FAR-ULTRAVIOLET PHOTOMETRIC RESPONSE OF MARE AND HIGHLAND APOLLO SOILS: LABORATORY INVESTIGATIONS IN SUPPORT OF LRO-LAMP OBSERVATIONS. U. Raut[1,2], P.L. Karnes[1], K.D. Retherford[1,2], M. Poston[1], M.W. Davis[1], Y. Liu[3], T.K. Greathouse[1], G.R. Gladstone[1,2], A.R. Hendrix[4], E.L. Patrick[1], P. Mokashi[1]. [1]Southwest Research Institute, Space Science and Engineering Division, San Antonio, Texas 78238, [2]Department of Physics and Astronomy, University of Texas at San Antonio, San Antonio, TX 78249, [3]Lunar and Planetary Institute/USRA, Houston, TX 77058, [4]Planetary Science Institute, Tucson, AZ, 85719 (uraut@swri.edu).

Introduction: The scarcity of laboratory far-ultraviolet (FUV) reflectance data of Apollo soils and soil-ice aggregates has been an impediment in constraining the spatial abundance and distribution of water/OH-species from Lunar Reconnaissance Orbiter's Lyman-Alpha Mapping Project (LRO-LAMP) observations. An accurate estimate of lunar water abundance via remote-sensing is critical to *in-situ* resource utilization (ISRU) and to sustain future lunar robotic and human explorations.

The general approach to determining the water abundance in the lunar regolith has been to generate synthetic spectra using radiative transfer models to match the LAMP spectra. Such a method requires optical constants of endmember species - lunar regolith and water ice - as model inputs to reproduce the observed spectra. Unfortunately, these fundamental properties of lunar soils and ice-soil aggregates remain largely uncharacterized in the FUV, which limits the accuracy of the lunar hydration estimate. For instance, the dayside abundance of hydrated species obtained from observing variations in the 165-nm absorption feature is constrained at 0-1% [1]. The water abundance in the permanently shadowed regions toward the lunar poles could be 1-2% [2] if intimately mixed with the regolith or as high as 10 % if present as frost [3].

We have started deriving these fundamental properties of lunar soils from the photometric analyses of the FUV phase curves of various Apollo soils measured in the Southwest Ultraviolet Reflectance Chamber (SwURC) [see Ref. 4 for additional details]. Here, we discuss key results from our photometric investigations on mare soil 10084 [4], and present preliminary results on additional mare and highland soil samples.

Results and Discussion: The FUV photometric response of canonical Apollo soil 10084 is well-characterized in our recent paper [4]. Fits of the Hapke model to the laboratory phase curves yield single scattering albedo w and the Henyey-Greenstein scattering parameters (b, c), which that determine the shape of the scattering lobe (Figure 1). We find soil 10084 to be a strong absorber in the FUV. The single scattering albedo w is < 0.1, implying a reflection probability for an FUV photon to be < 10%, following an encounter with an average 10084 grain. We note the reasonable agreement between SwURC measurements (black data) and the LAMP measured w (red data) for a sample mare region [5] (top panel of Figure 1), despite expected differences in soil porosity. The electrostatic tribocharging in low gravity lunar environment can result in highly-porous fairy castle-like structures [6] that are difficult to replicate in terrestrial laboratories.

Additionally, we found 10084 soil to be an *anisotropic backscatterer*. The positive values of the anisotropy parameter c at different wavelengths (see bottom panel of Figure 1) implies a stronger backward scattering (BS) lobe. The parameter $c = 0$ for isotropic scatterers and negative for forward scattering (FS) particles. The FUV b-c values agree well with the empirical *hockey stick* relationship derived from metadata analysis of ~ 500 samples in the visible-near infrared spectral region [7].

