Hubble Space Telescope

Cycle 15 GO Proposal

HST Observations of the Moon

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Scientific Category:	SOLAR SYSTEM
Scientific Keywords:	SURFACES OF PLANETS/MOONS/OTHER, VARIABILITY, ASTEROIDS, DUST
Instruments:	ACS
Proprietary Period:	12

Orbit Request	Prime	Parallel
Cycle 15	3	0
Cycle 16	3	0
Cycle 17	3	0
Total	9	0

Abstract

We propose to obtain high spatial resolution images of the Moon, including polarimetric images. These will be analyzed to obtain information on the grain size and composition of the surface, as well as compared to previous HST and Clementine observations in an investigation of the rate of "space weathering" on short (a few years or decades) timescales. The data can also be used to set a baseline for long term studies of changes in particulate surfaces exposed to the solar environment. This reddening and darkening of silicate surfaces is ubiquitous on atmosphereless bodies, but the rate at which it occurs is not well constrained, especially on short timescales.

Lunar observations under two gyro control are not currently possible, but it is hoped that should 3 gyro observations become possible, for example during a "3 gyro campaign", these observations would be executed.

Investigators:

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Number of investigators: 5

Target Summary:

Target	RA	Dec	Magnitude
APOLLO15			V = 3.4 +/- 1.0, surface V = 3.4 mag.sq. arcsec
REINERGAMMA			V = 3.4 +/- 1.0, surface V = 3.4 mag.sq. arcsec
SERENITATIS			V = 3.4 +/- 1.0, surface V = 3.4 mag.sq. arcsec

Observing Summary:

Target	Config Mode and Spectral Elements	Flags	Orbits
APOLLO15	ACS/WFC Imaging F502N		1
	ACS/WFC Imaging F658N		
	ACS/WFC Imaging F892N		
	ACS/WFC Imaging F475W		
	ACS/WFC Imaging F475W		
	ACS/WFC Imaging F475W		
REINERGAMMA	ACS/WFC Imaging F502N		1
	ACS/WFC Imaging F658N		
	ACS/WFC Imaging F892N		
	ACS/WFC Imaging F475W		
	ACS/WFC Imaging F475W		
	ACS/WFC Imaging F475W		
SERENITATIS	ACS/WFC Imaging F502N		1

Target	Config Mode and Spectral Elements	Flags	Orbits
	ACS/WFC Imaging F658N		
	ACS/WFC Imaging F892N		
	ACS/WFC Imaging F475W		
	ACS/WFC Imaging F475W		
	ACS/WFC Imaging F475W		

Total prime orbits: 3

• 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. Clark et al. (2002) summarize "space weathering" and its implications for understanding silicate surfaces in the solar system. They conclude "There is no quantitative understanding of the relative rates of the space-weathering processes and their optical effects." Nesvorny et al. (2005) investigate the rate of space weather among families of main-belt asteroids, but the shortest time scale they can measure is the age of the youngest family, or about 2.5 million years. We propose to investigate this rate at much shorter timescales, as well as to observe some enigmatic lunar surface features.

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 (e.g. Fig. 1). 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 of the surface with the Clementine data set (Kreslavsky et al. 2004, and Shkuratov et al. 2005) reveals 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 more quickly than the reduced iron and glass accumulation.

Imaging polarization observations:

The degree of polarization at phase angles near 100° on the Moon is controlled mostly by the characteristic particle size of the regolith. The calibration of the polarization observations in terms of the particle size is well established by numerous laboratory measurements of the lunar soil and its analogs. Earth-based images of the polarization degree and its anomaly (deflection from the regression on albedo) (Shkuratov and Opanasenko, 1992; Dollfus, 1998, 1999) show 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 spatial resolution gives 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 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 4Gy ago. Antipodal convergence of plasma generated by major collisions is trapped at depth. The remanent magnetic field can stand off solar proton bombardment, which prevents 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) show coarse particle signatures in the main part of the Reiner Gamma feature (Fig. 1).

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 several 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 “feature”, and infer constraints on the nature of swirls. We expect high-resolution images of polarimetric anomalies to give valuable information for regional geological inferences. Finally, we will 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 impact in 2001. The Apollo 15 landing site has been very well observed (Kreslavsky et al. 2004, and Shkuratov et al. 2005) 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 located to within 10 km 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. The ejecta blanket is expected to be at least 200m in diameter, based on brightness estimates of the flash. HST should be able to resolve this feature, which will subtend several WFC pixels.

