2015/03/26

Detecting Cool Dust in Type Ia Supernova Remnant 0509-67.5

(ranked as priority grade B for ALMA Cycle2)

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and

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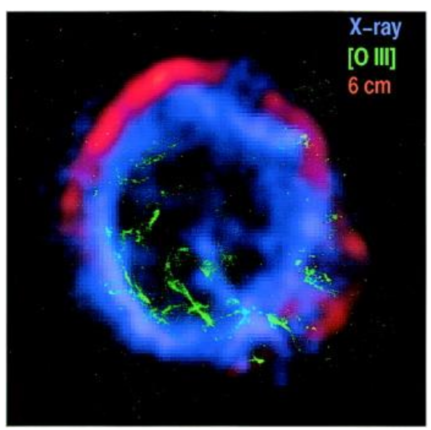
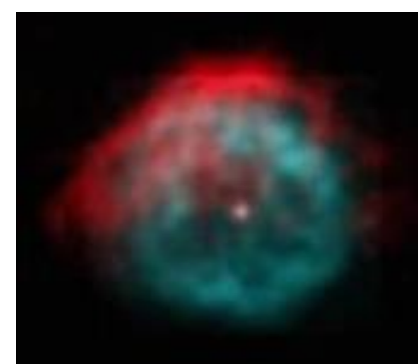




1-1. Introduction

Supernovae (SNe) are main sources of interstellar dust?

- a large amount of dust grains (>10^8 M_{sun}) are detected in host galaxies of quasars at redshift z > 5

  ➜ SNe must have play a dominant role as sources of dust
  ➜ more than 0.1 M_{sun} of dust per SN is needed to be ejected to explain such massive dust at high-z (Dwek+2007)

- SNe must be primary dust sources even in the present universe

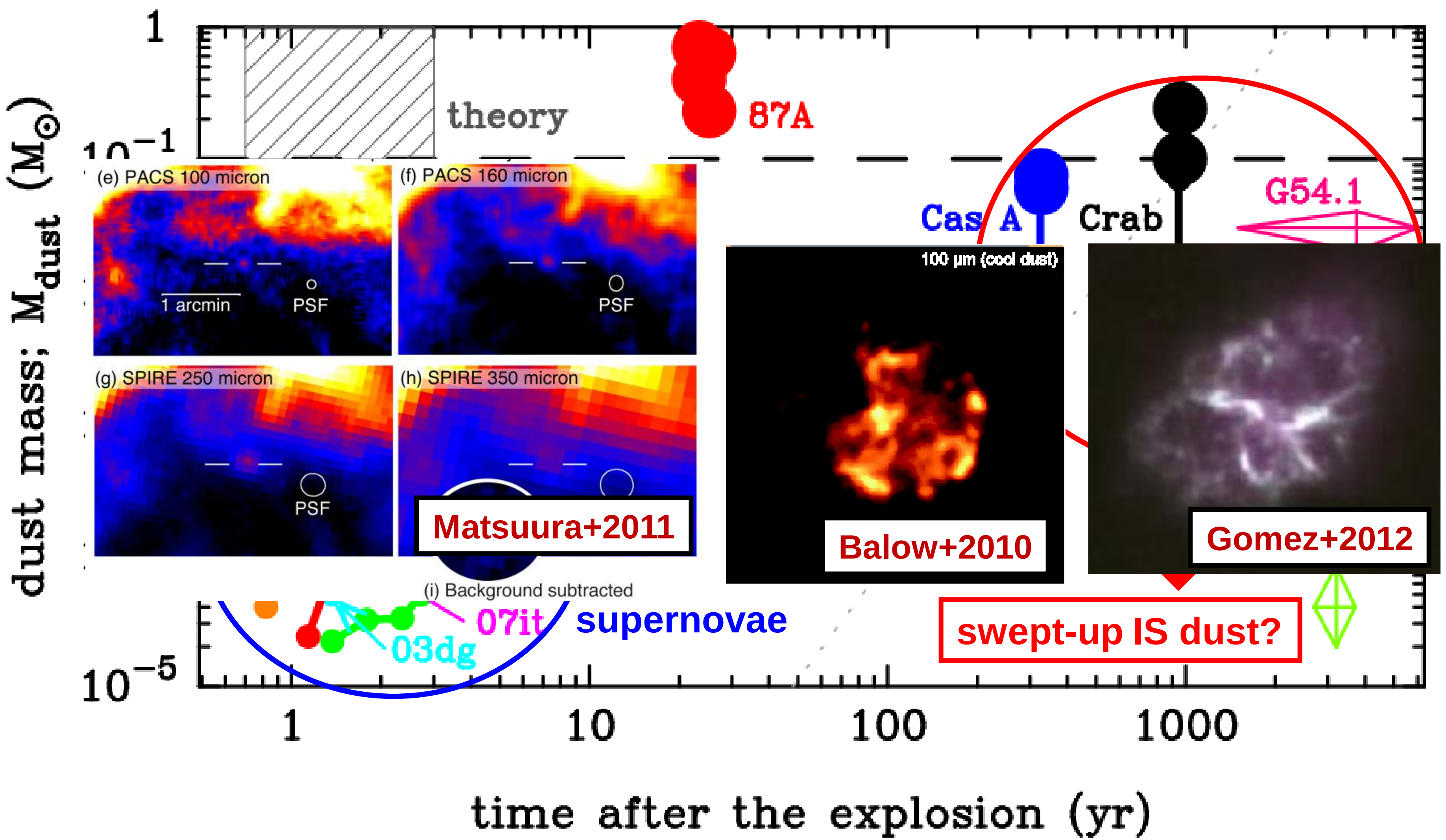
  ➜ comparable contribution with AGB stars (Dwek & Scalo 1980)

  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 (Todini & Ferrara 2001; Nozawa+2003; 2007)

