

Laser link experiment between Hayabusa2 laser altimeter and SLR stations

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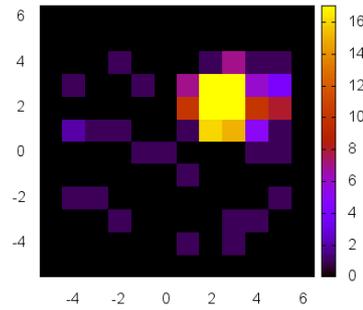
Thanks to : Hayabusa-2 spacecraft and ground station operation teams,
NASA DSN for TT&C microwave link,
and Toshi. Otubo for discussion on prediction files

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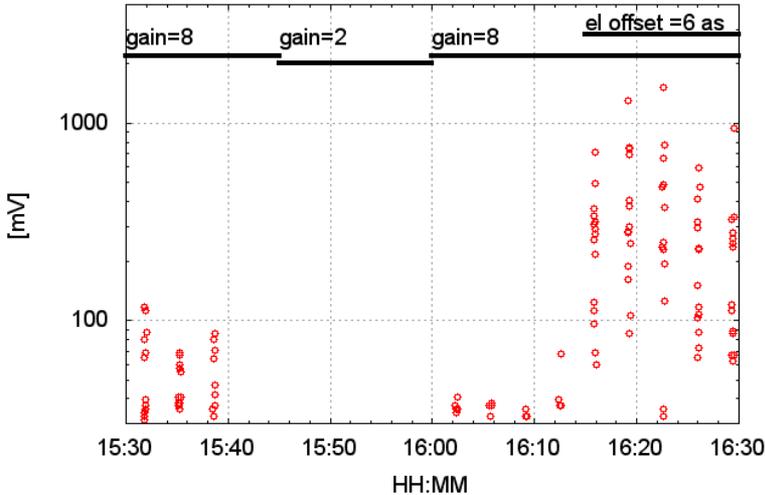
- purposes of experiment with achievements
- experimental setup
- results
- summary

