The University of Tokyo, Intelligence Space Systems Laboratory

On-orbit verification of luminance based target tracking and faint body extractions by a small telescope on the world's first micro-interplanetary space probe

Japan Aerospace Exploration Agency

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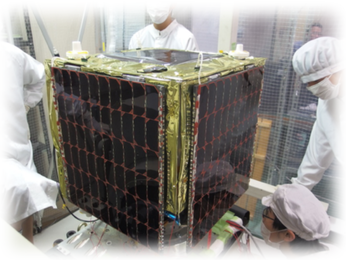
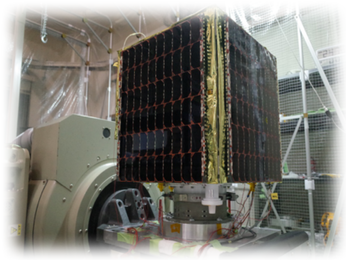
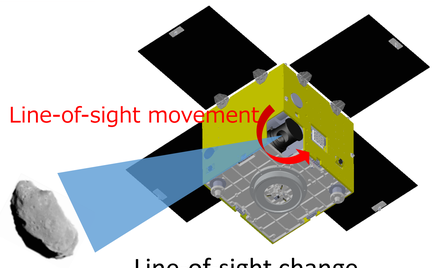
World's first interplanetary micro space probe





Flight model of PROCYON [1]

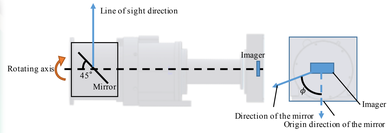


Line-of-sight change
during a close distance flyby

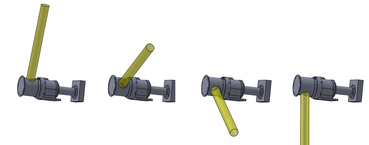
Proximate Object Close flYby with Optical Navigation (PROCYON) was the world's first interplanetary micro-spacecraft that had the full ability to achieve actual scientific survey such as observation of geocorona with the Lyman Alpha Imaging Camera. Other than the main technology demonstration mission, PROCYON had bonus goals to fly adjacent to an asteroid and to capture high-resolution images of its surface. See also: [1] SSC16-III-05.

Telescope for two purposes

Optical telescope of PROCYON



System description of
the rotatable mirror[2]



Line-of-sight direction change
by the rotatable mirror[2]

Specifications of the telescope

Pupil diameter	40mm
F-number	3.75
Focal length	150mm
Angle of view (Half the vertex angle)	2.6deg
Number of pixels	1088×2048
Size of a pixel	5.5μm

PROCYON is equipped with a telescope to achieve two objectives;

❶ Detect the target asteroid as early as possible

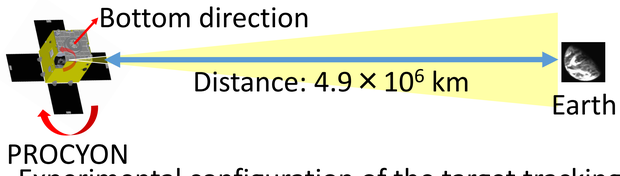
There is relative position uncertainty between the asteroid and PROCYON. The target should be detected 5 days before closest approach to perform trajectory correction maneuvers.

❷ Take pictures of the asteroid leading up to closest approach

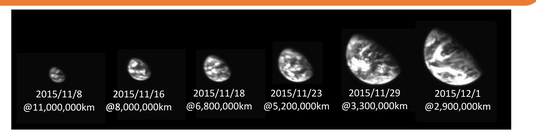
In the vicinity phase of the close distance flyby, PROCYON had a plan to capture high-resolution images, while the line-of-sight direction of the telescope was autonomously controlled using asteroid image processing on-board.

The small telescope should achieve the objectives with the same 4cm caliber barrel.

