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# On-orbit Performance of a Miniature Propulsion System on a 70 kg Space Probe to Explore Near-Earth Asteroids


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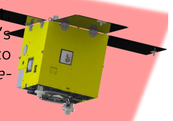
## *What is the micro-space probe,* PROCYON?

University of Tokyo, in 2003, developed and launched the world's first cubesat, XI-IV, into the orbit. In 2014, we challenged the world's first microsatellite, PROCYON, to develop *micro-deep-space-exploration*.



PROCYON (2014)
The first interplanetary microsatellite

XI-IV (2003)
The first cubesat

THE UNIVERSITY OF TOKYO

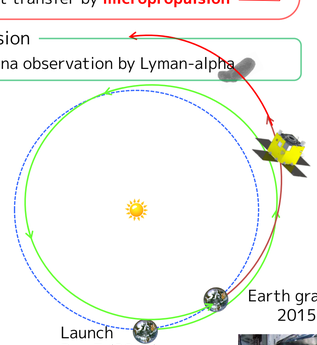
DEVELOPMENT SINCE 2013 SEPT.

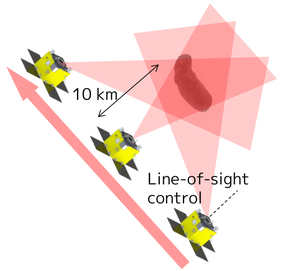
Nominal mission
Verification of bus technologies of micro-space probe: communication, attitude control, orbit determination, power generation, thermal control, and **micropropulsion**

Advanced mission
Verification of technologies for deep-space-exploration by a micro-space probe
- GaN high-eff.-deep-space communication
- Fast-fly-by observation of asteroid
- Orbit transfer by **micropropulsion**

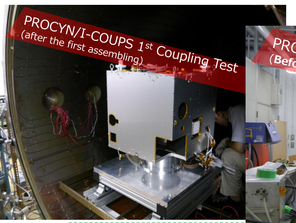
Science mission
Geocorona observation by Lyman-alpha

**Requirements to Propulsion**
- Multiple thrusters
  for RCS (reaction control system)
- High ΔV
  for orbit transfer of gravity assist
- High thrust
  for TCM (trajectory correction maneuver)

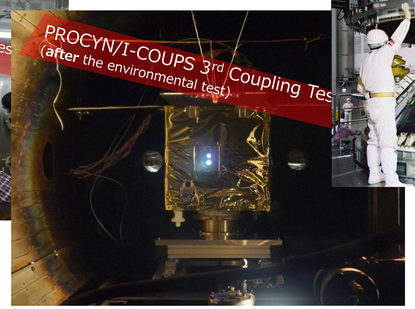


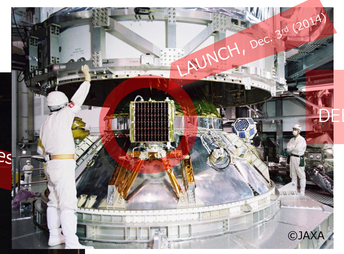




## *The PROCYON & I-COUPS,* Developed & Launched?

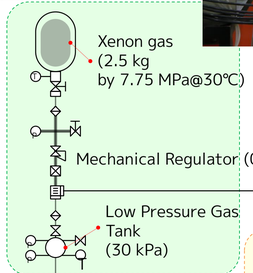


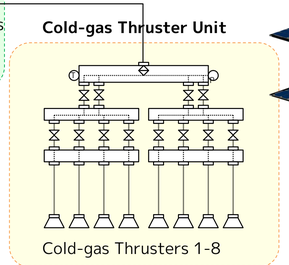




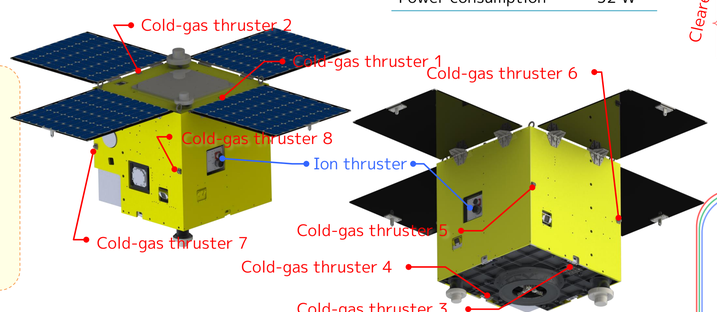

INTO DEEP SPACE




Valves of the cold-gas thrusters have redundant systems for open failures of thruster valves. Cut-off valves are equipped at upstream of the thruster valves, which divided into two groups. The cut-off valves have parallel configuration prepared for their close failures.

| Ion thruster | |
|---|---|
| Thrust | 300 μN |
| Specific impulse | 1080 s |
| Number of thrusters | 1 |
| Power consumption | 32 W |

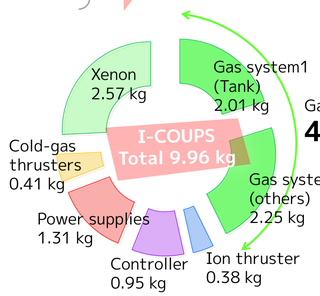


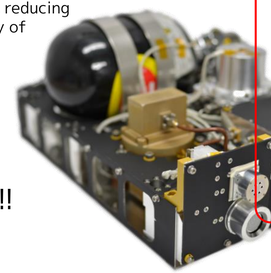

Cold-gas thruster unit has 8 cold-gas thrusters allocated at the center of each side of the probe as. Nozzle directions of all the thrusters were canted from the panel surface to provide both of rotational force for RCS and translational force for TCM.

