Thermo-physical modeling and the scientific scenario to evaluate thermal properties of Asteroid 1999 JU3 from Hayabusa2/Thermal infrared imager

（1999 JU3 の熱モデルと Hayabusa2 TIR を用いた熱物性評価シナリオ）

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ABSTRACT

We evaluated the accuracy of estimating thermo-physical properties of near earth asteroid 1999 JU3, which is the target asteroid of Japanese rendezvous mission, Hayabusa2. The thermo-physical study of the asteroid using the on-board thermal infrared imager will provide thermal inertia of the asteroid, which can be derived from the thermal phase delay of the diurnal profile of surface temperature. The uncertainly is less than 15% under the observing opportunities which will last until March 2019 after the arrival of the spacecraft in the middle of 2018. Moreover, we report the thermo-physical model we developed at present. We tested our model to compare our results to that of former works in the thermal model of the asteroid (21) Lutetia, using a numerical shape model. The result shows the instantaneous equilibrium approximation (0 $Jm^{-2}k^{-1}s^{-1/2}$) will be unrealistic even if the thermal inertia is very low (5 $Jm^{-2}k^{-1}s^{-1/2}$): the night side temperature is underestimated in zero inertia approximation (~90K). This will be significant in a complicated surface geometry of NEAs where the shadowed regions are radiatively not negligible over the surface.

1. Introduction

Thermal inertia of Near Earth Asteroid (NEA) is generally higher than that of Main Belt Asteroids (MBA), which implies the fundamental difference of the formational processes of the two types of small bodies. Thermal inertia is one of the key parameters to clarify the history of the planetary formations.

Thermal properties of the NEA has not directly been measured by spacecrafts with infrared remote sensing devices, whilst the thermal inertia of the small bodies in solar system is recognized as an important parameter to understand the physical state of the planetary surface at present as well as the formation history of the planetesimals along with the prediction demands to the dynamical evolutions of the potential earth impact asteroids.

The Hayabusa2 space craft will reach the target NEA (162173) 1999 JU3 in the middle of 2018. In this mission, the dayside temperature of the asteroid will be observed using the thermal infrared imager (TIR). This allows us to estimate the thermal inertia of the asteroid via the thermal phase delay of the diurnal profile of surface temperature. This method has advantage to determine the thermal inertia without being strongly affected by the other thermal properties; the bond albedo and thermal emissivity.

2. Methods

We simulated the expected images of the asteroid 1999 JU3 seen from TIR imager by means of numerical calculations where we approximate the asteroid shape to be spherical. We solved heat conduction equations under the boundary conditions of thermal emission from the surface and the realistic angle of the solar irradiance, considering the orbital elements of the asteroid (JPL small body database browser) and the orientation of the spin vector [4]. The free parameter in this calculation is thermal inertia; 0 to 1000 $Jm^{-2}k^{-1}s^{-1/2}$. This range is based on the observational results of the asteroid [1][3][4]. Bond albedo is 0.014 [9] and thermal emissivity is 0.9 in this study.

3. Result and discussion

As a result (Fig.1, 2 [7]), the observing opportunity will last until March 2019 after the arrival of the spacecraft in the middle of 2018. The accuracy of thermal inertia is less than 15% in the observing opportunities. The opportunities were well described in terms of the solar phase angles; less than 20 degrees.

