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Selenology Today is devoted to the publication of contributions in the field of lunar studies.

Manuscripts reporting the results of new research concerning the astronomy, geology, physics, chemistry and other scientific aspects of Earth's Moon are welcome.

Selenology Today publishes papers devoted exclusively to the Moon.

Reviews, historical papers and manuscripts describing observing or spacecraft instrumentation are considered.

The Selenology Today

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EDITORIAL

This issue of Selenology Today is composed of a single section including an article by Kurt Fisher about pre-event planning and practice imaging by lunar amateurs prior to the summer 2009 LCROSS impact.

The LCROSS candidate impact list is being continually refined by the NASA-LCROSS Team. Shortly before publication, an additional communication from LCROSS principal co-investigator Tony Colaprete indicates that Erlanger (Crater C) and Cabeus may be eliminated from the candidate target impact list shown in Table 3 of this article due to topographical masking. The slope of these targets may be too great to allow a conservative estimate ejecta cloud to rise above their rims and be visible to Earth-based observers. A west longitude southern pole substitute for Cabeus is being considered.

Because of its continual refinement, it was not feasible to publish a real time updated list of LCROSS candidate targets. Nonetheless, the editors of Selenology Today feel that pre-impact practice focused on the impact candidates listed in Table 3, to be the best currently available plan to prepare imagers for imaging the actual event.

The final selected LCROSS impact will fall somewhere within a CCD frame of one of the candidate targets listed in Table 3. Finally, the article recites a launch date of May 7 - the date based on the best available information on February 20, 2009.

Based on last minute information, this date may slip forward to the original April 25, 2009 00UT scheduled launch date or to another after the publication of this edition of Selenology Today. Before the impact, Selenology Today will be issued an addendum to this Edition #13 that will update the article for new developments.

The Geologic Lunar Research group (GLR) set out to coordinate its team of observers for this impact event. This will be done completely through the internet, specifically through the use of e-mail.

The editorial Board of Selenology Today will collect images including possible primary anaysis if any impact effect will be detected with amateur instrumentation.

We invite all readers of Selenology Today to send possible observations (positive or negative) to editorial board:

Selenology_today@christian-woehler.de and glrgroup@yahoo.com

GETTING READY FOR LCROSS:

A Practical Guide to Planning and Pre-Event Practice for Amateurs

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Abstract

This article provides practical suggestions for pre-event planning and practice imaging by lunar amateurs prior to the July or August 2009 LCROSS impact. Effective amateur pre-event imaging practice is complicated by the fact that the NASA-LCROSS Team has not issued an integrated magnitude estimate for the impact's ejecta curtain. Some statement regarding the curtain's size can be made. The LCROSS impact is planned to occur when either the rising terminator is between E14 and W60 (38% to 93% illuminated fraction) or the setting terminator is between E60 and W14 (93% to 38% illuminated fraction). For practice imaging of the northern candidate target area Nansen F west to Hermite A and the southern candidate target areas from Faustini west to Cabeus, Table 5 and Table 6 list dates of favorable libration to study topography. Table 9 lists near passages of the Moon with the Pleiades and Saturn for exposure calibration practice. Table 10 and Table 11 suggest practice imaging of the satellite MStar 3 Centaur rocket booster, International Id. 1999-023B, through April 2009 to simulate imaging of the outbound LCROSS-EDUS booster. Practice imaging and photometry of the dark interior of polar craters, the dark limb behind such craters and the night sky above them between now and July will aid amateurs to (a) become familiar with the topography of the extreme south and north polar limb, the visual impression of which varies widely from libration, (b) make pre-impact exposure best-educated-estimates with their camera, telescope and filter combinations in support of an uncertain one-shot imaging event, and (c) pre-impact characterization of the unknown brightness of the lunar surface inside the dark interior of a polar crater. Northern pole targets remain favored by the current scheduled launch date of May 7, 2009 00UT. A preliminary announcement as to candidate targets should be made after launch on May 7, 2009. The LCROSS Team will announce final target selections 30 days before impact in August or September, 2009 after collecting further initial imagery and remote sensing data from the Lunar Reconnaissance Orbiter (LRO).