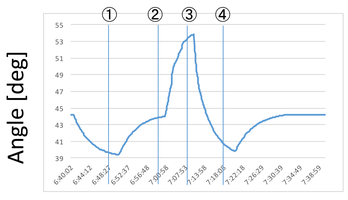
Visual feedback tracking experiment



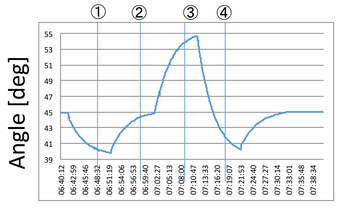
Experimental configuration of the target tracking



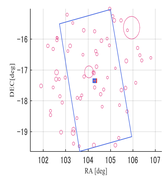
Earth pictures taken by the telescope



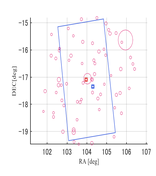
Time [HH:MM:SS]
Attitude control profile, Earth direction angle profile from bottom direction of PROCYON)



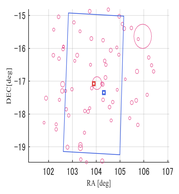
Time [HH:MM:SS]
Mirror direction control profile, mirror direction angle profile from bottom direction of PROCYON)



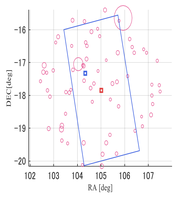
Field of view direction at ①



Field of view direction at ②



Field of view direction at ③

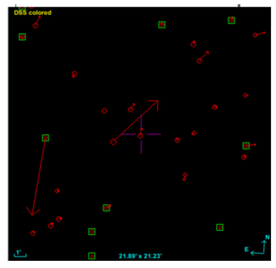


Field of view direction at ④

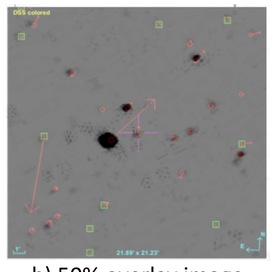
The on-board image feedback tracking technology was partly verified using Earth as a virtual target body. The apparent diameter of Earth at the time of the experiment was about 0.15 deg = 70 pixels. By looking at the field of view direction plots (①～④), there are some angular separations between central points (red ☐, desired direction of Earth) and the Earth directions (blue☐). It was simply explained the delay of the image processing.

Acknowledgements:
The present work was supported in part through the Leading Graduates Schools Program, "Global Leader Program for Social Design and Management," by the Ministry of Education, Culture, Sports, Science and Technology.

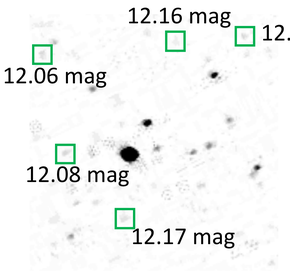
Dark-star detection experiment



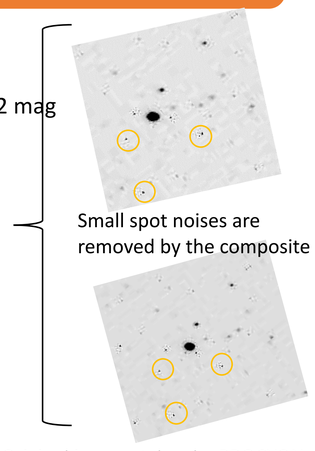
a) Star position from
Simbad Data Base



b) 50% overlay image
of right and left images



c) Composed image



d) Original images taken by PROCYON
(10 second exposure time)

Red Circle : Stars in the data base
Green Square: Darker stars than 12mag

PROCYON should detect 12th magnitude stars in order to find the target asteroid 5 days before arrival. A dark star detection experiment was performed to verify the detection capability. PROCYON was limited to a 4 cm aperture telescope for optical navigation, and the single-shot S/N ratio is not applicable for such dark star detection. Actually, many small spot noises can be observed in the original images taken by the small telescope (Fig. d). These spot noises cause miss detections of the dark stars. In order to remove these noises, two original images are composed based on some positions of dark stars, and Fig. c was generated. The composed image was compared with the star database, and several stars darker than 12th magnitude were detected.

References
[1] Funase, R., Inamori, T., Ikari, S., Ozaki, N., Nakajima, S., Ariu, K., Koizumi, H., Kameda, S., Tomiki, A., Kobayashi, Y., Ito, T., Kawakatsu, Y., "One-year Deep Space Flight Results of the World's First Full-scale 50-kg-class Deep Space Probe PROCYON and Its Future Prospects," 30th Annual AIAA/Utah State University Conference on Small Satellites, SSC16-III-05, Logan, Utah, Aug. 2016
[2] Ariu, K., Inamori, T., et al., "A Dimensionless Relative Trajectory Estimation Algorithm for Autonomous Imaging of a Small Astronomical Body in a Close Distance Flyby", *Advances in Space Research*, doi:10.1016/j.asr.2016.05.028,Volume 58, Issue 4, pp. 528-540, 2016.