DESTINY+ MISSION: FLYBY OF GEMINIDS PARENT ASTEROID (3200) PHAETHON AND IN-SITU ANALYSES OF DUST ACCRETING ON THE EARTH .

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Introduction: About 40,000 metric tons per year of extraterrestrial dust accrete onto the Earth [1]. While carbonaceous meteorites are rare (less than 5%) among meteorite collection, interplanetary dust particles (IDPs) generally include carbon and organic materials and their carbon contents are 5-10 times richer than those for carbonaceous meteorites. Dust particles are likely major carriers of carbon and organic matters to the Earth and potentially be precursors to the terrestrial life. Extraterrestrial dust particles are derived either from cosmic dust background or from meteor showers. The former consists mostly of IDPs which originate from miscellaneous comets and asteroids, with minor interstellar dusts (Fig. 1). The latter are meteoroids transported via dust trails or streams, where dust ejected from specific comets and asteroids, whose orbits cross that of the Earth (Fig. 1).

Asteroid (3200) Phaethon is a parent body of Geminid meteor shower [e.g. 2], which is amongst the most active meteor showers. While parent bodies of meteor showers are mostly comets, Phaethon is an Apollo type asteroid with carbonaceous, B-type reflectance spectra [e.g. 3]. Recurrent dust ejection at its perihelion (0.14 au) are reported [4-6], while no coma was observed around 1.5 au [7]. The dust ejection mechanism of the active asteroid remains unknown. Na depletion is reported for Geminid meteor shower [8] and higher dust density (2.9g/cm^3) is estimated [9], both of which hints volatile depletion possibly by solar heating. Phaethon is of great interest and significance because it is a carbonaceous asteroid providing dust to the Earth via dust stream, has a break-up body, 2005 UD [10], is possibly a breakup from main-belt asteroid 2 Pallas [11], experiences extensive solar heating at a small perihelion distance, and among the largest potentially hazardous body. Due to its scientific importance, Phaethon was a potential target for previous missions, such as Deep Impact and OSIRIS-REx. However, neither sample return, nor impact experiment nor rendezvous are difficult for Phaethon with a large relative velocity due to the large eccentricity and inclination. Only viable approach for Phaethon is flyby.

Mission overview: DESTINY+ (Demonstration and Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby and dUst Science) is a mission proposed for JAXA/ISAS Epsilon class small program, currently in the pre-project phase (Phase-A) with a launch targeted for 2022.

DESTINY+ is a joint mission of technology demonstration and scientific observation. It will demonstrate high performance electric propelled vehicle technology and high-speed flyby exploration of asteroid (3200) Phaethon. DESTINY+ aims to realize high-resolution imaging during close proximity flyby, high-accuracy navigation and wide-range observation, and these implemented for multiple small bodies (multi-flyby). Engineering challenges include proximity flyby navigation with adequate risk of collision, radio-optical hybrid navigation guidance and control, and autonomous imaging based on optical information for target tracking. System design of DESTINY+ is summarized in Table 1.

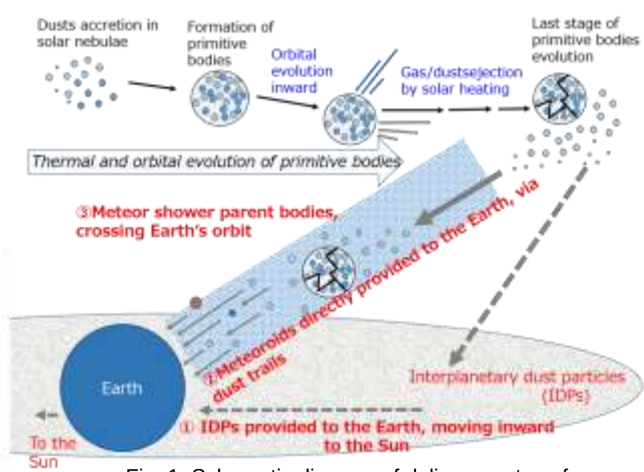

Fig. 1. Schematic diagram of delivery routes of dust accreting onto the Earth.

Table. 1. System design of DESTINY$^+$ spacecraft.

