Initial Operation Results of 50kg-class Deep Space Exploration Micro-Spacecraft PROCYON

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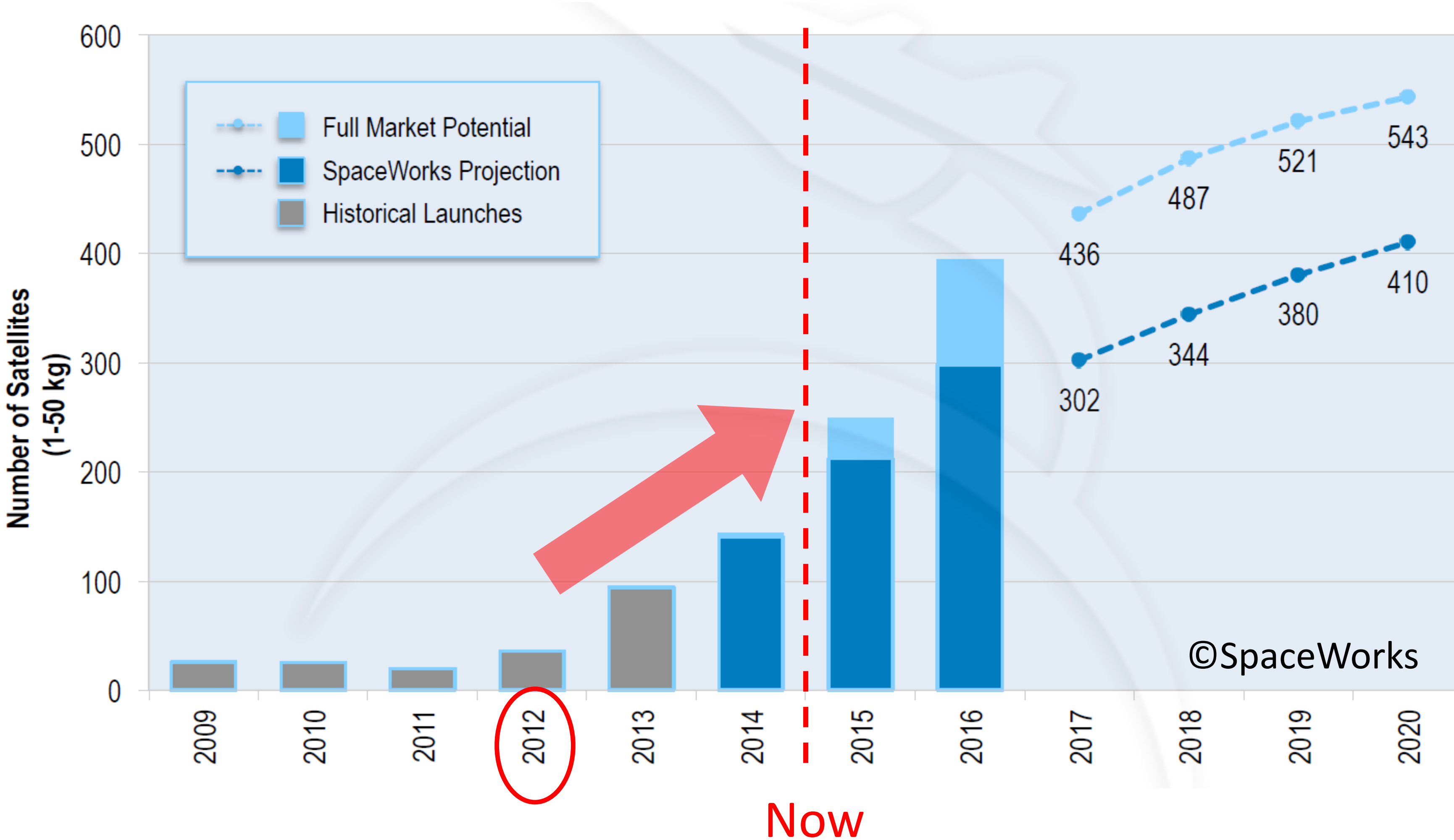
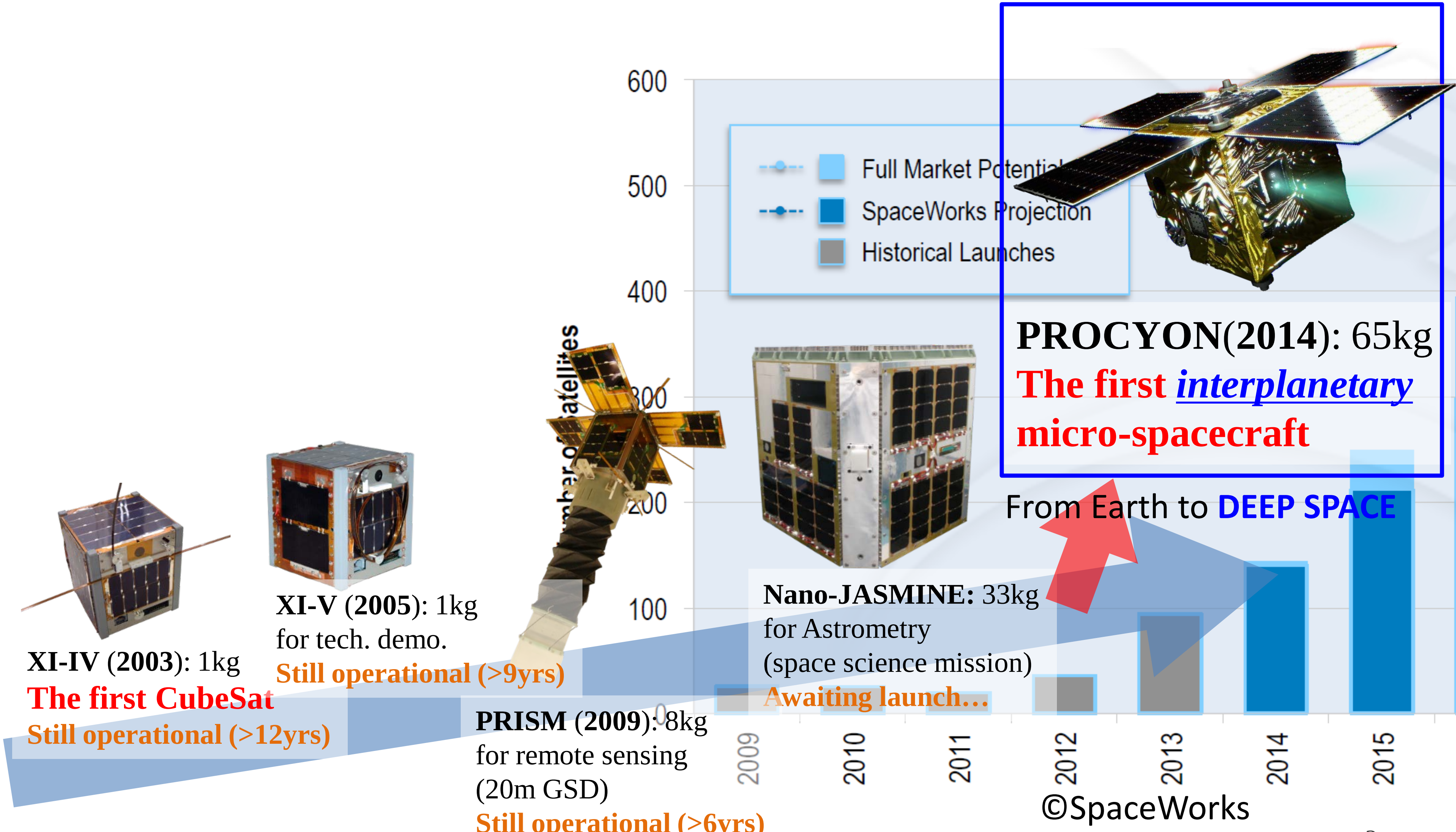
29th Small Satellite Conference, Logan, UT, USA

