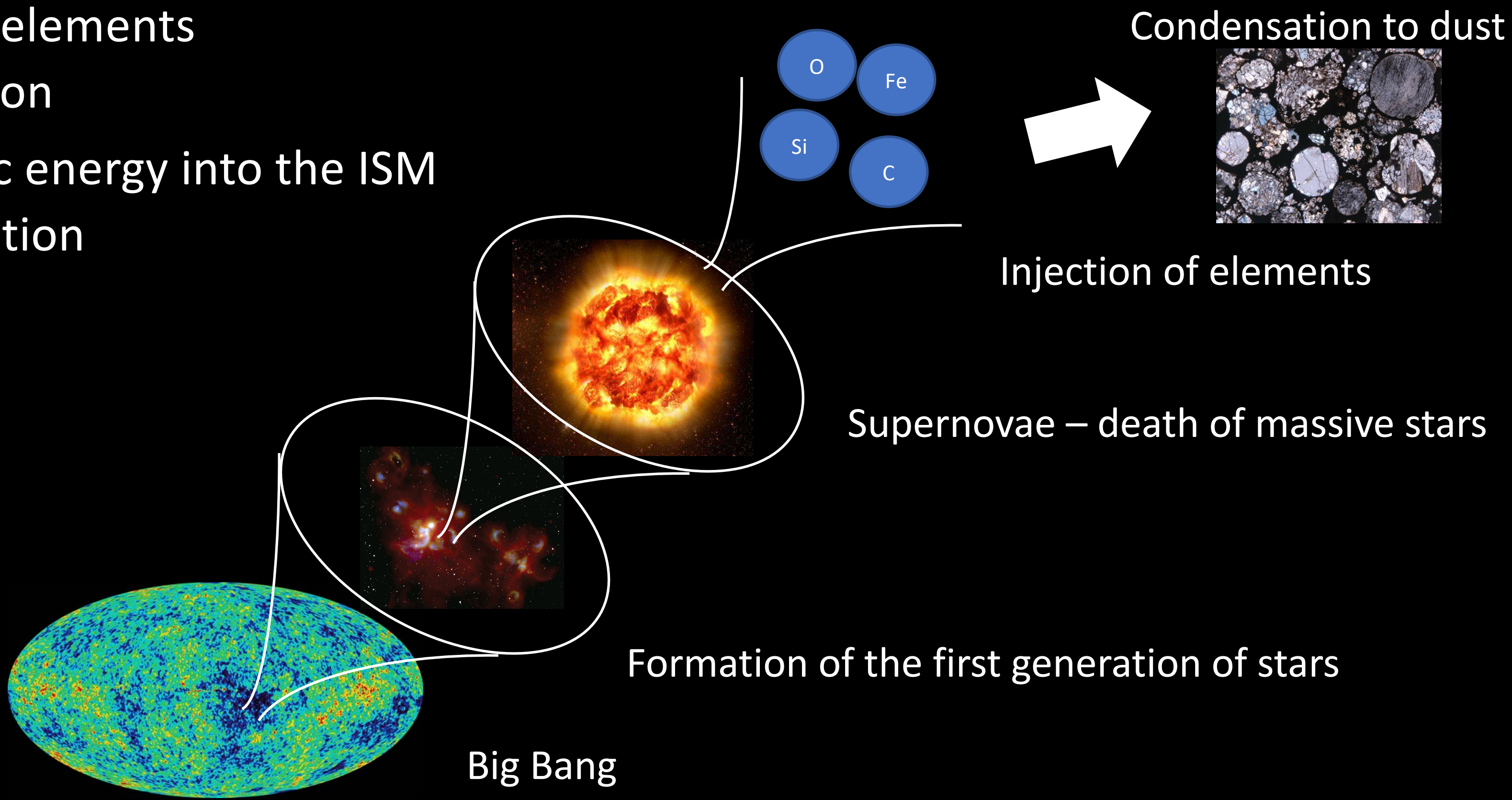
Supernovae and supernova remnants

Mikako Matsuura (Cardiff University)

Why are SNe & SNRs important?

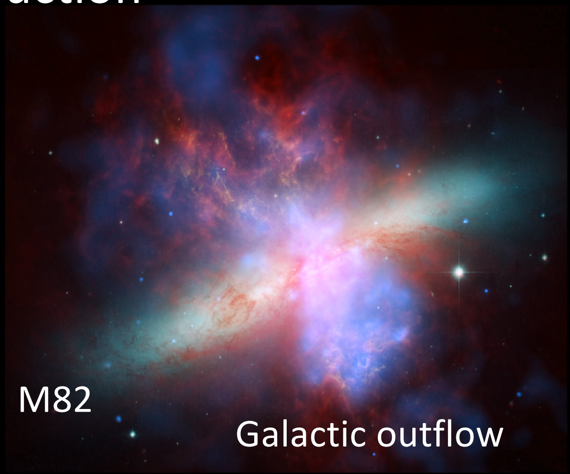
- Synthase heavy elements
  - dust formation
- Source of kinetic energy into the ISM
  - dust destruction

