Supernova remnants in AKARI mid-infrared all sky survey

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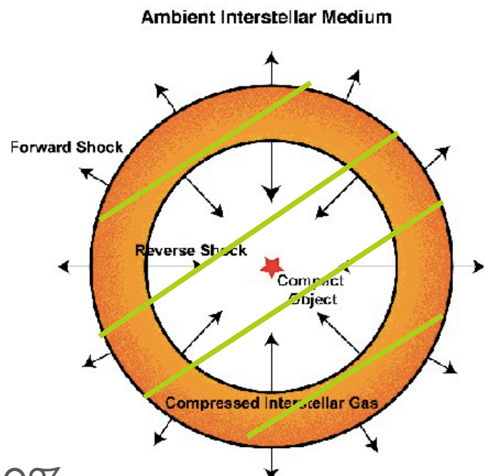
Introduction : Supernova remnant & dust

- Amount of dust in SNR?
  - + Newly formed dust in ejecta ~ 0.1 - 1 $M_{\odot}$
    - SN model calculation (Nozawa et al. 2003)
    - Observations of high-redshift galaxies (Morgan & Edmunds 2003 …)
  - + Dust in swept-up surrounding medium
    - Assume n_o = 1 cm^{-3} , …

      R = 6 pc, dust mass ~ 0.1 $M_{\odot}$ (Note: $M \sim R^3$)



  - - Destruction
    - Can be > 50%

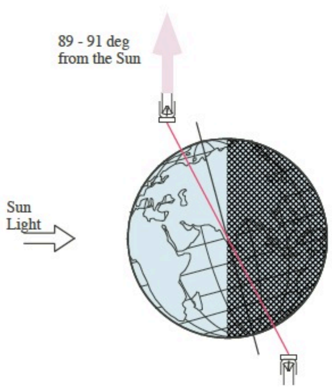
Cartoon from http://heasarc.gsfc.nasa.gov/docs/objects/snrs/cartoon.html

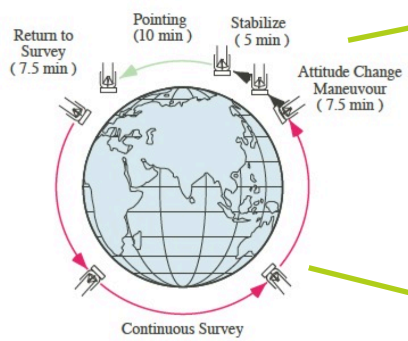
AKARI IR satellite

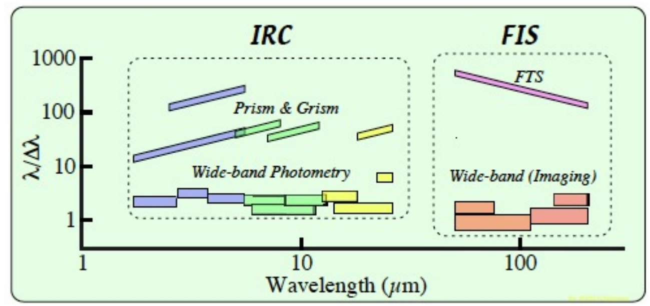
- IR surveyor/telescope
  - 68.5 cm
  - 2006. 2. – 2008. 8. (+ warm mission 2010. 2.)

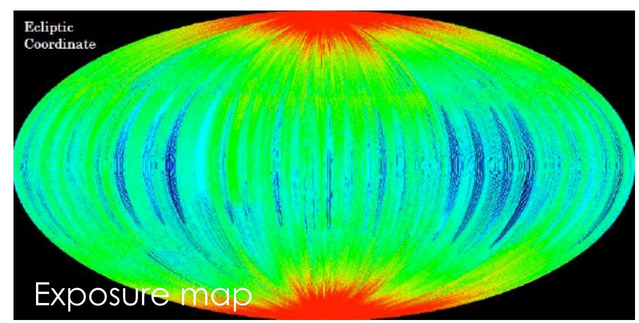
- 3 NIR + 2 MIR + 4 FIR band imaging (~10')
- NIR, MIR spectrometry

