DESTINY PLUS^{+}

Demonstration and Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby with reUSable probe

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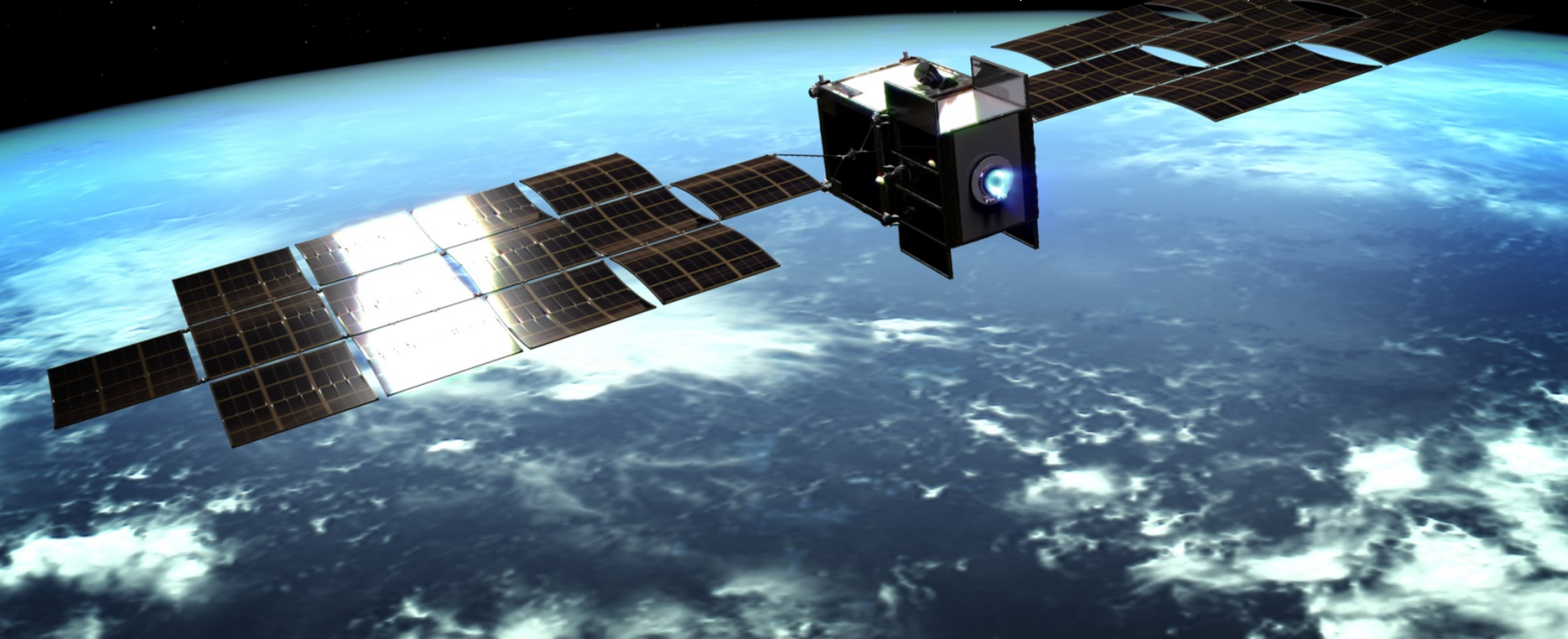
Phaethon mission science team (Japanese Society of Planetary Sciences)

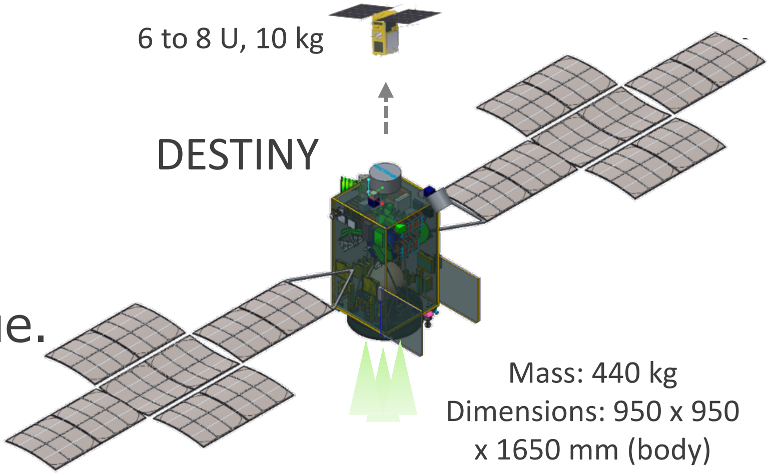


Overview of DESTINY$^+$

★ Candidate mission of JAXA/ISAS Epsilon-class small program currently under Phase-A study.

★ Mission to acquire leading technologies to enhance future deep space exploration technique.

PROCYON mini

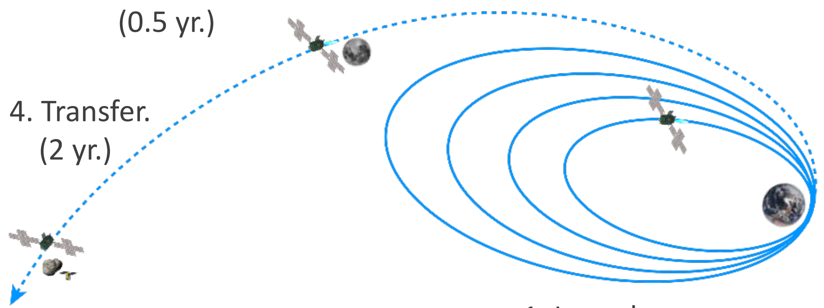


Mass: 440 kg
Dimensions: 950 x 950 x 1650 mm (body)

Epsilon Rocket

Low cost solid propellant rocket.

