DESTINY^{+}: Technology Demonstration and Exploration of Asteroid 3200 Phaethon

September 20, 2017

ISAS/JAXA

DESTINY^{+} Overview

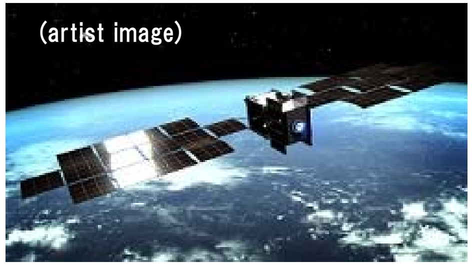
This mission is to acquire the compact deep space explorer technology, fly-by observation of a meteor shower parent body and in situ analysis of interplanetary dust for the following mission objectives.

<Science Mission>

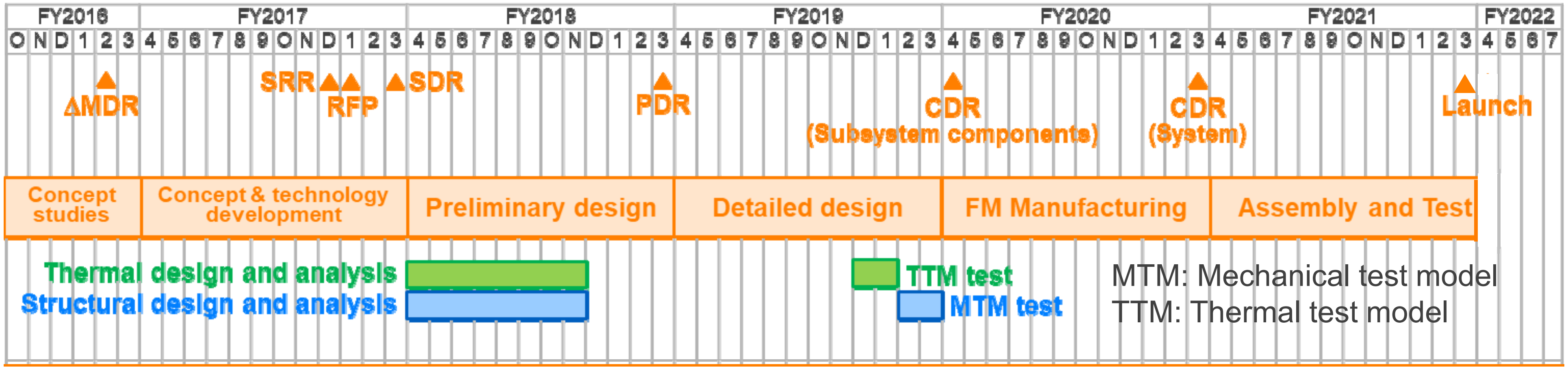
- Major Goal: Interplanetary dust particles are considered to be a major carrier of organic matter to the primordial earth enabling its habitability. Then, characterizing interplanetary dust particles arriving at the earth, and exploration of an active asteroid, a major source of interplanetary dust particles, are needed to be performed. What DESTINY+ will do are:
    - In-situ analysis of interplanetary dust particles.
    - Flyby exploration of an asteroid which is also well known as a parent body of a meteor shower.

<Engineering Mission>

- To advance space transportation technology using electric propulsion (EP) and expand its applications.
- To enhance opportunities for small-body explorations by developing innovative fly-by technologies.



Schedule (Tentative)   DESTINY^{+} will become a project in FY2018 and will be launched in 2022.



MDR: Mission definition review
SRR: System requirements review
RFP: Request for proposal
SDR: System definition review
PDR: Preliminary design review
CDR: Critical design review

Engineering Mission Objectives and Goals

DESTINY+

The engineering mission is to acquire navigation and exploration technology leading the space engineering and to contribute to the development of the next deep space mission, aiming at the following two objectives:

EMO1: Advance space transportation technology using electric propulsion (EP) and expand its applications.

EMO2: Enhance opportunities for small-body explorations by developing innovative fly-by technologies.

