DUST IN SUPERNOVAE AND SUPERNOVA REMNANTS

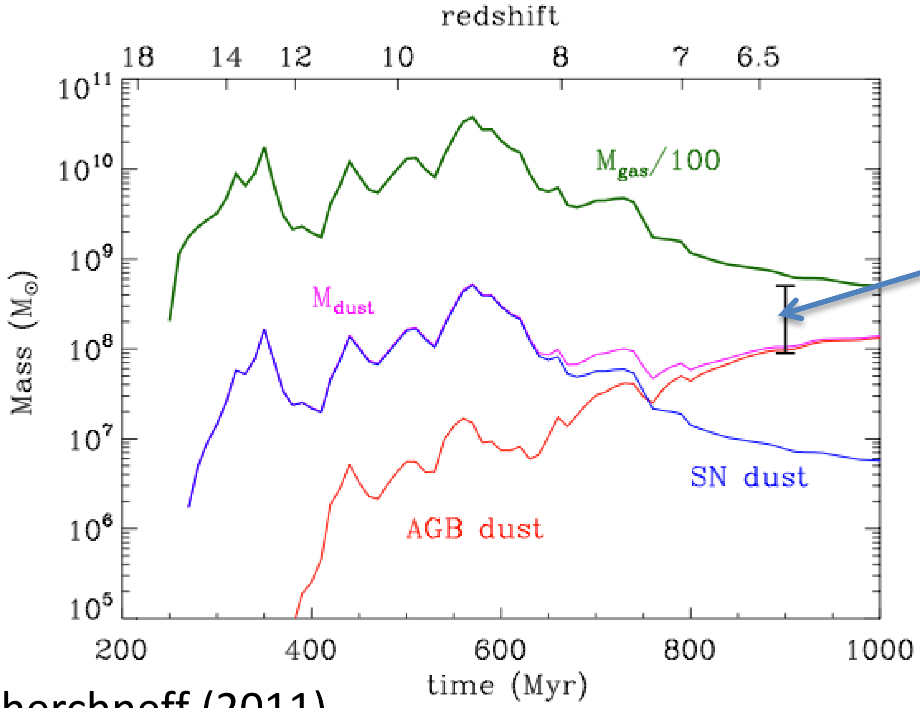
Mikako Matsuura (Cardiff University)

Supernovae and supernova remnants in the local galaxies (and the Milky Way)

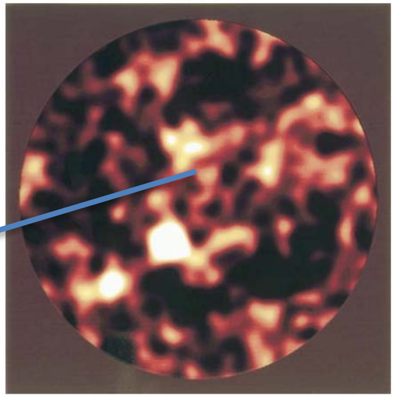
- Physics and chemistry of supernovae (SNe) / SN remnants (SNRs)
  - Dust formation
    - Dust mass
    - Dust composition
    - Chemical processes leading to dust formation
  - Nuclear synthesis / stellar yields
- Role of SNe on galaxy evolution
  - Chemical enrichment (elements + dust)
  - Star-formation trigger
  - Galactic outflow

Q: What are the major sources of dust in galaxies?

– Stellar origin (Core collapse SNe + AGB stars)



Dwek & Cherchneff (2011)

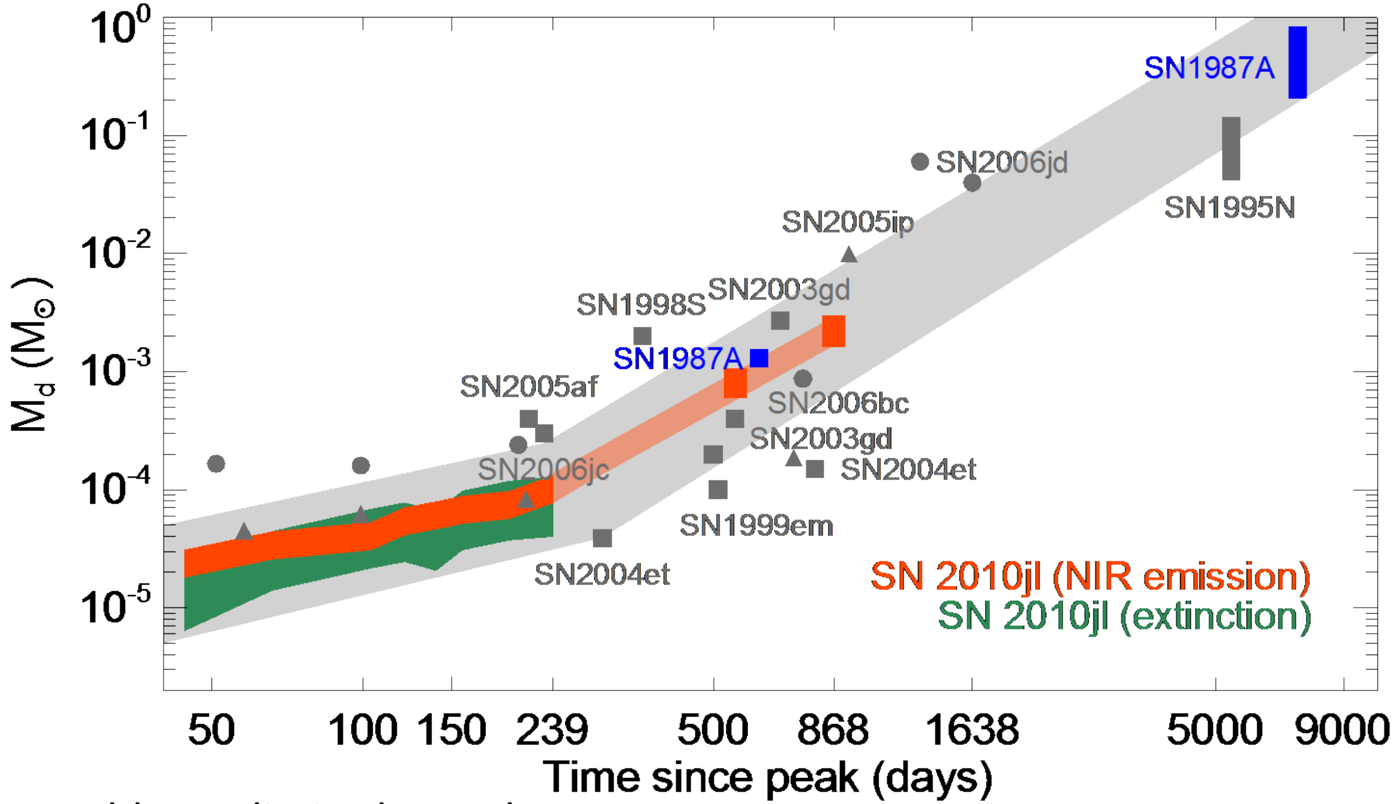


Submm galaxy
At z~6.4; ~0.4 Giga years
(e.g. Bertoldi et al. 2003)

