Numerical Simulation on the Thermal Moment from Ryugu-like Rough Surface Asteroid. H. Senshu[1], N. Sakatani[2], Y. Shimaki[2], Y. Yokota[2,3], T. Morota[4], S. Tanaka[2], and T. Okada[2]. [1]Planetary Exploration Research Center, Chiba Institute of Technology (2-17-1 Tsudanuma, Narashino, Chiba, 275-0016 Japan, senshu@perc.it-chiba.ac.jp), [2]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, 252-5210 Japan), [3]Kochi University, [4]Department of Earth and Planetary Science, the University of Tokyo (7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-0033 Japan).

Introduction: The surface temperature of an asteroid is controlled by solar radiation. If the surface is flat and the thermal conduction is negligible, the temperature distribution can be calculated from a simple energy balance between the solar radiation as the energy input and the thermal radiation into the space as the energy output. If the thermal conduction is not negligible the surface temperature profile is changed. In the morning a part of energy is transferred to subsurface so that the surface temperature remain cooler while in the evening the thermal flux from subsurface keep the surface region warm. This effect can be expressed analytically by one thermos-physical parameter, thermal inertia. Thermal inertia can be determined from an observation of the diurnal surface temperature profile and is used to estimate the thermal conductivity and/or the porosity of the surface material [1]. However, if the surface of the asteroid is rough, the relationship between the surface temperature profile and the thermo-physical parameters is not so straightforward [2-4].

The energy input by solar radiation to a rough surface is heterogeneous. A slope facing to the sun receive more energy than others, resulting patchy surface temperature distribution. An area in shadow does not receive solar radiation. The thermal radiation from an area might be absorbed by other area. This means that the energy output should not be the same with the simple product of thermal radiation by the total surface area. From the viewpoint of observation, the visible area in the rough area changes with the observation direction. The brightness temperature of a rough surface would be higher if the observation direction is similar to the solar direction while the brightness temperature would be lower if the temperature is observed from the opposite side from the sun [2-5]. In fact a thermal imaging camera on board Hayabusa2 (TIR) observed Ryugu from different direction in a few days and they found that the apparent temperature distributions are dissimilar to each other [6,7]. This means thermal moment forced on Ryugu is heterogeneous. The heterogeneity cause the change of orbit as known as Yarkovsky effect.

In this study, to evaluate the role of the thermal inertia and surface roughness on the Yarkovsky effect we calculate the thermal moment onto a spherical asteroid which has the same orbit, spin period, and spin axis direction with Ryugu.

Method: We have developed a numerical model to simulate the photometric condition and the thermal evolution of a rough surface [5,8]. In this model the roughness of the surface is expressed by two parameters: σ is the ratio of the variance of the random vertical replacement to the horizontal characteristic length and D is the number of division of each triangle polygon into 4 polygons (see [5] for more detail). In this study we fixed D to be 2 instead vary σ from 0.0 to 0.5. Assuming the spin rotation period, the direction of spin rotation axis, and solar distance, the diurnal thermal evolution of a rough surface at a latitude is simulated [5]. The thermal simulations for various latitude are carried out and then, put them onto a spherical surface and simulate the apparent temperature distribution taking into account the direction of observer (Fig 1).

We vary the observation direction freely to obtain the map of the power of the disk integrated thermal radiation. Finally the thermal radiation force is obtained by omni-directional integration of the disk integrated thermal radiation. The bulk thermal moment vector is divided into along and across the orbital motion of Ryugu.

Similar simulation is iteratively carried out along the orbit of Ryugu to obtain the time series of thermal moment from Jan. 2018 to Dec. 2019. Because the orbital period of Ryugu is about 1.3 yrs this time span contains more than one orbital rotation.

Numerical Result: Fig. 2 shows the time series of thermal moment onto the Ryugu-like spherical asteroid. As is shown in this figure, if the thermal inertia is as low as 10 in Si unit, the orbital motion is accelerated and decelerated depending on the phase of orbit. This is because Ryugu goes elliptical orbit so that the sub-solar point, where the maximum temperature is achieved, is on the trailing hemisphere before the perihelion and aphelion while it is on the leading hemisphere after perihelion and aphelion. Thus the orbital motion is accelerated before perihelion and aphelion while is decelerated after the passage of perihelion and aphelion.