(EMO: Engineering Mission Objective)

Expected outcomes

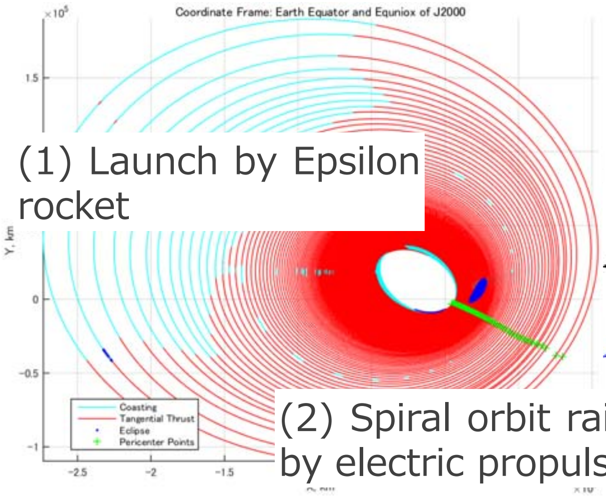
By demonstrating the deep space exploration platform using high performance electric propulsion system and compact and light weight equipment, Japan will be able to continuously conduct various deep space exploration at low cost / high frequency in the near future.

Science missions using current launch vehicles: X-ray UV from geoplasma, Energetic Neutral Atom, UV from M-type stars with planets, Integrated imaging of geoplasma, UV observation for extrasolar planets, Cosmic background radiation observation from the outer space of ecliptic plane

Science missions using bigger launch vehicles: Multiple sample return mission for NEO, Venusian climate observation by two orbiters, Martian dust observation by orbiter and airplane

Mission Profile

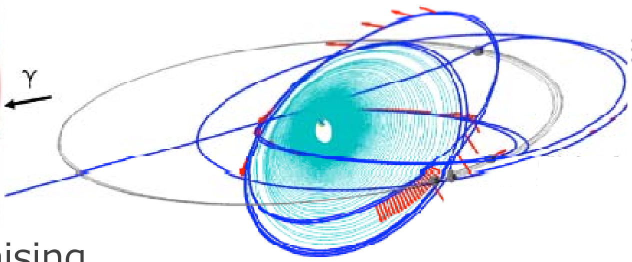
	Period	Operation Phase	Operation Events
(1)	1 month	Launch by Epsilon rocket	Initial functional checkout of spacecraft
(2)	0.5–2 year	Spiral orbit raising by EP	Escape from radiation belt, Arrival to Moon
(3)	0.5 year	Lunar swing-by	Connection to Phaethon transfer orbit
(4)	2 years	Transfer orbit to Phaethon	Sun Distance (0.75–1.00au), Earth Distance (<1.8au)
(5)	A few days	Phaethon flyby	Phaethon proximity operations, Earth Distance (1.7au)
(6)	0.5–1 year	Transfer orbit to Earth	Sun Distance (0.75–1.00au), Earth Distance (<1.9au)
(7)	A few days	Earth swing-by	Connection to the 2nd target transfer orbit
(8)	TBD	Transfer orbit to the 2nd target	



