Laser link experiment between Hayabusa2 laser altimeter and SLR stations

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Thanks to: Hayabusa-2 spacecraft and ground station operation teams, NASA DSN for TT&C microwave link, and Toshi. Otubo for discussion on prediction files
Contents

• purposes of experiment with achievements

• experimental setup

• results

• summary
Results at a glance

i) Detection frequency w.r.t. S/C scan
-> Rx. boresight determined

Hayabusa2 laser altimeter “LIDAR”

ii) Received intensity by LIDAR with receiver gain / ground pointing changes
-> confirmation of detection
- link budget

iii) Pulse intervals
-> clock freq. adjustment
Purposes of experiment / achievements

• Engineering demonstration
  – synchronized two-way (transponder) -&gt; uplink only
  – clock frequency transfer -&gt; OK by using pulse intervals

• Performance check
  – link budget -&gt; OK for uplink
  – telescope alignment -&gt; Rx. tel. w.r.t. S/C

at interplanetary distance

-&gt; the third example farther than lunar distance
  (after MESSENGER and Mars Global Surveyor)
Hayabusa2 LIDAR

Mizuno+ 2016 SSR

<table>
<thead>
<tr>
<th>Rx telescope ( &gt; 1 km)</th>
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<tbody>
<tr>
<td>diameter</td>
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<td>FOV</td>
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<td>detector</td>
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<th>Tx telescope</th>
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<tr>
<td>divergence</td>
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<thead>
<tr>
<th>Laser</th>
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<tbody>
<tr>
<td>wavelength</td>
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<tr>
<td>repetition</td>
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<tr>
<td>energy</td>
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<td>pulse width</td>
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<table>
<thead>
<tr>
<th>total mass</th>
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<tr>
<td>3.5 kg</td>
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<thead>
<tr>
<th>Observation mode</th>
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<tr>
<td>-ranging</td>
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<tr>
<td>-transponder</td>
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<tr>
<td>-dust detection</td>
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</table>

2014.12.3 Launch
2015.12.3 Swing by
2018.06    Arrival
... Observation ...
2019.12    Departure
2020.12    Return

target asteroid
162173 Ryugu
in Transponder mode, 
- two pulses can be detected in 1 [s] 
- extra 1 [s] needed for data acquisition 
- the pulse intervals are sent as telemetry data for onboard clock calibration
### SLR stations

16 days in total
- Oct. 3d
- Nov. 5d
- Dec. 8d

#### Oct. & Nov.

<table>
<thead>
<tr>
<th></th>
<th>NICT Koganei (JPN)</th>
<th>Mt. Stromlo (AUS)</th>
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<tbody>
<tr>
<td><strong>transmitter</strong></td>
<td>Q-SW Nd:YAG</td>
<td>Q-SW Nd:YAG</td>
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<tr>
<td><strong>laser wavelength, nm</strong></td>
<td>1064</td>
<td>1064</td>
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<tr>
<td><strong>Pulse energy, J</strong></td>
<td>1</td>
<td>2.2</td>
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<tr>
<td><strong>Pulse width, ns</strong></td>
<td>10</td>
<td>15</td>
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<tr>
<td><strong>Beam divergence, arcsec</strong></td>
<td>10</td>
<td>12</td>
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<tr>
<td><strong>Repetition rate, Hz</strong></td>
<td>10</td>
<td>170</td>
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<tr>
<td><strong>receiver</strong></td>
<td>InGaAs APD-array</td>
<td>IR enhanced Si-APD</td>
</tr>
<tr>
<td><strong>Telescope diameter, m</strong></td>
<td>1.5</td>
<td>1.8</td>
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</table>
S/C operation and data

• **Scanning operation** in transponder mode
  – to find out the direction of boresight w.r.t. S/C frame
  – step size = 1 mrad to cover 1 x 1 deg.$^2$, duration 40[s]
  – max. 17 shots were detected within a step
  – detection flags & pulse intervals were downlinked via microwave link

• **Pointing operation** in ranging mode (Dec.19)
  – received intensities w.r.t. ground telescope scan /gain
NG in Oct. and Nov. from JPN and AUS
OK in Dec. from AUS

RESULTS
Dec 11,#1-92
M2 offset 400um (FOV=18”)
Distance: 3.3M km
Rx footprint: 5,000 km

Dec 15,#1-158 (#92-last cloudy)
M2 offset nominal(FOV=12”)
Distance: 5.0M km
Rx footprint: 7,500 km

Boresight direction is almost determined within scan step size.
Rx. intensity by LIDAR

Received Intensity Data on 19 Dec. in Range Mode

- Changes of intensity in accordance with gain change / offset pointing
- Evidence of detection of ground laser pulses (not background emission etc.)

Enhancement due to ground telescope offset pointing
Pulse intervals

time-series pulse intervals
top : LIDAR
bottom: ground laser
(fixed offset subtracted)

Ground/LIDAR Pulse Interval

histograms of pulse intervals
(onboard clock adjusted)

bar : LIDAR
stair-step : ground laser

onboard clock frequency adjustment
~ 2 kHz (6 ppm of 300 MHz)

Onboard clock frequency was successfully adjusted by pulse intervals on the ground laser.
Summary

- Uplink one-way established at 6.6 M km
- Downlink signals not found
- Rx. boresight determined
- Clock frequency adjusted with pulse intervals
- Hayabusa2 became the third example of laser link farther than lunar distance

“Earth, Planets and Space” in revision