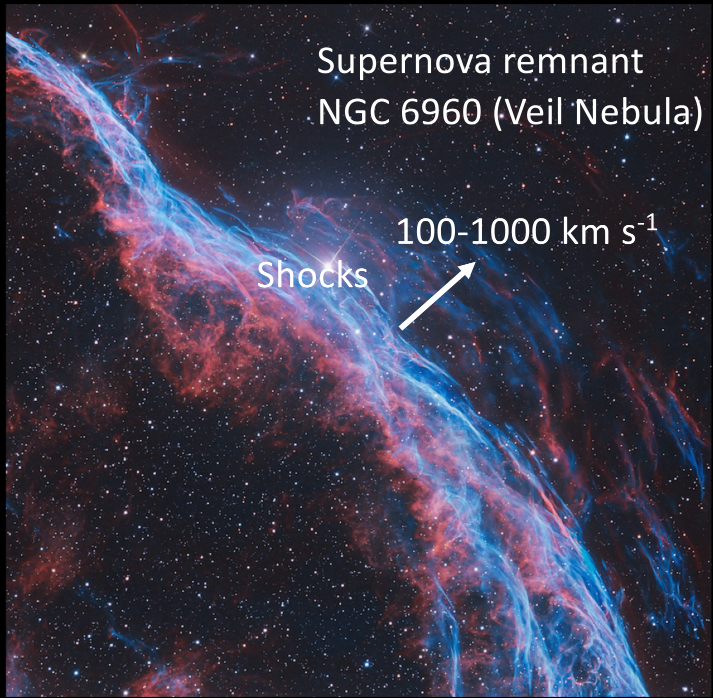
Path to the first dust in the Universe



Why are SNe & SNRs important?

- Synthase heavy elements
  - dust formation
- Source of kinetic energy into the ISM
  - dust destruction



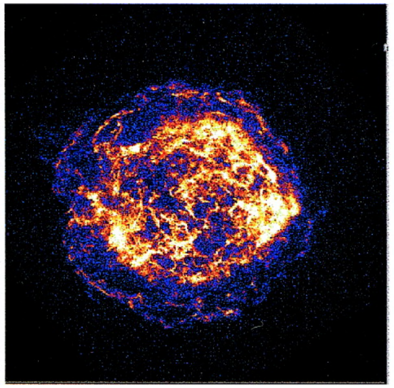


Key questions

- Are supernovae & supernova remnants dust producer or destroyer?
  - If dust producer:
    - What is the net dust mass?
    - What types of dust grains are formed?
  - If destroyer:
    - How efficient?
    - How does affect grain size distributions?

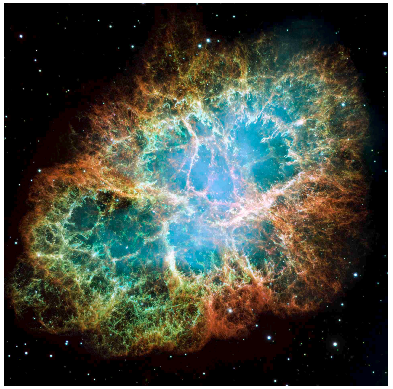
It is getting clear that SNe form substantial mass of dust using newly synthesized elements

Cassiopeia A (AD 1681?)



0.1-0.5 $M_\odot$

Crab Nebula (AD 1054)

