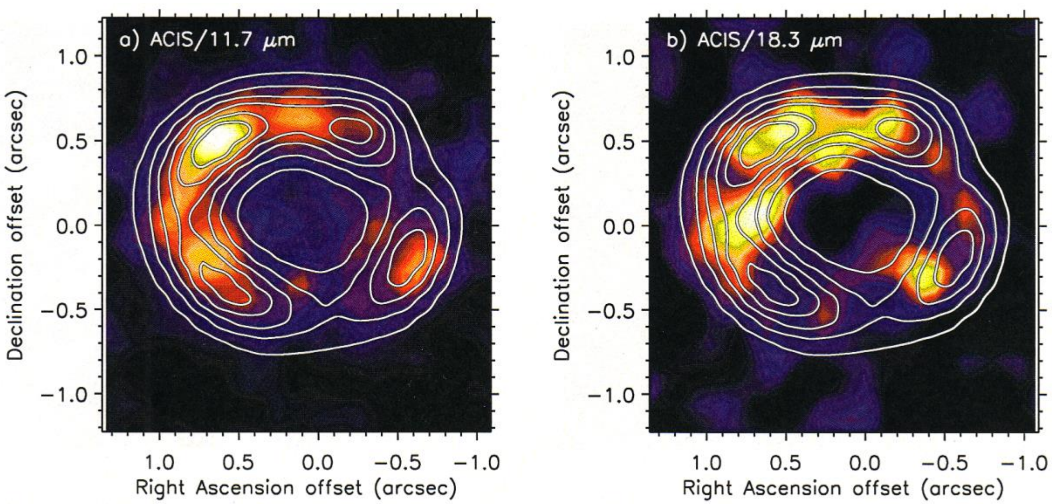
3-3. Expected IR images of SN 1987A



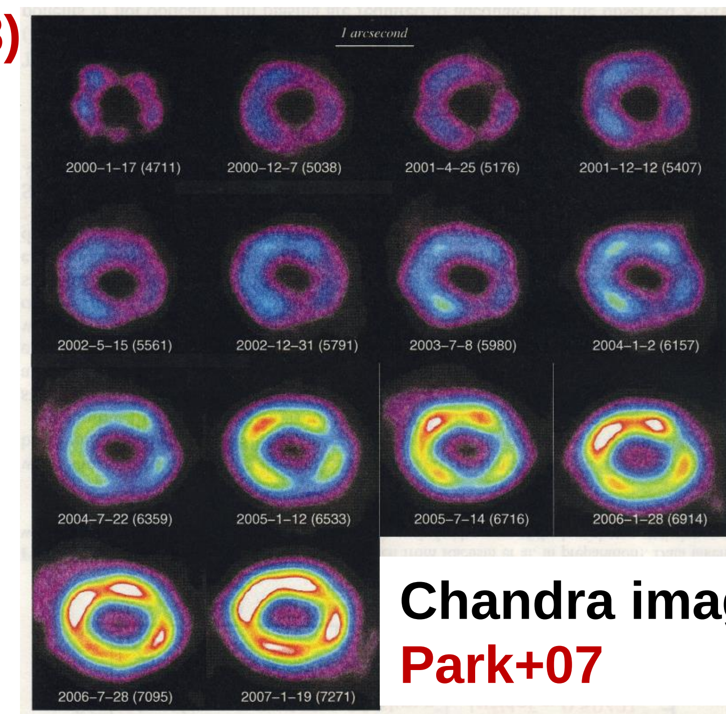
on 4 Oct 2003
Gemini T-ReCS
(λ = 10.36 μm)
2 pixels : 0.18"
(Bouchet+04)

AKARI
24 μm
(Seok+08)

SN1987A with MIMIZUKU
- spatially resolving equatorial ring
- multi-epoch ➔ evolution of CS dust
- MIR flux: 10-100 mJy