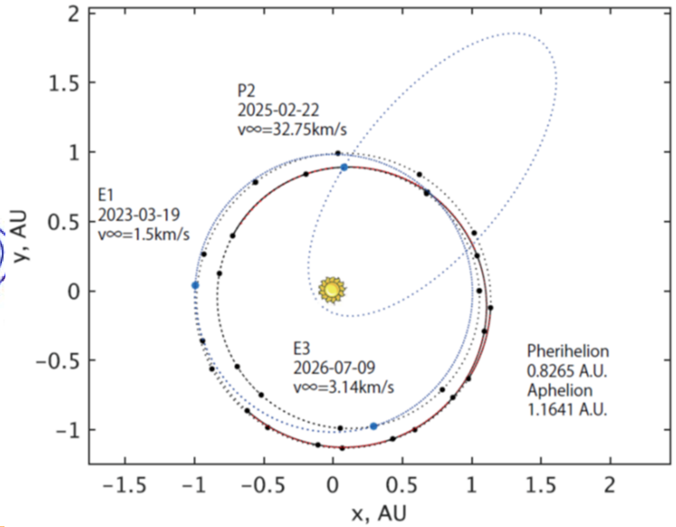
(1) Launch by Epsilon rocket

(2) Spiral orbit raising by electric propulsion

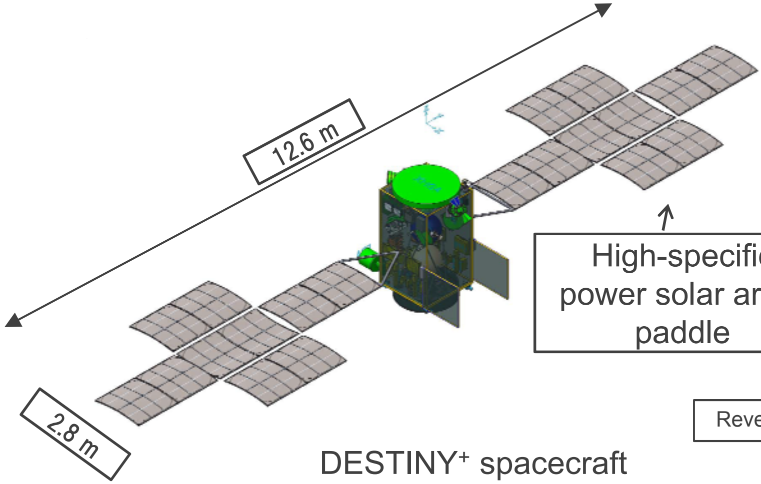
(4) Transfer orbit to Phaethon
(5) Phaethon flyby
(6) Transfer orbit to Earth



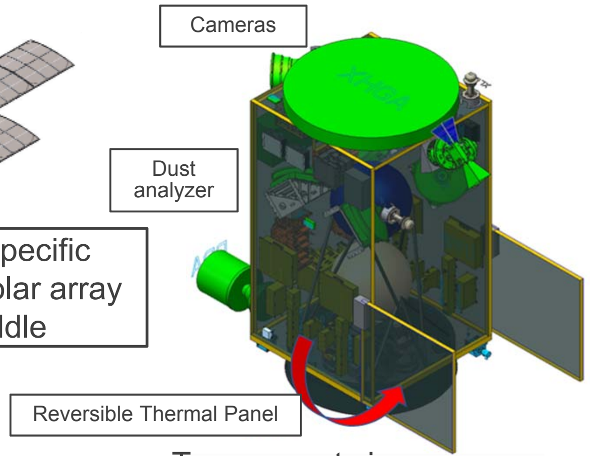
(3) Lunar swing-by



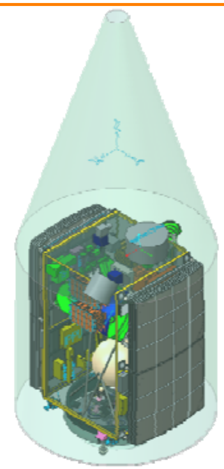
DESTINY^{+} Spacecraft System



DESTINY^{+} spacecraft
with solar array deployed



Transparent view
of spacecraft body

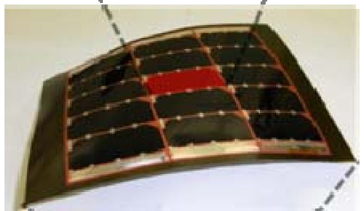


DESTINY^{+} spacecraft
onboard Epsilon rocket

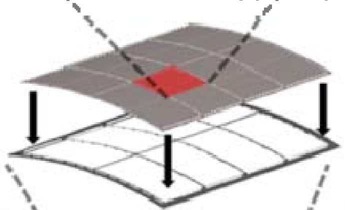
Mission period	> 4 years
Mass（Wet）	480 kg（including xenon of 60 kg and hydrazine of 15.4 kg）
Launcher	Epsilon rocket + kick motor
Trajectory	Initial: 230 km x 49913 km, 30.42 ° → Lunar swing-by → Phaethon transfer
Attitude control	3-axis (Error < 1 arc-min.)
Communication	X band (GaN SSPA, HGA 4 kbps, MGA 1 kbps, LGA 8 bps at 1.9 AU)
Solar array	High-specific power paddle (> 100 W/kg (World's highest class)), 2.3 kW (EOL)
Battery	Lithium-ion (42 Ah, 11 cells in series)
Propulsion	RCS (Hydrazine) + Ion engines（μ10 x 4）
Thermal control	Advanced devices (Deployable radiators, loop heat pipes)
Radiation dose	Approx. 30 krad (with aluminum shield of 3-mm thick)

