

DIRECT NUMERICAL SIMULATION OF THERMAL MOMENT ON AN ASTEROID WITH ROUGH SURFACE. H. Senshu¹, N. Sakatani², Y. Shimaki², Y. Yokota^{2,3}, and T. Morota⁴, ¹Planetary Exploration Research Center, Chiba Institute of Technology (2-17-1 Tsudanuma, Narashino, Chiba, 275-0016 Japan, senshu@perc.it-chiba.ac.jp), ²Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (3-1-1 Yoshinodai, Chuo-ku, Sagami-hara, Kanagawa, 252-5210 Japan), ³Kochi University, ⁴Graduate School of Environmental Studies, Nagoya University (Furo-cho, Chikusa-ku, Nagoya, Aichi, 464-8601 Japan).

Introduction: Asteroids are too small to retain the internal energy due to the accretion and radiogenic energies. Thus the thermal evolution of asteroids is controlled by the solar radiation and it was thought to be explained by a simple analytical model (e.g., [1]). However, if the surface of the asteroid is rough, the solar radiation is not uniform and the thermal evolution cannot be straightforward. Previous works [2-5] showed that the apparent temperature changes with the direction of the observer.

The change of the apparent temperature with the observation direction occurs not only in the case of a specific area but also of the disk integrated. It is well known that the distribution of the surface temperature changes with the thermal inertia. The maximum temperature is achieved after the noon depending on the thermal inertia, resulting the shift of the direction of the thermal radiation into the space even if the thermal radiation from each area is isotropic. The shift of the thermal radiation distribution accelerate or decelerate the orbital motion of the asteroid, as known as Yarkovsky effect.

Addition to this, when the surface of the asteroid is rough the thermal radiation from each area becomes anisotropic. In fact the temperature distributions on the asteroid 162173 Ryugu observed by TIR on board Hayabusa2 from two different position in a few days show obvious difference among them [6]. This can be explained by the effect of roughness. However it is not clear whether the surface roughness enhances or reduces the shift of the total thermal moment due to the thermal inertia.

In this study we numerically estimate the norm and direction of the total thermal moment from a Ryugu-sized spherical asteroid.

Method: We have developed a numerical model to simulate the photometric condition and the thermal evolution of a rough surface [5,7]. 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 move the position of observer 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.

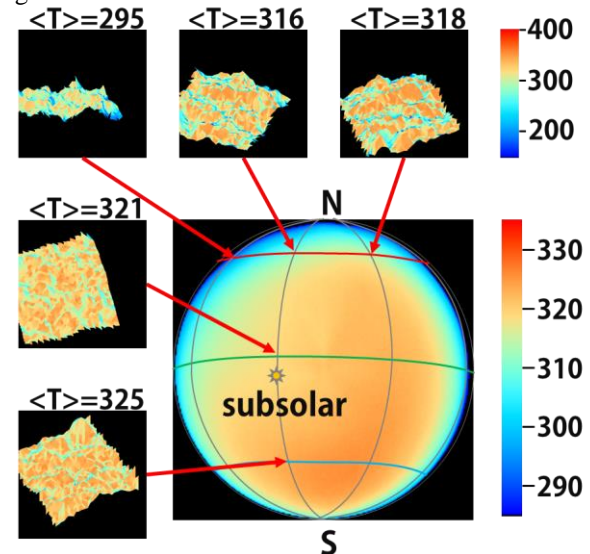


Fig. 1: Cartoon of Numerical Method.

The roughness parameter σ and the thermal inertia are assumed to be 0.3 and 400 in SI unit, respectively. Other parameters are compiled in Table 1

Numerical Result: Table 1 compiles the parameters we adopt in this study. We adopt the physical parameters of Ryugu on 1st Aug. 2018 as reference values except for the shape of the asteroid. We assume that the surface of the asteroid is rough in small scale but the shape is sphere in global scale for simplicity.

Table 1: parameters used in this model

radius	432 m
spin pole direction	(Ra,Dec)=(96.4, -66.4)
spin period	7.632 hr
date	2018-08-01
polygon number	32x32x2

division number	2
σ (roughness)	0.0(flat) to 0.5(rough)
thermal inertia	10, 100, 200, 400, 600, 800 in SI unit
density	1200 kg/m ³

Fig. 2 shows the contour map of the apparent temperature distribution as a function of the direction of observer for the cases with the thermal inertia of 400 in SI unit and the roughness parameter σ of 0.0 (flat) and 0.4 (rough). The horizontal axis represent the local time and the culmination point is at the 12 hrs. As is shown in this figure, the hot area expands in the rough surface case which causes the change of the direction of the total thermal moment. At the same time the maximum temperature decreases in the rough surface case which reduces the total thermal moment. Thus it is not clear whether the surface roughness enhance or reduce the Yarkovsky effect.