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



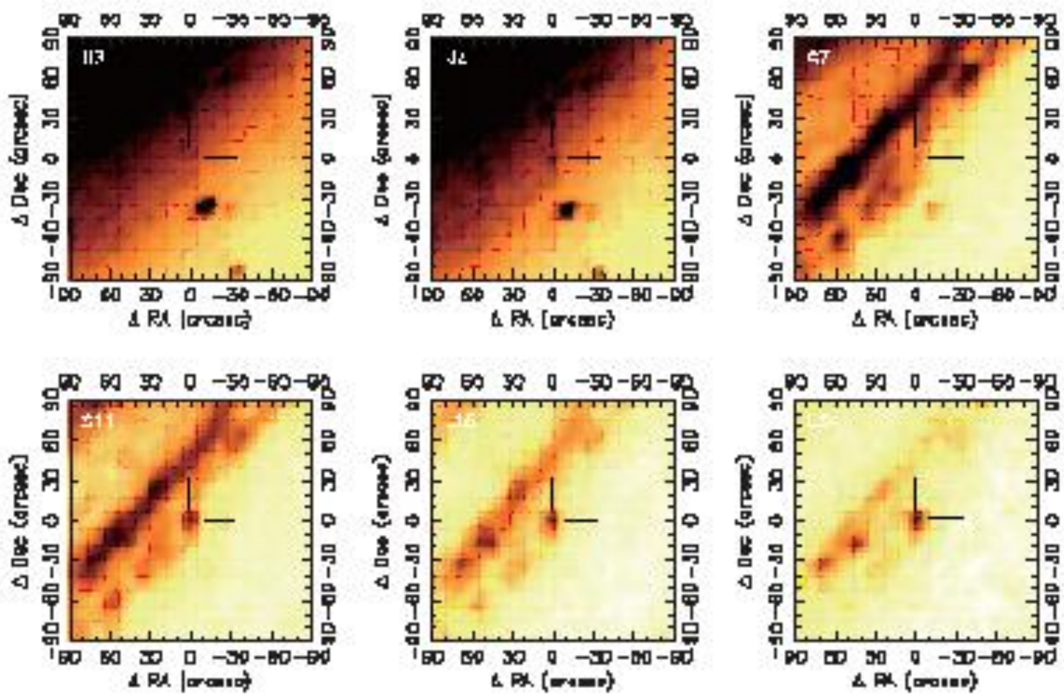
Chandra image
Park+07

4. Promising targets (2): SN 1993J

○ SN 1993J (Type IIb)

- host galaxy: M81 (d = 3.6 Mpc, northern sky)
- L band excess at >130 day (Matthews+02)
- strong interaction with CSM (Weiler+07; Chandra+09)

AKARI images at 13 yr post explosion



AKARI detected MIR emission from 1993J

What is the origin of IR emission?

