ALIGNMENT DETERMINATION OF HAYABUSA2 LIDAR. H. Noda[1], H. Senshu[2], K. Matsumoto[1], N. Namiki[1], S. Sugita[3], [1]National Astronomical Observatory of Japan (2-12 Hoshigaoka, Mizusawa, Oshu, Japan, hirotomo.noda@nao.ac.jp), [2]Planetary Exploration Research Center, Chiba Institute of Technology, Japan, [3]The University of Tokyo, Japan

Introduction: The asteroid explorer Hayabusa2 was launched on December 3, 2014. It arrived at the target asteroid 162173 Ryugu on July 27, 2018 and spent one year and a half observing the asteroid, sampling the surface material twice, and now it is on its way back to the Earth with samples of surface materials. One year after launch, in winter 2015, spacecraft was accelerated by Earth gravity assist for the transfer orbit toward the asteroid. Taking a chance when the spacecraft was in the vicinity of the Earth, we conducted a laser link experiment between ground laser stations and a laser altimeter called LIDAR (LIght Detection and Ranging) aboard Hayabusa2. Through the experiment, we estimated the boresight direction of the LIDAR by scanning the spacecraft attitude. Because the step size of the spiral search was 1 mrad, estimated boresight direction might have 1 mrad error [1]. This paper mainly focuses on another result of boresight determination during the proximity observation phase, by using time-series topographic data and image data taken by a visible imaging camera called ONC-T (Optical Navigation Camera Telescopic) [e.g. 2], then we compared the result with our previous study [1].

In Hayabusa2 mission, the orbit determination accuracy with ground-based 2-way range and range-rate measurement is the order of a few hundred meters, while the diameter of the target asteroid is about 1 km, meaning that the orbit accuracy is not enough for retrieving surface topography with the altimeter. Therefore, as a relatively quick method, we estimated the spacecraft trajectory by fitting laser altimetry data to an asteroid shape model [3]. In this method, the alignment information of the LIDAR and spacecraft attitude is used for determine the location of the altimeter footprints on the asteroid surface. Therefore the alignment error directly affects the accuracy of the trajectory determination, and consequently footprints of other instruments.

Methods and results: We tried three kinds of estimation of the field of view direction of LIDAR. First one is the result of laser link experiment already addressed above [1], and the second one is to fit time-series topographic data to a shape model of the asteroid, by using relatively reliable trajectory estimated by another method (details are described in [3]). Third one is addressed in this report: comparison of time-series LIDAR topography with camera images. In this method, we focus on surface boulders which give time-series topographic profile prominent features. During regular scientific mapping operation, the spacecraft stayed 20 km above the surface (which was called Home Position) which was almost located at a place between the asteroid and the Earth. At the Home Position, however, the diameter of the LIDAR footprint is as large as 30 meters (corresponding to the receiving telescope field of view size of 1.5 mrad) and not appropriate for field of view determination, therefore we selected data when the spacecraft was much closer to the surface. Among data in the gravity estimation operation on August 6, 2018, we found a suitable time period for field of view determination with passing of several small boulders at about 1.5 km altitude. The footprint diameter of this period was about 2.3 meters. Fig. 1 shows time-series LIDAR topography (top) and camera image (bottom), respectively. Time proceeds from right to left in the upper figure so that locations on boulders matches the camera image. Because of the asteroid rotation, LIDAR obtained topographic data almost along with a constant latitudinal line. Boulders are named from 1 to 11 in time order.

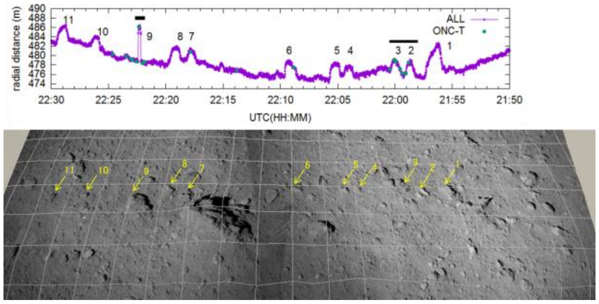

Fig.1 Time-series LIDAR topography and image data for alignment determination. Black bars in the top panel are the time periods we focused on. Images are mapped onto the shape model with a mapping tool with 2-degree longitudinal and latitudinal grid. LIDAR footprints are almost aligned with the line of 8 degrees in latitude in this time period.