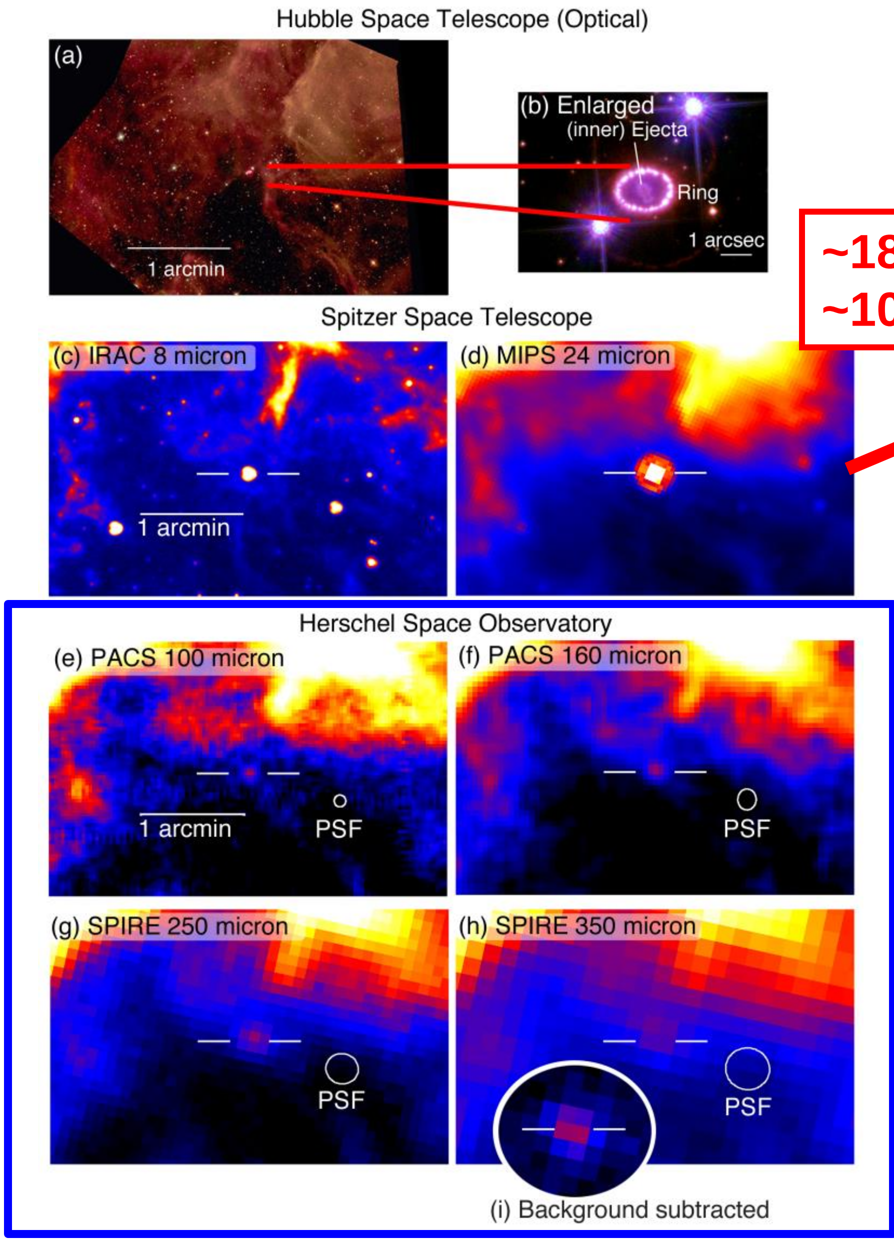
Dust formation in SNe is a key to disclose the origin and evolution of dust throughout the cosmic age

1-2. Summary of observed dust mass in CCSNe

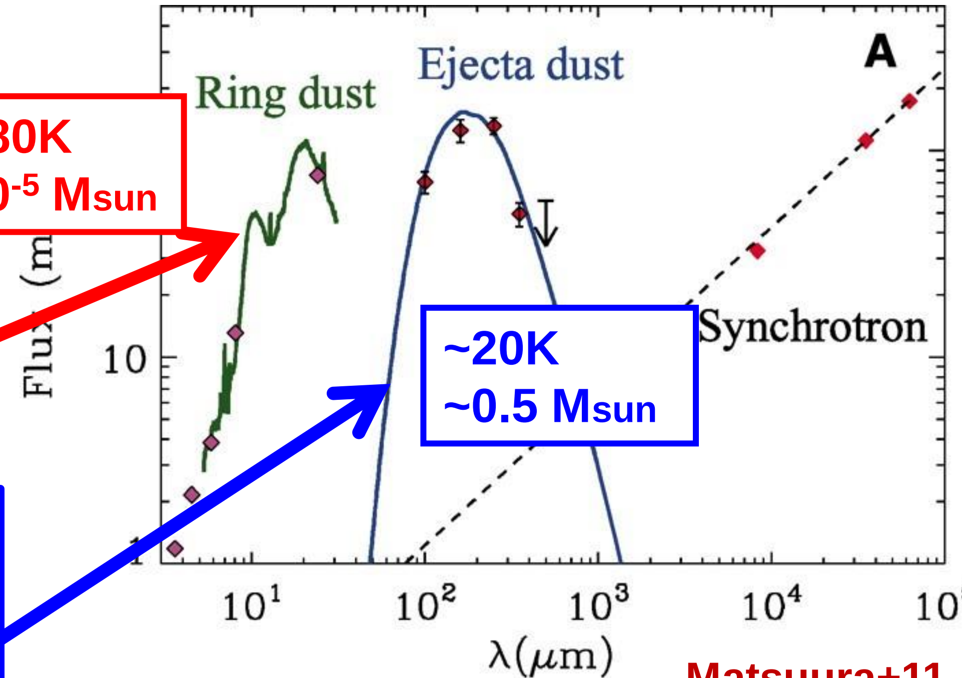


Far-IR to sub-mm observations are essential for revealing the mass of dust grains produced in the ejecta of SNe