★ Flyby asteroid 3200 Phaethon, a parent body of Geminid meteor shower, using a small satellite with a cubesat, which are launched by Japanese Epsilon rocket.



DESTINY^{+} Mission Concept

EMO1
Advanced deep-space transportation technology

EMO2
Compact avionics to improve deep-space probe capabilities

SMO1
Flyby of Asteroid 3200 Phaethon

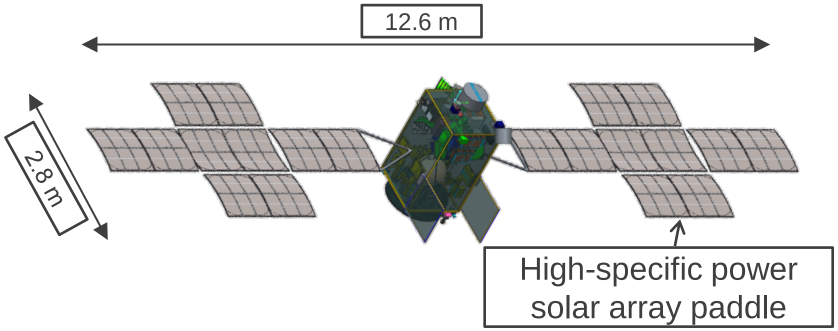
SMO2
Dust observation of IDP, ISD,dust trail, nearby Phaethon

EMO3
Innovative flyby technologies to enhance opportunities for small-body explorations (with PROCYON mini)

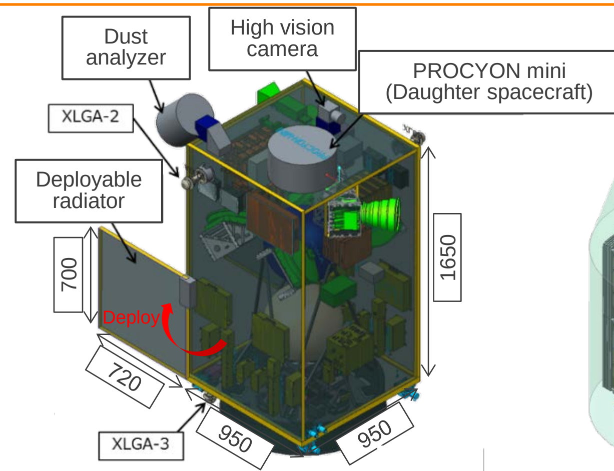
Joint mission of technology demonstration and science

EMO: Engineering Mission Objective
SMO: Scientific Mission Objective

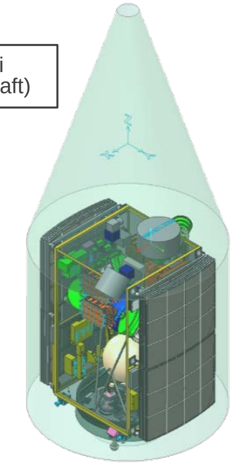
DESTINY Spacecraft System



DESTINY$^+$ spacecraft
with solar array deployed



Transparent view
of spacecraft body



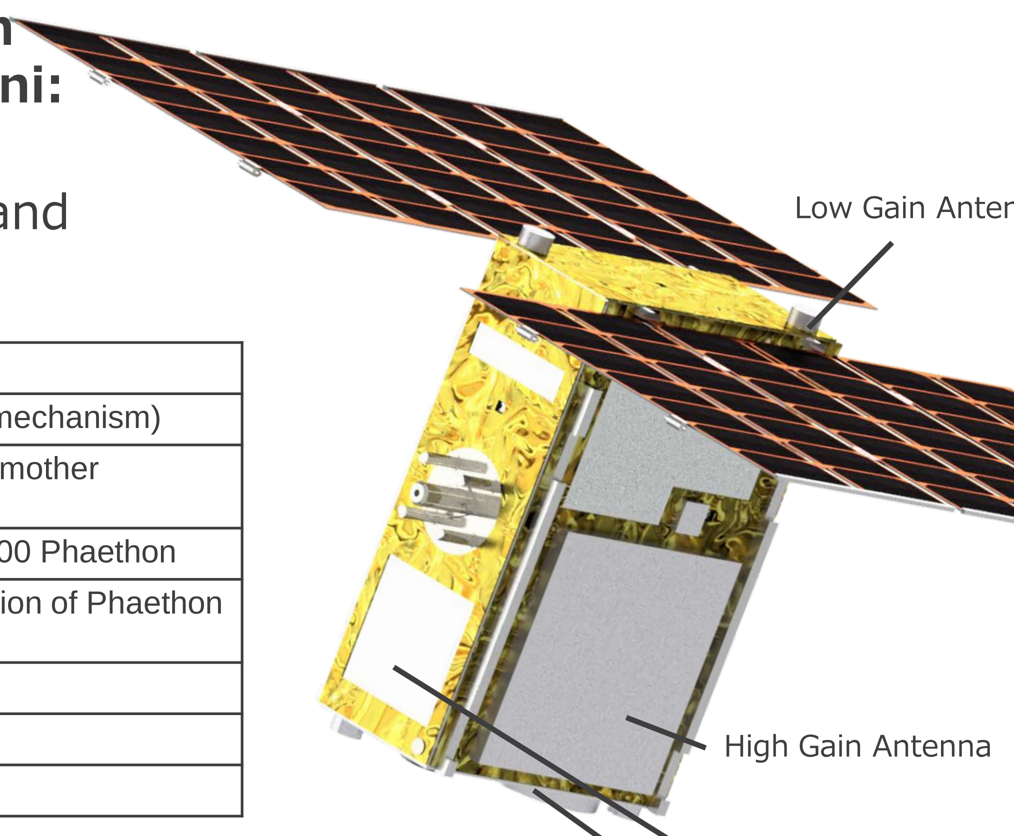
DESTINY$^+$ spacecraft
onboard Epsilon rocket

