8 Conclusions

8.1 Thermal modeling of near-Earth asteroids (NEAs)

We have developed and tested a detailed thermophysical model applicable to NEAs. Effects of convex irregular shape, spin state, surface roughness, and thermal inertia are explicitly taken into account. The model is applicable to all asteroids except for objects at the meter scale or smaller. This is the first such model shown to be applicable to NEAs.

A model like ours is required for reliable determination of thermal inertia. Moreover, it enables more accurate size and albedo determination compared to less detailed thermal models, which are frequently used.

8.2 Thermal inertia of NEAs

We have doubled the number of NEAs with measured thermal inertia. We have determined the thermal inertia of 5 NEAs. For 2 of these, we refine previously available estimates while the remaining 3 increase the total number of NEAs with measured thermal inertia from 3 to 6. For each object, we have also determined its size and albedo, and have constrained its surface mineralogy (taxonomic type). Our NEA targets range between 0.1 and 17 km in diameter.

The typical thermal inertia of NEAs, which was previously unknown, is around 300 J $s^{-1/2}K^{-1}m^{-2}$. The corresponding value for large main-belt asteroids (MBAs) is smaller by more than an order of magnitude, indicating significant differences in surface structure. Our result has recently been confirmed in a complementary study by Delbo' et al. (2007a). The corresponding thermal conductivity is 0.08 W $K^{-1}m^{-1}$.

Our results allow more realistic model calculations of the Yarkovsky effect, which is important in the assessment of the impact hazard.

Thermal inertia governs the Yarkovsky effect, a non-gravitational force known to influence the orbits of asteroids below some 20 km in diameter significantly. Uncertainties in the strength of the Yarkovsky effect dominate uncertainties in the assessment of the risk posed by objects such as (29075) 1950 DA, the asteroid with the largest currently known probability of impacting Earth.

The thermal inertia of asteroids correlates with size. Using our results, Delbo' et al. (2007a) found a power law relating the thermal inertia and diameter of asteroids. From this, they deduce a modified size dependence of the Yarkovsky effect and draw conclusions on differences between the size-frequency distributions of NEAs and similarly sized MBAs.

There is regolith on sub-km NEAs. The thermal inertia of NEAs is intermediate between that of lunar regolith and bare rock on Earth, indicating the presence of coarse regolith. Asteroid regolith is believed to be gravitationally retained collisional debris. With decreasing asteroid mass, the formation of regolith should be less efficient and skewed towards coarse grains, consistent with our findings. Our quantitative results may lead to an improved understanding of regolith formation through impact processes.

All NEAs studied by us have a thermal inertia significantly below that of bare rock. This is surprising, particularly so for two of our targets:

- (54509) YORP with a diameter of ~ 0.1 km and an ultrashort spin period of only ~ 12 min; the centrifugal force overwhelms gravity on most of its surface and would be expected to destabilize any regolith
- (25143) Itokawa, the target of a rendezvous with the Hayabusa spacecraft in 2005, was seen to be predominantly covered with boulders

We tentatively explain the reduced thermal inertia with a thin (mm scale) coating of particulate material, which may be stabilized by cohesion. We caution that further study is required. Alternatively, both objects may display an extremely large near-surface porosity at the mm–cm scale, but it remains to be studied whether realistic porosity models can explain the observed reduction in thermal inertia. In the case of Itokawa, both theories may be testable on the basis of obtained Hayabusa imagery, which was only partially analyzed so far.

8.3 Thermal inertia of an eclipsing binary

We have pioneered thermal-infrared observations of eclipsing binary asteroids. We have clearly detected the thermal response of the Trojan binary (617) Patroclus to mutual events, where respectively one component shadowed the other. This allowed us to determine their thermal inertia in a uniquely direct way, in addition to a more reliable diameter estimate.

The thermal inertia of Patroclus is around 90 J $\mathbf{s^{-1/2}K^{-1}m^{-2}}$, indicating a cover of relatively coarse regolith. No reliable information on the thermal inertia of Trojans has been available beforehand.

8.4 Physical characterization of spacecraft targets

Rosetta flyby target (21) Lutetia We have found the diameter of Lutetia to be 98.3 ± 5.9 km and its geometric albedo to be $p_\mathrm{V} = 0.208 \pm 0.025$, consistent with an M-type classification and with previous diameter estimates. In the past few years, spectroscopic results have been published which indicate a C-type-like surface. We can now rule out a low albedo typical of a C-type classification. Rosetta will fly by Lutetia in 2010.

Potential spacecraft target (10302) 1989 ML The NEA (10302) 1989 ML is among the most favorable spacecraft targets in terms of energy and flight time required to reach it. It has been taken as a working target for phase-A studies of the ESA mission Don Quijote, although virtually nothing was previously known about its physical properties. On the basis of Spitzer observations, for which we have been awarded Director's Discretionary Time, we have determined its diameter to be 0.28 ± 0.05 km and its albedo to be $p_\mathrm{V} = 0.37 \pm 0.15$. Combining our results with optical and near-infrared data we conclude that 1989 ML is an E-type object—note that only 4 E-type NEAs were known beforehand. Most probably, our results imply that 1989 ML is not a suitable target for Don Quijote.

Thermal-infrared characterization of potential spacecraft targets is time efficient. Only ~ 30 min of telescope time at the 3.0 m IRTF were required for our Lutetia observations, and only 1.2 h at the Spitzer Space Telescope in the case of 1989 ML, despite the faintness of the latter.