Formation of Dust Grains in the ejecta of Type Ia Supernovae

Takaya Nozawa1, Keiichi Maeda2, Takashi Kozasa3, Masaozumi Tanaka4, Ken'ichi Nomoto1, Hideyuki Umeda4

1IPMU (Institute for the Physics and Mathematics of the Universe), 2Hokkaido University, 3University of Tokyo

Introduction:
It has been suggested that Type Ia supernovae (SNe Ia) can be possible producers of interstellar dust. However, in contrast to core-collapse SNe, any observation of normal SNe Ia has never reported so far convincing evidence for the ongoing formation of dust grains in the expanding ejecta. We investigate the possibility of dust formation in the ejecta of SNe Ia, adopting the carbon-deflagration W7 model. The main aim of this study is (1) to reveal the composition, size, and amount of dust that can condense in the ejecta of SNe Ia, and (2) to clarify how the formation process of dust in the ejecta depends on the type of SNe. We also calculate the destruction of the newly formed dust by spattering in the shocked hot gas inside the supernova remnants (SNRs), to estimate the mass of dust that can be finally injected from SNe Ia into the interstellar medium (ISM).

Model:
- SN model: carbon-deflagration W7 model (Nomoto et al. 1984, Thielemann et al. 1986)
  - chemical composition in the ejecta (Figure 1)
  - stratified elemental composition with no mixing
  - temperature, density, and velocity of the gas (Figure 2)
  - gas density is much lower than that in Type II-P SNe
- Dust formation calculations (Nozawa et al. 2003, 2010)
  - nucleation and grain growth theory (Kozasa et al. 1989)
  - sticking probability: $\alpha = 0.1$ and 1.0
- CO and SiO molecules: complete and no formation

Results:
- For $\alpha = 1.0$, a variety of dust species can condense, according to the elemental abundance in each layer.
- Condensation times of dust grains are 100-300 days after the explosion (Figure 3a).
- The average grain radii are below $0.01\, \mu$m (Figure 3b), because of low gas density in SNe Ia with no H-envelopes.
- The total mass of dust formed in the ejecta is $3 \times 10^{-4} M_\odot$ to $0.2 M_\odot$ sun, depending on the sticking probability and formation efficiency of CO and SiO molecules (Table 1).

Discussion:
- thermal emission from newly formed dust (Figure 4)
- Formation of C grains must be suppressed to be consistent with the mid-IR spectra observed for normal SNe Ia.
  - energetic photons and electrons should destroy small clusters of C grains efficiently (Nozawa et al. 2008) "or"
  - outermost C-O layer of SNe Ia should be fully burned.
- Survival of newly formed dust in SNRs (Figure 5)
  - Unless the gas density around SNe Ia is low ($n_{H,0} < 0.01\, \text{cm}^{-3}$), the newly formed grains are almost completely destroyed.
  - SNe Ia is likely to be poor producers of interstellar dust.

Summary:
- For the sticking probability of unity, C, silicate, Si, and FeS grains can condense in the ejecta of SNe Ia at 100-300 days, which is much earlier than those (>300 days) in Type II-P SNe.
- Due to the low gas density in the ejecta of SNe Ia with no H-envelope, the average radii of newly formed grains are basically less than 0.01 $\mu$m and are smaller than those >0.01 $\mu$m in Type II-P SNe.
- The total mass of dust that can form in the ejecta of SNe Ia ranges from $3 \times 10^{-4} M_\odot$ sun to 0.2 $M_\odot$ sun.
- For the ISM gas density of $n_{H,0} > 0.1\, \text{cm}^{-3}$, dust grains formed in the ejecta are almost completely destroyed before being injected into the ISM.

References: