ASTEROID SHAPE RECONSTRUCTION EFFORTS IN HAYABUSA2 MISSION: A DRY-RUN TEST FOR LANDING SITE SELECTION WITH SIMULATED DATA.

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Introduction: Hayabusa2 spacecraft will arrive at the asteroid 162173 Ryugu in early summer of 2018 [1]. Global mapping observation campaign of the asteroid is planed after arrival, to select candidate sites for the first landing and sampling by the spacecraft. Determination of the asteroid shape and spin information is essential for the landing site selection (LSS). They are also scientifically important to understand nature of the asteroid.

Three methods are considered for asteroid shape modeling in the Hayabusa2 mission. Structure from Motion (SfM) is a method to be able to estimate a shape of the target object from multiple images (e.g. multiple exposures of a moving camera) [2]. SfM is a popular shape modeling method in computer vision, and there are many open source and commercial implementations. PhotoScan developed by Agisoft [3] is used in the Hayabusa2 mission. Stereophotoclinometry (SPC) developed by R. Gaskell [4] is adopted by many planetary missions including Hayabusa, NEAR Shoemaker, Dawn, Rosetta and OSIRIS-REx. Stereophotogrammetry (SPG), another stereo-based method developed by DLR, is also applied to several planetary image data sets [5]. Each method has its own advantages, so the most appropriate one will be used in each phase in a progress of the mission. As three methods will provide shape models of Ryugu independently, we can find a baseline on the asteroid shape by making comparison with these models.

The Hayabusa2 project carried out a dry-run test of LSS sequence in the last summer. The main purpose of the test is to simulate end-to-end activities in the LSS efforts including production of initial observation data, calibration, higher-level data analyses, evaluation of scientific values and safeness at sampling operation on the landing site candidates, and final decision making. All activities in the test are evaluated to satisfy mission requirements and the planned schedule. Problems found during the test will be solved until the actual mission phase in 2018. Hayabusa2 shape reconstruction study group also participated in this test, and produced shape models and relating data from simulated images and associated ancillary data.

The test is unique opportunity to know capability of methods for asteroid shape modeling, because the shape of a fake asteroid used in the test is known and can be compared as the ground truth to shape models reconstructed from the simulated images. We can evaluate accuracy of the obtained shape models and their by-products to the truth data. Here we report results of asteroid shape modeling in the LSS dry-run test.

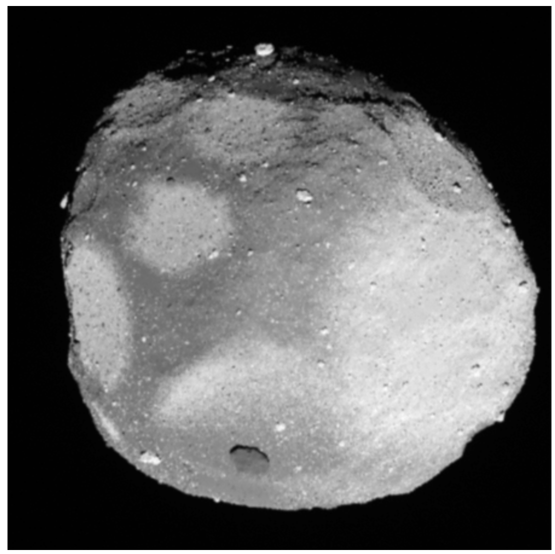

Fig. 1. Example of simulated images of ONC-T.

Data: The LSS data preparation (DP) team in the Hyabusa2 mission team designed a virtual asteroid Ryugoid, simulating the real Ryugu. The shape model of Ryugoid consists of ~ 0.4G polygons with a size much smaller than the resolution of camera observation.

Images of ONC-T, an imager onboard Hayabusa2 [6-7], are synthesized from the shape model by simulating observation conditions planned for the global mapping observation (Fig. 1). S/C trajectories, attitudes and other ancillary data associated with the simulated images are also produced from actual ones used in data generation and expected uncertainty of information. The global mapping observation of Ryugu by Hayabusa2 consists of three phases (Table 1). All observations contain sequential imaging covering the full rotation phase of the asteroid. Both Box-C and Mid Altitude observations are done at altitude lower than the Box-A observation, but their viewing geometries are different.

Table 1. Summary of Simulated ONC-T Images

Observation Phases	*Box-A*	*Box-C*	*Mid Alt.*
Altitude [km]	~ 20	5-7	~ 5
Resolution [m/pix]	~ 2.0	0.5-0.7	~ 0.5
Rot. Interval	3°	8°	15°
# of Images	208	94	80

Results: SfM and SPC were used to reconstruct the shape of Ryugoid during the test period, whereas the SPG team will join to the shape modeling effort after the LSS dry-run test. Both methods successfully produced shape models, and they were also used in following data analysis including geometric and photometric correction of color observations, production of mapped data, evaluation on thermal conditions on the surface, and safety assessment at the landing site candidates. Once the LSS DP team opened the truth data after the test, accuracy of the products was evaluated. Overall accuracy of the shape models is evaluated with RMS error of every polygon of a model to the truth.