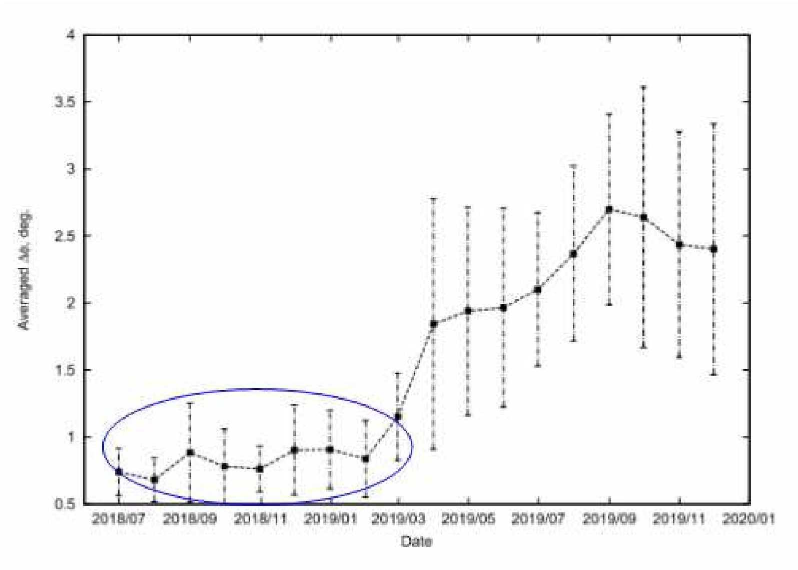

Fig. 1 The simulated the uncertainty of thermal phase delay of the diurnal temperature profile. The term before March 2018 will be the observing opportunity in the spin vector [4]. Error bars correspond to the parameter range of thermal inertia.

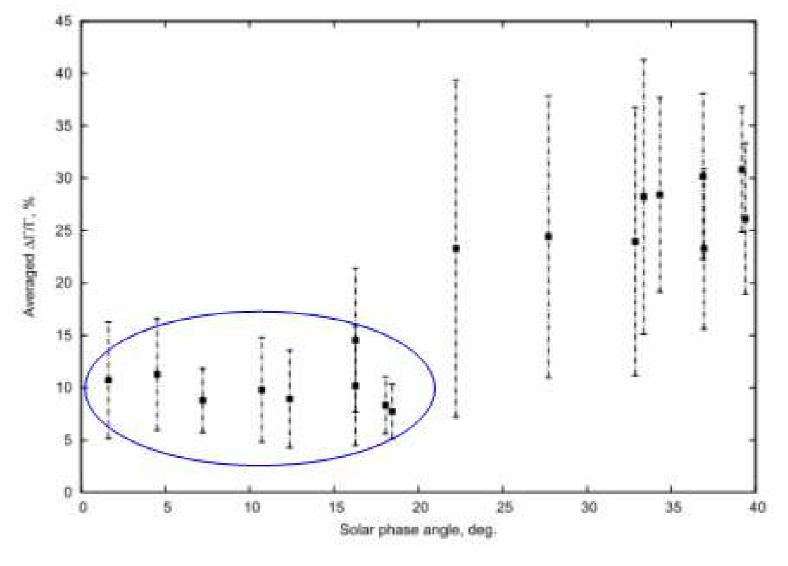

Fig. 2 The simulated the uncertainty to determine thermal inertia of the asteroid using the TIR imager against the solar phase angle. The observing opportunity in the spin vector [4] will be the term when the angle is less than 20 degrees. Error bars correspond to the parameter range of thermal inertia.

4. Reproduction of realistic temperature distribution

A thermo-physical modeling of the asteroid will be necessary to account for the observed temperature distribution over the surface with a none-spherical geometry and derive the thermal properties of the asteroid surface. We constructed our thermo-physical model (TPM) based on the works [8], which simulated realistic temperature variation with unsteady heat conduction and secondary heating effects; topographical shadowing, single scattering sunlight, and re-absorption of radiated energies from the surroundings on the surface.

We tested our implementations of the thermal model by calculating the surface temperature of the asteroid (21) Lutetia and compare our result to that of the thermal model in the literature [5] which derived the surface temperature based on the Space telescopic observations. The observational results shows very small thermal inertia ~ 5 $Jm^{-2}k^{-1}s^{-1/2}$ [5]. We used the numerical shape model which was reproduced based on flyby observations of the asteroid [2]. We used the model with spatial resolution of the total number of facets 24526. The bond albedo is 0.073 [6], thermal emissivity is 0.9, and the spin pole orientation in the ecliptic components is (λ,β) = (52.2,-7.8) degrees [6]. The rotational term is 8.17 hours [5]. The orbital element is from JPL small body database browser (Appendix A). The free parameter in this study is thermal inertia. We studied the thermal behaviors of our thermal model are in the two cases: (a) 0 and (b) 5 $Jm^{-2}k^{-1}s^{-1/2}$. Results of each models are shown in Fig.3. The global temperature distribution of our thermal model (b) agreed well to the literature [5], whilst the case (a) fails to match the result.