Results at a glance

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



Received Intensity Data on 19 Dec. in Range Mode

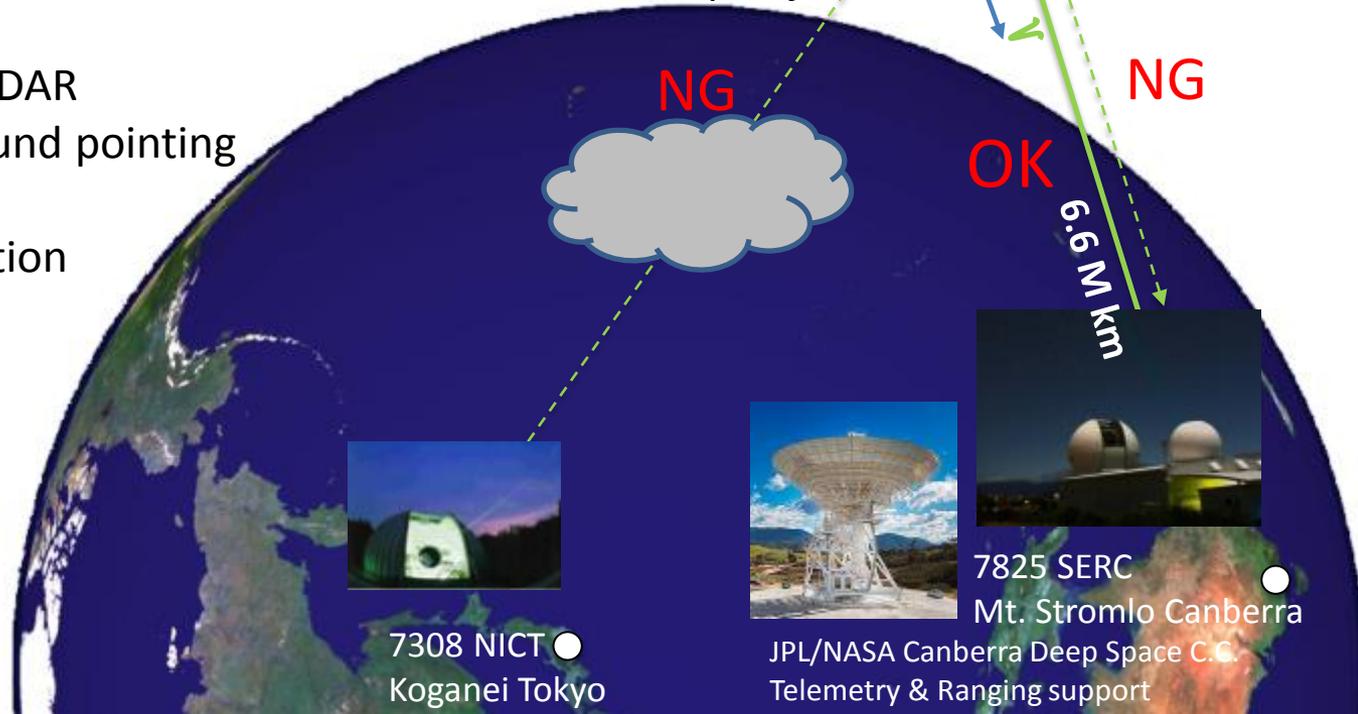


Hayabusa2
laser altimeter
"LIDAR"

- iii) Pulse intervals → clock freq. adjustment



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



Purposes of experiment / achievements

- Engineering demonstration
 - synchronized two-way (transponder) -> uplink only
 - clock frequency transfer -> OK by using pulse intervals
- Performance check
 - link budget -> OK for uplink
 - telescope alignment -> Rx. tel. w.r.t. S/C

at interplanetary distance

-> the third example farther than lunar distance
(after MESSENGER and Mars Global Surveyor)

