Detecting Cool Dust in SNRs in LMC and SMC with ALMA

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and

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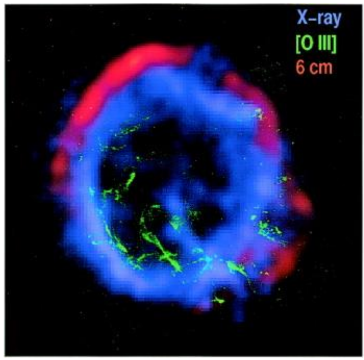

Targets

- **SN 1987A: our proposal for ALMA Cycle 0 and next plan for ALMA Cycle 1**
- **1E0102.2-7219: youngest SNR in SMC**

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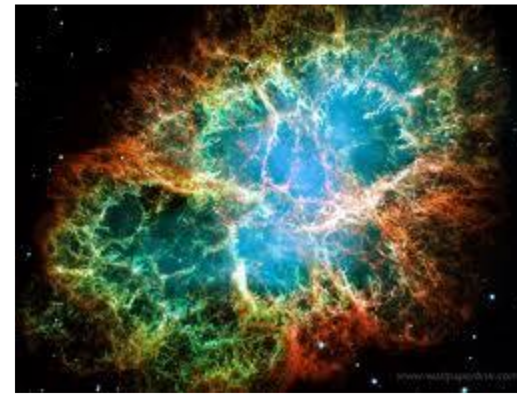
2012/6/11

1. SNRs at submm and millimeter wavelengths

- molecular lines and synchrotron emission from interaction regions between molecular clouds and SN blast waves



- synchrotron emission from pulsar wind nebulae

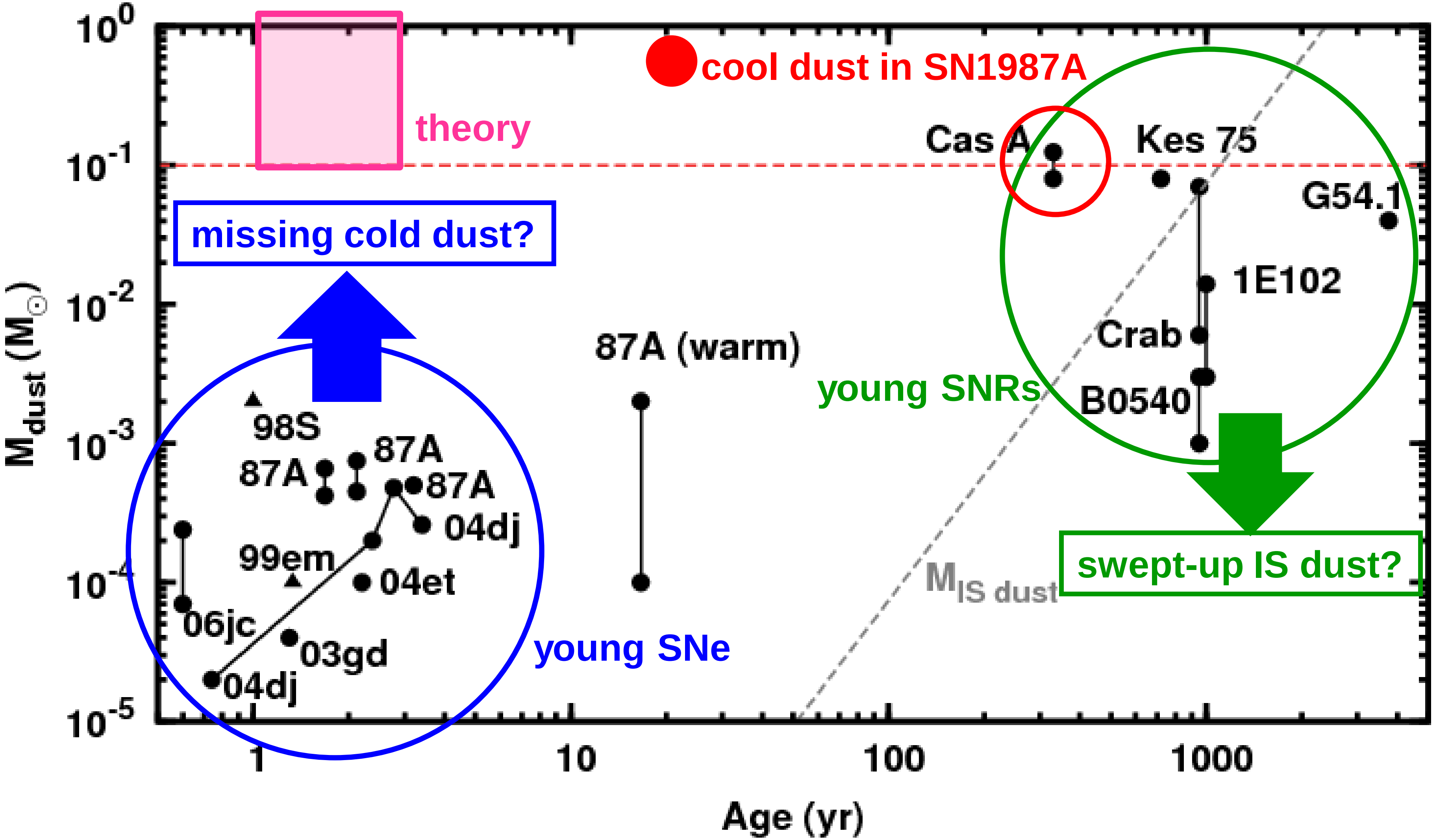
- thermal emission from cool dust which was formed in the expanding ejecta of SNe

