LRO-Lyman Alpha Mapping Project (LAMP) Maps of Lunar Far-UV Albedo.
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Abstract. Maps of polar far ultraviolet (FUV) albedo are being produced using the Lunar Reconnaissance Orbiter (LRO) Lyman Alpha Mapping Project (LAMP)'s innovative nightside observing technique. Similar dayside FUV maps are also being produced using more traditional photometry techniques. The quality of these maps increases with every UV photon collected from the surface. Importantly, the nightside technique allows us to peer into the permanently shaded regions (PSRs) near the poles, and determine their UV albedos. LAMP measurements indicate ~1-2% surface water frost abundances in a few PSRs based on spectral color comparisons, and we find that many PSRs may have porosities of ~0.7 based on relatively low albedos at Lyman-α [1].

Observations. The LRO-LAMP is a UV spectrograph (Figure 1) that addresses how water is formed on the Moon, transported through the lunar atmosphere, and deposited in permanently shaded regions (PSRs)[2,3]. LAMP far-ultraviolet (FUV) albedo maps are being produced to investigate the intriguing albedo differences that occur within PSRs.

LRO's polar orbit provides repeated observations of PSRs, enabling accumulation of UV signal with the photon-counting LAMP instrument over these locations. Lyman-α albedo maps obtained from Sept. 2009 to Feb. 2011 are shown in Figure 2 for the north and south poles.

Figure 1: LAMP instrument prior to LRO integration.

The LAMP instrument covers the 57-196 nm passband. Its 6°×0.3° slit, nominally pointed nadir, scans the surface in push-broom style, similar to other LRO instruments. LAMP routinely observes the Lunar nightside. The lunar dayside is also observed by switching to a pinhole mode following terminator crossings each orbit.

LAMP data products include nightside brightness maps of polar regions over specific wavelength ranges, similarly constructed albedo maps (i.e., brightness maps normalized by the varying illumination), and on-band to off-band ratio maps (i.e., on and off the expected FUV absorption band for water frost). See refs. [1&4] for details on how the maps are created. LAMP nightside maps are produced monthly, and these are combined for best-quality compilations as shown in Figure 2. A few instrument-related artifacts are removed as part of our data calibration and mapping pipelines, with time-dependent microchannel plate detector gain sag and low pulse amplitude signals the primary (flat-field) issues being remedied.

Current Results. The Lyman-α albedo maps shown in Figure 2 reveal lower albedo (darker blue here) regions within craters. The lower albedo regions are roughly correlated with the coldest PSR regions. This albedo darkening at Lyman-α is consistent with higher porosity ~0.7 (enhanced relative to a nominal ~0.4), based on modeling using functions described in Hapke 2008 [3]. Maps of reflected starlight at wavelengths longer than Lyman-α (121.6 nm) are also produced. They are of lower signal quality owing to the dimmer source of light at these wavelengths and the need to subtract detector background. However, regions within these longer wavelength maps are averaged over known PSR areas [6] to provide reasonable comparisons with models of lunar surface reflectance [7]. We find the spectral reddening of a few PSRs are well fit with 1-2% water ice abundances. This water ice necessarily resides directly on the surface. Revised estimates of the long-term stability of water frost to UV-photolysis reinforce this conclusion [1].

Polar maps of dayside FUV albedos will be presented. Comparisons between the nightside and dayside photometry techniques used for producing these respective maps help validate the use of Lyman-α and starlight as illumination sources. Seperate analysis of dayside spectra for selected regions complement the dayside maps, and are being used to investigate space weathering processes and hydrated surface regions [8]. A new lab study of the FUV reflectance properties of lunar simulants and water ice samples is underway to further characterize the UV photometry and test our photometry model-based conclusions. Initial maps of the equatorial region are also currently being computed. All of these LAMP map products are being compared with other LRO datasets to search for large scale trends and for interpretation of a few key sites [4].