We focus on the boulder 9, where LIDAR data showed higher topography than the vicinity for very short time. Enlarged topographic profiles with camera images are shown in Fig. 2. Green points indicate when the camera data are obtained. Green circles in images are drawn so that the center is located at (494, 497) with equivalent diameter of the LIDAR field of view size, which can retrieve time-series topographic profile well. Assuming this is the estimated boresight in the image, we applied this information to another time period, boulders 2 and 3, when camera data were obtained relatively continuously and at the same time topographic profile showed prominent features. The result is shown in Fig. 3. Green circles in images are the same meaning as Fig. 2. Obviously, when green circle covers boulders, LIDAR data show higher topography and vice versa. From these evidences, we concluded that point (494, 497) in the image is a good guess for the estimated boresight direction of LIDAR.

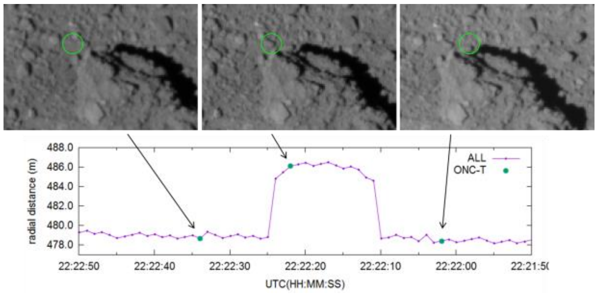

Fig. 2 ONC-T images when the LIDAR field of view passed boulder 9. Open green circles in images have 14-pixel diameter which corresponds to the same size as the field of view size of the long-range receiving telescope of LIDAR (1.5 mrad). The topographic profile can be retrieved when we set the center of the circle as (494, 497) in each image.

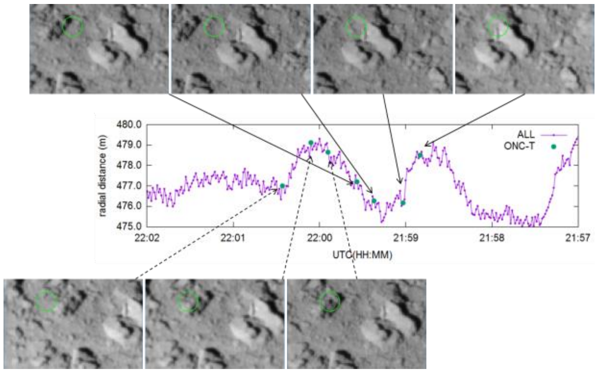

Fig. 3. We applied the LIDAR field of view position determined above to boulders 2 and 3, which are indicated as another black bar in the Fig. 1. We see topographic rises in the time-series profile when convex shape terrains are included in the circle.

Then we convert this direction to the spacecraft coordinate system by using rotation matrix between the camera and spacecraft coordinate system. The resultant field of view (thick black circle) with its center (purple small circle) is drawn in Fig. 4 marked as "this study", overlaid on the results of laser link experiment shown in [1]. Though it is shifted from the best-estimated area with dotted line, marked as "laser link exp." in paper [1] by less than 1 mrad, estimated field of view covers the areas where the laser pulses were detected in laser link experiment. The reason why laser pulses were detected in wider area than expected in the laser link experiment is not clear yet. Still, considering that independent methods for field of view determination give relatively same results, it is safe to conclude that laser link experiment is a good method for estimation of the boresight direction.

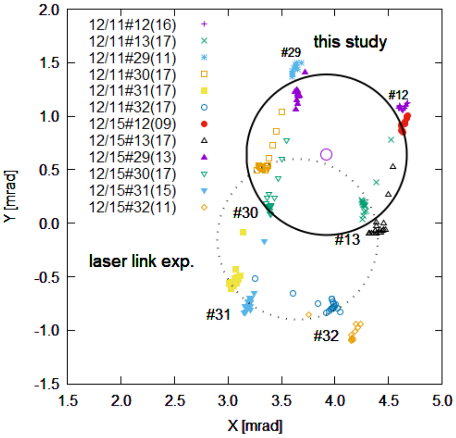

Fig. 4. A comparison of estimated LIDAR field of view direction in the laser link experiment and this study. A solid circle representing the result of this study is overlaid on the result of laser link experiment: each point show the direction where laser pulses from the ground station were detected in the laser link experiment. As a result, the field of view determined in this study lied on the other side of the results in the laser link experiment.

Acknowledgments: We used SPICE ancillary information system for data analysis of LIDAR ([4]) and the Small Body Mapping Tool for visualization of camera data ([5]).

References: [1] Noda H. et al (2017) *EPS*, *69 (2)*. [2] Suzuki H. et al (2018) *Icarus*, *300*, 341-359. [3] Matsumoto K. et al (2020) *Icarus*, *338*, Article 113574. [4] Acton, C. H. (1996) *Planet Space Sci.44(1)*, 65–70. [5] Ernst C. M. et al (2018) *LPSC 49th*, Abstract #1043.