Final products of two methods are shown in Fig. 2 with the truth model and error maps of the models. The RMSs of errors are 3.52 m for the SfM model, and 9.15 m for the SPC model. SfM works well to reconstruct the asteroid shape within a short processing time, which is one of the important advantages of this method. Even fine structures of boulders on the surface are well reconstructed. Because PhotoScan is not designed for direct import of space mission data, the original output shape is not scaled and not aligned in the body-fixed coordinate of the asteroid. The SfM products in the test are adjusted to the SPC models in a post process pipeline. The spin information is estimated by SPC with accuracies of less than 0.1 degree for the pole direction and 0.1 sec for the period at the final phase of the test. Although global representations in the SPC model are good, large errors are found in a smooth basin and around boulders (Fig. 2). The smooth basin has very few features for stereo matching. Because modeling of sudden change of slope around boulders with SPC requires exceptional treatments and will take much time, the SPC shape products released during the test remain unrealistic smoothed surfaces.

Several important lessons on shape modeling efforts are learned through the test. Schedule of product release could not been kept as planned during the test. Also, several defects in our products reported by data users. These problems are mainly caused by insufficient preparation of the data production sequence. Some of them have been fixed during and just after the test, and others will be refined until the arrival of Hayabusa2 to Ryugu in 2018.

References: [1] Watanabe S. et al. (2017) *Sp. Sci. Rev., 208*, 3-16. [2] Mori Y. and Hirata N. (2014) *LPS XLV,* Abstract #1760. [3] http://www.agisoft.com [4] Gaskell R.W. et al. (2008) *MAPS 43,* 1049-1061. [5] Preusker F. et al. (2012) *PSS 66,* 54-63. [6] Sugita S. (2015) *LPS XLVI*, Abstract #2169. [7] Kameda S. et al. (2017) *Sp. Sci. Rev., 208,* 17-31.

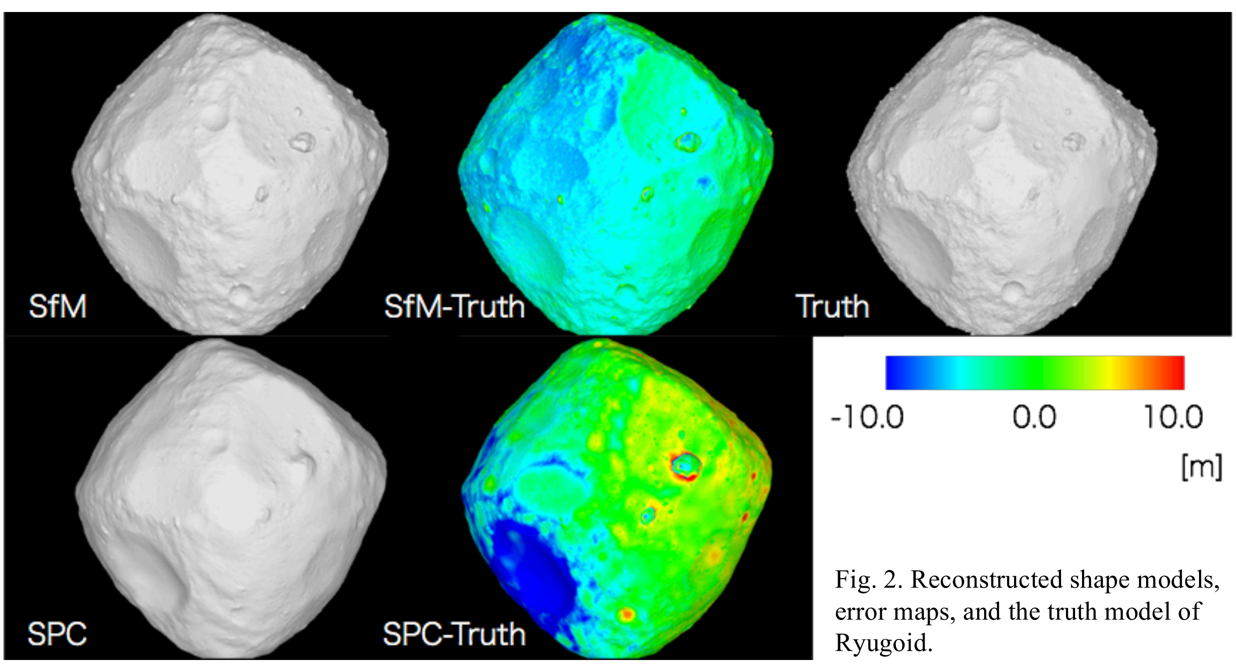

Fig. 2. Reconstructed shape models, error maps, and the truth model of Ryugoid.