  ➔ cool dust dominates the dust mass

  ➔ discovery of a huge amount of dust at $z > 5$

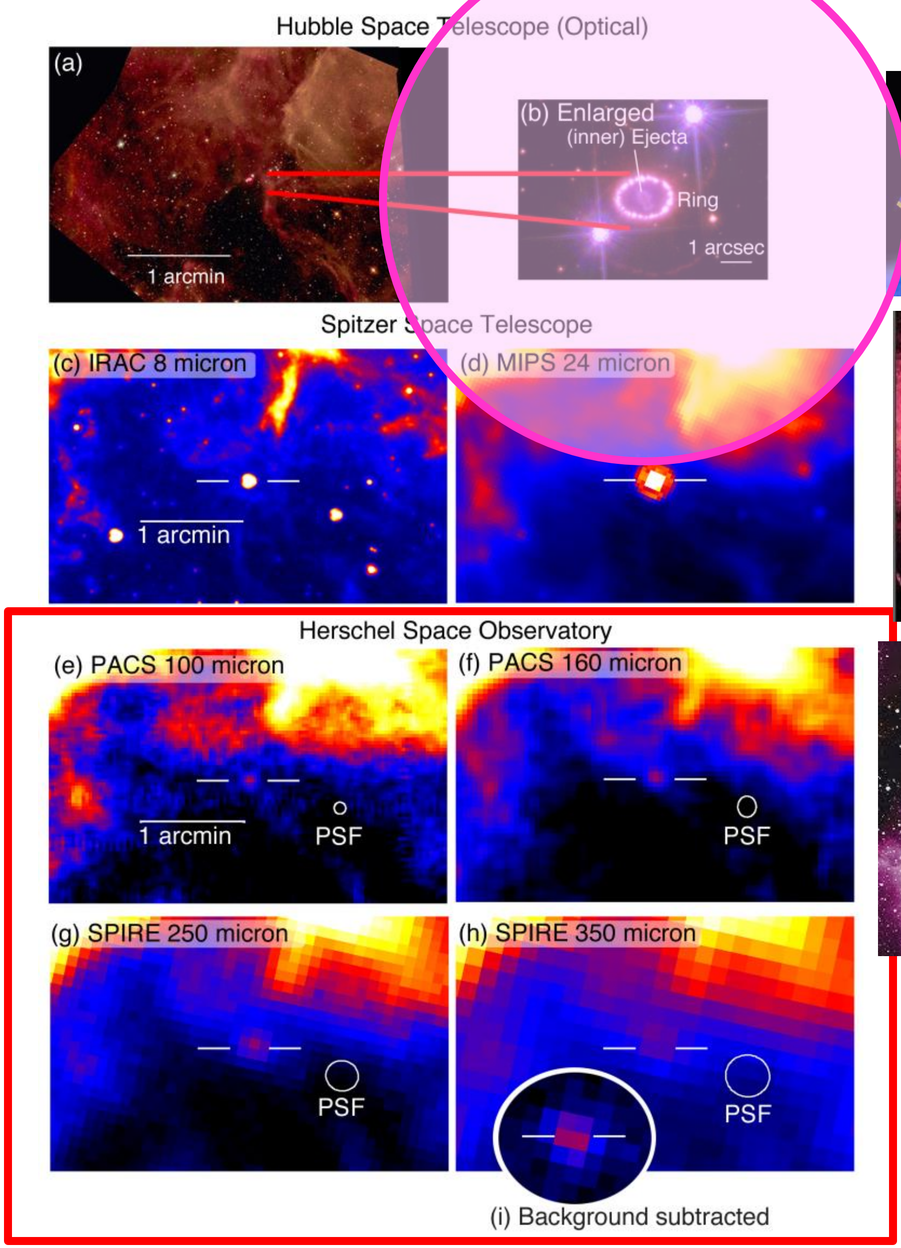
SNe are important sources of interstellar dust?

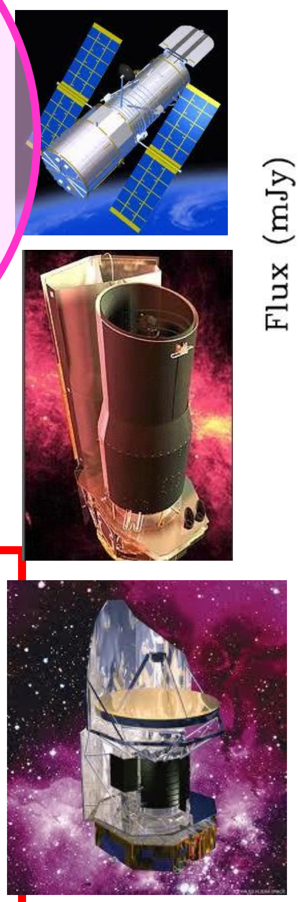
2. Summary of dust mass in core-collapse SNe



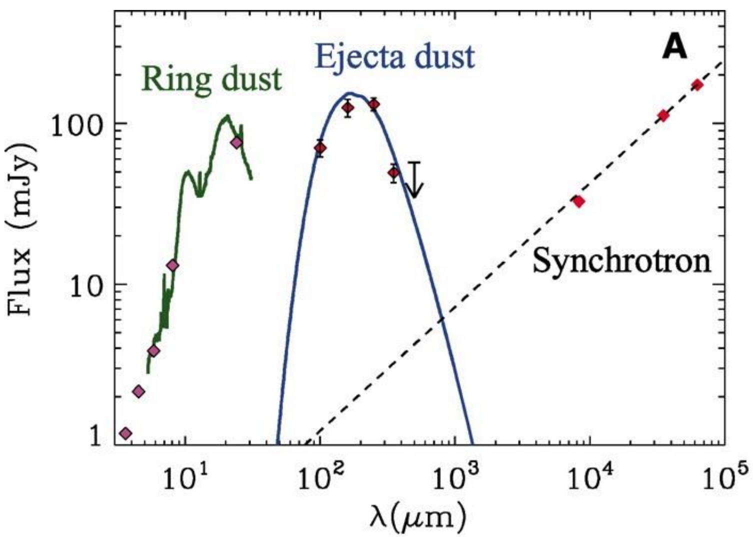
Far-IR to sub-mm observations are essential for revealing the mass of dust grains produced in the ejecta of SNe

3. Herschel detects cool dust in SN 1987A





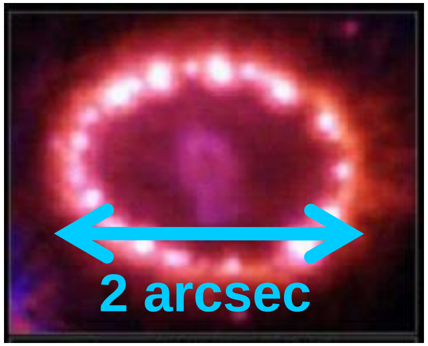
Matsuura et al. 2011



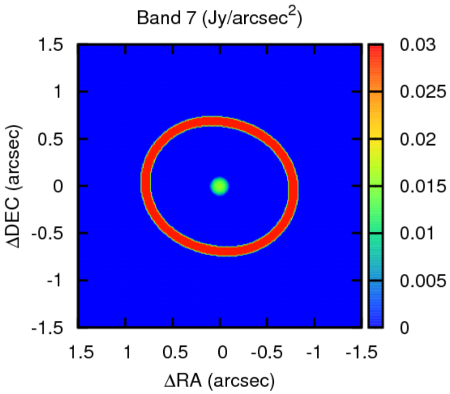
Herschel detects cool (~20K) dust of ~0.4-0.7 Msun toward SN 1987A!

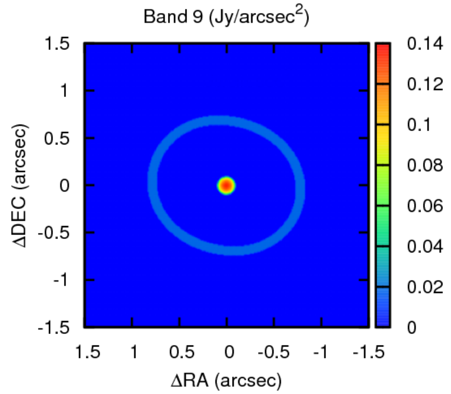
4. Resolving cool dust in SN 1987A with ALMA

