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The Bidirectional Reflectance of Apollo Lunar Soils

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Abstract

We have compared laboratory solar bidirectional reflectance measurements of a diverse set of Apollo soil samples with Lunar Reconnaissance Orbiter (LRO) Diviner orbital albedo measurements at the Apollo 11 and 16 landing sites. Preliminary results show good agreement between the laboratory and orbital measurements at low phase angles. We expect reasonable agreement between the Apollo 12, 15, and 17 landing sites once we complete those measurements.

1. Introduction

The objective of this work is to understand and analyze the solar reflectance of the Moon. We hope to improve our understanding of lunar photometry and physical properties of lunar surface layers. Our approach is to compare laboratory bidirectional reflectance distribution function (BRDF) measurements of Apollo soil samples to LRO Diviner observations of the landing sites. The laboratory and Diviner datasets provide independent and complimentary insights into the photometric properties of the lunar surface.

2. Samples

We used 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, Apollo 16) and a Apollo 17 soil sample (70181).

3. BRDF Measurements

We used the Bloomsburg University Goniometer (BUG) to make the Bidirectional Reflection Distribution Function (BRDF) measurements on the suite of Apollo samples. 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].

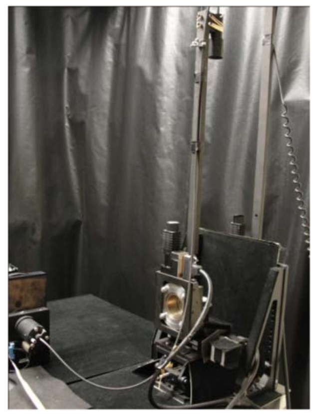

Figure 1. Bloomsburg University Goniometer (BUG) setup

We collected two different types of reflectance datasets. The standard set of BUG BRDF measurements include incidence angles (0º < i < 60º), emission angles (0º < e < 80º), and phase angles (3º < g < 140º), which provided us with 680 measurements per wavelength (Figure 2). We also obtained BUG data at high-incident angles. These measurements were acquired along and perpendicular to the

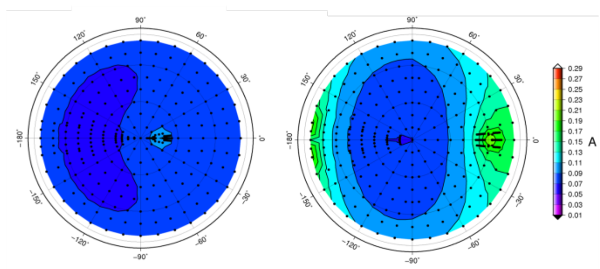

Figure 2. Apollo 11 BUG data 750nm, i=15 (left) i=60 (right). Colors represent lambert albedo, scale bar is from 0.01-0.29

principal plane axis and include incidence angles 0º < i < 75º and phase angles 3º < g < 155º, which gave us an additional 89 points per wavelength (for a grand total of 769 angle combinations). We used 6 spectral filters to obtain these data, 450, 550, 700, 750, 850 and 950nm.

4. BRDF Model Fits

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.

4. Diviner 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). Diviner is currently collecting data from an orbit of 50 kilometers above the lunar surface and an orbital period of two hours. At this altitude, the detector has a geometric field of view of 320 meters (in track) and 160 meters (cross track). 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 [2]. 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.

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 4 shows the Diviner solar channel data acquired within 3 km lat/lon boxes centered on the Apollo 11 landing site. The plots show a strong dependence of measured reflectance with phase angle. The data points show increased scatter at higher phase angles due to large-scale roughness and shadowing.

Figure 3. LRO Diviner Lunar Radiometer

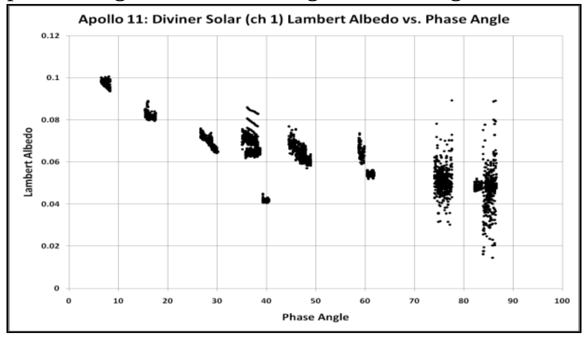

Figure 4. Diviner Channel 1 observations at the Apollo 11 landing site

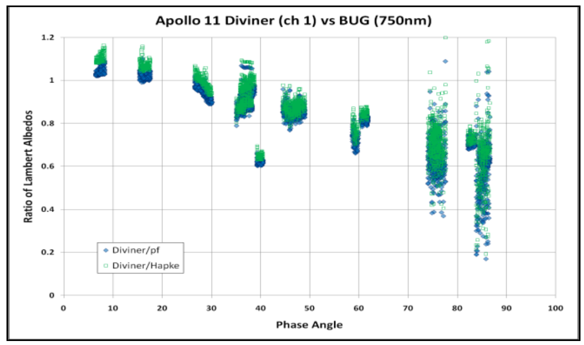

Figure 5. Ratio of Apollo 11 Diviner and models fitted to BUG albedos.

Comparisons of the Diviner Channel 1 Lambert albedos to the model calculated Lambert albedos of the lunar samples at the same photometric angles are shown in Figure 5. If the Diviner observations were in perfect agreement with the best fit models to the BUG data, then the Lambert albedo ratios would fall on the line y=1. The two measurements are in fairly good agreement at low phase angles. However there is a systematic negative trend at higher phase angles. This is likely due to the fact that the Diviner data are affected by shadows due to large-scale topography that are not present in the Apollo samples measured by BUG.

References

[1] Shepard, M. K., 32nd Lunar and Planetary Science Conference, Houston, TX, USA, Abstract #1015, 2001.
[2] Paige et al. (2010) SSR 150, 125.