- shock-heated dust
- newly formed dust
- IR light echo

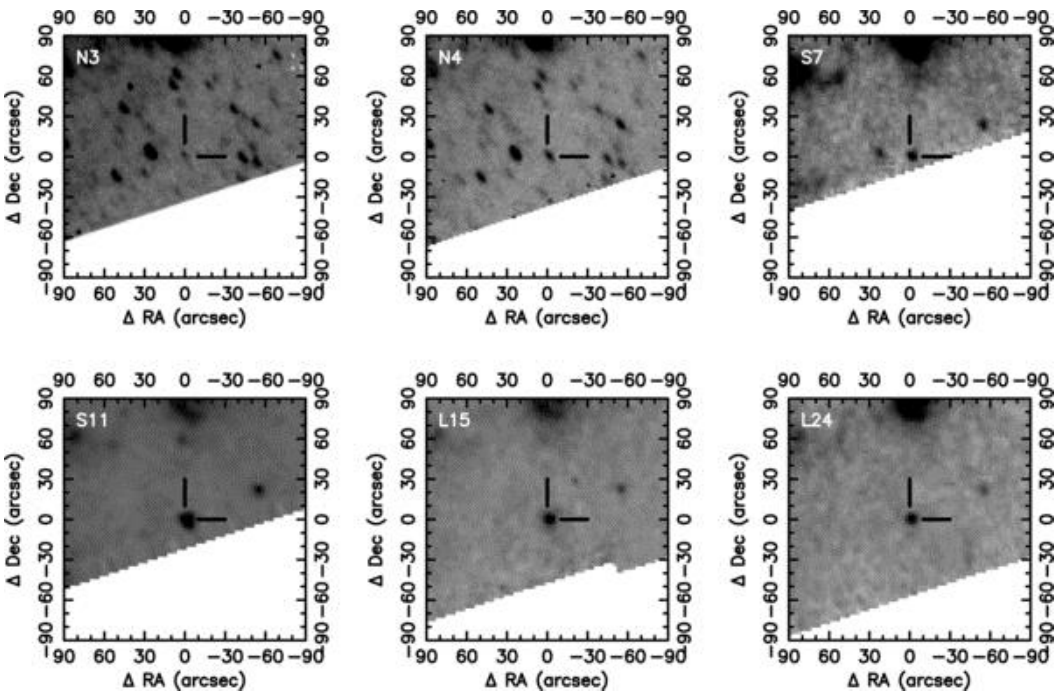
Arimatsu, TN, et al. in prep.

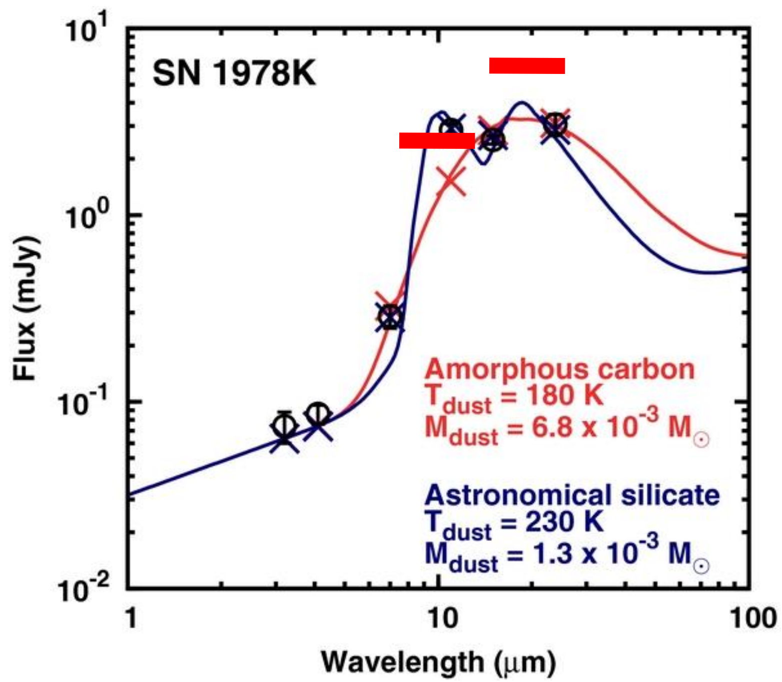
5-1. Promising targets (3): SN 1978K

○ SN 1978K (Type IIn)

- host galaxy: NGC 1313 (d = 4.1 Mpc, southern sky)
- X-ray luminous (Smith+07) → massive CSM