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

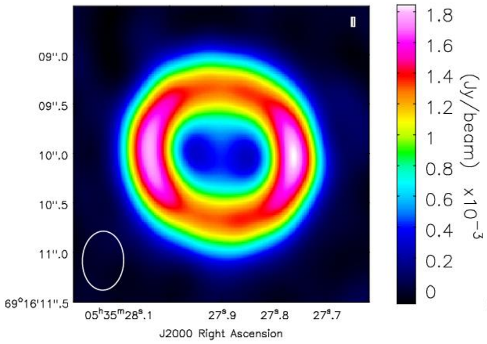


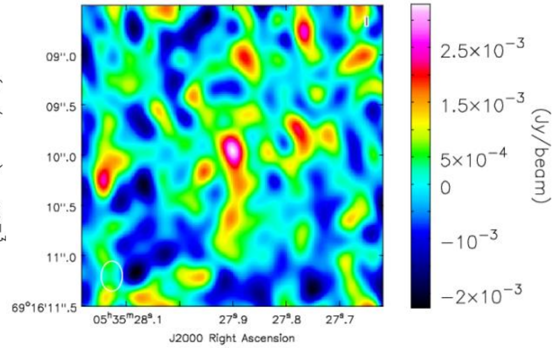
Band 7 (850 μm) **Band 9 (450 μm)**

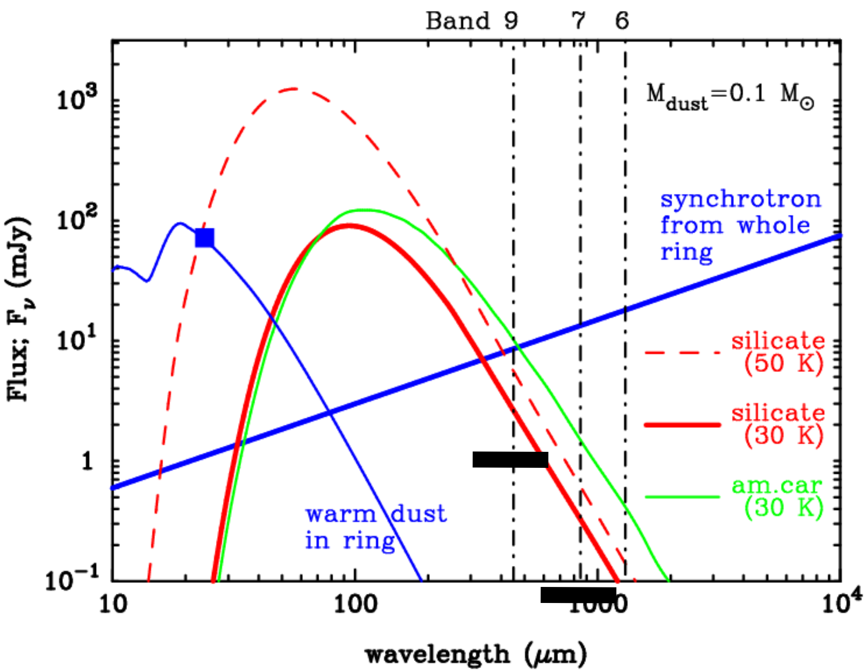




CASA simulation with extended config. (4 hrs)



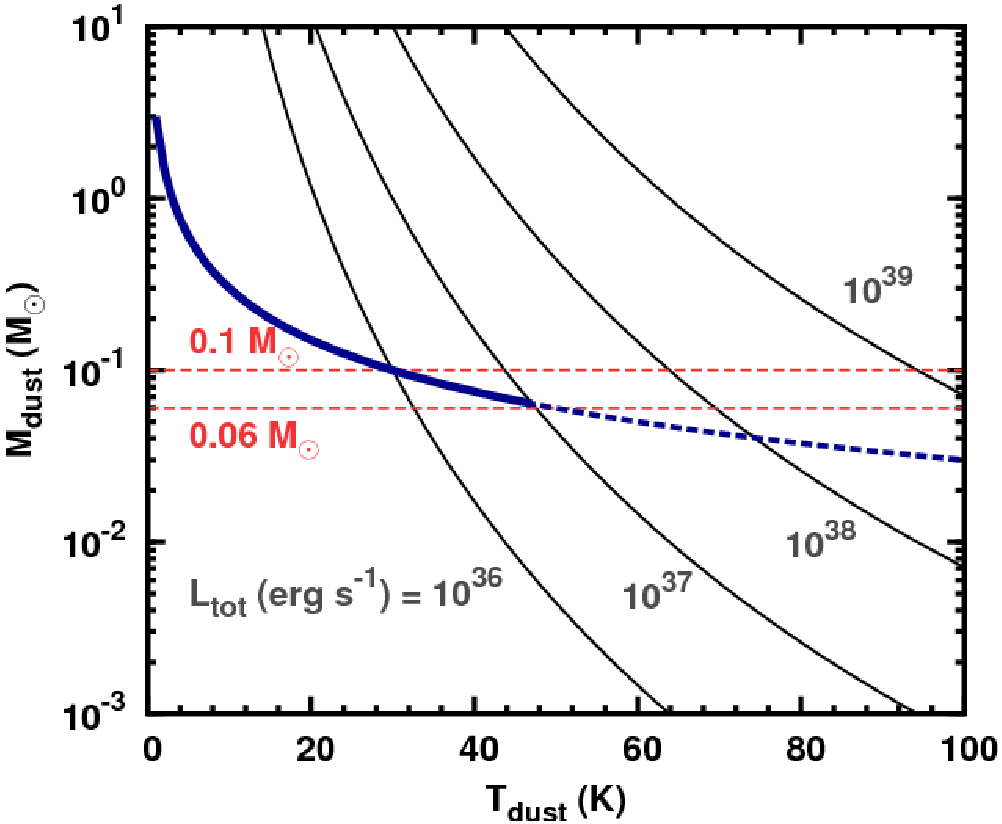




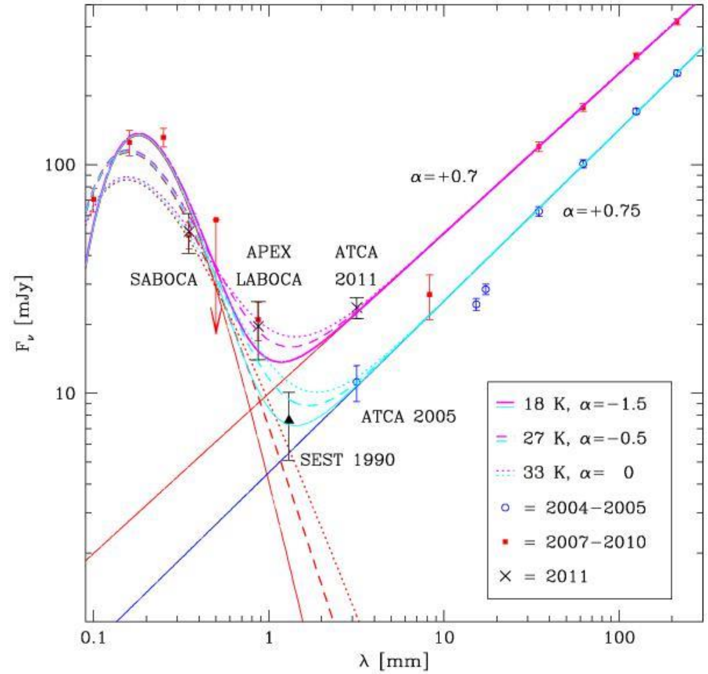
0.1 Msun of silicate
➔ 5σ detection at Band 9 !!