Hayabusa2 LIDAR

Mizuno+ 2016 SSR

Rx telescope (> 1 km)
diameter 11 cm
FOV 1.5 mrad
detector APD

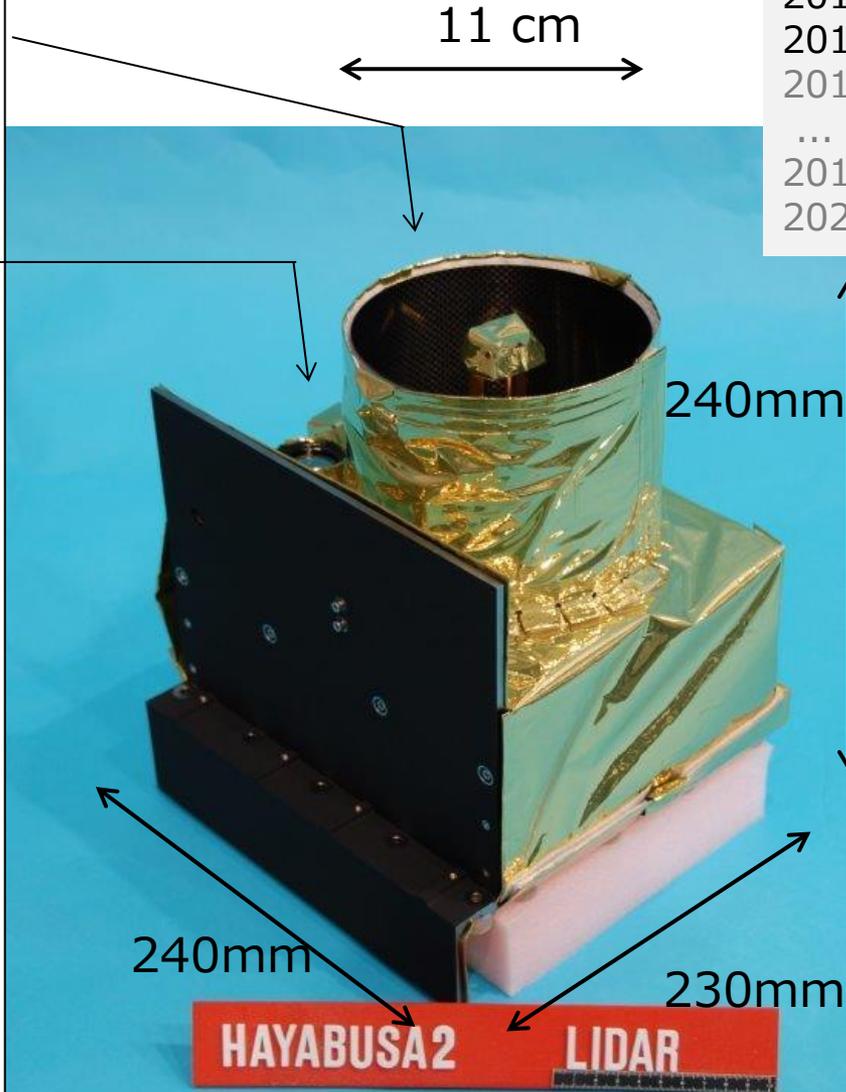
Tx telescope
divergence 2.5 mrad

Laser
wavelength 1064 nm
repetition **max. 1 Hz**
energy 15 mJ
pulse width 7 ns

total mass 3.5 kg

Observation mode

- ranging
- transponder
- dust detection

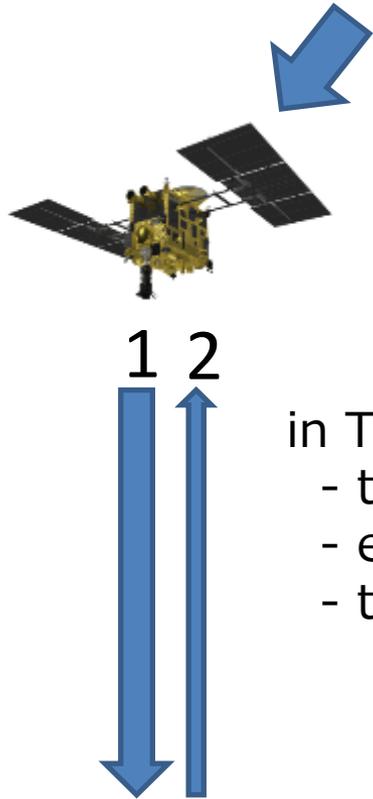


2014.12.3 Launch
2015.12.3 Swing by
2018.06 Arrival
... Observation ...
2019.12 Departure
2020.12 Return

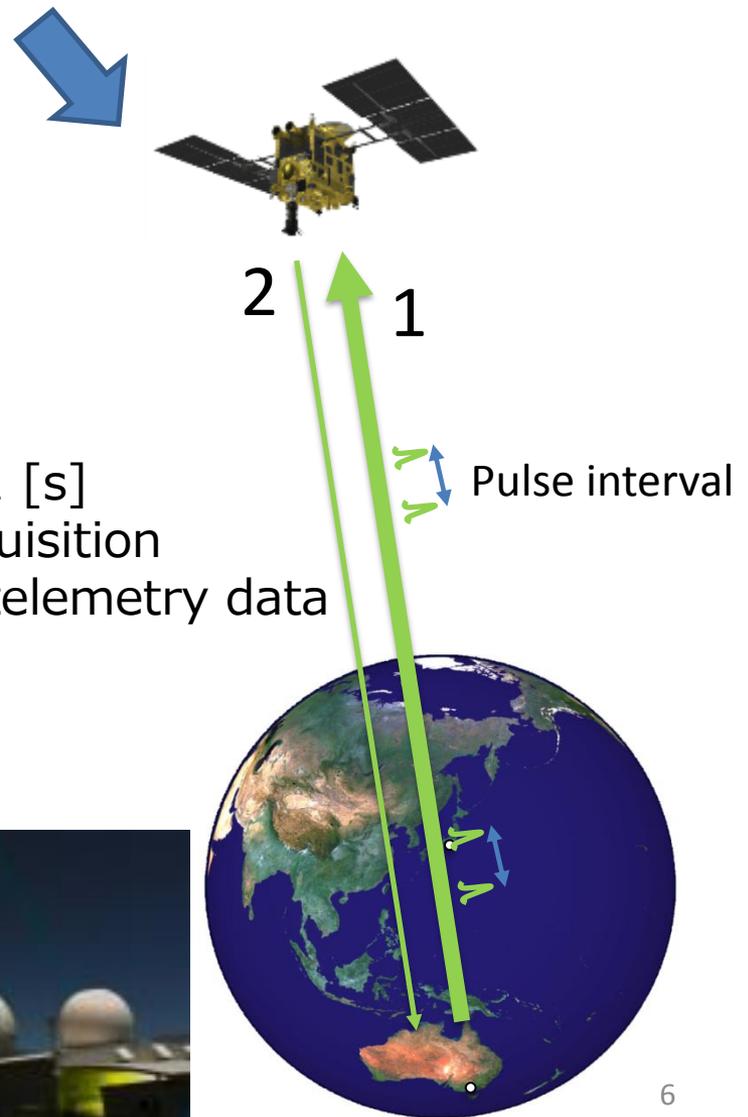


target asteroid
162173 Ryugu

Ranging mode



Transponder mode



in Transponder mode,

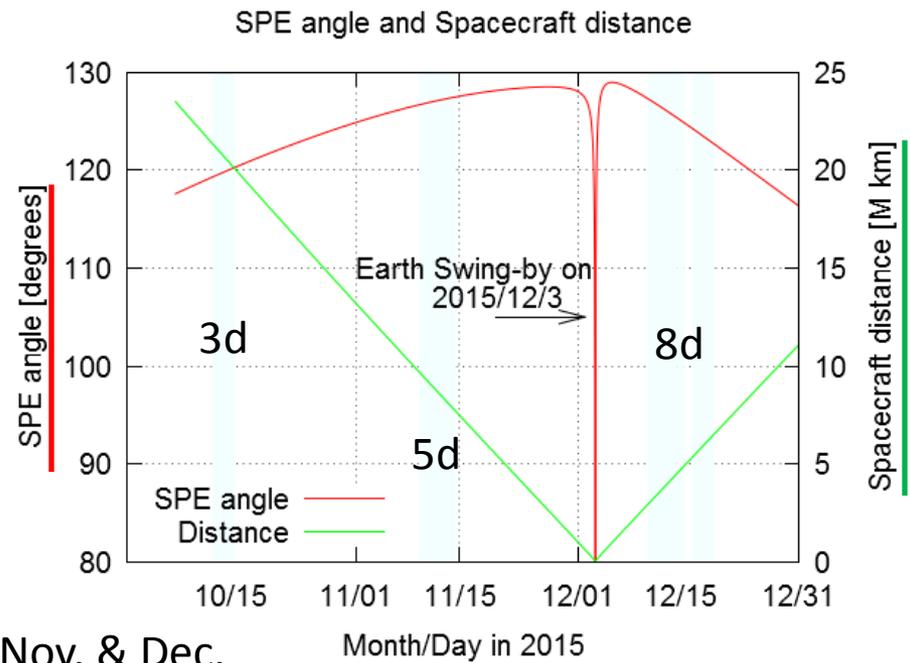
- two pulses can be detected in 1 [s]
- extra 1 [s] needed for data acquisition
- the pulse intervals are sent as telemetry data for onboard clock calibration



SLR stations

16 days in total

- Oct. 3d
- Nov. 5d
- Dec. 8d



Oct. & Nov.

Nov. & Dec.

Month/Day in 2015

	Oct. & Nov.	Nov. & Dec.
	NICT Koganei (JPN)	Mt. Stromlo (AUS)
transmitter	Q-SW Nd:YAG	Q-SW Nd:YAG
laser wavelength, nm	1064	1064
Pulse energy, J	1	2.2
Pulse width, ns	10	15
Beam divergence, arcsec	10	12
Repetition rate, Hz	10	170
receiver	InGaAs APD-array	IR enhanced Si-APD
Telescope diameter, m	1.5	1.8



S/C operation and data



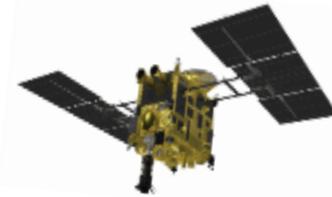
- **Scanning operation** in transponder mode
 - to find out the direction of boresight w.r.t. S/C frame
 - step size = 1 mrad to cover $1 \times 1 \text{ deg.}^2$, duration 40[s]
 - max. 17 shots were detected within a step
 - detection flags & pulse intervals were downlinked via microwave link
- **Pointing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

