Formation and Evolution of Dust in Various Types of Supernovae

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○ Abstract

The cosmic dust is a fundamental ingredient of the Universe and plays a vital role in many astrophysical phenomena. The reprocessing of stellar light by dust grains controls the energy balance in interstellar space and heavily alters the intrinsic appearances of stars and galaxies. Therefore, the investigation of origin and properties of dust grains is indispensable for uncovering the evolution history of the Universe from observations.

We introduce a series of our works on dust formation in supernovae (SNe) which are believed to be main producers of interstellar dust. We present the composition, size distribution, and mass of dust ejected from SNe that occur in the early universe and discuss their effects on the observations towards high redshift. We also show that the injection process of newly formed dust from SNe to the interstellar medium (ISM) depends on the type of SNe and describe how the importance of SNe as sources of dust shifts from the early universe to the present universe.

○ SNe as sources of dust in the early universe

– The submm observations have confirmed the presence of a huge amount of dust (> 10^8 Msun) in host galaxies of quasars at z > 5

In such an early epoch, SNe may be dominant sources of dust

– Dust formation calculations in the ejecta of SNe (Nozawa et al. 2003)

- Nucleation and grain growth theory (Kozasa et al. 1989)
- Models of Population III (Z = 0) SNe (Umeda & Nomoto 2002)
  Type II-P SNe (SNe II-P) : Mstar = 13, 20, 25, and 30 Msun
  Pair-instability SNe : Mstar = 170 and 200 Msun
- Dust destruction calculations in SN remnants (Nozawa et al. 2007)

– Results of the calculations

- Size distribution of dust after the destruction (Figure 1b)
  ➔ biased to large grains (> 0.01 μm, small grains are destroyed)
- Total mass of dust ejected from SNe into the ISM (Figure 2)
  ➔ 0.07-0.8 Msun in primordial SNe II-P for $n_{H,0}$ = 0.1-1 cm^{-3}
- Extinction curves expected in the early universe (Figure 3)
  ➔ quite flat (wavelengths-independent) (Hirashita et al. 2008)

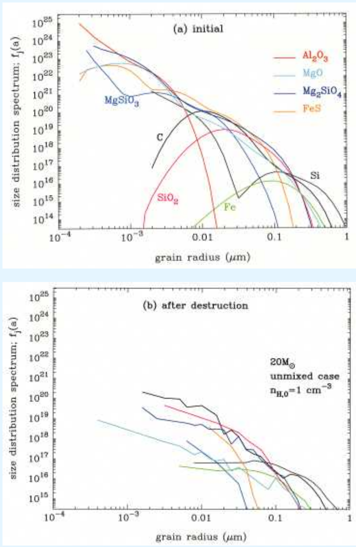

Fig. 1 – Differential size distribution spectrum of each dust species for Mstar = 20 Msun: (a) for the initial size distribution at the time of dust formation (before destruction) and (b) for the size distribution after dust destruction by the reverse shock for $n_{H,0}$ = 1 cm^{-3}.

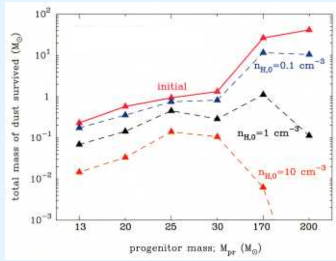

Fig. 2 – Total mass of dust ejected from Population III SNe into the ISM vs. the progenitor mass for the ISM gas densities of $n_{H,0}$ = 0.1 (blue), 1.0 (black), and 10 cm^{-3} (red). The solid line is for the initial dust mass at the time of dust formation.

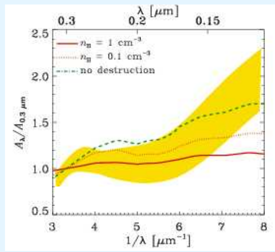

Fig. 3 – Extinction curves from the SN-dust model for $n_{H,0}$ = 1.0 cm^{-3} (solid) and 0.1 cm^{-3} (dotted), and the case without the reverse shock destruction (dashed). The shaded area shows the range observed for SDSS J1048+4637 at z = 6.2.

