UNEXPECTED THERMAL PROPERTIES OF THE NEAR-EARTH OBJECT (499998) 2011 PT.

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Introduction: Asteroids smaller than 150 meters may spin very fast, completing an entire rotation in a period of few tens of minutes. These small and fast rotating bodies are thought to be monolithic objects. Indeed, the weak gravitational force due to the small diameter, coupled with the large centripetal force caused by the fast rotation, do not make the rubble-pile structure feasible. However, a little is known about their internal and surface compositions, which are in turn important for several reasons: they may provide information about the formation and evolution of larger asteroids, helping in understand weathering processes, and they are fundamental in the planning of both deflection and asteroid redirect missions. In particular, it is not clear whether small and fast rotating bodies are able to retain a dusty-like regolith layer on their surface or not.

An indicator of the presence of regolith is a low surface thermal conductivity, smaller than ~0.1 W m^{-1} K^{-1}. In this work we develop a statistical method to set constraints on the surface thermal conductivity of (499998) 2011 PT, a small near-Earth object (NEO) that rotates with 11 minutes period. By combining an analytical model of the Yarkovsky drift, based on physical properties, with measurements of the semi-major axis drift obtained from astrometry, we estimated the surface thermal conductivity K.

Methods: The Yarkovsky effect is a thermal recoil force due to solar radiation, and it affects the motion of small bodies causing a secular drift in semi-major axis. The analytical model of the drift [1] depends on the orbital and the physical characteristics of the asteroid, i.e. the semi-major axis a, the diameter D, the density ρ, the thermal conductivity K, the heat capacity C, the obliquity γ, the rotation period P, the absorption coefficient α, and the emissivity ε. Among them, the thermal conductivity K is the most uncertain one, and it can vary of several orders of magnitude. If a measurement of the Yarkovsky effect is known from astrometry, comparing the model predicted drift-rate with the observed one allows to produce an estimate of the thermal conductivity K. Modeling the input parameters either by fixing their values if their uncertainty is negligible, by modeling the errors using a Gaussian distribution if they are measured, or by using a population-based distribution if they are unknown, permits a statistical estimation of the thermal conductivity K, obtained by performing a Monte Carlo simulation.

Parameters of 2011 PT. Asteroid 2011 PT is a near-Earth object with a semi-major axis of a = 1.3123 au and a measured absolute magnitude of H = 24.07 ± 0.42 mag. The semi-major axis a is kept fixed, since its uncertainty is very small. The heat capacity has not been measured, but it can be fixed using reasonable values deduced from measurements on meteorites. In our analysis we used C = 680, 800, 1000, 1200 J kg^{-1} K^{-1}. The emissivity is fixed to ε = 0.984, corresponding to the average value of meteorite's measurements.

The rotation period has been measured to be P = 0.17 ± 0.05 hr [2], while the semi-major axis drift determined from astrometry is (da/dt) = (-88.44 ± 14.6) $\cdot 10^{-4}$ au My^{-1} [3]. For these parameters we assumed a Gaussian distribution of the errors.

Diameter, density, and obliquity have not been measured, and their distribution are constructed using population-based models. First, an albedo distribution is constructed combining the NEOs orbital distribution model [4] and the NEOs albedo distribution [5] (see Fig. 1, top left panel).

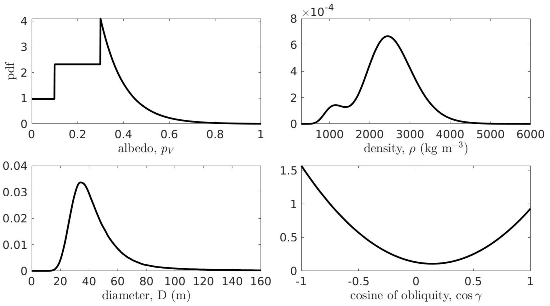

Fig. 1 Distributions of the albedo (top left), the density (top right), the diameter (bottom left), and the obliquity (bottom right) of 2011 PT.