Technology Demonstration

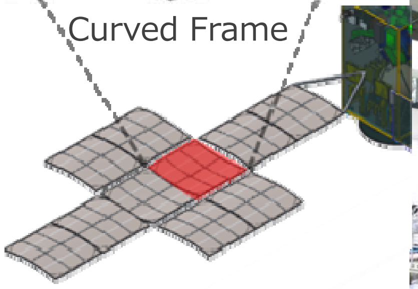
IMM 3J Solar Cell
t = 20 μm, Eff = 30.8 %



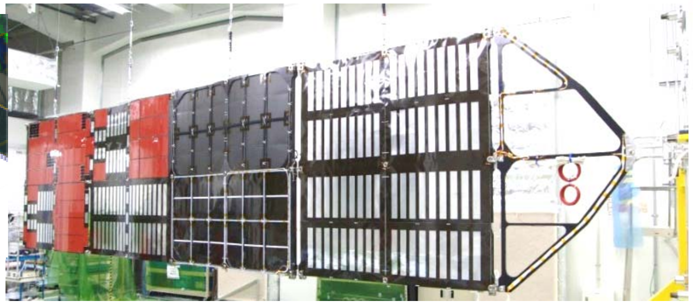
Glass-type Space Solar Sheet



Curved Frame



Light-weight Solar Array Paddle
Specific Power 138 W/kg

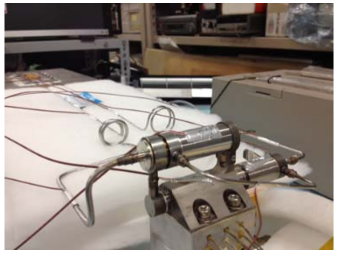


Main Paddle Deploy Test

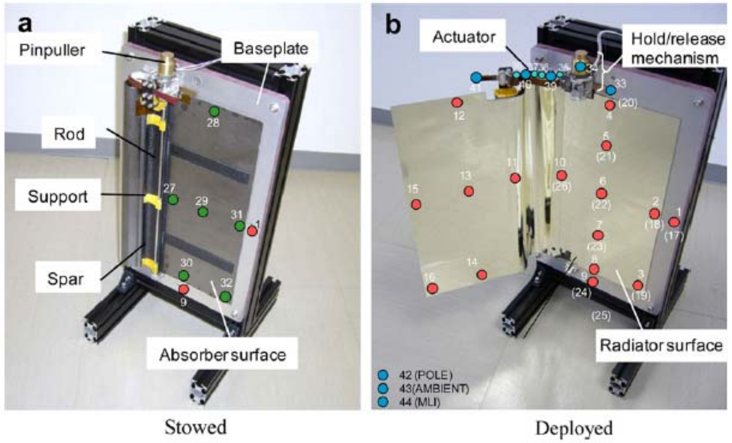
Ion Engines

HAYABUSA2(Thrust 30mN)

DESTINY$^+$(Thrust 40mN)
(Imagination)



