

Lunar Surface Processes

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Cycle 12 primary orbits: 3

Abstract

We propose to make three one-orbit observations of the Moon. The ACS/WFC will be used to make polarization images which will constrain surface properties of a diverse range of features. These properties include the median particle size, the average surface slope, and the rate of "space weathering" (e.g., Madey et al., 2002), which is the change in spectral properties of silicate surfaces with exposure to the interplanetary environment. In particular, we propose to image the Apollo 15 landing site, and a recent impact site in Mare Serenitatis, and the Reiner Gamma formation in Oceanus Procellarum. We also propose to re-image (in parallel) the region first imaged by HST in 1998 by program 7717, to see what changes may have occurred in the interim, in particular, if new impact sites are visible.

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Number of investigators: 9

Observing Summary:

Target	RA	DEC	V	Config/Mode/SEs	Flags	Orbits
Apollo15	00 00 0.00	+00 00 0.00	3.4	ACS/WFC/Imaging/F475W+POL0V, F475W+POL120V, F475W+POL60V, F658N+POL0V, F658N+POL120V, F658N+POL60V		1
LeonidSite	00 00 0.00	+00 00 0.00	3.4	ACS/WFC/Imaging/F475W+POL0V, F475W+POL120V, F475W+POL60V, F658N+POL0V, F658N+POL120V, F658N+POL60V		1
ReinerGamma	00 00 0.00	+00 00 0.00	3.4	ACS/WFC/Imaging/F475W+POL0V, F475W+POL120V, F475W+POL60V, F658N+POL0V, F658N+POL120V, F658N+POL60V		1
WFPCparallel	00 00 0.00	+00 00 0.00	3.4	WFPC2/Imaging/F437N, F502N, F673N, F953N	CPAR	1
NICMOSparal lel	00 00 0.00	+00 00 0.00	3.4	NIC1/Imaging/F095N, F113N, F164N, F187N	CPAR	1
Total orbit request:						5

- **Scientific Justification**

The surface of the Moon is covered by fine-grain soil (regolith). The regolith changes with time due to space weathering factors, such as micrometeorite bombardment (e.g., Pieters, 2000, Hapke, 2001), solar wind particle impact, flare or cosmic ray irradiation, or impact melt implantation from larger events (Madey et al. 2002, Sasaki et al, 2002). The regolith becomes darker, the red slope of the reflectance spectrum in the visible becomes steeper, and spectral features in the near infrared become more subdued. This is an effect of so-called regolith maturation, and is due to several processes, including accumulation of nanophase reduced iron on the regolith particles, decrease of the particle size, enrichment with glass material and agglutinates, establishing of specific millimeter-scale porous structure. Mature regolith is ubiquitous on the Moon. Fresh, immature material is excavated by meteorite impacts and exposed by landslides on the steepest slopes. Smaller impacts are much more frequent than larger; the steepest slopes are always short; and so the youngest, most immature material occurs on the Moon in small patches. Measuring of the optical properties of the most immature regolith is possible only at high resolution.

The Clementine mission to the Moon (Nozette et al., 1994) gave a global coverage of the lunar surface with multispectral images at 100 m resolution. (100 m in the center of the lunar nearside is about 0.055 arcsec as seen from the Earth.) These images were used in a great number of recent works and revealed much wider variety of the reflectance spectra than previous Earth-based observations, because small patches of highly immature surface were resolved (e.g., Pieters et al., 1994). Mapping of photometric properties (the dependence of the surface brightness on the illumination / observation geometry) of the surface with the Clementine data set (Kreslavsky and Shkuratov, 2003) revealed anomalies related to the recently disturbed regolith at small craters and Apollo-15 landing site. The photometric properties are controlled mostly by millimeter-scale regolith structure, while spectra are influenced mostly by the reduced iron and glass accumulation. The study of photometric anomalies at high resolution showed that the equilibrium millimeter-scale structure is established much quicker, than the reduced iron and glass accumulation.

