Development of a Large-Area Dust Detector Using Electric Field Probes for In-situ Measurement of Hypervelocity Micro-Dust Impacts

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Understanding the distribution and physical properties of cosmic dust is crucial for elucidating the growth processes of stars and the evolutionary history of planetary systems. Large micro-dust particles with radii exceeding 10 μm serve as key indicators of these processes. The classical model by Grün et al. (1985) [1] has established the collisional balance of the meteoritic complex, yet the supply processes and distribution of these larger grains remain a subject of ongoing discussion. Accurate modeling of this distribution is also vital for reducing foreground noise in infrared astronomy, as demonstrated by Kelsall et al. (1998) [2]. Furthermore, the detection of large interstellar grains, as discussed by Altobelli et al. (2016) [4], is critical for verifying interstellar material processing and even hypotheses related to panspermia (Wickramasinghe, 2010) [5]. However, due to their low spatial density, conventional detectors often lack the necessary sensing area to collect statistically significant data. To address this, we propose a lightweight, large-area detection method using electric field probes to measure the plasma generated by hypervelocity impacts.

The sensing principle focuses on the phenomenon of impact ionization. When a dust particle impacts a target at hypervelocity, it generates a plasma cloud. The resulting charge separation induces a transient change in the surrounding electric field, which can be captured as a voltage pulse by an antenna-like electric field probe. Unlike traditional metal-target detectors that rely on heavy shielding or specific materials, this method allows for a significant increase in the effective sensing area while maintaining a low mass budget, which is ideal for deep-space exploration missions.

The experimental phase of this research is conducted in collaboration with the Japan Aerospace Exploration Agency (JAXA). Utilizing the two-stage light-gas gun facility at the JAXA Sagamihara Campus, we perform hypervelocity impact experiments in the velocity range of 1 to 7 km/s. By analyzing the characteristics of the induced electric field signals—such as rise time and peak amplitude—we establish a quantitative correlation between the signal profile and the physical parameters of the dust, specifically mass and velocity. Furthermore, these experimental results are integrated with impact ionization models to develop an estimation algorithm capable of extrapolating data to hypervelocity regimes up to 80 km/s, typical of interstellar dust encounters.

The presentation will also discuss the optimization of antenna geometry to enhance detection sensitivity and the implementation of multi-signal discrimination logic to filter out non-dust events, such as cosmic ray showers. This research provides a fundamental engineering basis for the next generation of dust observation instruments, contributing to both space science and the mitigation of risks posed by space debris to orbiting spacecraft.