Pointed observation









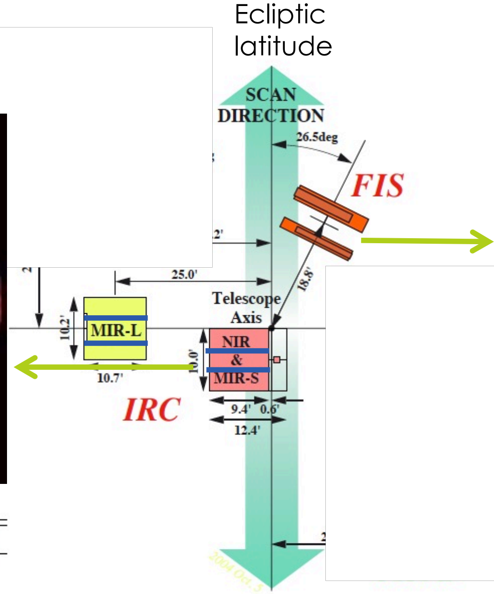
All sky survey
Low exposure around equator

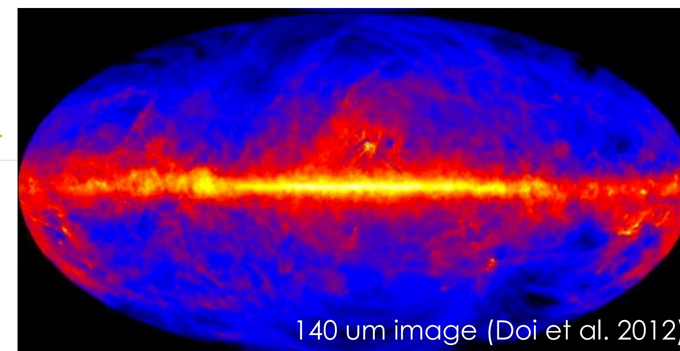
- MIR 9, 18, FIR 65, 90, 140, 160 um
- Scan sky along ecliptic latitude

All sky survey data

- MIR survey
  - Scan sky using 2 rows of IRC S, L
  - 4 pixel binning
- FIR survey
  - Scan sky using 4 FIS bands
  - Coverage > 99%

9 um image (Ishihara et al. 2010)