Mission period	> 4 years
Mass（Wet）	440 kg（including xenon of 60 kg and hydrazine of 15.4 kg）
Launcher	Epsilon rocket + kick motor
Trajectory	Initial: 230 km x 52708 km, 30.44 ° → Lunar swing-by → Phaethon transfer
Attitude control	3-axis (Error < 1 arc-min.)
Communication	X band (GaN SSPA on Mother spacecraft + Low-cost device on Daughter spacecraft)
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)

PROCYON mini Spacecraft System

PRoximate Object Close flYby with Optical Navigation (PROCYON) mini:

A miniature deep space probe with independent spacecraft bus system and scientific instruments.



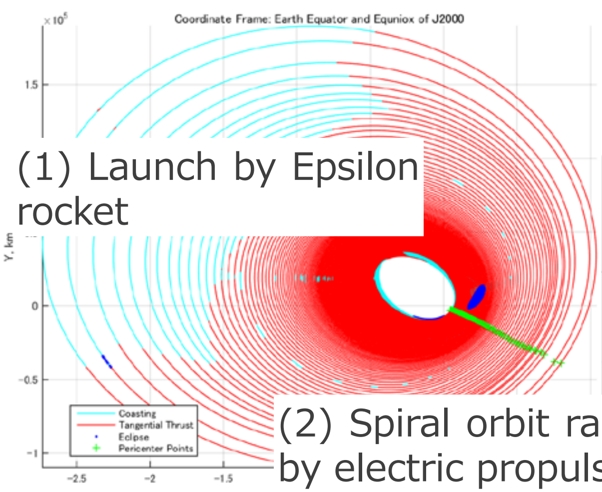
Size	6U – 8U CubSat (1U: 10x10x10 cm)
Mass（Wet）	15 kg (< 20 kg with separation/docking mechanism)
Launcher	Epsilon rocket + kick motor + DESTINY mother spacecraft
Trajectory	Heliocentric orbit for flyby of Asteroid 3200 Phaethon
Mission	Very low-altitude (<50km) flyby observation of Phaethon Rendezvous and docking in deep space
Attitude control	3-axis
Communication	X band
Propulsion	Gas-jet (Isp = 20–100 s)

PROCYON mini will be developed based on the **heritage from the two missions**:

- **PROCYON**
  the first interplanetary micro-satellite launched with Hayabusa-2 (2014)
- **EQUULEUS**
  6U CubeSat mission to fly to Earth-Moon L2 onboard SLS EM-1 (2019)

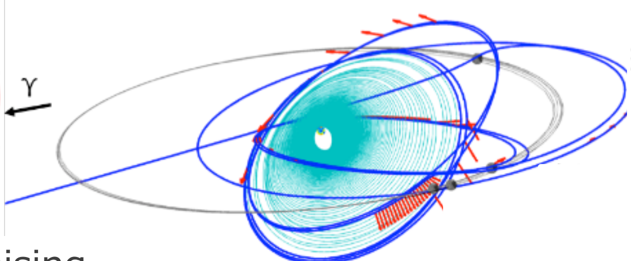
Mission Profile

	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	Aphelion (1.16au)
(5)	A few days	Phaethon flyby	PROCYON mini separation, Phaethon proximity operations, Rendezvous & docking
(6)	0.5–1 year	Transfer orbit to Earth	Perihelion (0.83au)
(7)	A few days	Earth swing-by	Connection to the 2nd target transfer orbit
(8)	TBD	Transfer orbit to the 2nd target	



