SPECTROGONIOMETRIC MEASUREMENTS AND MODELS OF LUNAR ANALOG SOILS. J.R. Johnson[1], M.K. Shepard[2], W. Grundy[3], [1]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, jrjohnson@usgs.gov, [2]Bloomsburg University, Bloomsburg, PA, [3]Lowell Observatory, Flagstaff, AZ

Introduction: Laboratory visible/near-infrared multispectral goniometer observations of seven lunar analog soils have been acquired using the Bloomsburg University Goniometer (BUG) [1-4]. Sufficient data were acquired at a variety of incidence, emission, and phase angles to provide constraints on Hapke radiative transfer models. These data and models will be useful for analyses of lunar surface observations acquired by orbital cameras and spectrometers flown on past and upcoming lunar missions [5-9].

Observations. Multispectral measurements of the samples were acquired at incidence angles of 0-60°, emission angles of 0-80°, and phase angles of 3-140° using the BUG facility, comprising 680 measurements per wavelength. Acquisition and calibration procedures are outlined in [1]. Seven samples with properties comparable to lunar (and to some extent asteroidal and mercurian) soils were observed in four narrowband filters (410, 550, 751, and 950 nm): the Minnesota Lunar Simulant MLS-1 sieved to < 1 mm and 500-840 μm size fractions, the historic JSC-1 lunar simulant sieved to <1 mm, and a new JSC-1 lunar simulant sieved to <1 mm (JSC-1A) and to an average grain size of 24 μm (JSC-1AF) from Orbitec Technologies Corp.; the FJS-1 simulant from Shimizu Corp., Japan (sieved to a median grain size of 70 μm); and a plasma-processed, glass-rich simulant created from the MLS-1 simulant. MLS-1 is a high-titanium crystalline basalt with a median grain size of ~100 μm and a chemical composition that approximates Apollo 11 soil [11-12], although the mineralogy and engineering properties are not ideal analogs to lunar soil. JSC-1 is a glass-rich (~50%) basaltic ash with a median grain size of ~ 70 μm, a composition more similar to Apollo 14 and 15 soils, and geotechnical properties more appropriate to lunar soil [13-14]. FJS-1 is Mt. Fuji basalt prepared to a median grain size of 70 μm, with a composition similar to Apollo 14 samples [15]. The glass-rich simulant is a synthetic, Ti-rich, mare-like material.

Analyses. Hapke models were run using Henyey-Greenstein (HG) phase functions to determine the asymmetry parameter (ξ) for a 1-term HG, and the *b* (asymmetry parameter) and *c* (backscattering fraction) parameters for a 2-term HG [16]. All models included the single scattering albedo (*w*) and macroscopic roughness parameter ($\bar{\theta}$), as well as the opposition effect magnitude (*B0*) and height (*h*). A reduced chi-square (χ_ν^2) estimate of goodness of fit was also derived. The error on each fitted parameter was estimated by testing how χ_ν^2 changed when a particular parameter was purposely varied from its original best-fit value [16].

Results. Figure 1 shows the bidirectional reflectance distribution function (BRDF) phase curves for all samples at 410 nm and 750 nm. The pronounced increase in BRDF values at high phase angles suggests an overall forward scattering sample character at both wavelengths. The JSC-1 and JSC-1A samples exhibit very similar phase curves. Two-term HG models tended to give the best model fits (as determined by the χ_ν^2 value). Values of *w* are shown as a function of wavelength for each sample in Figure 2. The fine-grained JSC-1AF sample exhibits higher *w* values than its coarser-grained JSC-1A split, as expected. The high *w* values for the < 1mm fraction of MLS-1 are consistent with the significant fine-grained fraction in this split compared to the 500-840 μm split . The 1-term HG asymmetry parameters were positive (forward-scattering) for all but the JSC-1 sample. This is consistent with the 2-term HG phase functions, most of which fall in the narrow, forward-scattering lobe in Figure 3, similar to the experimental results from [17] for spheres of various surface textures with a low density of internal scatterers. The FJS-1, JSC-1, and JSC-1A were more broadly backscattering (low *b*, high *c* values) than the other samples. The *h* values from 1-term HG models were elevated for the JSC-1AF and FJS-1 samples (~0.09-0.10), owing to the lower porosity of these fine-grained samples. However, the similar *h* values for the MLS-1 (500-840 μm) and glass samples likely result from their relatively uniform grain size. *B0* values were not well constrained by any of the models, but $\bar{\theta}$ values were lowest (8-18°) for the fine-grained samples (FJS-1, JSC-1AF, MLS-1 bulk), and 20-22° for coarser-grained samples.

Analysis of the JSC-1 sample by [10] modeled *w*, *h* and $\bar{\theta}$ values smaller than those presented here. Also, the 2-term HG *b,c* values modeled by [10] are indicative of a broader, more backscattering sample than shown here. These differences may result because [10] prepared their sample by "sprinkling 1-2 mm of loose material over a packed surface." Also, *b,c* values shown here are more forward scattering and narrower than the values computed by [19] from lunar and mercurian data, likely owing to differences between the laboratory sample surfaces and surfaces observed telescopically or from spaceborne systems.

