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海外の観測ロケットによる微小重力環境を利用した宇宙ダストの合成実験

Synthesis experiments of cosmic dust using microgravity environment obtained by overseas sounding rockets

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1. Introduction

In order to understand the processes of dust formation, we have conducted experiments to synthesize cosmic dust analogues such as silica[1)], silicate, and titanium carbide[2)] from the gas phase in the microgravity environment obtained using overseas sounding rockets of Black Brant IX of NASA and MASER 14 of SSC. To duplicate formation process of cosmic dust particles, starting material is thermally evaporated in gas atmosphere, which decreases mean free path. Otherwise, evaporated atoms/molecules directly hit to a chamber wall and just make a thin film. When the experiment performs on the ground, strong thermal convection is generated and nucleation environment becomes inhomogeneous.

On the other hand, in microgravity experiments, dust forms without disturbing the nucleation environment because the density difference convection is suppressed dramatically. Then, very uniform environment can be obtained, and nucleation occurs homogeneously in very high supersaturation. In addition, since the produced dust analogues suspend in the nucleation chamber for a relatively long time, spectral changes from the evaporation to the particle temperature cools can be measured in situ.

2. Experiments

In addition to the S-520 sounding rockets of JAXA for two times[3-4)], three overseas sounding rocket experiments have been conducted so far. The results indicate that non-classical nucleation must be taken into account to understand dust formation. Non-classical nucleation is an initial process of crystallization, which has recently become a hot topic in the field of crystal growth[e.g.5,6)]. Traditionally, crystals formed from the gas phase are thought to nucleate their seed crystals directly from atoms or molecules (classical nucleation). Non-classical nucleation is a nucleation process that goes beyond the conventional picture of nucleation, in which polymorphs compete[7)], crystal nuclei fuse with each other[2,8)], and formed nanoparticles become building blocks of the resulting particle[9)], for instance.

3. Results

For example, in an experiment to synthesize carbonaceous particles with a titanium carbide core, one of the pre-solar particles found in primitive meteorites, it was found that titanium carbide does not need to condense first, but that the multi-step process of homogeneous nucleation of carbon, heterogeneous nucleation of titanium carbide, nucleus fusion, and titanium diffusion can be used to form titanium carbide core-carbon mantle particles are formed (Figure 1) [2]. This is in complete contrast to the intuition that homogeneous nucleation and growth of titanium carbide must first occur, followed by heterogeneous nucleation of carbon. The presentation will include a discussion of the generality of the multi-step nucleation process.

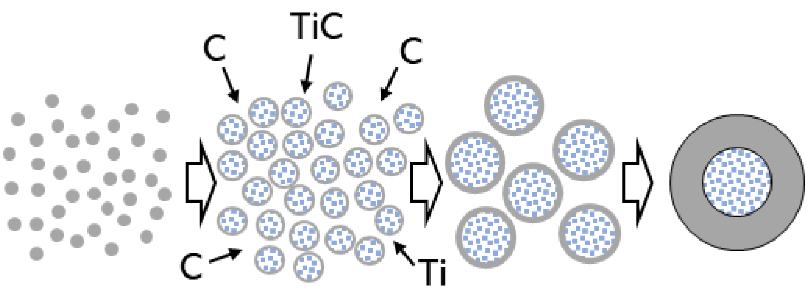

Figure 1. Schematic diagram of the formation process of core-mantle particles. Homogeneous nucleation of carbon occurs in a super-supersaturated state. While heterogeneous nucleation of titanium carbide occurs on its surface, the particles become larger and fewer in number as they fuse with each other. Internal diffusion of molecules forms a core of titanium carbide.

References

1) Y. Kimura, K. K. Tanaka, Y. Inatomi, F. T. Ferguson and J. A. Nuth III: Inefficient Growth of SiOx Grains: Implications for Circumstellar Outflows. The Astrophysical Journal Letters, **934** (2022) L10, DOI: 10.3847/2041-8213/ac8002.
2) Y. Kimura, K. K. Tanaka, Y. Inatomi, C. Aktas and J. Blum: Nucleation experiments on a titanium–carbon system imply nonclassical formation of presolar grain. Science Advances, **9** (2023) eadd8295, DOI: 10.1126/sciadv.add8295.
3) Y. Kimura, K. K. Tanaka, T. Nozawa, S. Takeuchi and Y. Inatomi: Pure iron grains are rare in the universe. Science Advances, **3** (2017) e1601992, DOI: 10.1126/sciadv.1601992.
4) S. Ishizuka, Y. Kimura, I. Sakon, H. Kimura, T. Yamazaki, S. Takeuchi and Y. Inatomi: Sounding-rocket microgravity experiments on alumina dust, Nature Communications, 9 (2018) 3820, DOI: 10.1038/s41467-018-06359-y.
5) J. J. De Yoreo, P. U. P. A. Gilbert, N. A. J. M. Sommerdijk, R. L. Penn, S. Whitelam, D. Joester, H. Zhang, J. D. Rimer, A. Navrotsky, J. F. Banfield, A. F. Wallace, F. M. Michel, F. C. Meldrum, H. Cölfen and P. M. Dove: Crystallization by particle attachment in synthetic, biogenic, and geologic environments. Science 349 (2015) 6760.
6) P. G. Vekilov, Crystallization tracked atom by atom. Nature, 570 (2019) 450.
7) Y. Kimura, H. Niinomi, K. Tsukamoto and J., M. García-Ruiz: In Situ Live Observation of Nucleation and Dissolution of Sodium Chlorate Nanoparticles by Transmission Electron Microscopy. Journal of the American Chemical Society, 136 (2014) 1762. DOI: 10.1021/ja412111f.
8) Y. Kimura, H. Miura, K. Tsukamoto, C. Li and T. Maki: Interferometric in-situ observation during nucleation and growth of WO_3 nanocrystals in vapor phase. Journal of Crystal Growth. 316 (2011) 196. DOI: 10.1016/j.jcrysgro.2010.12.074.
9) S. Ishizuka, Y. Kimura, S. Yokoi, T. Yamazaki, R. Sato and T. Hama: Self-Assembly of MoO_3 Needles in Gas Current for Cubic Formation Pathway. Nanoscale, 9 (2017) 10109–10116. DOI: 10.1039/C7NR02613G.