Cas A 超新星残骸中のダストの進化と熱放射

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1-1. Introduction

Dust in SNRs

• CCSNe are important sources of dust?
  ─ formation of dust in the ejecta of SNe
  ─ destruction of dust by the reverse shock
  ➔ What kind and how much amount of dust are supplied by CCSNe?

• physical processes of dust in shocked gas
  ─ erosion by sputtering and collisional heating

• IR thermal emission from shock-heated dust
  ➔ structure of circumstellar medium and mass-loss history of progenitor star

young remnants of CCSNe!
1-2. Cassiopeia A SNR

○ Cas A SNR

- age: \(~340\) yr (Thorstensen et al. 2001)
- distance: \(d=3.4\) kpc (Reed et al. 1995)

- SN type : Type IIb \((M_{\text{star}}=15-20\ M_{\odot})\)

(Usuda-san’s talk; Krause et al. 2008)
1-3. Aim of our study

- Formation of dust in the ejecta of Type IIb SN
  → composition, size, and mass of newly formed dust
  → dependence of dust formation process on types of SNe (on the thickness of H envelope)

- Evolution of dust in shocked gas within the SNR
  → What fraction of newly formed dust can survive and is injected into the ISM?

- Thermal emission from shock-heated dust
  → comparison with IR observations of Cas A
  → constraint to gas density in the ambient medium
2-1. Dust formation calculation

- **Type IIb SN model**
  (SN1993J-like model)

  - $M_{\text{eje}} = 2.94 \, M_{\odot}$
  - $M_{\text{H-env}} = 0.08 \, M_{\odot}$
  - $M_{\text{star}} = 18 \, M_{\odot}$

  - $E_{51} = 1$

  - $M(^{56}\text{Ni}) = 0.07 \, M_{\odot}$

- **Dust formation calculation**

  - non-steady nucleation and grain growth theory

  (Nozawa et al. 2003)

  - onion-like composition
2-2. Composition and mass of dust formed

<table>
<thead>
<tr>
<th>dust species</th>
<th>$M_{d,j} (M_\odot)$</th>
<th>$M_{d,j}/M_{d,\text{total}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>$7.08 \times 10^{-2}$</td>
<td>0.423</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>$6.19 \times 10^{-5}$</td>
<td>$3.7 \times 10^{-4}$</td>
</tr>
<tr>
<td>Mg$_2$SiO$_4$</td>
<td>$1.74 \times 10^{-2}$</td>
<td>0.104</td>
</tr>
<tr>
<td>MgSiO$_3$</td>
<td>$5.46 \times 10^{-2}$</td>
<td>0.326</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>$1.57 \times 10^{-2}$</td>
<td>0.094</td>
</tr>
<tr>
<td>MgO</td>
<td>$2.36 \times 10^{-3}$</td>
<td>0.014</td>
</tr>
<tr>
<td>FeS</td>
<td>$1.47 \times 10^{-3}$</td>
<td>0.009</td>
</tr>
<tr>
<td>Si</td>
<td>$5.07 \times 10^{-3}$</td>
<td>0.030</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>0.167</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>

**Total mass of dust:**

- $0.167 \, M_{\odot}$ in SN IIb
- $0.1-2 \, M_{\odot}$ in SN IIP

- Various kinds of dust can condense in each layer.
- Condensation time: 300-700 days.
2-3. Radius of dust formed in the ejecta

**Grain radius**

$\Rightarrow > 0.01 \, \mu m$ for SN IIP

$\Rightarrow < 0.01 \, \mu m$ for SN IIb

Dust grains formed in H-deficient SNe are small
3-1. Calculation of dust evolution in SNRs

**Model of calculations**
(Nozawa et al. 2006, 2007)

- ejecta model
  - hydrodynamic model for dust formation calculation
- ISM
  - \( T_{\text{gas}} = 10^4 \) K
  - \( \rho(r) = \frac{M}{4 \pi r^2 v_w} \) g/cm\(^3\)
    \( (M = 2 \times 10^{-5} M_{\text{sun}}/\text{yr}) \)
- treating dust as a test particle
  - erosion by sputtering
  - deceleration by gas drag
  - collisonal heating
    \( \Rightarrow \) stochastic heating
3-2. Evolution of dust in Cas A SNR

- Most of newly formed dust are destroyed in the hot gas because their radii are small.
4-1. Time evolution of IR SEDs for Cas A SNR

Data: Hines et al. (2004)
red: with SH
green: without SH
4-2. Dependence of IR SED on ambient density

\[ \dot{M} = 3.3 \times 10^{-5} \, \text{M}_\odot / \text{yr} \] (340 yr) \[ \rho \times 1.6 \]

\[ \dot{M} = 6.6 \times 10^{-5} \, \text{M}_\odot / \text{yr} \] (340 yr) \[ \rho \times 3.3 \]

\[ \dot{M} = 1 \times 10^{-4} \, \text{M}_\odot / \text{yr} \] (340 yr) \[ \rho \times 5 \]

\[ \dot{M} = 2 \times 10^{-4} \, \text{M}_\odot / \text{yr} \] (340 yr) \[ \rho \times 10 \]

Data: Hines et al. (2004)
red: with SH
green: without SH

\( M_d = 0.06 \, \text{M}_\odot \)
4-3. Contribution from circumstellar dust

\[ \dot{M} = 6.6 \times 10^{-5} \, M_\odot/\text{yr} \]

\[ \text{(340 yr)} \]

- **Red**: ejecta dust
- **Blue**: CSM dust

<table>
<thead>
<tr>
<th>Dust Species</th>
<th>Dust Size Distribution</th>
<th>$a_{\text{min}}$</th>
<th>$a_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C and Mg$_2$SiO$_4$</td>
<td>$f(a) \propto a^{-3.5}$</td>
<td>0.001 μm</td>
<td>0.5 μm</td>
</tr>
</tbody>
</table>

$M_C : M_{\text{sil}} = 3 : 7$
Summary

1) The radius of dust formed in the ejecta of Type IIb SN is relatively small (\(< 0.01 \, \mu m\)) because of low ejecta density.

2) Small dust grains formed in Type IIb SN cannot survive destruction by the reverse shock.

3) Model of dust destruction and heating in Type IIb SNR to reproduce the observed SED of Cas A is

\[
M_{d,eje} = 0.06 \, M_{\sun}, \quad M_{d,ism} = 0.03-0.07 \, M_{\sun}
\]

\[
dM/dt = 6.6 \times 10^{-5} \, M_{\sun}/yr
\]

\(\rightarrow\) ejecta-dust in denser clump

4) IR SED reflects the destruction and stochastic heating

\(\rightarrow\) density structure of circumstellar medium