EPSC Abstracts
Vol. 13, EPSC-DPS2019-1914-3, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

An Ultraviolet Examination of Global Lunar Regolith Maturation

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Abstract

NASA's Lunar Reconnaissance Orbiter carries with it two ultraviolet payloads, the Lyman Alpha Mapping Project and the Lunar Reconnaissance Orbiter Camera-Wide Angle Camera. The data collected from these instruments are providing, among other things, insight into the physical properties of the lunar regolith as it is modified by space weathering over lunar geologic time. Here we examine lunar space weathering from an ultraviolet perspective and show how it varies across the surface of the Moon.

1. Introduction

Due to lunar space weathering (solar wind, ion-, and micrometeorite bombardment), the surface of the Moon matures. Over time space weathering produces submicroscopic iron (SMFe) which becomes encased in glassy impact melt rhines and coats regolith grains. This process manifests in different ways depending upon the region of the electromagnetic spectrum you examine. Recent analyses of the lunar surface with Clementine near-infrared (NIR) data show evidence that regolith maturation varies in intensity as a function of latitude (Hemingway et al., 2015). As a result, the lunar regolith may mature at different rates depending upon latitude. However, it is unclear if this correlation holds true or is contradicted in other portions of the spectrum, like the ultraviolet (UV).

The Lunar Reconnaissance Orbiter (LRO) Lyman Alpha Mapping Project (LAMP) and the Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) offer the ability to assess and characterize this possibility, recording global observations of the lunar regolith between the far- (FUV) to near-ultraviolet (NUV; 80 to 690 nm). Here, we leverage these wavelength perspectives to examine the lunar surface in the UV and assess if the ultraviolet (UV) data agrees with NIR observations.

2. Data Sets and Analysis Approach

Global data products for both LAMP and LROC WAC color data are examined in this study. LAMP is a FUV (57-196 nm) push-broom photon-counting imaging spectrograph [2]. LAMP has also routinely collected both day and nighttime data of both polar and equatorial regions of the Moon. Here, global nighttime Lyman-α (Ly-α; 121.6 nm) normal albedo data are examined as it records the influence of space weathering on the lunar surface (**Figure 1**). LAMP is sensitive to the upper ~100-200 nm of a given medium, but in the highly porous lunar regolith may provide insights into slightly greater depths due to multiple scattering. The Ly-α data product is unique in comparison to all other LRO data sets in that it collects reflected light from surfaces that are diffusely lit by solar Ly-α scattered off of interplanetary H atoms from all directions. The Ly-α skyglow intensity varies with respect to the motion of the solar system. LAMP also collects bidirectional point sources from UV-bright stars that tend to be more plentiful in the southern hemisphere owing to the Galactic plane [2, 3] and dominantly influence the longer FUV wavelengths. While these data are calibrated in a fashion a bit more similar to bidirectional illumination, approximately 1,000 stars are factored into the calculation.

In contrast to the nighttime data, LAMP daytime illumination conditions are similar to the LROC WAC with multiple viewing geometries [4, 5], offering bidirectional illumination perspectives enabled by our Sun. Both of these data sets are factored into this analysis. Here we primarily utilize the WAC ultraviolet bands at 320, 360, and 415 nm.

3. Results

One of the immediately apparent differences between FUV and NUV/Vis observations of the Moon is that the relative brightness between mare and highlands reverses moving to shorter wavelengths in the FUV. This is due to the optical properties of minerals changing moving from the NUV to the FUV. Many of the other interesting new perspectives in the FUV include crater rays, pyroclastic deposits, photometric anomalies, and swirls, all of which have a low Ly-α albedo relative to their surroundings, contrasting with high NUV and VIS albedos of these deposits. This is because regolith particles are not transparent in the FUV and particle reflections dominate [6, 7]. Particularly near 120 nm where transition metals no longer dominate the reflectance properties. This provides a unique view of maturity nearly devoid of compositional effects that make quantifying maturation difficult in the VIS and NIR [8, 9]. In stark contrast, young craters show high Ly-α cavities and low Ly-α discontinuous ejecta.

Initial work examining LAMP daytime data products for lunar hydration and space weathering noted initial evidence that both vary with latitude [10]. Here, our examination of nighttime Ly-a albedo variation across the Moon provides some additional evidence of this variation. However, potential illumination sources (e.g., Earthshine) may be influencing these results and need to be further evaluated. Analyses of WAC NUV band observations is also underway.

4. Summary and Ongoing Work

As this analysis progresses, we are also performing laboratory work examining Fe-bearing silica gel analogs for space weathering. Specifically we are gathering spectra in the ultraviolet to examine variations in submicroscopic iron content and its influence on ultraviolet spectra. The aim is to have a better understanding space weathering systematics in the ultraviolet to better inform our results of LAMP and LROC WAC ultraviolet data sets.

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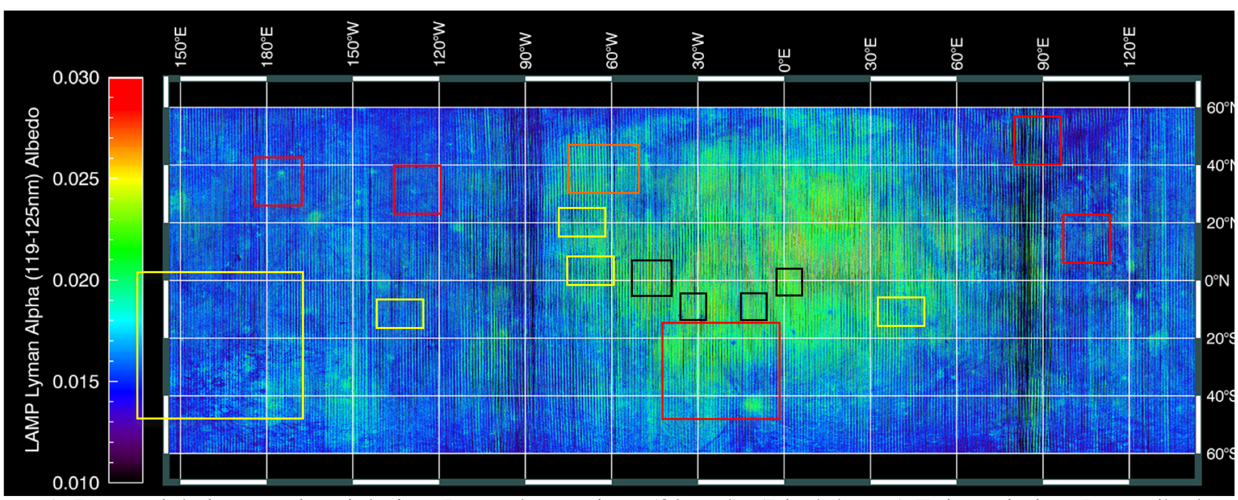

Figure 1: Lunar global non-polar nighttime Ly-α observations (30 ppd). (Black boxes) Enigmatic low Ly-α albedo features. (Yellow boxes) Observed lunar swirls. (Orange boxes) Discernable pyroclastic deposits. (Red boxes) Craters with high Ly-α albedo proximal ejecta and contrastingly low Ly-α albedo rays [1].