Dust production in Type II SNe; the case of SN 2004et

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Dust found in early galaxies

- $10^8$ Msun dust formed within $\sim 1$ Gyr
- candidate of dust producers in galaxies
  
  Type II SN
  
  Lifetime $\sim 10$ Myr
  
  AGB stars
  
  Lifetime $\sim 1$ Gyr
  
  Perhaps, Type II SNe are main dust producers,

although $> 0.1$ Msun per a SNe (Dwek 2007, etc)

250GHz contours of a $z=6.4$ QSO
(Bertoldi et al. 2003, CO map)

The age of $z\sim 6.4$ galaxy = 840Myr
3 Signatures for dust formation

1. **Linearly dropping magnitude with Increasing tau**

2. **Asymmetric blue-shifted emission lines**

3. **IR excesses**, which appear 1-3 years after the SN explosion as newly-condensed dust cools
Missing Dust mass problem

Q. Can we explain $10^8 \text{Msun}$ dust in early galaxies with SN dust?

A. No enough. It's difficult.

SN birth rate: $\sim 0.01 \text{ SNe / yr}$

Dust / a SN: $4 \times 10^{-4} - 0.02 \text{ Msun at } \sim 1-2 \text{ yr in } <10 \text{ SNe}$

Dust surviving efficiency at $10^5 \text{ yr}$: $< 0.5$

for Type II SNe evolved from 15 Msun stars (Kozasa et al. 2008)

Host galaxy: $\sim 13 \text{ Gyr}$

$\Rightarrow < 1.6 \times 10^6 \text{ Msun}$

Are dust mass in SNe underestimated?

Before final decision, we need to increase samples?
**SEEDS project**

**SEEDS - `Survey for the Evolution of Emission from Dust in Supernovae**

**Aim**
Search for signatures of newly formed dust in the SN ejecta. Quantify their contribution to the dust budgets of galaxies.

**Targets**
> 1 yr old Type II SNe in nearby galaxies (<15 Mpc)

**Data**
0.4-24 μm data taken by Gemini/WIYN/HST/Spitzer

**Method**
Using the 3-D Radiative transfer code MOCASSIN
SN 2004et in SN factory NGC 6946

- Discovered Sep 22, 2004
- 15-24 Msun red super giant
- 8th SN in the host Galaxy (0.08 Type II SNe / 1 year)
- Observed with Spitzer before explosion by the SINGS
- Total dust mass in NGC6946 $>9 \times 10^7$ Msun (Alton et al. 2002)
- From ~300 days, dust formation started (consist with theory)
- Increasing tau: 0.2 (300 d)/0.4 (400 d)/0.8 (460 d)/1.0 (690 d)
- At >1000 days, the magnitudes are NOT dropping.
Evaporated radius by explosion $\sim 10^{17}$ cm
SN ejecta speed $\sim 1300$ km/s @ Ha
$10^{17}$ cm $\div 1300$ km/s $\sim 32$ yr

No interaction between CSM and SN ejecta
$\Rightarrow$ scattered Light Echo
- Expansion velocity: $\sim 1300 \text{ km/s} @ \text{Ha}, \sim 1000 \text{ km/s} @ \text{[Fe II] line}$
  → standard picture of the stellar structure is KEEPING

- The flux density of Ni becomes stronger.
  → Evidence of radioactive decay (Fe $\rightarrow$ Co $\rightarrow$ Ni)
SED fitting using MOCASSIN

- For days 300, 360, 406, 464, 690, 828
  - Investigating temporal dust mass evolution
- the radii of the SN dust shell
  - Keeping Rout/Rin ratio = 1.3
- Smooth & Clumped dust grain distributions
  - clumped dust filling factor = 0.01
  - clumped dust density = 100x(smooth dust density)
- Carbon:Silicate = 60%:40%
- Local heating source
  - Diffuse Luminosity
  - Keep heating temperature (7,000 K)
SED model results smooth clumped

Day 300
- 4.5(−6) Msun
- 1.1(−5) Msun

Day 360
- 6.9(−6) Msun
- 1.8(−5) Msun

Day 406
- 1.8(−5) Msun
- 5.9(−5) Msun

Day 464
- 2.6(−5) Msun
- 1.1(−4) Msun

Day 690
- 2.2(−4) Msun
- 2.0(−3) Msun

Day 828
- 2.3(−4) Msun
- 2.1(−3) Msun
Temporal evolution of dust mass

- $1.5 \times 10^{-3}$ Msun (Clumped) – $1.6 \times 10^{-4}$ Msun (Smoothed) per yr
- Duration time of dust formation $\sim 30$ yr
- (Expected) surviving total dust after $10^5$ yr in SN2004et: $2 \times 10^{-2}$ Msun $<\sim\sim >0.1$ Msun (theory) for 15 Msun progenitor SN
Summary & Future works

We investigate dust production in SN 2004et

- We confirmed 3 dust formation signatures.
- We found a scattered light echo.
- We constructed SED models and estimated dust mass. The expected total dust mass is $<2 \times 10^{-2}$ Msun.
- If we perform far-IR observations, more dust might be found.
- To investigate surviving dust mass rate, it would be necessary to research dust around SNRe using the ALMA, Herschel, SPICA, JWST.
Spectra of SN 1987A