Growing trend of nano/micro-satellites



University of Tokyo’s experience



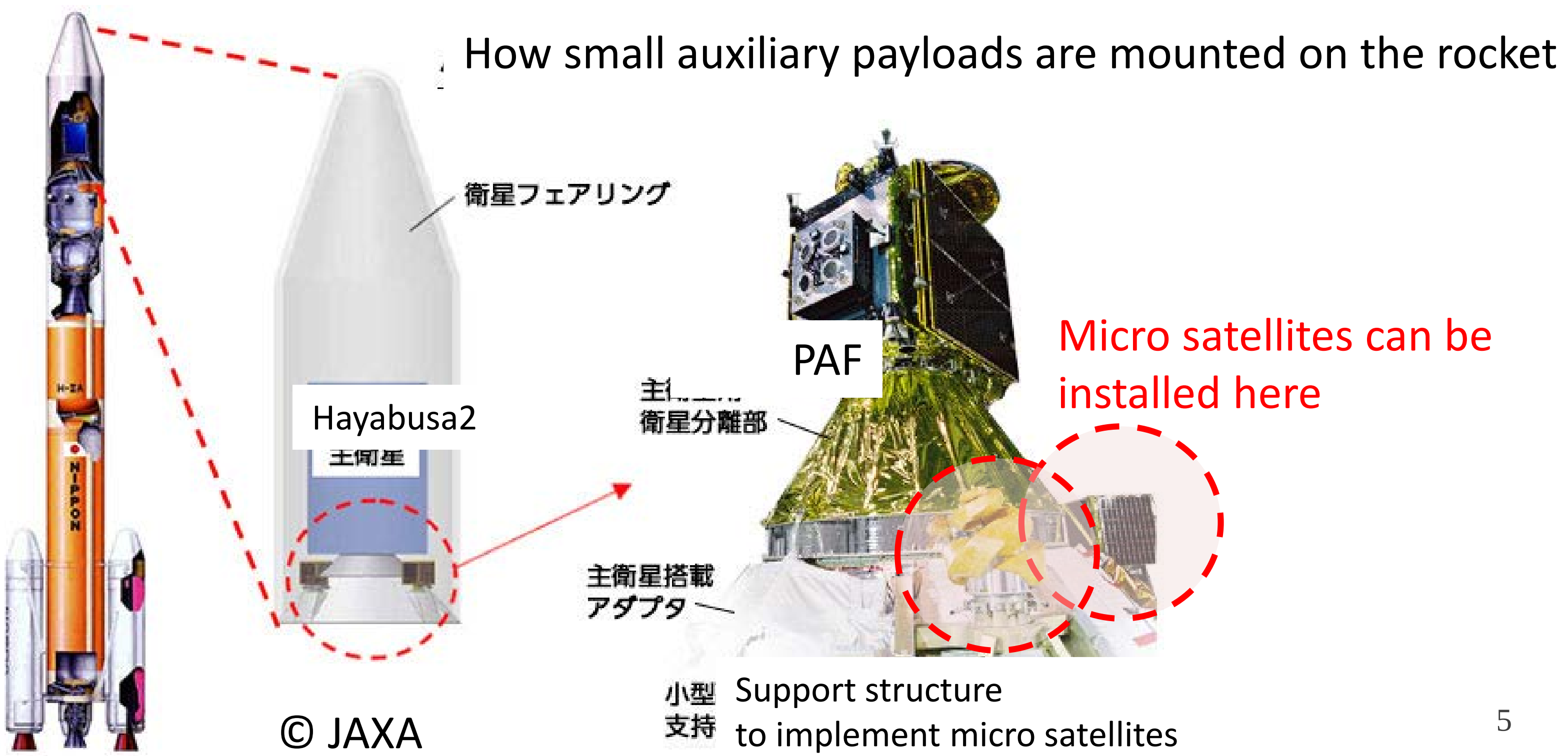
Outline

- PROCYON
  - Mission
  - Spacecraft design, development schedule
  - On-orbit achievements
- Future perspective of deep space small satellites

Beginning of PROCYON mission

“Rideshare” **interplanetary** launch opportunity with Hayabusa-2 was announced.

→Joint mission proposal by U of Tokyo and JAXA was approved (small sat experiences + deep space exploration experiences)



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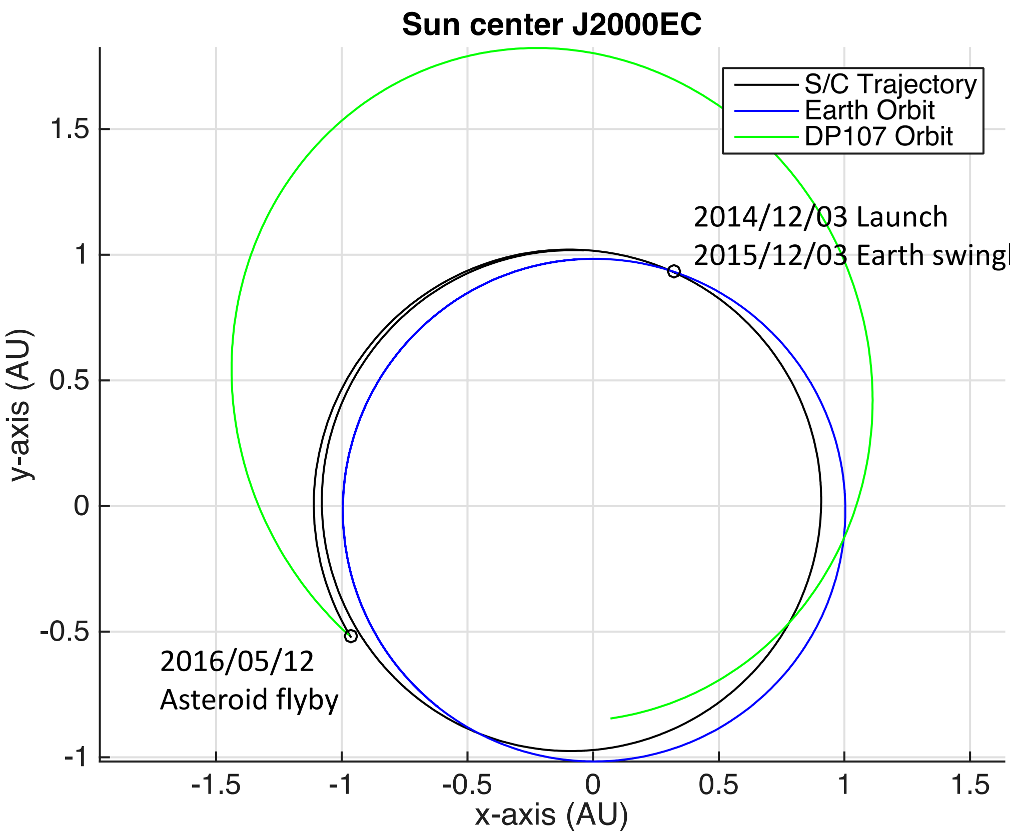
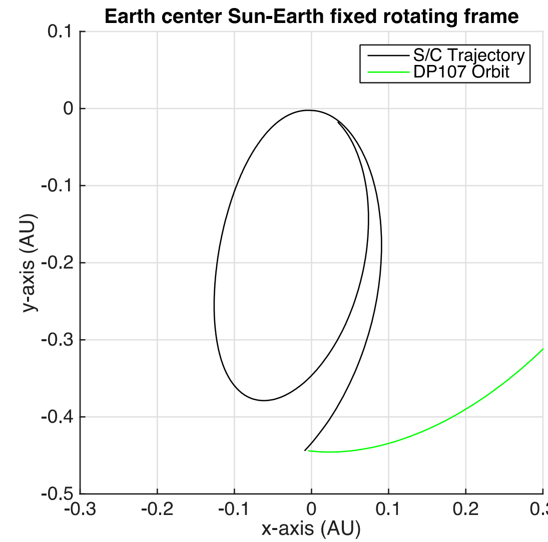
Trajectory plan to asteroid "2000 DP107"