Theoretical prediction: 0.1-1 Msun of dust per SN

Q. What are dust masses formed in supernovae?

Gall et al. (2014, Nature 511, 326)

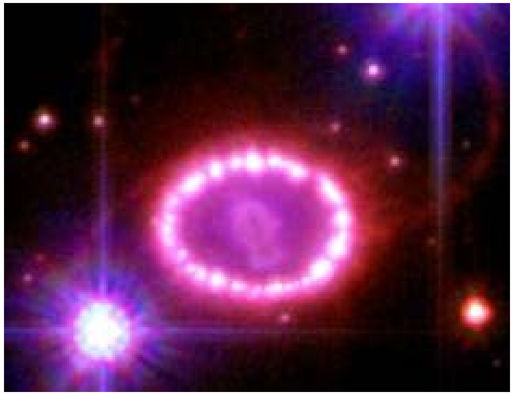


Current problem – limited sample

Time evolution of dust mass is largely unknown

Herschel detection of SN 1987A is the only dust measurements at late phase

Dust in SNe largely relies on one object – SN 1987A



LMC (50 kpc)

A large gap in the observed phases

- 450-777 days
- 10^{-4} $M_{\odot}$ of dust
- ~300-400 K
- MIR (Kuiper)

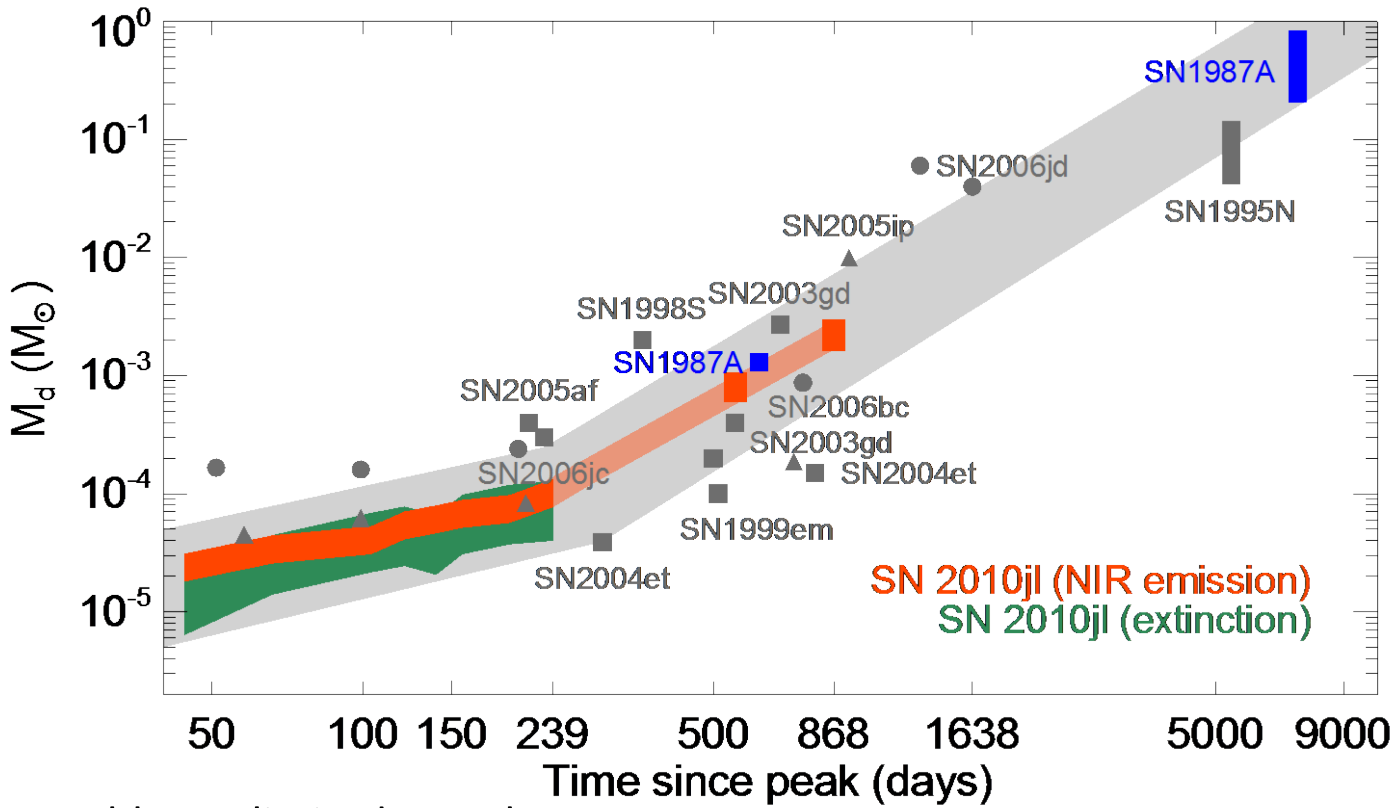
Wooden et al. (1993, ApJS 88, 477)

- 8500 days after the explosion
- 0.4-0.7 $M_{\odot}$ of dust
- ~17-25K
- FIR (Herschel / HERITAGE)

Matsuura et al. (2011, Science 333, 1258)

Q. What are dust masses formed in supernovae?

Gall et al. (2014, Nature 511, 326)



