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The Polarization of Moonlight as a Measure of the Refractive Index of the Lunar Regolith

A. Fearnside (1) and P. Masding (2)

(1) 2 The Cobbles, Woodend Farm, Boots Green Lane,
Allostock, Knutsford, WA16 9NG, United Kingdom
(asfearnside@hotmail.com)

(2) Imber House, Vale Road, Bowdon, WA14 3AQ, United Kingdom (zen32156@zen.co.uk)

Abstract

A method is presented for determining relative differences in the refractive index of telescopically observed lunar surface regions. This is achieved by exploiting a newly found relationship between the degree of linear polarization of moonlight emanating from a lunar surface region and the surface brightness of that region. Two different computational models are presented, each of which independently predict the newly found relationship.

1. Introduction

The degree of polarization of moonlight has been used to infer relative variations in regolith particle size. It has been suggested [2, 3, 4] that anomalies in an otherwise regular relationship (Umov's Law) between the maximum degree of polarization of light reflected from a lunar region and its associated albedo, are indicative of regolith particle size anomalies.

2. Lunar Observations

Figure 1 shows an example of the well-known linear relationship (Umov's Law) that exists between the surface distribution of brightness of a lunar region (e.g. Mare Serenitatis) and the corresponding distribution of the maximum degree of polarization of the reflected light. Obtained by a process of principal component analysis (PCA), a representative line drawn though this distribution emphasizes its linearity.

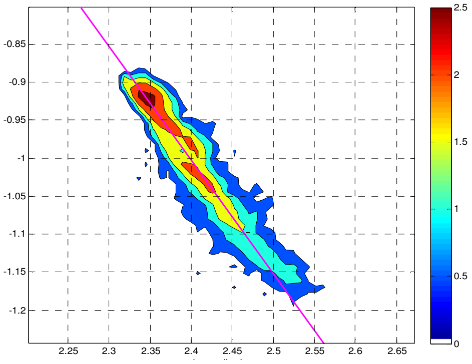

Figure 1: The maximum degree of polarization (*y*-axis) and surface brightness (*x*-axis) across Mare Serenitatis. Note the logarithmic scale on each axis. The colour bar indicates density of data points.

The extent of perpendicular deviation of any data point from the PCA line corresponds to what is here referred to as a "polarization anomaly". The spatial distribution of polarization anomalies across a flat lunar surface region may be mapped as shown in Figure 2. Some small mare craters possess a large halo of polarization anomaly. This may be due in part to the impact excavation of stratigraphic layers underlying a surface stratigraphy of different mineralogy.

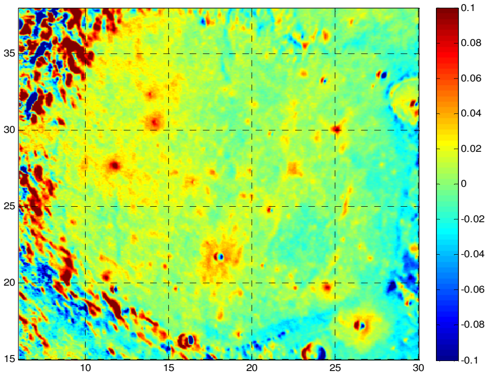

Figure 2: A map of polarization anomaly, and relative refractive index by inference, of Mare Serenitatis. Redder regions have a positive polarization anomaly above the PCA line of Figure 1, and bluer regions have a negative anomaly below it.

3. Modelling the Regolith

A regolith particle is modelled as a core of material coated by nano-phase iron spherules (npFe) embedded within the surface of the core particle to represent the effects of space weathering. Five structural particle parameters were randomly varied within representative ranges. The maximum degree of polarization and reflected light intensity were calculated for each combination of these parameters: (1) core size, *D*; (2) coating thickness, *d*; (3) npFe concentration in the coating; (4) core optical attenuation constant; (5) core refractive index, *n*.

3.1 Analytical Model

A first model represented the regolith as an isolated particle, illustrated schematically in Figure 3.

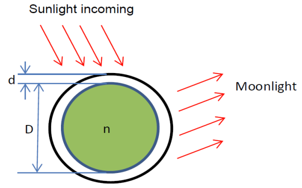

Figure 3: The isolated regolith particle of the analytical model.

3.2 Ray-Tracing Model

A second model represented the regolith as a collection of many particles individually differing in polygonal shape, orientation and position. Each possessed the five structural parameters as described above. Multiple illuminating rays were propagated through this pack of particles in three dimensions. Figure 4 shows an example.

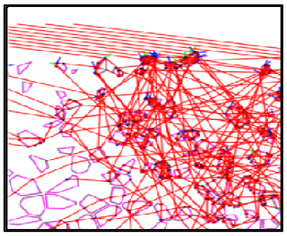

Figure 4: An example of a portion of a regolith particle pack according to the ray-tracing model, with some ray trajectories shown for illustration.

The result is plotted in Figure 5 for three different values of core refractive index, *n*, and many different values of all other structural parameters. Both models reproduce Umov's Law and demonstrate that a polarization anomaly is caused by refractive index differences.

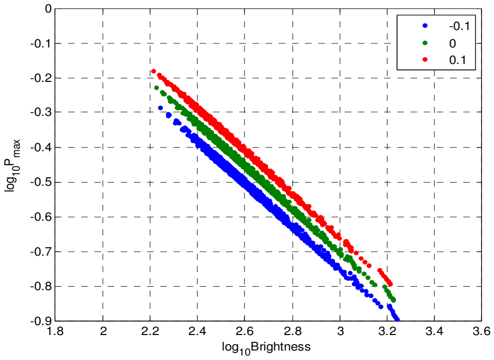

Figure 5: Reproducing Umov's Law using a regolith model. Differences in refractive index of +0.1 (red line) or -0.1 (blue line) relative to a nominal refractive index of 1.7 (green line) induce opposite but consistent and almost uniform polarization anomaly.

5. Summary and Conclusions

By interpreting polarization anomalies as being proportional to refractive index differences, one may use Umov's Law to map differences in the refractive index of regolith materials. Polarization anomalies appear to be caused in part by mineralogical anomalies, which in turn may be the cause of anomalies in regolith particle sizes resulting from differing mineral friabilities. Polarization anomalies may also be due in part to differences in the TiO_2 and FeO content of lunar glasses [1].

References

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