5. Constraining mass of cool dust in SN 1987A

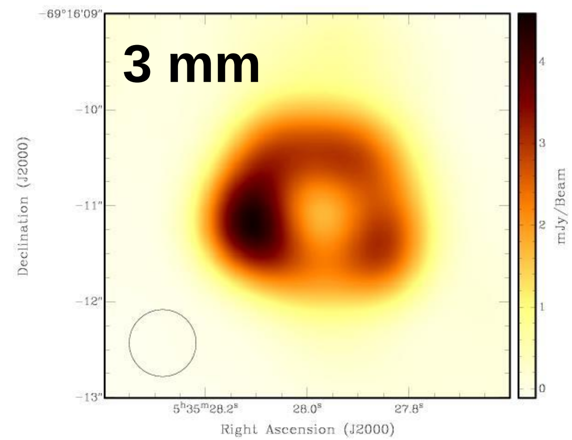
Herschel results had not yet opened at that time …



If detected with 2.7 mJy, more than 0.06 Msun of grains exist !!



Lakicevic+12, A&A, 541, L1



Lakicevic+12, A&A, 541, L2

6. 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

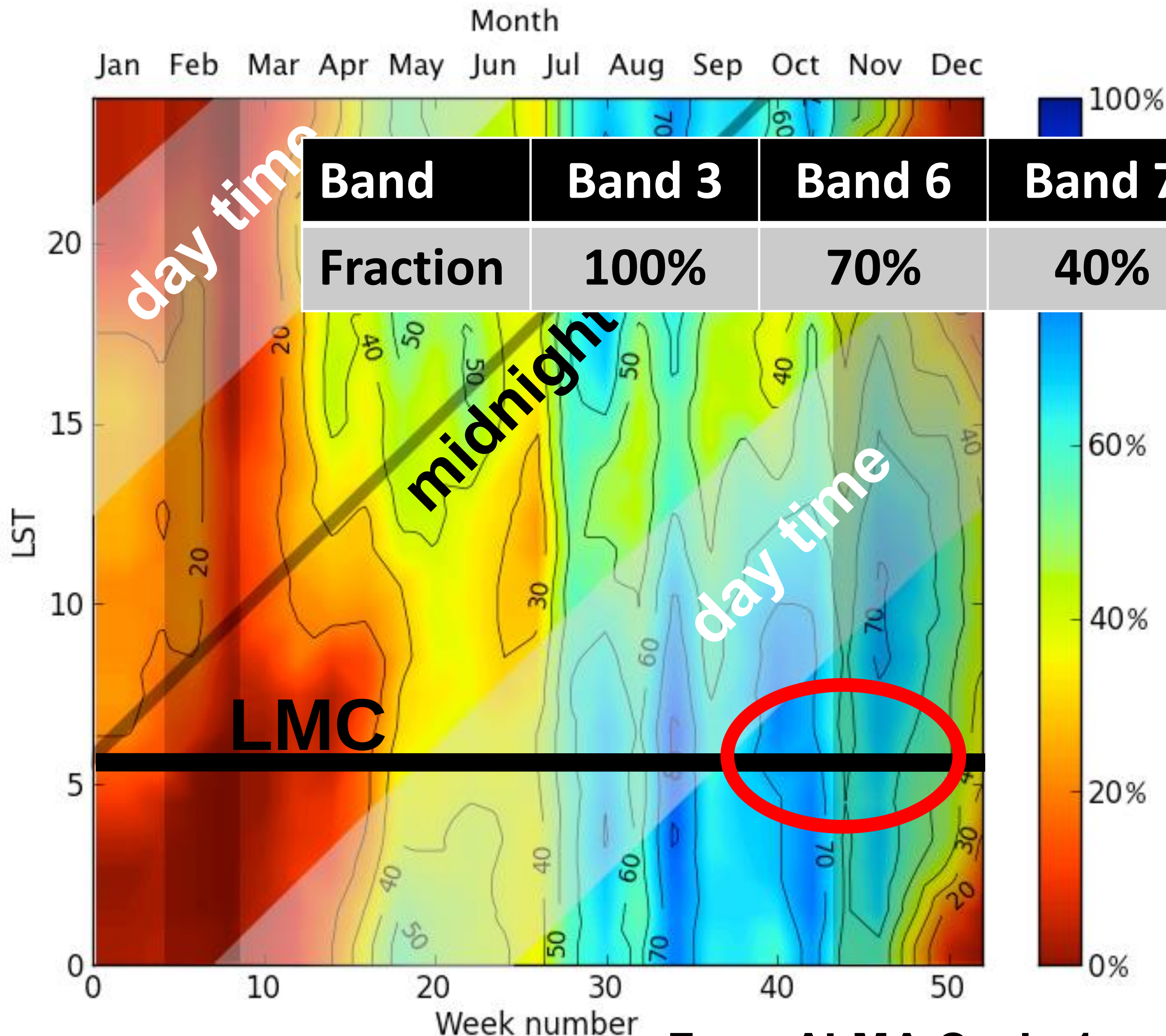
Band 9
extended configuration

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			
Cla			
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

7. Condition of atmosphere



Band	Band 3	Band 6	Band 7	Band 9
Fraction	100%	70%	40%	10%

From ALMA Cycle 1 proposer's guide

8. 12m-array configurations for ALMA Cycle1

compact ⟷ extended

	C32-1		C32-2		C32-3		C32-4		C32-5		C32-6	
Band (freq)	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale
Band 3 (100GHz)	3.7"	25"	2.0"	25"	1.4"	17"	1.1"	17"	0.75"	14"	0.57"	8.6"
Band 6 (230GHz)	1.6"	11"	0.89"	11"	0.61"	7.6"	0.48"	7.6"	0.33"	6.2"	0.25"	3.7"
Band 7 (345GHz)	1.1"	7.1"	0.59"	7.1"	0.40"	5.0"	0.32"	5.0"	0.22"	4.1"	0.16"	2.5"
Band 9 (675GHz)	0.55"	3.6"	0.30"	3.6"	0.21"	2.6"	0.16"	2.6"	0.11"	2.1"	0.08"	1.3"

Cycle0 proposal
(extended, Band 9)

Ang Res : 0.23”
Max Res : 1.5”

Cycle1 proposal

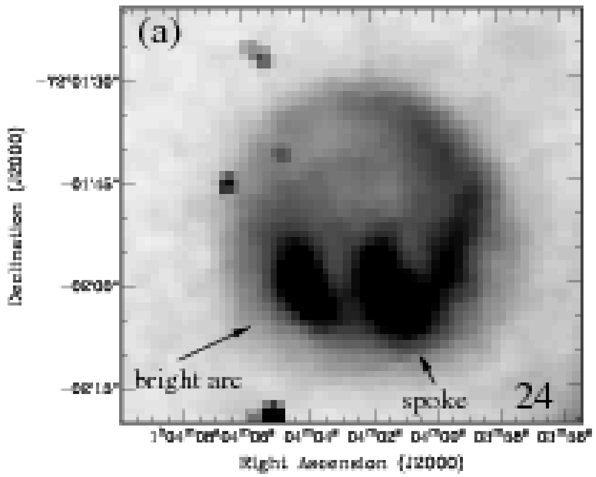
- **Band 6, 7, and 9**
- **C32-5 or C32-6 or mixed confguration?**

9. Possible target: SNR 1E0102, a twin of Cas A

・ SNR 1E0102

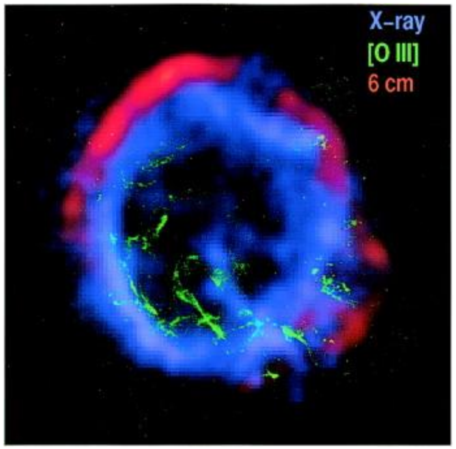
- O-rich (Type Ib?)
- age : ~1000 yr
- $M_{warm} \sim 10^{-3}$ M_{sun}
- M_{cool} ~ ???

