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A New Method to Determine the Grain Size of Planetary Regolith

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Abstract

Airless planetary bodies are covered by a dusty layer called regolith. The grain size of the regolith determines the temperature and the mechanical strength of the surface layers. Thus, knowledge of the grain size of planetary regolith helps to prepare future landing and/or sample-return missions. In this work, we present a method to determine the grain size of planetary regolith by using remote measurements of the thermal inertia.

1 Introduction

The thermal inertia,

$$\Gamma(r) = \sqrt{\lambda(r)\, C} \qquad (1)$$

describes the resistance of the near surface material of a Solar System body to follow diurnal changes in the irradiation and depends on the heat conductivity $\lambda(r)$ and the volumetric heat capacity C of the bulk regolith, respectively. The volumetric heat capacity is given by $C = \phi\, \rho\, c$, with the packing fraction ϕ, the mass density ρ and the heat capacity c of the regolith particles.

This implies that the thermal inertia depends on the material properties of the regolith and the degree of compaction of the regolith particle layers. Additionally, the thermal inertia is influenced by the grain size of the regolith particles since the heat conductivity is a function of the radius r of the regolith particles [3].

2 Method

In order to determine the grain size of planetary regolith (see Fig. 1), we used literature data of thermal inertiae measured for different airless bodies in the Solar System [1, 2]. For the calculation of the heat conductivity of the surface regolith we divided the analyzed bodies into stony (S), carbonaceous (C), and metallic (M) bodies. For each of the three classes, the mass density and heat capacity of the material were approximated by the laboratory measurements of these properties of representative meteorites [7]. Since the packing fraction of the surface regolith is unknown, we treated the packing fraction as a free parameter and varied it between $\phi = 0.1$ and $\phi = 0.6$ in intervals of $\Delta\phi = 0.1$. For each of the six packing densities, a corresponding heat conductivity value was derived.

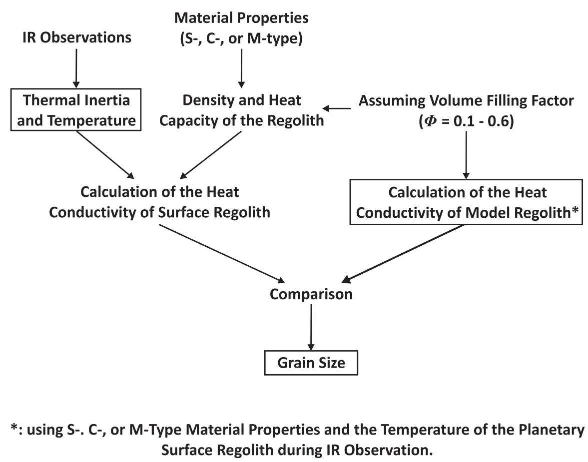

Figure 1: Strategy for the grain size determination of planetary regolith using thermal inertia measurements.

In general, the heat capacity and the thermal conductivity are temperature dependent. Thus, we also derived the surface temperatures of the analyzed bodies at the time of observation of their thermal inertiae.

With the knowledge of the thermal inertia, the surface-material properties and assumptions about the packing density of the regolith particles, the particle size of the surface regolith was derived from a comparison with a modeled heat conductivity of granular materials in vacuum [3].

In order to take the irregular shape of the regolith particles into account, the heat conductivity model was calibrated using ground-based measurements of the heat conductivity of Lunar regolith.

3 Results

We applied this method to various bodies for which thermal inertia measurements were available (see Fig. 2 for an example) and found that the derived mean particle size of the regolith follows an anti-correlation with the diameter and, thus, with the gravitational acceleration of the body (see Fig. 3). Small bodies (diameter less than $\sim 100\,\mathrm{km}$) possess a much coarser regolith, with typical particle sizes in the millimeter to centimeter regime, whereas large bodies (diameter greater than $\sim 100\,\mathrm{km}$) are covered by a much finer regolith, with grain sizes between $10\,\mu\mathrm{m}$ and $100\,\mu\mathrm{m}$.

The decrease in grain size can qualitatively be understood as a result of the collision history of the asteroids. Hyper-velocity impacts have led to a size discrimination of the regolith, which consists of those impact fragments whose velocities did not exceed the escape speed of the parent body. Smaller fragments gain higher velocities in impacts [6]. Thus, smaller bodies are covered by the coarser fragments, whereas large bodies are able to hold the larger fragments.

4 Summary and Conclusions

We have demonstrated a new method to determine the grain size of planetary regolith from remote observations. The analysis of the measured thermal inertia of various bodies shows that smaller bodies (diameter less than $\sim 100\,\mathrm{km}$) are covered by relatively coarse regolith grains with typical particle sizes in the millimeter to centimeter regime, whereas larger bodies (diameter greater than $\sim 100\,\mathrm{km}$) possess very fine regolith with grain sizes between $10\,\mu\mathrm{m}$ and $100\,\mu\mathrm{m}$.

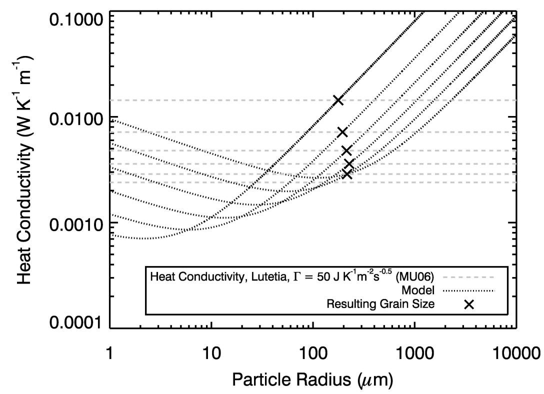

Figure 2: Grain size estimation for the surface regolith of Asteroid (21) Lutetia. Results of the regolith heat conductivity model (dotted curves) are shown for the different packing fractions of the regolith particles, $\phi = 0.1$ to $\phi = 0.6$, in intervals of $\Delta\phi = 0.1$. The heat conductivities derived from the thermal inertia measurement, $50\,\mathrm{J\,K^{-1}\,m^{-2}\,s^{0.5}}$ [5], are shown by the dashed lines.

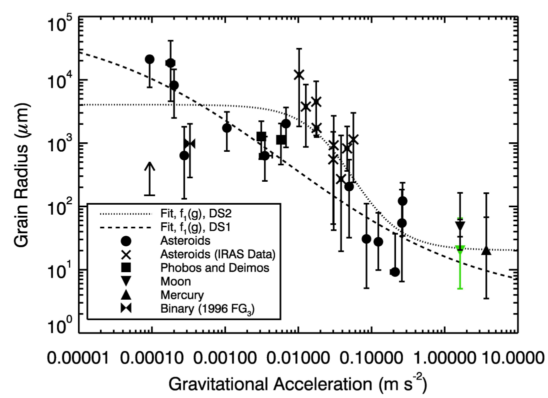

Figure 3: Dependence of the regolith grain size on the gravitational acceleration of the body. The fit function $f_1(g)$ (dotted and dashed curves) was fit to two different data sets: the first data set (DS1) consists of all asteroids excluding the IRAS asteroids (filled circles) and the second data set (DS2) consists of all asteroids including the IRAS asteroids (filled circles and crosses). Additionally, the measured size distribution of Lunar regolit [4] is shown by the green colored data.

Acknowledgements

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