A NEW MEASUREMENT OF THE ABSOLUTE SPECTRAL REFLECTANCE OF THE MOON.

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Introduction: The spectral reflectance of the Moon is an important property for studies of lunar geology, quantitative physical modeling of the moon, and in-flight calibration of spacecraft sensors [1-3]. Previous studies have claimed that telescopic absolute reflectance values for the Moon are greater than laboratory reflectance measurements by a factor of two [4-7]. In order to confirm these results, we performed ground-based observations of the lunar surface using a visible/near-infrared spectroradiometer and compared the measured lunar surface radiance to solar radiance corrected for atmospheric scattering and absorption. These data were compared to previously obtained laboratory reflectance measurements from Apollo soil samples.

Equipment: We performed ground-based radiometric measurements of the Moon using an 8-inch aperture f/10 Schmidt-Cassegrain telescope (Celestron, Torrance, CA, USA) and a field spectroradiometer covering wavelengths from 0.4 to 2.5 µm (Analytical Spectral Devices, Inc., Boulder, CO, USA). These two instruments were optically linked by a custom optical interface designed so as to match the f-numbers of the telescope and the fiber optic. The sampled area on the lunar surface was approximately 1200 kilometers in diameter.

Observations: Observations of the Moon were performed on the evening of 17 November 2002 from the summit of Haleakala Volcano on the island of Maui, Hawai‘i, USA. At this altitude, 3063m, the air is essentially free of dust and aerosols. Observing conditions on the night of the observations were excellent, with the sky being exceptionally clear and dry. The timing of the observations was intended to provide data with light reflected off the Moon at a phase angle of approximately 30 degrees, matching the laboratory reflectance measurements collected from Apollo soil samples; the actual phase angle at the time of observation was 23 degrees. Beginning at 2138 hours, sixty measurements apiece were collected while the instrument was centered on Mare Serenitatis, the southern highlands, and the dark sky (about 3 lunar diameters away from the Moon). A video camera (a charge-coupled device attached to a manual zoom telescopic lens) mounted on the telescope housing and connected to a video monitor was used to target the telescope.

Atmospheric Modeling: Atmospheric transmission and incident solar radiance were calculated using the MODerate resolution TRANsmission (MODTRAN) algorithm [e.g., 8]. To accurately model the atmosphere, current atmospheric conditions (including variables such as temperature, pressure, and mixing ratio) are incorporated into the model. Two parameters in the MODTRAN model were manually adjusted: H_20 vapor and aerosol content. To model the water vapor of the atmosphere on the night of the observations, mixing ratio values (i.e., the ratio of the mass of water vapor to the mass of dry air) collected from the 17 November 2002 12 Z Hilo, Hawai‘i radiosonde sounding were used [9]. A continuum analysis was employed on the water vapor absorption feature between 1325 µm and 1460 µm to determine that the amount of water vapor was modeled correctly. Using the temperature profile reported by the radiosonde, the height of the trade wind inversion on the night of the observations was calculated to be 2.2 km. Since the observation site on Haleakala is about 3 km above sea level, it was well above this trade wind inversion. Consequently, the aerosol content of the atmosphere at this time was negligible, and the aerosol value was set to zero. Incorporating these inputs, the MODTRAN algorithm was used to determine both the atmospheric transmission and the incident solar radiance at the top of the atmosphere on the night of the observations.

Data Analysis: Spectral radiance at the spectrometer was calculated based on the ASD factory calibration files. The amount of atmospheric light scattering was estimated by the dark sky measurements performed on the evening of the observation. The spectral transmission through the telescope and the optical interface was calculated on 26 November 2002 using results obtained in a laboratory. Incorporating all of the data described above, the spectral reflectance of the Moon was calculated as:

$$R_{moon} = \frac{L_{Moon,spectrometer} - L_{Dark\ sky}}{T_{optics} \bullet T_{atm} \bullet L_{Sun,\ TOA}}$$

where,

R_{moon} = Spectral reflectance of the Moon

$L_{Moon,\ spectrometer}$ = Spectral radiance of the moon as measured at the spectrometer

$L_{dark\ sky}$ = Spectral radiance of the dark sky as measured at the spectrometer

T_{optics} = Spectral transmittance of the telescope and optical interface

T_{atm} = Spectral transmittance of the atmosphere

$L_{Sun,\ TOA}$ = Spectral radiance of the Sun at the top of the atmosphere

The results of this calculation are shown in Figure 1.

Results: Although our optical system was centered upon Mare Serenitatis, the viewable area on the Moon was so large that it included both highland and mare regions. Consequently, we expect that our measured absolute spectral reflectance values reflect a mixture between lunar highlands and mare endmembers. Furthermore, the viewable area may have been off the limb of the Moon leading to an underestimation of lunar surface reflectance.