AKARI images at 28 yr post explosion





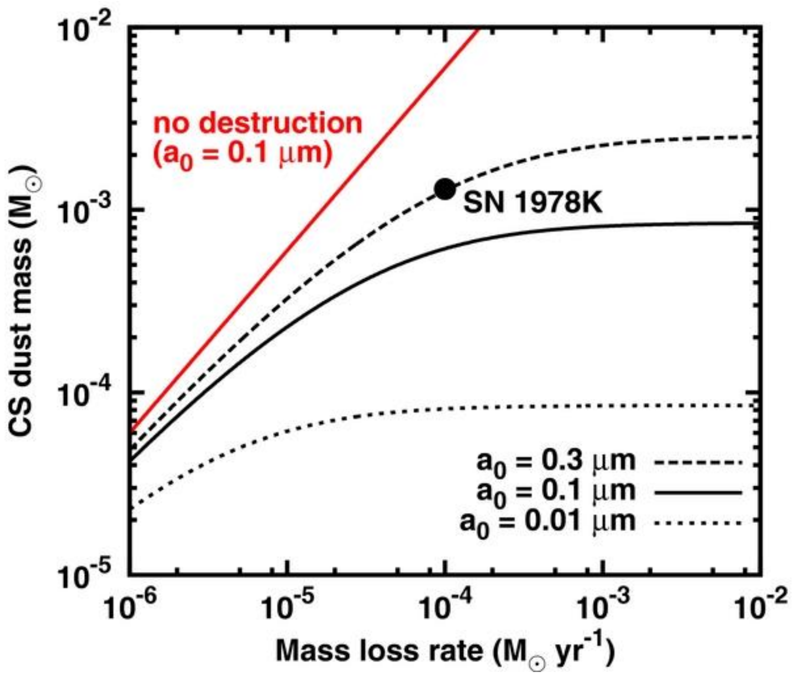
silicate
T_{dust}=230K, $M_{dust} \sim 10^{-3} M_{sun}$
$L_{IR} \sim 1.5 \times 10^{39}$ erg/s

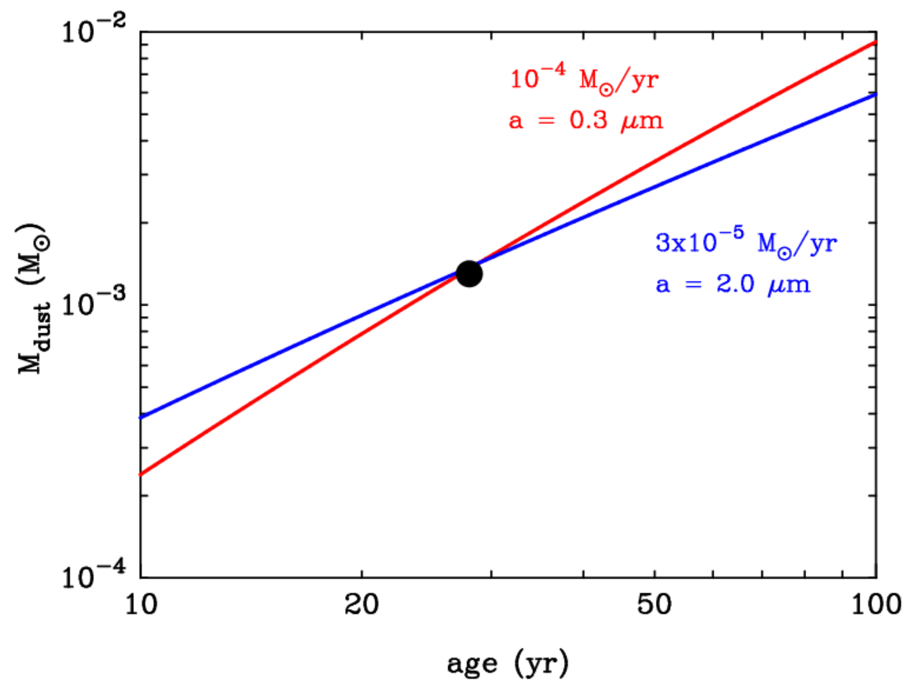
Tanaka, TN, et al. (2012)

5-2. Origin of MIR emission from SN 1978K

○ MIR emission from SN 1978K

- IR luminous: $L_{IR} = 1.5 \times 10^{39}$ erg/s
  ➔ ruling out emission of newly formed dust and IR echo
- thermal emission from shock-heated CS dust





