Mid-infrared Observations of Aged Dusty Supernovae

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special thanks: Tanaka, M., Arimatsu, K., Ohsawa, R., Sakon, I.
1-1. Origin of IR emission from SNe

- Dust formation in the ejecta
- Dust formation in dense shell

- IR light echo by CS dust
- Shock heating of CS dust
1-2. Summary of observed dust mass in CCSNe

FIR to sub-mm observations have revealed the presence of massive ($>0.1\ M_{\text{Sun}}$) dust grains in the ejecta of CCSNe.
1-3. Observing SNe in nearby galaxies

SNe are important sources of interstellar dust?

- Unresolved problems of dust formation in SNe
  - what is the cause of difference in dust mass observed in MIR/FIR?
  - when does dust start to form?
  - what is the main composition of newly formed dust?
  - what is a typical size of dust?
  - what fraction of SNe forms dust?

- recent unobserved SNe in MIR
  - SN 2011dh (M51, d = 8.1 Mpc)
  - SN 2011fe (M101, d = 6.7 Mpc)

SN 2004et (d = 5.6 Mpc, Kotak+09)
M\text{dust} \sim 10^{-4} \text{ M}_{\odot}, T_{\text{dust}} \sim 650\text{K}
2. Observing CS dust in aged dusty SNe

Exploring the evolution of CS dust by MIR observations of SNe 5-100 yr after explosions with MIMIZUKU
3-1. Promising targets (1): SN 1987A

- **SN 1987A (Type II-pec)**
  - host galaxy: LMC (d = 50 kpc, southern sky)
  - interacting equatorial ring
  - ring diameter: 2” (=0.5 pc @ 50 kpc)

IR-mm SED of 23-years old SN 1987A

- on 2009 Apr (Larsson+11)
- on 1994 Feb (Burrow+95)
3-2. Properties of CS dust around SN 1987A

- IR light curve
- MIR SEDs

- IR fluxes increase in all bands by a factor of ~3 between 17 yr and 22 yr

- properties of CS dust in ER
  - silicate
  - $T_{\text{dust}} = 180$ K
  - $M_{\text{dust}} = 10^{-6}$-$10^{-5}$ $M_{\odot}$
  - $L_{\text{IR}} = 10^{36}$-$10^{37}$ erg/s
    (Seok+08, Dwek+08)

- grain radius: $a = 0.02$-$0.2$ $\mu$m
  - relatively large
3-3. Expected IR images of SN 1987A

on 4 Oct 2003
Gemini T-ReCS
(\(\lambda = 10.36 \, \text{\mu m}\))
2 pixels : 0.18”
(Bouchet+04)

AKARI
24 \(\mu m\)
(Seok+08)

SN1987A with MIMIZUKU
- spatially resolving equatorial ring
- multi-epoch \(\rightarrow\) evolution of CS dust
- MIR flux: 10-100 mJ y

On 6 Jan and 1 Feb 2005 (Bouchet+06)

Chandra image
Park+07
4. Promising targets (2): SN 1993J

- **SN 1993J (Type IIb)**
  - host galaxy: M81 (d = 3.6 Mpc, northern sky)
  - L band excess at >130 day (Matthews+02)
  - strong interaction with CSM (Weiler+07; Chandra+09)

AKARI detected MIR emission from 1993J

What is the origin of IR emission?
- shock-heated dust
- newly formed dust
- IR light echo

Arimatsu, TN, et al. in prep.
5-1. Promising targets (3): SN 1978K

**SN 1978K (Type IIIn)**
- host galaxy: NGC 1313 (d = 4.1 Mpc, southern sky)
- X-ray luminous (Smith+07) → massive CSM

AKARI images at 28 yr post explosion

- **SN 1978K**
  - Amorphous carbon
    - $T_{dust} = 180$ K
    - $M_{dust} = 6.8 \times 10^{-3} M_\odot$
  - Astronomical silicate
    - $T_{dust} = 230$ K
    - $M_{dust} = 1.3 \times 10^{-3} M_\odot$

silicate
$T_{dust}=230K, M_{dust} \sim 10^{-3}M_{sun}$
$LIR \sim 1.5 \times 10^{39}$ erg/s

