LABORATORY AND DIVINER BIDIRECTIONAL REFLECTANCE MEASUREMENTS OF APOLLO SOILS.

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Introduction: The goal of this work is to analyze and understand the solar reflectance of the Moon. Our approach is to compare laboratory bidirectional reflectance measurements of several different Apollo soil samples with Lunar Reconnaissance Orbiter (LRO) Diviner orbital solar albedo measurements at the Apollo soil sample sites. to study and understand the solar reflectance of lunar soil.

Samples: CAPTEM provided us with five representative lunar soil samples: a typical low albedo mare sample (10084, Apollo 11), a low titanium basaltic sample with impact breccias (12001, Apollo 12), an Apollo 15 sample (15071), a high albedo lunar highlands soil (68810 & 61141, Apollo 16) and a Apollo 17 soil sample (70181).

Laboratory Methods: We used the Bloomsburg University Goniometer (BUG) to make the Bidirectional Reflection Distribution Function (BRDF) measurements on the suite of Apollo samples exposed to standard ambient laboratory conditions. The BUG instrument consists of a filtered, chopped and collimated light source and a solid-state detector [1]. The source is a 100 W quartz halogen bulb and is attached to an arm that moves 0-65º degrees in incidence and 0-180º degrees in azimuth, 60 cm away from the sample. The detector has a 1 cm field of view for normal viewing geometry. It is attached to an arm that moves 0-80º in emission angle, 80 cm away from the sample. The source and detector move along three independent axes [1].

We collected two different types of reflectance datasets (total of 769 angle combinations). The standard set of BUG BRDF measurements include incidence angles (i = 0-60º), emission angles (e = 0-80º), and phase angles (g = 3-140º).The high-incident angle set are along and perpendicular to the principle plane axis and include incidence angles of i=0-75º and phase angles of 3-155º. We used 6 filters to obtain these data, 450, 550, 700, 750, 850, 950nm.

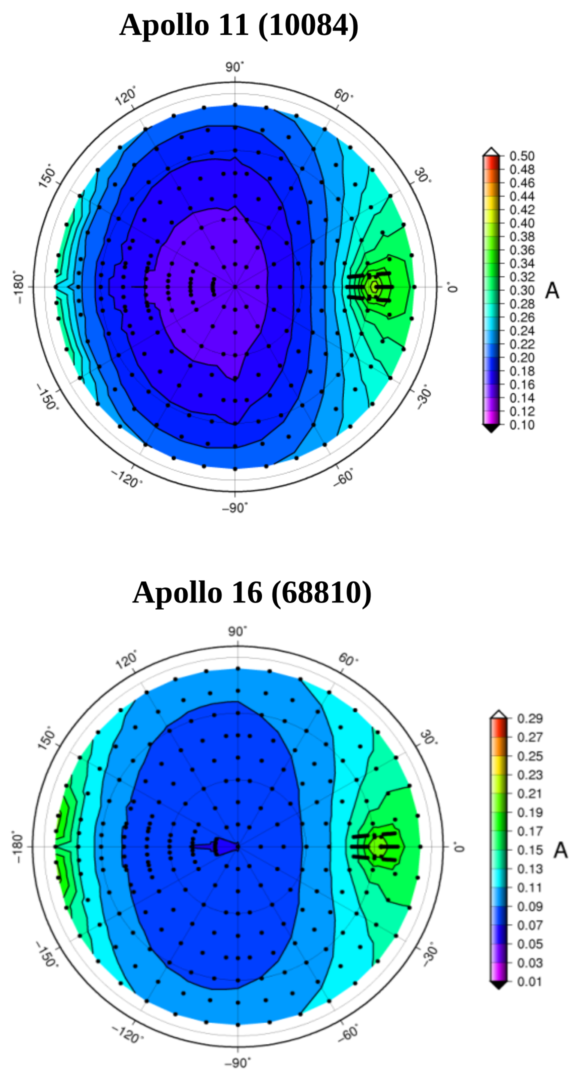


Figure 1: Contour plots of standard BUG emission and azimuth angles for i=60°. The illumination source is along the positive X axis. The radial coordinate is emission angle (to 90°) and the azimuthal coordinate is azimuth angle, where 0^0 azimuth defines the plane of incidence. The principal plane is oriented along the x axis. The black dots indicate the angular positions of the BUG measurements (acquired to emission angles of 80°). The colors represent lambert albedo.

