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YORP effect on the simple models of asteroids

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Abstract

The YORP effect may cause rotation evolution of an asteroid. However, the relationship between the YORP effect and shape of asteroids has not been understood. Based on the thermal physical model (TPM) and the polyhedral asteroid model, this study develops an algorithm to estimate the YORP moment, and calculates these on several simple models of classical asteroids' shapes. These Analysis could reveal the shape factors that mainly define YORP acceleration or deceleration, and enhance the comprehension of YORP mechanism.

1. Introduction

The YORP effect, mainly arising from the thermal re-radiation, is now considered one of the factors that may significantly change the rotation of an asteroid over a million years. The study of the YORP effect plays a vital role in understanding the evolution of asteroids, the formation of binary systems, and the origin and development of the solar system. There are several methods on the evaluation of the YORP effect in the existing literature. Nevertheless, because of the extreme sensitivity of the YORP effect to small-scale topography[1], no simplified estimation of YORP acceleration or deceleration is proposed. To find out the decisive shape factor of the YORP torque, we establish an algorithm of YORP calculation based on thermal physical model (TPM)[2] and the asteroid polyhedral model, and then apply the algorithm to simple models of classical asteroids. These simple models include top-shaped models, ellipsoidal models. Some of these above models with craters or boulders in different scales.

2. Calculation of YORP effect

In our calculation, we assume the thermal re-radiation on the surface of an asteroid to be Lambertian, and consider partial blockage of the sky for horizon elevation. Based on TPM, asteroids have non-zero thermal inertia, and the surface temperature T of an explicit asteroid is solvable. The recoil force of a surface element and the YORP moment can be estimated using the following equations,

$$\mathrm{d}\boldsymbol{F} = \frac{\varepsilon\sigma T^4}{3\pi c_0}\mathrm{d}S\int_0^{2\pi}\begin{pmatrix}\cos^3\varphi(\eta)\cos\eta \\ \cos^3\varphi(\eta)\sin\eta \\ 1-\sin^3\varphi(\eta)\end{pmatrix}\mathrm{d}\eta \qquad (1)$$

$$\boldsymbol{M}_{\mathrm{YORP}} = \oint\!\!\!\oint_S \boldsymbol{r}\times\mathrm{d}\boldsymbol{F} \qquad (2)$$

where η is the azimuth of the surface element, $\varphi(\eta)$ describes the self-blockage, ε is the thermal emissivity, σ is the Stefan-Boltzmann constant, c_0 is the speed of light, and $\boldsymbol{r}$ is the vector from the center of mass to the surface element.

3. Typical shapes of asteroids

Though the real asteroids have diverse appearance, there are some classical shapes, such as top-shaped, ellipsoidal, plate-shaped and boomerang-shaped. Top-shaped asteroids, such as 162173 Ryugu and 101955 Bennu, are ubiquitous and arouse extensive exploration recently. These asteroids are always thought to be YORP accelerated and deformed. However, traditional method reckons the YORP moment based on refined polyhedral model of a real asteroid, and is hard to reflect the influence of a single parameter of the YORP effect. Therefore, we adopt simple models to represent the shape of the classical asteroids. The simple models include top-shaped models and ellipsoidal models, as shown in figure 1. For a simple model, we adjust the shape parameters (i.e., the height and axis position of top-shaped models), or add a crater or boulder in different scales, and then use Delaunay triangulation to get a series of polyhedral models. By calculating and analyzing the YORP moment of these models, we could find the connection between the characteristic shapes, shape parameters, thermal inertia and the YORP effect.

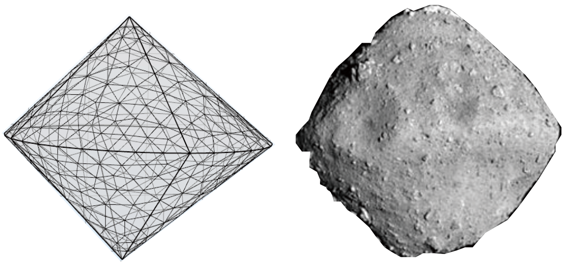

Figure 1: Top-shaped polyhedral model and asteroid 162173 Ryugu.

4. Conclusions

This study can help to qualitatively understand the influence of various shape parameters of asteroids on the YORP effects, and will help to reveal the formation and evolution of different asteroid structures. Moreover, it is of considerable significance to the target selection and target physical properties characterization of future asteroid exploration missions. In addition, this study comes up with a method to gain vast data of the relationship between shape models and YORP moments. Combining these data with deep learning may give a quick judgment of the YORP effect of an asteroid with complex topography.

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