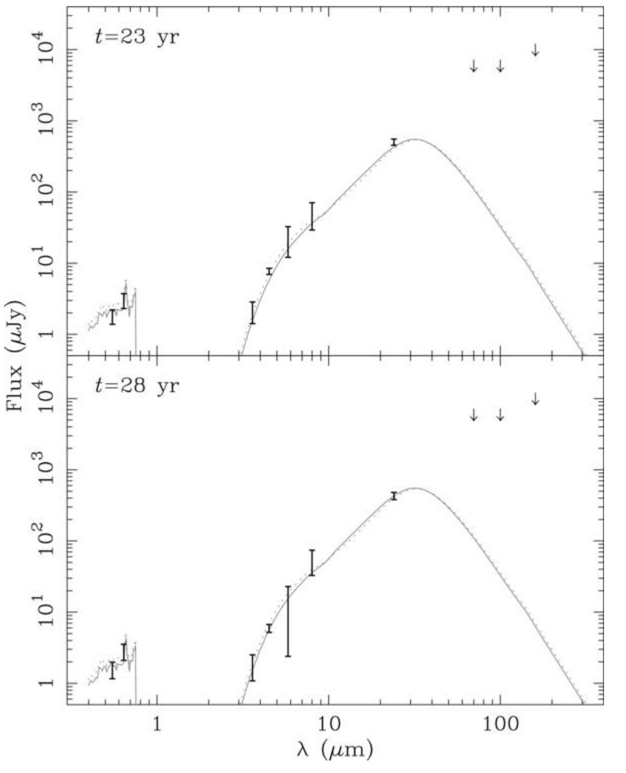
large initial radius of CS dust;
a_0 ~ 0.3 μm (Tanaka+12)

Multi-epoch IR observations of aged SNe are essential !!

6-1. MIR observations of other aged dusty SNe

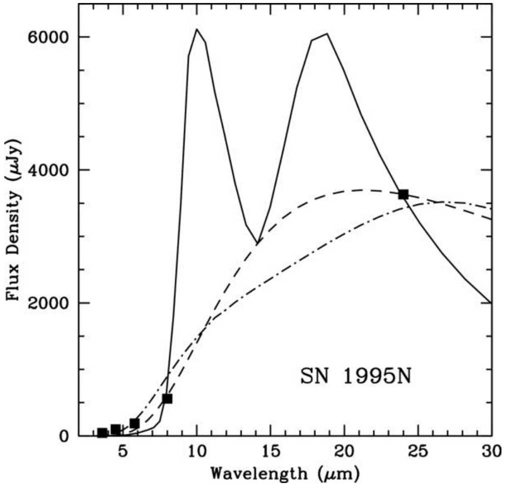
○ SN 1980K (Type II-L)

- host galaxy: NGC 6946
  (d = 5.6 Mpc, northern sky)
- T_{dust} = 200 K, M_{dust} ~ 10^{-4} M_{sun}
  (L_{IR} ~ 10^{38} erg/s)
- IR echo by IS dust (Sugerman+12)



○ SN 1995N (Type IIn)

- host galaxy: Arp 261
  (d = 24 Mpc, southern sky)
- T_{dust} = 240 K, M_{dust} ~ 0.1 M_{sun}
  (L_{IR} ~ 7.7×10^{40} erg/s)
- CS dust heated by radiation
  from shocked region (van Dyk 2013)



6-2. Other possible targets

in addition to SN 1987A (II-pec), SN 1993J (IIb), SN 1978K (IIn), SN 1980K (II-L), SN 1995N (IIn)