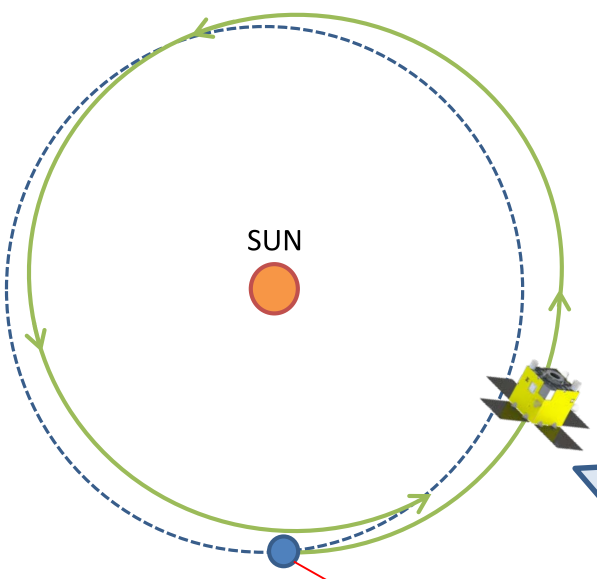
(Sun-Earth fixed rotational frame)

What is the asteroid "2000 DP107"

- Binary asteroid (asteroid with "satellite")
- PHA (Potentially Hazardous Asteroid)

Primary Mission

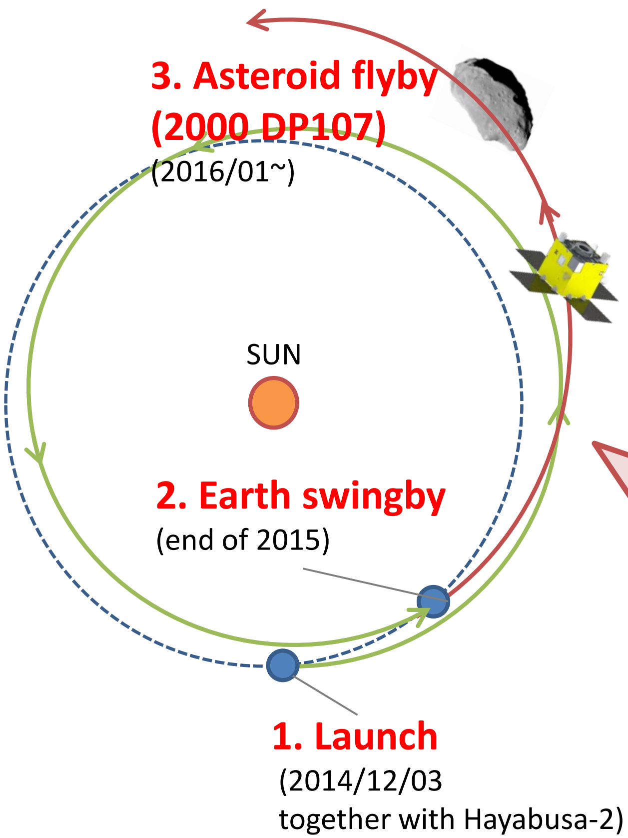
Demonstration of micro-spacecraft <u>bus</u> system for deep space exploration (requires 2~3 months)



- **Power** generation/management (>240W)
- ***Deep space thermal design** (to accommodate wide range of Solar distance (0.9~1.5AU) and power consumption mode (EP on/off))
- **Attitude** control (3-axis, 0.01deg stability)
- ***Deep space communication & navigation**
  - <u>High efficiency</u> (GaN SSPA, >30%)
  - <u>High RF output</u> (>15 W)
  - <u>Precise nav</u> by novel "Chirp DDOR"
- ***Deep space micro propulsion system**
  - <u>RCS</u> for attitude control/momentum management (8 thrusters)
  - <u>Ion propulsion</u> system for trajectory control (1 axis, Isp=1000s, thrust=300uN, overall ΔV=400m/s)

Secondary (advanced) Mission

Engineering/Scientific mission to advance/utilize deep space exploration (~L+1.5yr)



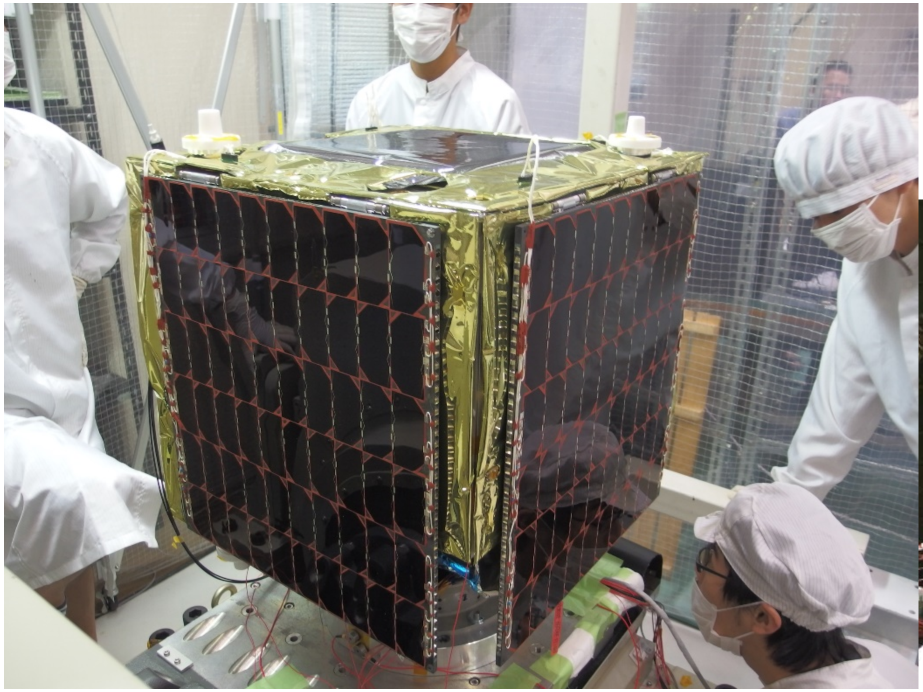
[engineering mission]

1. **Deep space maneuver** to perform Earth swingby and trajectory change to target an asteroid flyby
2. **High-res observation of an asteroid during close (<30km) and fast (~10km/s) flyby**
   - Optical navigation and guidance to an asteroid
   - Automatic Line-of-sight image-feedback control to track asteroid direction during close flyby

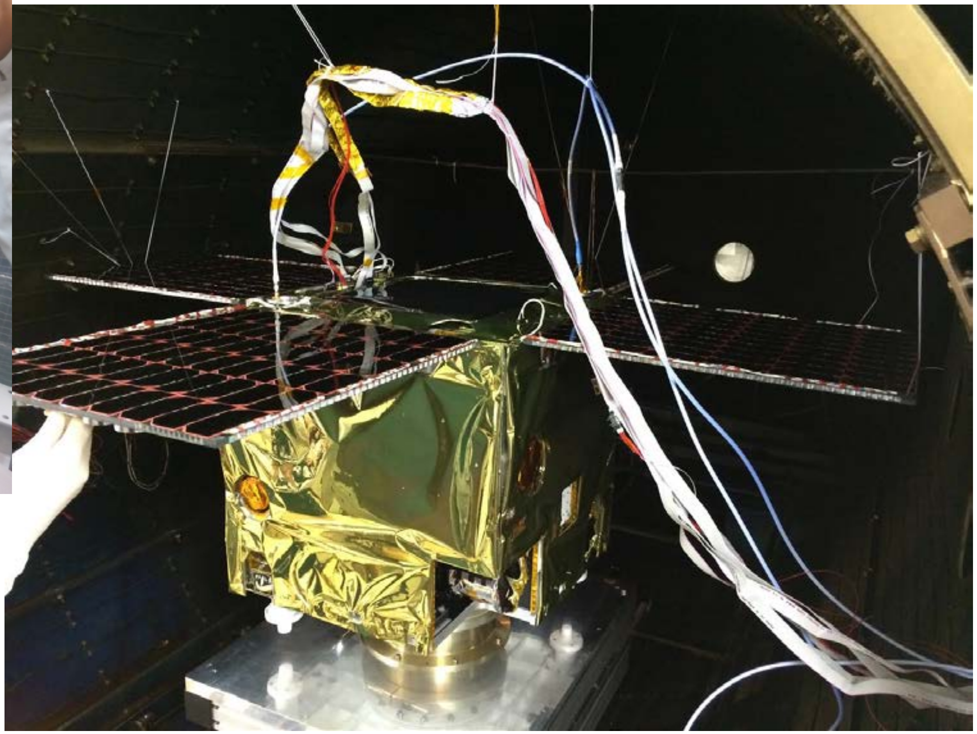
[scientific mission]