Current problem – limited sample

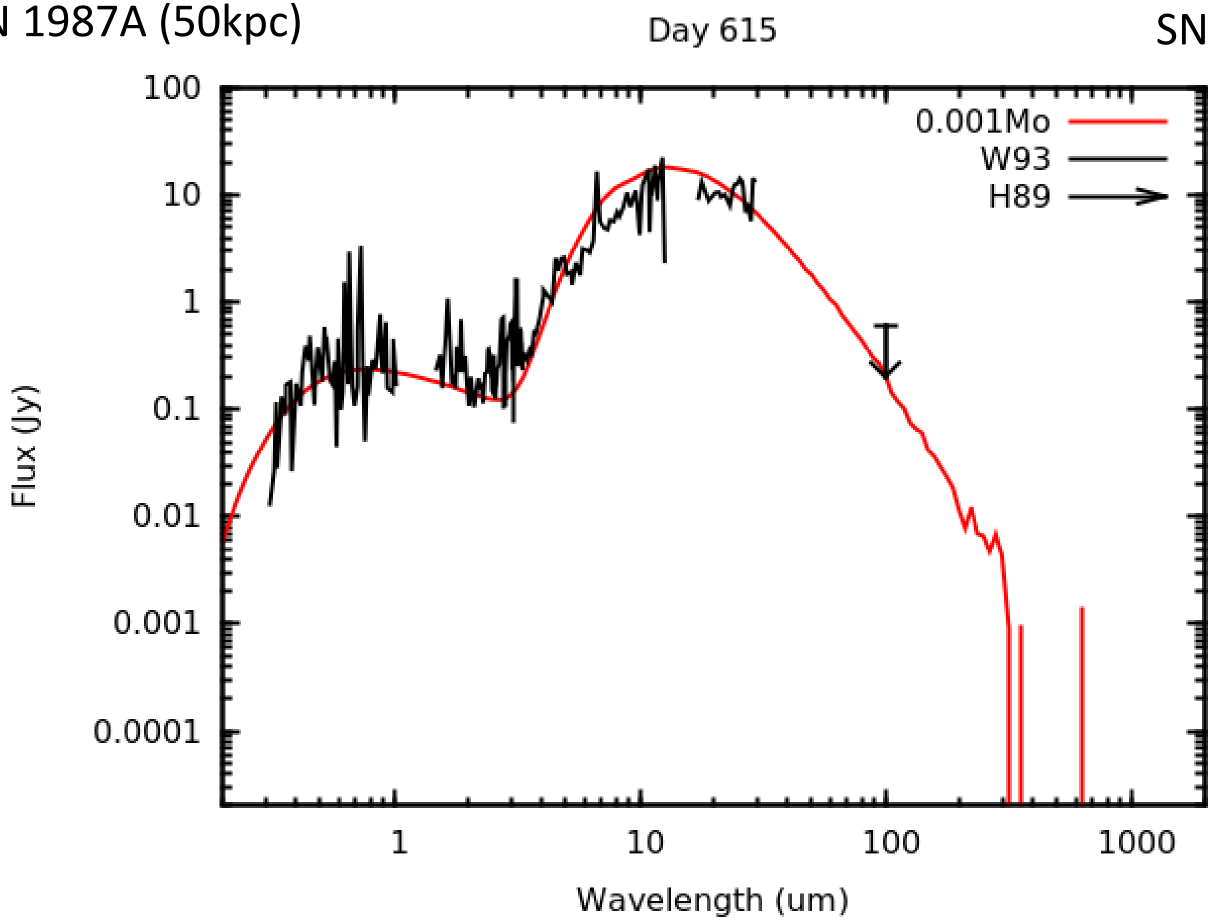
Time evolution of dust mass is largely unknown

Herschel detection of SN 1987A is the only dust measurements at late phase

Time evolution of the SED

SN 1987A (50kpc)

SN at 5 Mpc



1 mJy

0.1 mJy

0.01 mJy

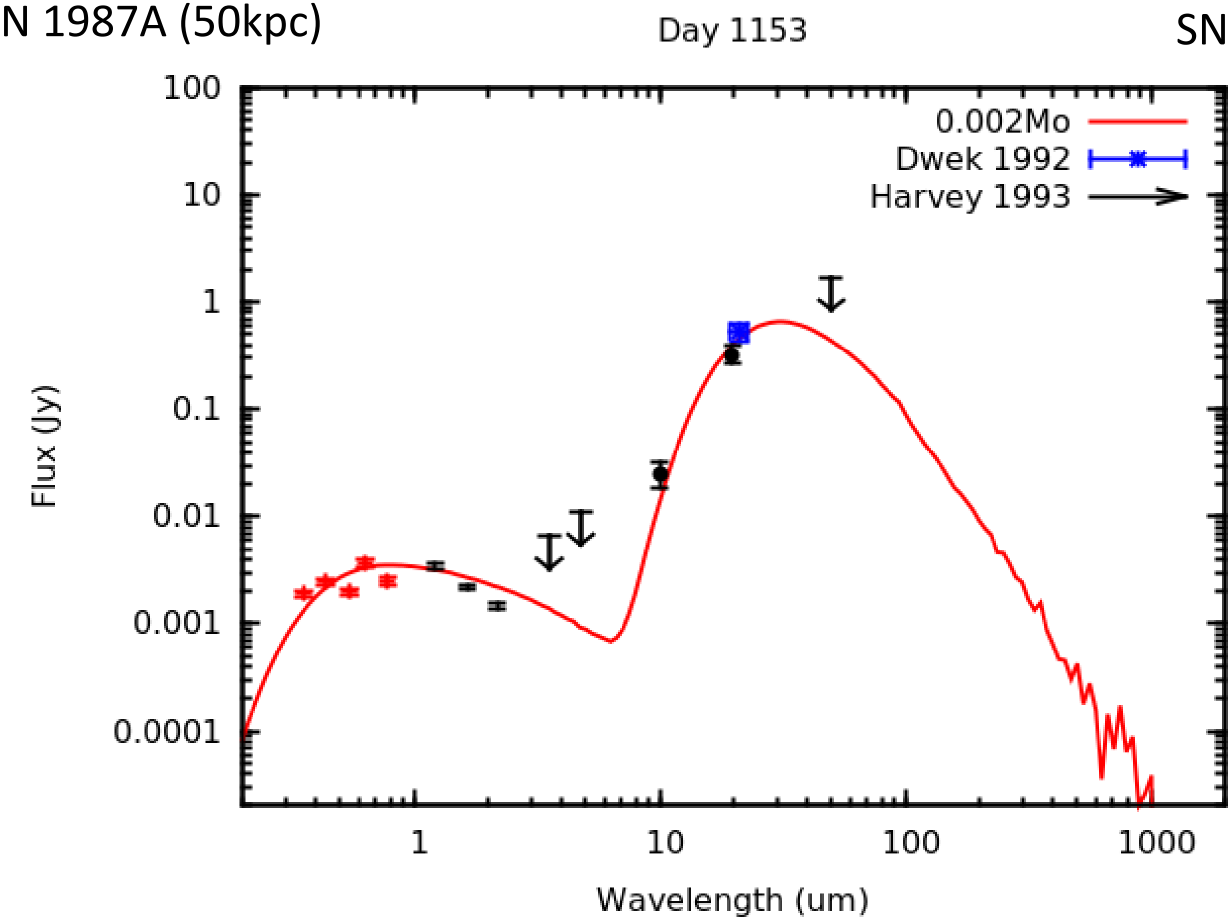
The peak of SED shifted to longer wavelength in time

Wesson et al. (2014)

Time evolution of the SED

SN 1987A (50kpc)

