L latitudinal variation in the color of the lunar maria and implications for space weathering

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1 Introduction and Summary

Space weathering alters the optical properties of exposed surfaces over time, complicating the interpretation of spectroscopic observations of alien bodies like asteroids, exomoons, and the Moon. Solar wind and micrometeoroids are thought to be the dominant agents of space weathering, causing exposed surfaces to darken and redden with time, and weakening spectral absorption features, but the relative contributions of these agents are not well understood.

Using both Clementine and UVVIS reflectance data, we report a previously unrecognized systematic latitudinal variation in the near-infrared spectral properties of the lunar maria. We argue that this color trend, which matches the color signature observed at lunar swirls, is the result of reduced solar wind flux at high latitudes. This result could have implications for the interpretation of spectral observations from different latitudes and could help to distinguish between the effects of solar wind and micrometeoroid bombardment [2,6].

2 Color Signature of Lunar Swirls

Lunar swirls are optical anomalies that accompany many of the Moon's crustal magnetic anomalies. Swirls are bright, superficially resembling immature surfaces such as young impact craters [8-9]. However, swirls exhibit spectral characteristics that are distinct from those associated with impacts [10-11] (Fig. 1). We quantify the two distinct color trends with parameters α and β, defined below (Fig. 2).

3 Latitudinal Color Variation

The color of the surface is mainly controlled by mineralogy—this is most obvious in the contrast between the bright, anorthositic highlands and the dark, basaltic maria. The global latitudinal color variation we report here is therefore not apparent until compositional differences are taken into account. Once a specific composition is substituted into the model, the color becomes clear, the latitudinal regions are darker and higher in the 950 nm/750 nm band ratio than high latitude regions of the same composition [5].

Similar trends occur over a range of distinct compositions and are especially consistent across the lunar maria (Fig. 3b). In addition to controlling for composition, we verified that the latitudinal color trends we observe are not artifacts of phase angle changes in the Clementine data (Fig. 4), nor can they be explained by contamination from highland material [1].

The latitudinal color variation is unlike the color trends associated with impacts but statistically equivalent to those associated with swirls (Fig. 3), suggesting a common mechanism. Solar wind flux is a good candidate because it is reduced both with increasing latitude (due to increasing incidence angle) and at swirls, where strong magnetic fields may be partially shielding the surface from the impinging solar wind (11-13) (Fig. 5). In contrast, micrometeoroid flux is reduced at high latitudes, but not at magnetic anomalies [14].

4 What is this telling us?

Solar wind saturation takes place so rapidly that, even with a 90% reduction in flux, the surface becomes saturated [15]. This suggests that (1) it is not controlled by total accumulation of solar wind ions, but instead by some flux-dependent equilibrium—and, between regolith gardening and solar wind-induced alteration of exposed grain surfaces.

Over larger scales of a few kilometers, the overall color contrast of the surface exhibits considerable variability in ε, whereas variability in β is low (Fig. 1b). This suggests that the equilibrium δ is reached so rapidly that we do not observe variability in its value over short distances but perhaps at very young craters, whereas the evolution of ε occurs gradually, as impact crater transitions into mature soils over longer timescales (Fig. 6).

Based on these observations, and on comparisons with M results [22], we propose that solar wind weathering takes place relatively rapidly and involves significant darkening and reddening, due to the accumulation of nanophase iron [4,23]. The gradual transition from bright craters to darker basaltic soils (thermal and solar wind) is the weakening of spectral absorption features along with some additional darkening (Fig. 6). Since it involves no further change in the solar wind-flux dependent δ, the latter progression (increasing in fluctuation) and the soil's disintegration into increasingly finer grains [25].

References