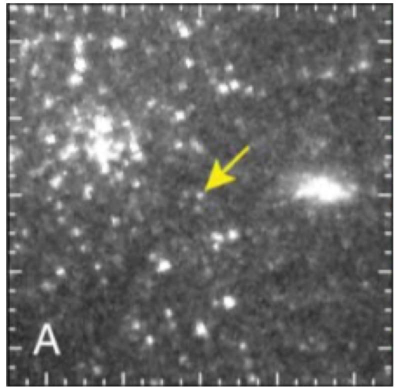


0.03-0.05 $M_\odot$

Supernova 1987A

~0.5 $M_\odot$

SNe in nearby galaxies

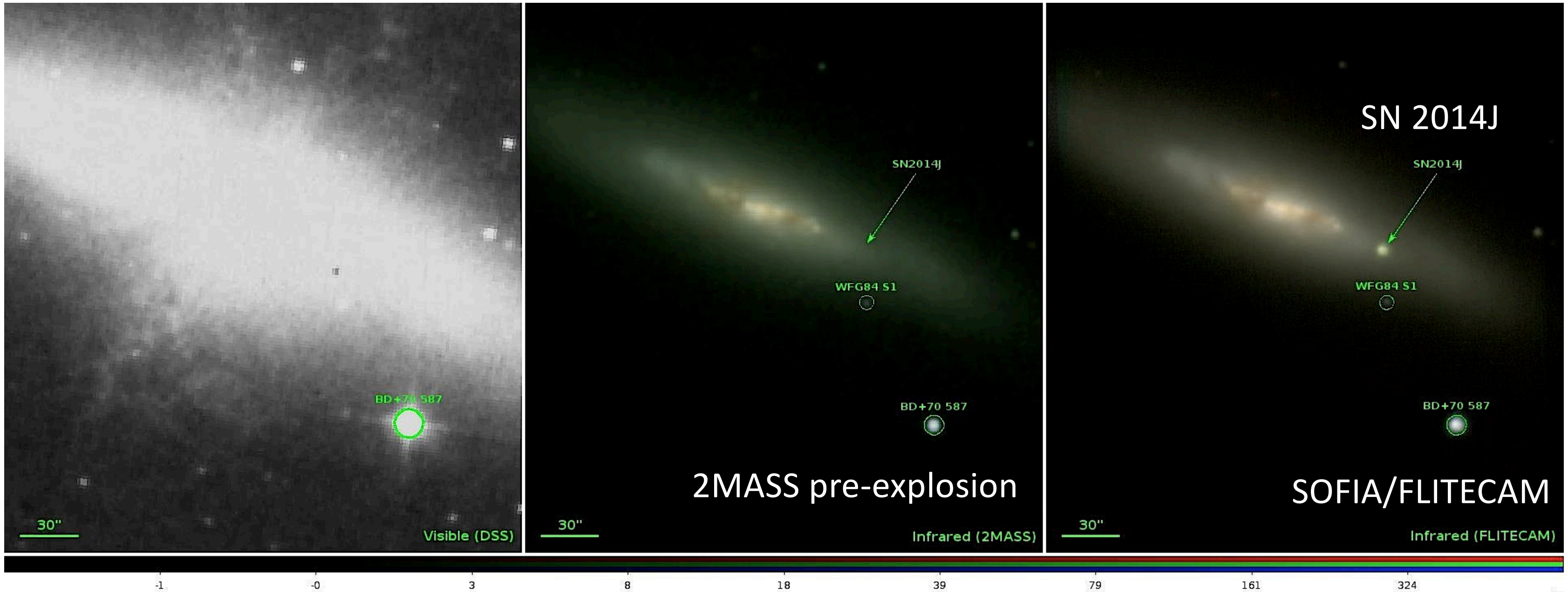


0.0001–0.02 $M_\odot$?

IR dust observations: only ~10 SNe + SNRs

e.g. Sugerman et al. (2006), Matsuura et al. (2015), De Looze et al. (2017; 2019)

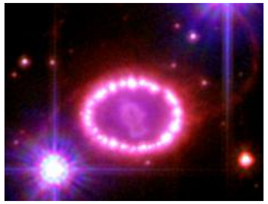
Target opportunity – extra-galactic SNe

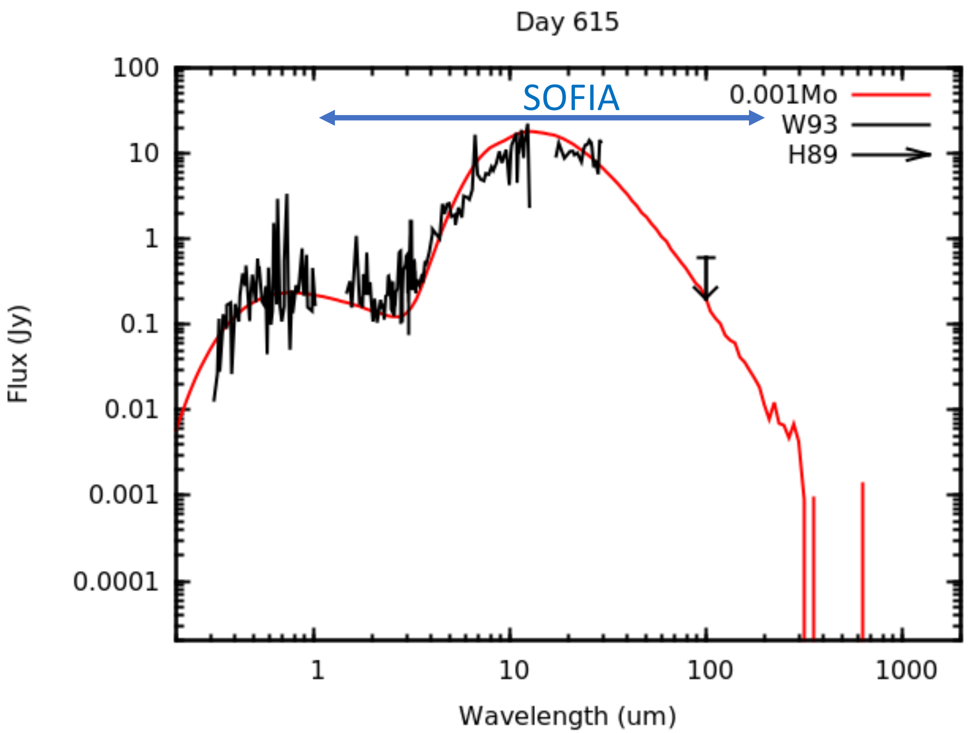


SOFIA observations of SN 2014J in M82 – unfortunately no dust

Template for extragalactic SNe – Time evolution of SN 1987A

SN 1987A (50kpc)