1. **Wide-view observation of geocorona** with **Lyα imager** from a vantage point outside of the Earth's geocorona distribution

External View of PROCYON

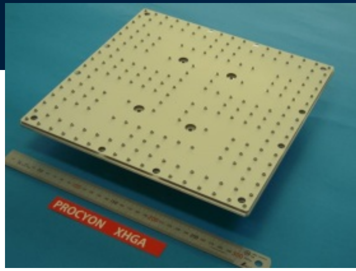


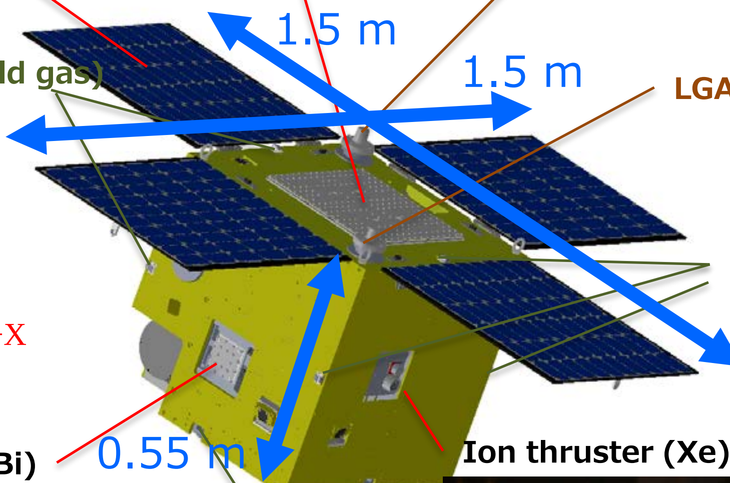
(SAP stowed)

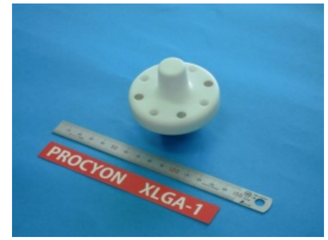


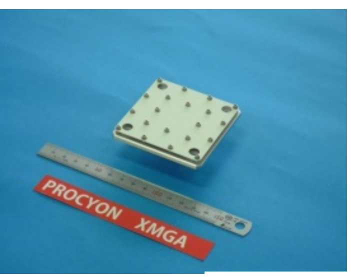
(SAP deployed)

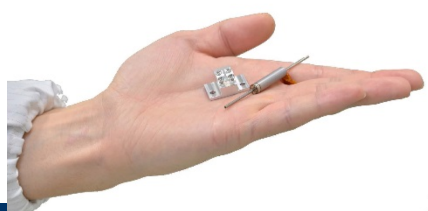
External View of PROCYON

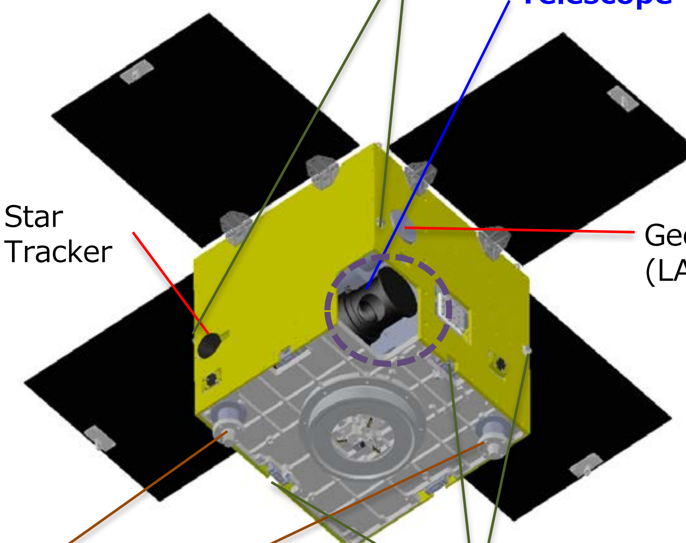




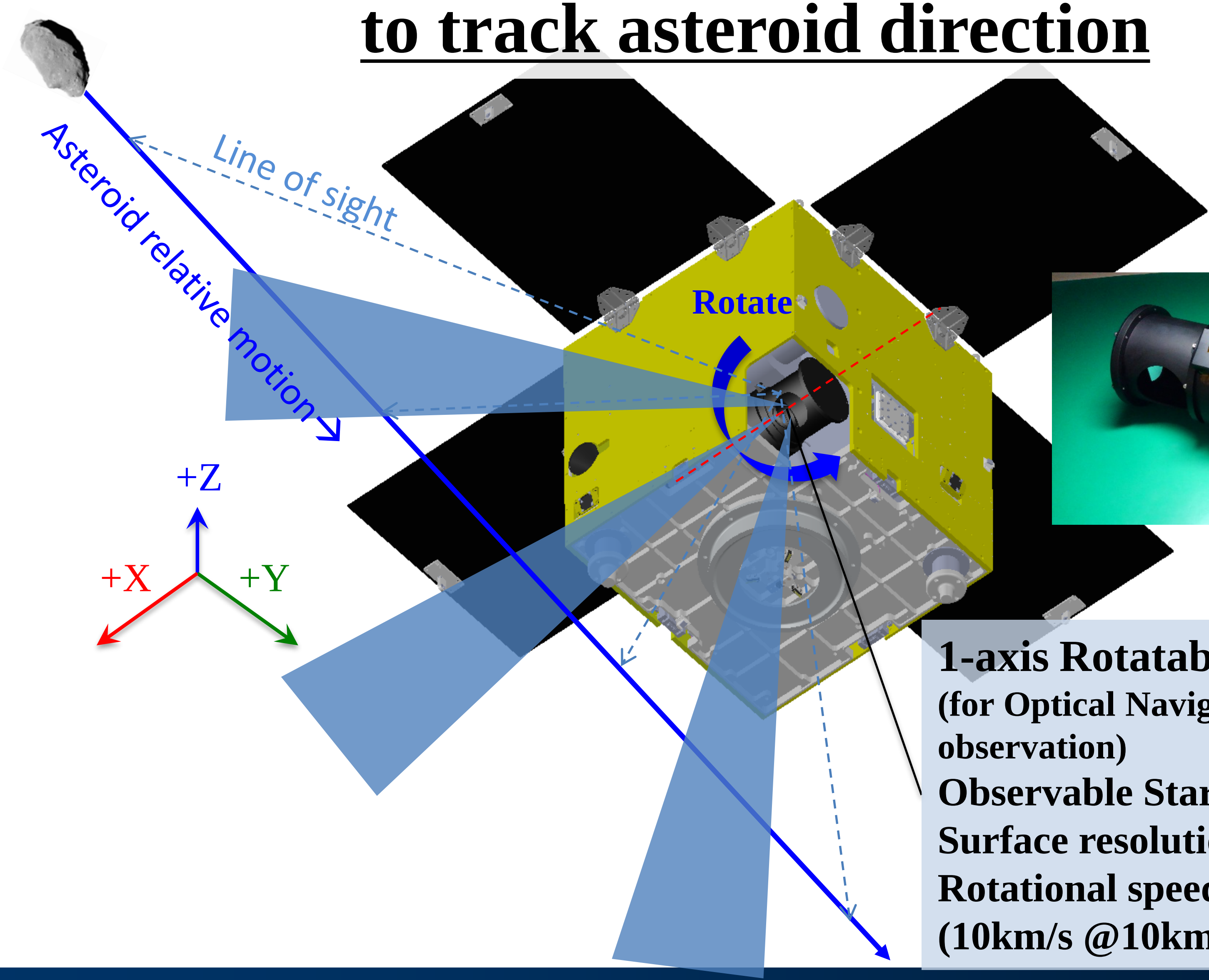


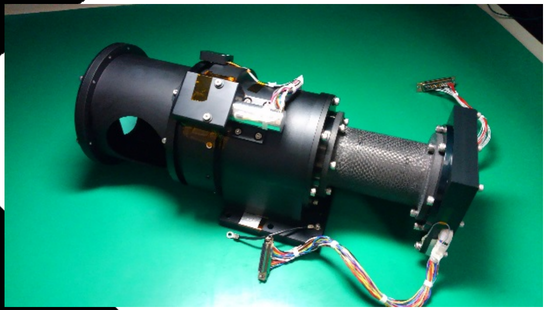






Real-time Line-of-sight image-feedback control to track asteroid direction





1-axis Rotatable Telescope

(for Optical Navigation and flyby observation)