S/C scan

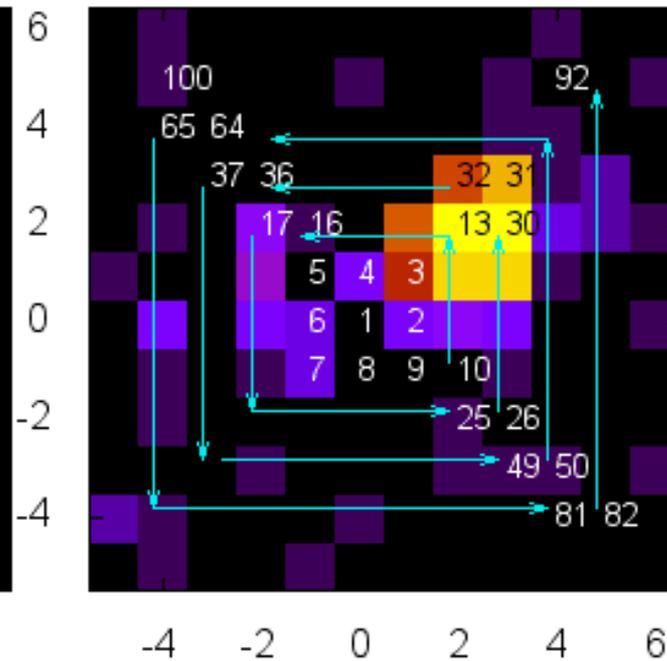
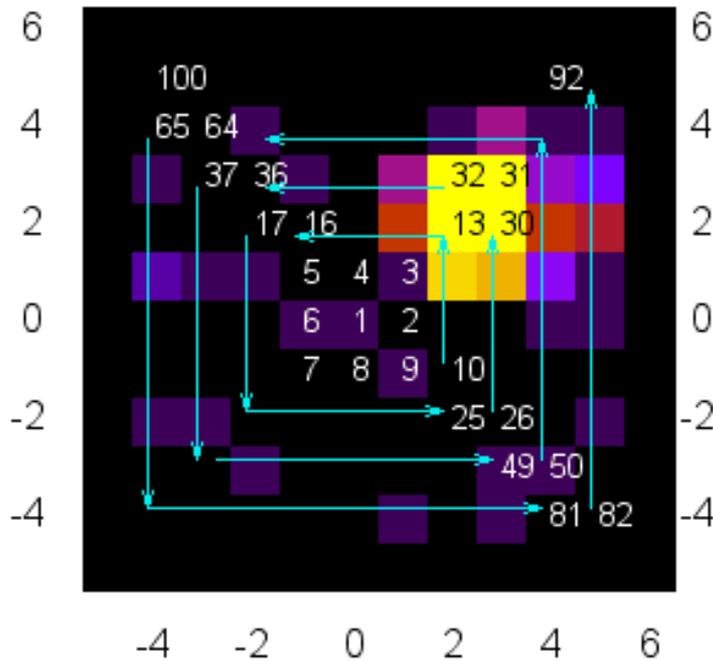


Dec 11, #1-92
 M2 offset 400um (FOV=18")
 Distance: 3.3M km
 Rx footprint: 5,000 km