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1. Introduction

Sometime between mid-July and early August 2009, the LCROSS shepherding satellite will guide a 2,000 kg Centaur engine and fuel tank, called the Earth Departure Upper Stage (EDUS), at 2.5 km sec^{-1} for impact into the permanently shadowed region (PSR) of a polar crater. NASA scientist's principal scientific objective is to determine whether a substantial hydrogen or water (H_2O) resource exists in portions of lunar polar craters that are permanently shadowed. The resulting impact will provide lunar amateurs with a unique, once-in-a-lifetime imaging opportunity with uncertain characteristics.

An analogous impact crater and ejecta cloud from Apollo 14's Saturn IVB booster impact booster was captured in an Apollo 16 Panorama camera image sometime after the actual impact. Figure 1. The crater is about 40 m in diameter; the ejecta cloud extends for about 1 km around the crater; the scale bar is 1 km. One ejecta ray extends outside the image frame for about 5km from the impact crater.

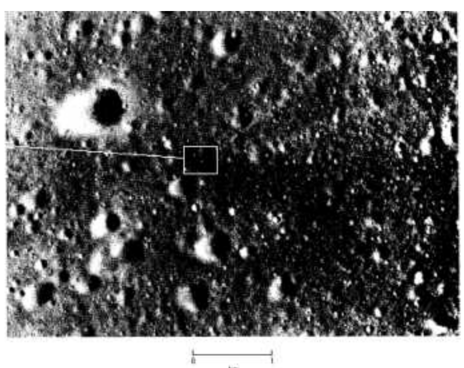


Figure 1 - Apollo 14 Saturn IVB impact crater and ejecta blanket from Fig. 29-52 in Whitaker (1972) (modified). Photo courtesy of NASA.

There are four events with uncertain visibility related to the summer 2009 LCROSS experiment. Two other events probably cannot be imaged or visually observed.

<u>First</u>, within the first 10 hours of mission launch, it may be possible to image excess hydrogen and oxygen fuel dumps from the Centaur booster after trans lunar insertion.

<u>Second</u>, within the first 30 mission hours, it may be possible to image the LCROSS-LRO

(Lunar Reconnaissance Orbiter) and LCROSS-EDUS satellite during its initial trans lunar orbit.

Third, it may be possible to image the empty Centaur booster is its three month lunar cruise orbit and before impact. It is unlikely, but warrants further investigation that it may be possible to image the Centaur booster-LCROSS shepherding satellite as it crosses the bright limb of the Moon. In theory, it is possible that on impact the initial flash could be seen, but this is unlikely, as most areas within permanently shadowed regions at the poles are obscured by crater rims. In theory, very favorable librations could make the point of impact and initial flash visible. A crater about 20 meters in diameter and 3 meters deep will be formed.

Fourth, for western hemisphere observers near the Pacific Coast, the impact ejecta dust curtain, if visible, should express within the first 60 seconds of impact and extend between 5 km (low-bound) and 30 km (high-bound) of the lunar surface. Southern continent observers in the western hemisphere are most favored by an impact during the first week of August, 2009. For North western hemisphere observers, the Moon will at a low altitude.

Because the impact point is obscured by a crater rim, after the impact Earth based-observers will be unable to image the post-impact crater.

If a water resource is present in the impact crater, within 25 minutes and extending for 24 hours after impact, an OH vapor molecular cloud is expected to form. If water is present, then solar radiation is expected to disassociate H_2O into an OH vapor cloud extending as much as 100km above the lunar surface. This OH vapor cloud will be visible at 308nm and 3000nm - wavelengths normally beyond the limits of amateur spectroscopy, photometry filters and CCD cameras.

Finally, there is a speculative possibility that an ionized H cloud will form that may be detectable as increased signals above a baseline solar spectrum. H_2O splits into OH- and H+. Pre-event and post-impact H*a* or H*b* images or spectroscopy images could be compared to detect an increased signal. Whether this speculative H cloud might be captured by a long-period exposure is worthy of further amateur discussion between now and the summer 2009 impact.