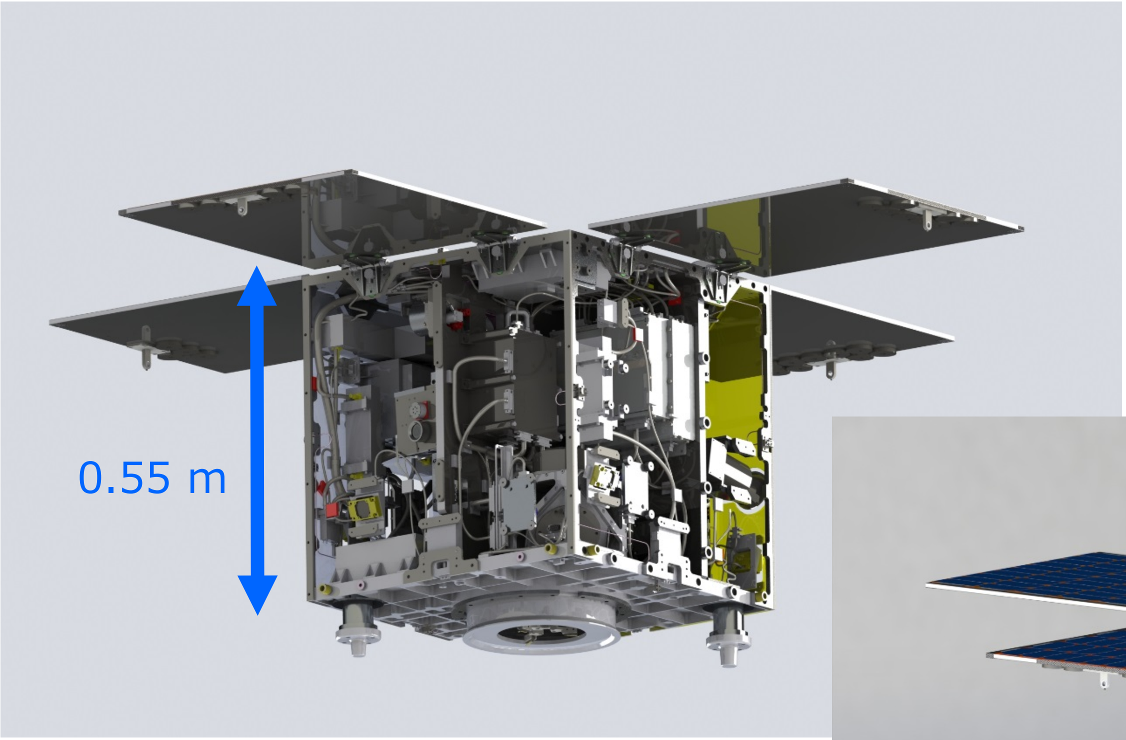
Observable Star Magnitude: 12

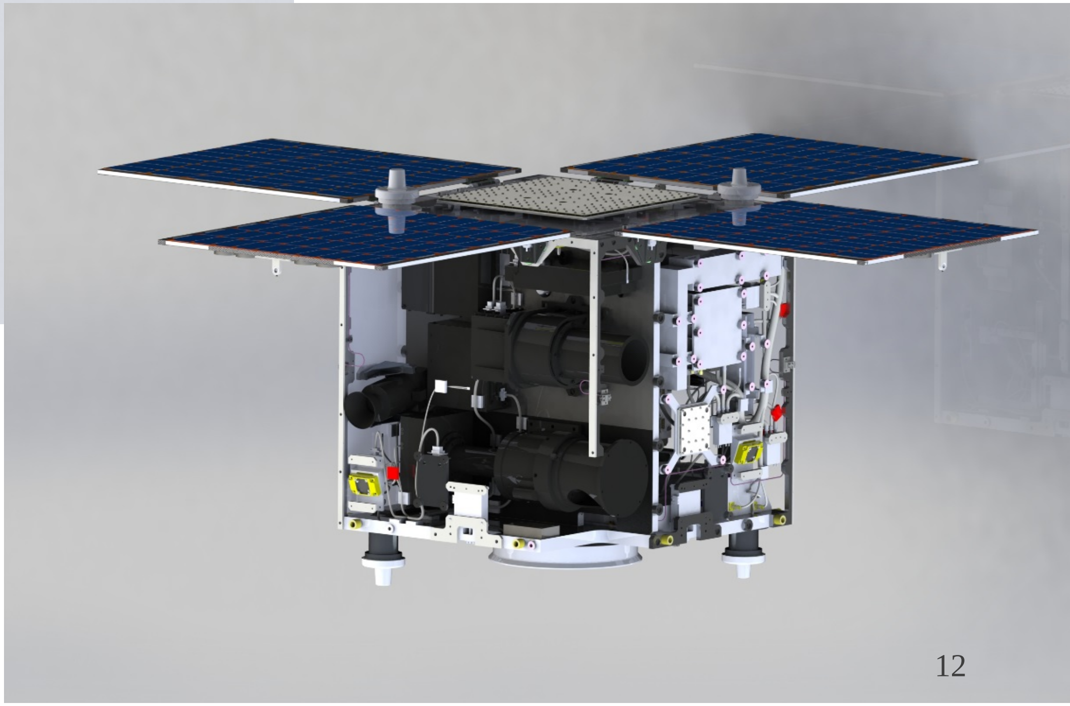
Surface resolution: ~1[m]@10km

Rotational speed: <55[deg/s]

(10km/s @10km)