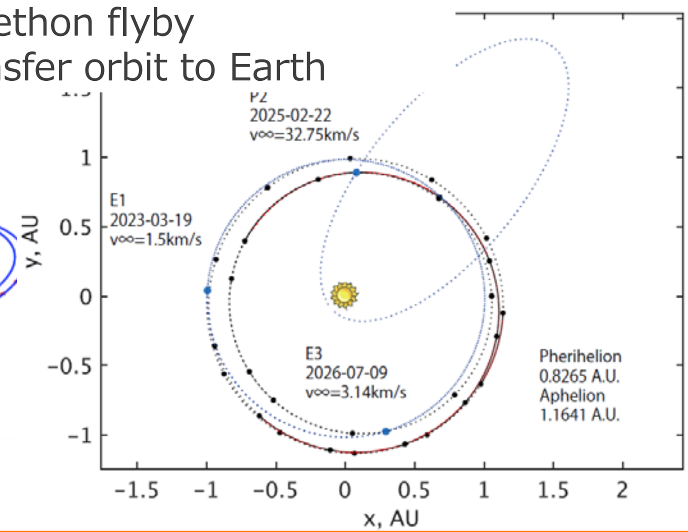
(1) Launch by Epsilon rocket

(2) Spiral orbit raising by electric propulsion

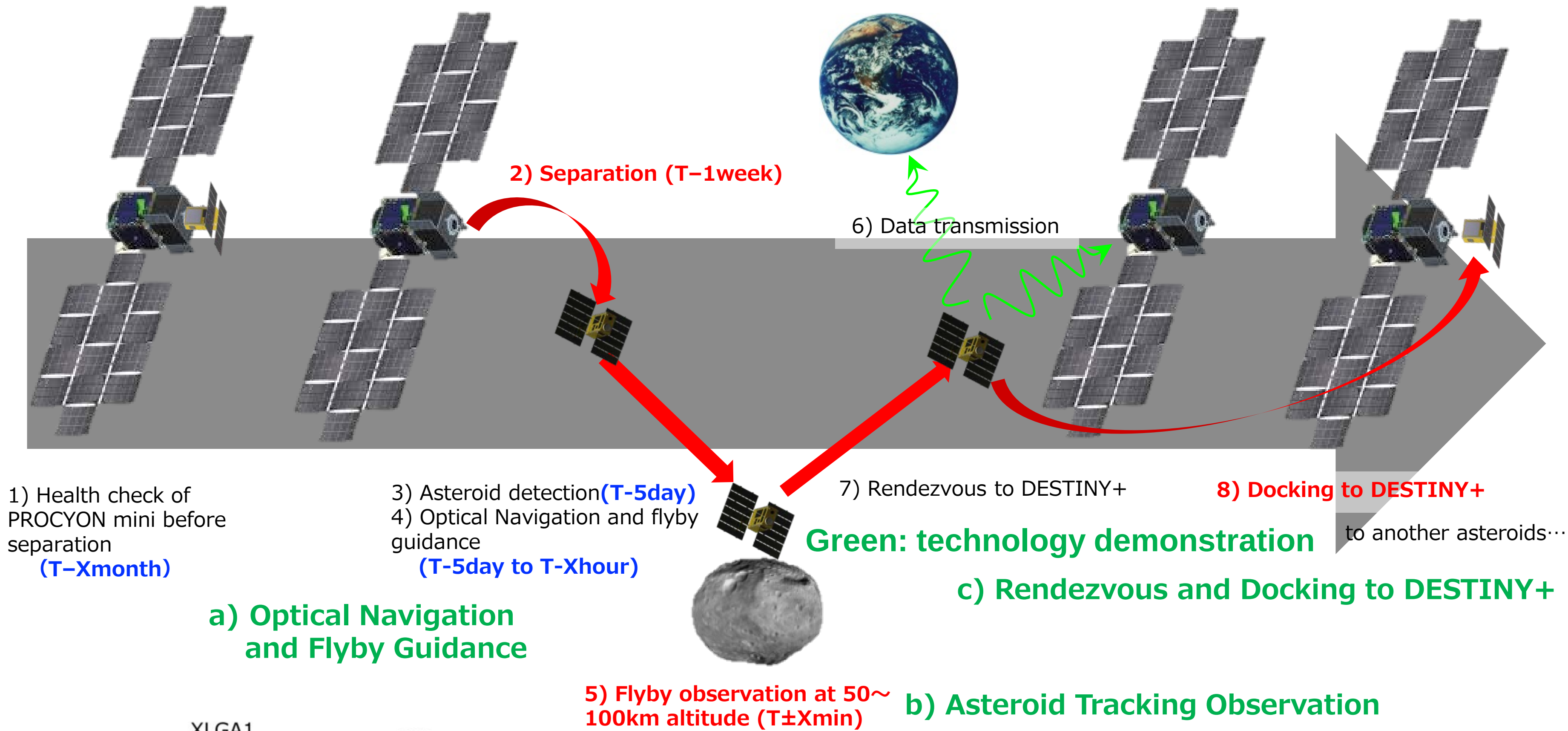


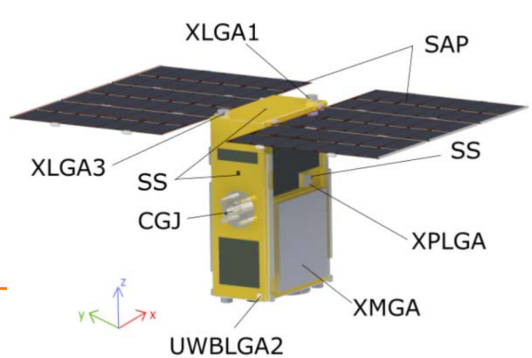
(3) Lunar swing-by

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



Flyby Operation





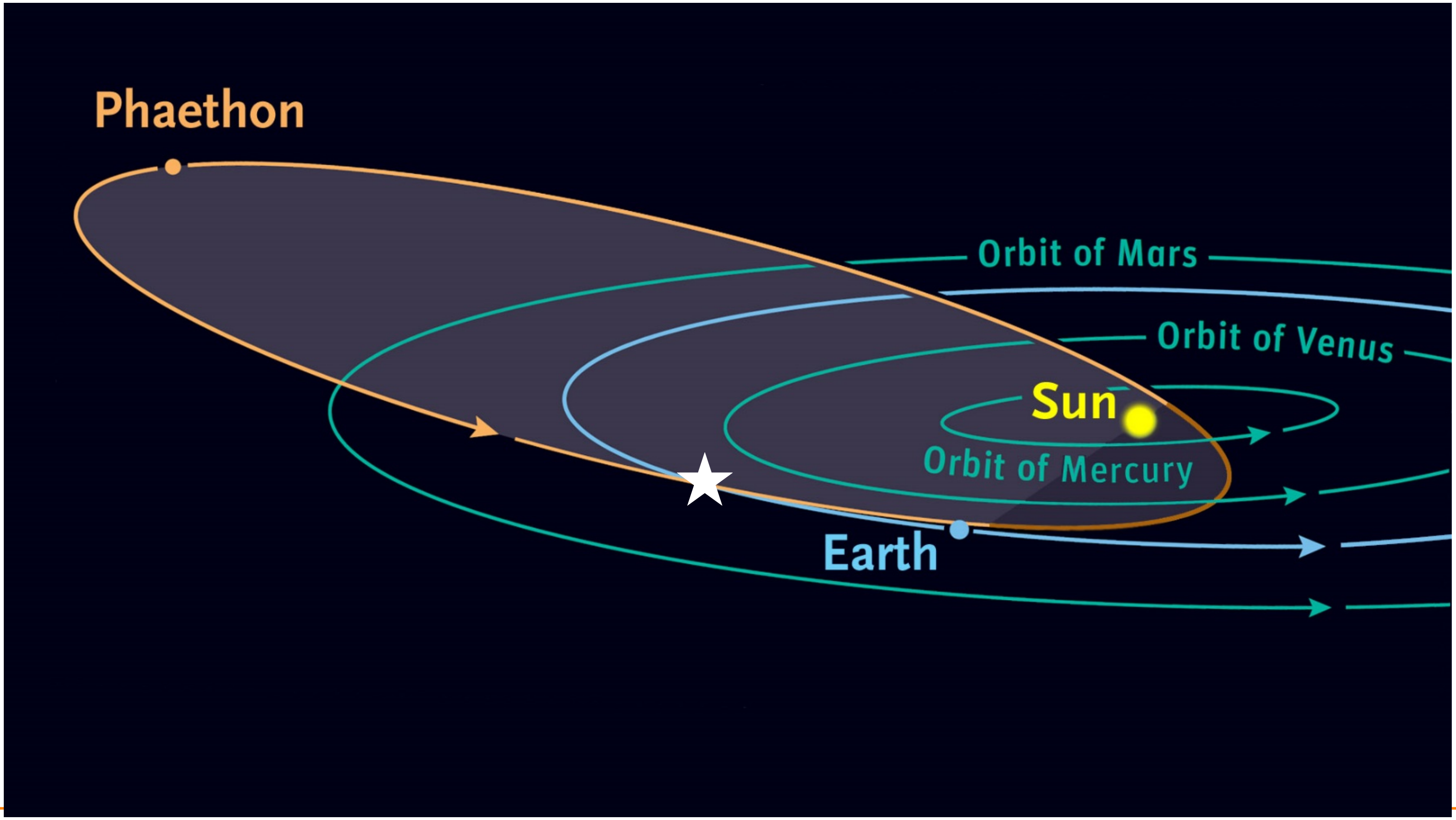
<u>Asteroid tracking observation</u>
PROCYON mini **automatically tracks the asteroid** to observe it continuously. Because of its **very low altitude flyby (high resolution)** and high speed (25km/s) and high angular rate to track, the mission is challenging but meaningful.

