50kg-class Deep Space Exploration Technology Demonstration Micro-spacecraft PROCYON

Ryu Funase, Hiroyuki Koizumi, Shinichi Nakasuka
Department of Aeronautics and Astronautics, The University of Tokyo
Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan; +81-3-5841-0742
funase@space.t.u-tokyo.ac.jp

Yasuhiro Kawakatsu, Yosuke Fukushima, Atsushi Tomiki, Yuta Kobayashi, Jun'ichi Nakatsuka, Makoto Mita, Daisuke Kobayashi, Taku Nonomura
Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency
Yoshinodai 3-1-1, Sagamihara-shi, Kanagawa 229-8510; +81-50-3362-7836
Kawakatsu.Yasuhiro@jaxa.jp

ABSTRACT

University of Tokyo and Japan Aerospace Exploration Agency (JAXA) are developing a 50kg-class micro-spacecraft named "PROCYON" for deep space exploration. PROCYON will conduct two missions: 1) demonstration of micro-spacecraft bus system for deep space exploration, and 2) demonstration of asteroid close flyby observation. In order to develop the spacecraft with very low cost (less than a few million dollars), most of the bus system is based on that of Earth-orbiting micro satellite, excluding the communication system and propulsion system which are newly developed for the deep space mission. PROCYON is scheduled to be launched at the end of 2014 together with Japanese second asteroid sample return spacecraft Hayabusa-2. The success of PROCYON will demonstrate that a small-scale spacecraft for deep space exploration can be built with very low cost, which will enable more frequent and challenging deep space exploration.

INTRODUCTION

In recent years, the size and cost of Earth-orbiting satellites have been reduced, and frequent launch and operation of satellites has been realized. The first step of this big wave was the launch of CubeSats, 1kg nano-satellites, made by several universities including University of Tokyo in June 2003 [1]. A number of universities around the world now have been building nano-satellites for the purpose of students' education and technology demonstration, and several venture companies are pursuing the practical use of nano-satellites in the area of earth observation, space science, or space demonstration [2].

On the other hand, deep space exploration, not Earth-orbiting mission, still remains large-scale (>500~1000 kg) and high-cost (>100 million ~ 1 billion dollars) mission. The risk of failing such a large mission causes the difficulty to execute challenging and advanced mission, although the deep space exploration itself should be challenging in nature. In order to overcome such difficulty, small-scale and low-cost deep space mission should be realized, and it will contribute to high-frequent and challenging deep space exploration.

For the first step of this attempt, Intelligent Space Systems Laboratory (ISSL) at the University of Tokyo and the Japan Aerospace Exploration Agency (JAXA) started to develop 50kg-class micro-spacecraft for deep space exploration in the fall of 2013. The spacecraft is called PROCYON (PRoximate Object Close flYby with Optical Navigation). PROCYON is scheduled to be launched together with Japanese second asteroid sample return spacecraft Hayabusa-2 [3] at the end of 2014. As of June 2014, PROCYON is in the phase of its final integration test.

MISSION OF PROCYON

PROCYON has two missions: 1) demonstration of micro-spacecraft bus system for deep space exploration, and 2) demonstration of asteroid close flyby observation.

Fig. 1 shows the mission sequence of PROCYON. PROCYON will be launched with Hayabusa-2 and initially inserted into an Earth resonant trajectory that allows the spacecraft to come back to the Earth by solar electric propulsion. Within several months after the launch, the first mission (demonstration of the bus system) will be completed. Then, PROCYON will perform DSM (Deep Space Maneuver) using its miniature ion propulsion system so that the spacecraft will come back to the Earth for Earth swingby. The Earth swingby, which is scheduled at the end of 2015, will direct the spacecraft trajectory to its target asteroid. In the Earth swingby, we intend not to expand spacecraft velocity (V-infinity) but to change the direction of outgoing velocity; in that sense, we should say "retargeting" [4]. The Earth swingby will enable the spacecraft to expand a number of candidate asteroids for flyby operations.

PROCYON will perform close flyby trajectory guidance by optical navigation and will pass within 50 km distance from the asteroid. Flyby velocity will be less than 10 km/s relative to the target asteroid. During the close flyby, automatic tracking observation of the asteroid will be conducted using a camera with a scan mirror and onboard image feedback control which enables LOS (Line Of Sight) maneuver while maintaining the spacecraft attitude (Fig. 2).