Internal View of PROCYON





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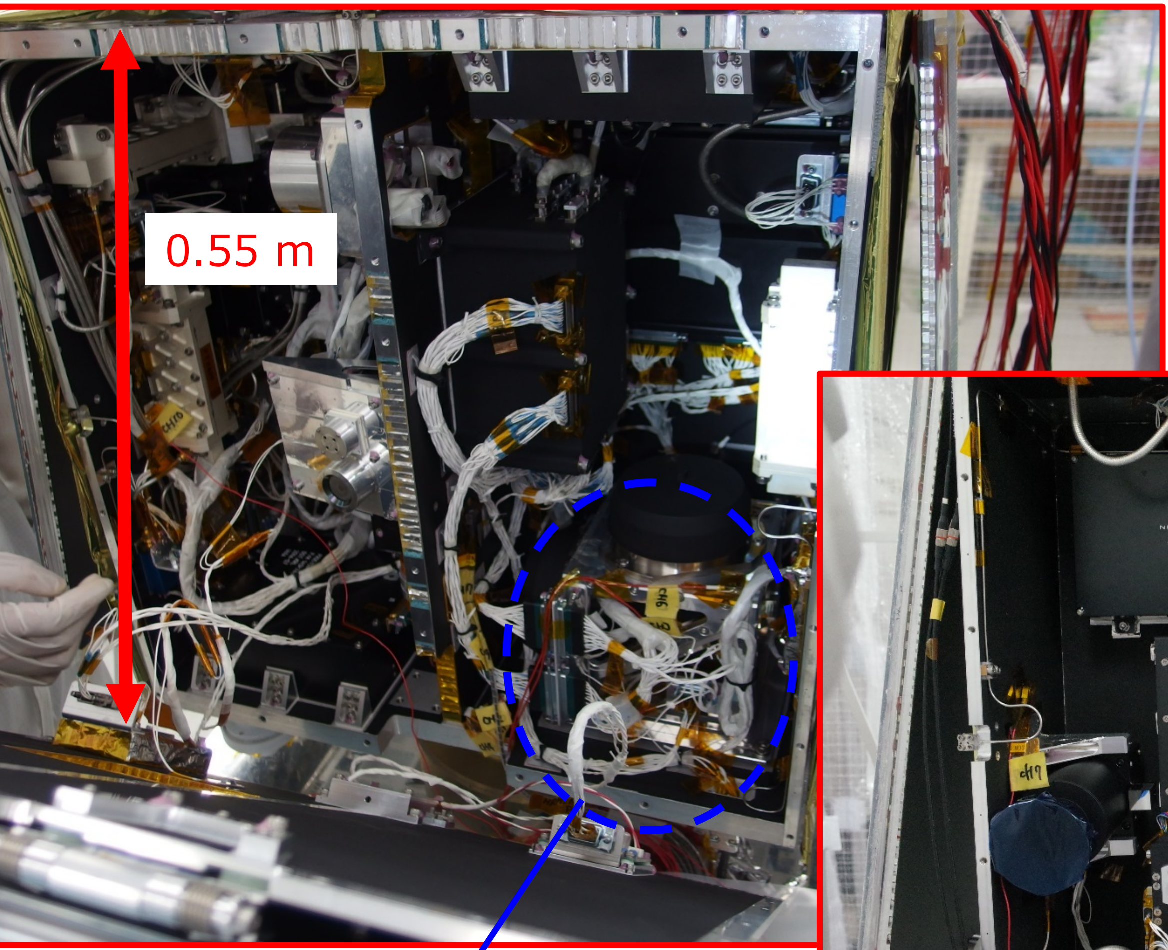
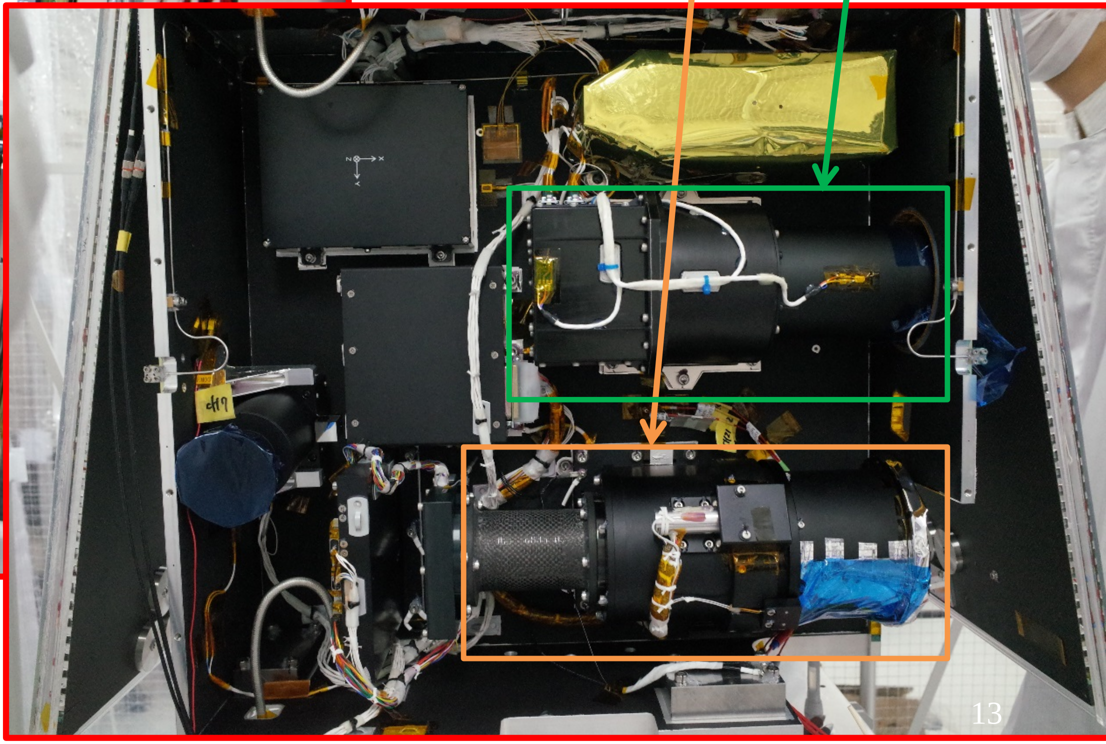
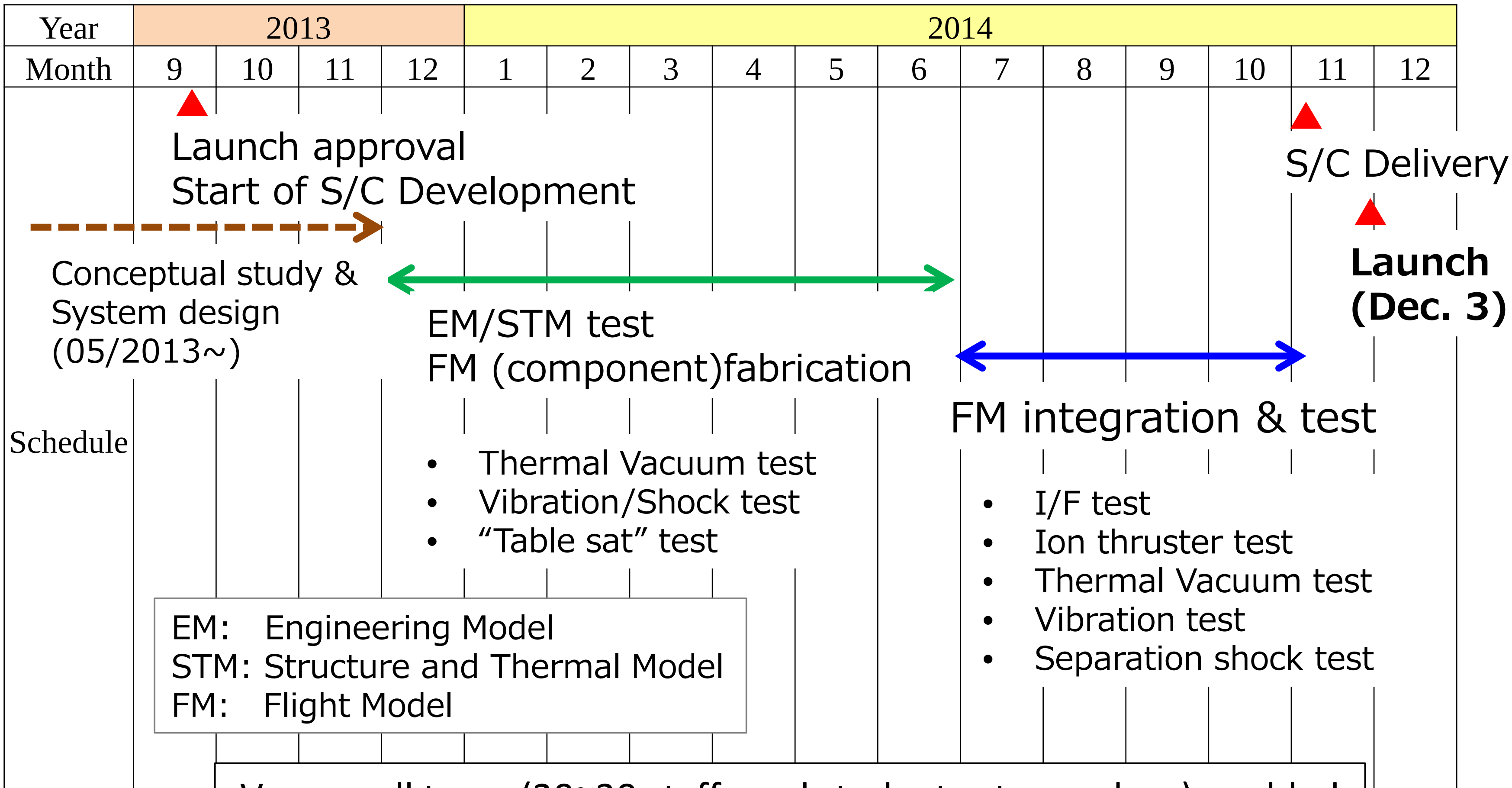