The albedo distribution is converted into both diameter and density distribution. The diameter is determined using the relation $D = 1329\ \mathrm{km}/p_V^{1/2} \cdot 10^{-H/5}$, assuming a Gaussian distribution for the absolute magnitude. We found a most likely diameter of 35 meters (see Fig. 1, bottom left panel). The density is generated according to three albedo categories. We associate $p_V < 0.1$ to the C-complex, $0.1 \leq p_V < 0.3$ to the S-complex, and $p_V \geq 0.3$ to the X-complex. Then, a value of the density ρ is generated assuming a log-normal distribution for the density of each asteroid complex (see Fig. 1, top right panel), using the mean values and uncertainties of Table 1. We found a most likely density of about 2450 kg m^{-3}. Finally, we assume γ to be distributed according to the NEOs obliquity distribution [6] (see Fig. 1 bottom right panel).

Table 1 Densities of the three asteroid complexes.

Complex	Density (kg m^{-3})
C	1200 ± 300
S	2720 ± 540
X	2350 ± 520

The low thermal conductivity of 2011 PT: We performed Monte Carlo simulations choosing one million random combinations of input parameters. The distribution of thermal conductivity obtained for C = 800 J kg^{-1} K^{-1}, together with the smoothed probability density function obtained using the kernel density estimation, are shown in Fig. 2.

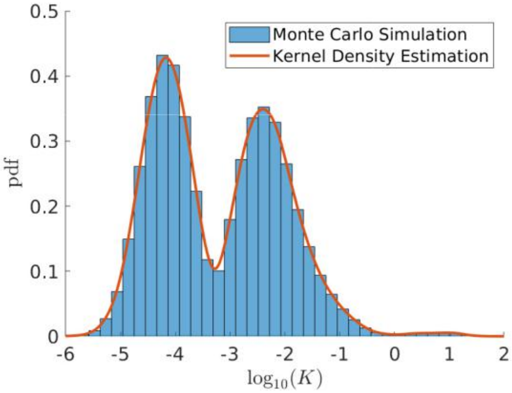

Fig. 2 Distribution of the thermal conductivity of 2011 PT, obtained for C = 800 J kg^{-1} K^{-1}.

The distribution is bi-modal, with a first most likely value at around 0.00006 W m^{-1} K^{-1} and the second one at around 0.005 W m^{-1} K^{-1}. Moreover, the probability for the thermal conductivity K to be smaller than 0.1 W m^{-1} K^{-1} results to be about 0.99. We obtained similar results for heat capacity C = 680, 1000, 1200 J kg^{-1} K^{-1}, with the second peak in the distribution of K moving towards slightly smaller values as the heat capacity increases. Overall, the probability for K to be smaller than 0.1 W m^{-1} K^{-1} resulted to be larger than 0.95.

The low thermal conductivity solution is explained by the combination of the very-fast rotation and the relatively large semi-major axis drift. If the thermal conductivity were large, the fast rotation would spread the thermal gradient on the surface of the asteroid, preventing a large semi-major axis to be achieved. On the other hand, a low thermal conductivity would be able to keep a temperature difference between the day-side and the night-side of the asteroid, producing a larger semi-major axis drift.

Regolith retention mechanism: Values of thermal conductivity associated to the second peak are compatible with the porous lunar regolith sampled during the *Apollo 11 mission*, composed by dust of 50 µm of average radius, while the first peak at lower conductivity would suggest an even smaller size of the grains. Although it is not clear what effect might be able to retain small gravel particles on the surface of super-fast rotators, we tested the hypothesis of the existence of a cohesive force, such as van der Waals forces, that creates a superficial electric field. The strength of the cohesive force is represented by the bond number $B = 10^{-5}\, g_A^{-1}\, d^{-2}$, where g_A is the ambient gravity and d is the grain diameter. Stability of surface material requires a bond number larger than ten. Assuming the nominal rotation period, we computed the ambient gravity g_A as a function of the diameter D of the asteroid and the density ρ, using a spherical model for the shape of 2011 PT. We then computed the maximum grain diameter d by imposing a bond number equal to ten, and we found an upper limit for the grain size between 1 and 4 millimeters, well above the diameter of the average diameter of lunar dust.

Summary and Conclusions: We found two most likely values of the surface thermal conductivity to be around 0.0001 and 0.005 W m^{-1} K^{-1}, and constrained K to be smaller than 0.1 W m^{-1} K^{-1} with a probability >95 percent. These values suggest the presence of regolith-like materials on the surface of 2011 PT. This is the first case that a low thermal conductivity solution for a small and super-fast rotating asteroid has been obtained with such high probability, possibly providing new insights into physical properties of these small intriguing bodies.

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