Figure 2 summarizes estimates of the visual brightness of the LCROSS-EDUS during its initial trans lunar cruise during mission days 1 through 5:

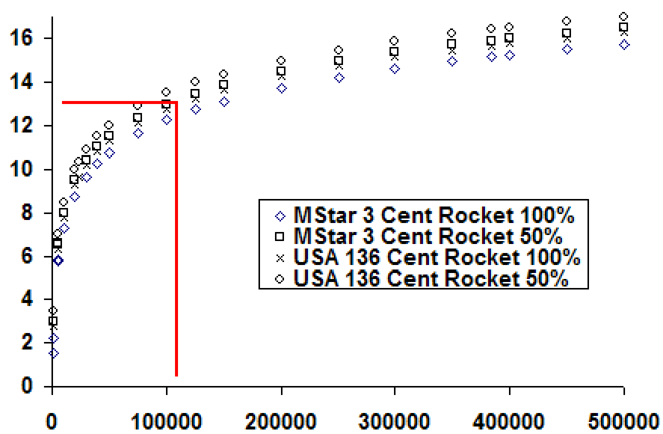


Figure 2 – Estimates of LCROSS-EDUS satellite magnitudes during initial Earth-Moon trans lunar cruise during mission days 1 to 5. y in mags; x in kilometers. (*See* discussion under Section 6.2; *compare* Figure 44, below).

During the first 30 hours of the initial trans lunar cruise, the LCROSS-EDUS booster conservatively should be visible using 10 to 12 inches of aperture to a distance of 100,000 km to 125,000 km from Earth.

NASA (2009f) issues a simple qualitative statement that “mission scientists estimate that the Centaur impact plume may be visible through amateur-class telescopes with apertures as small as 10 to 12 inches.” But the NASA-LCROSS Team has not issued estimates of the integrated magnitudes of the LCROSS-Centaur impact ejecta curtain in a form useable to amateur imagers for imaging practice.

The LCROSS Team has published two estimates of the size of the ejecta curtain - an early high-bound and a more recent low-bound estimate - as summarized in Table 1:

By	Id	Size km	Size arcsecs	T secs
Bart (2008) Slides 19-20; Wooden (2008), Sl. 2	LCROSS Team CBEIM (low-bound dust)	~ 10 x 5	> 3" x 2.5"	40-60
Heldmann (2006a), Sls 17-21	High-bound – ice & vapor	~ 35km	18" height	150-200

Table 1 - LCROSS Team estimates of EDUS impact ejecta curtain size at Earth as of 25 Jan. 2009 (T-secs means seconds after impact).

A third description of the predicted size of the ejecta cloud – related to the low-bound ejecta curtain – is recited in NASA (2008d) - a November 26, 2008 NASA LCROSS press release: "The densest and brightest part of the LCROSS ejecta plume is expected to extend two to four kilometers above the crater rim, which corresponds to 13 to 26 pixels in these images[,]" referencing a pixel scale of 0.3 km per pixel or about 8km by 4km.

In March 2009, Summy et al. (2009) published a fourth LCROSS Team description of the impact ejecta curtain, but they only include a graphical depiction of the dust ejecta curtain. Summy et al.'s figure does not allow an accurate estimate of the ejecta dust cloud size. But figure appears consistent with Bart (2008), Wooden (2008) and Table 1 for 50 seconds after impact.

It is expected that the LCROSS Team will issue an estimate of the likely magnitude of the ejecta curtain for use by amateurs between mission launch but before the impact event during August or September 2009.

Whatever apparent brightness the ejecta cloud will have will contrast against a 12 to 17 mpsas Earthshine illuminated lunar surface features and/or 4 to 6 mpsas Moonshine sunlight illuminated features (Montañés-Rodríguez and Goode, Sept. 2007).

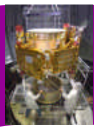
Because there currently is no official published LCROSS visual magnitude estimate that can be relied upon by amateurs, pre-planning event practice is difficult to undertake. As discussed in Section 8.3, a recommended practice integrated magnitude interval is between 0.9 magnitudes and 8.9 magnitudes. This corresponds to the faintest predicted integrated magnitude that can be seen against an upper median mpsas of the bright lunar limb (3.6 mpsas) and the faintest integrated magnitude that can be seen against the brightest upper median mpsas of the dark lunar limb (11.6 mpsas).

Because of the lack of predicted integrated magnitude for the ejecta curtain nothing can be concluded with any reasonable certainty. Based on currently available information, the assertion in NASA (2009f) that the EDUS impact will be sufficiently bright that it can be observed and imaged by amateurs using 10" or more of aperture cannot be corroborated here.

Under the low-bound scenarios and during the first 60 seconds after the impact, the dust cloud will slightly extend above the rim of Faustini or a north polar target, providing visual observers and imagers with a thin, line-like extended target.