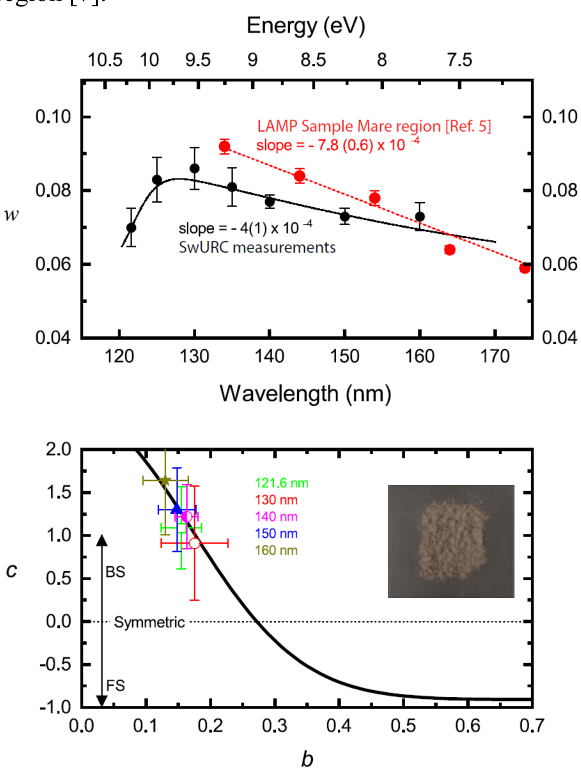

Figure 1: Top panel shows the λ dependence of the 10084 soil (bottom panel inset – 10084 on the sample tray) single scattering albedo w (black) which is in good agreement with LAMP w for a sample mare region [5]. In the bottom panel, we plot the anisotropy parameter c against the lobe shape parameter b. The $w < 0.1$ values and positive values for c implies 10084 soil is a dark, anisotropic backscatter in the far-ultraviolet.

We extend our measurements and Hapke analysis to a new batch of Apollo soils from different geological regions – mare (15041, 15601) and highlands (61141, 71061) soils – presenting similar grain size distribution but varied maturity index (I_s/FeO).

We show in Figure 2 the preliminary phase curves for mare soil 15041 and highland soil 71061 measured at Ly-a, 130 and 160 nm. The function f_{BRDF} (sr^{-1}) is the bidirectional reflectance distribution function (BRDF), which essentially is the bidirectional reflectance with correction applied to account for detector solid angle and projection geometry. Note the curves at 130 and 160 nm are vertically shifted for clarity.