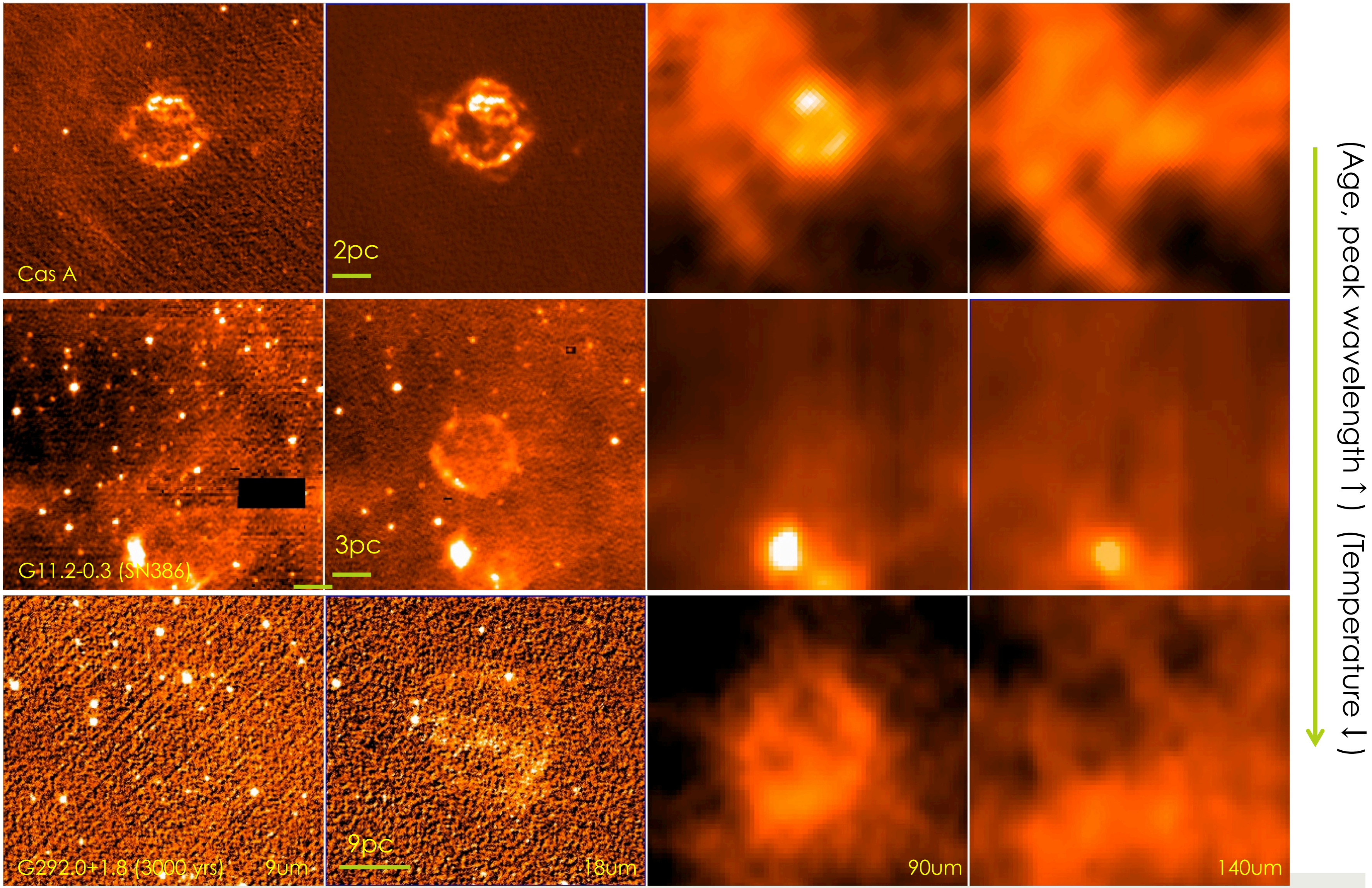


140 um image (Doi et al. 2012)

Filter band (Camera)	S9W (MIR-S)	L18W (MIR-L)
Wavelength‡	6.7–11.6 μm	13.9–25.6 μm
Isophotal wavelength	8.61 μm	18.39 μm
Effective bandwidth	4.10 μm	9.97 μm
Sampling rate (period)	22.27 Hz (44 ms)	
Scan rate (exposure*)	$216''\mathrm{s}^{-1}$ (11 ms)	
Reset rate (period)	0.074 Hz (13.464 s)	
Operation	256×2 pix	
Operated row	117^{th}, 125^{th}	
Binning	4×1 pix	
Virtual pixel scale	$9''.36 \times 9''.36$	$10''.4 \times 9''.36$
Detection limit (5σ)	50 mJy†	120 mJy†

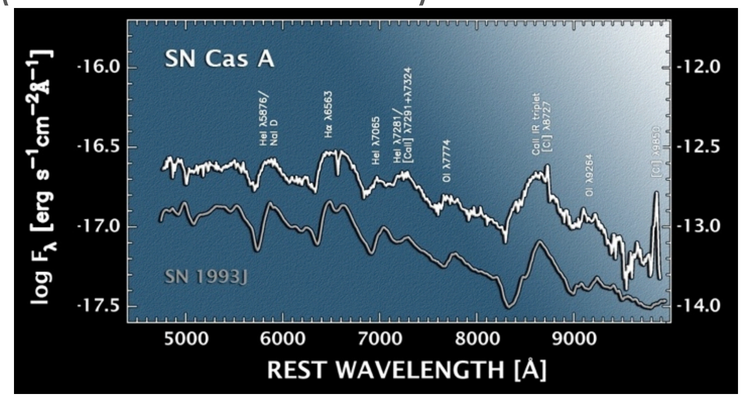
BAND	*N60*	*WIDE-S*	*WIDE-L*	*N160*	
Band center	65	90	140	160	[μm]
Effective band width*	21.7	37.9	52.4	34.1	[μm]
Pixel scale	26.8	26.8	44.2	44.2	[″]
Pixel pitch	29.5	29.5	49.1	49.1	[″]
Detection limit (1σ)	12	2	7	4	[MJy/sr]