NASA (2008f) is an entertaining 4 minute NASA-LCROSS Team video that summarizes the information in this article can be seen via the internet. It includes an animation of an ejecta plume somewhat larger than the high-bound estimate ejecta plumes discussed here.

Elphic et al. (2007) adds a wild-card to these professional and amateur estimates in the form of a proposed "wet pocket" hypothesis. The LCROSS Team Current Best Estimate Impact Model (CBEIM) estimates are based on an assumed, conservative 1% hydrogen and/or water content in target crater lunar regolith. Elphic et al. (2007) suggest that pockets of "wet" regolith may be preserved by burial beneath 1 meter of the surface and those pockets contain a maximum 20% water or molecular hydrogen content. Under this hypothesis, Lunar Prospector failed to produce evidence of polar H_2O because the maximum crater depth that Prospector could excavate, given its relatively light mass, was at most 1 meter. The LCROSS EDUS impact will excavate to a depth of about 3



meters.

If this less-likely, high-bound hypothesis proves to be true, the assumptions of the LCROSS Team Current Best Estimate Impact Model (CBEIM) will be invalidated and their CBEIM cannot be expected to accurately predict either the size or brightness of the ejecta curtain. If the optimistic Elphic et al. (2007) hypothesis is correct, the impact may have a much different brightness when viewed or imaged from Earth.

2. The inherent uncertainty surrounding the impact event

Science is about answering questions about unknown matters. Uncertainty is inherent in any experiment that seeks to discover the unknown.

2.1. Uncertainty concerning the ejecta cloud magnitude

Amateurs will mostly be interested in detecting the ejecta dust cloud from the EDUS impact – the most visually dramatic part of the mission. LCROSS Team publications acknowledge the inherent uncertainty in their CBEIM predications regarding the size and magnitude of this extended object.

With respect to LCROSS Team high-bound estimates, Schultz (2007) cautions that Earth-based observers should not be overly optimistic:

> The total ejected mass is predicted to be ~250,000kg but most of this mass will be deposited within three crater-radii of the crater rim. For reference, ~ 2800kg would be ejected greater than an altitude of 2km approximately 50s after impact, with the ejecta curtain achieving a diameter of ~ 8km across. Above an altitude of 10km, the total mass would be ~1000kg, 110s after impact with a curtain now 40km across. *These represent ideal conditions*. In reality, the ejecta curtain will likely exhibit clumps and irregularities as they achieve very large distances from the point of impact. *Any estimates of ejecta mass above an altitude of 10km is subject to great uncertainty due to the breakdown of scaling relations at very high ejection speeds*, i.e., early stages of crater growth."

With respect to LCROSS team low-bound estimates, Heldmann et al. (2008) also notes the that the low-bound CBEIM models include design margins to assure mission success. Low-bound estimates should be considered conservative. Thus, observers should not be overly pessimistic:

> To aid in the formulation of the LCROSS mission and measurement design, a compilation of model results has been built which summarizes the current best estimate for the impact event. This summary, called the Current Best Estimate Impact Model (CBEIM), includes both high and low values for a variety of relevant physical quantities including crater dimensions and ejecta velocities. In most cases the "current best estimate" was used for design purposes, however, on a case-by-case bases additional "margin" was allowed for by using the model results between the best estimate and the modeled low estimate (e.g., *often the values closer to the low-end expectation for the total ejected mass above 2 km were used in order to build in margin*).

Experience during another impact mission is consistent with these cautions regarding uncertainty. Richardson, Melosh and Greenberg (2003) also did pre-encounter impact modeling for the July 3, 2005 Deep Impact event. According to Sky & Telescope (2009), the Deep Impact ejecta cloud was more than 100 times its pre-event predicted size because the surface at the impact site was different than that assumed for pre-event models. McRobert (2005) and Univ. of Maryland and NASA (2008d) reported that this resulted in an ejecta cloud so large that it increased the brightness of Comet 9P/Tempel 1 by 2 apparent magnitudes and was observed by amateurs at 130,000,000 km using 9 to 24 inches of aperture (Bennion, 2005 (*e.g.* - animated image); NASA-JPL Horizons Ephemeris Service (1.3 x 10^8 km distance).