<u>Rendezvous and docking to DESTINY+</u>
PROCYON mini returns to DESTINY+ to fly to another asteroids. For these rendezvous and docking, we adopt advanced radiometric observation technology, such as the use of Ultra Wide Band (UWB) transiver, and magnetic docking systems.

Flyby point

★In-bound orbit toward the perihelion

★At descending node (heliocentric distance: ~1AU, geocentric distance: ~1AU) on the ecliptic plane.



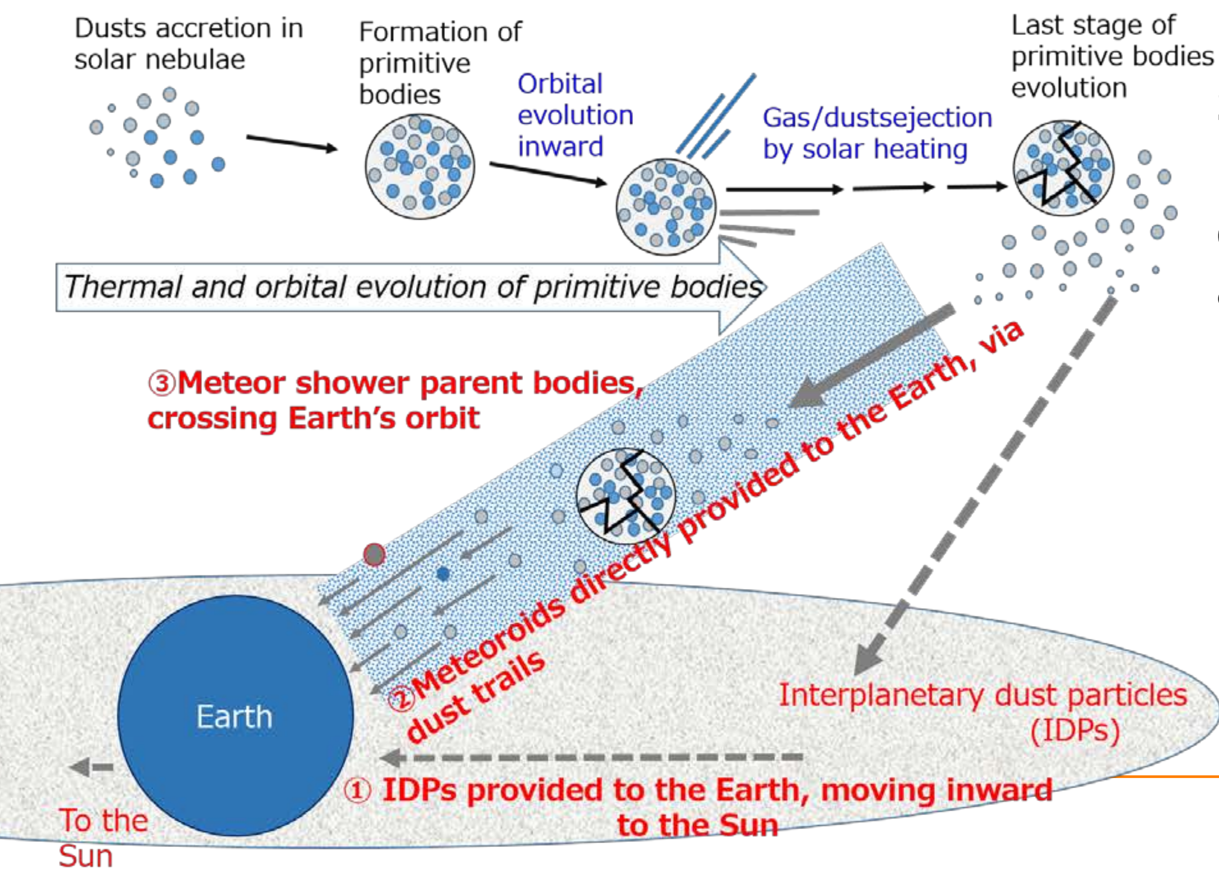
(Sky & Telescope, 2014)

Big Picture of DESTINY+

★ Dusts as Key providers of organic matters to the Earth.