SNR images from AKARI all sky survey : Young SNRs



Similar progenitor types

- Cas A
  - Type IIb (Krause et al. 2008)



- G11.2-0.3, G292.0+1.8

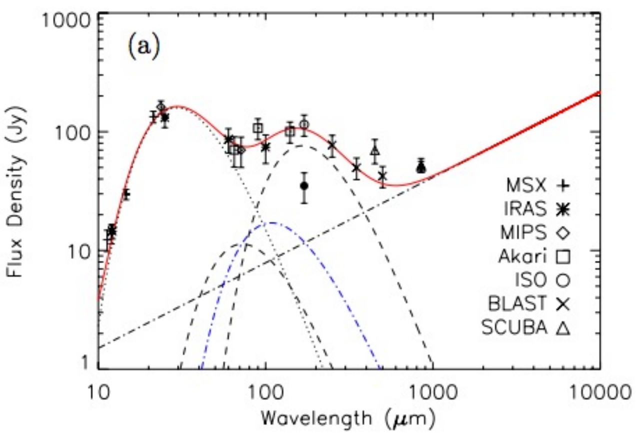
Supernova Remnant	Supernova Type	Age (yr)	P_0 (ms)	B (10^{12} G)
Crab..	IIP	950	20	4
3C 58	IIP	2400	50	4
PSR 0540−69	Ib/c	800	40	5
Kes 75	Ib/c	1000	30	48
MSH 15−52	Ib/c	1700	10	14
G292.0+1.8	IIL/b	3200	40	10
G11.2−0.3....................................	IIL/b	1600	60	2
G54.1+0.3	IIP, Ib/c	1500	100	10
G292.2−0.5................................	IIP, Ib/c	1700	≪200	41

Chevalier 2005

Spectral shapes of three SNRs

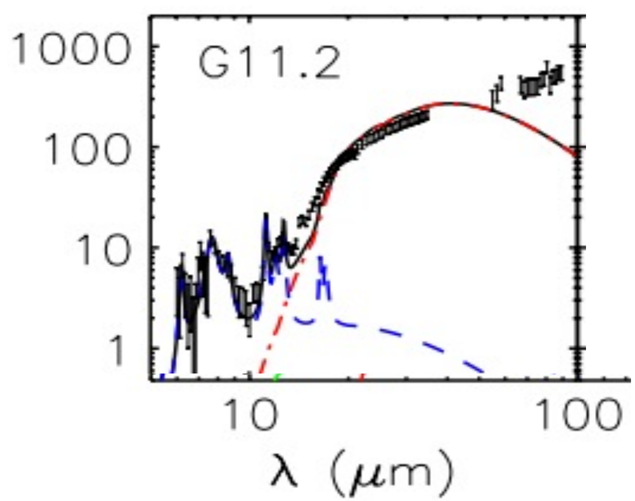
- SN Type IIL/b (Chevalier 2005)
  - Dust mass < 1M$_\odot$

Cas A



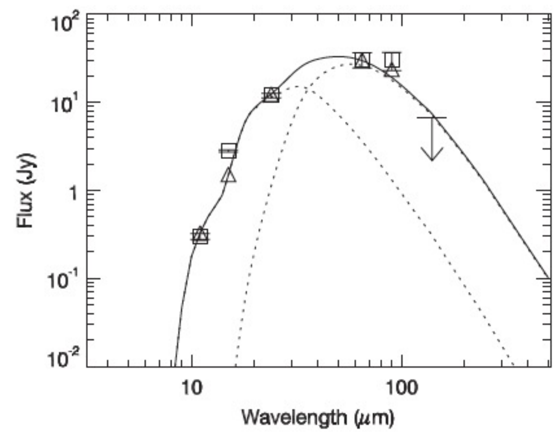
$M_{d,h}$ ~ 3 x 10^{-3} $M_\odot$, T_h ~ 99 K
(Sibthorpe et al. 2011 ;
Additional cold dust?)

G11.2-0.3



M_d ~ 8.8 x 10^{-3} $M_\odot$
(Andersen et al. 2011 ;
Background issue?)

