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GALILEO PHOTOMETRY OF APOLLO LANDING SITES. P. Helfenstein[1], J. Veverka[1], J.W. Head[2], C. Pieters[2], S. Pratt[2], J. Mustard[2], K. Klaasen[3], G. Neukum[4], H. Hoffmann[4], R. Jaumann[4], H. Rebhan[4], A.S. McEwen[5], M. Belton[6], [1]Cornell University, Ithaca, NY 14853, [2]Brown University, Providence RI 02912, [3]Jet Propulsion Laboratory, Pasadena CA 91109. [4]Deutsche Luft und Raumfahrt, 8031 Oberpfaffenhofen, FRG, [5]U.S.Geological Survey, Flagstaff, AZ, [6]Kitt Peak National Observatory, NOAO, Tucson AZ 85719

As of December 1992, the Galileo spacecraft performed its second and final flyby (EM2) of the Earth-Moon system, during which it acquired Solid State Imaging (SSI) camera images of the lunar surface suitable for photometric analysis using Hapke's [1,2,3] photometric model. These images, together with those from the first flyby (EM1) in December 1989, provide observations of all of the Apollo landing sites over a wide range of photometric geometries and at eight broadband filter wavelengths ranging from 0.41 μm to 0.99 μm. We have completed a preliminary photometric analysis of Apollo landing sites visible in EM1 images and developed a new strategy for a more complete analysis of the combined EM1 and EM2 data sets in conjunction with telescopic observations and spectrogoniometric measurements of returned lunar samples.

No existing single data set, whether from spacecraft flyby, telescopic observation, or laboratory analysis of returned samples, describes completely the light scattering behavior of a particular location on the Moon at all angles of incidence (i), emission (e), and phase angles (α). Earthbased telescopic observations of particular lunar sites provide good coverage of incidence and phase angles, but their range in emission angle is limited to only a few degrees because of the Moon's synchronous rotation. Spacecraft flyby observations from Galileo are now available for specific lunar features at many photometric geometries unobtainable from Earth; however, this data set lacks coverage at very small phase angles ($\alpha < 13°$) important for distinguishing the well-known "opposition effect" [3]. Spectrogoniometric measurements from returned lunar samples can provide photometric coverage at almost any geometry; however, mechanical properties of prepared particulate laboratory samples, such as particle compaction and macroscopic roughness, likely differ from those of those on the lunar surface. In this study, we have developed methods for the simultaneous analysis of all three types of data: We combine Galileo and telescopic observations to obtain the most complete coverage with photometric geometry, and use spectrogoniometric observations of lunar soils to help distinguish the photometric effects of macroscopic roughness from those caused by particle phase function behavior (i.e., the directional scattering properties of regolith particles).

DATA SOURCES AND CALIBRATION:

Galileo SSI Images: Radiometric calibration of the EM2 frames is described elsewhere in this volume [4]. The calibration of the EM1 frames differ from the EM2 calibration in that the flat-field correction was accomplished with preflight data. In addition, EM1 frames were corrected for the spectral transmission, aperture, and ghost images introduced by the SSI's deployable quartz dust cover (removed shortly after EM-1). Dust particles accumulating on the cover introduced removable blemishes in the EM1 images that are not present in the EM2 frames. The relative spectral sensitivity of the SSI is currently still under study; however, calibrated SSI images of Venus, Jupiter, the Moon, 951 Gaspra, and standard calibration stars suggest the relative spectral response of the camera differs from predicted by less than 5% through most filters, but perhaps as much as 11% to 49% at violet (0.41 μm), methane-2 (0.89 μm), and 1-micron (0.99 μm) bandpasses. The SSI's absolute radiometric accuracy has not yet been fully checked so that, in this study, we have used Galileo measurements only in a relative photometric sense and used spectrogoniometry of returned lunar samples to fix reflectance values on an absolute scale.