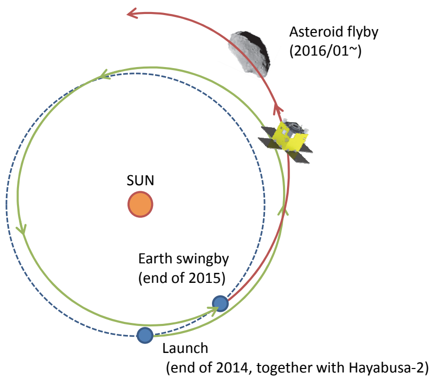

Figure 1: Overview of mission sequence of PROCYON

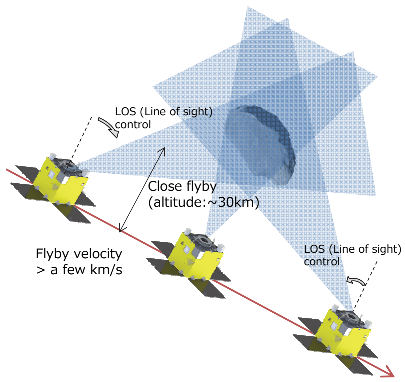

Figure 2: Asteroid close flyby observation by onboard image feedback control

PROCYON SYSTEM CONFIGURATION

The external view of PROCYON is shown in Figs. 3 and 4. Fig. 5 shows the system block diagram of PROCYON. The specification of the spacecraft is shown in Table 1. Most of the bus system of PROCYON is based on that of 50kg-class Earth-orbiting micro satellite, excluding the communication system and propulsion system, which are newly developed for deep space mission.

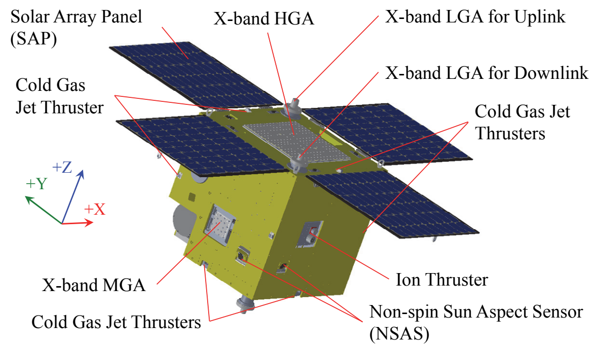

Figure 3: External view of PROCYON (top view)

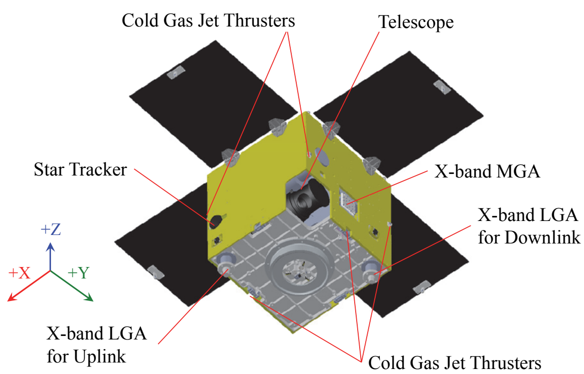

Figure 4: External view of PROCYON (bottom view)

Communication System

The communication system of PROCYON consists of X-band transponder (XTRP), high-power (15 W output) GaN-based solid state power amplifier (SSPA), tone generator for DDOR (Delta Differential One-way Range) orbit determination, isoflux low gain antennas (LGAs), flat antennas (MGA and HGA) and other passive components (switches, diplexer and band pass filters). XTRP and SSPA are newly developed for this mission. Miniaturization is achieved by utilizing COTS (Commercial Off The Shelf) components. The communication system of PROCYON is compatible with 64m Japanese deep space antenna, as well as DSN (Deep Space Network).

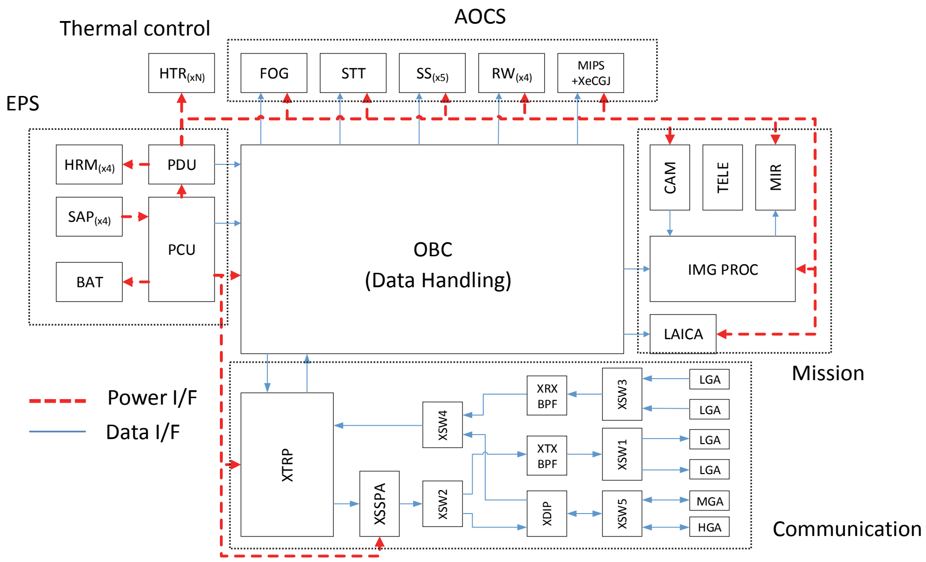

Figure 5: System block diagram of PROCYON

Table 1: Specification of PROCYON

Structure	Size	0.55m x 0.55m x 0.67m + 4 SAPs (Solar Array Panels)
	Weight	<70kg (wet)
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)
Propulsion	RCS	Xenon cold gas jet thrusters x8, ~20mN thrust, 24s Isp
	Ion propulsion	Xenon microwave discharge ion propulsion system
		250 uN thrust, 1000s Isp
	Propellant	2.5 kg Xenon (for both RCS and ion propulsion)
Communication	Band	X-band (for deep space mission)
	Antenna	HGA x1, MGA x1, LGA x2 (for uplink), LGA x2 (for downlink)
	Output	15 W

