Dust Formation and Evolution in Envelope-Stripped Core-Collapse Supernovae

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○ Abstract

Core-collapse supernovae (SNe) are considered to be one of the important sources of interstellar dust. However, it has not been explored how the size and amount of dust formed in the ejecta depend on the types of SNe. We investigate the composition, average radius, and mass of dust formed in the ejecta of envelope-stripped Type Ib and Type IIb SNe, and compare to those in Type II-P SNe with massive hydrogen envelopes.

We find that the total mass of dust formed in Type Ib/IIb SNe is 0.1-1.5 Msun and is in the range of the estimates of dust mass in Type II-P SNe. However, the average radii of newly formed grains in Type Ib/IIb SNe are found to be less than 0.01 μm, which is about one order of magnitude smaller than those formed in Type II-P SNe. This implies that the size of dust formed in the ejecta is heavily affected by the outer envelope mass. We also calculate the destruction of newly formed grains by the reverse shock in Type IIb SN remnants (SNRs) and find that these small grains are almost completely destroyed in the shocked gas. Thus, we conclude that envelope-deficient SNe are unlikely to be major sources of dust.

○ Dust Formation in Type Ib SN 2006jc (Nozawa et al. 2008)

— Calculation of dust formation in the SN ejecta (Nozawa et al. 2003)

— Model of SN 2006jc (Tominaga et al. 2008)

Mejecta = 4.9 Msun (M_{ZAMS} = 40 Msun, Z = 0.02), Ekin = 10^{52} erg s^{-1}

— Results of dust formation calculations

- The average radii of dust formed are less than 0.01 μm (Figure 1), because of a low gas density resulting from no envelope (Figure 2)
- Total mass of dust that can form in the ejecta is 1.45 Msun

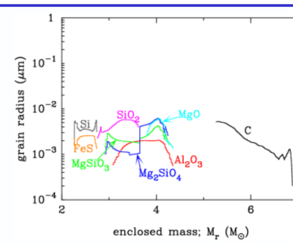

Fig. 1 – Average radii of dust grains formed in the ejecta of Type Ib SN 2006jc as a function of enclosed mass.

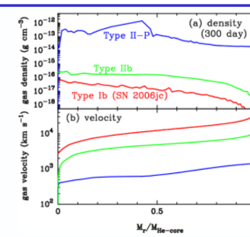

Fig. 2 – (a) Gas density and (b) velocity at 300 days after the explosions within the He core for SN models of Type Ib (red), Type IIb (green), and Type II-P (blue) with M_{eje} = 17Msun, M_{env} = 13.2Msun, and E_{kin} = 10^{51}erg (Umeda & Nomoto 2002). The mass coordinate is normalized by the He core mass.

○ Dust Formation in Type IIb SNe (Nozawa et al. 2010)

— Models of Type IIb SN: SN 1993J-like

Mejecta = 2.94 Msun (M_{ZAMS} = 18 Msun, Z=0.02), Ekin = 10^{51} erg s^{-1}

— Results of dust formation calculations

- The average grain radii are below 0.01 μm (Figure 3), being much smaller than those (> 0.01 μm) formed in Type II-P SNe (Figure 4)
- Total mass of dust formed in the ejecta is 0.167 Msun

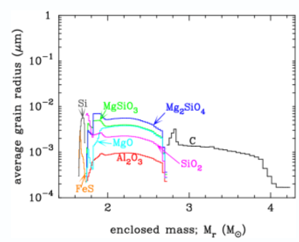

Fig. 3 – Same as Figure 1, but for Type IIb SN model.

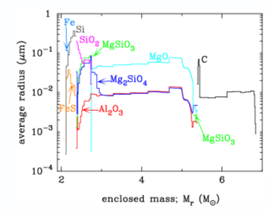

Fig. 4 – Same as Figure 1, but for Type II-P SN model.

○ Evolution of Dust in Type IIb SNe (Nozawa et al. 2010)

— Calculation of dust evolution in SNRs (Nozawa et al. 2007)

- treating the dynamics of dust grains and their destruction due to sputtering, along with the time evolution of shock propagation
- Dust model: results from the above dust formation calculation

— Results of dust evolution calculations

- Newly formed small grains are completely destroyed in the shocked gas for $n_{H,0} \geq 0.1$ cm^{-3} before being injected into the ISM (Figure 5)

➔ Envelope-poor SNe Ib/IIb are unlikely to be main suppliers of interstellar dust grains

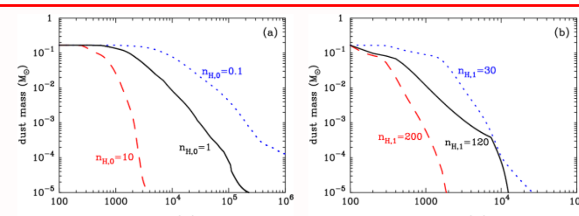

Fig. 5 – Time evolution of the total mass of the newly formed dust within the Type IIb SNRs; (a) the uniform CSM with $n_{H,0}$ = 0.1 cm^{-3} (dotted), 1 cm^{-3} (solid), and 10 cm^{-3} (dashed), and (b) the stellar wind CSM with $n_{H,1}$ = 30 cm^{-3} (dotted), 120 cm^{-3} (solid), and 200 cm^{-3} (dashed), respectively, corresponding to the mass-loss rates of 2x10^{-5}, 8x10^{-5}, and 13x10^{-5} Msun yr^{-1}.

○ Comparison with Infrared Observations of Cassiopeia A SNR

— The observed infrared spectrum of Cas A SNR is well reproduced by our self-consistent model of dust formation and evolution (Figure 6)

➔ warm dust of 0.008 Msun and cool dust of 0.072 Msun

— AKARI and Herschel detect cool (35-40 K) dust towards Cas A (Figure 7)

➔ estimated mass of cool dust is 0.03-0.075 Msun (Sibthorpe et al. 2010; Barlow et al. 2010) ➔ very consistent with our calculation!

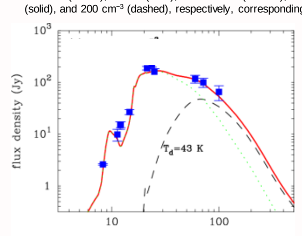

Fig. 6 – Comparison between the infrared observations (blue dots, Hine et al. 2004) of Cas A SNR and the calculated dust emission spectrum (red) in Type IIb SNR for $n_{H,1}$ = 120 cm^{-3} at 330 yr. The green and black broken lines are, respectively, the contributions from the shocked and unshocked dust.

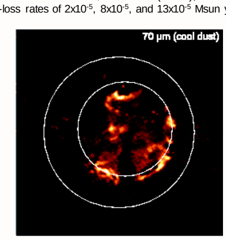

Fig. 7 – Herschel image of Cas A at 70 μm subtracted by the normalized *Spitzer* MIPS 24 μm image (Barlow et al. 2010). The image is 7' on a side. The inner and outer circles depict the positions of the reverse and forward shocks, respectively (Gotthelf et al. 2001). This image manifests the emission from cool dust that has not been swept by the reverse shock

○ Summary

— In Type Ib/IIb SNe without massive envelopes, the radii of dust grains formed are small (< 0.01 μm)

➔ Size of dust formed in the ejecta depends on the SN types through the mass of outer envelope

— Because of their small sizes, the newly formed grains are almost entirely destroyed inside the SNRs

➔ Envelope-stripped Type Ib/IIb SNe are not likely to be important sources of interstellar dust

— Our dust formation and evolution models well reproduce the observed IR emission from Cas A SNR

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