G292.0+1.8



M_d ~ 4.8 x 10^{-2} $M_\odot$, T ~ 47 K
(Lee et al. 2009)

Dust formation?

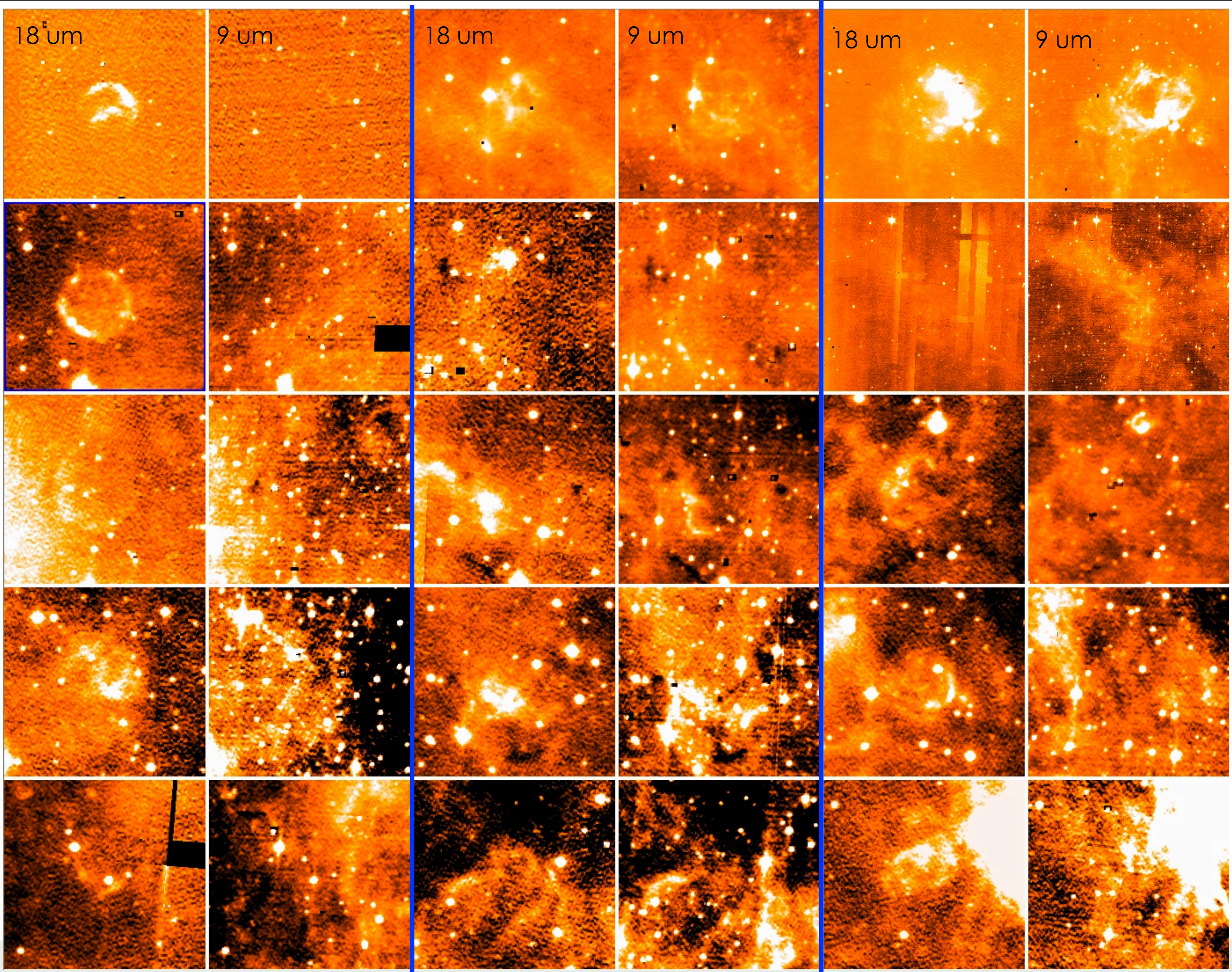
- Measured dust masses at three SNRs
  - Dust mass < $1M_{\odot}$
    - They are total dust mass !
      - Swept-up surrounding dust + ejecta dust
      - Amount of newly formed ejecta dust is small
    - Possible undetected cold dust?
      - Cannot rule out
        - In such case, dust mass can be large (e.g. > $1M_{\odot}$)

