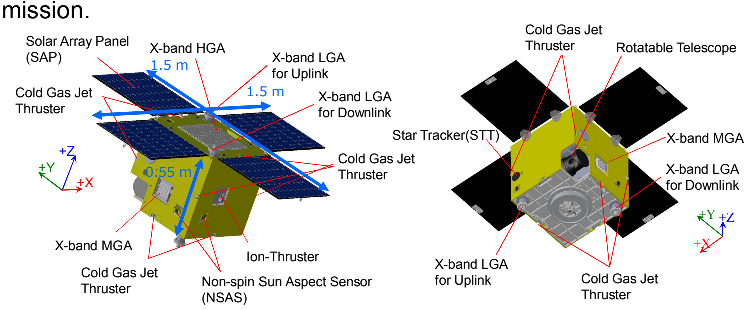
超小型深宇宙探査実証機PROCYONの軌道設計及び運用状況

川端洋輔(東大)
尾崎直哉(東大), 杉本理英(JAXA), 廣瀬史子(JAXA), Campagnola Stefano(JAXA), Yam Chit Hong(JAXA),
Sarli Bruno(総研大), 陳泓儒(九大), 小倉聡司(東大)，蟻生開人(東大)，船瀬龍(東大), 川勝康弘(JAXA)

1. Introduction

PROCYON (PRoximate Object Close flYby with Optical Navigation) is a 50kg-class micro-spacecraft developed by the University of Tokyo and the Japan Aerospace Exploration Agency (JAXA), based on the expertise acquired on past satellites developed at The University of Tokyo[1-3]. PROCYON was launched in an Earth resonant trajectory on December 3rd , 2014 as a secondary payload with Hayabusa 2 mission.



The mission objective is <u>to demonstrate micro-spacecraft bus technology for deep space exploration</u> and <u>proximity flyby to asteroids performing optical measurements.</u>

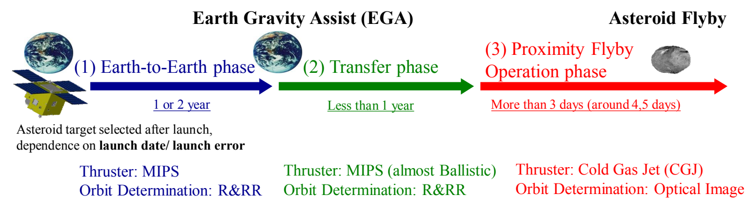
2. Mission Objectives and Scenario

<u>Success Criterion</u>: Summing system is adopted.

	Success Criterion	Point	Sum
Primary Mission Objective	Success in the power generation, thermal control , attitude control (by CGJ) , communications, and orbit determination in deep space	50	50
	Success in the Operation of MIPS in deep space	20	70
	Achievement of a certain level of velocity increase by MIPS	30	100
Secondary Mission Objective	Success in the communication with SSPA made from GaN	50	150
	Success in a differential VLBI technology for deep space navigation between Hayabusa2 and PROCYON	50	200
	Return to Earth one year later by the trajectory control	100	300
	Success in Earth swing-by and injection into transfer phase	50	350
	Capture the asteroid by the telescope from far	50	400
	Approach to the asteroid by the optical navigation, Success in asteroid imaging as an object having a size	100	500
	Success in a continuous imaging of asteroids from close range by the tracking control	100	600

CGJ : Cold Gas Jet
MIPS : Miniature Ion Propulsion System
GaN : Gallium nitride
SSPA: Solid State Power Amplifier
VLBI : Very Long Baseline Interferometry

<u>Earth Gravity Assist Scenario</u>



- Target asteroids are selected from the full asteroid database of the IAU Minor Planet Center with more than **600,000** asteroids.
- <u>System Requirements and Operation Constraints make the trajectory design complicate.</u>

<u>Trajectory Control Method:</u>

PROCYON has I-COUPS (Ion thruster and COld-gas thruster Unified Propulsion System) developed for PROCYON to use 2 propulsion methods according to situations:

MIPS: Low Thrust & High I_{sp} — For Interplanetary maneuver
CGJ: High Thrust & Low I_{sp} — For Close approach operation

There is a possibility that some parameters differ from assumptions. Some aspects of the operation and limited information make estimations of actual parameters complicate.

3. Mission characteristic

Most of the mission design aspect are driven by subsystem requirements.