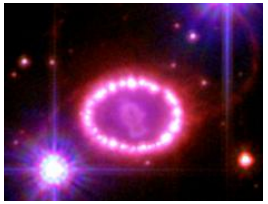


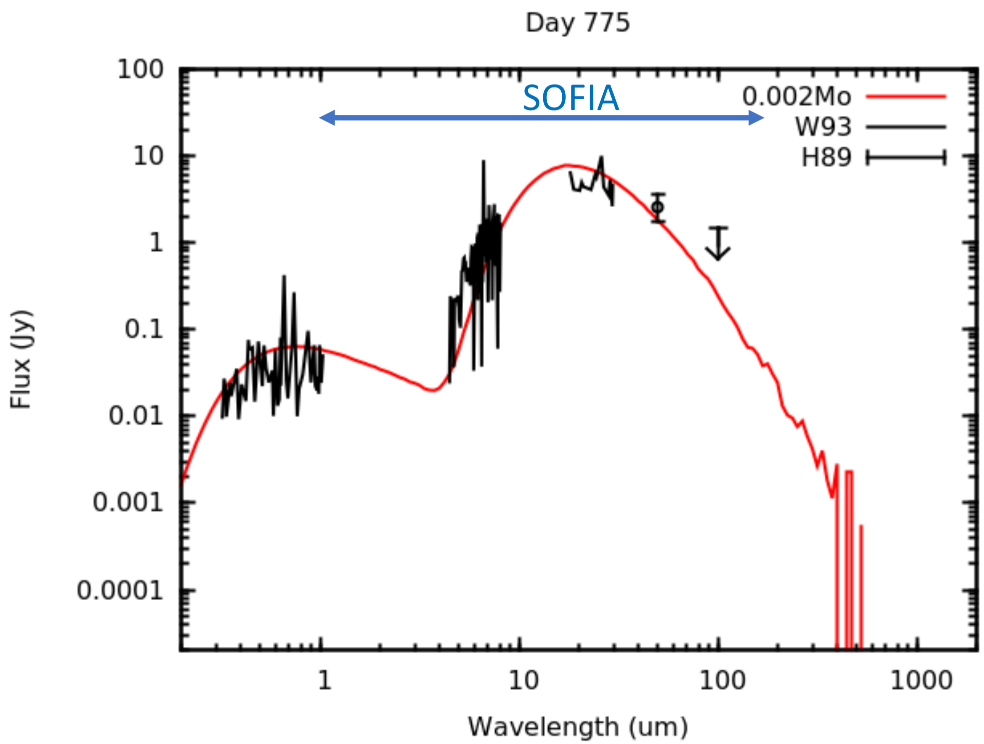
- The peak of SED shifted to longer wavelength in time
- The inferred mass increases in time?
    - 0.001 $M_{\odot}$ at day 615

Harvey et al. (1989), Wooden et al. (1993), Bouchet & Danziger (1993),Wesson et al. (2015)

Template for extragalactic SNe – Time evolution of SN 1987A

SN 1987A (50kpc)



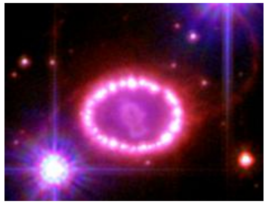


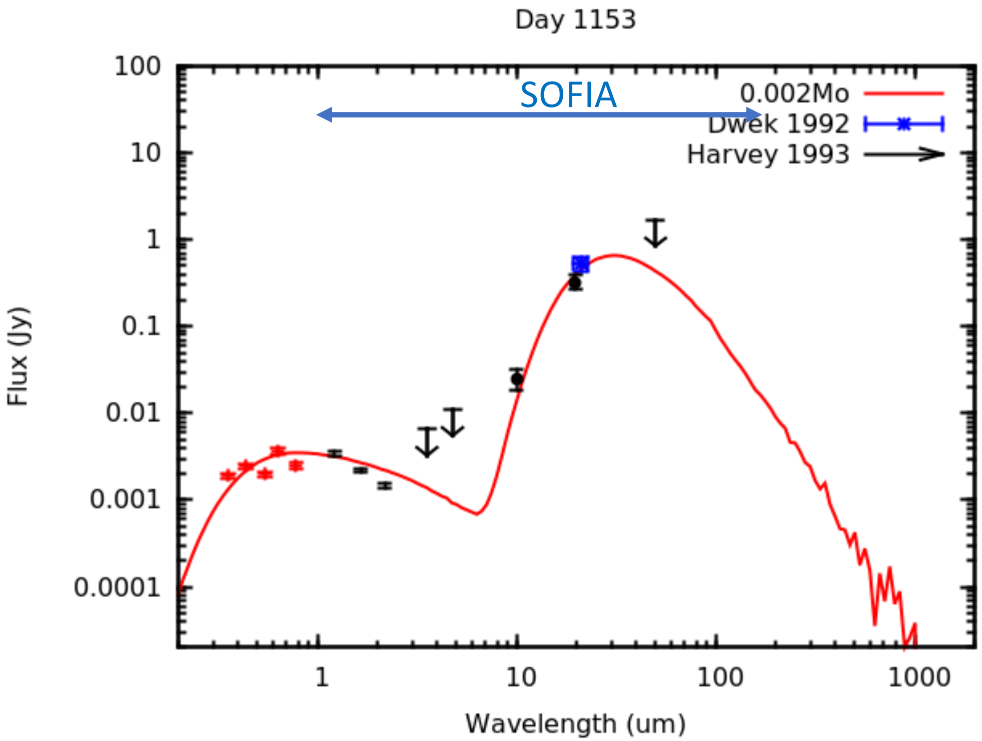
- The peak of SED shifted to longer wavelength in time
- The inferred mass increases in time?
  - 0.001 $M_{\odot}$ at day 615
  - 0.002 $M_{\odot}$ at day 775

Harvey et al. (1989), Wooden et al. (1993), Bouchet & Danziger (1993),Wesson et al. (2015)

Template for extragalactic SNe – Time evolution of SN 1987A

SN 1987A (50kpc)