24 μm



Stanimirovic+05

X-ray, radio



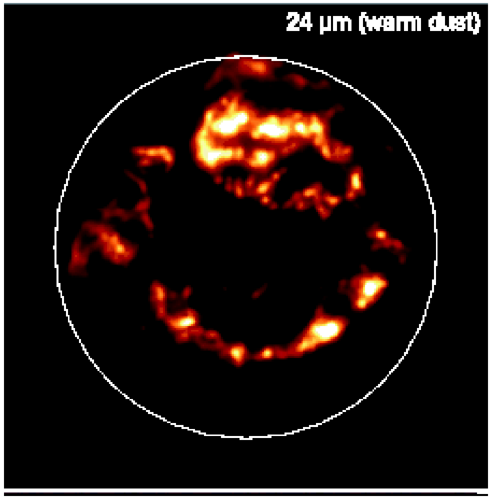
Gaetz+00

・ Cassiopeia A

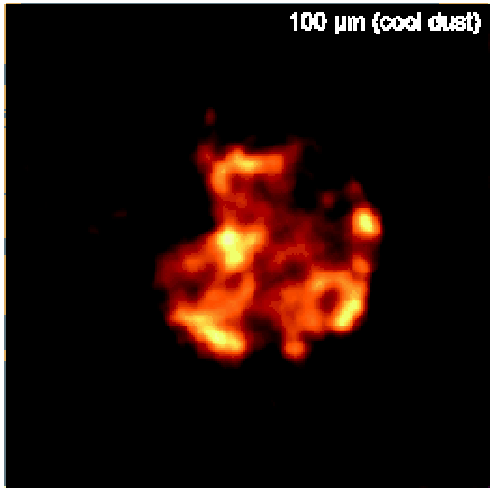
- Type IIb
- age : 330 yr
- $M_{warm} < 10^{-2}$ M_{sun}
- $M_{cool} \sim 0.07$ M_{sun}

Cas A model (Nozawa+10)

24 μm



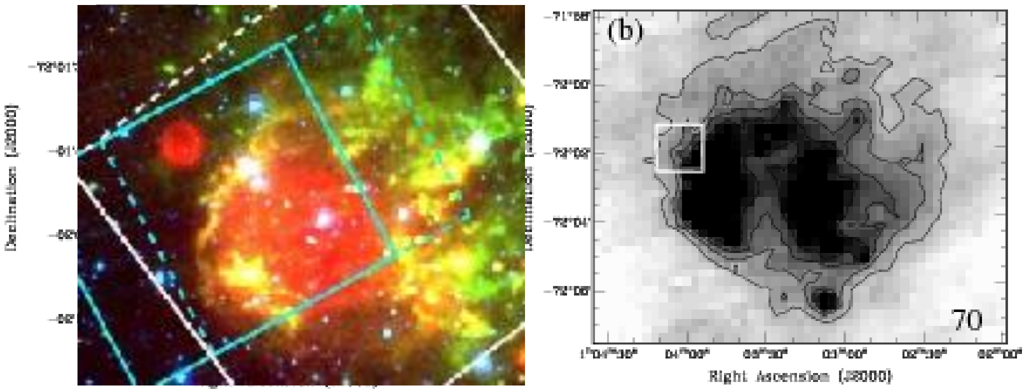
100 μm



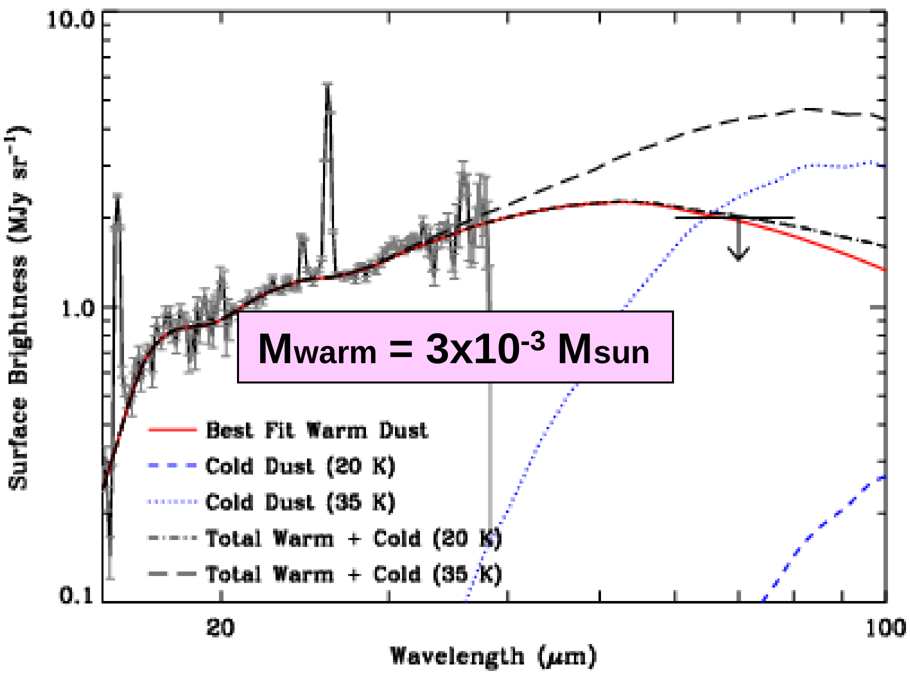
Barlow+10, A&A, 518, L138

10. IR observations of SNR 1E0102

24 μm 70 μm



Spitzer; Stanimirovic+05



Sandstrom+09, ApJ, 696, 2138

- **SNR 1E0102 in SMC**
  - age : ~1000 yr
    youngest CCSNe
  - diameter : ~40”
    (= 12 pc @ 60 kpc)
  - similar to Cas A