★ Understand origin and nature of dusts accreted to Earth,

★ Study physical and chemical properties of dusts en route to delivery and geology of dust-providing parent bodies



Science targets:

1. IDPs (miscellaneous dusts from comets & asteroids) with minor interstellar dusts
2. Meter shower dust trail (direct dust delivery from known source).
3. Meteor shower parent bodies (Known dust sources)

Key questions to be resolved

(1-1) Contribution of cometary vs. asteroidal dusts in IDPs

★Long-standing questions from telescopic observation of zodiacal clouds and sample analyses of IDPs.

(1-2) Chemical composition of interstellar dusts (ISDs) in the solar system

★No organic materials found in 36 ISDs detected by Cassini Cosmic Dust Analyzer (CDA) (Altobelli et al., 2016)

★Can ISD be organics provider to the solar system and Earth?

(2) Size variation, flux, composition of meteoroids in dust trail and nearby Phaethon

★ No benchmark measurements of dust trails & meteor shower PB

(3) Dust ejection mechanism of active asteroids

★ Dust ejection of comets have been studied by previous missions, i.e. Stardust, Deep impact , and ROSETTA

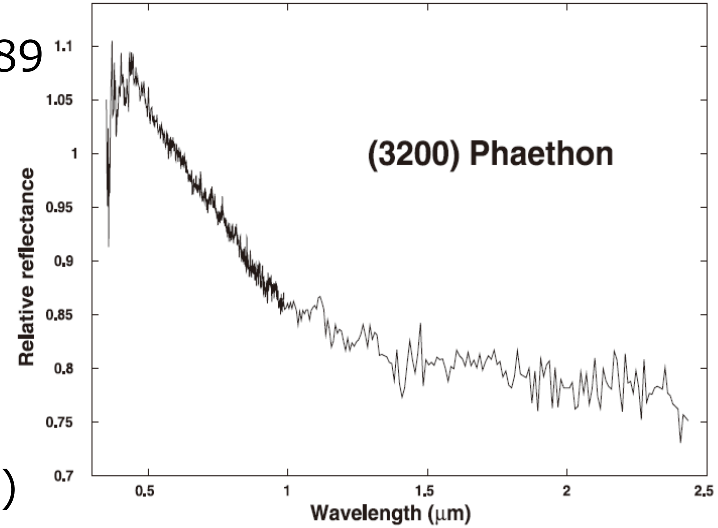
Annual meteor showers & their parent bodies
DESTINY+ target: active asteroid Phaethon

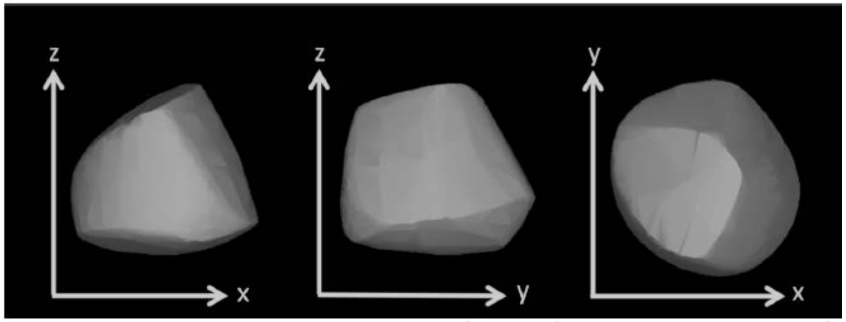
Meteor shower	Active window (peak day)	Velocity	ZHR*	Parent body
Quadrantids	01/01-01/05 (1/3)	41km/s	120	Asteroid 2003 EH1, Comet 1490Y1
April Lyrids	04/16-04/25 (4/22)	49km/s	18	Comet Thatcher
η-Aquarids	04/19-05/28 (5/5)	66km/s	60	Comet1P/Halley
Southern δ-Aquarids	07/12-08/19 (7/28)	41km/s	20	Comet1P/Halley
Perseids	07/17-08/24 (8/12)	59km/s	100	Comet 109P/Swift-Tuttle
October Draconids	10/06-10/10 (10/8)	20km/s	var	Comet 21P/Giacobini-Zinner
Orionids	10/02-11/07 (10/21)	66km/s	23	Comet 1P/Halley
Southern Taurids	09/25-11/25 (11/5)	27km/s	5	Asteroid 2004TG10
Northern Taurids	09/25-11/25 (11/12)	29km/s	5	Comet 2P/Encke
Leonids	11/10-11/23 (11/17)	71km/s	var	Comet 55P/Tempel-Tuttle
Geminids	12/07-12/17 (12/14)	35km/s	120	Asteroid 3200Phaethon
Ursids	12/17-12/26 (12/22)	33km/s	10	Comet 8P/Tuttle

*Zenithal Hourly Rate (ZHR): The number of meteors a single observer would see in one hour under a clear, dark sky if the radiant of the shower were at the zenith. Var: variable

