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FOSSIL: Fragments from the Origins of the Solar System and our Interstellar Locale

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Abstract

Interplanetary and interstellar dust particles (IDP and ISD) continually bombard the Earth. They ablate in the atmosphere, and their trajectories change due to drag forces by the time ground based optical and/or radar observations could fully characterize them. These particles carry valuable information about their parent bodies that can now be fully harvested by in situ dust measurements, using newly developed instrumentation. Placing dust instruments onboard a near-Earth spacecraft will revolutionize our understanding of the composition of interstellar and interplanetary dust, contributing to our fundamental understanding of the evolution of our solar system, and will improve our dust hazard models for the safety of crewed and robotic missions to Mars and other destinations.

1. Interstellar Dust

The observations of the inward transport of interstellar dust [1] provide a unique opportunity to explore dusty plasma processes throughout the heliosphere. The flux, direction, and size distribution of interstellar dust can be used to test our models about the large-scale structure of the heliospheric magnetic field, and its temporal variability with solar cycle [2]. Interstellar dust particles are entrained in the flow of interstellar gas across our solar system and can be identified by their narrow speed distribution and directionality [1].

2. Interplanetary Dust (IDP)

The orbital elements of dust particles that are generated, for example, by active comets; by impacting dust onto the surfaces of airless bodies; or by collisions between asteroids, are initially similar to their parent bodies. Collections of such particles form meteoroid streams. Depending on the size of these grains, their initial orbital elements will change and randomize over timescales of centuries or longer, and they become part of the sporadic background of meteoroids. In general, long period comets (LPC) likely come from the Oort Cloud, and short period comets likely originate from the Kuiper Belt. Main belt asteroids have moderate inclinations, and nearly circular orbits. Hence, the orbital elements of the offspring dust particles from comets and asteroids can be used to identify their parents.

3. Instrumentation

FOSSIL is envisioned to carry multipole copies of the Dust Experiment (DEX) instrument. DEX is an in situ, high-resolution compositional dust analyzer developed specifically for the detection and analysis of interstellar dust (ISD) and interplanetary dust particles (IDP). It measures the dust speed and mass distributions, as well as its elemental and chemical composition [4]. It is based on the proven measurement method of Cassini's Cosmic Dust Analyzer (CDA) instrument [5]. Compared to CDA, however, it provides a larger effective target area to collect a statistically significant number of dust impacts and provides a drastically higher mass resolution due to its use of a unique ion-optics design. Individual dust particles entering the instrument pass through a set of grid electrodes and impact a 0.5 μm thick target layer of high-purity rhodium. A charge sensitive amplifier (CSA) attached to the target measures the impact-generated charge which is a function of the particle's mass and speed. A mass spectrum is obtained for each particle from the time-of-flight (TOF) analysis of the impact generated atomic and molecular ions. The target is biased at +3 kV to provide positive ion acceleration, and reflectron type ion optics is used to enable resolving powers in excess of m/dm > 200. The electrostatic field is shaped by a set of biased rings and one curved grid electrode to provide spatial and temporal focusing of the accelerated ions. The centrally located ion detector is a single plate, 40 mm diameter, small pore-size microchannel plate detector with a high dynamic range and sensitivity even for minor species. DEX records a wide mass range of 1 – 500 u to identify elemental and molecular ions and to reveal the chemical and mineralogical makeup of impacting particles. DEX may also be implemented with a negative ion detection mode that could deliver critical new information of the makeup of ISD/IDP particles.

Operationally, DEX is an event-driven instrument. A trigger for data acquisition is derived from the impact charge signals detected on the target, the ion grid, or the ion detector. The TOF spectra are recorded at a rate of 250 MS/s on two analog channels from an unevenly split anode behind the microchannel plate (MCP) detector achieving a high dynamic range. The impact charge and auxiliary signals are sampled at 12.5 MHz Each trigger event is time-stamped, post-processed, and checked for validity before data compression. The DEX low-mass mechanical design consists of a simple aluminium shell structure that provides support for the biased electrodes of the TOF analyser and the grids over its aperture. The centrally located ion detector, along with the front-end CSAs are integrated into the bottom of the instrument. The electronics box (not shown), housing the high- and low-voltage power supplies, the digital and processing boards, is mounted near the instrument. The interpretation of the measured impact spectra is supported by laboratory calibration measurements using analog dust sample materials and the DEX engineering prototype [6,7].

4. Summary and Conclusions

The DEX instrument is capable of measuring the mass, charge, composition, and velocity vector of impacting dust particles. By deriving the orbital elements of dust particles their source regions can be identified. This presentation will summarize the scientific rationales for the ***FOSSIL*** mission concept to carry the DEX instruments onboard a proposed Earth orbiting spacecraft on a highly elliptic trajectory to mitigate near-Earth environment interferences. ***FOSSIL*** will explore the diversity of the chemical makeup of a broad range of bodies in our solar system and beyond, offering a powerful approach to testing the genetic relationships between small body reservoirs.

References

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