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Surface Properties of Asteroids from Mid-Infrared Observations and Thermophysical Modeling

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In loving memory of
Felix Müller (1948–2005).
Wish you were here.

Abstract

The subject of this work is the physical characterization of asteroids, with an emphasis on the thermal inertia of near-Earth asteroids (NEAs). Thermal inertia governs the Yarkovsky effect, a non-gravitational force which significantly alters the orbits of asteroids up to $\sim$ 20 km in diameter. Yarkovsky-induced drift is important in the assessment of the impact hazard which NEAs pose to Earth. Yet, very little has previously been known about the thermal inertia of small asteroids including NEAs.

Observational and theoretical work is reported. The thermal emission of asteroids has been observed in the mid-infrared (5–35 µm) wavelength range using the Spitzer Space Telescope and the 3.0 m NASA Infrared Telescope Facility, IRTF; techniques have been established to perform IRTF observations remotely from Berlin. A detailed thermophysical model (TPM) has been developed and extensively tested; this is the first detailed TPM shown to be applicable to NEA data.

Our main result is the determination of the thermal inertia of 5 NEAs, increasing the total number of NEAs with measured thermal inertia to 6. For two of our targets, previously available estimates are refined, no reliable estimates have been available for the remaining three. The diameter range spanned by our targets is 0.1–17 km.

Our results allow the first determination of the typical thermal inertia of NEAs, which is around 300 J $s^{-1/2}K^{-1}m^{-2}$ (corresponding to a thermal conductivity of $\sim$ 0.08 W $K^{-1}m^{-1}$), larger than the typical thermal inertia of large main-belt asteroids (MBAs) by more than an order of magnitude. In particular, thermal inertia appears to increase with decreasing asteroid diameter.

Our results have been used by colleagues to estimate the size dependence of the Yarkovsky effect, thus explaining the apparent difference in the size-frequency distribution of NEAs and similarly sized MBAs.

Thermal inertia is a very sensitive indicator for the presence or absence of particulate material on the surface, a fact that is widely used in, e.g., Martian geology. Our estimate of the typical thermal inertia of NEAs is intermediate between values for lunar regolith and bare rock, indicating that even sub-kilometer asteroids are covered with coarse regolith. This is consistent with spacecraft observations of the 0.32 km wide NEA (25143) Itokawa obtained in 2005.

The correlation of thermal inertia with size indicates a trend of smaller objects having coarser and/or thinner regolith than larger objects. This may allow an improved understanding of regolith formation through impact processes.

The first thermal-infrared observations of an eclipsing binary asteroid system are reported. To this end, the Trojan system (617) Patroclus has been observed using Spitzer. It is demonstrated that such observations enable uniquely direct thermal-inertia measurements. In particular, we report the first reliable estimate of the thermal inertia of a Trojan.

Additionally, two targets of future spacecraft encounters, (21) Lutetia and (10302) 1989 ML, have been observed. Their size and albedo has been determined and their surface mineralogy constrained. Our results for 1989 ML, in particular, are relevant in the current planning of the ESA mission Don Quijote.

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