2.2. Uncertainty regarding the nature of the lunar soil at the impact site

Good experiments seek to resolve substantial questions regarding unknown matters where scientific minds can reasonably disagree. Such disagreement leads to controversy. LCROSS seeks to answer the significant question of whether future lunar exploration will be easier because a key live-off-the-land resource is present on the lunar surface, or whether lunar exploration will be harder because resources must be lifted from Earth to lunar L3 and L4 storage depots. Important questions and reasonable disagreement breeds controversy and makes for robust discussion. LCROSS is not an exception to this pattern of discourse.

The history of research concerning hypothesized lunar polar ice also is a classic example of the interplay of theory and observation. It is this interplay that makes the LCROSS experiment such an engaging and developing science story for amateurs to follow.

Uncertainty in the outcome of the EDUS impact is caused by the unknown characteristics of the impact site that LCROSS seeks to discover. Those uncertain characteristics, according to Jutzi and Benz (2006) and Jutzi and Benz (2008) concern (1) the concentration, nature and depth of known elemental hydrogen deposits, (2) the density and porosity of the lunar regolith (grain size and surface strength), and (3) the inclination of the terrain at the point of impact (*e.g.* - striking the side of a small hill). Shuvalov and Trubetskaya (2008) question that the percentage of regolith below 1 meter raised into the ejecta curtain may not be sufficient.

Scientific debate centers on two key questions: First, whether the natural processes that might deposit water layers in polar regolith are sufficient to create and preserve detectable layers of frost or ice. Second, whether the impactor, considering that a significant portion of its mass is contained in a hollow container, will excavate a sufficient mass of lunar regolith and will raise that mass to a sufficient height where a water or OH molecular signal can be detected by spectroscopy.

Watson, Murray and Brown (1961) proposed theories of lunar polar ice that reasoned comet impacts on the Moon would spray large areas with water ice and vapor. They suggested that some ejecta from a water-heavy cometary impact might trap water-ice in cold, permanently shadowed polar craters. Slade, Butler and Muhleman (1992) re-invigorated early theories by the discovery – through radar reflections – of ice in the permanently shadowed polar craters of Mercury. If ice can exist so close to the Sun, surely it must exist at the lunar poles?

Lucey et al. (2006) recite that Apollo lunar rock returns established a mean water content of lunar rocks at 0.045%.

Arnold (1979) outlined the parameters of the trapping and preservation of lunar polar H_2O deposits. There are three primary sources for H deposition into lunar regolith: (1)

solar wind reduction of lunar soil, (2) meteoroid impact, and (3) cometary impact. H_2O molecules in impact ejecta can skip or “sputter” across the lunar surface by a process of absorption and re-excitation in jumps of 120 to 250 km. Meteorite “gardening” reworks the lunar surface on the order of 10^4 years to a depth of 1 to 2 meters. Considering lunar polar precession, some craters at the poles may have been permanently shadowed on the order of 2 billion years. These permanently shadowed craters can form cold traps in which sputtering H_2O and disassociated OH molecules can be trapped and preserved. Once photo-dissociated, H molecules can be stripped from Moon since the solar wind can accelerate H atoms to escape velocity. OH molecules have 17 times the mass of H atoms and, hence, require 17 times the energy to reach lunar escape velocity. Unlike hydrogen, sunlight cannot provide sufficient energy to accelerate OH to lunar escape velocity. Instead, OH molecules skip or “sputter” across the lunar surface by a process of absorption and re-excitation. Arnold concluded that to trap H_2O or OH molecules, the craters must be sufficiently large and have sufficiently deep shadows to maintain temperatures below 200 Kelvins (-73 degs Celsius). Arnold estimated that the minimum diameter of a shadowed polar crater that would maintain such low temperatures at 30 meters.

Arnold (1979) created a model for possible lunar deposits: most-probably buried, but also exposed, ice banks in permanently shadowed craters.

Debate over Arnold’s model continued through the 1990s. Hodges (1991) reexamined Arnold’s model and concluded that effective transport of H_2O or OH molecules by sputtering was not possible. Free argon in the lunar regolith would combine and trap any free water molecules. If there is no transport mechanism, there can be no lunar polar ice. Hodges concluded that the “[p]rospects for finding useable resources for water ice in lunar polar cold traps appears bleak.”