There is an example of putative identification of a new crater on the Moon: Buratti and Johnson (2003) use the Clementine data set to identify a 1.5 km crater related to a flash observed in 1953. We should be able to unambiguously identify the Serernitatis site by comparing HST and Clementine images. Even a negative result will be informative, by providing observational constraints for models of flashes (e.g., Artem'eva et al. 2001, Yanagisawa and Kisaichi, 2002).

Parallel observations with WFPC2:

At nominal roll for the proposed observations of Oceanus Procellarum with ACS/WFC, the WFPC2 FOV covers 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 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.

Conclusion:

We propose to observe three sites on the Moon, using ACS with F475W and polarizing filters, as well as unpolarized narrowband filters. This will determine the surface properties (median grain size, spectral characteristics). 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 will allow us to investigate a wide variety of terrains in the visible and near IR, and investigate future observations. Note that no planned lunar mission includes polarizers.

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, 2005) report significant color differences among main belt asteroids and their companions, in HST observations made in cycle 9. They attribute this to "space weathering" on the companions while the primary bodies have their surfaces "reset" by impacts.

References:

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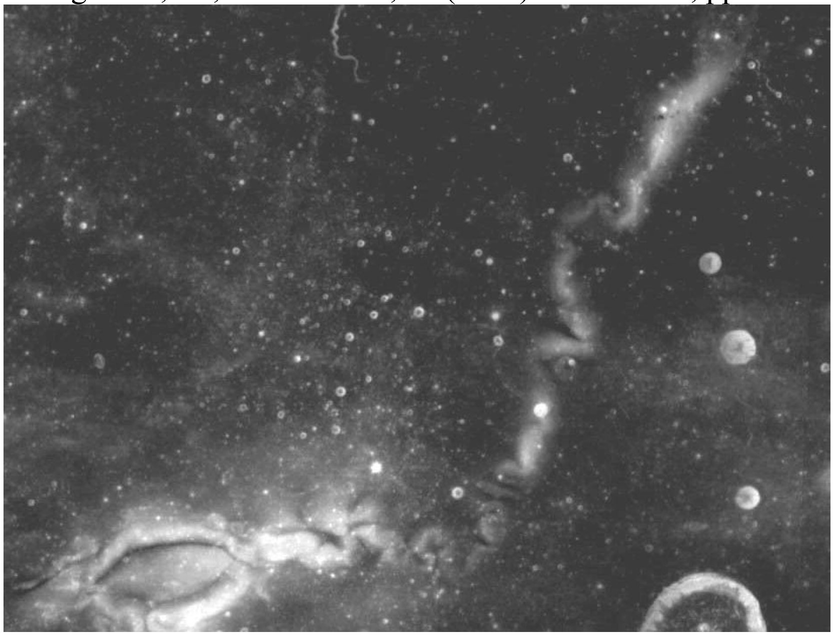

Figure 1: Clementine image of the enigmatic swirl feature Reiner Gamma. This feature is a typical swirl pattern located on the nearside in Oceanus Procellarum. It is the most prominent of several swirls that can be found on the nearside. The tight swirls form hooks and tails and drape small post-mare craters and other relief. The enigmatic dark lanes are darker than the surrounding mare but are also typical of the numerous farside patterns. 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 (100 m in the center of the lunar nearside is about 0.055 arcsec as seen from the Earth).

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 are 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).