Tanaka, TN, et al. (2012)
5-2. Origin of MIR emission from SN 1978K

- IR luminous: \( L_{\text{IR}} = 1.5 \times 10^{39} \text{ erg/s} \)
  \(\rightarrow\) ruling out emission of newly formed dust and IR echo

- thermal emission from shock-heated CS dust

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multi-epoch IR observations of aged SNe are essential!!
6-1. MIR observations of other aged dusty SNe

SN 1980K (Type II-L)
- host galaxy: NGC 6946
  (d = 5.6 Mpc, northern sky)
- $T_{\text{dust}} = 200$ K, $M_{\text{dust}} \sim 10^{-4}$ M$_{\odot}$
  ($L_{\text{IR}} \sim 10^{38}$ erg/s)
- IR echo by IS dust (Sugerman+12)

SN 1995N (Type IIIn)
- host galaxy: Arp 261
  (d = 24 Mpc, southern sky)
- $T_{\text{dust}} = 240$ K, $M_{\text{dust}} \sim 0.1$ M$_{\odot}$
  ($L_{\text{IR}} \sim 7.7 \times 10^{40}$ erg/s)
- CS dust heated by radiation from shocked region (van Dyk 2013)
6-2. Other possible targets


- **nearby Type IIIn SNe**
  - SN 1998S (IIIn) \(d = 17\) Mpc
    (Pozzo et al. 2004)
  - SN 2005ip (IIIn) \(d = 30\) Mpc
    (Fox et al. 2011, 2012)

- **very nearby Type II-P SNe**
  - SN 2002hh (II-P) \(d = 5.6\) Mpc
    (Barlow et al. 2005)
  - SN 2004et (II-P) \(d = 5.6\) Mpc
    (Kotak et al. 2009, Fabbri et al. 2011)
  - SN 2004dj (II-P) \(d = 3.5\) Mpc
    (Szalai et al. 2011, Meikle et al. 2011)
7. Promising targets (3): NGC 300OT

**NGC 300OT (SN imposter)**

- host galaxy: NGC 300 (d = 1.9 Mpc, southern sky)
- IR luminous \( \rightarrow \) eruption of dust-enshrouded star

**opt/IR SED of the progenitor**

![SED plot for NGC 300 and SN2008S](image)

- **Berger+09**
  - NGC 300: T \( \approx \) 338±7 K, R = (4.9±0.3)\( \times \)10^{15} cm, L = 5.8\( \times \)10^4 L_\odot
  - SN2008S: T \( \approx \) 440 K, R \( \approx \) 2.4\( \times \)10^{15} cm, L \( \approx \) 4.0\( \times \)10^4 L_\odot

**Prieto+09**

- Carbon
  - T_{dust} = 400K
  - M_{dust} \sim 10^{-4} M_\odot
  - LIR \sim 2\times10^{39} \text{ erg/s}

**Ohsawa+10**

- Dust formation
  - T_{dust} = 600-800K
  - M_{dust} > 10^{-5} M_\odot
  - LIR \sim 10^{39} \text{ erg/s}

- \( \sim 100 \text{ day} \)
- \( 400-600 \text{ day} \)
8. Summary

- Dust formation in SNe ($t = 1-3$ yr, $d < 5$ Mpc)
  - formation time, composition, and mass of dust
  - what fraction and what type of SNe produce dust?

- CS dust in aged SNe ($t = 5-30$ yr, $d \sim 5$ Mpc)
  - dust formation condition in stellar winds
  - dust mass and temperature $\Rightarrow$ gas density, dust size
  - mass-loss history of the progenitor stars
    $\Rightarrow$ diversity of SN types, evolution of massive stars

- Dust-enshrouded optical transients ($d \sim 2$ Mpc)
  - Effect on UV/opt light curves, or hidden SNe?