Conversely, Morgan and Shemansky (1991) reexamined Arnold (1979) concluded that although at a greatly reduced transport rate compared to Arnold, OH molecules could be transported by sputtering to cold lunar polar ice traps and create ice layers up to 1 centimeter thick. But the lifetime of such deposits would be limited by the period in which the top 1 meter of the lunar regolith was recycled by meteorite impact “gardening” and by interstellar cosmic ray induced H Lyman evaporation of OH molecules. Even if cold-trapped in permanently shadowed craters, galactic cosmic rays striking the lunar surface can still evaporate ice. Morgan and Shemansky concluded that it might be possible for frost layers to be deposited and preserved, if such water-layers were buried by the ejecta blankets from nearby meteorite impacts before cosmic rays evaporated them. A thin overburden of regolith would prevent evaporation of the ice layer. Morgan and Shemansky predicted that: “[a] core tube driven into a permanently shadowed region would reveal an uneven pattern of alternating horizons of ice and regolith.”

Further observations from the 1998 Lunar Prospector mission re-invigorated the lunar polar ice debate. Feldman et al. (1998) reported low resolution neutron spectrometer scans of the Moon’s poles by Lunar Prospector detected elevated hydrogen concentrations (Goldstein et al., 1999; Feldman et al., 2000). Feldman et al. (2000) noted that Lunar Prospector scan data was calibrated using the hydrogen content in lunar rocks returned from Apollo missions and a low resolution map of elevated hydrogen concentrations at the lunar poles was generated. The low resolution Lunar Prospector hydrogen maps show H diffusely spread across the lunar poles.

However, the Lunar Prospector neutron spectrometer could only detect the presence of elemental H. Prospector could not determine identity of the molecules in which the hydrogen might be combined, i.e. – OH, H_2O or other hydrogen sulfides.

At the end of the mission on July 31, 1999, the Lunar Prospector satellite was crashed into south polar crater Shoemaker generating a 1 meter deep crater. OH or H_2O was not detected in its small ejecta plume. Goldstein et al. (2001) concluded that the negative result was caused by the dark limb of the Moon acting as a cold sink that quickly trapped most of the measurable volatiles from the impact.

Margot et al. (1999) surveyed potential cold traps at the poles using topographic data generated by radar interferometry. They estimated that pole-ward of 87.5 degrees at each pole, there were potentially 1,030 such cold-traps in permanently shadowed regions (PSRs) with a combined surface area of 2,550 sq km.

Feldman, Maurice and Lawrence et al. (2001) concluded that a 2 billion year "gardening" rate would be required to preserve water ice at 2 meters below the surface of the regolith.

Hodges (2002) reexamined the evidence for transport mechanisms and meteoritic gardening, repeating his earlier review, Hodges (1991). Hodges concluded that applying conservative transport parameters "the concept of water ice at the lunar poles is insupportable." Hodges also estimated the rate of lunar regolith turnover from meteoritic gardening to a depth of 15cm at once in 1 gigayear.

Bussey et al. (2003) re-examined the minimum latitude at, the best diameters for and the best locations for permanently shaded polar regions within craters based on Pike's 1977 relationships between crater depth and diameter (Pike, 1977; Pike, 1976). Bussey et al. (2003) computed the temperatures inside Pike-type simulated craters to characterize those craters that would have be sufficiently permanent and cold in order to be candidate lunar ice craters. Then Bussey et al. (2003) examined Clementine polar mosaics and identified all craters within 12 degrees of the poles that potentially could contain polar ice. 832 small craters were identified in the north polar region; 547 craters were identified in the south polar region. Together, these 1,379 craters contained about 7,500 sq. kilometers in permanently shadowed regions. Bussey et al. (2003) includes polar maps marking the locations of those craters. Their work updated the 1999 survey by Margot et al. Bussey et al. (2003) also proposed a significant new concept: ultra-shadowed craters-within-shadowed-craters may be the best cold trap candidates for lunar polar ice.