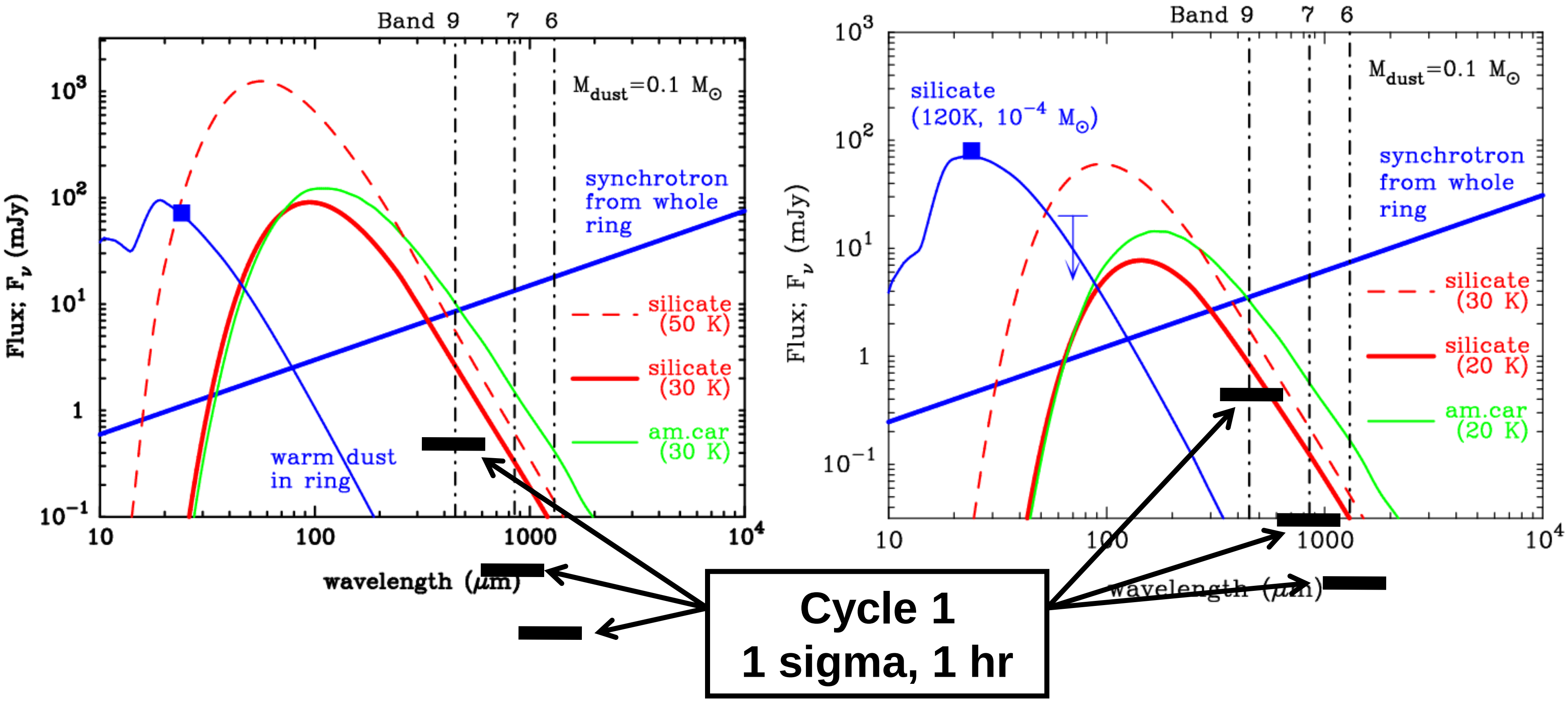
- **hot dust mass**
  - M_{warm} = 8x10^{-4} M_{sun}
    (Stanimirovic+05)
  - M_{warm} = 0.014 M_{sun}
    (Rho+09)

- **cool dust mass**
  - M_{cool} < 0.6 M_{sun}
    with T_{dust} = 20-30 K
    (Sandstrom+09)

11. Comparison with SED of SN 1987A

IR SED of SN 1987A

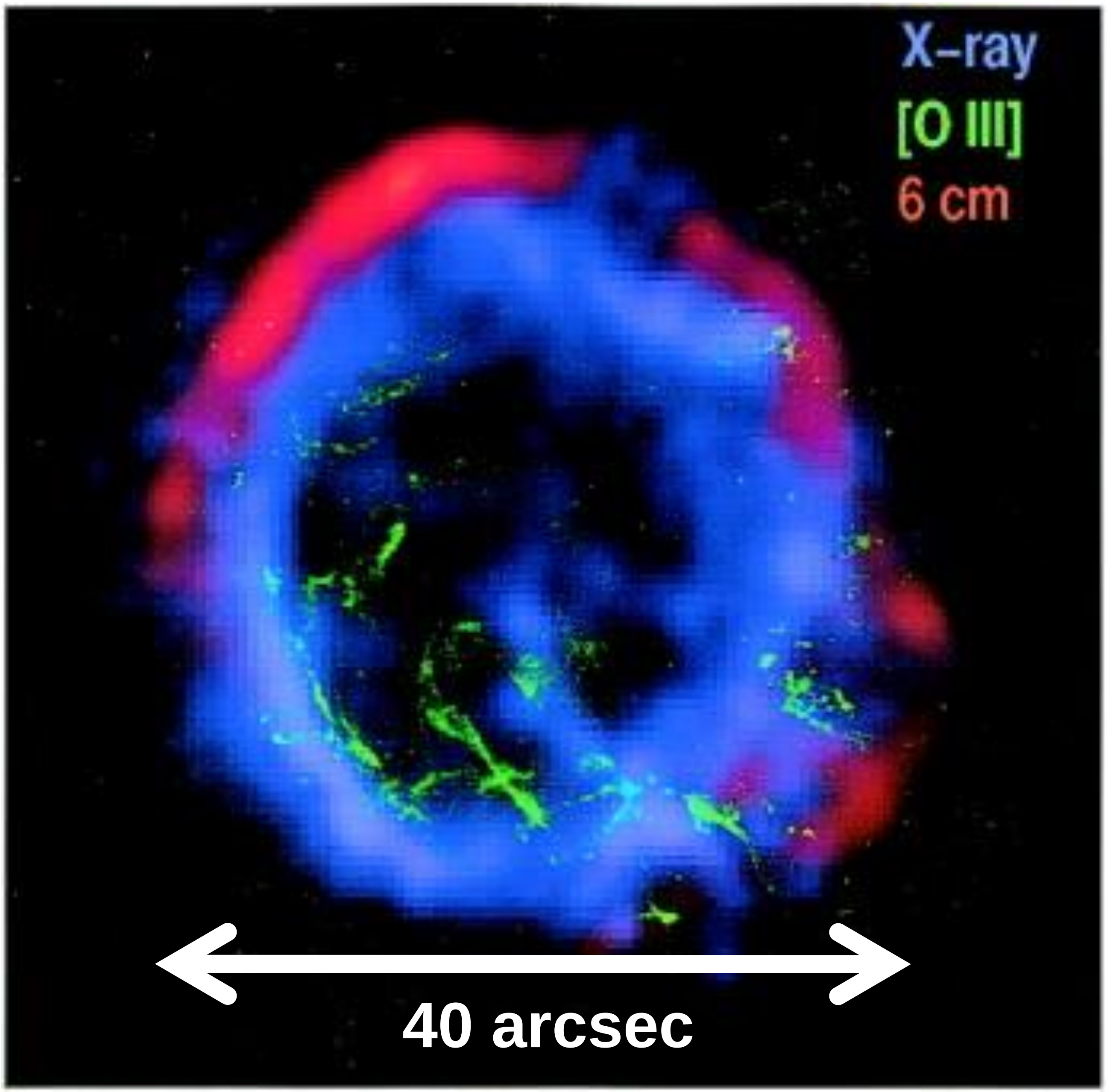
IR SED of SNR 1E0102



IR-to-radio SEDs of SN 1987A and 1E0102 are similar

But ..