Imaging polarization observations:

The degree of polarization of light scattered by the Moon is controlled mostly by the characteristic particle size of the regolith. Due to numerous laboratory measurements of the lunar soil and its analogs, the calibration of the polarization measurements in terms of the particle size is rather well established. Earth-based images of the polarization degree and its anomaly (deflection from the regression on albedo) (Shkuratov and Opanasenko, 1992; Dollfus, 1998, 1999) showed grain size variations due to regional geology; this demonstrates the usefulness of such maps for geological studies. Some of the youngest resolved material is in coarse grains, while spectrally immature crater rays show little polarimetric anomaly. Study of polarization at high resolution would give information about rates of particle size change in the maturation process.

Polarimetric measurements can be also useful to approach the mystery of swirls. Origin of these albedo features on the Moon (mostly farside) is a subject of hot debate between advocates of cometary impact (Schultz and Srnka, 1980; Hawke and Bell, 1981, 1987; Pinet et al., 2000) and magnetic shielding (Hood et al., 1979, 1989). The hypothesis for cometary impact argues that that the swirls were produced by the hypervelocity collision of denser portions of cometary gas and dust against the upper regolith. Because of the low

density, the collision primarily scoured and melted portions (microns thick) of the upper surface layer. The plasma stream of ions and electrons associated with the coma became compressed at the surface during the collision, thereby amplifying and trapping the field in the quenched regolith. This hypothesis is supported by key observations: the very young age of the swirls (draping young surfaces), photometric properties (including strong forward scattering relative to surrounding surfaces due to compression and erosion of the lunar regolith), intricate patterns of both dark and light veins, and correlation with strong magnetic fields. The observed forward scattering property was compared to the scouring of the regolith created during the Apollo landings, which altered the surface reflective properties in a similar manner (although with no melting). The magnetic shielding model argues that an ancient magnetic field was created during the formation of the major impact basins 4Ga. Antipodal convergence of plasma generated by major collisions and was then trapped at depth. The remanent magnetic field then stood off solar proton bombardment, which they proposed prevented further darkening of the surface. The first hypothesis predicts changes in the upper surface structure (smoother on average) with possible coarsening due to small impacts associated with micro-impacts accompanying the collision but little compositional change. The latter hypothesis predicts no change in the photometric function and no change in surface properties, especially any phase angle effects. Groundbased polarimetric anomaly maps by Shkuratov and Opanasenko (1992) showed coarse particles signature for the main part of the Reiner Gamma feature (Figure 1). The Reiner Gamma feature is a typical swirl pattern located on the nearside in Oceanus Procellarum. It is the most prominent of several swirls that can be found on the nearside. The tight swirls form hooks and tails and drape small post-mare craters and other relief. The enigmatic dark lanes are darker than the surrounding mare but are also typical of the numerous farside patterns.

No mission to the Moon has had a polarimeter onboard, and there are no polarimetric data on the Moon except the Earth-based telescopic observations. Taking into account current plans of space missions, for the next 5 (probably, more) years observations with HST will be the only possibility to obtain high-resolution polarimetric images of the Moon.

We propose to take a series of polarimetric images for a part of the lunar surface with ACS/WFC. We would use these images to obtain particle size signatures of the freshest small craters and their ejecta, and infer constraints on particle size alteration time scale in the maturation process. We will obtain particle size signature of resolved details in the Reiner Gamma “tail”, and infer constraints on the nature of swirls. Besides, analogously to spectral and photometric properties, we expect high-resolution images of polarimetric anomalies to give valuable information for regional geological inferences. Finally, we would like to demonstrate the value of polarimeter as a prospective instrument for future missions to atmosphereless Solar System bodies.

Targets:

In addition to Reiner Gamma, a couple of interesting targets are nearer the center of the lunar disk: the Apollo 15 landing site and the site of an impact of a Leonid meteor in 2001. The Apollo 15 landing site has been very well observed (Kreslavsky and Shkuratov, 2003) and will provide a check on this technique. We also have an exciting chance to observe a fresh impact on the Moon: on 2001 Nov. 18, 23:19:15 UT at least three observers recorded a bright flash in Mare Serenitatis (Figure 2). This flash was observed by at least three videorecorders, and can be placed to high accuracy thanks to the bright Earthshine illuminating the Moon. Comparison of this crater’s ejecta colors and polarimetric qualities to

those of surrounding features will provide information on the rate of surface maturation. Even if the actual crater is too small to resolve, the ejecta blanket should subtend several pixels.