Dec. 11

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

Dec. 15



center=
 best-estimated
 boresight direction
 before launch

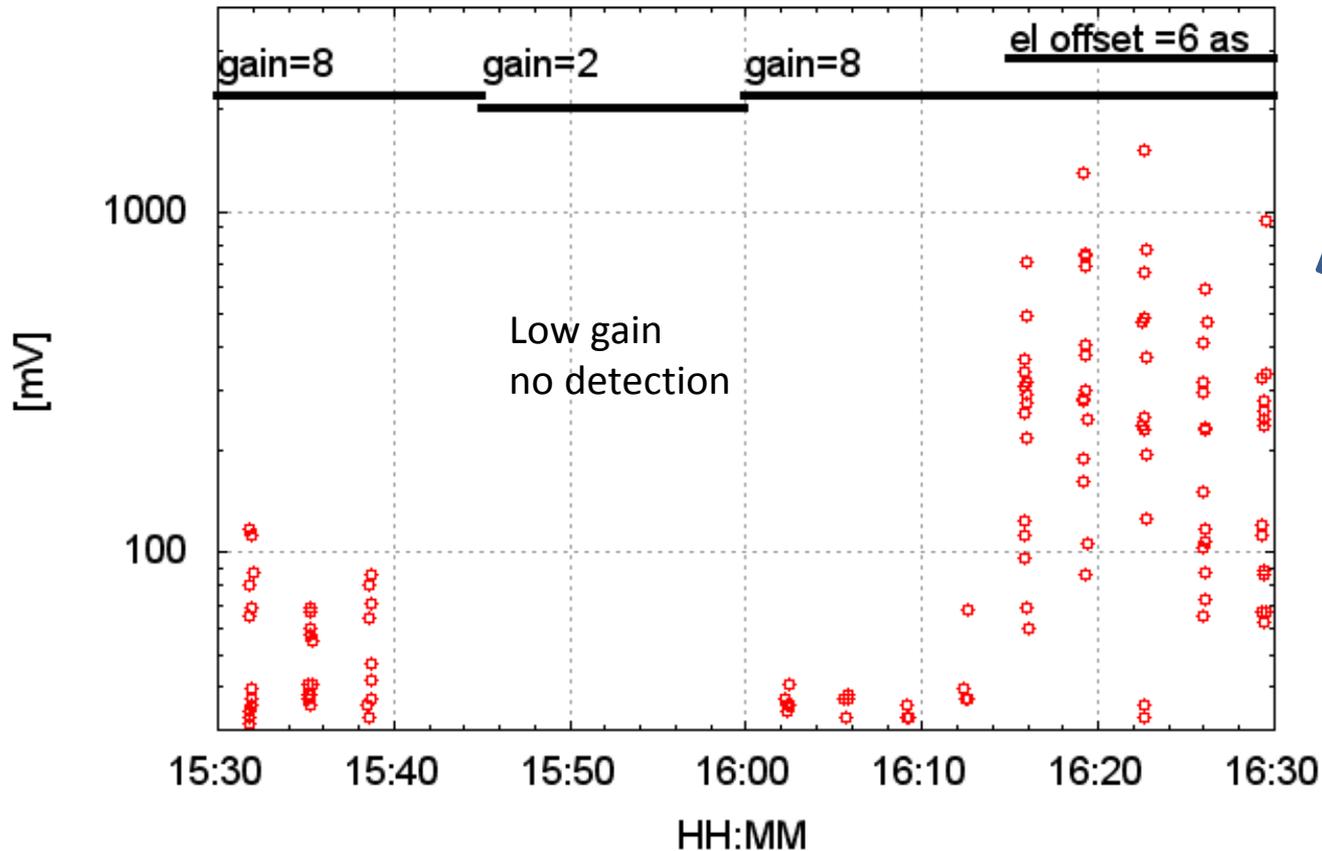
Declination ↑
 ← Right Ascension



Boresight direction is almost determined within scan step size

Rx. intensity by LIDAR

Received Intensity Data on 19 Dec. in Range Mode

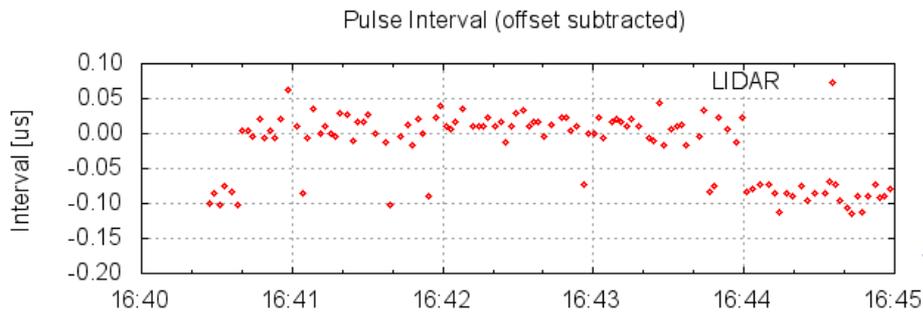


enhancement
due to ground telescope
offset pointing

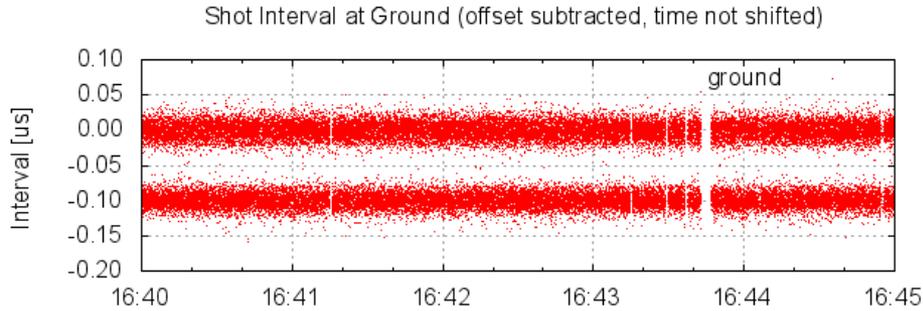


