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Dust simulations for the Destiny$^+$ mission to (3200) Phaethon

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Abstract

The JAXA/ISAS Destiny$^+$ spacecraft will be launched to the active asteroid (3200) Phaethon in early 2023. Among the proposed core payload is an in-situ dust instrument based on the Cassini Cosmic Dust Analyzer (Srama et al., 2011). We use the ESA Interplanetary Meteoroid Engineering Model (IMEM, Dikarev et al., 2005a,b), and the interstellar dust module of the Interplanetary Meteoroid environment for EXploration model (IMEX; Sterken et al., 2013; Strub et al., 2018) to study detection conditions and fluences of interplanetary and interstellar dust with a dust analyzer on board DESTINY$^+$.

1. The Destiny$^+$ Mission

The DESTINY$^+$ (Demonstration and Experiment of Space Technology for INterplanetary voYage Phaethon fLyby with reUSable Probe) mission has been selected by the Japanese space agency JAXA/ISAS (Kawakatsu and Itawa, 2013; Arai et al., 2018). The mission target is the active near-Earth asteroid (3200) Phaethon. The spacecraft will be launched in early 2023, a close flyby of Phaethon is planned for August 2026 at a heliocentric distance of 0.87 AU.

One of the science instruments on board will be the DESTINY$^+$ Dust Analyzer (DDA; Kobayashi et al., 2018). DDA is an upgrade of the Cassini Cosmic Dust Analyzer (CDA) which very successfully investigated dust throughout the Saturnian system (Srama et al., 2011). DDA will be an impact ionization time-of-flight mass spectrometer capable of analyzing submicron and micron sized dust grains with a mass resolution of $m/\Delta m \approx 150$. DDA will measure the mass, velocity vector, charge, elemental and isotopic composition of impacting dust grains during its four years of interplanetary voyage between Venus' and Earth's orbits, as well as during the close fly-by at Phaethon.

2. Dust Simulations

We study the detection conditions of interplanetary and interstellar dust particles for the DDA instrument. For interplanetary dust, we use the Interplanetary Meteoroid Engineering Model (IMEM; Dikarev et al., 2005a,b). We simulate interstellar dust with the interstellar dust module of the Interplanetary Meteoroid environment for EXploration model (IMEX; Sterken et al., 2012, 2013; Strub et al., 2013, 2018). Both models simulate dust densities in interplanetary space, and they are the most up to date models for the dynamics of micrometer and sub-micrometer sized dust in the inner solar system presently available. The close fly-by at Phaethon is not considered in this work.

The IMEM model is based on infrared observations of the zodiacal cloud by the Cosmic Background Explorer (COBE) DIRBE instrument, in-situ flux measurements by the dust detectors on board the Galileo and Ulysses spacecraft, and the crater size distributions on lunar rock samples retrieved by the Apollo missions. It simulates the dynamics of cometary and asteroidal dust in the planetary system.

The IMEX interstellar dust (ISD) model consistently follows the dynamics of micrometer and submicrometer sized interstellar particles ($0.05\,\mu\mathrm{m}$ to $5\,\mu\mathrm{m}$) that are exposed to solar gravity, solar radiation pressure and the time-varying interplanetary magnetic field (IMF). In the model, the dust density in the solar system is calibrated with the Ulysses interstellar dust measurements (Strub et al., 2015) which is the largest continuous interstellar dust data set from a dedicated dust instrument presently existing. Due to the variable IMF, the IMEX ISD model is time-dependent, contrary to IMEM. We use IMEM and IMEX to study the time-resolved flux and dynamics of interplanetary and interstellar dust particles in the inner solar system and the requirements to detect these particles with DDA.

Trajectory data for DESTINY$^+$ were provided by JAXA/ISAS (data set 4800014). The trajectory covers a time period of 1474 days, from 24 September 2024 to 07 October 2028, beginning with the spacecraft's escape from Earth orbit.

3. Results

- The dust flux, average impact speed and impact direction of interplanetary and interstellar dust grains onto DDA are strongly variable in time. The modulation is largely due to the spacecraft motion around the Sun, but also due to size-dependent forces acting on the grains, leading to grain size-dependent variations in dust spatial density.
- A statistically significant number of interplanetary and interstellar dust particles can be detected and analysed in-situ with DDA during the interplanetary cruise of DESTINY$^+$, which is presently planned to last four years.
- Impact speeds of interstellar impactors can exceed $60\,\mathrm{km\,s^{-1}}$, while those of interplanetary grains are in the range $5-20\,\mathrm{km\,s^{-1}}$.
- During long mission periods the grain impact speed can be used as a descriminator between interstellar and interplanetary particles and likely also to distinguish between cometary and asteroidal grains.
- The average approach direction of small ISD grains ($\lesssim 0.3\,\mu\mathrm{m}$) is rather independent of grain size.
- Larger ISD grains which are dominated by gravity can be preferentially detected in the gravitational focussing region downstream of the Sun. The approach direction of these grains significantly differs from that of the smaller grains.

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