Thermal Loop Heat Pipe

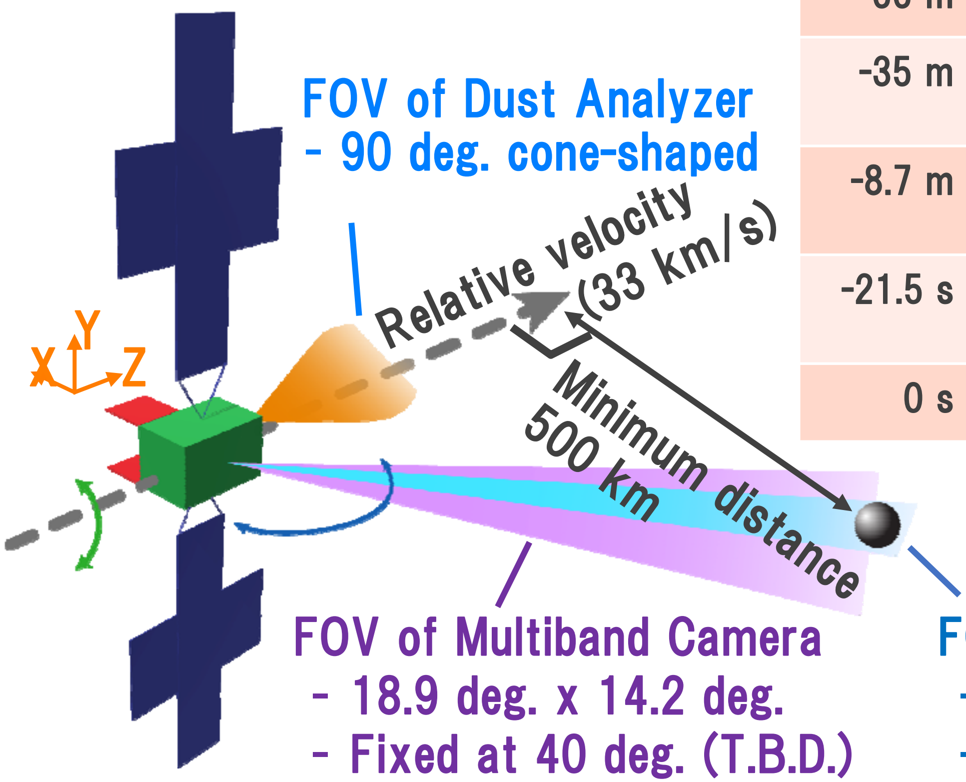


Reversible Thermal Panel

Advanced thermal control enables ion engine operation under illuminattion by sunlight in Earth orbit.

Flyby Observation of 3200 Phaethon

Time	Distance	Event
-7.3 h	860000 km	Start observing light curve
-65 m	125000 km	Detect Phaethon
-55 m	105000 km	Attitude correction
-35 m	65400 km	Start tracking Phaethon with mirror of telescopic camera
-8.7 m	17000 km	Start observation with telescopic camera
-21.5 s	868 km	Start observation with multiband camera
0 s	500 km	Closest approach to Phaethon