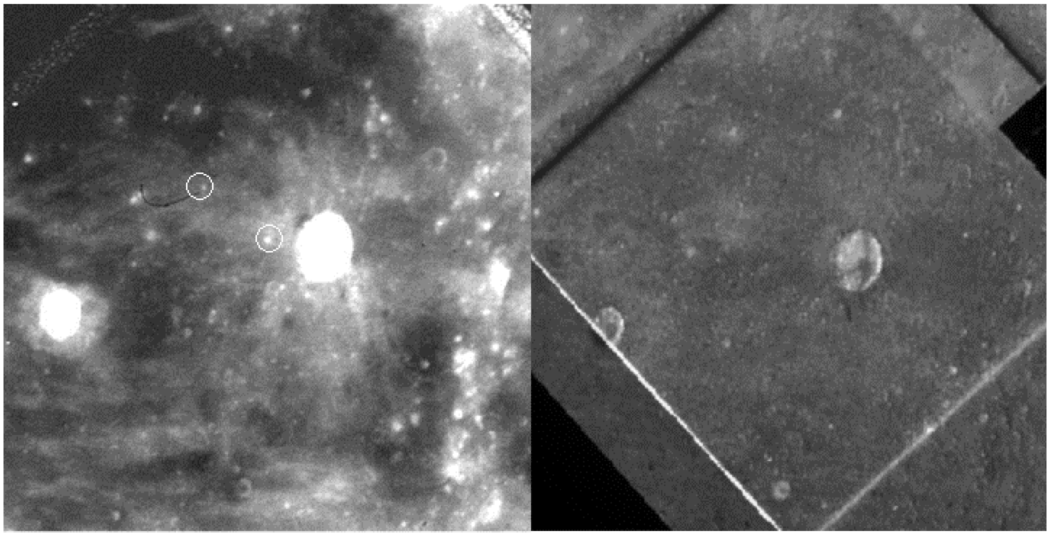

Figure 3: HST images of the region near crater Kepler, including craters Milichius A and B. Note that some small craters in the albedo image (circled, left) disappear in the slope image (right, lighter color means bluer continuum slope), while other comparably sized craters are visible in both. This 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 three 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 (9° N selenographic latitude 58° W selenographic longitude). One orbit will be sufficient to observe each target. The polarization maximum near 90^o phase will constrain the observations near to within a couple of days of first or last quarter moon, depending on the target.

Each site will be imaged with a series ACS/WFC images. All images will be taken in the same spectral filters (F502N, F658N, and F892N) and also with the F475W and changing polarization filters, for maximum spatial and spectral information. As many images as possible for single orbit should be obtained—see discussion below. The WFPC-2 may be operated in parallel when it will observe some part of the Moon at the primary observation's pointing and orientation. We will not use the NICMOS in parallel as the data have no counterpart to enable a time series, and to relieve the load on HST's transmitters.

The ACS exposure time calculator gives the following times to reach full well (SNR = 580 with $2e^-$/ADU) on the Moon (V=-12.7, radius = 15.9 arcmin, surface brightness = 3.4 mag/sq."):

Filters:	Time for SNR=580 in WFC:	ETC number:
F502N	1.06s	ACSIMAG38488
F658N	0.5s	ACSIMAG38492
F892N	0.63s	ACSIMAG38493
F475W + POL0V	0.15s	ACSIMAG38468

These simulations use CR-SPLIT=1 for all of the observations, but a simulated phase II shows that this series of six exposures (including three polarizers) can easily fit in one HST orbit only with CR-SPLIT=NO. Some drift between exposures is inevitable in HST lunar observations. This drift will have the effect of "dithering" the observations. Post observation alignment is trivial for a bright target like the Moon. The time estimate is based on a simulated phase II visit using APT v. 14.0. We will use a gyro acquisition as is necessary for lunar observations.

Dollfus (1998) measured polarization between 10 and 25 percent (depending on albedo) on the lunar surface. Given the equation in the ACS Instrument Handbook (sect. 5.1), with P = 0.1 and SNR = 600 per pixel, the error in polarization $\sigma_p = 0.0014$, well below the instrumental polarization of 2% quoted there for the WFC. These polarimetric observations should be easy to do. Calibration for these observations may be challenging but Kreslavsky et al. (2004) and Shkuratov et al. (2005) report successful observations of as little as 0.2 % polarization variation on with ACS. Observations of standard stars in calibration program 9661 and observations of the Moon would be sufficient to obtain robust polarimetric calibration for the F475W with polarizers by the method of Kreslavsky et al. (2004), and Shkuratov et al. (2005). Note that we want to observe the spatial variation in polarization more than the absolute level, however.

Parallel observations in the WFPC-2 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 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	30707
F502N	1.4s	30709
F673N	0.3s	30710
F953N	1.0s	30711

The Two-Gyro Mode Handbook (sect. 4.3.5) states that external science observations will not be allowed in gyro mode, but does not state why. Our hope is that this and similar proposals will encourage STScI to find a way to work around this limitation (STScI policy is to develop capabilities for which there is a demand). Our exposures will be quite short and the target area large, so we do not expect the relatively small errors in pointing and tracking in two-gyro mode to degrade our science significantly. According to the chart in the summary of two-gyro mode capabilities, observations near 90° phase angle should be easy to achieve. Alternatively, it is hoped that HST will be refurbished, or that STScI will execute a "3 gyro campaign", that will enable these observations to be executed.

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, James Garvin's 10719 and John Caldwell's program 7717. Comparison with the proposed observations with our WFPC parallel data and with Garvin's Apollo 15 observations is part of our science goal. No polarization observations were carried out as part of Caldwell's or Garvin's programs.

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) at the 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.

10719—"Mapping Resources Potential of the Lunar Surface for Human Exploration"—PI James Garvin This DD proposal imaged the Apollo 15 and 17 landing sites, as well as the region around Aristarchus crater. Storrs et al. (2006) presented a preliminary reduction of this data.