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Fine-Grained Regolith on the Young Asteroids (1270) Datura and (5026) Martes

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Abstract

Regolith is found on most, if not all, solid planetary surfaces but its formation timescales are uncertain, especially on asteroids. To place constraints on these timescales, we characterised the surface properties of two "young asteroids" with estimated ages of <600 kyr. The two asteroids were observed in the thermal-infrared with the ESO VLT VISIR instrument, and thermal modelling of the data surprisingly found the presence of fine-grained regoliths on both asteroids.

1. Introduction

Space missions and remote sensing observations have shown that most, if not all, solid planetary surfaces are covered by a regolith layer, i.e. a surface layer comprised of centimetre-sized or smaller particles [1]. Regolith generation is believed to arise from micrometeorite impact gardening and fracturing by thermal fatigue [1]. Both processes require time to grind the regolith grains down to smaller sizes but the timescales involved are uncertain. However, it has been recently suggested that thermal fatigue should be the dominant mechanism for small asteroids [1].

Thermal inertia (i.e. a material's resistance to temperature change) can be used as a qualitative measure of the regolith grain size (i.e. low and high thermal inertia values arise from small and large regolith grains, respectively) [2], and can be determined through thermophysical modelling of suitable thermal-infrared observations [3]. Such observations and models have successfully been applied to a range of Solar System bodies to infer their likely regolith grain sizes (e.g. see [2] and [3] for a brief review). For the lunar surface, LRO Diviner observations and modelling have shown that the thermal inertia values of impact ejecta surrounding lunar craters are related to the estimated ages of those craters (i.e. determined by crater counting) [4]. In particular, older craters are surrounded by impact ejecta with lower thermal inertia values than that surrounding younger craters, and confirms that time is needed on the lunar surface to grind the regolith grains down to smaller sizes.

For asteroids, a previously identified trend of decreasing thermal inertia with increasing asteroid size was thought to be related to the relative ages of those asteroids because larger asteroids are generally older than smaller asteroids [5]. However, recent work has demonstrated that this apparent size trend could be a manifestation of temperature-dependent thermal inertia, and that this size trend can be reduced/removed when the asteroid thermal inertia measurements are corrected to a common heliocentric distance [6]. Therefore, it is not clear what timescales are needed for regolith generation on asteroid surfaces.

Fortunately, asteroid families and unbound asteroid pairs allow the ages of their member asteroids to be determined through backwards dynamical integrations [7]. Therefore, they can be used to place chronological constraints on asteroid regolith generation if their thermal inertia values are also measured. Two suitable "young asteroids" with well-constrained dynamical ages are the main-belt asteroids (1270) Datura and (5026) Martes, which we investigate in this work with ESO VLT VISIR observations and thermophysical modelling.

2. (1270) Datura and (5026) Martes

(1270) Datura is the largest member of a small asteroid family (i.e. 17 currently known members) located in the innermost part of the main asteroid belt [8]. This collisionally produced family has an estimated age of 450 to 600 kyr, and its members consist of S and Q type sub-classes. (5026) Martes is the largest member of an unbound asteroid pair (i.e. its counterpart asteroid is 2005 WW113), and has an estimated separation age of just 18 kyr [9]. It has a C-type spectral class. Both (1270) Datura and (5026) Martes have previously derived light-curve shape models [8][9].

3. ESO VLT VISIR Observations

We observed (1270) Datura and (5026) Martes in May and April 2016, respectively, with the VISIR instrument located on ESO's VLT telescope in Chile (see Table 1). The thermal-infrared observations were obtained in imaging mode, and standard star observations were conducted at airmasses that bracketed the asteroid observations. The images were reduced using the VISIR image processing pipeline, and photometry was performed using standard techniques on the reduced images to give the measured asteroid fluxes.

Table 1: Summary of ESO VLT VISIR observations obtained in 2016.

Asteroid	Date	r (AU)	Δ (AU)	α (°)	Wavelengths (μm)
Datura	27/5	2.2	1.2	10	8.7, 10.7, 11.5, 12.5
Martes	10/4	2.2	1.5	21	8.7, 11.5

4. Thermophysical Modelling

To determine the thermal inertia values of (1270) Datura and (5026) Martes, thermophysical modelling was performed using the ATPM [10] with the previously derived light-curve shape models. In particular, the ATPM computes the surface temperature distribution of an asteroid by solving 1D heat conduction for each triangular facet of the asteroid shape model. A surface boundary condition is included for each facet that ensures conservation of energy between incoming radiation (i.e. direct solar illumination plus scattered light between facets), heat conducted into the sub-surface (i.e. dictated by thermal inertia), and radiated energy (i.e. thermal emission). Rough surface thermal-infrared beaming is also included by a fractional coverage of hemispherical craters. Model surface temperature distributions are produced for a range of thermal inertia values, and the model emitted flux is derived by summing the Planck function across facets visible to the observer. The model fluxes are then compared against the measured fluxes using χ^2 fitting to find the best-fit parameters and their uncertainties. Table 2 summarises the ATPM fitting results of the VISIR data for (1270) Datura and (5026) Martes.

Table 2: Summary of thermophysical properties derived by the ATPM.

Asteroid	Size (km)	Geometric Albedo	Thermal Inertia (J m^{-2} K^{-1} $s^{-1/2}$)
Datura	7.5	0.27	20 ± 5
Martes	10.7	0.04	40 ± 30

5. Summary and Conclusions

The low thermal inertia values determined for (1270) Datura and (5026) Martes imply that both asteroids are covered by fine-grained regoliths. Furthermore, their thermal inertia values are comparable to that measured for several main-belt asteroids that are much larger [3]. This could imply that the regolith generation processes take place on timescales much shorter than previously thought, as suggested by [6]. Alternatively, the fine-grained regoliths could be related to the formation mechanisms of the asteroids themselves, i.e. a catastrophic collision for (1270) Datura and YORP spin-up/rotational fission for (5026) Martes. Further observations and modelling of asteroids with known ages will help place additional constraints on the regolith generation timescales.

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