1-3. Herschel detects cool dust in SN 1987A



SED of 23-years old SN 1987A

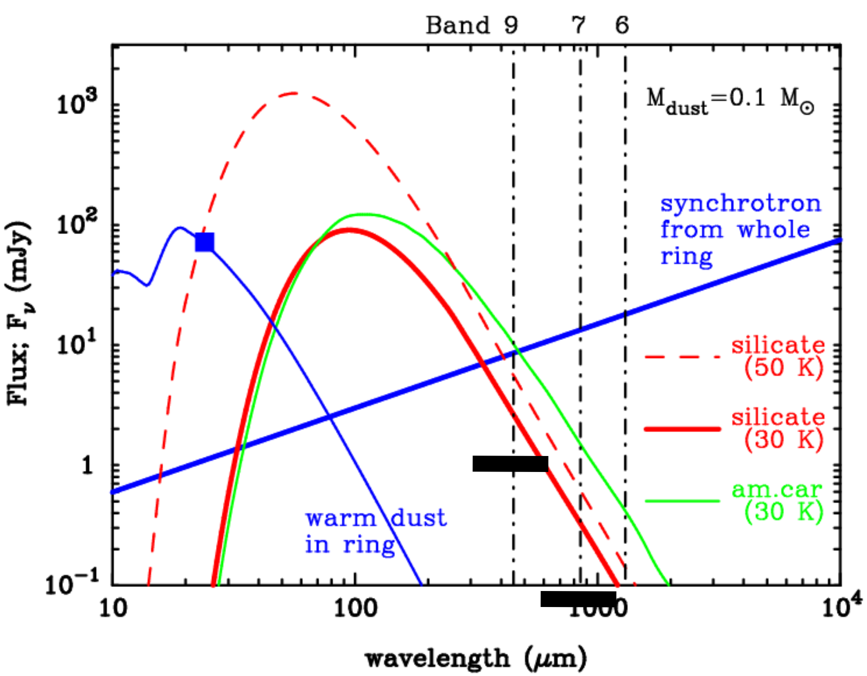


Matsuura+11

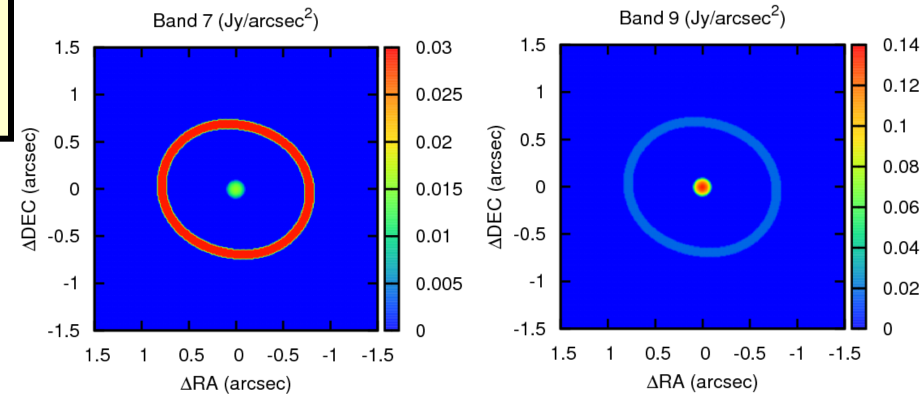
Herschel detected cool (~20K) dust of ~0.4-0.7 Msun toward SN 1987A
➔ SNe are production factories of massive dust grains

1-4. Resolving cool dust in SN 87A with ALMA

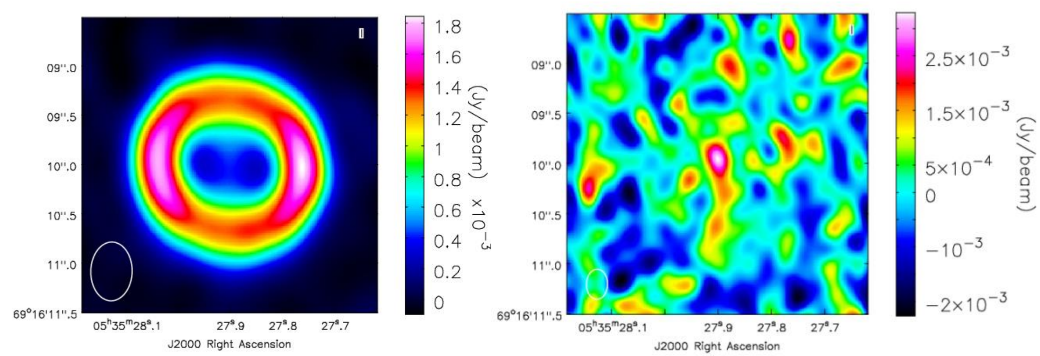
ALMA Cycle 0 Proposal
'Detecting cool dust in SN1987A'
(TN, Tanaka, et al.)



Band 7 (850 µm) **Band 9 (450 µm)**



CASA simulation with extended config. (4 hrs)

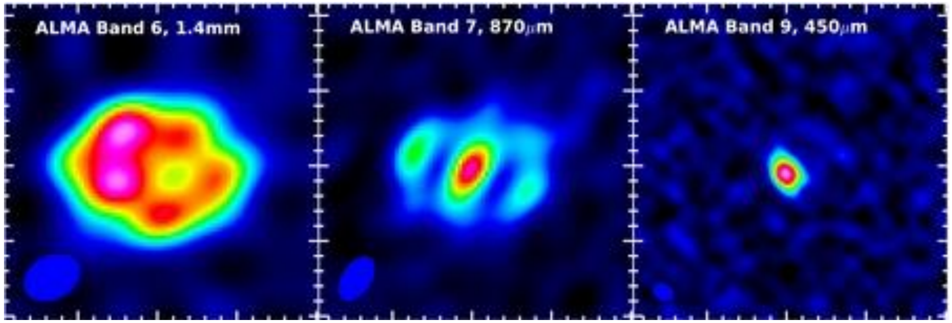


0.1 Msun of silicate
➔ 5σ detection at Band 9

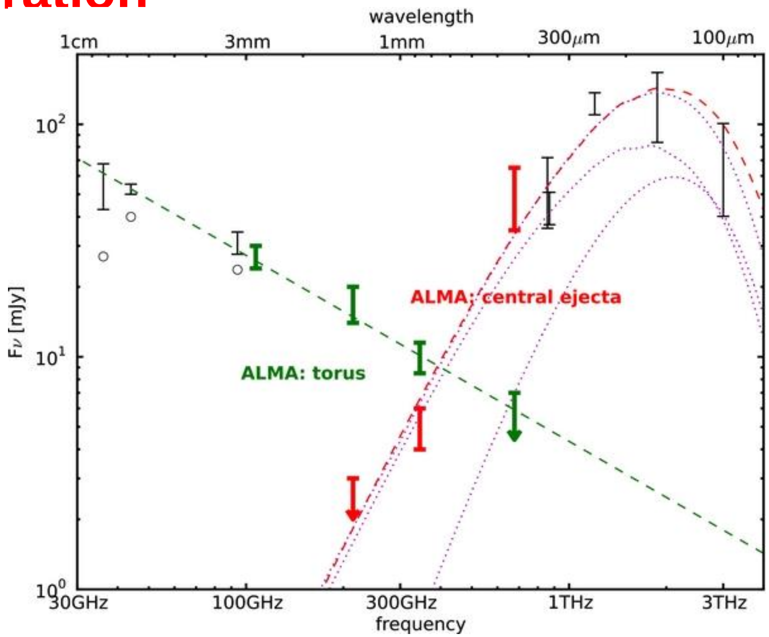
1-5. ALMA reveals dust formed in SN 1987A

- Detecting Cool Dust in SN 1987A ➜ not executed
  (Nozawa, Tanaka, Moriya, Minamidani, Kozasa)
  Band 9, extended configuration

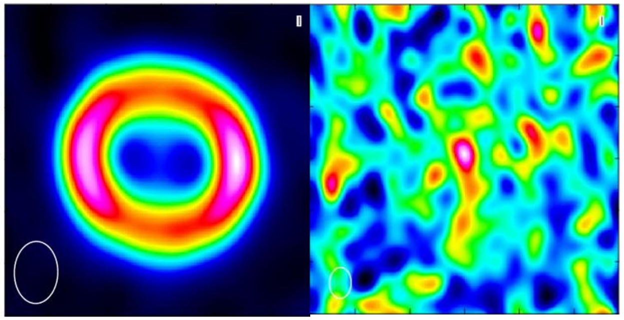
- SN87A: A Unique Laboratory for Shock and Dust Physics
  (Indebetow, McCray, Matsuura, + 27 coauthors)
  Band 3, 6, 7, and 9, compact configuration



Indebetouw+2014



CASA simulation
by Tanaka, T.



