Galactic Archaeology: Near-Field Cosmology and the Formation of the Milky Way
ASP Conference Series, Vol. 458
W. Aoki, M. Ishigaki, T. Suda, T. Tsujimoto, N. Arimoto, eds.

Formation and Evolution of Dust in Various Types of Supernovae

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Abstract. We demonstrate how the formation and destruction processes of dust in supernovae (SNe) depend on the type of SNe classified through the mass of their outer envelopes. We show that, for Type II-P SNe with massive hydrogen envelopes, relatively large grains ($\gtrsim$0.01 μm) can condense in the ejecta, and that ~0.1–1 $M_\odot$ of dust can be injected into the interstellar medium. On the other hand, for Type IIb/Ib/Ia SNe with no massive envelope, the radii of newly formed grains are considerably small, less than 0.01 μm, so the dust grains are almost completely destroyed in the shocked hot gas. These results suggest that envelope-retaining SNe can be major sources of dust, whereas envelope-deficient SNe are likely to be minor dust sources.

1. Introduction

Supernovae (SNe) are considered to be rapid and efficient producers of dust grains. In the ejecta of SNe, dust grains can form within the He core where the densities of condensible heavy elements are much higher than in the outer envelope. On the other hand, the newly formed dust can subsequently undergo the erosion due to sputtering in the hot gas swept up by the reverse and forward shocks. Thus, the size distribution and mass of dust finally ejected from SNe to the interstellar medium (ISM) are regulated by these two processes. However, both processes depend on the type of SNe through their envelope mass. In this proceedings, to show this dependence, we describe the results for a series of our works on the calculations of dust formation in the ejecta of various types of SNe and dust destruction in the shocked gas inside the SN remnants (SNRs).

2. Dust Formation and Evolution in Type II-P SNe

Type II-P SNe (SNe II-P) are core-collapse SNe (CCSNe) that retain massive H envelopes at the explosions. Nozawa et al. (2003) find that 0.1–1 $M_\odot$ of dust grains can condense in the ejecta of SNe II-P and that the grain radii range from 0.0005 μm up to 1.0 μm, with the average radius larger than ~0.01 μm. Meanwhile, the fates of the newly formed grains within SNRs depend on their initial radii $a_{\rm ini}$ (Nozawa et al. 2007); small grains of $a_{\rm ini} \lesssim 0.01$–0.05 μm are trapped in the hot gas to be entirely destroyed, while larger grains are injected into the ISM without being eroded significantly. For interstellar hydrogen densities of $n_{\rm H,0}$ = 1.0–0.1 cm^{-3}, SNe II-P can supply 0.07–0.8 $M_\odot$ of dust to the ISM, so that SNe II-P can be primary sources of interstellar dust.

3. Dust Formation and Evolution in Type IIb/Ib SNe

Type IIb/Ib SNe (SNe IIb/Ib) are CCSNe that have lost almost all or all of their H envelopes before the explosions. Because of the less massive envelopes, SNe IIb/Ib have very high expansion velocities of the He core, resulting in much lower gas densities than in SNe II-P. The dust formation calculations in a SN Ib (Nozawa et al. 2008) and a SN IIb (Nozawa et al. 2010) show that the total masses of dust formed in SNe IIb/Ib are in the range of 0.1–1.5 $M_\odot$ and are comparable with the dust mass formed in SNe II-P. However, too low gas density in the He core of SNe IIb/Ib prevents dust grains from growing up to the radii larger than 0.01 μm. Nozawa et al. (2010) also investigate the evolution of dust in the Type IIb SNRs. They find that the newly formed grains are almost completely destroyed in the hot gas for the ISM densities of $n_{\rm H,0} \geq 0.1$ cm^{-3}. This is because the grain radii are considerably small and because the early arrival of the reverse shock at the He core causes more efficient destruction of dust. Given that both of these result from the small-mass envelopes of SNe IIb/Ib, envelope-stripped CCSNe are not expected to furnish a significant amount of dust to the ISM.

4. Dust Formation and Evolution in Type Ia SNe

Type Ia SNe (SNe Ia) are considered to be thermonuclear explosions of C–O white dwarfs that have released the H and He envelopes during their evolutions. Nozawa et al. (2011) show that at most ~0.1–0.2 $M_\odot$ of dust can condense in the ejecta of SNe Ia. On the other hand, as is the case of SNe IIb/Ib, the gas density in SNe Ia is much lower than SNe II-P, so the radii of newly formed grains are found to be below ~0.01 μm. Therefore, these small grains cannot survive the destruction within the SNRs, which allows us to conclude that SNe Ia may not be important sources of interstellar dust.

Acknowledgments. This research has been supported in part by World Premier International Research Center Initiative (WPI Initiative), MEXT, Japan, and by the Grant-in-Aid for Scientific Research of the Japan Society for the Promotion of Science (20340038, 22684004, 23224004).

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