12. SNR 1E0102 is too extended!



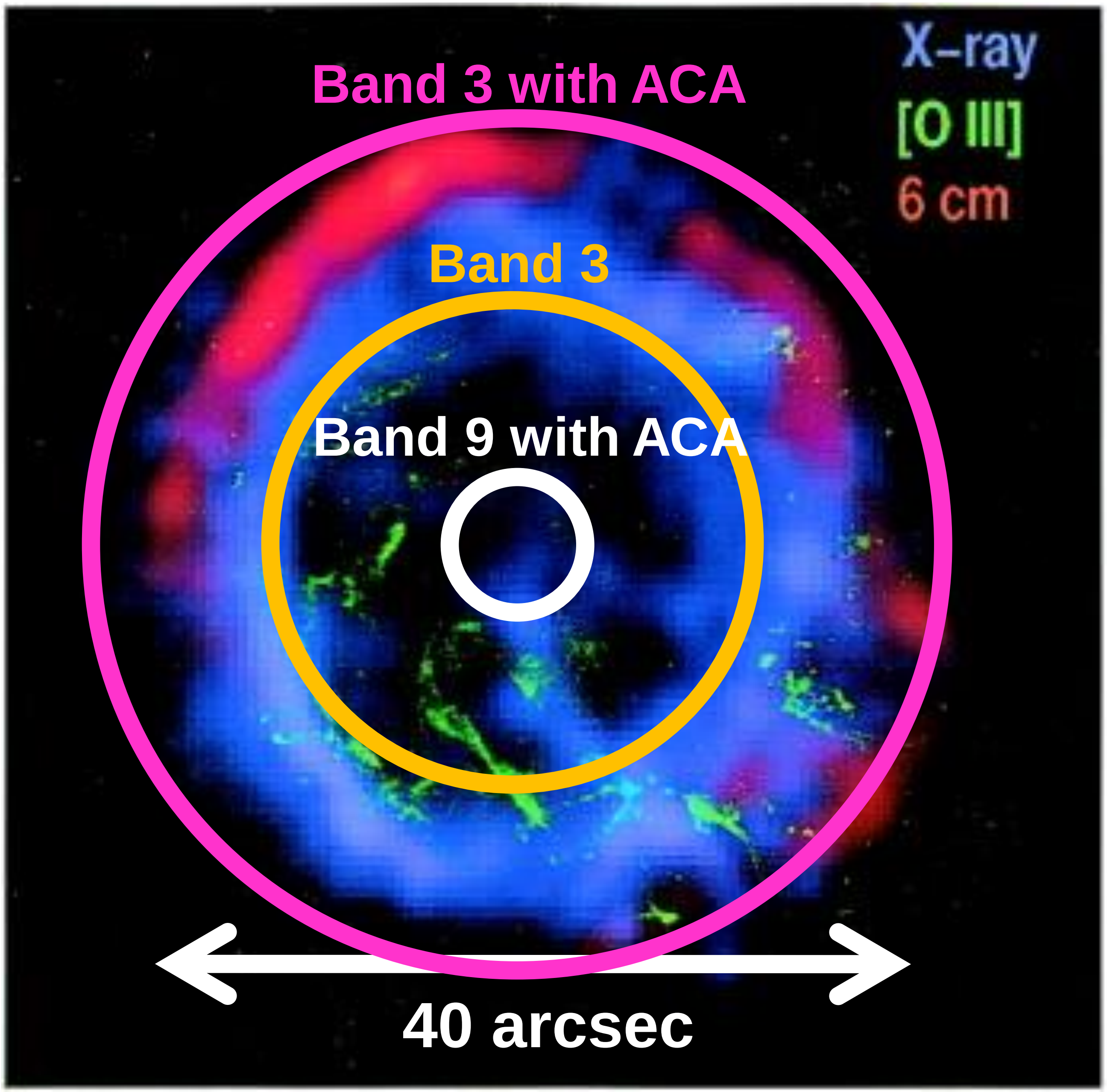
13. Array & ACA combinations

	C32-1		C32-2		C32-3		C32-4		C32-5		C32-6	
Band (freq)	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale
Band 3 (100GHz)	3.7"	25"	2.0"	25"	1.4"	17"	1.1"	17"	0.75"	14"	0.57"	8.6"

- **Use of ACA requires 3 times more times**
- **Atmospheric correction is not available on ACA**
- **Total Power (TP) is not available for continuum**

	C32-1 & ACA 7-m Array		C32-2 & ACA 7-m Array		C32-3 & ACA 7-m Array		C32-4 & ACA 7-m Array	
Band (freq)	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale	Ang Res	Max Ang Scale
Band 3 (100 GHz)	3.7"	44"	2.0"	44"	1.4"	44"	1.1"	44"
Band 6 (230 GHz)	1.6"	19"	0.89"	19"	0.61"	19"	0.48"	19"
Band 7 (345 GHz)	1.1"	13"	0.59"	13"	0.40"	13"	0.32"	13"
Band 9 (675 GHz)	0.55"	6.5"	0.30"	6.5"	0.21"	6.5"	0.16"	6.5"

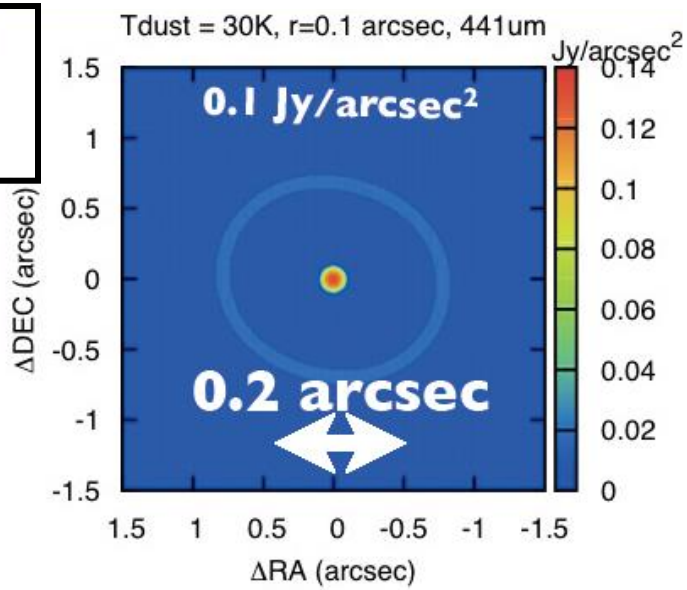
14. What is the best strategy for SNR 1E0102?



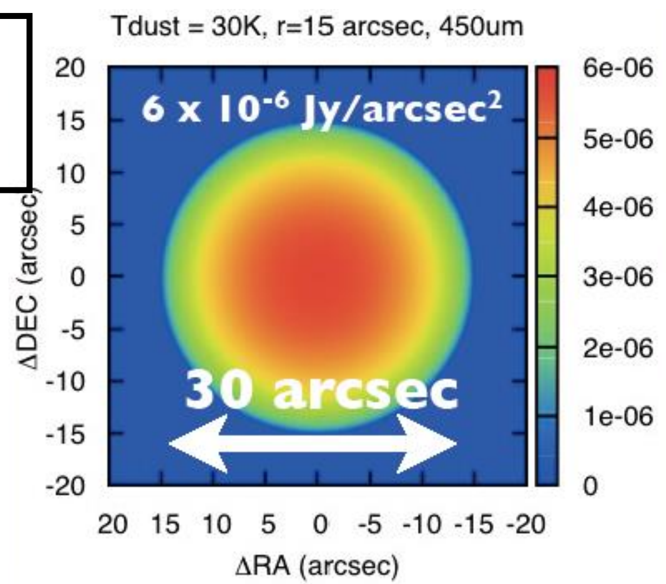
SN 1987A

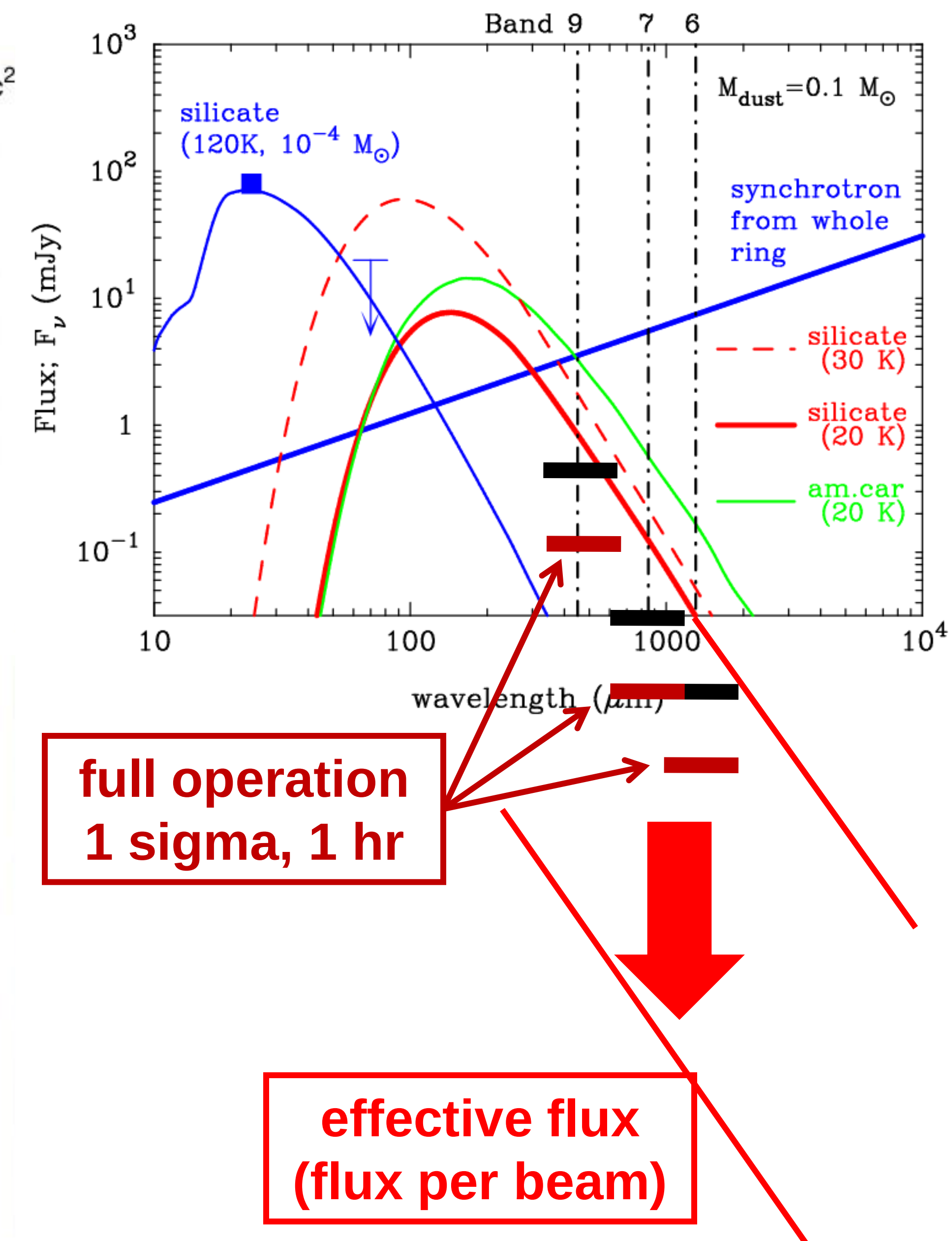
15. Flux estimates necessary for detection

1987A
Band 9



1E0102
Band 9





16. Summary

Detecting cool dust in SNRs with ALMA

- **SN 1987A** (radius: 0.5 arcsec)
  - Spatially resolved images in Band 6, 7, and 9
  - Possibility of detecting molecular lines?

- **1E0102.2-7219** (radius: 20 arcsec)
  - too large and too faint (almost impossible)

  ➔ it seems too hard to detect continuum emission from cool dust in any other SNRs..

A-1. How dense is cool dust in 1E0102?

- **1E0102.2-7219**

  R = 15 arcsec ➔ 1.3×10^{19} cm = 4.4 pc @ 60 kpc

  what is the mass of dust if ISM dust is included in the sphere with this radius?

  $$M_{dust} \sim (4\pi R^3 / 3)\, D\, (n_H\, m_H)$$

  $$= 0.077\ M_{sun}\ (D / 0.01)\ (n_H / 1\ cm^{-3})$$

- **Cassiopeia A**

  R = 100 arcsec ➔ 4.8×10^{18} cm = 1.6 pc @ 3.4 kpc

A-2. Importance of molecular lines in SN 1987A

- **CO and SiO molecules were detected around 300 days after explosion in SN 1987A**
  (CO and SiO were confirmed in many dust-forming SNe)

- **Measuring the expansion velocity of the ejecta**

- **CO molecule has been detected in Cas A SNR**

- **All condensible metals have to be tied up in dust grains to explain 0.4-0.7 M_{sun} of dust in SN 1987A**
  ➔ CO and SiO molecules can survive??

- **How much CO and SiO line fluxes can contribute the continuum flux?**
  ➔ expected mass of CO and SiO: ~10^{-3} M_{sun}

A-3. Summary of molecular lines

Band 3: 84-115 GHz
Band 6: 211-274 GHz
Band 7: 275-373 GHz
Band 9: 607-720 GHz

・CO molecule

v=0, 1-0: 115.271 GHz (B3)
v=0, 2-1: 230.538 GHz (B6)
v=0, 3-2: 345.796 GHz (B7)
v=0, 4-3: 461.041 GHz
v=0, 5-4: 576.268 GHz
v=0, 6-5: 691.473 GHz (B9)

・SiO molecule

v=0, 2-1: 86.847 GHz (B3)
v=0, 3-2: 130.269 GHz
v=0, 4-3: 173.688 GHz
v=0, 5-4: 217.105 GHz (B6)
v=0, 6-5: 260.518 GHz (B6)
v=0, 7-6: 303.927 GHz (B7)
v=0, 8-7: 347.331 GHz (B7)

v=0, 15-14: 650.958 GHz (B9)
v=0, 16-15: 694.296 GHz (B9)