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# Photometric studies: from natural granular surface materials in laboratory to lunar regolith from orbit

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## Abstract

We apply Hapke's photometric model (1993) on both terrestrial natural granular surface samples and multiangular data of the lunar surface acquired by SMART-1/AMIE camera, using the photometric parameters derived from well-characterized volcanic materials in laboratory as benchmarks to help better understand photometric results from orbital data.

## 1. Introduction

Most of airless bodies' surfaces are covered by a thin superficial layer called the regolith, which can provide information on their volcanic histories, interiors, and impact processes through the study of volcanic deposits (e.g., mare basalts, pyroclastics on the Moon) and widespread ejecta around craters. But except for the lunar samples brought back to Earth, the only way to study a planet's surface so far remains the use of remote-sensing techniques. Among them, photometry can be used to determine the physical properties of surface particles, such as grain size, roughness, scattering behaviors… In this work we implement Hapke's 1993 semi-empirical bidirectional reflectance model [5], frequently used for the photometric study of regoliths. Its parameters are used to characterize a granular material from reflectance data acquired with various angular and illumination conditions. However, such observational variety is still difficult to obtain from space, and laboratory works performed on known materials appear to be useful benchmarks for the matter of interpreting results from orbital data.

## 2. Experimental photometric study

Various volcanic samples with diverse content of rock, minerals, and glass fragments have been measured with the spectro-imaging device ISEP (Observatoire Midi-Pyrénées, Toulouse, France, [2]): fresh basalt (France), volcanic sand (Iceland), pyroclastics (Japan), olivine (Hawaii), basalt (Hawaii), amorphous basaltic glass (controlled melt of fresh basalt). Some samples are homogeneous (e.g., olivine) whereas others are complex mixtures (e.g., pyroclastics), allowing the role of the sample composition and texture on the photometric modeling to be investigated. The different materials have been sorted into granulometric classes between a few tens of µm to 2 mm, and measured under about 20 carefully chosen geometrical configurations spanning the multiangular space as regularly as possible in terms of incidence, emission, azimuth, and phase angles (25°≤phase≤130°) [12]. Hapke's 1993 model relies on 6 parameters, but since no phase angle smaller than 25° can be measured, only 4 are discussed here (the opposition effects cannot be addressed): the macroscopic surface roughness θ (0°≤θ≤45°), the single scattering albedo w (0≤w≤1), the asymmetry parameter b (0≤b≤1) and the backscattering fraction c (0≤c≤1). The last two are included within the phase function described by a 2-term Henyey-Greenstein function (e.g., [7]). Data are inverted using a dedicated genetic algorithm successfully implemented earlier [1, 2, 3, 6, 9]. The modeled phase functions match well the observations, and the different natural surface samples present significant differences according to their compositions and grains sizes. Macroscopic roughness values goes from ~5° to ~25°, and c vs. b parameters appear scattered on a similar L-shaped trend as in [8], with samples comprising a significant proportion of fresh glass or monocrystals clearly extending and exploring some new part of the trend.

## 3. Lunar crater Lavoisier

A study of multiangular observations of the lunar crater Lavoisier made by the AMIE camera onboard the European spacecraft SMART-1 [10] has been undertaken, with phase angles ranging from 26° to

83° [11]. The inversion process was the same as the one used to process ISEP data. 22 selected local regions as homogeneous as possible have been chosen, with varying albedos. Observed phase functions are very well reproduced, and the photometric parameters show a general backscattering behavior with high macroscopic surface roughness (θ~20-25°). Dark patches considered to be pyroclastic deposits within Lavoisier [4] display similar sets of photometric parameters, thus confirming their surface state homogeneity. But they are not significantly different from other "non-dark" patches on the crater's floor, which could be the result of a greater extent of the pyroclastic deposits than initially thought, or these deposits may have been homogenized with their surroundings (e.g., through space weathering processes). On the contrary, the regions within the assumed pyroclastic deposit of Lavoisier F share photometric parameters distinct from all the other studied regions, being the roughest and least backscattering, hinting at a distinct textural and/or compositional pyroclastic deposit from those within Lavoisier crater. The parameters values in this study are in agreement with the general lunar photometric behaviors found in the literature, especially the backscattering properties. They are also compatible with the photometric behaviors found for a number of samples analyzed with ISEP.

# 6. Conclusion

Specific photometric characteristics of various natural surface volcanic materials have been determined, and show that the retrieval from orbital data of the local surface physical properties of the regolith within Lavoisier crater is realistic. As more complete datasets will be produced from ongoing or soon-to-come missions (e.g., Dawn, Messenger, Selene-2, Bepi-Colombo…), a more precise characterization of planetary surfaces should be achieved.

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