SN at 5 Mpc



1 mJy

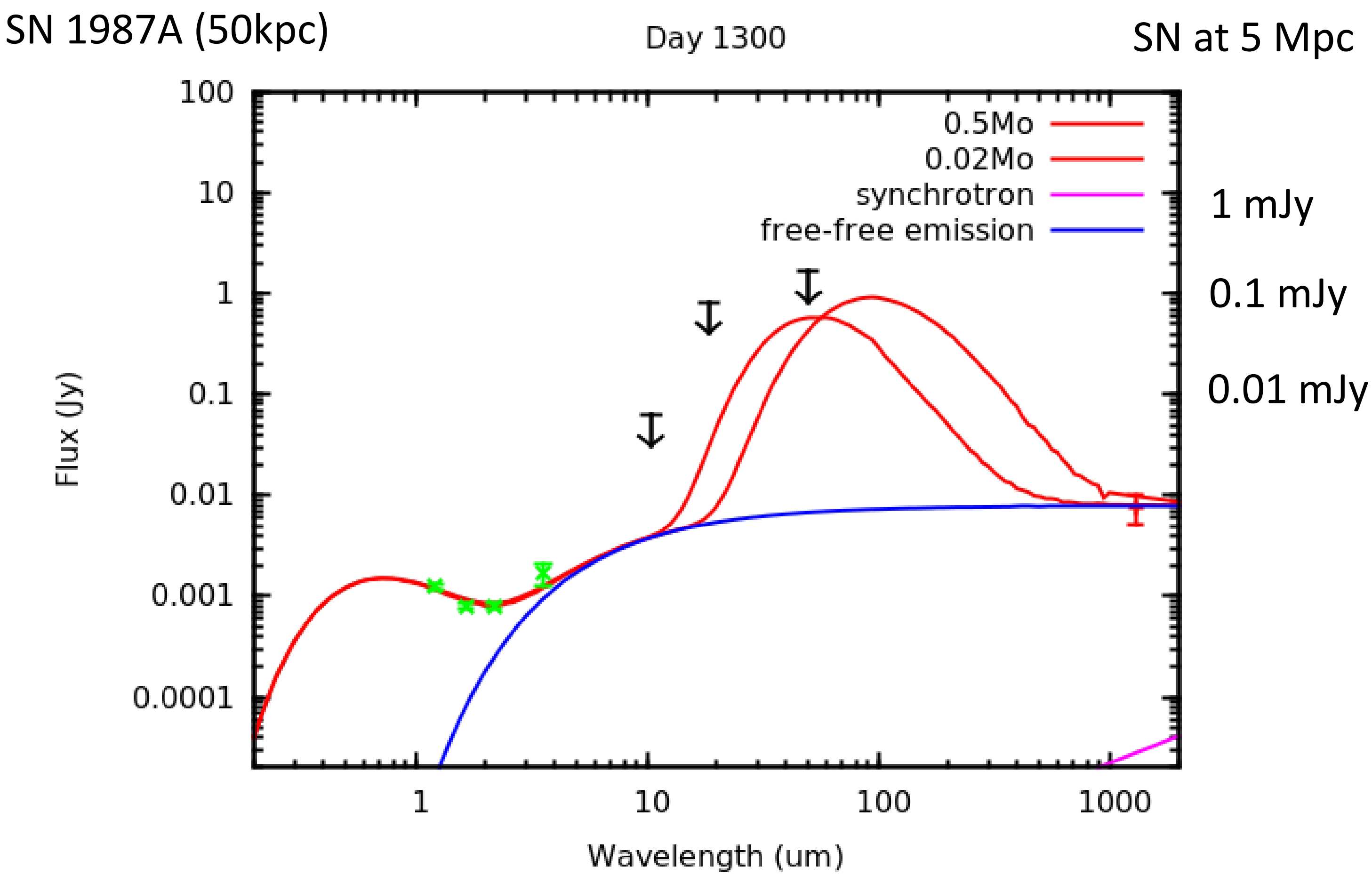
0.1 mJy

0.01 mJy

The peak of SED shifted to longer wavelength in time

Wesson et al. (2014)

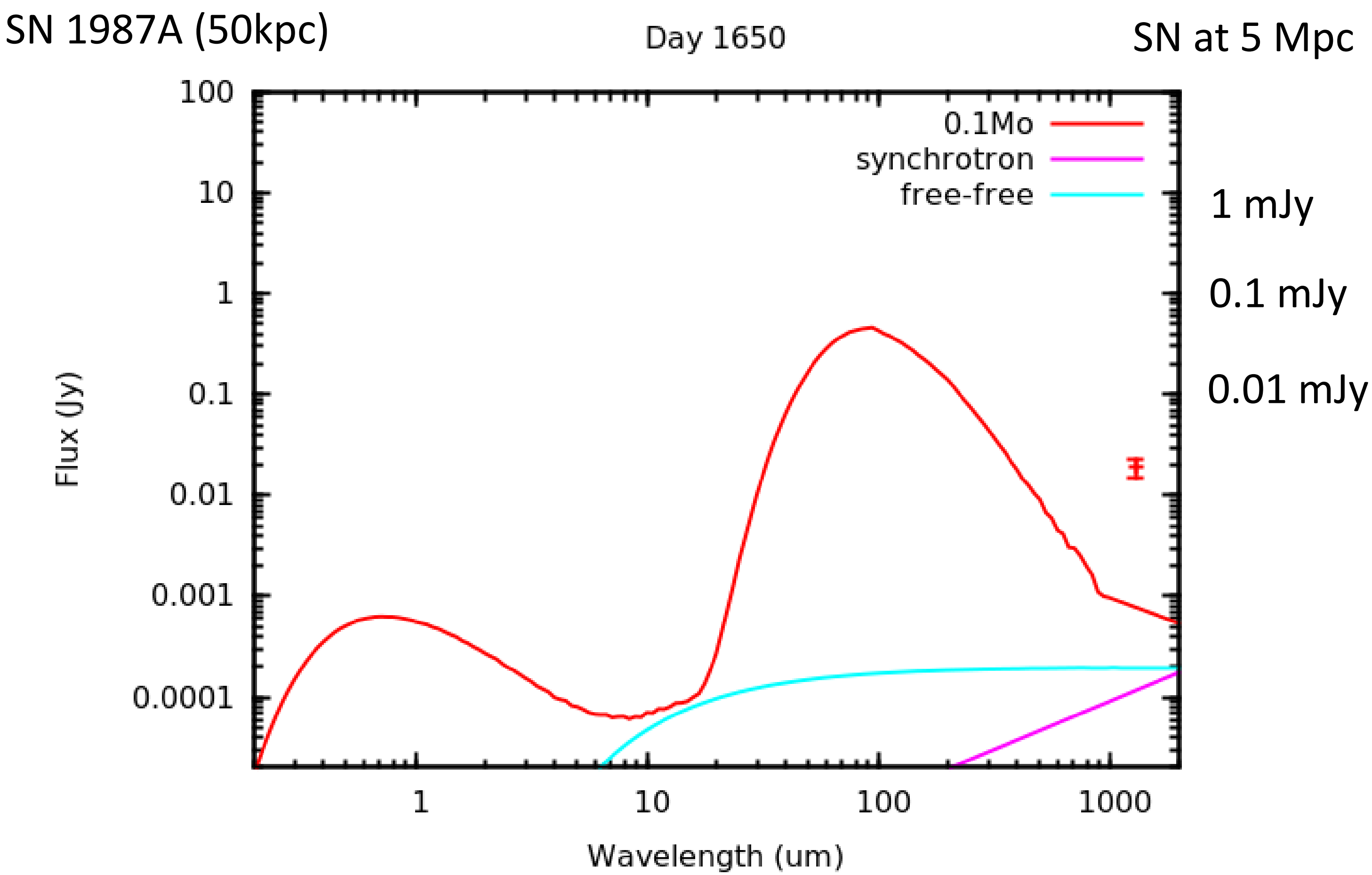
Time evolution of the SED



The peak of SED shifted to longer wavelength in time

Wesson et al. (2014)

