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The case for depth-dependent thermal properties of asteroids: evidence from Earth-based observations

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Abstract

We investigate the thermal inertia of a large number of asteroids and find significant evidence for depth-dependence of thermal properties, such as density and thermal conductivity.

1. Introduction

For all types of lander missions to asteroids some prior knowledge of the surface properties of the target is important for success. Observing the thermal emission from asteroids with thermal-infrared telescopes enables predictions of surface structural properties, such as the presence of fine regolith, rubble-like regolith or low-porosity rock/metal. This difference can be seen in the thermal inertia values:

$$\Gamma=(\kappa\rho C)^{0.5} \qquad (1)$$

(κ: thermal conductivity, ρ: density, C: heat capacity). The thermal emission signature depends on the material properties down to the depth to which the diurnal heat wave penetrates. A measure of this is the skin depth, d_s, which is the depth at which the amplitude of the heat wave is reduced to 1/e of its value at the surface:

$$d_s = (2/\omega)^{0.5}\,\Gamma/\rho C, \qquad (2)$$

where ω is the angular spin rate.

2. Thermal inertia estimator

The calculation of thermal inertia using thermophysical models requires high quality thermal-infrared observations taken at different times, a shape model and spin state information. These demanding requirements have limited the number of asteroids with measured thermal inertia. In previous work [1] we presented a novel means to estimate the thermal inertia of any asteroid based on knowledge of its astrometric geometry, spin axis and thermal-infrared emission, which we refer to as the "NEATM Thermal-Inertia Estimator". With currently available archival thermal-infrared data this technique can be used to we estimate thermal-inertia values for some 1000 asteroids, depending on spin-vector availability.

Since then the number of asteroids with thermophysically modeled thermal inertia have gone from around 60 to almost 300, e.g. [2]. We compare results from our thermal-inertia estimator with newly available results from thermophysical modelling and discuss possible improvements to the estimator.

3. Thermal inertia deduced from Earth-based observations

We review results, including observations of eclipses/occulations of binary asteroids, variability of thermal inertia with temperature, and further analysis of the results of Harris and Drube, 2016, which suggest that asteroid thermal inertia is in general strongly depth dependent. While, the interpretation of such results is still in progress, we note that depth-dependence of thermal inertia would have important implications for scientific lander missions to asteroids, future in-situ asteroid resource utilization, and planetary defence, including calculations of Yarkovsky orbital drift.

4. Summary and Conclusions

We use our NEATM-based thermal-inertia estimator results, together with other observational results, to investigate the thermal properties of asteroid near-surface structure. Evidence is growing for significant depth-dependence of thermal properties, such as density and thermal conductivity.

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References

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2. Hanuš, J., et al., *Thermophysical modeling of main-belt asteroids from WISE thermal data.* Icarus, 2018. **309**: p. 297-337.