Propulsion System for Attitude and Orbit Control

Micro propulsion system named I-COUPS (Ion thruster and COld-gas thruster Unified Propulsion System) is also newly developed for PROCYON [5]. I-COUPS is a propulsion system that unifies an ion thruster called MIPS (Miniature Ion Propulsion System) and multiple cold-gas thrusters. The ion thruster provides 250 μN of thrust with a specific impulse of about 1000 s, which is used for DSM. The cold-gas thrusters, which provide about 20 mN of thrust with 24 s of specific impulse are used for both the reaction wheel desaturation and the asteroid flyby trajectory correction maneuver. The weight of the propulsion system is less than 10 kg including about 2 kg of propellant (Xenon). Such lightweight property is realized by sharing the gas system for both ion thruster and cold-gas thrusters.

DEVELOPMENT STATUS

The piggyback launch of PROCYON together with Hayabusa-2 was approved on September 2013, and since then, the spacecraft has been developed. After the completion of the spacecraft system design, we built STM (Structure and Thermal Model) to verify the mechanical and thermal design of the spacecraft. Vibration test (March 2014, Fig. 6) and thermal vacuum test (April 2014, Fig. 7) was successfully conducted, and we are in the phase of final integration and test of flight model (as of June 2014).

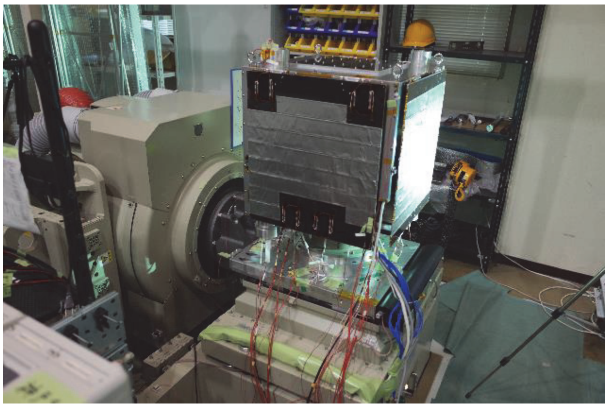

Figure 6: Vibration test of STM

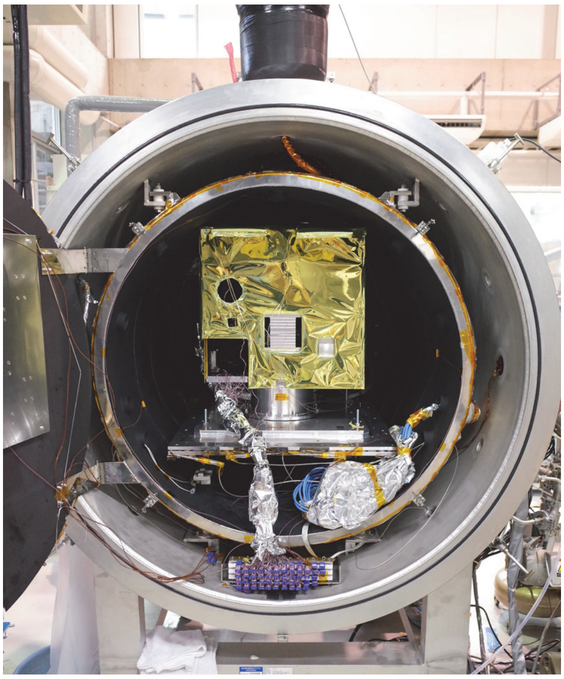

Figure 7: Thermal vacuum test of STM

CONCLUSION

University of Tokyo and JAXA is developing a 50kg-class micro-spacecraft PROCYON for deep space exploration. PROCYON has two missions: the first is the demonstration of micro-spacecraft bus system for deep space exploration, and the second is the demonstration of asteroid close flyby observation by a camera with a scan mirror and onboard image feedback control capability. Most of the bus system of PROCYON is based on that of 50kg-class Earth-orbiting micro satellite, which enables very quick and low-cost spacecraft development. COTS-based deep space communication system and miniature propulsion system are newly developed.

The main purpose of the development of PROCYON is to demonstrate that a small-scale spacecraft for deep space exploration can be built with very low cost (less than a few million dollars). The success of PROCYON mission will contribute to the realization of high-frequent and challenging deep space exploration.

PROCYON is scheduled to be launched together with Japanese second asteroid sample return spacecraft Hayabusa-2 at the end of 2014, and as of June 2014, the spacecraft is in the phase of its final integration and testing.

References

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