Campbell et al. (2006) conducted 20-m resolution, 13-cm-wavelength radar imaging of the south polar region and found no radar reflections consistent with surface ice, similar to that returned from ice at Mercury's poles. They concluded that the elemental hydrogen found by Lunar Prospector must be diffused throughout the polar regolith: "If the hydrogen enhancement observed by the Lunar Prospector orbiter indicates the presence

of water ice, then our data are consistent with the ice being present only as disseminated grains in the lunar regolith." *Id.*

Elphic et al. (2007) reprocessed Lunar Prospector hydrogen detection data and produced higher resolution hydrogen resource maps. Their resource maps associated Lunar Prospector elemental H concentrations with smaller polar sized craters. Elphic et al. (2007) concluded that in 19 km diameter Shackleton crater, "the derived count rates are consistent with 10% of the crater floor area having 20-wt% water-equivalent hydrogen." LCROSS Team members concluded that this may indicate a crater scaling effect to hydrogen resource concentration. Bart (2008, Slide 10). Larger craters above 50 km diameter, like Shoemaker, are less likely to contain high concentrations of hydrogen or water concentrations. Faustini was predicted to have 0.3% to 0.4% water content by weight.

In a second October 2008 deconvolution analysis of Lunar Prospector neutron detector data, Eke et al. (2008) concluded that the elemental H found by Lunar Prospector was not diffuse – it is concentrated in cold traps: "[T]he Lunar Prospector data alone require the polar hydrogen excess to be concentrated into the permanently shaded cold traps, rather than being more diffusely distributed. In some craters the concentration of hydrogen is sufficiently high that it corresponds to 1 wt% water." Eke et al. (2008) (at Figure 4) plotted DEM computed regions of permanently shadowed cold traps over their deconvoluted Lunar Prospector H concentration maps. Their Figure 4 graphically illustrates the association between cold traps and higher H concentrations.

In November 2008, Haruyama et al. (2008) imaged the interior of 10.5 km diameter south polar Shackleton to a resolution of 10 meters using Kaguya's Terrain Camera (Wood, 2008a (image)). They concluded that the lack of high albedo surfaces inside Shackleton precluded surface ice, but does not exclude that "water-ice that is present may be buried by a thin regolith (lunar soil) layer . . ."

The LCROSS Team and independent researchers have devoted significant effort to modeling the physical ejecta cloud that will result from the EDUS impact, the size of the impact crater and the likely brightness of that ejecta cloud, as seen both from an Earth and spacecraft viewpoint (Ernst and Schultz, May 2008 (high-velocity gun shooting solid pyrex spheres – initial impact flash); Hermalyn et al., March 2009 (high-velocity gun shooting hollow-sphere); Jutzi and Benz, 2006 (solid sphere impactor model); Jutzi and Benz, Feb. 2008); Korycansky et al., 2008 (solid sphere impactor model); Schultz , 2007 (crater scaling relationships); Shuvalov and Trubetskaya, 2008 (hollow sphere impactor model); Summy et al., 2009 (OH, H20 and ejecta dust cloud modeling); Wooden, 2008 (ejecta curtain reflectance model). For summaries of conclusions, *see* Bart (2008) at Slides 13-20; Bussey (2008a) at Slides 11-15; Heldmann (2006a) at Slides 14-20; and Wooden (2008) at Slides 2, 21-24.

These current LCROSS efforts are built, in part, on earlier work simulating crater impacts and the resulting dust ejecta clouds and vapor clouds by Schultz and Gault (1985), Schultz and Gault (1986a) and Schultz and Gault (1986b).

One of the more difficult aspects of modeling the LCROSS impact is that the EDUS booster is a complex hollow shape. The LCROSS Team predicts that the EDUS will make a crater about 3 meters deep – sufficient to excavate any hypothesized buried ice layers beneath 1 meter (Bart, 2008; Bussey, 2008a) and Heldmann, 2006a).

In February 2008, Shuvalov and Trubetskaya (2008) also modeled the predicted size of the EDUS's impact crater, using theoretical sphere shapes. Shuvalov and Trubetskaya concluded that because the EDUS is a hollow shell, it will excavate an impact crater 3 meters deep but most of the ejecta plume will consist of materials excavated from the upper 1 meter of meteorite "gardened" regolith. Shuvalov and Trubetskaya concluded that "[i]f the ice-rich regolith is covered by a layer of dry regolith more than 0.5–1 m thick, the ice may even not appear in the ejecta plume, thus significantly reducing the importance of the planned experiment." *Id.*

Hermalyn, Schultz and Heineck (March 2009) conducted follow-up high-velocity gun experiments using hollow-spheres, as opposed to the solid spheres used in Ernst and Schultz (2008). They found that hollow spheres were associated with lower dust curtain ejection angles that "depart from main-stage power-law excavation flow." The early high-speed ejecta consists of fine materials that have a relatively small volume compared to the total ejected amount. More testing and modeling will need to be done to characterize the ejection pattern of hollow spheres.