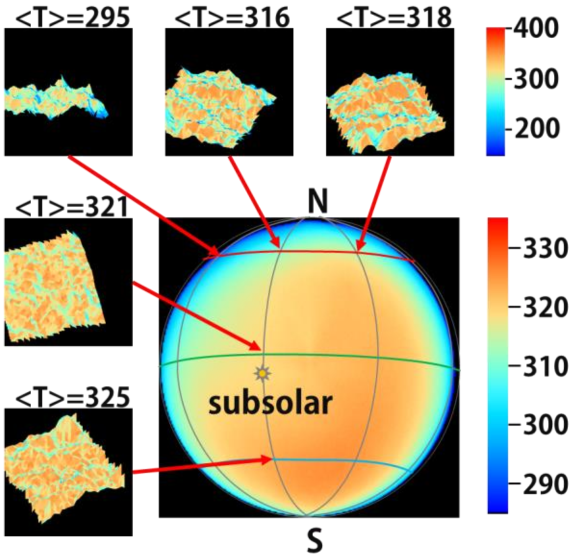

Fig. 1: Image of Numerical Method. The main panel represent simulated thermal image and inserts are image of the rough surface corresponding to the latitude and the observation angle. The roughness parameter σ and the thermal inertia are assumed to be 0.3 and 400 in SI unit, respectively.

On the other hand if the thermal inertia is larger than 100 in SI unit, the thermal moment decelerate the orbital motion throughout the orbit. This is because Ryugu's spin rotation is retrograde and the maximum temperature is achieved after the noon, which is on the leading hemisphere of the asteroid.

The upper panel shows along-orbit thermal moment onto flat (σ=0) asteroid while the lower panel is σ=0.4 (rough). The difference among them are limited but the thermal moment is smaller for rougher asteroid. This is because rougher surface has larger surface area so that the surface temperature is lower.

The shape of the asteroid used in this study is a sphere and is not the same with real Ryugu (double top-shape). To check the effect of shape we divide the along-orbit thermal moment by the source latitude range (Fig. 3). On 1st Aug. 2018 the subsolar latitude is near the equator (5.8S) but the thermal moment from southern (summer) hemisphere is obviously larger than that from northern (winter) hemisphere, which seems consistent with Fig. 1. The thermal moment from the middle latitude of summer hemisphere is comparable to that from the equator. This suggest that the thermal moment on Ryugu is similar to that onto similar sized spherical body.

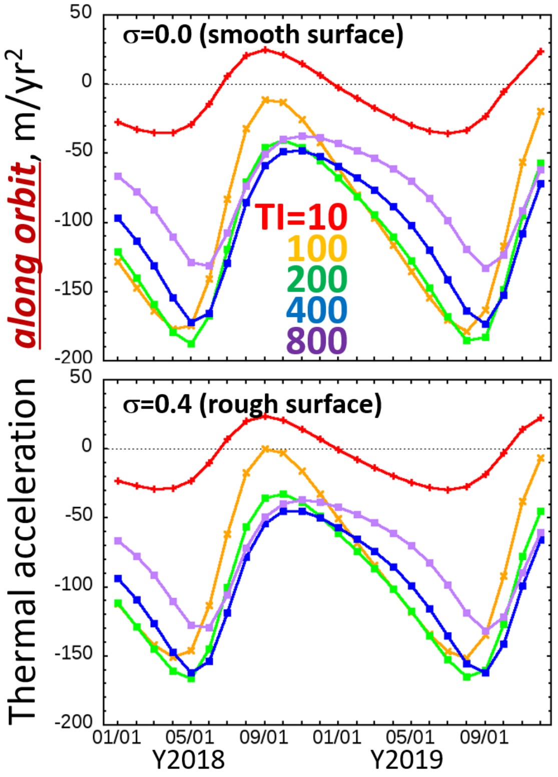

Fig.2: Calculated thermal moment along the orbit

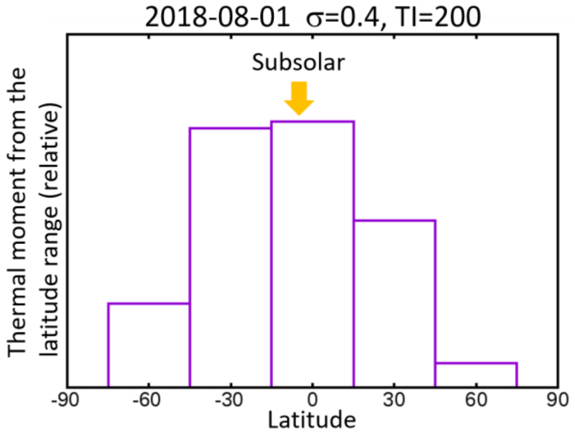

Fig.3: Distribution of thermal moment.

References: [1] Takita, J. et al. (2017) *Space Sci. Rev.*, 208 (1-4): 287-315. [2] Rozitis, B. and S. F. Green (2011), MNRAS 415, 2042-2062. [3] Davidsson, B. J. R. and H. Rickman (2014) Icarus243, 58-77. [4] Davidsson, B. J. R. et al. (2015) Icarus 252, 1-21. [5] Senshu, H. et al. (2018) *LPSC 49th*, Abstract #2363. [6] Okada, T. et al. (2020) *submitted*. [7] Shimaki, Y. et al. (2020) *submitted*. [8] Senshu, H. et al. (2017) *LPSC 48th*, Abstract #1950.