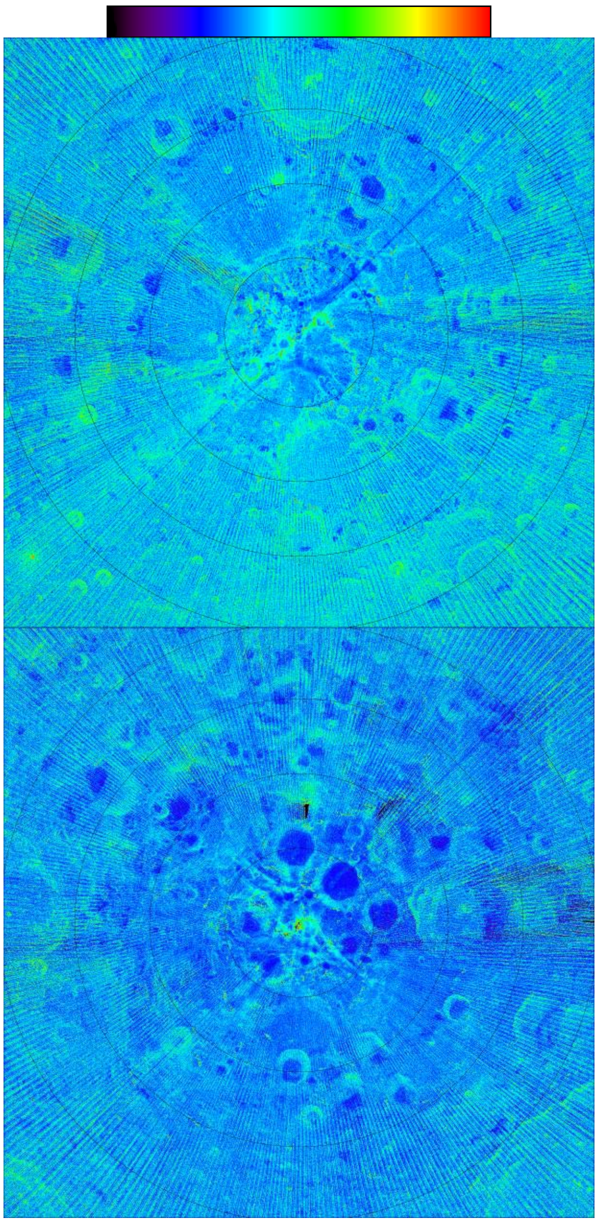

Figure 2: LAMP Lyman-α albedo maps, North (top) and South (bottom). Black circles indicate 2.5° latitude increments from the poles. Color-bar runs from 0 to 10% albedo.

Extended Mission. We plan to capitalize and expand upon these recent discoveries in the proposed LRO mission extension through Sept. 2014. More EUV/FUV surface reflectance data (60-190 nm) at a variety of incident and emission angles is needed to improve signal, spectral, and photometric quality and further develop our innovative nightside UV reflectance technique for determining surface porosity. We plan to target UV-interesting regions and focus on key PSRs identified by LRO/LEND and MiniRF as potentially water-rich, which will provide improved sensitivity for these crucial data. Global searches of water signatures *outside of PSRs* with LAMP will confirm and/or elucidate the findings of surface water/hydroxyl and its variability with infrared Chandryaan-M3/Cassini-VIMS/EPOXI data. EUV (60-110 nm) albedos, photometry, and potential space-weathering signatures of solar system bodies are largely unknown – LAMP Moon measurements with better EUV calibration in the extended mission will be the baseline for comparative studies, and will aide calibration for all EUV astronomy.

References

[1] Gladstone, G. R. et al., Far-Ultraviolet Reflectance Properites of the Moon's Permanently Shadowed Regions, *J. Geophys. Res., 117,* E00H04, 2012.

[2] Gladstone, G. R., and 15 coauthors, LAMP: The Lyman Alpha Mapping Project on NASA's Lunar Reconnaissance Orbiter Mission, *Space Sci. Rev., 150,* 161-181, 2010.

[3] Gladstone, G. R. et al., LRO-LAMP Observations of the LCROSS Impact Plume, *Science, 330,* 472-476, 2010.

[4] Retherford, K. D., et al., LRO/LAMP Far-UV Albedo Maps of the Lunar Poles, in prep, 2012.

[5] Hapke, B. Bidirectional reflectance spectroscopy 6. Effects of porosity, *Icarus, 195,* 918–926, 2008.

[6] Mazarico et al. 2011, Illumination conditions of the lunar polar regions using LOLA topography, *Icarus, 211,* 1066–1081.

[7] Mishchenko, M. I., et al., Bidirectional reflectance of flat, optically thick particulate layers: An efficient radiative transfer solution and applications to snow and soil surfaces, *J. Quant. Spectrosc. Rad. Transf., 63,* 409–432, 1999.

[8] Hendrix, A. R., et al., Lunar Albedo in the Far-UV: Indicator of Hydrated Materials and Space Weathering, *submitted to JGR,* 2011.