EM1 frames provide useful coverage only for Apollo 12, 14, and 15 sites, with Apollo 12 and 14 having the most complete phase angle coverage from 19° to 130°, at spatial resolution of 4 km/pixel or better. Broadband SSI spectral coverage using most SSI filters was consistently obtained throughout the encounter. Clear filter (CLR) images were acquired only in the early stages of the encounter at large phase angles ($\alpha > 90°$) while methane-1 filter (0.73 μm) was obtained later in the encounter ($\alpha < 90°$). EM2 coverage will provide data for all of the Apollo sites $14° \le \alpha \le 123°$. In this preliminary study we have focused only on EM1 coverage of Apollo 12 and 14.

RELAB Spectra of Apollo Soil Samples: Reflectance spectra of four Apollo soil samples (Apollo 11, 10084; Apollo 12, 12070; Apollo 14, 14259; Apollo 16, 62231) were obtained relative to a Halon reflectance standard using the RELAB [5] spectrogoniometer at Brown University (Pieters et al. 1991). High-resolution spectra ($\Delta\lambda = 0.01$ μm) of each sample [6] were acquired over $0.35 \le \lambda \le 2.5$ μm. All spectra were obtained within the scattering plane over a wide range of incidence ($0° \le i \le 60°$), emission ($0° \le e \le 60°$), and phase angles ($10° \le \alpha \le 110°$). In order to scale the sample/halon reflectance ratios to absolute radiance factors, we evaluated the absolute reflectance of Halon at all laboratory photometric geometries from a best-fit of Hapke's photometric model to National Bureau of Standards Halon reflectance data [7] ($\tilde{\omega}_0$=0.999997, h=0.79, B_0=1.51, g=0.415, where $\tilde{\omega}_0$ is single scattering albedo, h and B_0 are parameters of Hapke's opposition surge function, and g is the asymmetry factor in the well-known Henyey-Greenstein particle phase function). The high-resolution RELAB spectra were convolved with the Galileo camera and aperture cover transmission functions for each filter bandpass [8] and a solar spectrum to derive "Galileo equivalent" spectral radiance factors.

Earthbased Telescopic Data: We employed two separate sources of telescopic observations. For the Apollo 12, we used data of Shorthill et al.[9]. The effective wavelength of these data is about 0.45 μm, making it most similar to the violet (0.411 μm) Galileo observations. Their spatial resolution is about 2 km. over phase angles from 2.3° to 112°. There are no observations from Shorthill et al. (1969) near Apollo 14. Anticipating the need for such data, work was undertaken at the Deutsche Forschungsanstalt für Luft-und Raumfahrt (hereafter referred to as DLR) to acquire Earthbased telescopic CCD observations of various lunar terrains at Galileo broadband wavelengths. We have used preliminary data [10] from this source for the Apollo 14 site at a single wavelength (0.40 μm), and over phase angles from 3°-50°.

PRELIMINARY RESULTS: Our purpose in this study is to obtain well-constrained fits of Hapke's photometric parameters for the Apollo 12 and 14 sites at all SSI bandpasses. For each site, our most complete photometric angle coverage is at violet wavelengths. We began by obtaining violet-filter fits for all of the Hapke parameters with the non-linear least squares method described in Helfenstein and Veverka [10]. Since Hapke's θ and h parameters represent mechanical properties of the regolith (macroscopic roughness and regolith compaction) they should be the same at all wavelengths. Thus, for the remaining filters, we fixed θ and h at their best-fit violet-filter values and need only seek optimal values of $\tilde{\omega}_0$, B_0, and b and c parameters of the particle phase function.

Our preliminary best-fit parameters allow us to predict how the spectral properties of lunar materials change with phase and, more importantly, why these changes occur. For both areas studied, the phase functions of average particles become more strongly backward and less strongly forward scattering with increasing wavelength. The colors of lunar soils change with photometric geometry: lunar materials become "redder" with increasing phase angles for 0° to 90°, but the trend reverses and materials become "bluer" as phase angles increase beyond 90°. This effect has long been known from telescopic observations; however, we now understand that it is caused by the fact that the particle phase function behavior changes with wavelength. In addition, RELAB data for Apollo 16 samples indicate that the effect is more pronounced for highland soils than for mare soils. We expect that the addition of EM2 coverage will not only refine our fits for Apollo 12 and 14, but will provide observations for Apollo 11, 15 and 16, and 17 as well.

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