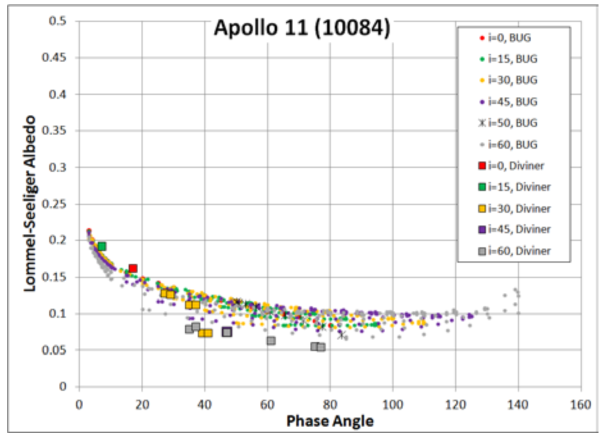
BRDF Models: One of the main motivations for this work is to obtain a full BRDF and find a model that fits the Apollo 11 and 16 datasets. This lets us create BRDF's at any combination of photometric angles. We successfully fit two models to the BUG BRDF data, Hapke's theoretical BRDF model and an empirical BRDF ("PF") model that we developed for the Apollo samples.

Orbital Observations: The Diviner Lunar Radiometer Experiment on the Lunar Reconnaissance Orbiter is an infrared and solar radiometer with nine spectral channels (ranging from 0.35 to 400 microns) [2]. The instrument has obtained solar reflectance measurements of the Moon in a broadband solar channel, Channel 1, from 0.3 to 3.0 microns wavelength. Most of these measurements have been acquired in a nadir pushbroom mapping mode near e=0, from an orbital altitude of 50 km. The solar channel on Diviner is calibrated once per orbit and is done so by rotating the instrument toward space and looks at an aluminum calibration target for 30-50 seconds. [2] Diviner is currently collecting data from the LRO frozen orbit, which has an altitude of approximately 100 km over the Apollo landing sites, which yields a geometric field of view of approximately 320 meters cross track for nadir viewing.

In addition to the calibration procedure, the LRO spacecraft is routinely rolled to obtain high-resolution Lunar Reconnaissance Orbiter Camera (LROC) stereo images of the Apollo landing sites and other areas of interest on the lunar surface, thus providing more complete BRDF coverage. Figure 2 shows the BUG Apollo sample measurements and the Diviner solar channel data acquired within 1.5 km lat/lon boxes centered on the Apollo 11, and 16 and landing sites, which have the most complete angular coverage to date. The plots show a strong dependence of measured reflectance with phase angle. The data points show increased scatter at higher phase angles.

Conclusions and future work: The laboratory and Diviner datasets provide complementary and independent insights into the photometric properties of the lunar surface. The limited bidirectional reflectance measurements obtained by Diviner at the Apollo 11, 12, 15, 16 and 17 landing sites are in good general agreement with laboratory goniometer measurements at the same angles, especially at low phase angles. At higher phase angles, the Diviner measurements are lower, suggesting that roughness and shadowing at spatial scales smaller than the Diviner footprint are a significant factor.

The Diviner team has designed a targeting tool that will enable us to use Diviner's internal off-nadir pointing capability to obtain a more extensive and complete set of bidirectional reflectance measurements of selected regions of interest, including the Apollo landing sites. We will start acquiring new data for the planned observations over the next several months.



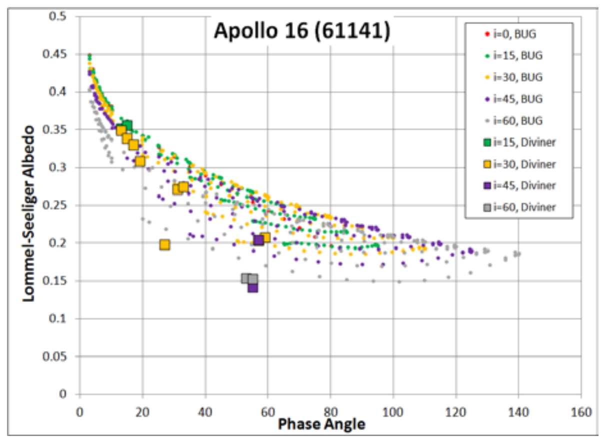


Figure 2: The BUG Apollo sample measurements and the Diviner solar channel data acquired within 1.5 km lat/lon boxes centered on the Apollo 11, and 16 and landing sites. The Lommel-Seeliger Albedo corrects for first order photometric variations due to incidence and emission angle. The Lommel-Seeliger albedo (A_{ls}) is related to the Lambert Albedo (A_L) by $A_{Ls}=A_L(\mu_0+\mu)$. The plots show a strong dependence on measured reflectance with phase angle.

References: [1] Shepard, M. K., 32nd Lunar and Planetary Science Conference, Houston, TX, USA, Abstract #1015, 2001. [2] Paige et al. Space Sci. Rev. 150, 125, 2010.