EXPLORING REFLECTANCE STANDARDS IN THE FAR ULTRAVIOLET: PRECURSOR CALIBRATION STUDIES FOR LUNAR SIMULANTS AND APOLLO SOILS IN THE SOUTHWEST ULTRAVIOLET REFLECTANCE CHAMBER (SwURC). U. Raut, P.L. Karnes, K.D. Retherford, M.W. Davis, Y. Liu, E.L. Patrick, P. Mokashi. Southwest Research Institute, Space Science and Engineering Division, San Antonio, Texas 78238.
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Introduction: Laboratory measurements of far ultraviolet (FUV) spectral properties of many common minerals and ices that serve as regolith analogs of many Solar System bodies are few to non-existent. This scarcity of reliable and systematic laboratory spectroscopic data has hindered the interpretation of prevalent FUV observational data obtained from earth-based telescopes or interplanetary missions. For instance, observations of the several permanently shadowed regions (PSRs) of the moon by LRO/LAMP showed relative reddening in their spectra that is best explained by the presence of 1-2% water frost mixed with the lunar regolith [1]. Such a result, derived from photometric modeling of the observed FUV albedo, would benefit from laboratory verification, which led to the development of the Southwest Ultraviolet Reflectance Chamber (SwURC). One major science objective of the SwURC is to perform comprehensive, laboratory-based characterization of bidirectional reflectance distribution function (BRDF) of water ice, lunar simulants, Apollo soils and ice-soil aggregates at FUV wavelengths (115-180 nm) in support of LAMP data. To the best of our knowledge, the only existing FUV measurement of lunar soil was performed decades ago [2]. We intend to improve over this existing dataset, specifically with respect to the vacuum conditions, counting statistics and sampling intervals, and geometry (i.e. BRDF measurements at multiple emission/phase angles), in addition to obtaining ground truth BRDF data for icy lunar soils, critical to assessing the water ice content in the cold craters in the poles of our moon.

Previous studies [2-4] in the ultraviolet (200-400 nm) investigated several materials such as Spectralon™, $BaSO_4$, MgF_2, silica and others as potential diffuse reflectance standards since their optical properties were not well-characterized below 250 nm. While absolute BRDF measurements of weakly reflecting simulants and Apollo soils is possible in the SwURC, bypassing the need for standards, we have nonetheless, following precedence, investigated the far ultraviolet spectral properties of a few materials like $BaSO_4$ and fumed silica and in the far ultraviolet, as precursor experiments to JSC-1A simulants and Apollo soils and ice-soil mixtures. Prior to diffuse reflectance experiments, we calibrated the SwURC against known reflectivity of MgF_2 and SiC-coated Al mirrors in specular geometry.

Experimental Setup: The measurements reported here were conducted in the SwURC, a high-vacuum (base pressure ~10^{-8} Torr) ultraviolet reflectance chamber. High-purity $BaSO_4$ powder (Sigma-Aldrich, 99.998% purity, based on Trace Metal Analysis) filled

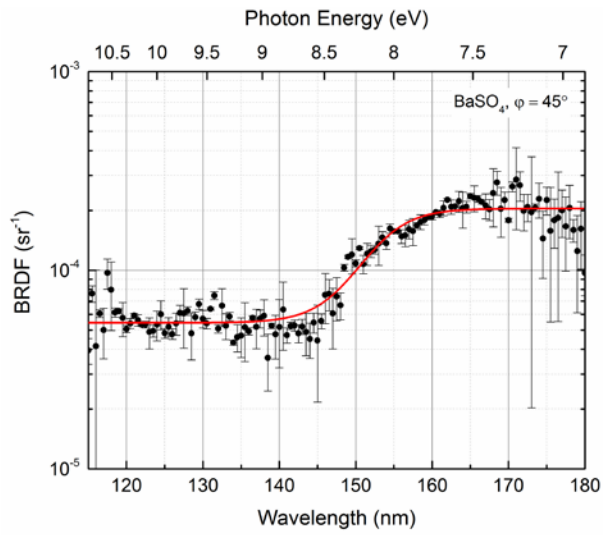

Figure 1: Bidirectional reflectance spectra of $BaSO_4$ powder at 45° phase angle shows an absorption onset at 160 nm or 7.7 eV. The red curve is a guide to the eye.

a cm-deep circular trough on an anodized aluminum sample tray. The $BaSO_4$ powder was subject to a ~ 250 °C, 24 hours vacuum bake-out prior tray assembly. The tray is mounted horizontally on an LN_2-cooled Cu holder, coupled to a linear actuator that moves the tray in or away from the optical beam path.