- Detecting newly formed dust in AKARI survey

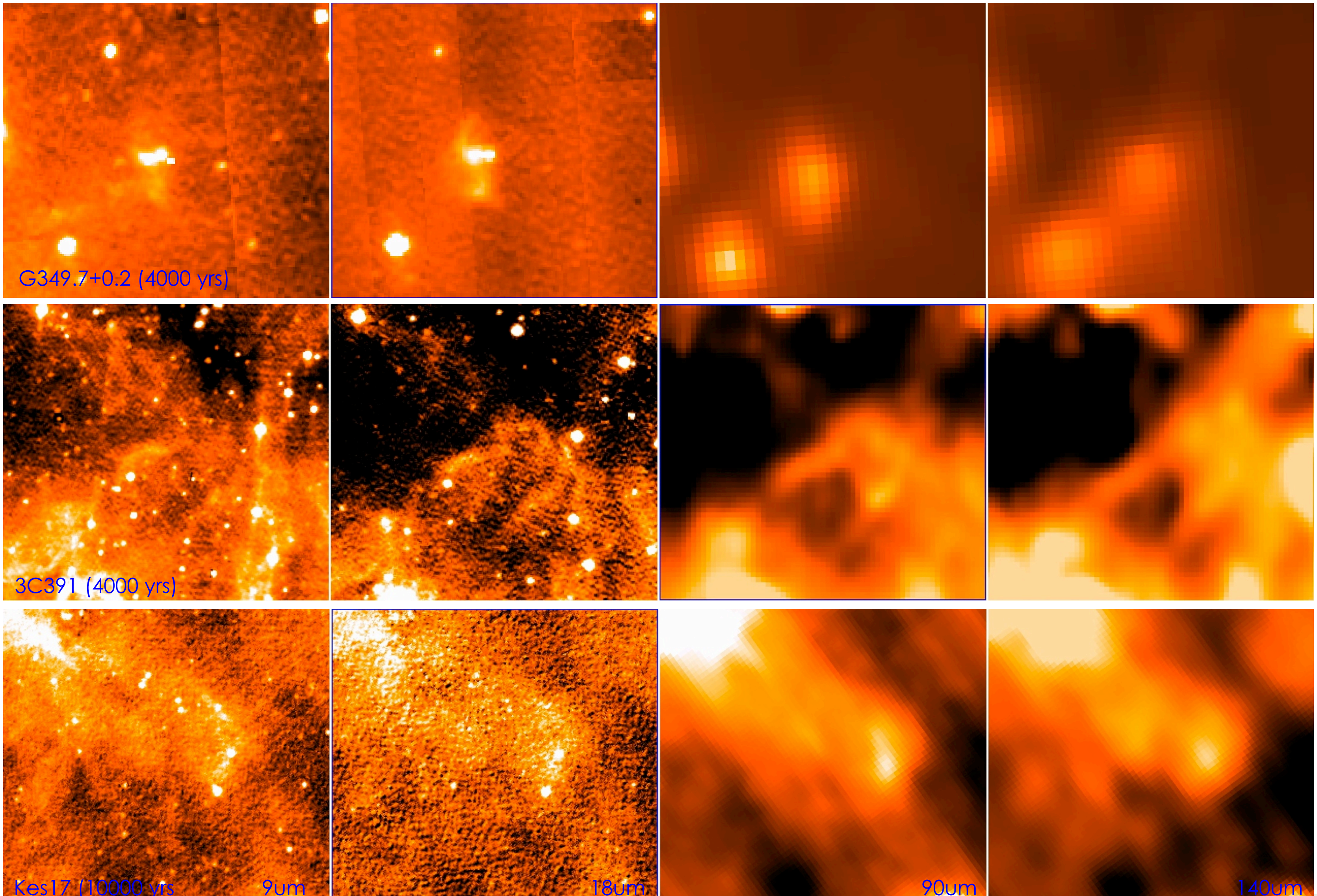
==⇒ Finding SNR which is far brighter than above three!