Time evolution of the SED



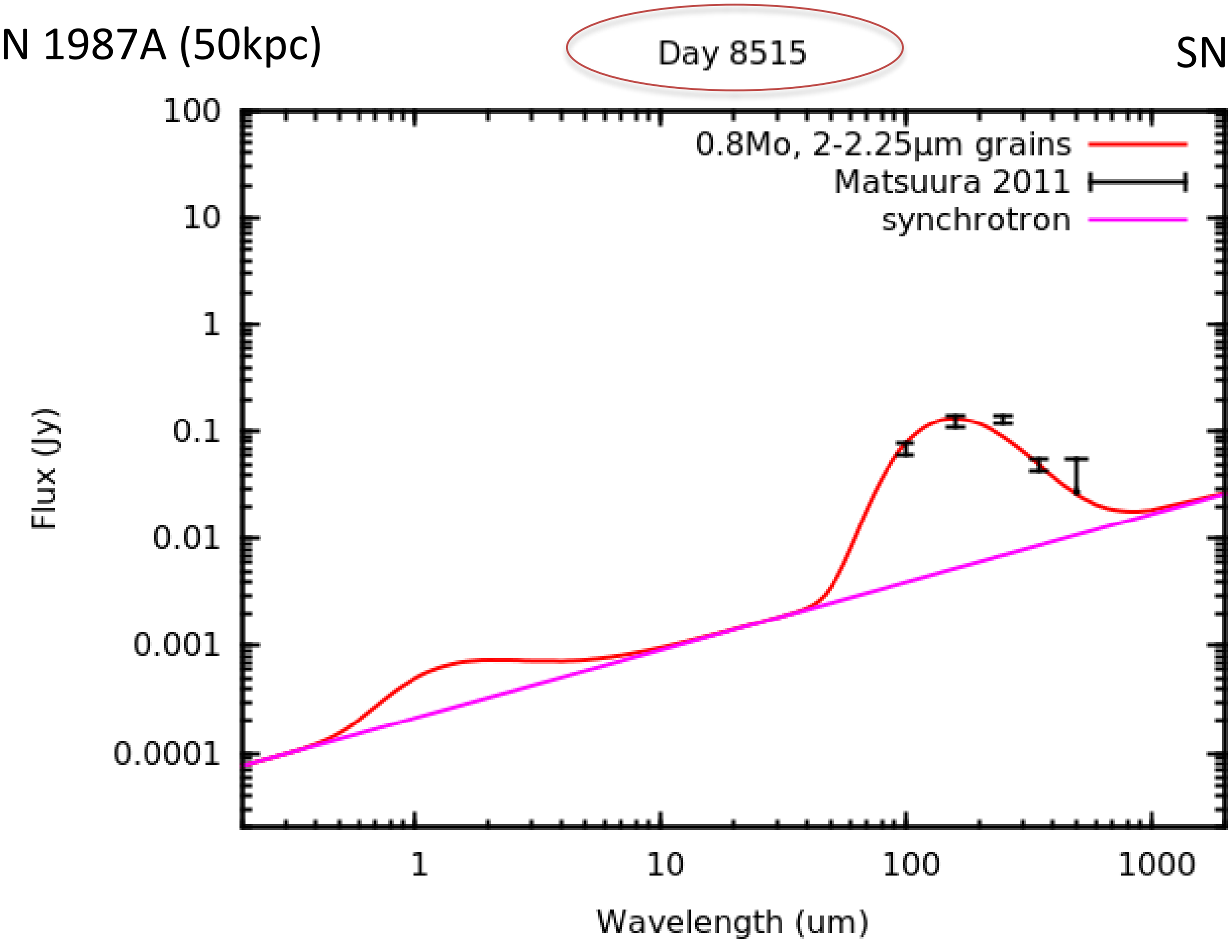
The peak of SED shifted to longer wavelength in time

Wesson et al. (2014)

Time evolution of the SED

SN 1987A (50kpc)

SN at 5 Mpc

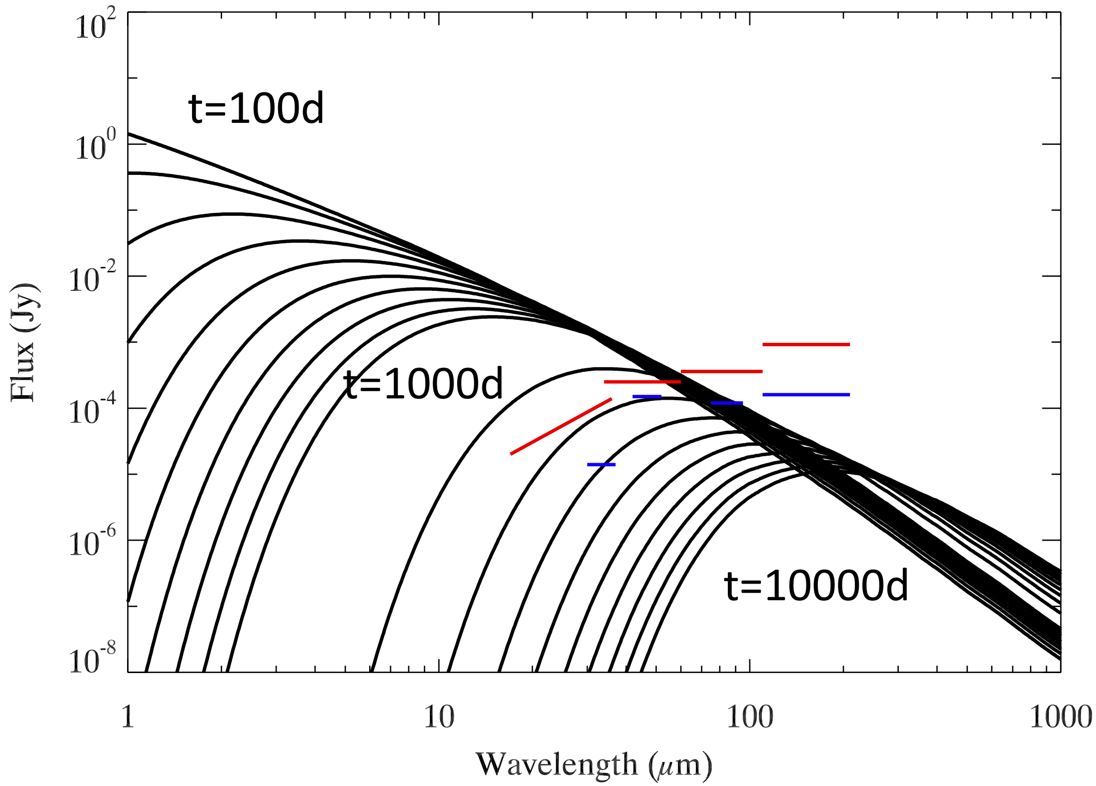


Q: When and how large mass of dust was formed?