A 30 W deuterium lamp feeds a grating monochromator which provides monochromatic light that is collimated with a pair of reflective cylindrical mirrors, prior to illuminating our sample at a fixed 45° incidence. A channeltron detector (Photonis 5901 Spiraltron, CsI-coated) is rotated in the principal plane over emission angles of -70° to + 90° with respect to the surface normal to collect diffuse light reflected by the $BaSO_4$ powder. The angular steps can be as small as 0.01°. The reflected signal at emission angles ranging from -60° to -30° is compromised by glint artifacts as the detector holder approaches the source, which we disregard. Further, we also measure the incident beam

intensity by retracting the sample tray and directly intercepting the beam with the detector positioned at 135°. The intensity of the reflected light at a particular emission or phase angle is divided by the incident beam intensity to yield the BRDF. The spectra are collected at 0.5 nm resolution (compared to 4 nm sampling interval of the previous study [2]) over 115-180 nm.

Results: Figure 1 shows the absolute bidirectional reflectance spectra of $BaSO_4$ collected at phase angle φ of 45° (phase angle is the angle between incidence and emission). The low reflectance, $< 5 \times 10^{-3}$ sr^{-1}, suggests $BaSO_4$ is a stronger absorber in the FUV. The spectrum is featureless, except for an onset of absorption < 160 nm. We intend to identify the electronic transition associated with this absorption feature. The signal-to-noise ratio worsens above 170 nm due to a loss in detector sensitivity above this wavelength.

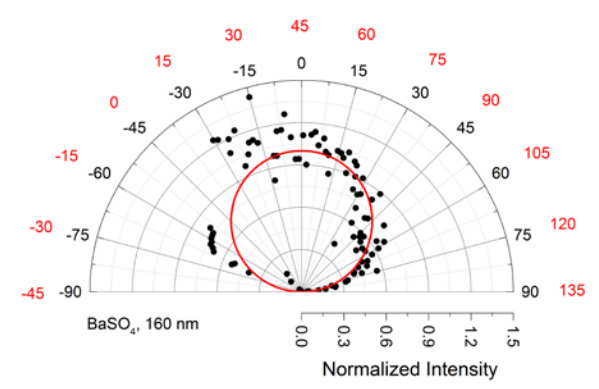

Figure 2: Angular distribution of the reflected flux at λ = 160 nm from $BaSO_4$. The angular dependence closely follows a cosine distribution (red curve), indicating $BaSO_4$ behaves as a Lambertian reflector. The departure from the cosine profile at φ ~ ±15° is due to glint artifacts in our setup.

We show the polar representation of the angular dependence of the reflected flux at a specific wavelength of 160 nm, (at the absorption edge) in Figure 2. The black numbers in the angular axis are the emission angles with respect to the surface normal, while the red numbers are the phase angles, which is the angle between emission directions with respect to the fixed incidence. The reflected light intensity closely follows a cosine distribution (indicated by the red curve) suggesting BaSO4 powder behaves as a Lambertian reflector even at FUV wavelengths.

Future plans: Pending minor modifications to the SwURC roughing and foreline pump lines to minimize drag lift of fine dust during evacuation, we are ready to begin bidirectional reflectance studies of JSC-1AC/F lunar simulants and Apollo soils (# 10084, in house). We are also in the process of incorporating a calibrated gas-dosing system with a micro-capillary array doser to allow controlled deposition of water ice onto lunar simulants and soil to create ice-soil aggregates of high relevance to LAMP data of the PSR regions of our moon.

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Reference: [1] Gladstone, G.R., et al., Far-ultraviolet reflectance properties of the Moon's permanently shadowed regions. Journal of Geophysical Research: Planets, 2012. **117** (E12). [2] Wagner, J.K., B.W. Hapke, and E.N. Wells, Atlas of reflectance spectra of terrestrial, lunar, and meteoritic powders and frosts from 92 to 1800 nm. Icarus, 1987. **69**(1): p. 14-28. [3] Hapke, B., et al., Far-UV, visible, and near-IR reflectance spectra of frosts of H_2O, CO_2, NH_3 and SO_2. Icarus, 1981. **47**(3): p. 361-367. [4] Cloutis, E.A., et al., Ultraviolet spectral reflectance properties of common planetary minerals. Icarus, 2008. **197**(1): p. 321-347.