Parallel observations with WFPC2:

At nominal roll for the proposed observations of Oceanus Procellarum with ACS/WFC, the WFPC2 FOV scans the eastern part of Procellarum and the southern part of Mare Imbrium and includes the region near the crater Copernicus. This region contains high albedo and spectral contrasts associated with ejecta from Copernicus and Kepler, and various units of mare basalts. This region will partly overlap the region imaged with WFPC-2 within program 7717 (see Figure 3).

We propose to take a series of images with WFPC2 with the same filters as used in the program 7717. Overlapping parts of the images will be used to study photometric properties of the surface. High photometric precision and calibration accuracy of WFPC2 images together with the wide difference in the phase angles will allow quantitative study of the spectral dependence of the phase function and its correlation with albedo. Albedo and spectral diversity of this area favor this kind of study.

The ratios of images taken in different filters would give maps of spectral ratios with high accuracy and reliable absolute calibration. They can be used to improve Clementine calibration and to make it possible to apply the lunar spectra / composition+maturity calibration relationships (e.g., Lucey et al, 1998) to the asteroids.

Parallel observations with NICMOS:

At nominal roll for the proposed observations the NICMIS NIC1 camera FOV will scan the mare surface of northeast part of Oceanus Procellarum and highlands near crater Mairan. This area has high spectral contrasts and contains sites of very unusual reflectance spectra. We propose short observations in narrowband filters with the NIC1 camera. These should not saturate in the first couple of reads of the SCAMRR sequence (see "Description of the Observations") and will yield interesting information on the 1-2 μm reflectance at high spatial resolution. The NICMOS polarizers are too broad for use in any but the unsupported BRIGHTOBJ mode.

Conclusion:

We propose to observe three sites on the Moon, using ACS with polarizing filters. This will determine the surface properties (median grain size, surface slope, reddening). The Apollo 15 site offers a wide variety of surface features and has been well observed from the ground, and so will serve as a calibration site for this technique. The Reiner Gamma and Leonid impact sites offer intriguing insights into unusual lunar surface features and will allow us to constrain the rate of "space weathering" and its role in various situations on the Moon. Parallel observations in the WFPC-2 and NICMOS will allow us to investigate a wide variety of terrains in the visible and near IR, and investigate future observations.

Even a minor impact, such as the Apollo Saturn SIV-B stage hitting the Moon, will create a crater and turn over the top layer of the lunar regolith for several hundred meters. Observation of the sites of well-timed impacts can allow us to place constraints on the rate of space weathering. Such constraints could be used to date other features on the lunar surface, or on other silicate surfaces: Storrs et al. (2002, 2003) report significant color differences among main belt asteroids and their companions, in HST observations made in cycle 9, which they attribute to "space weathering" on the companions while the primary bodies have their surfaces "reset" by impacts.

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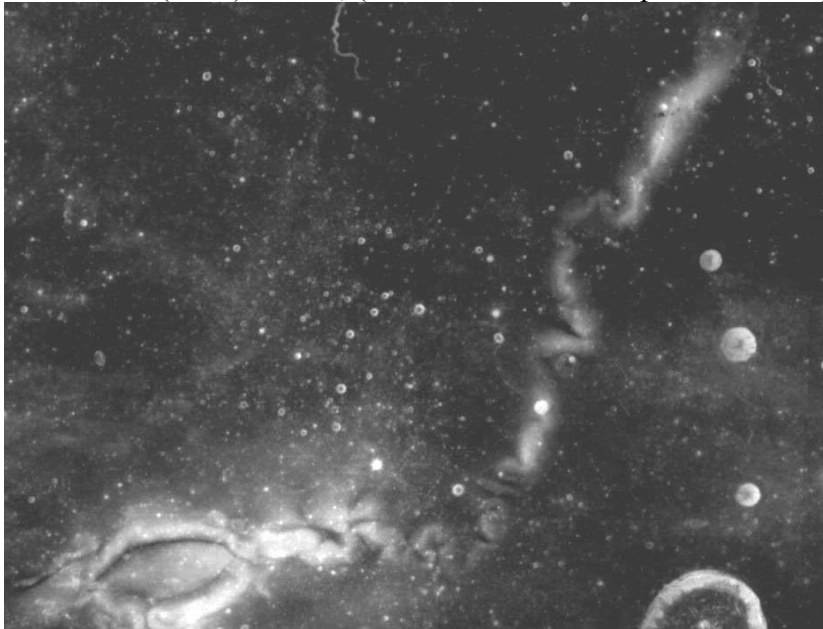