Wesson et al. (2014)

SPICA opportunity
Measuring dust mass / time evolution

Evolution of supernova SED at 5 Mpc



Mainly SIM + SAFARI SW band

Spectroscopic limits

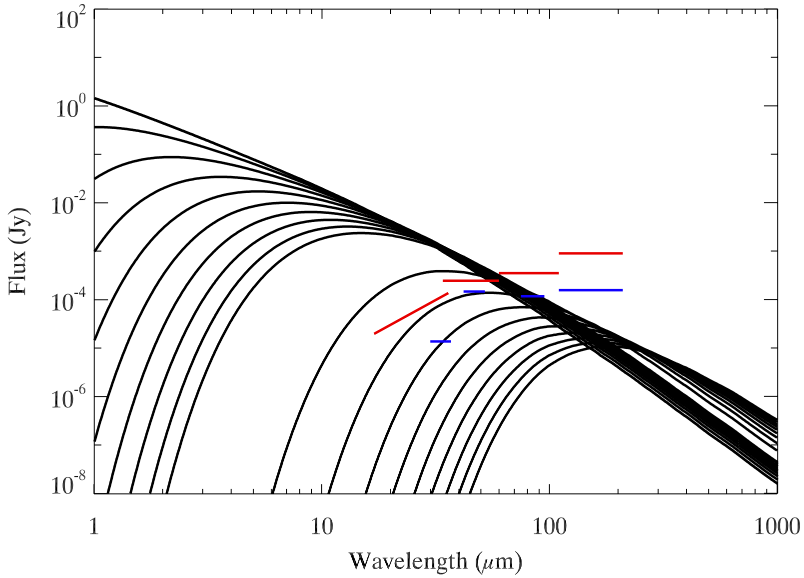
Point source limits

Analytical fits to dust mass increase from Gall et al. (2014) &
temperature drop from Cherchneff & Dwek (2010)

Very crude plot (c.f. inconsistent to SN 1987A) – SPICA measurements are desperately needed

SN dust with SPICA

- Prospects of SPICA
  - From MIR to FIR
  - Formation and evolution of dust in SNe
  - Better sensitivity = larger sample; more than SN 1987A
  - First opportunity to monitor time evolution

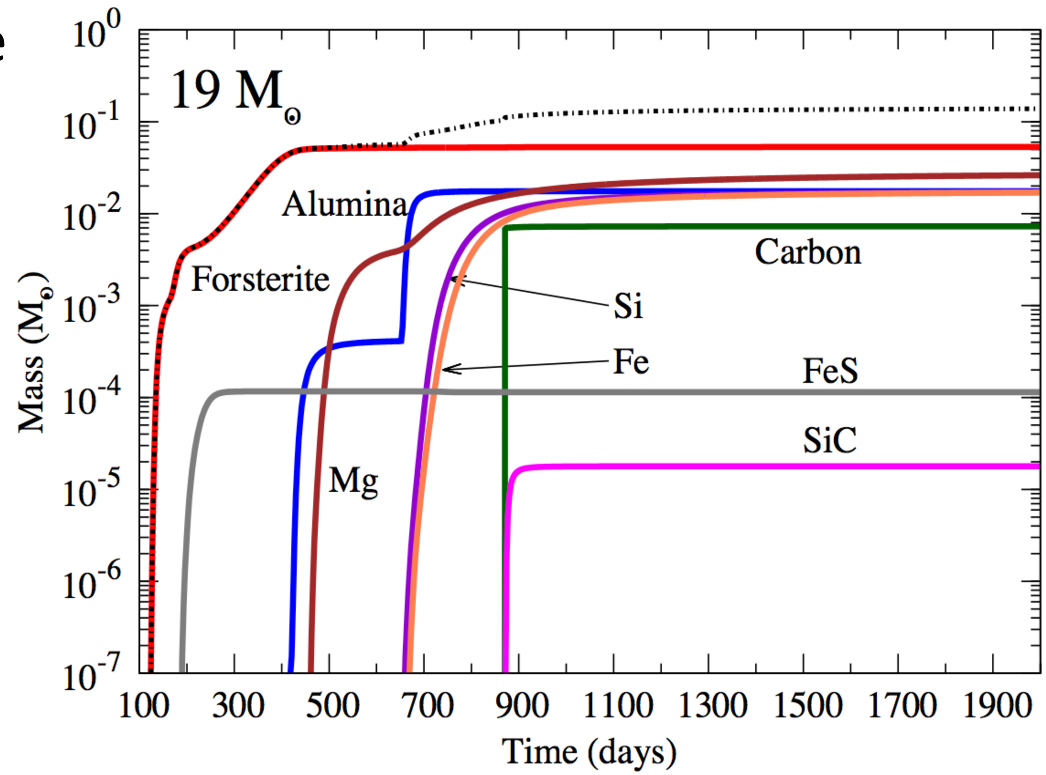


- SAFARI
  - Statistically, ~7 SNe may explode within 10 Mpc in 5 year mission
- SMI
  - Tens of SNe within 50 Mpc in 5 years

Time evolution of dust mass (theory)

- Not simple gradual increase of dust mass in time
- Instantaneous dust formation

Theoretical calculations of time evolution of dust mass



Sarangi & Cherchneff (2015)

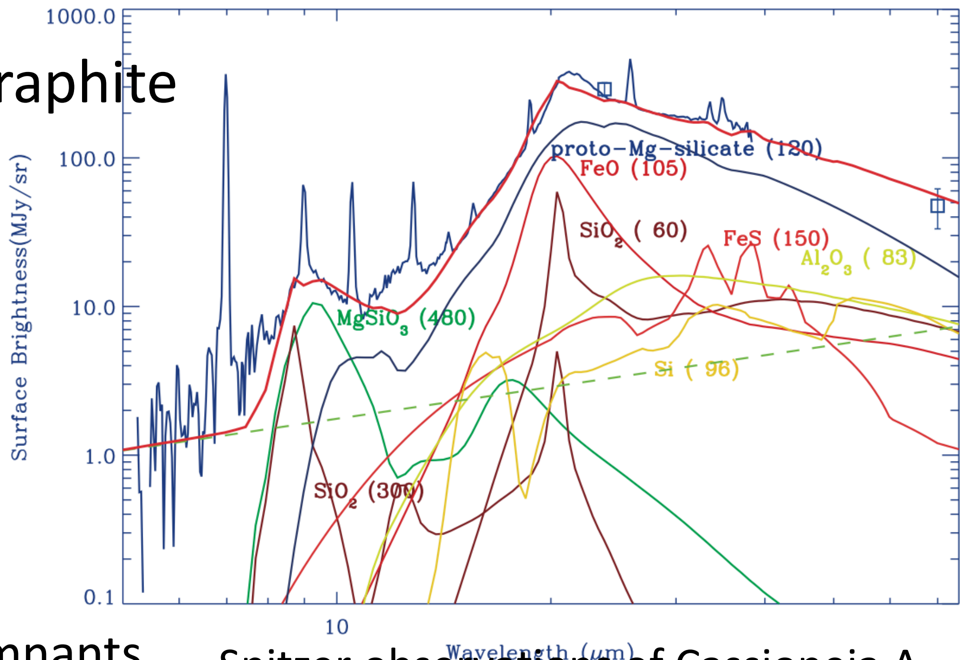
Dust compositions

Dust compositions of SNe are unknown

Cas A – 'Only' study of dust compositions

~10 dust compositions

+ Fe & amorphous carbon / graphite



Spitzer observations of Cassiopeia A
(Rho et al. 2008)

- SMI + SAFARI spectra
- Targets:
  - Newly exploded SNe
  - Galactic + Magellanic Clouds SN remnants

Dust in supernovae and supernova remnants

- Newly developed research field

- SPICA – First real opportunity to 'statistical' studies of dust in supernovae
  - Can supernova make significant (0.1-1 Msun) mass of dust?
  - What kind of dust grains are formed in supernovae?
  - Would the dust mass increase in time?