	Earth to Earth phase	Transfer phase
Operation	・MIPS Operation Duty $d_{IPS} \leqq 0.7$ (Constraint)	
Power	・Solar energy flux $E_s \geqq 812[W/m^2]$ (MIPS Operation mode)	・Solar energy flux $E_s \geqq 585\ [W/m^2]$ (CGJ Operation mode)
Commu-nication		・Earth Distance $D_E \leqq 0.57[AU]$ at Proximity Flyby phase ・Declination of the spacecraft from the Usuda Deep Space Center (UDSC) $\delta_{SC} \geqq -56.13$ [°]
Thermal		・$0.9[AU] \leqq$ Solar Distance $D_S \leqq 1.5[AU]$
Asteroid Flyby		・Target asteroid can be observable 3days before the closest approach ・Relative velocity with the asteroid $V_{rel} \leqq 30[km/s]$

Spacecraft

Mass	Initial Total Mass[kg]: 66.928 Fuel Mass(Xe)[kg]: 2.5
Structure	0.55m×0.55m×0.67m (SAPs close) 1.5m×1.5m×0.67m (SAPs open)
Attitude Control System	Reaction Wheels (×4) 3-axis Fiber Optic Gyro (×1) Star Tracker (×1) Non-spin Sun Sensors (×5) 1-axis Rotatable Telescope (×1) (asteroid obs. and optical nav.)
Miniature Ion Propulsion System (MIPS) using Xe	Thrust[mN]: 0.30 Isp[s]: 1000.0
Cold Gas Jet (CGJ) using Xe (×8)	Thrust[mN]: 22.0 Isp[s]: 24.5
Communication System	X band TT&C, 1 X-HGA, 1 X-MGA, 2 X-LGA(Downlink), 2 X-LGA(Uplink)

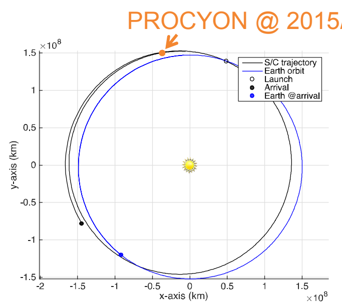
4. Trajectory Design Result and Current Status

PROCYON is now in Earth-to-Earth transfer phase. The launch result and the ion engine performance are being analyzed. Together with the orbit determination data, the trajectory is redesigned to minimize the propellant mass with jTOP, a in-house trajectory optimization that implements a direct method.

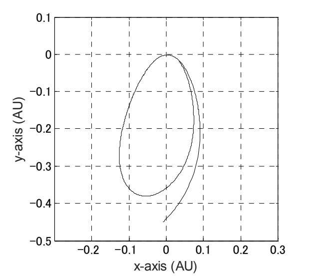
Orbital Elements of PROCYON (J2000 Ecliptic Coordinate)

Semi-major axis [km]	Eccentricity	Right ascension of the ascending node[deg]	Inclination [deg]	Argument of perigee[deg]
1.4988×10^8	0.0874	250.6	6.820	95.59

<u>Example of a trajectory to a candidate of target asteroids:</u>



Example of Trajectory in J2000 Ecliptic Coordinate



Example of Trajectory in Sun-Earth fixed rotating frame

<u>Current Status:</u>

<u>PROCYON has almost completed its “Primary Mission Objective”.</u>
The acceleration test by MIPS (Miniature Ion Propulsion System) is ongoing and PROCYON’s acceleration was observed.
Some parameters of PROCYON (e.g. MIPS and CGJ) will be updated by using orbit determination data and telemetry data for the **more precise trajectory design** and **Proximity Flyby phase.**

References

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[2] Komatsu, M. and Nakasuka, S. "University of Tokyo Nano Satellite Project 'PRISM'." Transactions of the Japan Society for Aeronautical and Space Sciences, Vol. 7, pp. 19–24, 2009.
[3] Sako, N., Hatsutori, Y., Tanaka, T., Inamori, T., and Nakasuka, S. "Nano-JASMINE: A Small Infrared Astrometry Satellite." 21st Annual AIAA/USU Conference on Small Satellites. UT, USA, August 2007.

Achievements

[A] Ozaki, N., Funase, R., Nakajima, S., Yam, C. H., Campagnola, S., Sarli, B., Sugimoto, Y., Chen, H., Ogura, S., Kawakatsu, Y., and Nakasuka, S., "Preliminary Mission Design of PROCYON: A Micro Spacecraft to Asteroid," 24th International Symposium on Space Flight Dynamics, Maryland, U.S.A., May 5-9, 2014.
[B] Yam, C. H., Sugimoto, Y., Ozaki, N., Sarli, B., Chen, H., Campagnola, S., Ogura, S., Kawabata, Y, Kawakatsu, Y., Nakajima, S., Funase, R., Nakasuka, S., "Launch Window and Sensitivity Analysis of an Asteroid Flyby Mission with Miniature Ion Propulsion System: PROCYON," 65th International Astronautical Congress, Toronto, Canada, Sep. 29-Oct. 3, 2014, IAC-14-C1.9.9.
[C] Sugimoto, Y., Campagnola, S., Yam, C. H., Hirose, C., Sarli, B., Chen, H., Ogura, S., Kawabata, Y., and Funase, R. " Design and Operation of a Micro-Spacecraft Asteroid Flyby Mission: PROCYON." 25th AAS/AIAA Space Flight Mechanics Meeting. Williamsburg, VA, U.S.A., Jan. 2015.