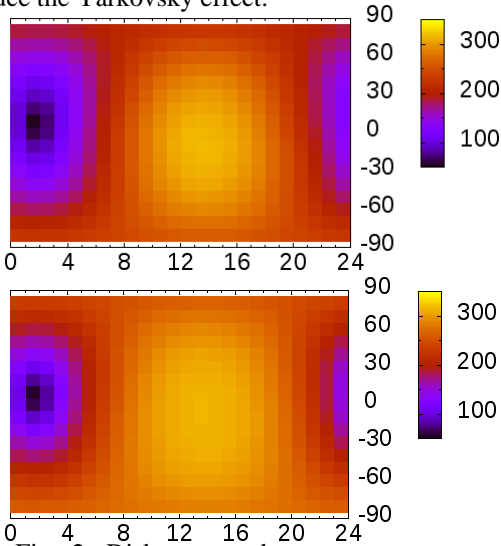


Fig. 2: Disk averaged temperature as a function of the observation direction. The surface roughness is 0.0 (flat) for the upper and 0.4 (rough) for the lower panels.

Fig. 3 represents the total thermal moment as a function of the thermal inertia and the roughness of the surface. In this calculation X-axis represents the solar direction and the Z-axis is same with the spin axis. Y axis is defined in right-handed system. The X directional moment should be canceled by the solar radiation. The Z directional moment is caused because the subsolar point is on the southern hemisphere. The Y directional moment, which decelerates the orbital motion of Ryugu because it spins backwards, is on the order of 100 m/yr². The deceleration effect changes with the roughness by up to 20%, but the tendency is not straightforward. The maximum value is achieved when the roughness $\sigma=0.2$.

Summary: We evaluated numerically the effect of the surface roughness on Yarkovsky effect on Ryugu-sized asteroid. Our numerical result showed the orbital motion of the asteroid is decelerated by the order of 100 m/yr². This dislocation might be measureable during the 1.5yrs mission phase of Hayabusa2.

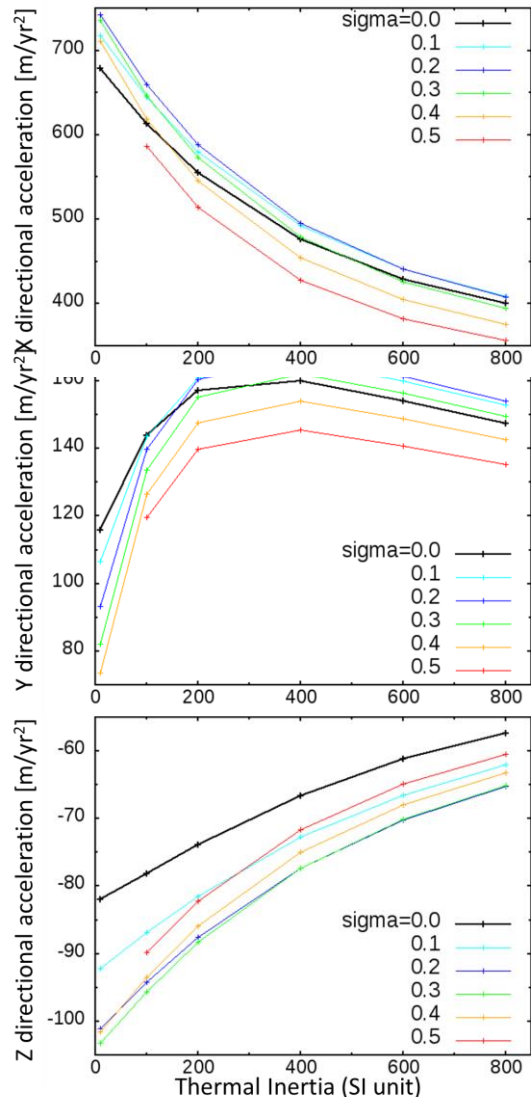


Fig. 3: Total thermal moment for each direction.

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) *Icarus* 243, 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. (2019) *LPSC 50th*, this issue. [7] Senshu, H. et al. (2017) *LPSC 48th*, Abstract #1950.