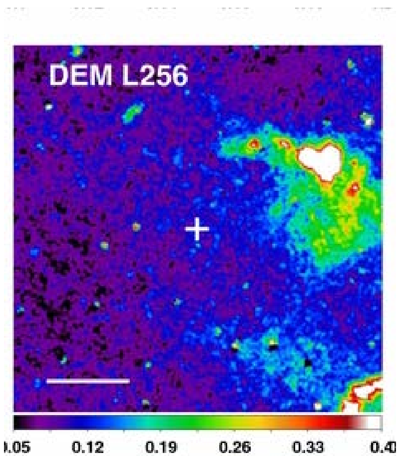
  - Can supernovae be the major source of dust in galaxies?
    - What was the expected dust compositions in early universe?

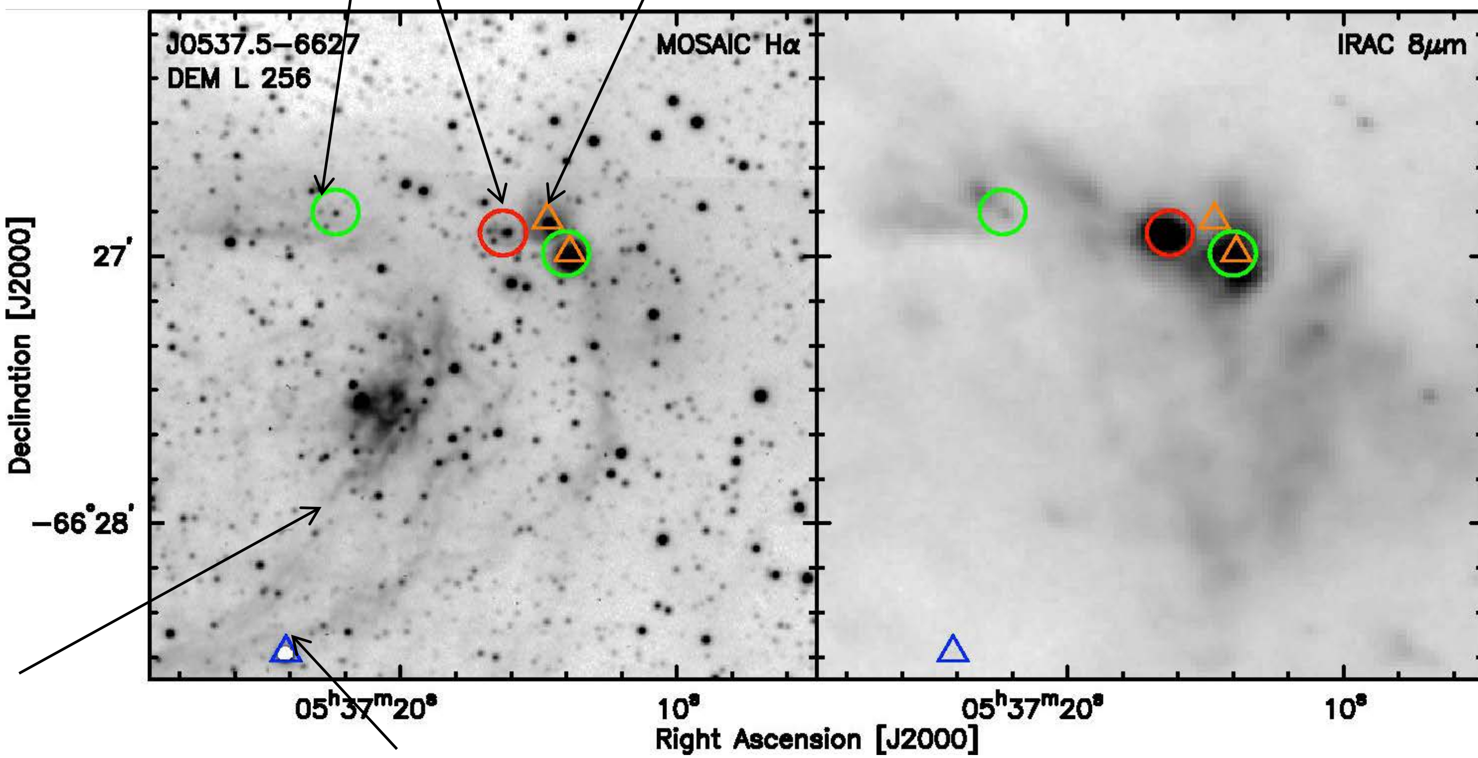
SPICA opportunities: SN triggered star-formation

Supernova remnant in the Large Magellanic Cloud + Young stellar objects

YSOs

O-type star





Filaments (SNR)

B-type star

Close-up of the northwest rim of SNR J0537.5−6627 (DEM L256)

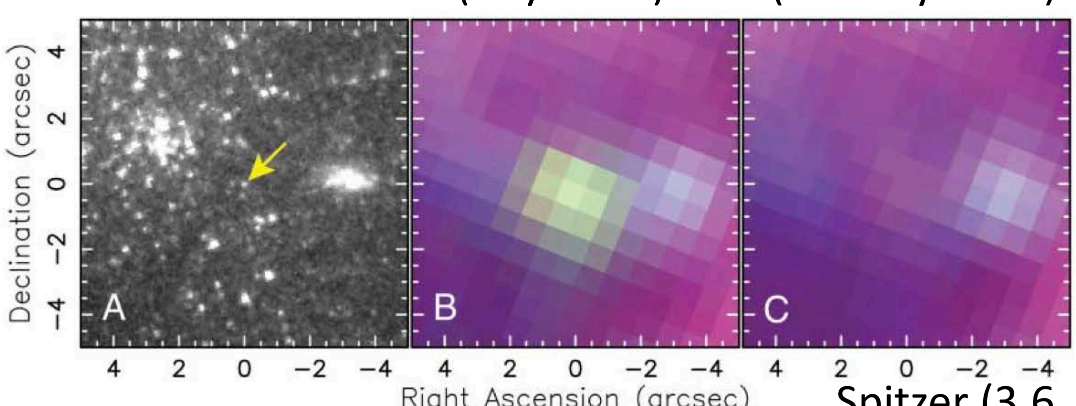
Desai et al. (2010)