ALMA confirmed ~0.5 Msun of dust formed in the ejecta

1-6. Our status for ALMA Cycle1 proposal

- Detecting Cool Dust in SN 1987A ➜ failed
  (Tanaka, Nozawa, Moriya, Minamidani, Kozasa)
  Band 7 and 9

- SN 1987A: A Unique Laboratory of Shock, Molecular and Dust Physics ➜ succeeded
  (Indebetow, McCray, Matsuura, + 22 coauthors)

・SN 1987A: the best target to detect cool dust formed in the ejecta

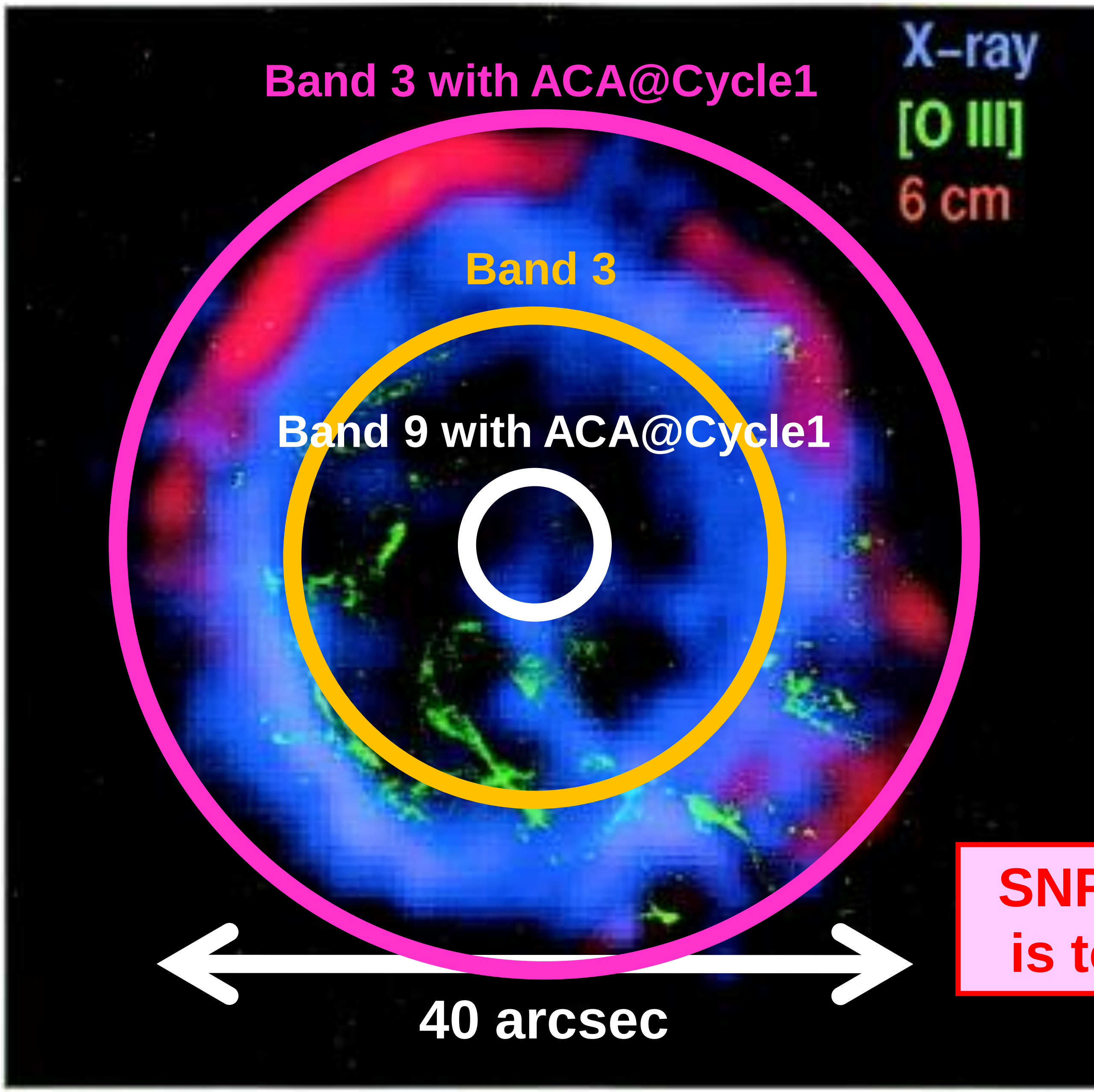
- nearest SN ever observed (in LMC)
- young (~27 yr) and compact (~2" in diameter)

・other candidates

- extragalactic SNe (D >~5 Mpc) ➔ too distant (too faint)
- Galactic SNRs (d >~1') ➔ too old (too extended)

SNe and SNRs in LMC/SMC are the promising targets!