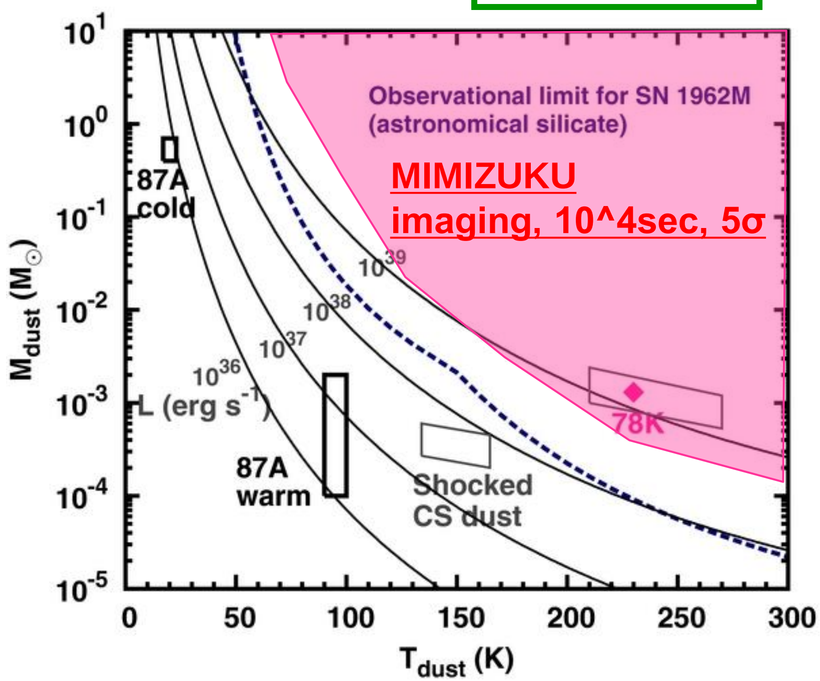
○ nearby Type IIn SNe

- SN 1998S (IIn) (d = 17 Mpc) (Pozzo+04)
- SN 2005ip (IIn) (d = 30 Mpc) (Fox+11, 12)

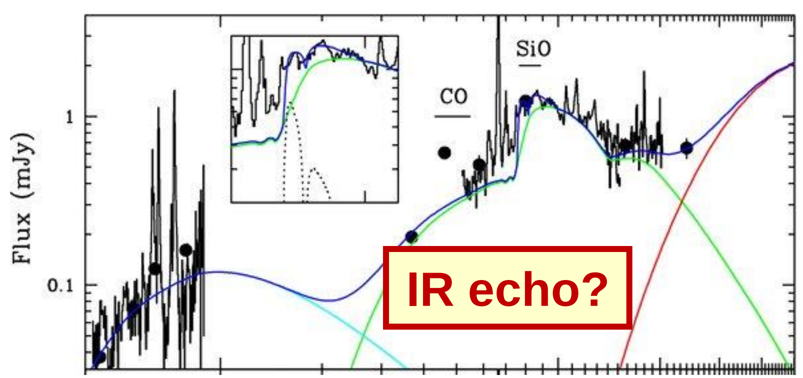
○ very nearby Type II-P SNe

- SN 2002hh (II-P) (d = 5.6 Mpc) (Barlow+05)
- SN 2004et (II-P) (d = 5.6 Mpc) (Kotak+09, Fabbri+11)
- SN 2004dj (II-P) (d = 3.5 Mpc) (Szalai+11, Meikle+11)

d = 5 Mpc



Tanaka, TN, et al. (2012)



SN 2004et (Kotak+09)