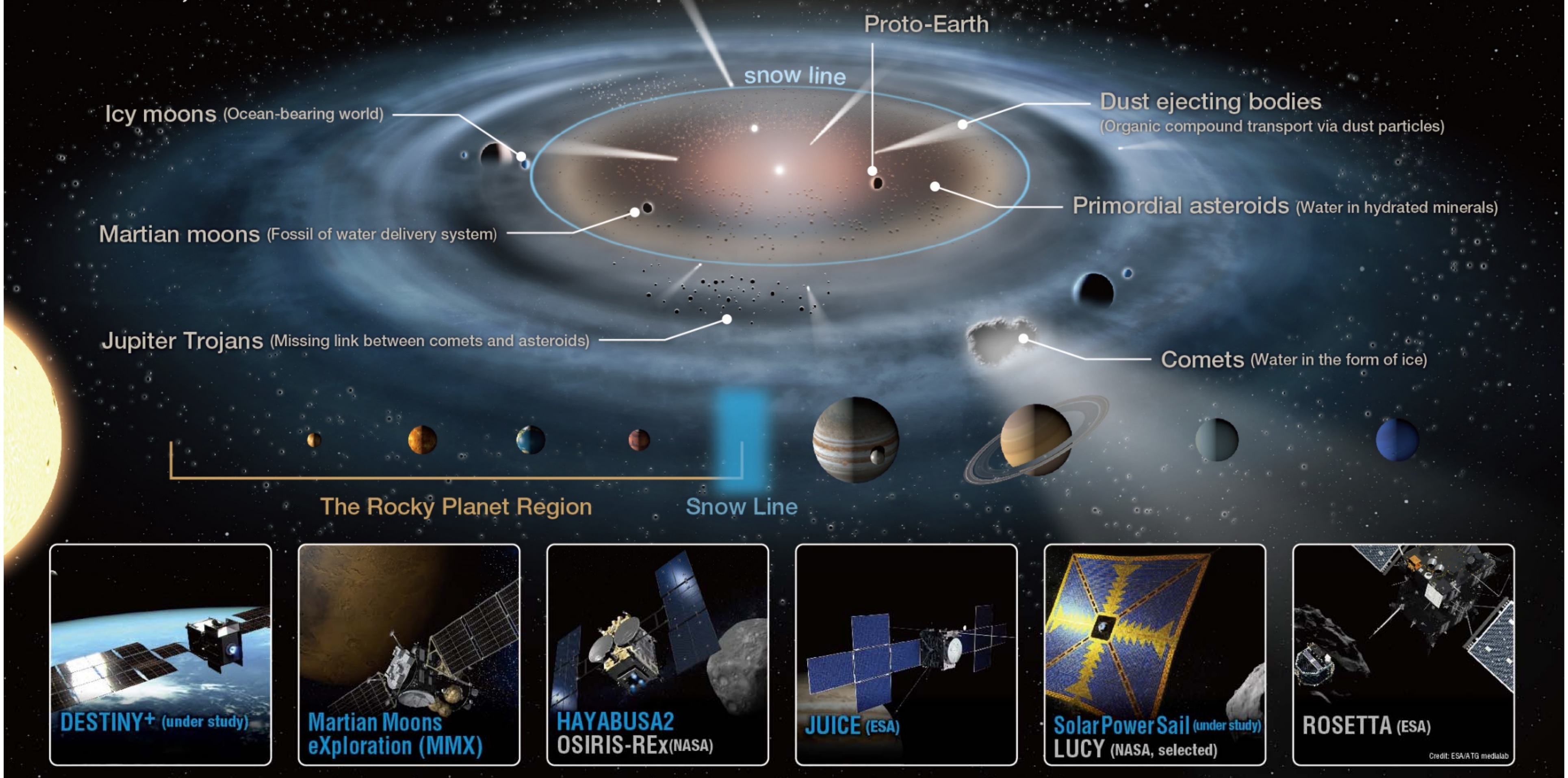
DESTINY$^+$ Scientific Background

- Primitive bodies, i.e. comets and carbonaceous asteroids, are reservoirs for organics and water.

ISAS Small Body Exploration Strategy

Many small bodies are born outside the snow line. These are initially comet-like but can evolve to show a variety of faces.
By delivering water and organic compounds, these small bodies may have enabled the habitability of our planet.

When, who and how?



The fleet of ISAS small body missions explores these questions

DESTINY^{+} Scientific Background

- Primitive bodies, i.e. comets and carbonaceous asteroids are reservoirs for organics and water.
- Organics and water need to be delivered from the outer-solar system to Earth for its habitability. The key question addressed by DESTINY^{+}:

"How can organics and related light elements, i.e. C, H, O, N be transported to Earth?"

- Key word in DESTINY^{+} science

"Cosmic dusts" as a major carrier of organics to the primordial Earth.

Cosmic dusts as major organics carriers

■ 40,000 ton/yr accretion of cosmic dust to Earth (Love & Brownlee, 1993).

■ Dusts of >100 μm are melted or vaporized during atmospheric entry

■ Dust of <100 μm reach ground at the rate of 2,500 ton/yr .

→～50 times greater mass than meteorites

■ Smaller sizes: key to remain unaltered

■ lab analyses show:

- High carbon content (5-10 x carbonaceous chondrites)

- Organic matters, interstellar dust included.

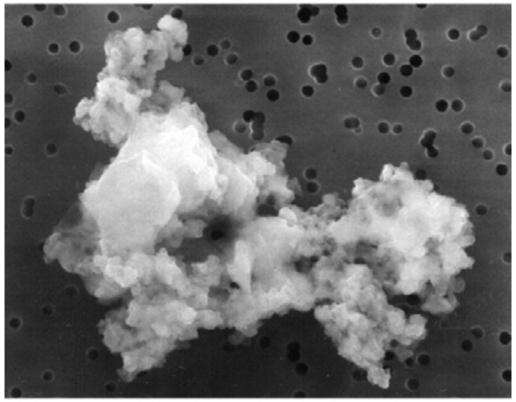


Image: NASA (FOV:10um)

□ Chemical data available from dust

Particles collected in the stratosphere and on the ground, but no clue for their origin.

□ Origin?:

Short-period comets, asteroidal bands, or active asteroids?