Mission Period	> 4 years
Mass	480 kg (including 60 kg Xenon and 15.4 kg Hydrazine)
Launcher	Epsilon rocket + kick motor
Trajectory	230 km x 49913 km, 30 deg. → Lunar swing-by → Phaethon transfer
Attitude control	3-axis (Error < 1 arc-min.)
Communication	X band (GaN SSPA, HGA 4 kbps, MGA 1 kbps, LGA 8 bps at 1.9 AU)
Solar Array	High-specific power light-weight paddle (138 W/kg, 4.7 kW (BOL), 2.6 kW (EOL))
Battery	Li-ion (42 Ah, 11s1p)
Propulsion	RCS (Hydrazine) + Ion thrusters (μ10 x 4)
Thermal control	Loop heat pipes, Reversible Thermal Panels
Radiation dose	Approx. 30 krad (with aluminum shield of 3-mm thick)

Science goal of DESTINY$^+$ is to understand the nature and origin of cosmic dust brought to the Earth, in the context of exogenous contribution of carbon and organics to the origin of terrestrial life. The science mission objectives are to measure physical properties (velocity, orbit, mass) and chemical composition of interplanetary and interstellar dust particles around 1 au during deep space cruising phase, and to conduct geological observation of Phaethon to understand dust ejection mechanism of active asteroid and surface compositional variation, and analyze dust particles from Phaethon during high-speed flyby (33 km/sec).

Mission profile: DESTINY$^+$ spacecraft is injected into an elliptical orbit around the Earth by an Epsilon launch vehicle and then the electric propulsion is used to raise the orbit to reach the moon. Subsequently, it escapes from the Earth's gravity sphere through multiple lunar gravity assists, and heads for Phaethon after cruising by electric propulsion in deep space, and finally conducts flyby observation. A flyby point is around descending node of Phaethon with a geocentric distance of 1.72 au and a heliocentric distance of 0.87 au. After Phaethon fly-by, DESTINY$^+$ may head for another target asteroid such as 2005 UD, a breakup body of Phaethon, as an extended mission. The summary of mission profile is shown in Table 2.

Table. 2. Mission profile of DESTINY$^+$.

	Period	Operation
1	1 month	Launched into a highly elliptic orbit (230 x 49913 km) by Epsilon rocket
2	0.5-2 years	Spiraled orbit raising by electric propulsion
3	0.5 years	Lunar swing-by
4	2 years	Phaethon transfer orbit (Aphelion 1.16 au)
5	Several days	Phaethon flyby
6	0.5-1 years	Earth swing-by transfer orbit (Perihelion 0.83 au)
7	Several days	Earth swing-by
8	T.B.D.	Transfer orbit to next target

Science payloads: DESTINY$^+$ has three science payloads, panchromatic telescopic camera (TCAP), VIS-NIR multiband camera (MCAP) and dust analyser (DDA) for science observation. The three payloads in relation to science requirements are shown in Fig. 2. Dust analyzer is developed with a heritage of Cosmic Dust Analyzer (CDA) onboard Cassini and provided by a team led by Stuttgart University [12]. TCAP and MCAP are developed by a team led by Planetary Exploration Research Center, Chiba Institute of Technology. TCAP is equipped with a tracking mirror. The observation profile during flyby and the current design of the cameras are presented by Ishibashi et al. [13].

Phaethon observation campaign: Phaethon approached the Earth as close as 10,000,000 km in December 2017. Variable observation of Phaethon, such as photometric, spectroscopic, polarimetric and radar observation were successfully conducted over the world [e.g.14, 15]. These observation data are crucial to better characterize Phaethon for further mission plan and detailed payload design for DESTINY$^+$.

References:

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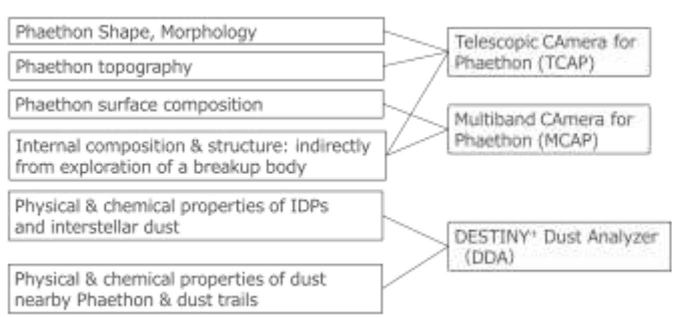

Fig. 2. Science requirements and payloads for DESTINY$^+$.