Figure 1 shows our measured absolute lunar spectral reflectance, as well as reflectance spectra for mature lunar mare and highland samples obtained in the laboratory. The highlands value is a reflectance spectrum of Apollo sample 62231, a mature (I_s/FeO = 91) sample used in the calibration of the Clementine UVVIS and NIR cameras [10,11]. The mare value is a reflectance spectrum of Apollo sample 15041, a mature (I_s/Fe0 = 94) mare sample analyzed in detail by the Lunar Soil Characterization Consortium [12,13]. As expected if there is no inherent discrepancy between ground-based and laboratory reflectance measurements, our measured absolute lunar spectral reflectance values fall between the highlands and mare values. Further error analysis work is currently being performed to confirm these results.

References: [1] Anderson J. M. et. al. *Publications of the Astronomical Society of the Pacific, 111*, 737-749. [2] Murchie S. M. et. al. *Icarus, 140*, 66-91. [3] Kieffer H. H. et. al., *Proc. SPIE*, *3870*, 193-205. [4] Blewett D. T. et. al (1997) LPS XVIII, Abstract #1161. [5] Blewett D. T. et. al. (1997) *Icarus, 129*, 217-231. [6] Hillier J. K. et. al. (1999) *Icarus*, *141,* 205-225. [7] Shkuratov Y. G. et al. (2001) *Solar System Research*, *35*, 29-34. [8] Berk et. al. (1999) *Proc. SPIE*, *Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research III,* Volume 3756. [9] University of Wyoming Dept. of Atmospheric Sciences: Upper Atmosphere Soundings Archive. http://weather.uwyo.edu/ upperair/sounding.html. [10] Pieters C. M. (1999) *New Views of the Moon II*, Abstract #8025. [11] NASA Planetary Data System, Spectroscopy Subnode. http://www.planetary.brown.edu/pds/AP62231.html [12] Pieters C. M. et. al. (2000) LPS XXXI, Abstract #1865. [13] NASA Planetary Data System, Spectroscopy Subnode. http://www.planetary.brown.edu/pds/15041Kdata.txt

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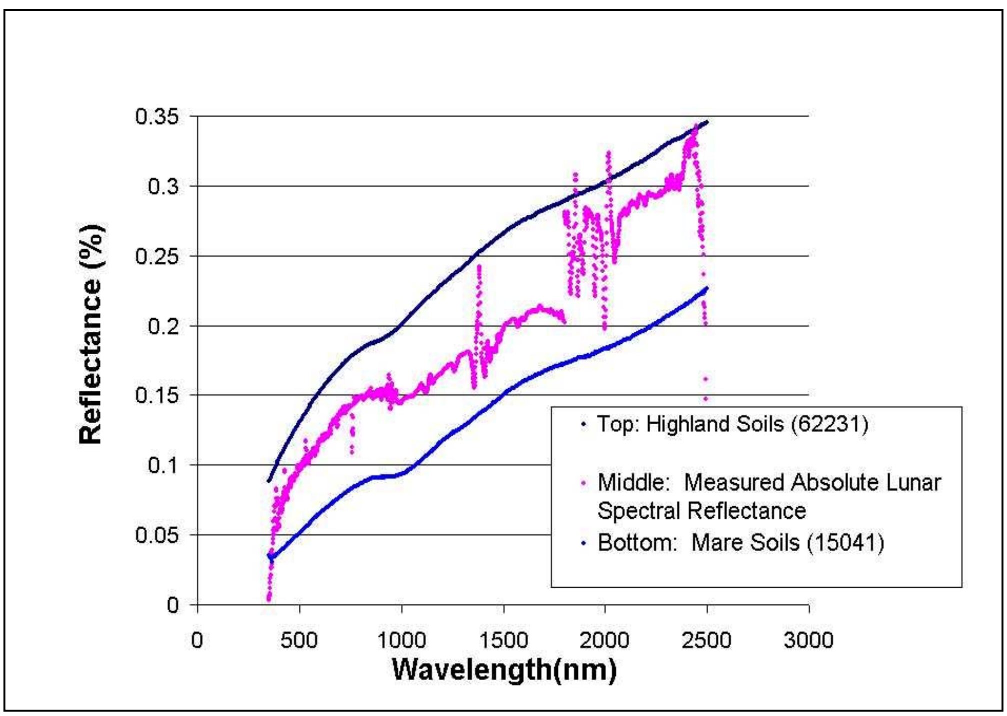

Figure 1. Our measured absolute lunar spectral reflectance values compared with a mature highlands sample reflectance spectrum and a mature mare sample reflectance spectrum.