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Early stages of grain formation studied by microgravity experiments

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Numerous amounts of tiny solid particles, called grains or dust, have been widely distributed in the interstellar environment. The tiny solid particles with the size of typically less than 100 nm in size strongly affects to the energetic balance in the interstellar environment, supplies its surface as a substrate for formation of complex molecules in a molecular cloud, and becomes a building block of a planetary system in a young stellar object. Therefore, understanding the formation process of grains formed in the gas outflow from evolved stars such as asymptotic giant blanch stars or supernovae, is crucial to unveil material evolutions in the universe. Unfortunately, however, most of grains have not been known how it forms. To understand the formation processes of grains, we performed microgravity experiments using S-520 sounding rockets of JAXA and aircrafts of Diamond Air Service Inc., Japan.

Grain analogues, such as iron, nickel, alumina, silica and so on, were synthesized from a hot vapor in a specially designed experimental chamber in a microgravity condition during a parabolic flight of the rocket or aircraft. The hot vapor gradually cools and turns into a particle via homogeneous nucleation with a very high supersaturation, which was observed by means of a double-wavelength Mach–Zehnder-type laser interferometer or a specially designed infrared spectrometer. Interferometer gives us the nucleation temperature and concentration, which are similar nucleation conditions of natural grains formed around evolved stars [1]. Time resolved infrared spectra give us intermediate phases of nucleating grain analogues. After the experiment, the S-520 rocket, regrettably, fall onto the Pacific Ocean and sink into the water together with the produced particles by design. Instead, we analyze a resulting particle by using the aircraft, although the quality and the duration of microgravity cannot be compared with a sounding rocket.

Two physical parameters of sticking probability and surface free energy of nanometer sized particles are most important to expect the characters of grains in the universe based on a nucleation model. Nevertheless, we have only a data of bulk surface free energies and expect one for sticking probability to discuss material evolution in the universe. Here, we present a sticking probability of iron nanoparticles determined based on the result of these in-situ observations and show the difficulty of the formation of metallic iron dust in the ejecta of a supernova [1]. In addition, we also present two step nucleation of alumina via a liquid phase as an intermediate based on time-resolved infrared spectra of the particles during nucleation and growth under the microgravity environment. Such infrared spectra of intermediate phases will tell us an origin of infrared features astronomically observed.

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