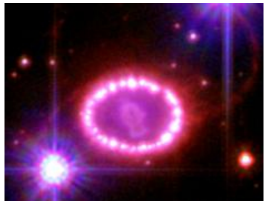


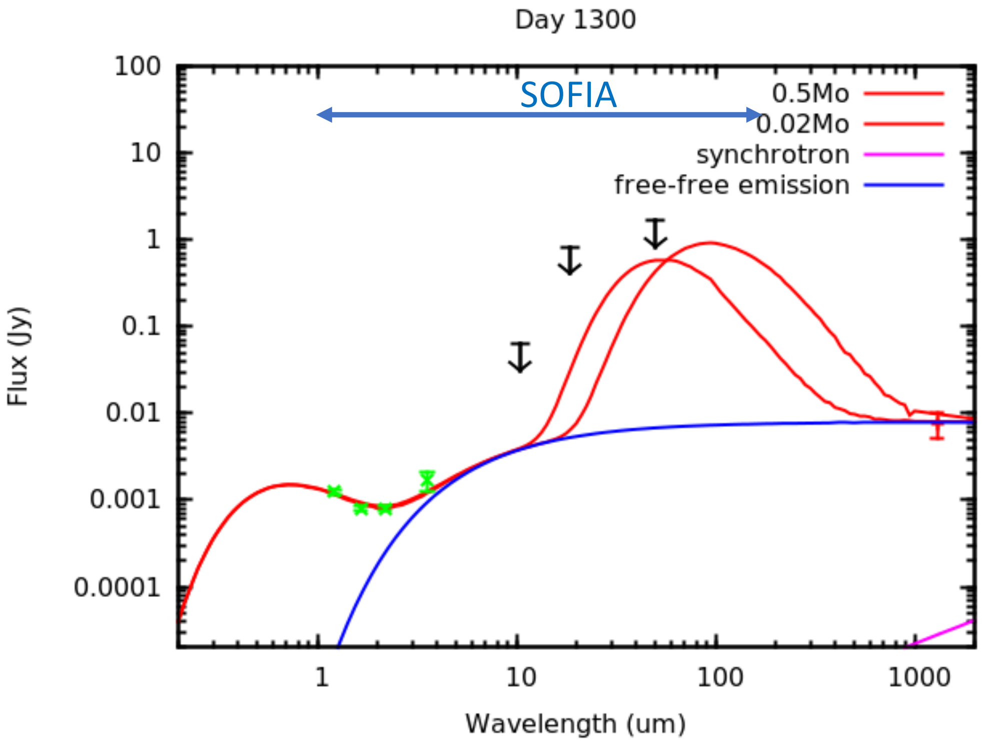
- The peak of SED shifted to longer wavelength in time
- The inferred mass increases in time?
  - 0.001 $M_\odot$ at day 615
  - 0.003 $M_\odot$ at day 1153

Harvey et al. (1989), Wooden et al. (1993), Bouchet & Danziger (1993),Wesson et al. (2015)

Template for extragalactic SNe – Time evolution of SN 1987A

SN 1987A (50kpc)



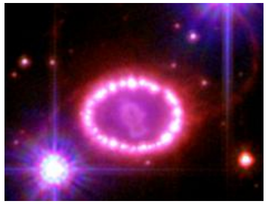


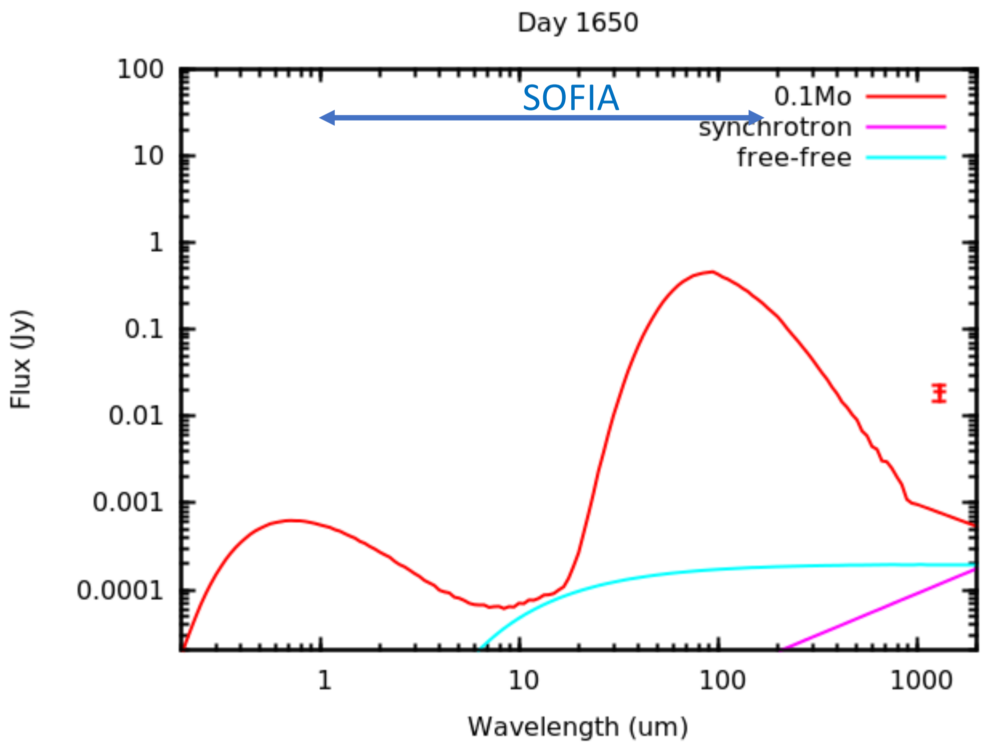
- The peak of SED shifted to longer wavelength in time
- The inferred mass increases in time?
  - 0.001 $M_\odot$ at day 615
  - 0.6 $M_\odot$ at day 8515

Harvey et al. (1989), Wooden et al. (1993), Bouchet & Danziger (1993),Wesson et al. (2015)

Template for extragalactic SNe – Time evolution of SN 1987A

SN 1987A (50kpc)





- The peak of SED shifted to longer wavelength in time
- The inferred mass increases in time?
  - 0.001 $M_\odot$ at day 615

Harvey et al. (1989), Wooden et al. (1993), Bouchet & Danziger (1993),Wesson et al. (2015)

But can SN dust survive the impact of reverse shock?

Theoretical models	Dust destruction rate %
Reverse shocks	
Nozawa et al (2007)	100
	45
Bianchi and Schneider (2007)	97
Nath et al (2008)	1
Silvia et al (2012)	4–56
	5–93
Micelotta et al (2016)	20
	50

Micellotta et al. (2018)

Unique opportunity to witness SN dust – reverse shock encounter

SN 1987A

Located at the Large Magellanic Cloud (LMC) – 50 kpc away

Nearest SN explosion in 400 years

Time evolution of SN 1987A ejecta + circumstellar ring (red supergiant material)

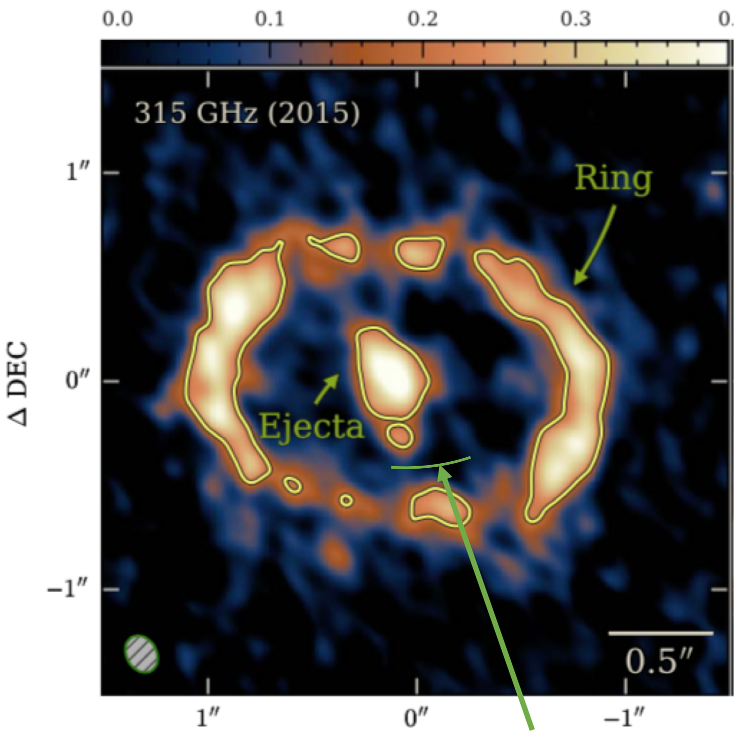
HST Hα

France et al. (2010); Fransson et al. (2013)

