

**HIGH POROSITY NATURE OF THE TOP-SHAPE C-TYPE ASTEROID 162173 RYUGU AS OBSERVED**

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**Background:** On 27 June 2018 Hayabusa2 Spacecraft arrived at the Home Position (HP) ~20 km above the sub-Earth point of near-Earth C-type asteroid Ryugu. After two months observation of a telescopic optical camera (ONC-T) we constructed global shape models of Ryugu [1, 2]. In order to evaluate the consistency of shape models we used two independent methods; the stereophotoclinometry (SPC) technique [3] and the Structure-from-Motion (SfM) technique [4]. While the SPC-based model (Fig. 1) reproduces well the global shape and topographic features on the surface, the SfM-based model [1] shows better representation of topological features at steep slopes like large boulders. Except for boulders the two models are in good agreement with each other.

**Low Bulk Density:** Physical parameters of Ryugu were obtained from the initial Hayabusa2 observations [1]. Here we will summarize the data related to bulk density of Ryugu. The total volume obtained from the SPC-based shape model is  $0.377 \pm 0.005 \text{ km}^3$ . Gravity measurement in August 2018 revealed that the aster-

oid's mass is  $(4.50 \pm 0.06) \times 10^{11} \text{ kg}$ . The bulk density is thus derived as  $1.19 \pm 0.03 \text{ g cm}^{-3}$ .

The density is significantly smaller than bulk densities ( $1.6$  to  $2.4 \text{ g cm}^{-3}$ ) measured for "hydrated" C-type asteroids having the  $0.7\text{-}\mu\text{m}$  absorption (Ch- and Cgh-type) [5]. However, it remains within the  $0.8\text{--}1.5 \text{ g cm}^{-3}$  range measured for BCG-types (B-, C-, Cb-, and Cg-type), which might be related to unheated icy asteroids [5]. Based on VNIR spectra obtained by ONC-T and a NIR spectrometer (NIRS3) Ryugu was confirmed to be Cb-type [2, 6]. Thus, low bulk density of Ryugu is consistent with the spectral type.

**High Porosity:** NIRS3 observations indicate that hydrated minerals are widely spread on the surface of Ryugu [6]. The presence of water ice, which would be plausible for the low bulk densities of main-belt C-complex asteroids, is unlikely for near-Earth asteroid Ryugu because the radiative equilibrium temperature (~250 K) is higher than the ice sublimation temperature (~230 K) at its central pressure of ~8 Pa and the thermal diffusion time of Ryugu is estimated to be

much shorter than the typical dynamical lifetime of near-Earth asteroids ( $\sim 10^7$  yr) [1]. Note that the parent body of Ryugu located in the Main Belt might have water ice and low density of Ryugu could be ascribed to loss of volatile components without subsequent compaction.

The total porosity of Ryugu is derived if we assume the grain density of the asteroid. If we adopt the grain densities of CM carbonaceous chondrites (CCs), the derived total porosity is 57% to 63%. If we adopt those of Orgueil CI CC, the predicted total porosity is 50 to 52%.

The estimated total porosity is even higher than that of rubble-pile asteroid Itokawa ( $44 \pm 4\%$ ) [8, 9], indicating that asteroid Ryugu is also a rubble pile. This is consistent with a theory arguing that all Solar System bodies with diameter of  $\sim 1$  km should be rubble piles [10] and might have formed from reaccumulation of fragments generated by catastrophic disruption events of  $\sim 100$ -km sized parent bodies [11].

**Top Shape:** Hayabusa2 reveals that Ryugu is a top-shape asteroid; a prominent elevated ridge around the equator. The average surface tilt angle in both side of equatorial ridge is  $34 \pm 4^\circ$  relative to its spin axis (Fig. 1). Ryugu is the first top-shape asteroid to be directly observed up close by a spacecraft.

Derived surface slopes to the equipotential surface assuming the present shape and uniform interior demonstrate minimal variation with latitude if, at some epoch, Ryugu had a spin period of 3.5 hours (about half of the current value) [1]. This suggests that the top shape was formed by centrifugally induced structural failure during a rapid rotation era including the original reaccumulation stage that formed Ryugu [12]. When a spheroidal asteroid spins rapidly, a deformation process might be induced either on the surface or in the interior, depending on the internal structure. The high porosity nature of Ryugu as well as no significant offset between the centers of figure and gravity suggest that the internal tensile strength of the asteroid is uniform and low. This suggest that the deformation of interior structural failure would be preferable [13].

**Discussion:** The  $2.72\text{-}\mu\text{m}$  absorption feature of Ryugu observed by NIRS3 is similar to those of heated/shocked CI/CM chondrites [6]. However, the fraction of these meteorites are relatively small whereas BCG types are abundant, so that another meteoritic counterpart of BCG types are expected. Pyroxene-rich interplanetary dust particles (IDPs) are considered to originate from BCG-types based on the mid-infrared spectroscopy [5, 2]. If high porosity BCG types are very fragile, they should be destroyed at the atmospheric entry, which is consistent with the scanty of BCG-originated meteorites. The presence of large

boulders on Ryugu, however, may contradict the weakness of fragments of the asteroid. Thus, comparative studies of IDPs with Ryugu (and Bennu) based on the NIR spectra and sample analyses are the key to understand the origin and evolution of BCG-type asteroids.

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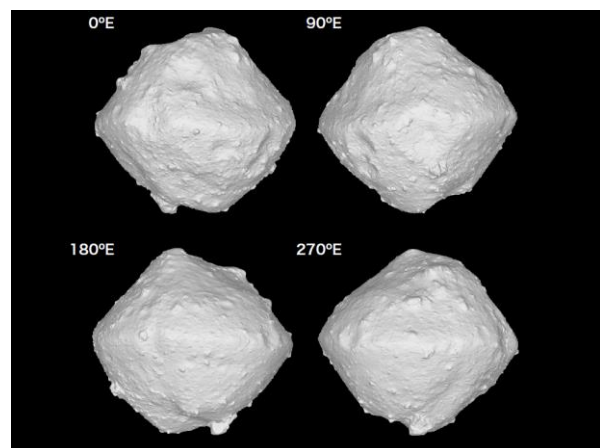


Figure 1. The SPC-based shape model (SPC20181204) viewed from 4 different directions (labeled central longitudes) of the equatorial plane of Ryugu. Generating a polygon model with 3,145,728 facets based on total 1,217 ONC-T images.