○ Dust formation in various types of SNe : Case of SNe Ia

– SNe Ia model : carbon-deflagration W7 model
(Nomoto et al. 1984, Thielemann et al. 1986)

– Results of the calculations

- The average radii of dust formed are below ~0.01 μm, due to a low gas density in SNe Ia with no H-envelopes
- Total mass of dust that can form in the ejecta is ~0.1 Msun
- Newly formed small grains are completely destroyed in the shocked gas for $n_{H,0}$ > 0.01 cm^{-3} before being injected into the ISM (Figure 4)
  ➔ Envelope-poor SNe such as SNe Ia/Ib/IIb are unlikely to be main producers of interstellar dust (Nozawa et al. 2008, 2010, 2011)

○ Observational evidence for massive dust in core-collapse SNe

– The observed infrared spectrum of Cas A SN remnant is reproduced by our dust formation and evolution model (Figure 6, Nozawa et al. 2010)

➔ warm dust of 0.01 Msun and cool dust of 0.07 Msun

– Herschel detects cool dust towards SN 1987A (Figure 5)

➔ estimated mass of cool dust : 0.4-0.7 Msun (Matsuura et al. 2011)

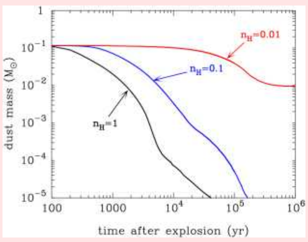

Fig. 4 – Time evolution of the total mass of the newly formed dust within the Type Ia SN remnants expanding into the ISM with $n_{H,0}$ = 0.01, 0.1, and 1.0 cm^{-3}.

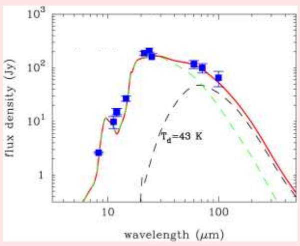

Fig. 5 – Comparison between the infrared observations (blue dots) of Cas A and the calculated dust emission spectrum (red) in a Type IIb SN at 330 yr. The green and black dashed lines denote the contributions from theshocked and unshocked dust, respectively.

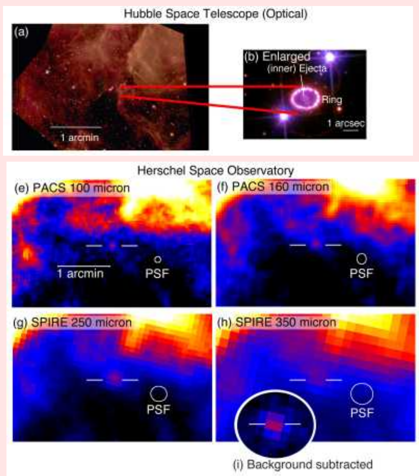

Fig. 6 – Herschel image of SN 1987A at (e) 100 μm, (f) 160 μm, (g) 250 μm, and (h) 350 μm, together with (a) the Hubble optical images. In panel (b), the enlarged view of the Hubble optical image is shown. The two white horizontal lines indicate the position of SN 1987A measured from radio observations. The PSFs shows the angular resolution of the Herschel instruments. In the insert, the background-subtracted 350 μm image is given.

○ Discussion

– In the early (metal-poor) universe : SNe would be major sources of interstellar dust

- Massive stars are likely to dominate, and the mass loss from massive stars would be less efficient
  ➔ SNe explode as Type II-P, supplying a significant amount of dust grains (~0.1-1.0 Msun per SN)

– In the present (metal-rich) universe : SNe would be minor sources of interstellar dust

- Low-mass stars are dominant, and the mass loss from massive stars would be more efficient
  ➔ Envelope-stripped SNe such as Type Ia/Ib/IIb are main components of SN and supply little dust

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