SPICA observing strategy

- Targets: newly (<5 years) exploded SNe within 5-10 Mpc
  - Pre-explosion image (by JWST/Herschel) or early epoch image (<90 days after the explosion) we be helpful to identify the dust excess
  - Monitor the variability with every month initially and every 3-4 months
  - Coordination with JWST to cover near-&mid-IR

SN 2003gd

NGC 628 (July 2004) (January 2005)

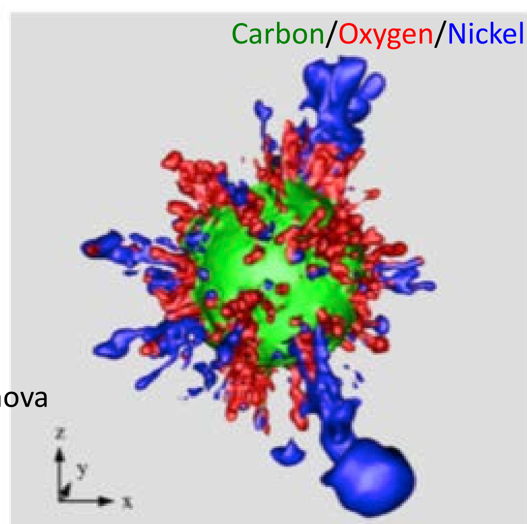


Spitzer (3.6, 4.5 and 8.0 micron)

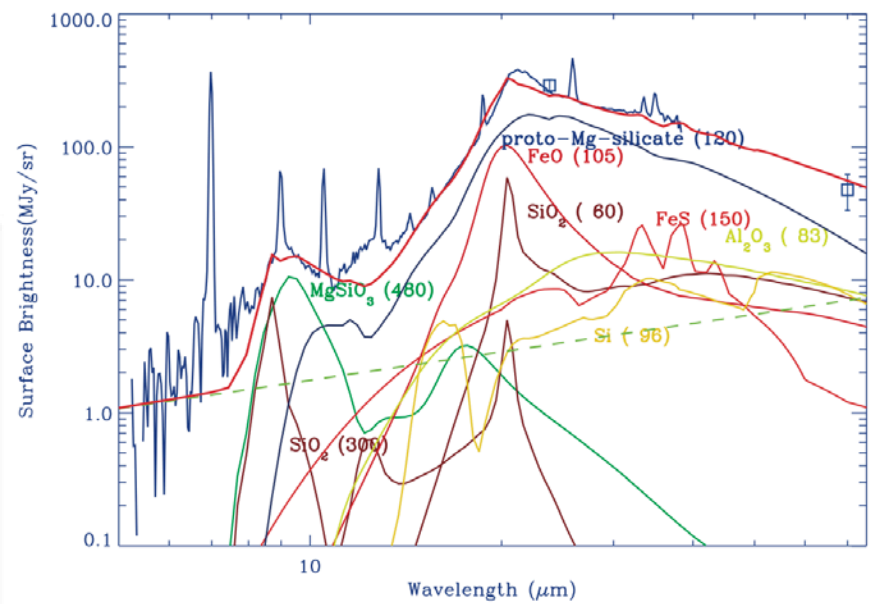
Fig. 1. Hubble and Spitzer Space Telescope images of a 10″by 10″ field centered on the position of SN 2003gd. (**A**) HST WFPC2 image taken in the F606W filter in which the SN progenitor (arrow) was identified (*15*, *18*), with a resolution of 0.″045 pixel^{-1}. (**B** and **C**) False-color SST IRAC images of the SN taken on (B) 28 July 2004 and (C) 15 January 2005, showing the 3.6-µm (blue), 4.5-µm (green), and 8.0-µm images (red). All IRAC images were processed by the SINGS collaboration to a final resolution of 0.″75 pixel^{-1}.

Supernovae and supernova remnants in the local galaxies (and the Milky Way)

- Physics and chemistry of supernovae (SNe)/supernova remnants (SNRs)
  - Dust formation
    - Dust composition
    - Chemical processes leading to dust formation
  - Nuclear synthesis / stellar yields
- Role of SNe on galaxy evolution
  - Chemical enrichment (elements + dust)
  - Star-formation trigger
  - Galactic out



Hydrodynamical simulation of supernova explosion (Hammer et al. 2010)



Dust features detected in Cassiopeia A (Spitzer observations; Rho et al. 2008)

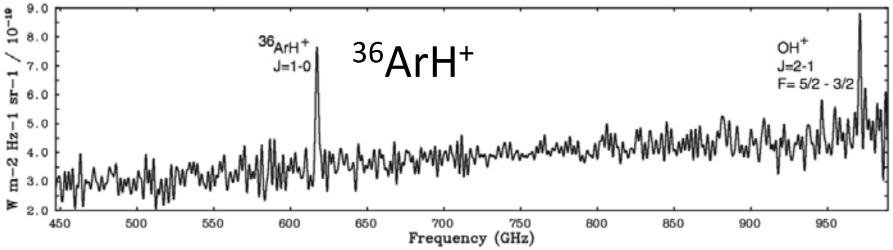
Potential SPICA opportunity

Explosive nuclear synthesis/stellar yields

Potential SPICA detections of isotopologues in SNe/SNRs can constrain isotope ratios

First detection of noble molecular ion

Crab Nebula

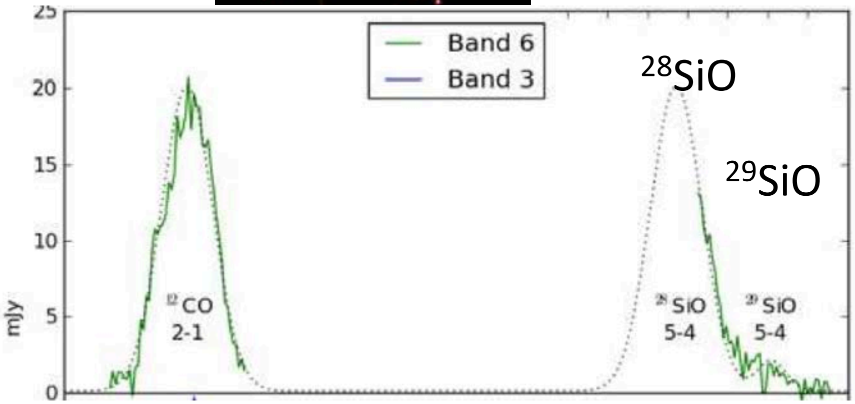


Crab Nebula
$^{36}Ar/^{38}Ar>2$
$^{36}Ar/^{40}Ar>4$

Earth Atmosphere
$^{36}Ar/^{38}Ar$: 5.32+-0.01
$^{36}Ar/^{40}Ar$: 0.003

Barlow et al. (2013, Science 342, 1343)

Rotational lines of ^{29}SiO and ^{28}SiO



ALMA
$^{28}Si:^{29}Si$ ~ 10:1

Explosive nuclear synthesis
$^{28}Si:^{29}Si$=9:1

Kamenetzky et al. (2013, ApJ 773, L34)
Matsuura et al. (to be submitted)