Seismic wave propagation on asteroid Ryugu induced by the impact experiment of the Hayabusa2 mission

*Gaku Nishiyama[1], Taichi Kawamura[2], Noriyuki Namiki[3], Benjamin Fernando[4], Kuangdai Leng[4], Takanao Saiki[5], Hiroshi Imamura[5], Yasuhiko Takagi[6], Kei Shirai[5], Masahiko Hayakawa[5], Chisato Okamoto[7], Hirotaka Sawada[5], Yuichi Tsuda[5], Kazunori Ogawa[5], Masahiko Arakawa[7]

1. University of Tokyo, 2. Institut de Physique du Globe de Paris, 3. RISE Project, National Astronomical Observatory of Japan, 4. University of Oxford, 5. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 6. Aichi Toho University, 7. Kobe University

Recently, multiple space exploration missions have revealed that asteroids are affected by active surface renewal. Such mass movement has also been observed on 162173 Ryugu, which was explored by the Japanese spacecraft Hayabusa2 from June 2018 to November 2019. While there are several processes that can account for both lateral and vertical mass transport of asteroid regolith, the most plausible hypothesis has been global vibration, that is, impact-induced seismic shaking. The Hayabusa2 was expected to observe such impact-induced seismic shaking through the Small Carry-on Impactor (SCI) operation based on previous numerical simulations and laboratory experiments which suggest that the energy of this impact experiment is high enough to generate boulder movement around a newly formed crater. In April 2019, the SCI operation was successfully conducted and provided surprising images of crater ejecta taken by a Deployable CAMera 3 (DCAM3). Later, the Hayabusa2 Optical Navigation Camera (ONC) took an image of the periphery of the SCI crater in order to compare it with the image taken prior to the SCI impact. The images show that the impactor made a crater of about 13 m in diameter, but boulders located around the edge of the crater appear unmoved by the seismic waves supposedly produced by the SCI impact. Aiming to explain this unexpected observation, we conduct seismic wave propagation modelling with a wide range of elastic parameters of Ryugu.

Using a fast modelling code for 3D seismic wave propagation, AxiSEM3D, we numerically simulate seismic shaking on asteroids, changing rigidities, quality factors and seismic efficiencies (the conversion ratio of impactor’s kinetic energy to seismic wave energy). Following previous studies, an isotropic seismic moment tensor of explosion form is assumed. Through the comparison between simulations and observations, we find that quality factor smaller than 0.5 or seismic efficiency smaller than 10^{-7} are required. However, such an extremely low quality factor seems unrealistic because anelastic heat generation and scattering in anhydrous asteroid regolith are expected to be too small to reduce wave energies rapidly. Thus, we consider very low seismic efficiency more plausible. The reason for such a low seismic efficiency can be resulted from the powdery behavior of regolith. Seismic waves propagate through powdery materials only if the elastic stress is lower than its yield strength. Assuming that the yield strength of regolith is 1 kPa as laboratory experiments, calculated boulder’s lateral movement would be always smaller than 1 m. This hypothesis may account for the absence of regolith lateral movement observed in the SCI operation during the Hayabusa2 mission and indicate that the low yield strength of regolith possibly limits the seismic wave propagation on asteroids, making the apparent seismic efficiency small.

Keywords: Hayabusa2, asteroid, seismology, surface evolution, Ryugu