Figure 1: Clementine image of the enigmatic swirl feature Reiner Gamma. Note how the inner slopes of craters appear bright due to downslope movement exposing fresh material. Reiner Gamma does not have such topography to explain its unusually high albedo. Structures at the smallest spatial scales point up the necessity of high-resolution imagery to study this feature. Image is ~150x200 km.



Figure 2: 2001 Nov. 18 23:19:15 UT impact on Mare Serenitatis. The terminator is to the upper right, the (dark) limb is to the lower left. The bright impact spot (top center) does not appear in the immediately preceding frame, but does appear (with diminishing brightness) in the next couple of frames (each 1/60 sec.). All images available from <http://iota.jhuapl.edu/leo01n26.htm>. Note that Earthshine illuminates the lunar features and allows accurate position determination of this feature (image covers most of the unilluminated lunar disk).

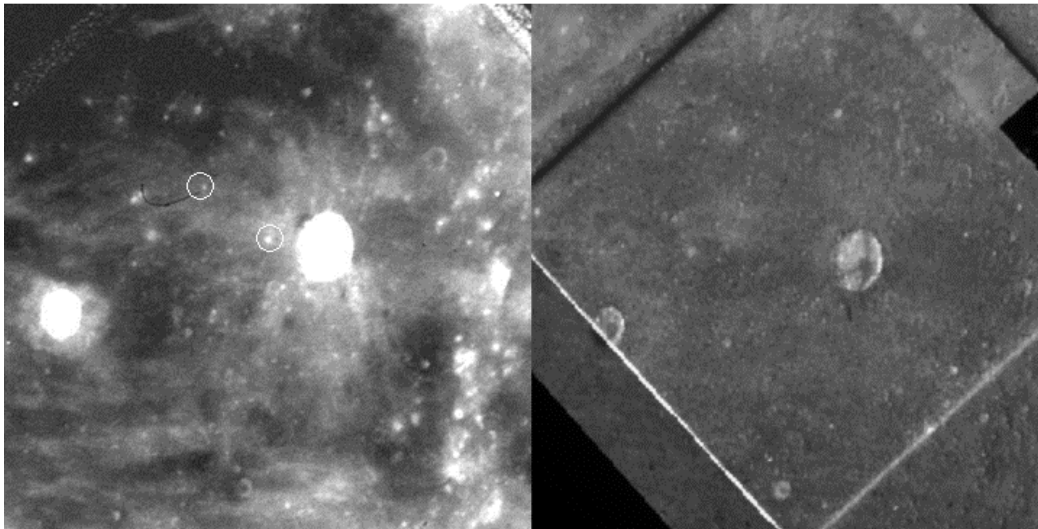


Figure 3: HST images of the region near crater Kepler, including craters Milichius A and B. Note that some small craters in the albedo image (circled, left) disappear in the slope image (right, lighter color means bluer continuum slope), while other comparably sized craters are visible in both. This indicates that the craters that “disappear” are older than their counterparts. Note that the image on the left has been dramatically stretched to show small albedo variations (so

that bright craters are saturated), while the image on the right is a composite of several images and so contains a lot of artifacts. A color version is available on the “Moon” link at <http://www.towson.edu/~astorrs>. Images are ~90km across.

• **Description of the Observations**

We propose to observe several sites on the Moon. These include the Apollo 15 landing site, a well-observed fresh (2001) crater in Mare Serenitatis, and the Reiner Gamma formation in Oceanus Procellarum. One orbit will be sufficient to observe each target.