## *What is the unified-micropropulsion,* I-COUPS?

OUR SOLUTION

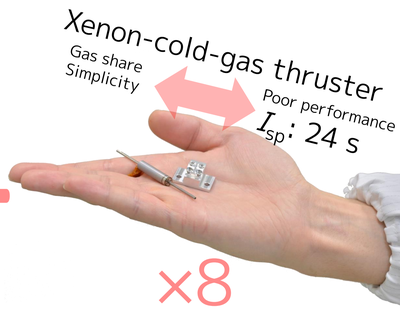
I-COUPS [άɪkú:z] (**I**on thruster and **CO**ld-gas thruster **U**nified **P**ropulsion **S**ystem) is a micropropulsion system equipped with ion thruster and multiple cold-gas thrusters to . The ion thruster and cold-gas thrusters shares the same gas system, xenon gas. For downsized-propulsion system, mass of gas-feeding system becomes dominant rather than propellant. Hence, reducing dry-mass of gas system is a key of micropropulsion system.



**MIPS-FM on H4**
Total mass: 8.1 kg
**Xenon: 0.9 kg**
Volume: 39 x 26 x 15 cm³
**Power: 27 W**
**Thrust: 200 μN**
**Isp: 740 s**
**Delta V: 140 m/s**
(for 50 kg S/C)

MIPS (Miniature Ion Propulsion System) is a micropropulsion system equipped with an ion thruster developed for the 60-kg, LEO-satellite HODOYOSHI-4, and the ion thruster successfully conducted its first operation in space on Oct. 28th, 2014. The I-COUPS was developed based on this MIPS.




Extremely simple structure of cold-gas thrusters and gas sharing with ion thruster enabled light weight and compact micropropulsion system that provides full-set propulsion ability: orbit transfer, reaction control, and high thrust.

## *The first interplanetary micro-spacecraft,* In-Flight Operation

Initial checkout of the propulsion system started on Dec. 5th, 2014, two days after the launch. In one month, the project team successfully finished the checkout of the COTS-based high-pressure gas system, cold-gas thrusters, and the ion thruster. Torque by the cold-gas thrusters was confirmed by the angular momentum change of the space probe and thrust of the ion thruster was confirmed and measured by Doppler shift of the communication wave.

The ion thruster accumulated the total operation time up to 223 hours after solving problems #01-04. The averaged ion beam current was 5.62 mA corresponding to the thrust of 346 μN. The thrust coefficient γ_T was updated to 0.964 according to the thrust estimated from the Doppler data. The beam current showed a trend of gradual decrease by 1.7% over 200 hours.

Problems exposed in the flight operation of the ion thruster
1. ~~Leakage at the ion thruster valve~~
2. ~~Error control of the pressure regulation valve~~
3. ~~Occasional freeze of the controller~~
4. ~~Gradual increase of the neutralizer voltage~~
5. High voltage anomaly of the ion thruster

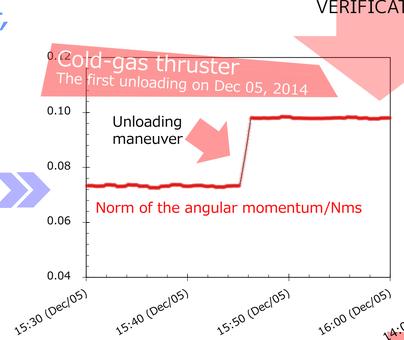
Cleared

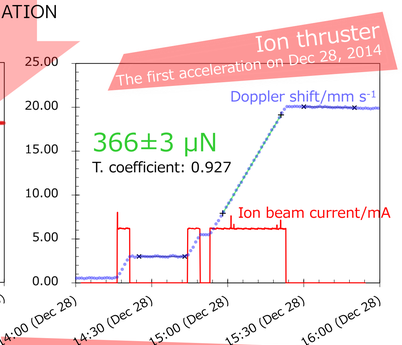
#01-04 were found in the initial checkout and solved by changing the operating conditions/methods. #05 appeared after the 223-h operation. Recovery operation for the problem #05 has continued to clear the expected cause, grid-short.

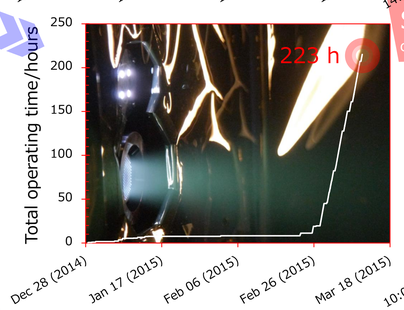
***Achievement**, up to today*

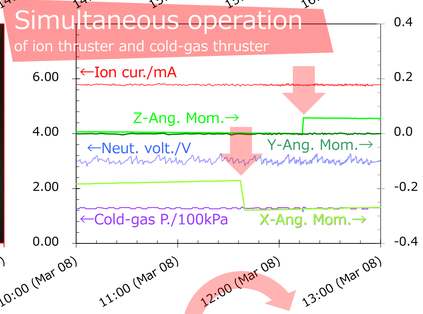
The miniature propulsion system has operated for more than 6 months, as the first interplanetary micropropulsion.
- COTS-based micro-EP subsystems, including the high-pressure gas system, have been in good health.
- The cold-gas-thrusters are successfully working over 103 operations
- The ion thruster operated in 223 hours

VERIFICATION




PROCYON has no gimbal system and cold-gas thruster unloading is necessary, typically once a two days. Gas ejection from the cold-gas thrusters had potential to increase the gas pressure surrounding the space probe and to disturb the operation of the ion thruster. The unloading maneuver was conducted with continuous-operation of the ion thruster and it showed no interference with its operation.