References: [1] Shepard, M.K., in *Solar System Remote Sensing Symposium*, abstract #4004, LPI, 2002; [2] Johnson, J.R., et al., *JGR*, 111, E12S07, doi:10.1029/2005JE002658, 2006; [3] Johnson, J.R., W.M. Grundy, and M.K. Shepard, *Icarus*, 171, 546-556, 2004; [4] Shepard, M.K., and P. Helfenstein, *JGR*, 112, E03001, 2007; [5] Pieters, C. et al., *LPSC XXXVIII*, #1295; [6] Kieffer, H. H. and Stone, T. C., Astron. J. 129, 2887-2901, 2005; [7] Hillier, J.K., et al.,, Icarus, 141, 205-225, 1999; [8] Domingue, D., and F. Vilas, LPSC XXXVI, #1978, 2005; [9] Kaydash, V.G., LPSC XXXVIII, #1692, 2006; [10] Gunderson, K., et al., Plan. Space Sci., 54, 1046-1056, 2006; [11] Goldich S.S., *Science*, 171, 1245, 1970; [12] Weiblen, P. W., et al., Engineering, Construction, and Operations in Space II, Amer. Soc. of Civil Eng., v. 1, p. 98, 1990; [13] McKay D.S., et al., JSC-1: a new lunar soil simulant, Engineering, Construction, and Operations in Space IV, Amer. Soc. of Civil Eng., 1994; McKay D.S. et al, LSCP, XXIV, 963-964, 1993; [14] Clark, J.L., et al., Space Resources Roundtable IV, abstract 6023, 2004; [15] Kanamori, H., et al., Proc. Sixth Inter. Conf. Expos. on Eng., Constr. and Oper. in Space, p. 462, 1998; [16] Johnson, J.R., et al., *JGR*, 111, E02S14, doi:10.1029/2005JE002494, 2006; [17] McGuire, A.F., and B.W. Hapke, *Icarus*, 113, 134-155, 1995; [18] Johnson, J.R., et al., LPSC XXXVIII, abstract 1288, 2007; [19] Warrell, J., Icarus, 167, 271-286, 2004.

Acknowledgments: We thank P. Bartlett. M. Gustafson, and R. Morris for contributing samples to this work, and to the Planetary Geology and Geophysics program for funding.

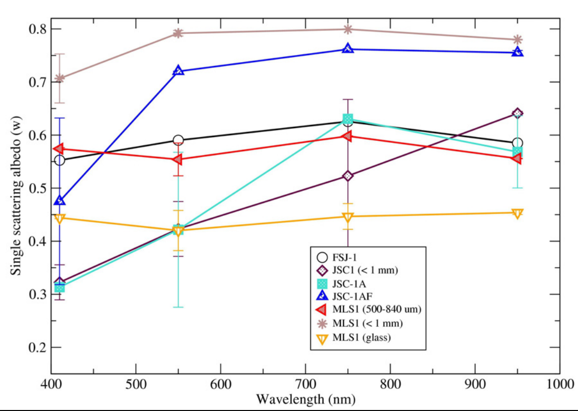

Figure 2. Single scattering albedo values from 2-term HG models for all samples. Note increase in albedo for fine-grained JSC-1AF sample and MLS-1 bulk samples.

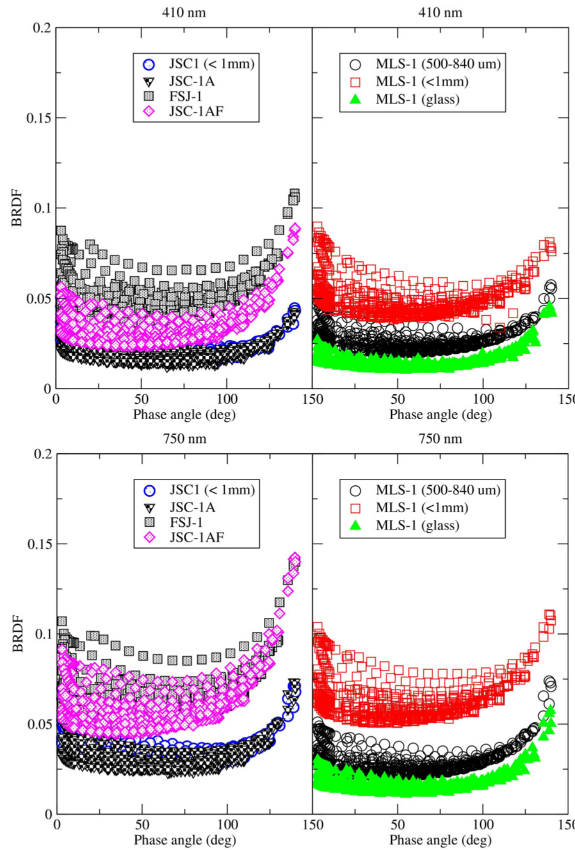

Figure 1. Bidirection reflectance distribution function (BRDF) phase curves for all samples at 410 nm (top) and 750 nm (bottom), demonstrating forward scattering (elevated BRDF values at high phase angles).

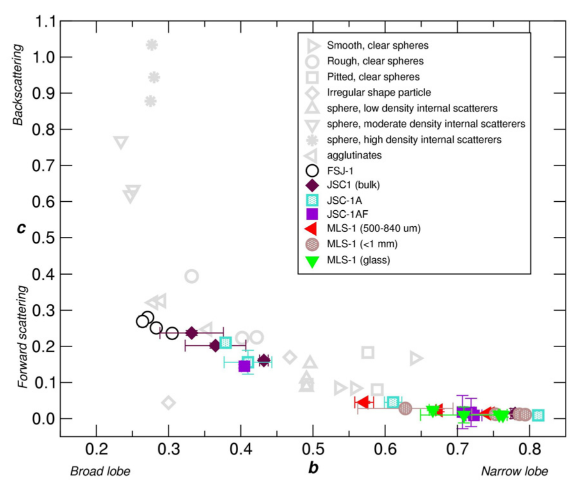

Figure 3. Two-term Henyey-Greenstein (HG) phase function parameters for all soils shown with values for synthetic particles from laboratory work by [17]. Asymmetry parameter *b* (narrow scattering lobes = large values) and backscattering parameter *c* (backscattering materials = large values) [cf. 17-18].