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Developing a Thermal Destruction Model for low-q NEAs

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Abstract

A thermal destruction mechanism has been proposed as the cause for the increasing dearth of asteroids observed at smaller perihelion distances. We develop a thermophysical model here to better understand the potential effectiveness of this mechanism, particularly as it relates to the perihelion distance, albedo, and other thermophysical properties of an asteroid. Surface and sub-surface temperatures are used to aid our understanding of the contributing factors pertaining to the thermal destruction of NEAs.

1. Introduction

Asteroids with orbital perihelia (q) interior to Mercury's orbit (i.e. with $q < 0.38$ au) are subjected to the most extreme solar radiation environment in the Solar System. Previous work has indicated a deficit of near-Earth asteroids (NEAs) in orbits with $q < 0.4$ au, compared to a model of the expected population [1]. This work furthermore uncovers an albedo dependence of the distance at which the model of the expected NEA population diverges from the observed population. Specifically, the fraction of low-albedo (< 10%) asteroids diminishes at larger distances than those with a higher albedo (> 10%). This observational-model discrepancy could be explained by a temperature-dependent mechanism that acts to destroy asteroids via extreme internal thermal gradients experienced during perihelion passage.

1.1 Hypothesis

Our initial hypothesis within this project is that thermal disruption is the primary cause of the under-observed population of NEAs. Here we wish to more precisely understand thermal disruption as a function of thermophysical properties for modeled asteroids using a diverse set of orbital parameters. We anticipate that low-albedo asteroids will always exhibit a greater diurnal temperature range compared to high-albedo asteroids with the same q.

2. Methods

In this work we develop, test, and employ a thermophysical model (TPM) to predict surface and internal (near-surface) temperatures for a set of low-q model asteroids over an entire orbital revolution. The TPM used here is modified from [2] in order to account for seasonal changes in the incoming solar radiation (insolation) and length of the solar day. In addition to orbital parameters such as semi-major axis (a) and eccentricity (e), the input TPM parameters for the (spherical) modeled asteroid include the albedo, thermal inertia & diffusivity, spin obliquity, and time of the northern solstice. A version of the TPM that accounts for temperature-dependent thermal diffusivity is also developed for use.

We track and compile the changes in diurnal maximum and minimum surface temperatures throughout an orbital revolution, as a function of albedo, thermal inertia, q, spin rate and obliquity. Additionally, we extract the maximum spatial temperature gradients for each object being simulated.

3. Model Results

An example output from a TPM run is given in Fig. 1 for an NEA having a Bond albedo of $A = 0.1$, with orbital elements of $e = 0.6$ and $a = 1$ au. Peak equatorial surface temperatures during perihelion reach just over 600 K, with a diurnal range of 320 K.

The temperature depth profile of the same NEA during its perihelion approach is shown in Fig 2. The extreme insolation changes with time produce a sharp daytime spatial temperature gradient of around 300 K for the topmost 5 cm. The nighttime temperature drop over the same depth is over 50 K. These thermal conditions are expected to result in thermal shock cracking as demonstrated in [3].

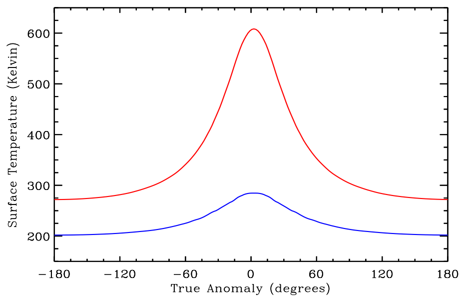

Figure 1: Maximum (red) and minimum (blue) equatorial surface temperatures as a function of true anomaly for an NEA with q = 0.4 au, A=0.1, and thermal inertia of 300 J m^{-2} K^{-1} $s^{-1/2}$.

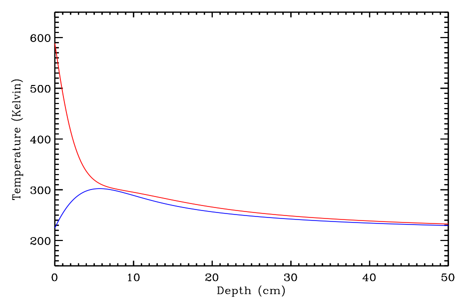

Figure 2: Temperature depth profile near perihelion of the same NEA shown in Figure 1.

4. Summary

Surface and subsurface temperatures of NEAs are modeled over an entire orbital revolution using a TPM. We show that the temperature changes for a low albedo NEA with q = 0.4 au are within the regime of thermal cracking experiments and thus – over time - can provide a means of destruction for NEAs experiencing intense solar radiation.

Acknowledgements

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