- If none, no dust at observed epoch of SNR evolution
  - Destruction by reverse shock (Nozawa et al. 2011)
  - SN type should be considered

MIR bright SNRs (0° < l < 40°; ~15/~100)



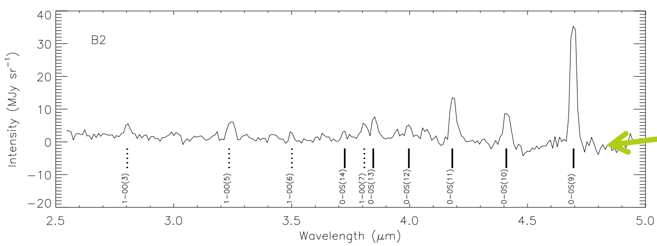
Some of them are bright at 9 & 18 um: SNRs in dense medium

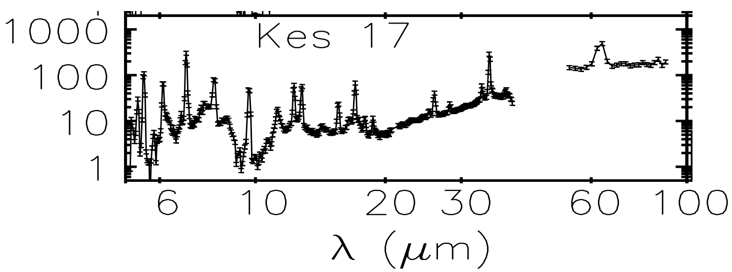


Bright at broad IR bands
(SNR interactions with dense medium are known)

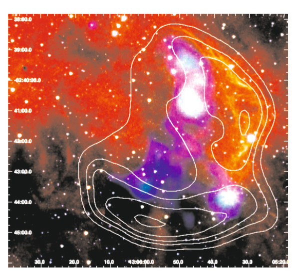
Kes17 Spitzer & AKARI observations

- Bright western shell (3-160um)