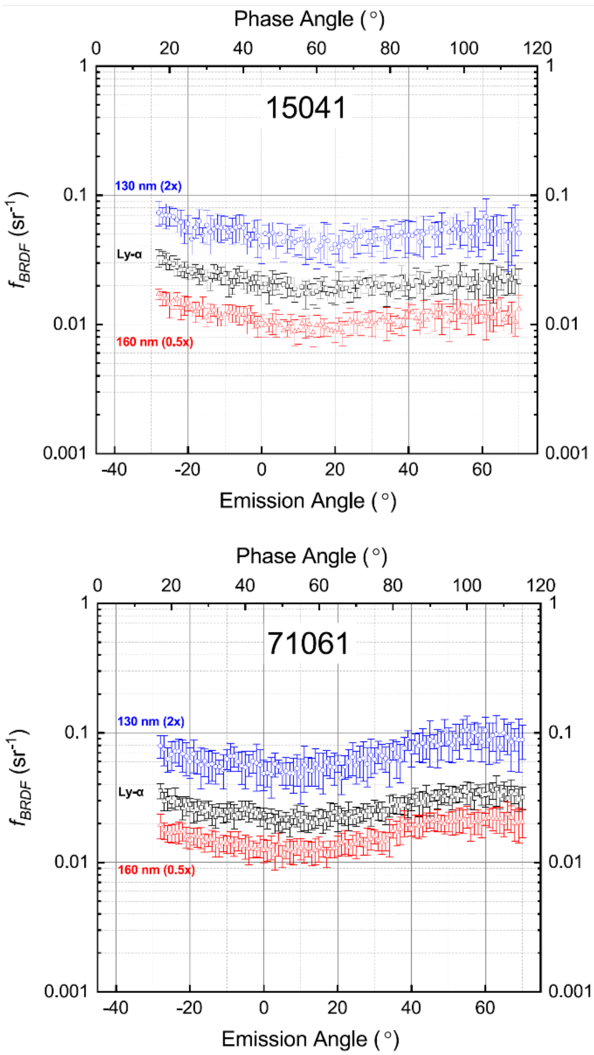

Figure 2: Preliminary phase curves for mare soil 15041 (top) and highland soil 71061(bottom) at three different wavelengths measured in the SwURC. Note the curves for 130 and 160 nm are vertically shifted for clarity. The forward scattering peak is more pronounced for the highland soil than the mare soil 15041 and also10084 [4]. Hapke analysis will reveal the degree of anisotropy in the scatter lobe for these Apollo soil samples.

As in the case of 10084 [4], we find the Apollo soils are generally dark in the far-ultraviolet. A prominent difference is the pronounced forward scattering peak towards ~ 105° phase angle in the highland sample. This forward scattering peak is suppressed in 15041, similar to 10084 [4]. We intend to perform repeat measurements together with rigorous Hapke analysis to quantify *w* and reveal the shape and anisotropy of the scattering lobe for the Apollo soil samples and correlate them to mineralogical or maturity differences.

Ultimately, we intend to generate a far-ultraviolet spectral library consisting of Apollo soil optical constants (*n*, *k vs.* λ) reduced from the single scattering albedo spectra. We will consider ESPAT and other evolving versions of Hapke-Melamed scattering formalisms that take into account the grain size distributions [8]. To complement the available grain size distributions [9], we will employ techniques such as confocal scanning laser microscopy to estimate the size distribution of each sample studied. Figure 3 shows a 3D image of JSC-1A simulant grains and height distribution (inset). The lunar soil optical constants from our efforts can be used in radiative transfer models to improve constraints on hydration abundance on the lunar surface at FUV sensing depths.

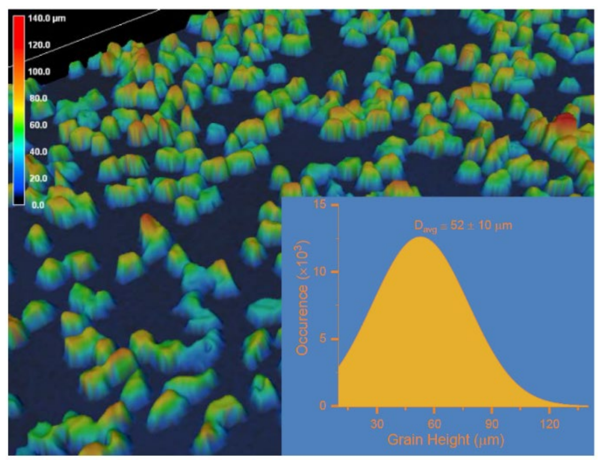

Figure 3- A 3D image of JSC-1A grains and the height distribution (inset) showing an average grain size ~ 52 ± 10 um using an in-house confocal scanning laser microscope.

References:

[1] Hendrix et al., (2012) *JGR, 117,* E12001. [2] Gladstone et al., (2012) *JGR, 117,* E00H04. [3] Hayne et al., (2015), *Icarus*, 255 (supplement C). [4] Raut et al., (2018) *JGR, 123, 1221*. [5] Liu et al., (2018) *JGR, 123,* 2550. [6] Hapke, B. and van Hoen, H. (1963), *JGR, 68, 4545*. [7] Hapke, B. (2012), *Icarus*, 221, 1079. [8] Hapke (2012), *Theory of Reflectance and Emittance Spectroscopy*, Cambridge University Press. [9] Meyer, C. (2012), *Lunar Sample Compendium*.