2-1. Young Type Ib SNR 1E0102-72.3 in SMC

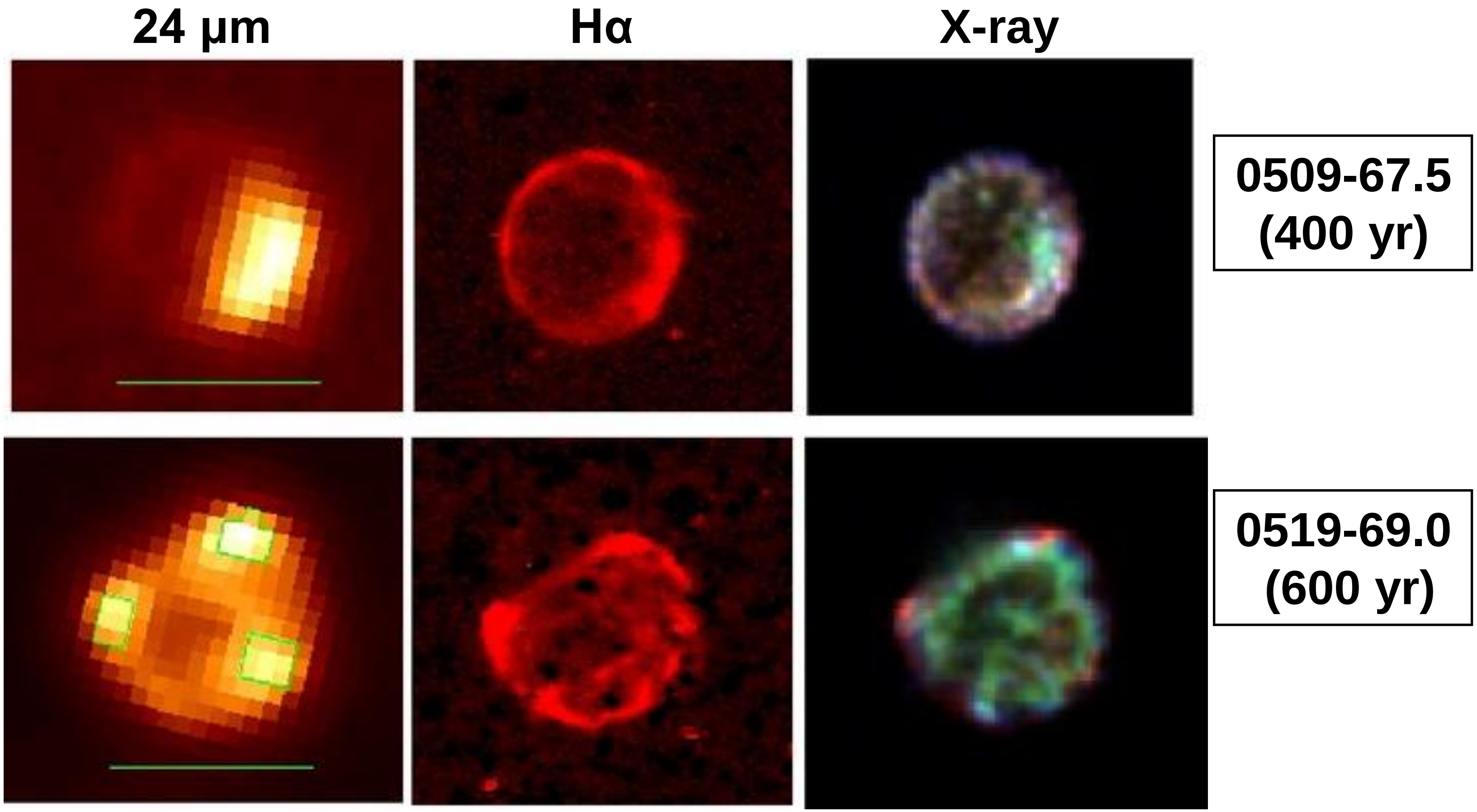


SNR 1E0102-72.3
(age: ~1000 yr)

➔ known as a cousin of CasA

SNR 1E0102.72.3 is too extended!

2-2. Young Type Ia SNRs in LMC



Borkowski+2006

shock-heated interstellar dust ➜ $M_{dust} < 3 \times 10^{-3}\ M_{sun}$

young (~500 yr) SNe Ia in LMC seem too extended (radius~15")

3-1. Cycle2: SNe Ia as sources of Fe grains

○ Missing-iron problem

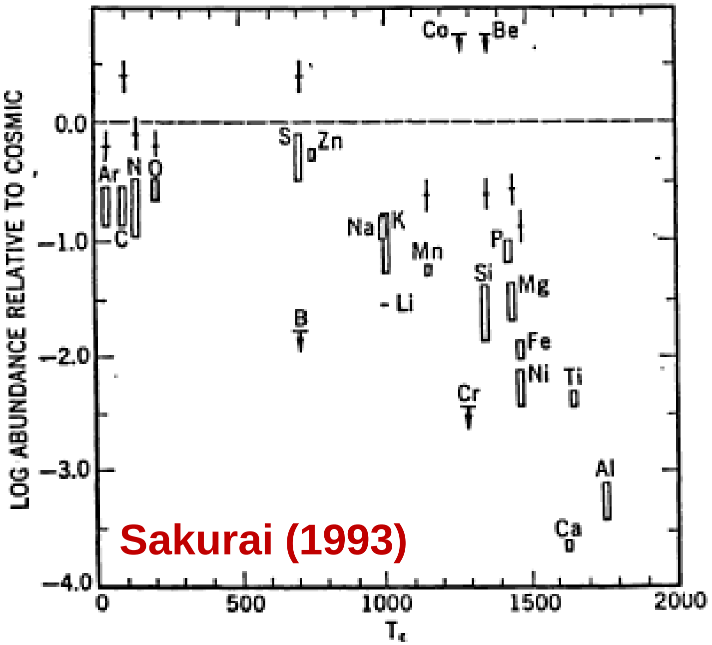
more than 99% of interstellar Fe atoms must be locked in dust grains

what grain species tie up iron?

- astronomical silicate ($Mg_{1.1}Fe_{0.9}SiO_2$)

➜ no clear evidence for Fe-rich silicates

- Fe/FeS grains? Or any other forms?



○ Origin of Fe-bearing grains ➜ SNe Ia

SNe Ia produce more iron (~0.7 M_{sun}) than CCSNe (~0.07 M_{sun})