Spacecraft specifications

Structure	Size	0.55m x 0.55m x 0.67m + 4 SAPs (Solar Array Panels)
	Weight	<70kg (wet)
Power	SAP	Triple Junction GaAs, **>240W**(1AU,θs=0,BOL)
	BAT	Li-ion, 5.3Ahr
AOCS	Actuator	4 Reaction Wheels (RW), 3-axis Fiber Optic Gyro (FOG)
	Sensor	Star Tracker (STT), Non-spin Sun Aspect Sensor (NSAS)
		Telescope (for optical navigation relative to the asteroid)
	Performance	**<0.002[deg/s], ~0.01[deg] (pointing stability)**
Propulsion	**RCS**	Xenon cold gas jet thrusters x8, ~22mN thrust, 24s Isp
	Ion propulsion	Xenon microwave discharge ion propulsion system
		0.3 mN thrust, 1000s Isp, **~400m/s ΔV capability (for 65kg s/c)**
	Propellant	2.5 kg Xenon (shared by RCS and ion propulsion)
Communication	Frequency	X-band (for deep space mission)
	Antenna	HGA x1, MGA x1, LGA x2 (for uplink), LGA x2 (for downlink)
	Output power	**>15 W (RF output), >30% (GaN XSSPA)**
Payload	Weight	**~10kg** (asteroid observation camera + Lyman alpha imager)

1 year of development schedule



Very small team (20~30 staffs and students at one place) enabled
quick decision making for quick development

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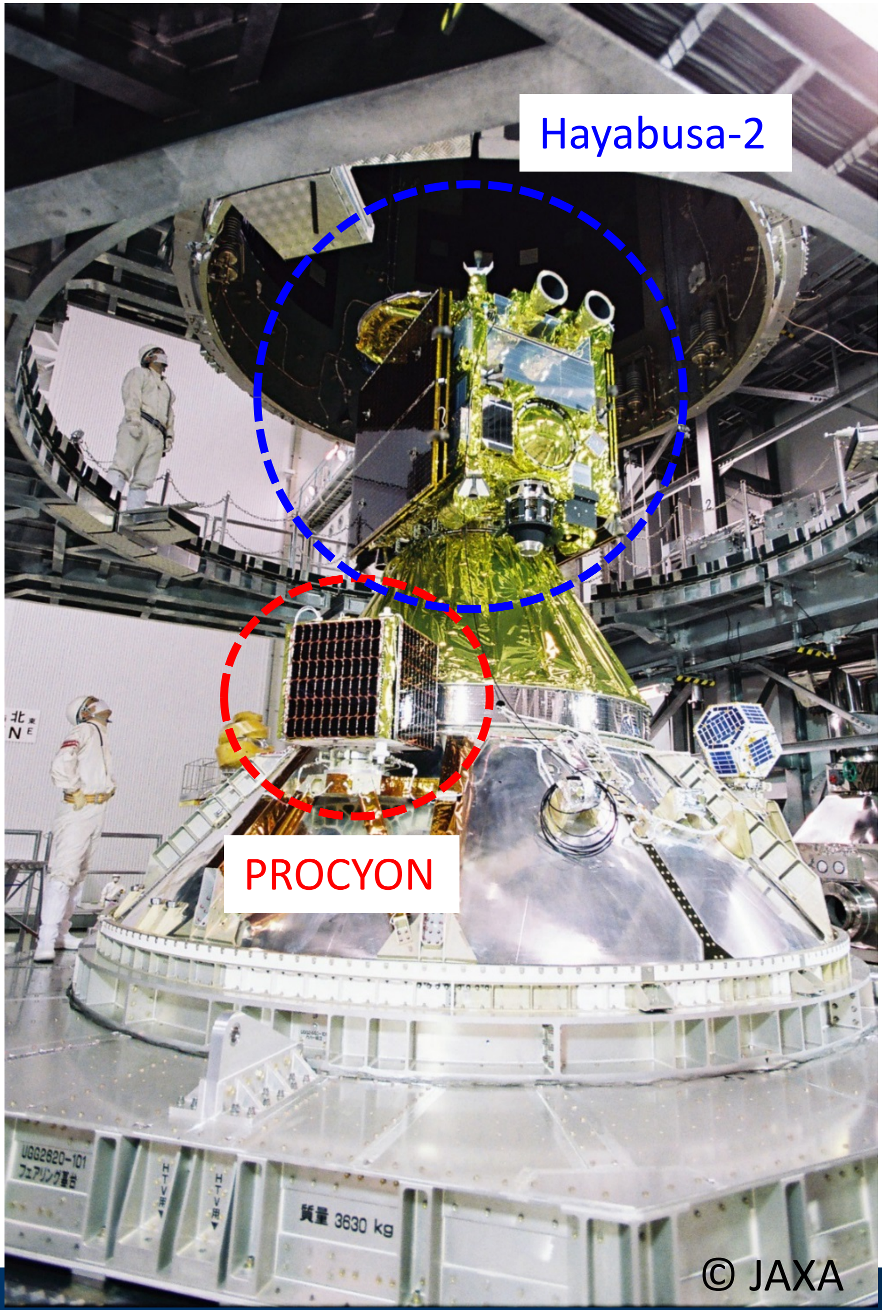
  - **On-orbit achievements**

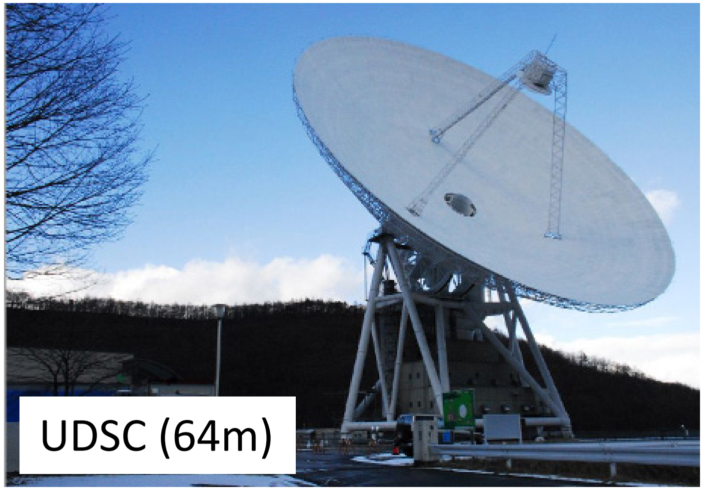
- Future perspective of deep space small satellites

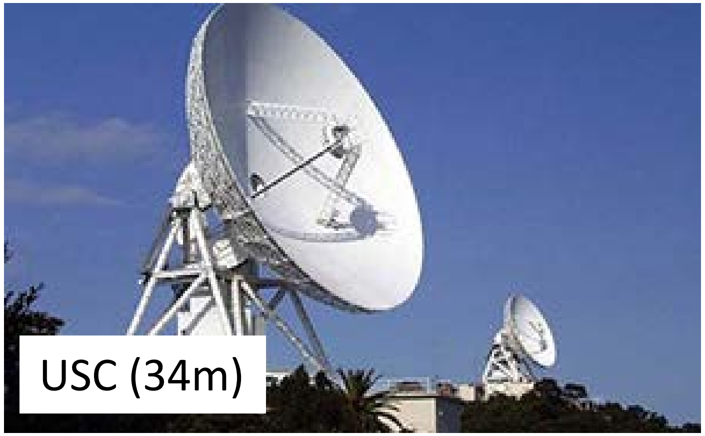

Hayabusa-2
PROCYON
© JAXA


H-IIA rocket
NIPPON
H-IIA
F26
© JAXA

Ground Stations

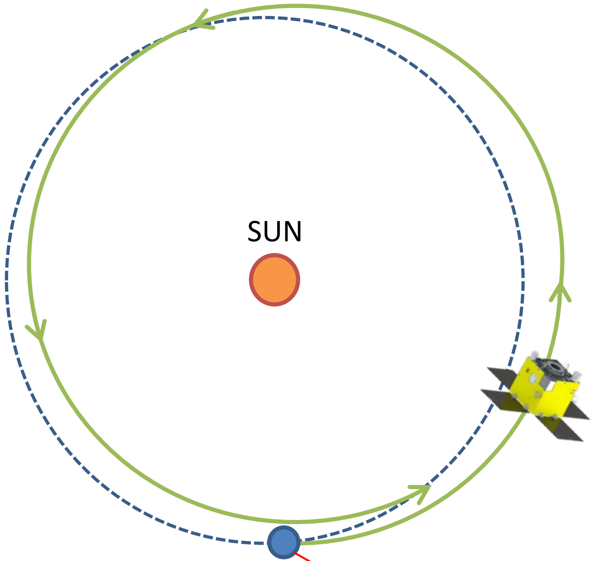
- Japanese Deep Space Stations
  - UDSC(64m)
  - USC(34m): primary station
  - USC(20m) (only for initial tracking operation)
- International collaboration for "Chirp DDOR" navigation experiments
  - JPL(DSN)
  - ESA