Unique opportunity to witness SN dust – reverse shock encounter

SN 1987A

ALMA dust

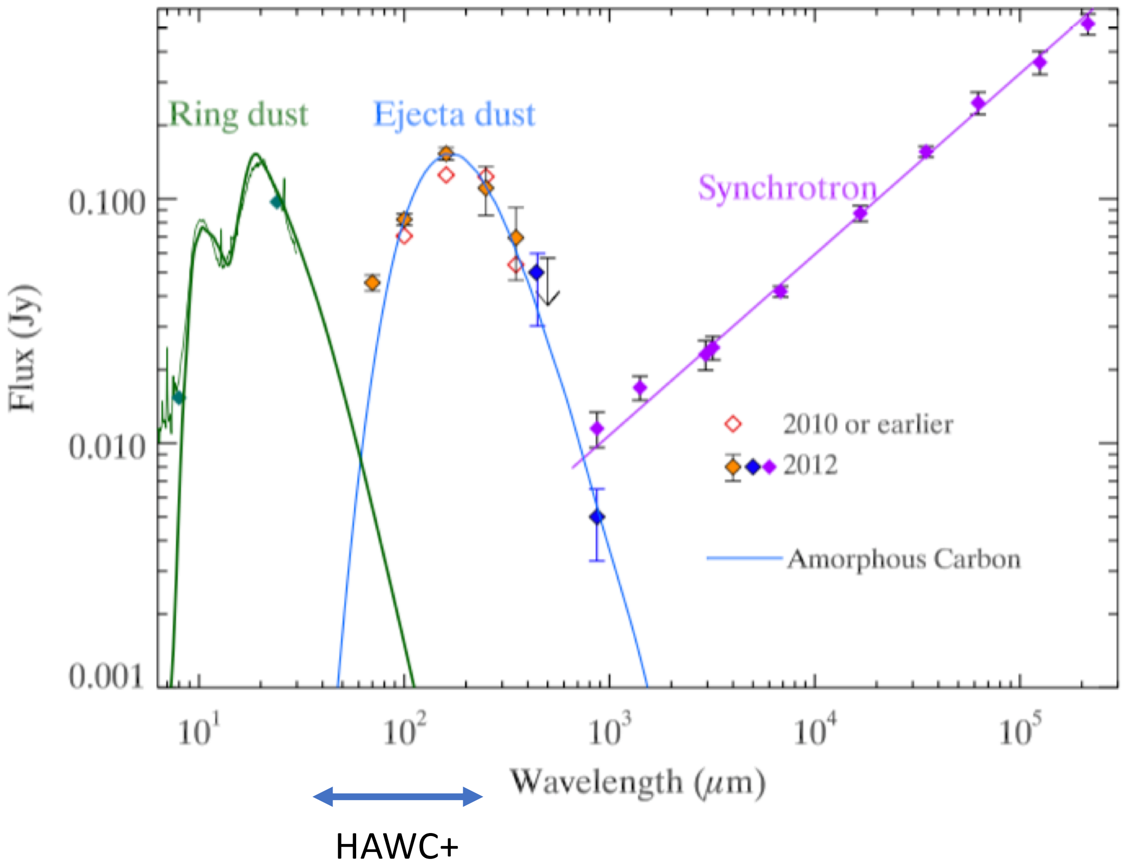


Reverse shock (in 2003)

With a speed of ~1000-5000 km s^{-1} (0.003-0.02 arcsec per year) in projected velocity, the reverse shock should have hit ejecta dust

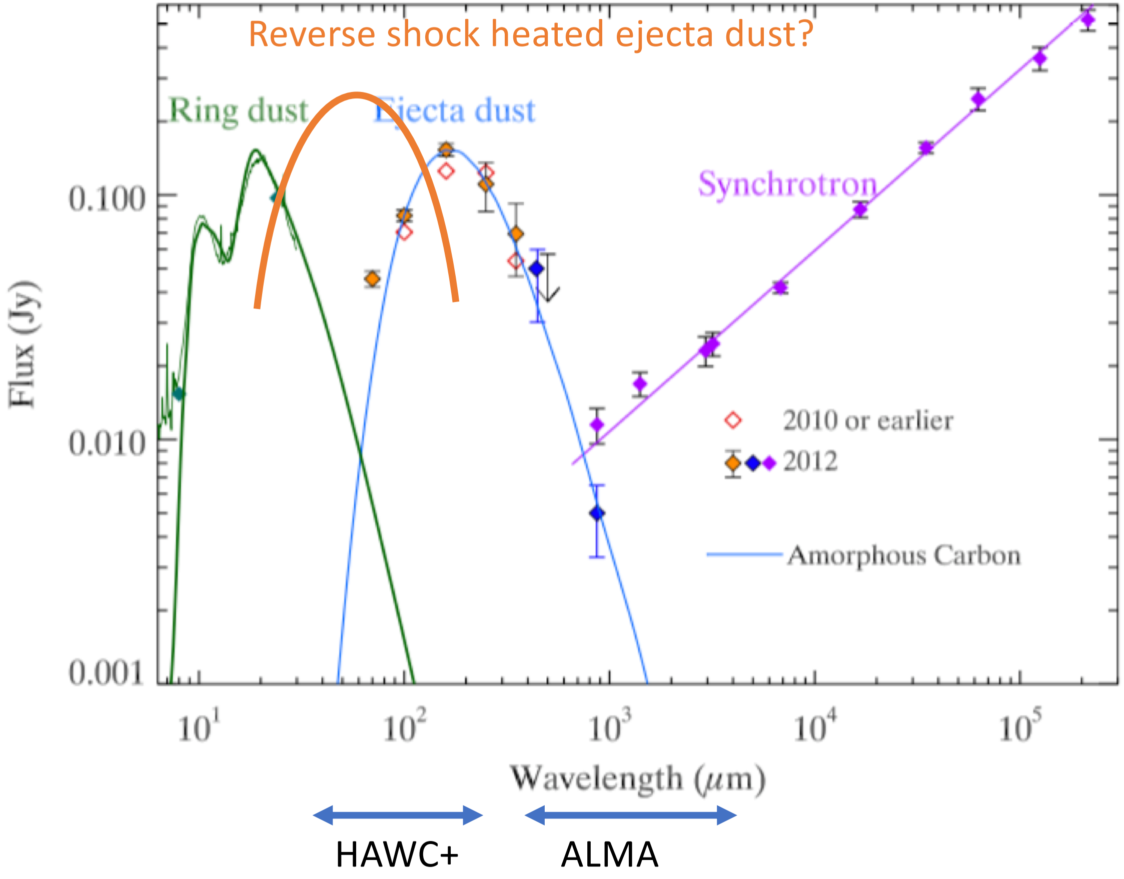
Cigan et al. (2019)

Only SOIFA (+JWST?) can observe this historical event



Detecting any change in the temperature of FIR ejecta dust requires SOFIA HAWC+ upgrade