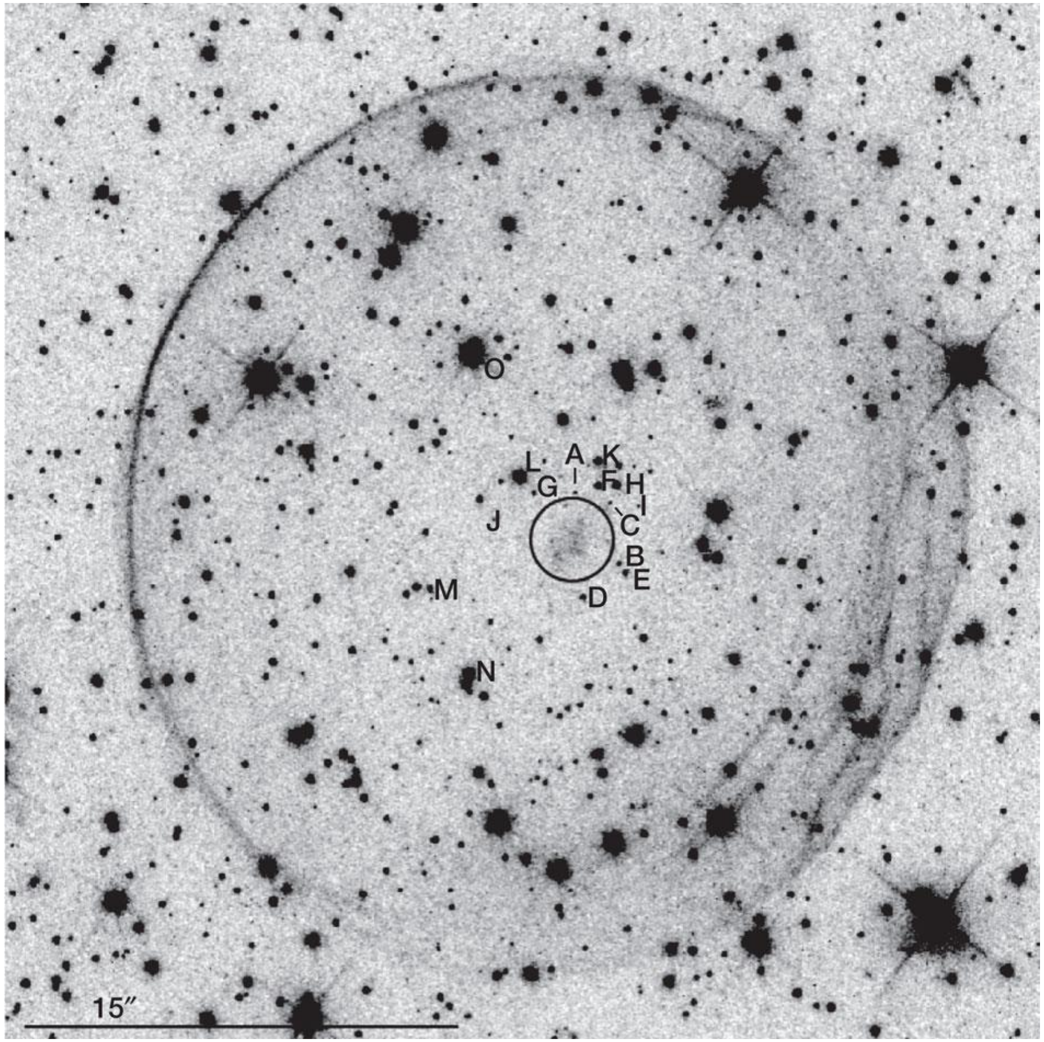
➜ no evidence for massive dust in the ejecta of Type Ia SNe

upper limit of dust mass: M_{dust} < ~10^{-3} M_{sun} (Gomez+2012)
from Herschel FIR observations of Kepler and Tycho SNRs

Can SNe Ia synthesize Fe grains in the ejecta or not?

3-2. Where is the companion star of SNR 0509?

optical image of SNR 0509-67.5 in LMC



Schaefer & Pagnotta+12

· explosion channel of SNe Ia

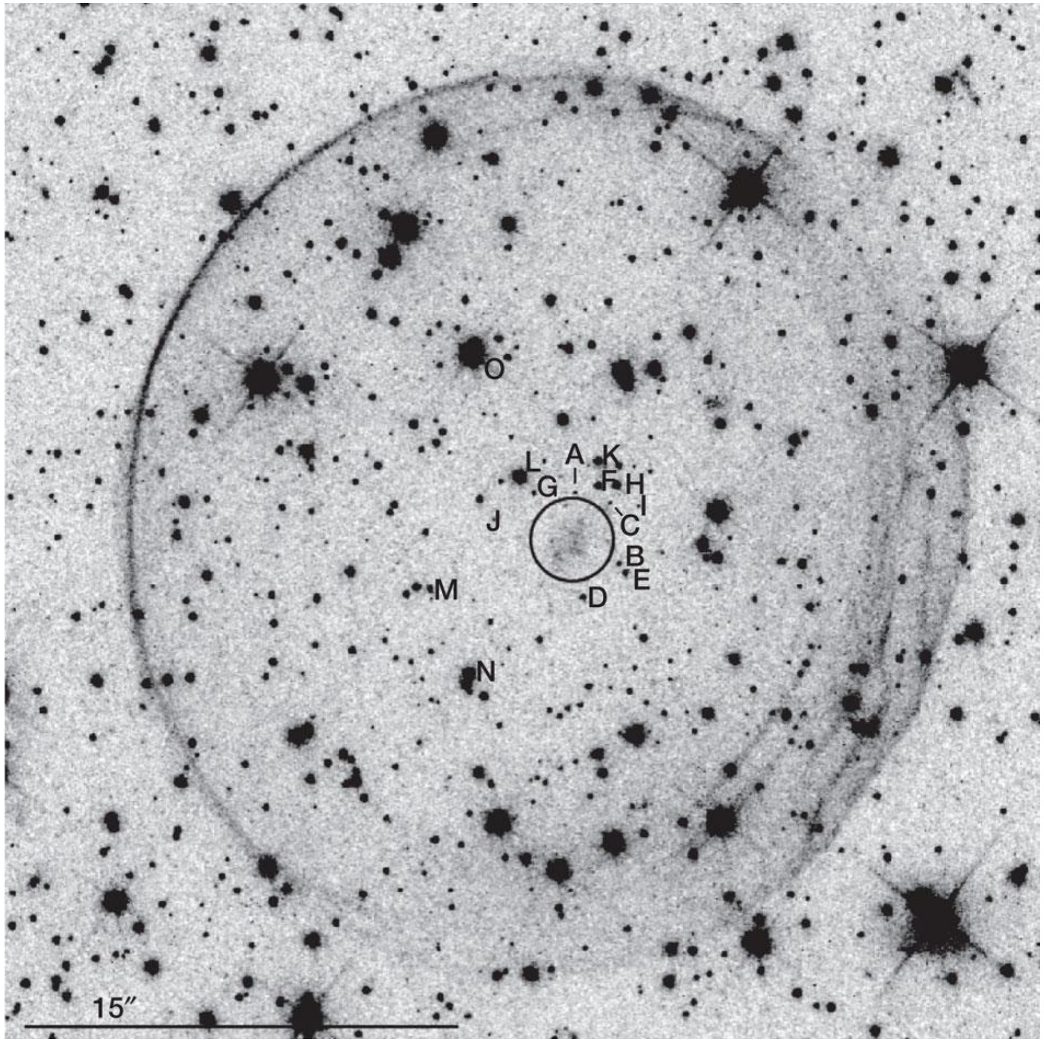
- single degenerate
  WD + MS (or Giant)
  ➜ companion star left
- double degenerate
  WD + WD
  ➜ no companion star left

no companion star in central region of SNR 0509-67.5
➔ double degenerate?

However …
there is diffuse emission in the central region
- background galaxy?
- associated with the SNR?

3-3. Where is the companion star of SNR 0509?

optical image of SNR 0509-67.5 in LMC



Schaefer & Pagnotta+12

Radius of the central circle :
1.5” = 1.1x10^{18} cm @ 50 kpc

V_{exp} = 850 km/s @ 410 yr

corresponds to Fe core !