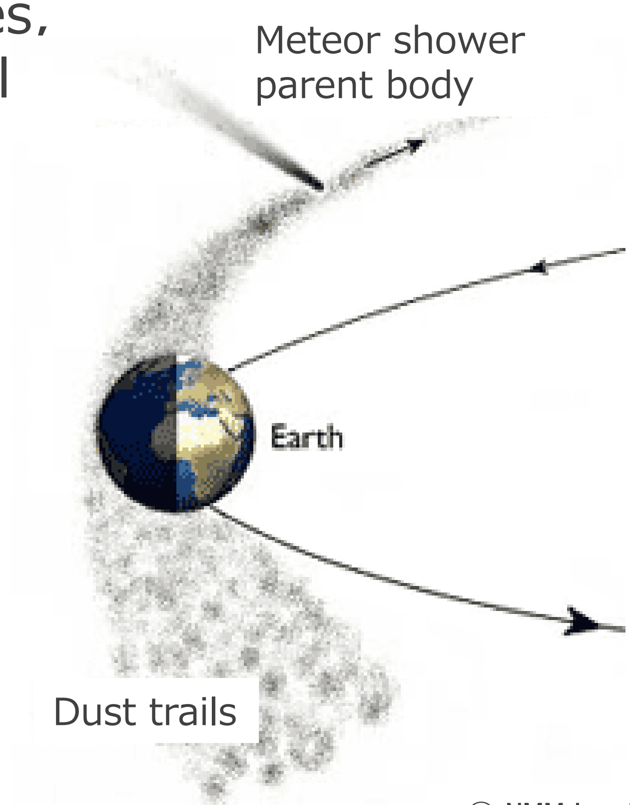
Scientific rationale of DESTINY$^+$

- Understanding meteor shower parent bodies, which are **known dust sources**, are critical in addressing the fundamental question on **transport of extraterrestrial organics to Earth**.

- Meteor shower parent bodies are either comets or **active asteroids**.

Great results from Rosetta on the former. The latter has not been explored yet despite great science interest.

- Meteor shower parent bodies cross the Earth's orbit and are thus **potentially hazardous bodies**. There is a **space guard context** in their exploration.



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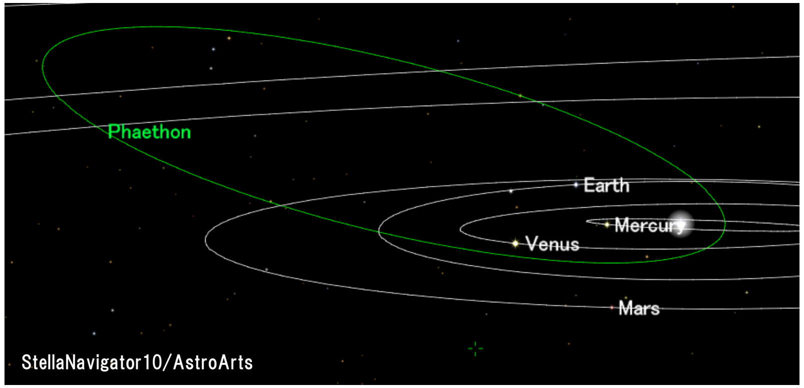
http://certificate.ulo.ucl.ac.uk/modules/year_one/ROG/comets_meteors_meteorites/conWebDoc.13857_files/Comet-debris-200.gif

Science mission scenarios of DESTINY+

- Conduct in-situ dust analyses of dusts during cruising in interplanetary space.
- Flyby Phaethon at its descending node, in-bound orbit toward its perihelion.
- Phaethon is
  - Parent body of Geminid meteor shower
  - Active asteroid
  - Carbonaceous asteroid
  - Largest potentially hazardous asteroids



1. To characterize interplanetary dust particles at 1 au by in-situ analyses: physical properties (velocity, orbit, mass) and chemical composition.
2. To understand dust ejection mechanism by studying geologic features of the active asteroid via remote sensing upon flyby.
3. To characterize dust particles ejected from the known source of Phaethon during its flyby campaign period.

Science mission scenarios of DESTINY$^+$

We have been talking about organic transport within the solar system.
A question of different but similar kind: How was carbon (C) brought in to the solar system upon its formation?

There is an idea that 70 percent of C came in the form of interstellar dust particles, not in the form of gas. This remains to be understood.

DESTINY+ also

④ Characterize interstellar dust particles that access the neighborhood of Earth in the solar system.

Science Payloads (under evaluation)

Link with science mission requirements

SSR1.1 In-situ analyses of cosmic dusts
SSR1.1.1 In-situ analyses of interplanetary dust particles
SSR1.1.2 In-situ analyses of interstellar dust particles

SSR1.2 In-situ analyses of nearby Phaethon and dust trails

SSR2.1 Shape of Phaethon

SSR2.2 Surface topography of Phaethon

SSR2.3 Surface composition of Phaethon

SSR2.4 Internal structure and composition of Phaeton

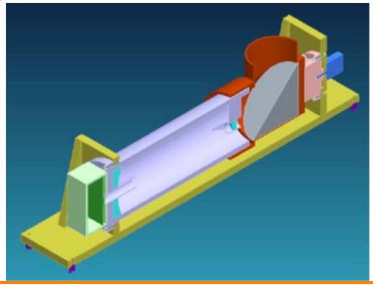
SSR2.4.1 Multi-flyby of break-up body of Phaethon (2005UD)