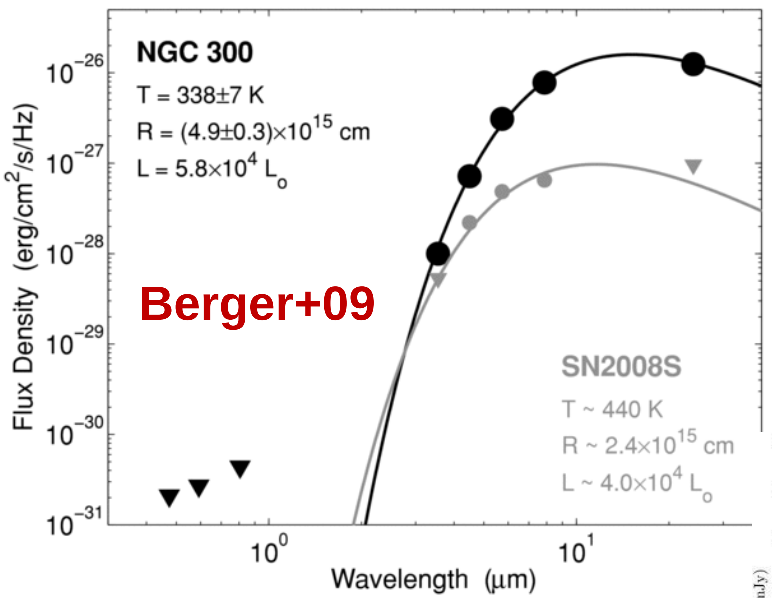
7. Promising targets (3): NGC 300OT

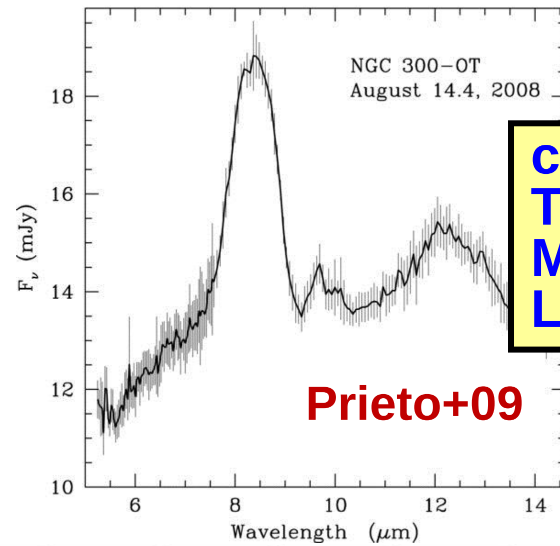
○ NGC 300OT (SN imposter)

– host galaxy: NGC 300 (d = 1.9 Mpc, southern sky)

– IR luminous ➔ eruption of dust-enshrouded star

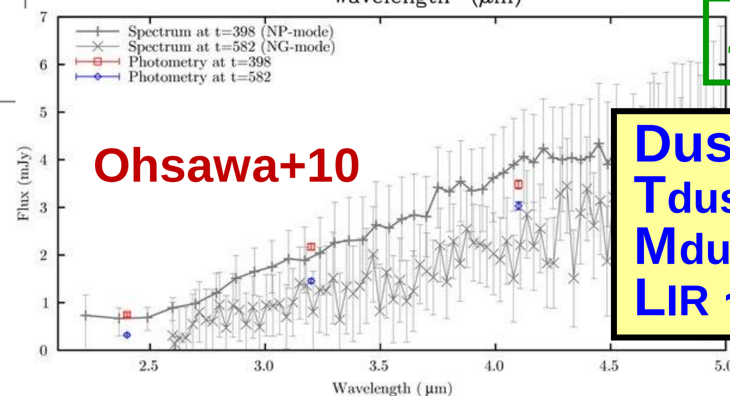
opt/IR SED of the progenitor





~100 day

carbon
T_{dust} = 400K
M_{dust} ~$10^{-4}M_{sun}$
L_{IR} ~ 2×10^{39} erg/s



400-600 day

Dust formation
T_{dust} = 600-800K
M_{dust} > $10^{-5}M_{sun}$
L_{IR} ~ 10^{39} erg/s

8. Summary

○ Dust formation in SNe (t = 1-3 yr, d < 5 Mpc)

- formation time, composition, and mass of dust
- what fraction and what type of SNe produce dust?

○ CS dust in aged SNe (t = 5-30 yr, d ~ 5 Mpc)

- dust formation condition in stellar winds
- dust mass and temperature ➔ gas density, dust size
- mass-loss history of the progenitor stars

  ➔ diversity of SN types, evolution of massive stars

○ Dust-enshrouded optical transients (d ~ 2 Mpc)

- Effect on UV/opt light curves, or hidden SNe?