Supposition

Diffuse emission within the central circle may be optical lights scattered by Fe grains formed in the ejecta

3-4. Dust formation in SNe Ia

○ if my supposition is correct …

the optical depth for scattering must be high enough ($\tau_{sca} \sim 1$)

$$\tau_{sca} \sim 1.0\ (\kappa_{sca} / 1.86\times10^4\ \mathrm{cm^2/g})\ (M_{dust} / 0.1\ M_{sun})$$

- $\kappa_{sca} = 1.86\times10^4\ \mathrm{cm^2/g}$ at λ=0.65 μm for a = 0.1 μm
- $\kappa_{sca} = 1.70\times10^3\ \mathrm{cm^2/g}$ at λ=0.65 μm for a = 1.0 μm

κ_{sca} is too low for a < 0.01 μm

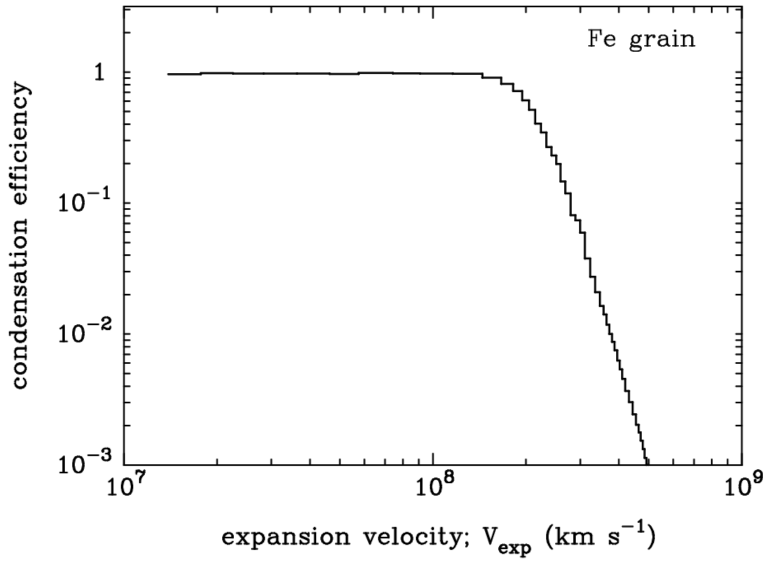
➜ relatively large (>~0.1 μm) radius of Fe grains
dust mass as high as ~0.1 M_{sun}

○ Dust formation calculations

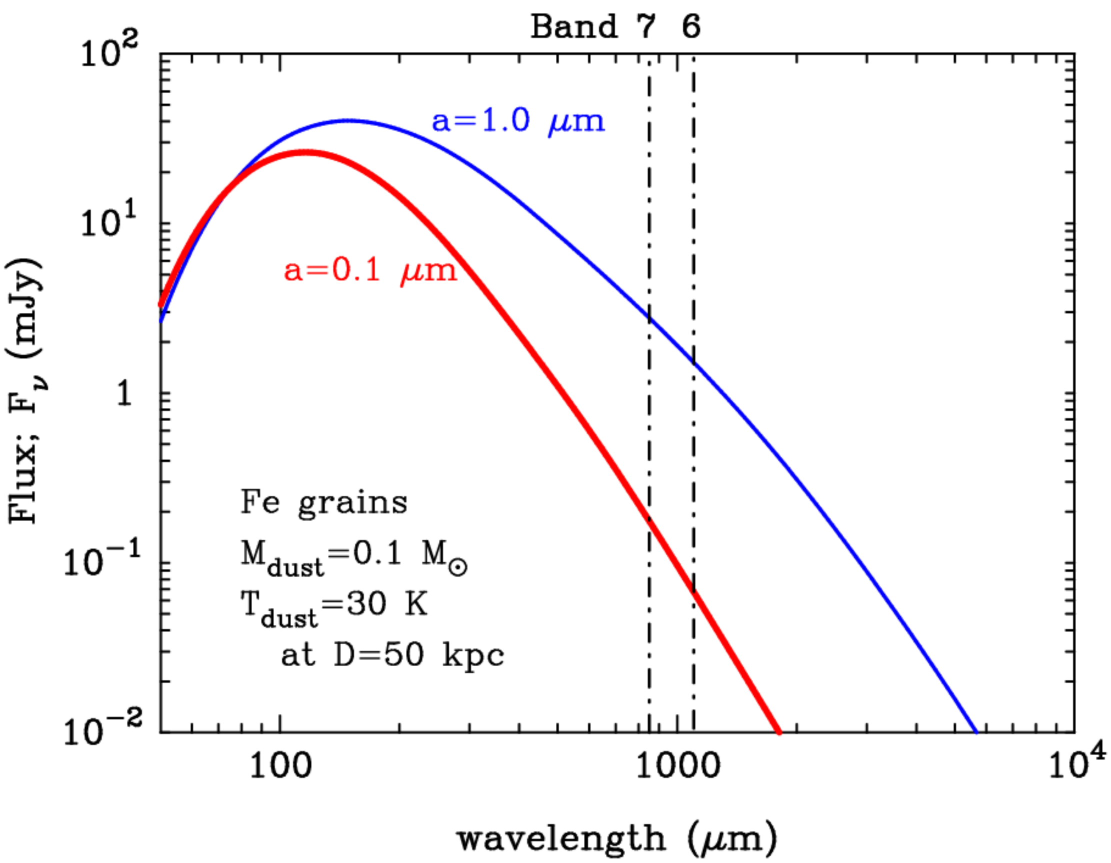
Fe grains can efficiently condense at the inner region of V_{exp} < ~2000 km/s

- dust radius: < 0.01 μm
- dust mass: ~0.05 M_{sun}

➜ Fe grains form in dense clumps?