The comparison of these two cases show the thermal inertia is highly sensitive to the surface temperature of night side (or shadowed) regions; there is significant difference (~90K) in the surface temperature of asteroid between the small differences of 0 and 5 $Jm^{-2}k^{-1}s^{-1/2}$. The zero thermal inertia approximation might cause unrealistic results and fail to reproduce the brightness temperature of the asteroid because this approximation underestimates the amount of radiation energy that the imaging device detects.

Strictly, there are some local region that have different absolute values of the surface temperature between the model (b) and the literature [5]. This seems to be caused by the effect of surface roughness; our thermal model has not implemented the effect in numerical calculations at present. Moreover, the spatial resolution of our thermal model is about half of that of the literature [5], which might cause this as well. We will investigate the effect of surface roughness whether this effect is comparable to thermal inertia, which is one of our works.

(a) Thermal inertia = 0 $Jm^{-2}k^{-1}s^{-1/2}$ (b) Thermal inertia = 5 $Jm^{-2}k^{-1}s^{-1/2}$

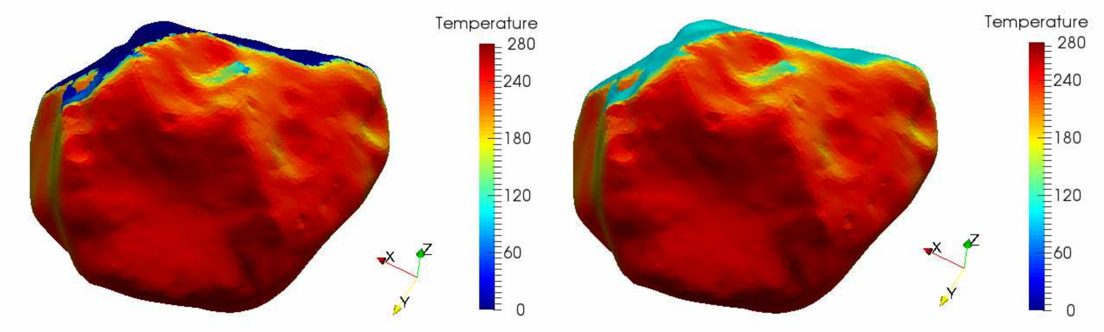

Fig.3 The simulated image of Asteroid (21) Lutetia in our TPM; (a) zero thermal inertia; (b) 5 $Jm^{-2}k^{-1}s^{-1/2}$. These configurations of the asteroid images correspond to the Fig. 5 in the literature [5]. The date of the image is on Oct 17 in 2007. We assumed no macroscopic surface roughness. The shape model is from NASA/PDS [6].

5. Summary and Conclusion

The thermo-physical estimation of 1999JU3 from Hayabusa2 TIR will be feasible to provide the thermal inertia less than 15% in the uncertainty under the observing opportunities under the solution of spin vector [4]. The timing is described well in terms of the solar phase angle (less than 20deg.) and this condition will last until March 2018 after the arrival of the spacecraft in the middle of 2018.

The thermal inertia is a key parameter when we analyze and reproduce the spatially resolved temperature distribution of the asteroid. Even a small difference of thermal inertia can change a considerable amount of surface temperature, especially in the night side region, when the thermal inertia can be considered nearly zero. Careful treatment of thermo-physical properties are required in thermal modeling of asteroids.

Appendix A Orbital Elements

The orbital element of asteroid (21) Lutetia is from JPL small body database browser;
a=2.44AU, e=0.165, i=3.06deg., peri=250.16deg., node=80.89deg.
pt=2457274.077825558333JED.
Orbital Elements at Epoch 2457000.5 (2014-Dec-09.0) TDB.
Reference: JPL 90 (heliocentric ecliptic J2000).

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