Primary mission results

Demonstration of micro-spacecraft bus system for deep space exploration (requires 2~3 months)



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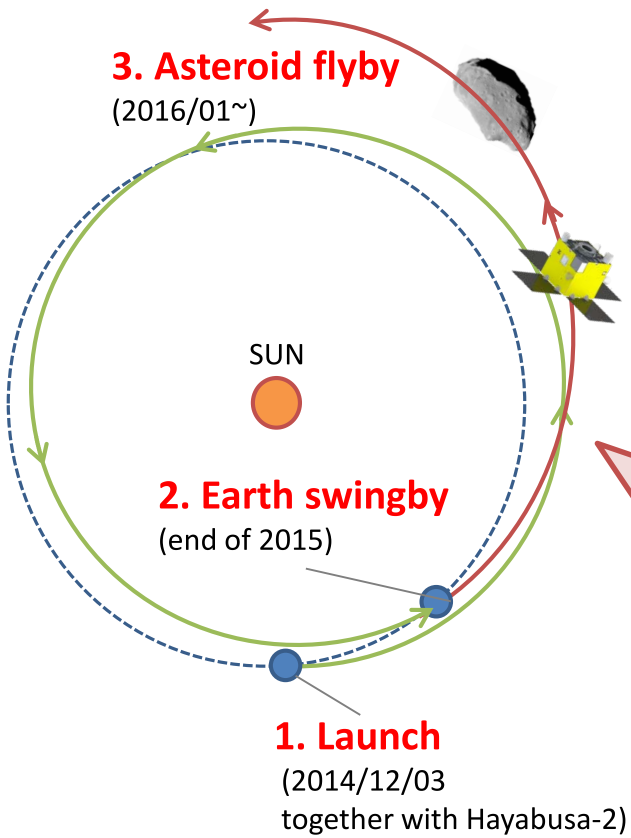

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[scientific mission]

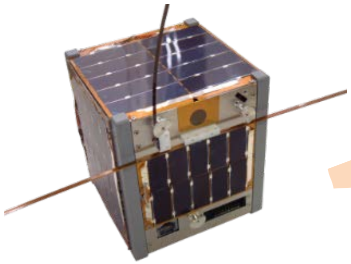
- ✓ **Wide-view observation of geocorona** with **Lyα imager** from a vantage point outside of the Earth's geocorona distribution

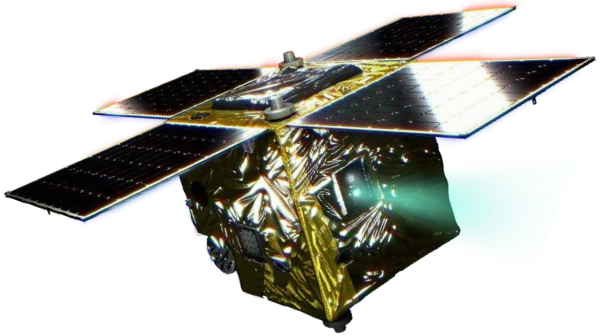
Mission status

- **Demonstration of deep space bus system**
  → success!
- **Scientific mission** (geocorona observation)
  → success!
- All the mission were successful excluding **the long-time deep space maneuver** and the subsequent **asteroid flyby**.

- demonstrated the capability of this class of spacecraft to perform deep space mission by itself and it can be a useful tool of deep space exploration.

Future perspective of deep space exploration by small sats





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Future perspective of deep space exploration by small sats

Large spacecraft (>100kg)
- Large payload capacity,
- high reliability,
- but high-cost, long development

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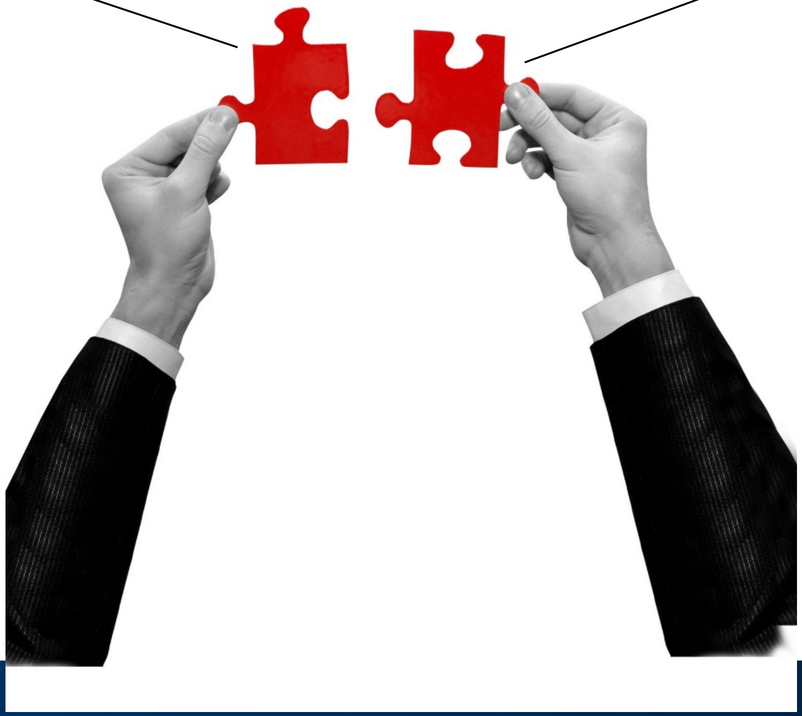
Small spacecraft (<~50kg)
- **Low-cost,**
- **quick** development,
- but **limited functions/reliability**



Future perspective of deep space exploration by small sats

- **Possible missions by small spacecraft (applications)**
  - **precursor** to a larger mission (e.g. Human planetary exploration, asteroid mining, etc)
  - **small-scale mission** for **"focused" science** with limited instruments

- Trajectory/Launch options ***"Don't miss any chance to ride"***
  - **Rideshare (direct escape) + Earth swingby + small Delta-V**
    → flexible target selection (asteroid/comets/planets) via Earth-swingby
  - **Rideshare (Lunar mission, LTO) + Lunar swingby + small Delta-V**
  - **Piggyback/Rideshare (E-M L1/L2, S-E L1/L2) + very small Delta-V**
    → flexible target selection by choosing departure time
  - **Piggyback** to any destination (**mothership-daughtership(s) mission**)

  - (Dedicated launch of (multiple) small spacecraft)

- **International collaboration** is essential!
  - Maximize the science return from limited number of deep space launch opportunities from limited countries (US, Europe, Japan, etc.)
  - by sharing ideas, components, subsystems, spacecraft, launch opportunities, etc.

Summary

- Univ. of Tokyo and JAXA successfully developed the **world's first 50kg-class micro-spacecraft PROCYON** at very low-cost within very short time (~1year).
- The launch and operation of PROCYON was successful
  → micro-spacecraft can be a **useful tool of deep space exploration**.
  - **Low-cost** and **quick** development
  - **Flexibility** to <u>quickly respond to a wide variety of launch opportunity</u>
- Future prospects of deep space exploration by small sats
  - ***"Do not miss any chance to ride"***
  - **Maximizing the outcome of deep space exploration** by the combination of large mission and small mission.
- **International collaboration** for future low-cost small deep space mission is essential and welcome!
  - Sharing ideas, components, sub-systems, spacecraft, launch opportunities
- We would like to contribute to advancing our knowledge of the solar system.