3-5. Expected SEDs of Fe grain emission



Flux density from Fe grains with M_{dust} = 0.1 M_{sun}
T_{dust} = 30 K

For a = 0.1 μm,
0.18 mJy in Band 7
0.07 mJy in Band 6

For a = 1.0 μm,
2.5 mJy in Band 7
1.4 mJy in Band 6

5 sigma detection in 6 hours

If the source is detected, this is the first detection of the formation of massive dust grains in SNe Ia !
➜ great step to solve the missing-iron problem

3-6. Origin of the central diffuse emission

THE DIFFUSE SOURCE AT THE CENTER OF LMC SNR 0509−67.5
IS A BACKGROUND GALAXY AT $z = 0.031$

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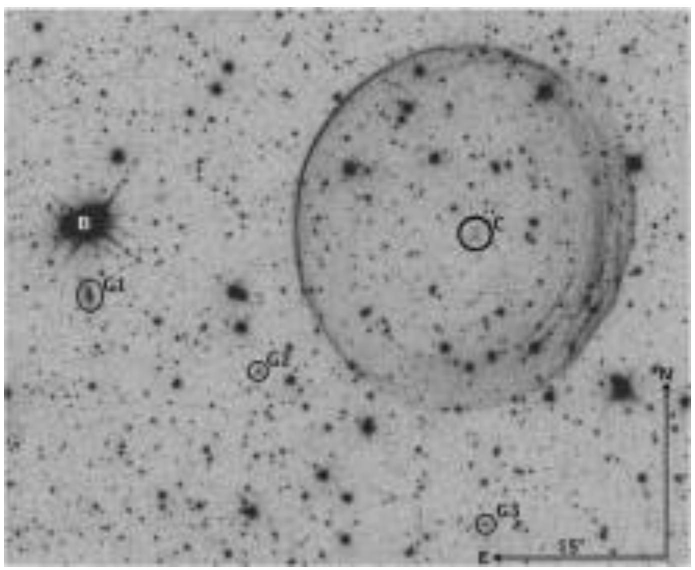
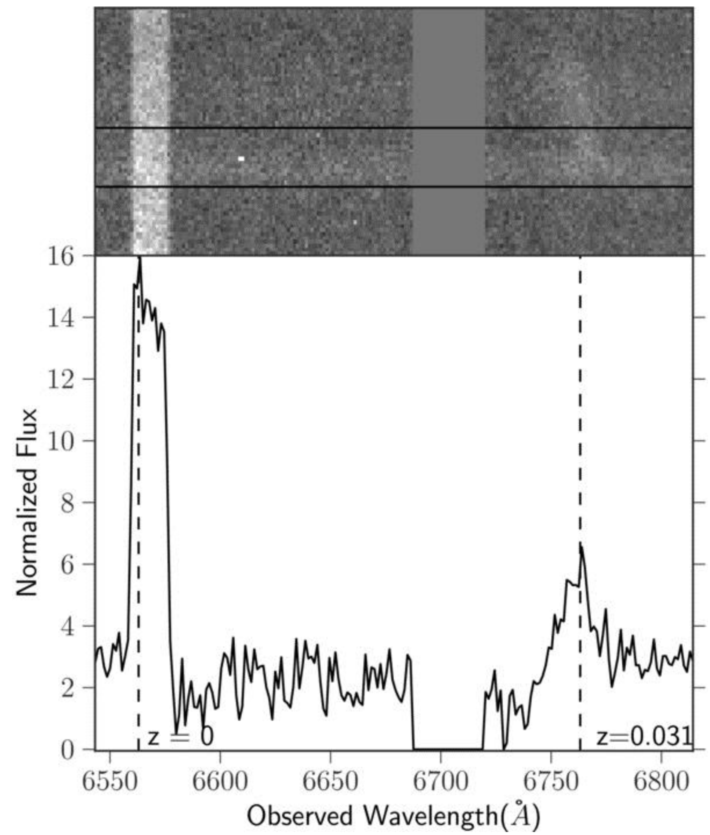


there are many red background galaxies around SNR 0509-67.5



4-1. Towards ALMA Cycle3

○ Probing dust grains in luminous blue variables (LBVs)

- **How much dust grains can be formed in LBV winds?**
  ➜ **Massive stars can enrich the interstellar medium through the formation of dust grains in stellar winds**

- **Dust formation in stellar winds of LBVs is challenging from a view of dust formation theory**
  ➜ **good laboratory for understanding dust formation process in astrophysical environments**

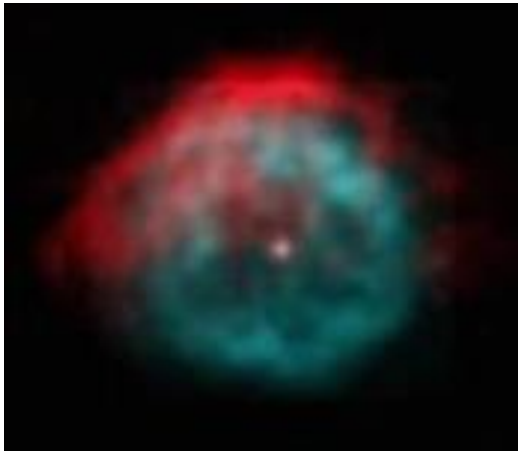
- **The presence of circumstellar dust is useful for giving insight into mass-loss mechanism and evolution of massive stars**
  ➜ **LBVs as progenitors of Type IIn SNe**
  ➜ **casting a problem on stellar evolution theory**

- **Optically thick dust winds obscure the central stars and SNe**
  ➜ **Affecting the progenitor mass estimate and the observed rate (frequency) of CCSNe**

4-2. Proposals accepted in Cycle0

○ Number of proposals in Category 5: 8 (out of 112)

(1) R scl (carbon AGB), Maercker, M., et al.
(2) SN 1987A (SNR), Nozawa, T., et al.
(3) Red Rectangle (PPN), Bujarrabal, T., et al.
(4) IRC+10216 (carbon AGB), Cernichao, J., et al.
(5) SN 1987A (SNR), Indebetow, R., et al.
(6) IRC+10216 (carbon AGB), Decin, L., et al.
(7) Eta Carina (LBV), Abraham, Z., et al.
(8) Boomerang Nebula (PPN), Sahai, R., et al.



Buemi+2010

Candidates of dust-obscured LBVs

- Eta Carina
- AFGL 2298 (IRAS18576+0341) (Ueta+2001)
- AG Car (Voors+2000)

4-3. Proposals accepted in Cycle1

○ Number of proposals in Category 5: 21 (out of 196)

(1) SN 1987A (SNR), Indebetow, R.
(2) Red Rectangle (PPN), Bujarrabal, T., et al.
(3) R Sculotoris (carbon RG), Maercker, M., et al.
(4) Helix nebula (PN), Huggins, P., et al.
(5) IRC+10216 (carbon AGB), Cernichao, J., et al.
(6) NGC 6302 (PN), Hirano, N., et al.
(7) IRC+10216 (carbon AGB), Decin, L., et al.
(8) Betelgeuse (RSG), Kervella, P., et al.
(9) VVV-WIT-01 (variable), Minniti, D., et al.
(10) Boomerang Nebula (PPN), Sahai, et al.
(11) IRAS 16432-3814 (bipolar nebula), Sahai, R., et al.
(12) WISE J180956.27-330500.2 (variable), Yamamura, I., et al.
(13) Crab nebula (SNR), Karagaltsev, O., et al.
(14) others: CCSNe (1), NSs (1), GRB (1), AGB star (1), M-dwarfs (1), low-mass stars (1), massive stars (1)
(15) unknown (1), AFGL 4176?