Reiner Gamma will be imaged with a series ACS/WFC images, starting from 9° N selenographic latitude 58° W selenographic longitude; each next image is shifted to the east by 6 - 9 arcsec. All images will be taken in the same spectral filter (F475W) with changing polarization filters, for maximum spatial information. Since the plane of polarization is known for the Moon with high accuracy, overlapping of two images with properly chosen polarization filters is enough to obtain the polarization degree. As many images as possible for single orbit should be obtained—see discussion below. The WFPC-2 and NICMOS operated in parallel (see below).

The observations of the Apollo 15 site and of the fresh impact will be made with the ACS WFC F475W and F658N and polarizing filters, with the WFPC-2 and NICMOS operated in parallel where feasible. The ACS exposure time calculator gives the following times to reach full well (SNR = 600 with $2e^-/ADU$) on the Moon ($V=-12.7$, radius = 15.9 arcmin, surface brightness = 3.4 mag/sq.”):

Filters:	Time for SNR=600 in WFC:	ETC number:
F475W, POL_V	0.18s	26770
F658N, POL_V	2.23s	26792

These simulations uses CR-SPLIT=2, so each filter combination will take 18 minutes (including two 5.8 minute buffer dumps). Thus we can fit three of these filter combinations into one HST visibility period (that is, one F filter and three different polarization directions), using a gyro acquisition as is necessary for lunar observations. This is a conservative estimate, as the polarizers only illuminate a 70” square on the WFC and so only this subarray needs to be read out. If the buffer dump time scales linearly with the area read out, the overhead should only be about 0.7 min. (instead of 5.8m) per exposure and a complete set of polarimetry images will only take about 24 minutes—we should be able to get two colors per orbit easily, for a full suite of photometric and polarimetric information. If time allows, we would add a very red observation, such as F850LP, to try to get the 1 μm silicate feature.

Parallel observations in the WFPC-2 and NICMOS will also provide information on other regions of the Moon. In particular, when ACS is observing the impact sites in Oceanus Procellarum, the WFPC-2 will be imaging the region between craters Copernicus and Kepler, and thus place constraints on the rate of weathering of features observed the last time HST imaged the Moon. We propose to use the F437N, F502N, F673N, and F953N filters for the WFPC-2 observations, to constrain the visible continuum and the depth of the 1 μm silicate absorption feature:

WFPC-2 filter:	Time for SNR=230 in WF:	ETC number:
F437N	4.5s	30007

F502N	1.4s	30008
F673N	0.3s	30009
F953N	1.0s	30010

NICMOS observations in the NIC1 camera and narrowband filters F095N, F113N, F164N, and F187N, which outline the 2 μm silicate feature:

NIC1 filter:	Time to saturate:	ETC number:
F095N	8.8s	27530
F113N	5.4s	27557
F164N	3.1s	27592
F187N	3.6s	27710

We can't use the polarizers, they saturate in less than 0.3s. These parallel observations will map regolith maturation over a variety of terrain, and provide a baseline for future targeted observations.

- **Special Requirements**

We will have to constrain the orbits for times when the target areas are appropriately illuminated, but these constraints can be fairly loose—a day or two one way or the other shouldn't make a big difference.

- **Coordinated Observations**

No coordinated observations are necessary.

- **Justify Duplications**

The only duplications will be to the previous HST observations, John Caldwell's program 7717. No polarization observations were carried out as part of this program.

- **Previous Related HST Programs**

7717—“STIS spectroscopy of Jupiter, Saturn, Titan and the Moon in the UV”--PI John Caldwell This GTO program spent one orbit on the Moon, taking STIS spectra of Mare Imbrium for use in making reflectance spectra of solar system objects. The WFPC-2 was operated in parallel, and imaged an area starting at Copernicus and moving half-way to Kepler and back. These results were reported by Storrs et al. (1999): Proc. 30th Lunar and Planetary Science Conf., Mar 15-19, 1999, p. 28 (abs #1880).

8539—“Using the Impact of the Lunar Prospector into a South Polar Cold Trap to Detect Water Ice on the Moon”—PI Ed Barker This DD proposal took long slit STIS spectra at various points around the limb of the Moon before and during the impact of the Lunar Prospector spacecraft into a perennially dark polar crater. No OH radicals were

observed. Storrs was heavily involved in planning and scheduling these observations, and in data reduction.