Only SOIFA (+JWST?) can observe this historical event

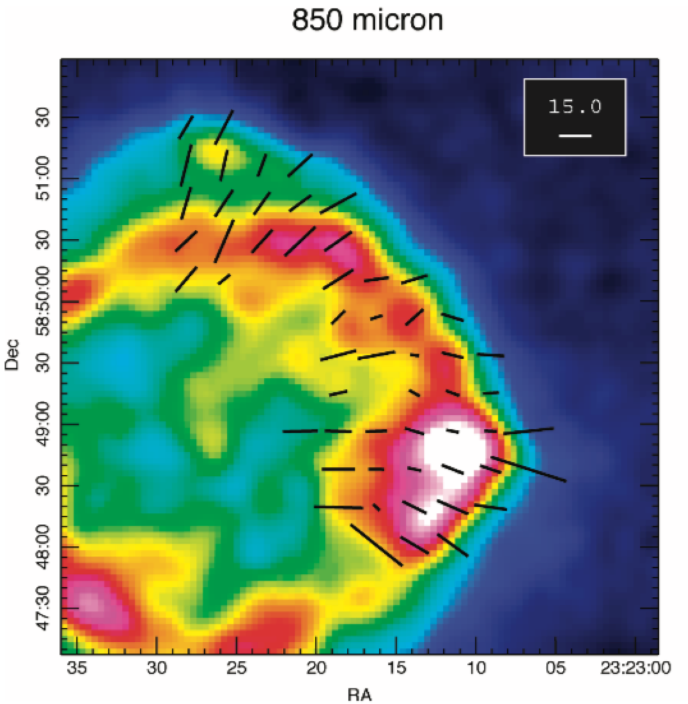


Detecting any change in the temperature of FIR ejecta dust requires SOFIA HAWC+ upgrade

FORCAST will retire by that time? JWST?

What types of grains can be formed or survived?

Polarization of SNR Cassiopeia A



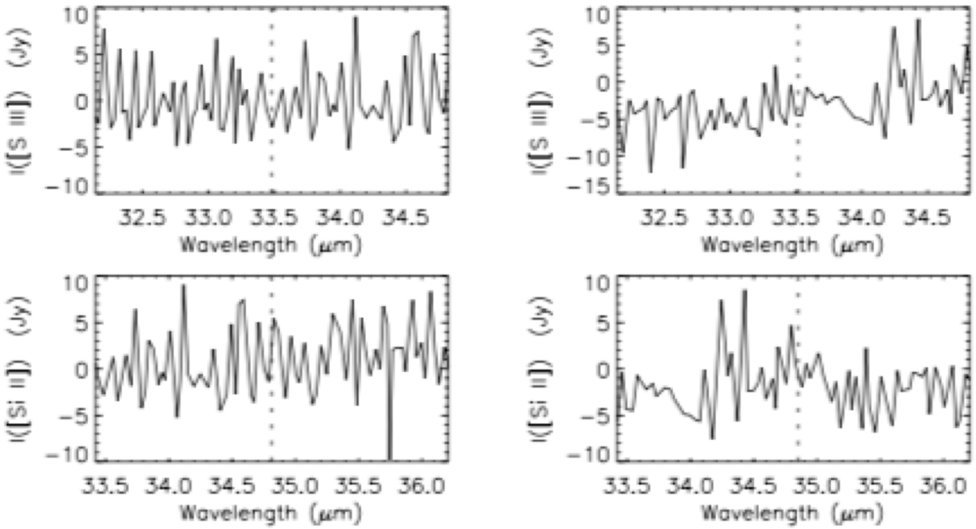
Dunn et al. (2009)

HAWC+ upgrade enables to study more SNRs than Cassiopeia A (Crab Nebula, Tycho, Kepler)

What is the cooling of SNRs?

Theoretical prediction for SN 1987A
-> and other SNRs, such as Cas A?

These important cooling lines fall into the gap between Herschel PACS (>55 μm) and JWST MIRI (<28 μm) -> FIFL-LS extension to 43 μm



ISO/SWS spectra of Cassiopeia A (Arendt et al. 1999)

Table 4. Dominant cooling transitions for each zone. (SN1987A)

Zone	Cooler	Fraction
Fe/He	[Fe II] 25.99 μm	94%
	[Fe II] 14.98 μm*	5%
	[Fe I] 24.04 μm	1.5%
Si/S	[Si I] 68.47 μm	63%
	[Si I] 44.81 μm	22%
	[Si I] 129.68 μm	15%
O/Si/S	[O I] 63.19 μm	35%
	[Si I] 68.47 μm	32%
	[O I] 44.06 μm*	17%
O/Ne/Mg	[O I] 44.06 μm	33%
	[O I] 63.19 μm	29%
	[Si I] 68.47 μm	16%
O/C	[O I] 63.19 μm	41%
	[O I] 44.06 μm*	40%
	[Si I] 129.68 μm	7%
He (core)	[Fe II] 25.99 μm	46%
	[Si I] 68.47 μm	23%
	[Si II] 34.81 μm	16%
H (core)	[Si II] 34.81 μm	59%
	[O I] 63.19 μm	19%
	[Fe II] 25.99 μm	15%

Jerkstrand et al. (2011)

Near future opportunities of SOFIA

- Dust production and destruction by SNe and SNRs
- Dust compositions
- Cooling lines