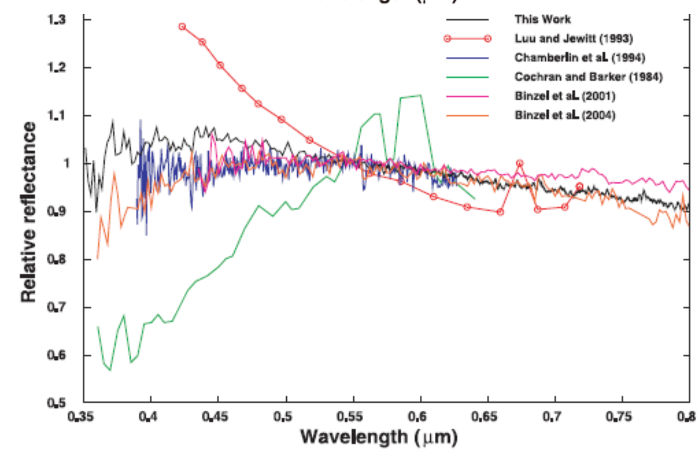
3200 Phaethon

- Apollo-type NEA, Spectral type: B-type,
- Perihelion:0.14 AU, Aphelion:2.4 AU, Eccentricity:0.89
- Albedo 0.11 +/- 0.2
- D=~ 5.1 km (Largest PHA& near-Sun asteroids)
- Inclination 22 deg, relative velocity 35 km/S
- Orbital period : 1.4 yr, Rotational period: 3.6 hr
- Rotational axis inclined to 85 deg (in avg)
- Breakup body: 2005UD (Ohtsuka et al., 2006)
- Possibly breakup from 2 Pallas (De Leon et al., 2010)

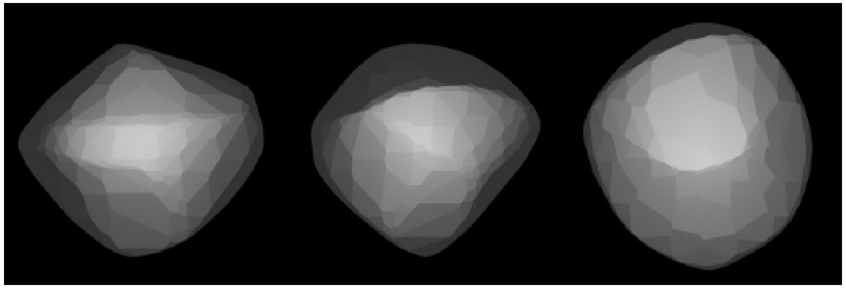




(Ansdell et al., 2014)



(Licandro et al., 2007)



(Hanus et al., 2016)

Active asteroid Phaethon

- Parent of Geminid meteor shower

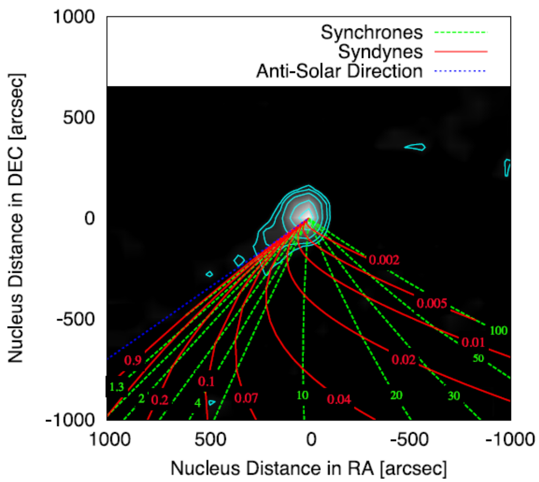
  Na depletion of meteoroids (kasuga et al., 2005)

- Dust tail @ perihelion

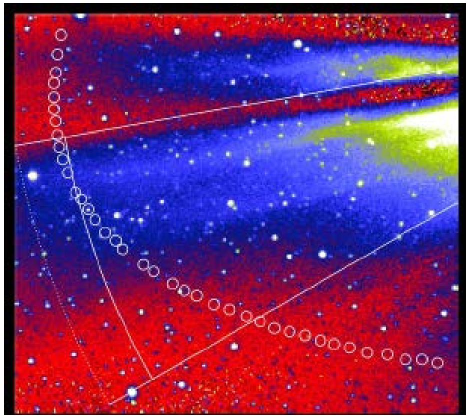
  (Jewitt & Li, 2010, Jewitt et al., 2013)

  Dust ejection mechanism unknown:
  Sublimation/radiation pressure/fast rotation

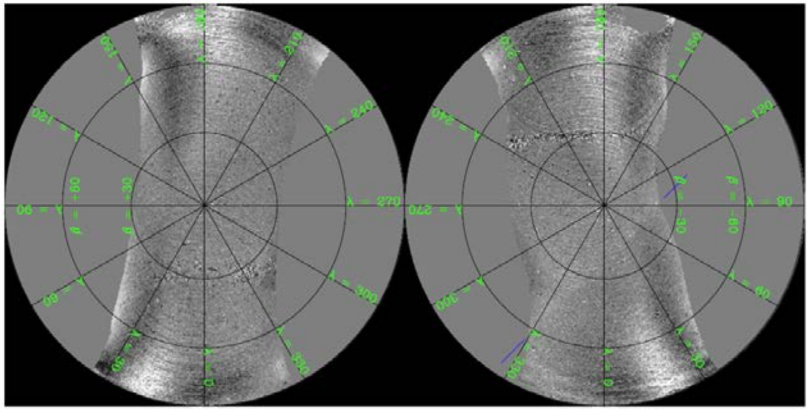
- Dust trail for Phaeton discovered by thermal emission of Diffuse Infrared Background Experiment (DIRBE) onboard Cosmic Background Explorer (COBE). (Arendt, 2014)



