Dust formation by Supernova 1987A

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Current major problems

How much dust can be formed in supernovae?

Can SNe be important source of dust in the ISM of galaxies?
SN 1987A

- Located in the Large Magellanic Cloud (50 kpc)
- Closest SN explosion detected in 400 years
  - Evolution of supernova remnants
    - Real-time astronomy
Detection of cold dust

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

Herschel 250 micron from HERITAGE (Meixner et al 2013)
Spitzer 8 micron + 24 micron
Dust mass in SN 1987A

- Significantly large dust mass:
  - 0.4-0.7 M\(_\odot\) of dust
- Previously reported dust mass: 10\(^{-6}\) - 10\(^{-4}\) M\(_\odot\)
- Progenitor star: 20 M\(_{\odot}\)

Matsuura et al. (2011, Science 333, 1258)
Questions raised by communities

Surprisingly large inferred dust mass (0.4-0.7 Msun)
A large mass of dust must have formed in the SN ejecta where rich metals are available
  – 20 Msun of the progenitor star
  – 2 Msun of the metal mass

• Are the detection real?
• Are dust from ejecta?
  – Alternatives: progenitor, ISM
• Any contamination of lines into broad band photometric measurements
  – dust mass may be overestimated?
Questions raised by communities

• Surprisingly large inferred dust mass (0.4-0.7 Msun), supposed to be from the SN ejecta
  – 20 Msun of the progenitor star
  – 2 Msun of the metal mass

• Are the detection real?
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CO detection in Herschel spectra

- First detection of sub/mm molecular lines in supernovae/supernova remnants
Cold molecular gas in the ejecta of SN 1987A

$^{12}\text{CO} J=2-1$

$^{28}\text{SiO}$

FWHM~ $2300$ km s$^{-1}$

$^{12}\text{CO} J=1-0$

$^{29}\text{SiO}$

(Kamenetzky et al. 2013)
CO Temperature & mass

ALMA optically thick
Kamenetzky et al. 2013

• >0.01 $M_\odot$ of CO; $T\sim39$ K
• larger than previously CO reported mass (5x10$^{-5}$ $M_\odot$ at $d\sim255$-days; Spyromilio et al. 1988)

CO line contaminations: <12 % of in-band flux to SPIRE 350 micron band
dust is the dominant contributors to photometry bands
Chemical modelling

CO mass increases in time

Sarangi & Cherchneff 2013
The ejecta of SN 1987A

- Cold and dense gas in the ejecta < 25 years after the explosion
  - ~20 K of dust
  - <100 K of molecules
- Rich with molecules and dust
- Efficient cooling with adiabatic, lines and dust radiations
What are the major sources of dust in galaxies?

- **Two hypotheses**
  - Stellar origin (SNe + AGB stars): On average 0.1 Msun of dust per SNe
  - ISM grain growth

Submm galaxy
At z~6.4; ~0.4 Giga years
(e.g. Bertoldi et al. 2003)
Summary of Herschel studies of SN 1987A

• Cold dust and molecules from the SN ejecta
  • Far-IR: dust in the ejecta (0.4-0.7 Msun)
  • Molecules (<100 K; 0.05 Msun)

• Time scale of dust condensation is unknown

• SNe can be significant source of dust in the ISM