A 3D Modeling of Shadow Hiding Opposition Effect on Asteroid Ryugu. Y. Yokota¹, R. Honda², D. Domingue³, E. Tatsumi¹, S. E. Schröder³, M. Matsuoka², L. Riu², A. Longobardo², S. Sugita⁴, T. Morota⁵, N. Sakatani¹, C. Honda⁴, Y. Cho⁶, S. Kameda¹, T. Kouyama⁵, M. Yamada⁵, M. Hayakawa¹, H. Senshu¹, H. Suzuki¹², K. Yoshioka⁶, H. Sawada¹, K. Ogawa¹, and K. Yumoto⁵, ¹JAXA. (3-1-1 Yoshino-dai, Chuo-ku, Sagamihara, Kanagawa, Japan, yokota@planeta.sci.isas.jaxa.jp), ²Ehime Univ., Japan, ³Planetary Science Institute, USA, ⁴Luleå Univ. of Technology, Sweden, ⁵AIST, Japan, ⁶Univ. Paris-Saclay, France, ⁷INAF, Italy, ⁸Univ. of Tokyo, Japan, ⁹Univ. of Aizu, Japan., ¹⁰Rikkyo Univ., Japan. ¹¹Chiba Inst. Tech, Japan, ¹²Meiji Univ., Japan.

Introduction: The surface of the C-type asteroid Ryugu (equatorial radius = 502 ±2 m [1]) was observed by the Hayabusa2 Telescopic Onboard Navigation Camera (ONC-T) images in 2018 and 2019 [2]. Our previous analysis [3,4] of the data show that there is a regional distribution of Hapke’s photometric parameters [5,6] other than single scattering albedo on the Ryugu surface (Fig. 1). The Hapke parameter $h$, width of the opposition effect, also has a regional distribution. This parameter is considered to contain information on the texture and porosity of the topmost layer. In this study, in order to interpret that parameter’s distribution, we used a 3D model to simulate the Shadow Hiding Opposition Effect (SHOE). The previous study [4] employed a simpler version of the Hapke’s photometric model. There is a more complex version of the Hapke model that includes a porosity parameter [7], but before proceeding, we attempted to compare simulations and observations in the form of phase curves.

Method: SHOE is described as a shadow effect inside a porous particle layer [5]. To simulate this effect, we set up a particle layer space as shown in Fig. 2(a) and randomly placed polygonal particles as shown in Fig. 2(b). To reduce the number of triangular facets, the shape of each particle is a cube instead of a sphere. The orientation each particle is randomized. Since this study focuses only on the SHOE, the particles are stationary in the model space and gravity is not taken into account. Since no exclusion process is used when placing the particles, their positions may overlap. For this reason, the number of generated particles was not used in the porosity calculation, but sampling measurements were made in the generated particle layer.

The photometric function on the cubic surface was assumed as a Lommel-Seeliger function ($= \cos i / [\cos i + \cos e]$). Remote sensing observations show that Ryugu’s normal albedo is very small (~0.04) [e.g. 8,9]. Therefore, the Coherent Backscatter Opposition Effect [e.g. 10] due to multiple scattering is not considered in this study.

Emission angle $\epsilon$ of the simulated observation was fixed to 0 [deg]. Phase angle $\alpha$ (= incidence angle $i$) was varied from 0 to 10 degrees to generate simulated image (400 x 400 pixels) for each geometry condition. The pixels of each image were averaged to derive the simulated intensity of light under that geometry. The intensities were normalized at phase angle 0 degree.

Results: Fig. 3 shows the phase curves of the SHOE obtained from the particle layer 3D simulation. In the background of Fig. 3, the distribution of Ryugu’s fitted phase curve is shown as a density map. Since it cannot be compared with the simulation with the parameter $h$ directly, the model phase curves were drawn from those derived Hapke parameter sets of [4].

The particle layer was simulated with seven different porosities. Comparison of the phase curves shows that the simulated curve with 81.9% porosity is the closest to Ryugu.

Discussion: The relationship between porosity and relative reflected light intensity at a phase angle of 5 degrees is shown in Fig. 4.

Applying the simulated results to the phase curve variation on Ryugu, we can estimate that the porosity of Ryugu’s surface varies globally from 81% to 86%.

In Fig. 3, the observed fit curve has a steeper slope than the simulated phase curve at the right end of the figure at a phase angle of 10°. The reason may be that the single particle phase function was not included in the photometric function at the simulated particle surface (isotropic scattering). This will be improved in a future work.

Figure 1. Maps of the derived Hapke parameters on Ryugu (After [4]). Three free-parameter case.

Figure 2. (a) Simulation condition. (b) An example of the generated particle layer. Case of porosity 81.9%.

Figure 3. Phase curves derived from the 3D model SHOE simulation.

Figure 4. Relationship between the porosity and normalized intensity at phase angle 5 [deg.].