DESTINY Dust Analyzer（DDA)

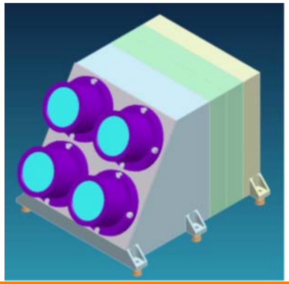
DDA model image

Telescopic Camera for Phaethon (TCAP)

Multiband Camera for Phaethon (MCAP)



TCAP model image

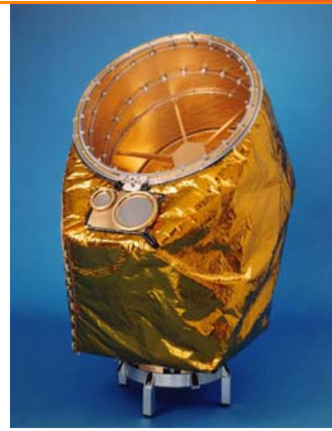


MCAP model images

DESTINY+ Dust Analyzer (DDA)

- Capable of in-situ analysis of mass, speed, direction and composition
- Advantage for high-speed dust measurement
- Larger sensitive area for effective dust detection and analyses
- Heritage and refined from Cassini Cosmic Dust Analyzer (CDA).
- Dust Analyzer developed by Stuttgart Univ. (PI: Prof. Ralph Srama)

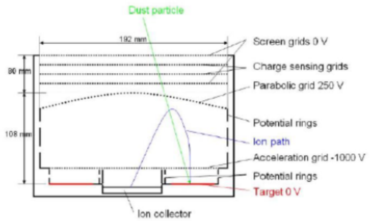
	CDA	DDA
Sensor	Dust analyzer + charge detection	Dust analyzer + Trajectory detection
Measurable parameters	Mass, speed, charge, flux, composition	Mass, speed, charge, flux, composition and arrival direction
Parameters		
Mass range	10^{-15} g to 10^{-9} g	10^{-16} g to 10^{-6} g
Speed range	2 to 40 km/s (10%)	5 to 100 km/s (<10%)
FOV	±28°	±45°
Arrival direction	N/A	<10°
Sensitive area	0.007 m^2	0.011 m^2
Mass resolution	$M/\Delta M$ >20-50	$M/\Delta M$ >150
Charge	2×10^{-15} to 5×10^{-13} C	> 10^{-16} C


Cassini CDA

Europa clipper SUDA

Images are provided by Stuttgart Univ.

Beyond CDA: Analyzer and trajectory sensor



- Dust speed (Trajectory Sensor)
- Dust trajectory (Trajectory Sen.)
- Dust mass (Trajectory Sensor)
- Dust charge (Trajectory Sensor)
- Dust composition (Mass Analyser)
- Dust flux

How to determine ISD,
is trajectory sensor necessary?

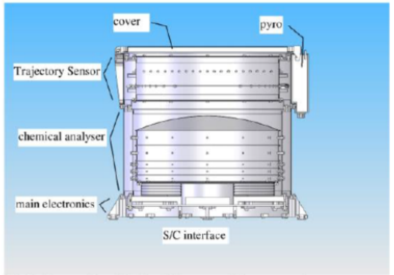


Fig. 6: Cross section of the Dust Telescope and its components.

M/dM >100 (very conservative, to be improved by increasing size of the instrument)

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Slide credit: Stuttgart Univ.

Summary

DESTINY^{+} is a small mission whose high science values are enabled by engineering. Scientific mission objectives are

1. To characterize interplanetary dust particles (including interstellar dusts) at 1 au, by in-situ dust analyses of the physical properties (velocity, orbit, mass) chemical composition.
2. To understand dust ejection mechanism of an active asteroid by studying its geology.
3. To characterize dust particles ejected from Phaethon during its flyby campaign.

Engineering mission objectives are

1. To advance space transportation technology using electric propulsion (EP) and expand its applications.
2. To enable frequent opportunities for small-body explorations by developing innovative fly-by technologies.