(Jewitt & Li, 2010)



(Jewitt et al., 2013)



(Arendt, 2014)

Science Mission Goals

SMG1: Understanding physical & chemical properties and origin of dust:

SMG1.1 IDPs (with interstellar dusts)

SMG1.2 dust trail

SMG1.3 Nearby Phaethon

flux, mass, velocity (<10%), orbit (<10 deg), composition for dusts with mass (10^{-19}～10^{-9}kg)

SMG2: Understanding meteor shower parent body

SMG2.1 Morphology

SMG2.2 Surface geology (<5 m/pix)

SMG2.3 Surface composition (<100 m/pix)

390nm (UV end of IOM), 550nm (albedo determination)
700nm (phyllosilicate), 850nm (reddening evaluation)

SMG2.4 Interior structure & composition (extra)

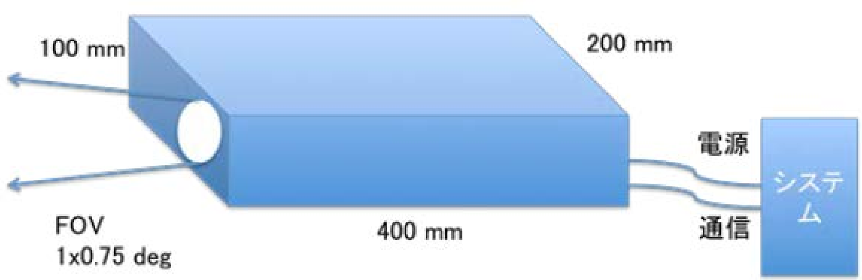
Science payloads (under evaluation)

Relation of mission requirement and science payloads

＊ Option payloads

- SSR1.1.1 Shape, Morphology
- SSR1.2.1 Surface geology
- SSR1.3.1 VIS-NIR reflectance spectra
- SSR1.4.1 Internal structure: breakup body
- SSR1.4.2 Internal structure: Impact exp.
- SSR2.1.1 Physicochemical natures of IDPs Detection of interstellar dust
- SSR2.2.1 Physical & chemical properties of nearby Phaethon & dust trails

- DESTINY telescopic camera (TCAP)
- DESTINY multiband camera (MCAP)
- PROCYON-mini multiband camera*
- DESTINY Dust analyzer（DDA）
- PROCYON-mini Mini dust analyzer*



DESTINY telescopic camera

DESTINY Dust analyzer（DDA）

Specification of science payloads

DESTINY+

Instruments	Mass [kg]	Specification
Telescopic camera (TCAP)	1.5	FOV: 0.94deg x 0.71deg、 Spatial resolution: 5m/pix (5μrad/pix)
Multiband camera (MCAP)	3	Wavelength: 390～850nm 4 bands nominal Spatial resolution: 100m/pix(0.1mrad/pix)
Dust analyzer (DDA)	5	Measured items: Dust mass(10^{-16}~$^{-6}$g)、velocity(<10%)、direction (<10deg), charge、flux、composition, ΔM/M>150

PROCYON-mini (Option)

Instruments	Mass[kg]	Specification
Wide-angle multiband camera	1	Wavelength: RGB,700, 900nm、 Spatial resolution: 5m/pix ` 50km
Mini dust analyzer (MDA)	0.8	Measured items: Dust mass(10^{-16}~$^{-6}$g)、velocity(<10%)、charge、flux、composition, ΔM/M>25)

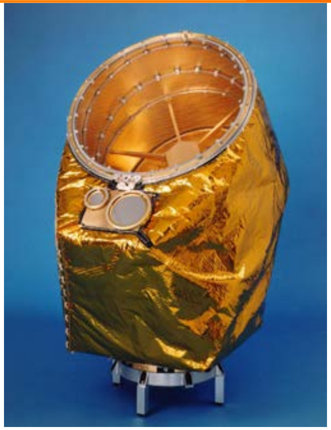
DESTINY+ Dust Analyzer (DDA)

Importance of Dust Analyzer

★ Heritage 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/ΔM >20-50	M/ΔM >150
Change	$2\text{x}10^{-15}$ to $5\text{x}10^{-13}$ C	> 10^{-16} C



Cassini CDA

Europa clipper SUDA

2017 Dec. Phaethon Observation campaign

(1)Radar observation Arecibo & Goldstone thanks to support of Dr. Jim Green of NASA.

(2) VIS-NIR Spectroscopic observation

0.7-2.5 um: NASA IRTF/SpeX
1.9-4.2 um: NASA IRTF/SpeX LXD
0.3-0.8 um: Kuipier 61
Color Phase Curves: 20“ Telescope
5-20 um: NASA IRTF/MIR SI

with collaboration with Dr. Reddy of LPL, U of Arizona

(3) Hubble telescope for dust observation nearby Phaethon and dust trail submitted by US scientist

(4) JCMT/SCUBA-2(sub-millimeter) for dust observation nearby Phaethon and dust trail submitted by US scientist

(5) (Possible) visible and infrared observation by Subaru thanks to JAXA/ISAS and NAOJ

(6) Obs campaign with 1m class telescopes thanks to domestic and international collaboration

Summary

DESTINY$^+$:

- Demonstrates advanced technologies, for deep space explorations, such as, electric propulsion, compact avionics, innovative fly-by technologies.
- Flyby asteroid 3200 Phaethon, parent of Geminid meteor shower, using a small satellite with a cubesat, which are launched by Japanese Epsilon rocket.
- Conduct in-situ dust analyses during cruising and flyby, and surface imaging upon high-speed flyby.