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

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**World’s first interplanetary micro space probe**

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.

**Visual feedback tracking experiment**

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.

**Telescope for two purposes**

PROCYON is equipped with a telescope to achieve two objectives;

1. Detect the target asteroid as early as possible
2. 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.

**Dark-star detection experiment**

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.

**Acknowledgements:**

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**Table: Specifications of the telescope**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Pupil diameter</td>
<td>40mm</td>
</tr>
<tr>
<td>F-number</td>
<td>3.75</td>
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<tr>
<td>Focal length</td>
<td>150mm</td>
</tr>
<tr>
<td>Angle of view</td>
<td>2.6deg</td>
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<tr>
<td>Number of pixels</td>
<td>1088 x 2548</td>
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<tr>
<td>Size of a pixel</td>
<td>5.5μm</td>
</tr>
</tbody>
</table>

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**Image credits:**

- Flight model of PROCYON [1]
- Bottom direction
  - Distance: $4.9 \times 10^6$ km
  - Earth
- PROCYON Experimental configuration of the target tracking
- Earth pictures taken by the telescope
- Field of view direction at ①
- Field of view direction at ②
- Field of view direction at ③
- Field of view direction at ④
- Optical telescope of PROCYON
- System description of the rotatable mirror[2]
- Line-of-sight direction change by the rotatable mirror[2]