changes of intensity in accordance with gain change / offset pointing
-> evidence of detection of ground laser pulses (not background emission etc.)

pulse intervals



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

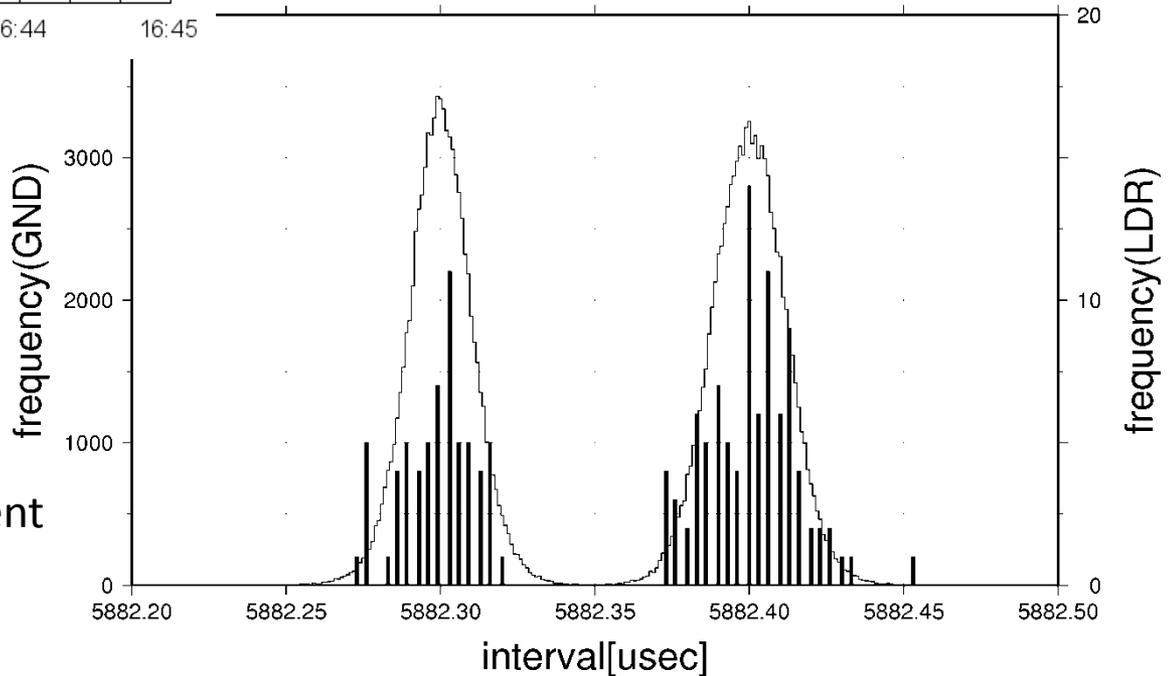


Ground/LIDAR Pulse Interval

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



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JPL/NASA Canberra Deep Space C.C.
Telemetry & Ranging support

