BIDIRECTIONAL SPECTROSCOPY OF RETURNED LUNAR SOILS: DETAILED "GROUND TRUTH" FOR PLANETARY REMOTE SENSORS C. M. Pieters[1], S. Pratt[1], H. Hoffmann[2], P. Helfenstein[3], J. Mustard[1]. [1]Brown Univ., Providence, RI 02912; [2]DLR, Oberphfaffenhofen FRG; [3]Cornell Univ.

The Galileo spacecraft is the first of perhaps many to study the Moon with a variety of sophisticated sensors during the 1990's. In addition to the exploratory science that is being performed from this initial return to the Moon (see 1), the Galileo encounter with the Earth-Moon system was also an exceptional planetary encounter because its sensors could benefit from "ground truth" information about the surface obtained during Apollo. We have samples from a few locations on the lunar nearside and know the physical and compositional properties of surface material in detail. The effects of space weathering, or soil development, in transforming rocks and breccias to mature regolith is also well documented in the returned samples and provides a confident link to remote observations.

From early comparisons of telescopic and laboratory spectra of lunar materials (2) we know that mature lunar soils best represent the regional properties of the Apollo site observed with remote sensors and that rock powders, and immature soils, are more representative of recently exposed material, such as at fresh craters (3, 4). Early spectroscopic measurements of lunar soils in the laboratory focused on analysis of variations associated with maturity and bulk composition of lunar materials (2, 3, 5). Spectral measurements were normally obtained using an integrating sphere, thus eliminating any variations that might arise from viewing geometry.

Current advanced sensors looking at the Moon from a spacecraft will need to have information about the surface for the specific geometry of the observations. As Galileo flew by the Earth-Moon system in December 1990, it obtained data for the sunlit surface of the Moon under changing lighting conditions that ranged from phase angles (a) of >100° to about 20°. For individual locations, of course, the geometry of incident radiation (i) and emergent reflected radiation (e) varied greatly. Since it has been demonstrated from telescopic measurements that the color of the Moon varies with viewing geometry (6), a more detailed analysis of the spectro-photometric properties of lunar soil samples was initiated in order to provide the necessary information for more extensive ground truth information and calibration of advanced spectroscopic sensors. Summarized in Figures 1-4 are preliminary results of bidirectional reflectance measurements of returned lunar soil samples obtained under many of the geometric conditions presented to a passing or orbiting spacecraft such as Galileo. These data will be analyzed more quantitatively to derive full photometric properties.

Four representative mature soil from mare and highland Apollo sites were selected for analysis: 62231, 14259, 12070 and 10084. Bidirectional spectra were obtained from 0.35 to 2.5 μm @ 10 nm sampling resolution for the geometric configurations indicated in Table 1. [Spectra over a wider range and with higher resolution were obtained for a few configurations.] All spectra were obtained relative to a halon standard. Corrections for non-Lambertian scattering properties of halon are available for the more extreme geometries (e.g. 7) [initial tests indicate a multiplicative factor, with little if any spectral adjustment].

Figure 1 presents the bidirectional reflectance spectra for all four soils for the e = 0 series listed in Table 1. The flattest ('bluest') spectra are those obtained at the smallest phase angle (10°). The entire suite of data for Apollo 16 soil 62231 are shown in Figure 2. These data are scaled to unity at 0.73μm to allow comparisons of the color variations with viewing geometry. In general, the higher phase angle is the redder spectrum in any given series. The relatively smoothly varying character of these variations is shown in Figure 3 for the i = 60 series of 62231 spectra compared to the spectrum for the standard geometry, i=30, e=0°. The unscaled data of Figure 3 also demonstrates the strong backscattering properties observed for all lunar soils over the range of geometry measured. In spite of the notable color variations of lunar soil spectra that occur with viewing geometry, lunar relative color (ratio of one spectrum to another obtained at the same geometry) does not vary greatly over large changes in viewing geometry. Shown in Figure 4 are unscaled reflectance spectra for the i = 60 series of Apollo 11, 12, and 14 soils relative to Apollo 16 soil, demonstrating the small, but constant relative reflectance for lunar materials over a range of viewing conditions. [This characteristic was particularly important during calibration of the Galileo SSi data (see 1).]

On the other hand, as opposition geometry is approached (i, e, and *a* approach 0), both relative and absolute color deviate significantly from the systematics described above. Spectral contrast in absorption bands is reduced and the continuum from the visible to about 1 μm becomes flatter, or distinctly 'bluer'.

References: 1. Belton M. et al. (1991) these volumes; Head J.W. et al., these volumes; Greeley R. et al., these volumes; Pieters et al, these volumes; **2.** McCord T.B. and Adams J. B. (1973) *The Moon*, 7, 453-474; **3.** Adams J.B. and McCord T.B. (1971) *Science*, 171, 567-571; **4.** Pieters C. (1986) *Revs. Geophys. Res.*, 24, 557-578; **5.** Adams J.B. and McCord T.B. (1973) *PLPSC4th*, 163-177; **6.** Lane A.P. and Irving W.M. (1973) *Astron. J*, 78, 267-277; **7.** Mustard J.F. and Pieters C.M. (1989) *J. Geophys. Res.*, 94, B10, 13619-13634.

Table 1: Geometry of Lunar Soil Spectra
Measured with RELAB

i	*e*	*a*	*i*	*e*	*a*
10	0	10	10	50	40
20	0	20*			
30	0	30	40	20	20
60	0	60°	40	10	30
			40	-20	60
20	0	20*	40	-60	100
20	40	20			
20	50	30	60	40	20
20	60	40	60	20	40
20	-40	60	60	0	60°
20	-60	80	60	-10	70
			60	-20	80

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