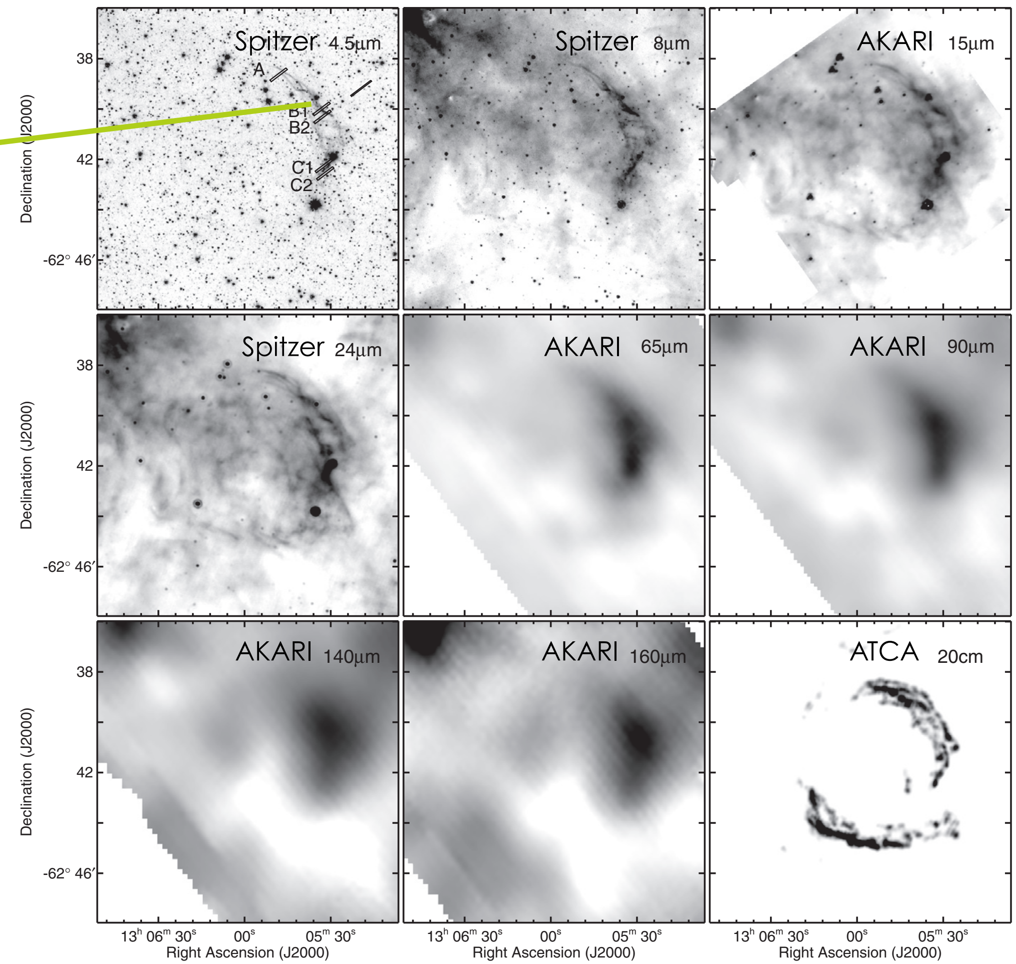




Spitzer IRS & MIPS SED spectra
(Andersen et al. 2011)

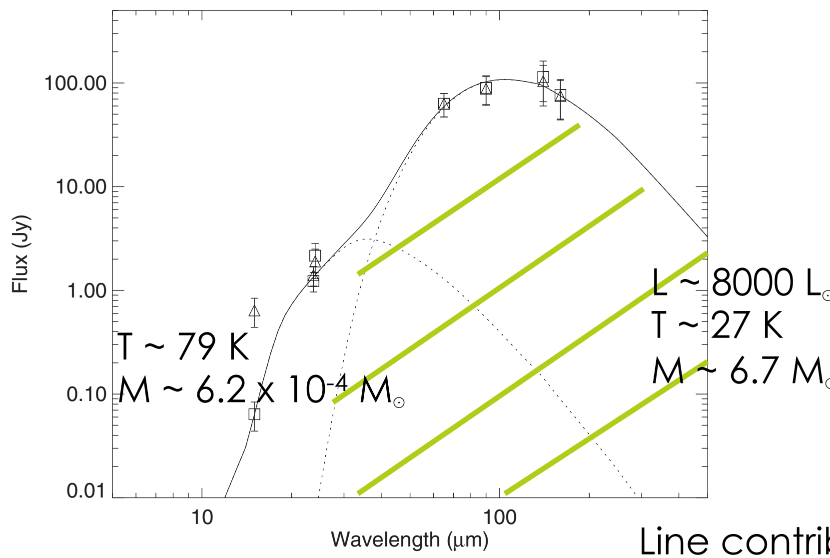


X-ray[blue] IR[red]: MMSNR
(Combi et al. 2010)



Dust in western shell

- Two Temperature modified BB fit
  - Grain: Milky way (Draine 2003)



Line contributions are subtracted using Spitzer IRS & MIPS SED spectra

- Luminous FIR emission or Large amount of dust!
  - Note: hot gas mass: 8-15 M$_\odot$ (XMM, Combi et al. 2011)

Possible origin of FIR emission

- Assuming clumpy structure
    - H_2 clump + less dense inter-clump (10^2-10^4 cm^{-3} ?)

- Shock-heated dust in swept-up inter-clump medium
    - Large grain size

$$T_{eq}(K) \approx 0.60 n_e^{0.168} a^{-0.168}(\mu m) T^{0.252}$$

$a \uparrow \Rightarrow T_d \downarrow$ (Dwek & Arendt 1992)

- Ejected dust from evaporating cloud
    - Efficiency

- Shock becomes radiative and its radiation illuminates dust
    - Southern shell

Summary

- SNRs in AKARI all sky survey
- Three young SNRs
  - SN type IIL/b
    - Small amount of dust
    - If newly formed dust exists, such SNR may be bright even in AKARI survey in general !
- SNRs in dense medium
  - Bright IR emission
    - Bright at 9 and 18 um
  - Mechanism of bright FIR is unclear
    - If shock-excited, it suggests large grain size