The year 2008 also saw a dramatic illustration of the role of uncertainty and serendipitous discovery in search for extra-terrestrial water. In May 2008, NASA (2008i) reports that the Mars Phoenix Lander settled on what appeared to be a slab of carbon dioxide ice buried by a thin soil layer.

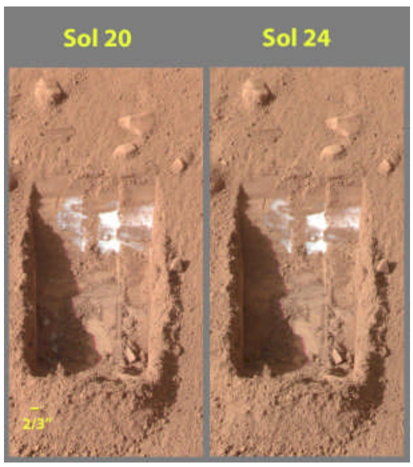


Figure 3 – Atmospheric evaporation of water ice crystals (small blue crystals in shaded lower left corner of trench) over four days at Phoenix landing site, Mars, June 2008 (NASA, 2008j). Photo Courtesy of NASA.

On June 20, 2008, NASA (2008j) reported that the Phoenix mission confirmed the presence of subsurface water ice at high north Martian latitudes. Considering the geographic size the northern Martian latitudes, that Phoenix serendipitously could land directly on a carbon dioxide ice slab and a water ice frost layer defies statistical probability.

2.3. Given the uncertainty, should amateurs image?

Wood (2008b) gives sage advice with respect expectations regarding these impact event: “[A]ll amateurs should attempt to image the event because there are too many variables to really make robust predictions – and observations are more authoritative than theory!"

In the remainder of this article, recommended pre-event amateur imaging practice is discussed first. Second, the LCROSS mission and each of the four LCROSS related imaging opportunities are discussed.

3. Impact targets

3.1. LCROSS target impact crater candidates

In November 2008, NASA (2008d) requested amateur imaging assistance for the following candidate targets for the LCROSS impact:

Target	Dia. km	Area	Lunar coords.
Region A – in Nansen F		North polar	84.45 N, 62.2 E
Crater F – k.n.a. Fibiger	17.7	North polar	86.2 N, 38.4 E
Faustini	41.5	South polar	87.5 S, 83.1 E
Shoemaker	50.9	South polar	88.3 S, 43.4 E

Table 2 - Candidate EDUS impact targets as of November 2008 (NASA, 2008d).

The USGS Gazetteer of Planetary Nomenclature lists the coordinates of Faustini as S87.3 E77.0. Therefore, the target described as Faustini in NASA (2008d) probably refers to a permanently shadowed region within Faustini.

Bart and Colaprete (March 2009) issued an expanded candidate list and maps for both the southern and northern areas. The expanded March 2009 candidate target list is:

Target	Dia. km	Area	Lunar coords.
Region A – in Nansen F	n/a	North polar	84.45N, 62.2E
Region D –area adjacent Nansen F	n/a	North polar	85.3N, 48.0E
Fibiger – f.n.a. Crater F	17.7	North polar	86.2N, 38.4E
Erlanger – f.n.a. Crater C	9.9	North polar	86.9N, 28.6E
Crater E – unnamed crater near NP	~13	North polar	89.1N, 93.3E
Hermite A – f.n.a. Crater B	20	North polar	87.8N, 47.1W
Faustini	41.5	South polar	87.5S, 83.1E
Shoemaker	50.9	South polar	88.3S, 43.4E
Cabeus	98.0	South polar	84.9S, 35.5W
Shackelton	19.0	South polar	89.9S, 0.0E

Table 3 - Candidate EDUS impact targets, revised March 2009 (Bart and Colaprete, 2009).

This March 2009 candidate list is provisional and a final candidate will be selected, in part, based on initial imagery and remote sensing data from LRO (Bart and Colaprete, 2009).

For the purposes of this article, the narrower November 2008 list target candidates identified in NASA (2008d) and Table 2 are discussed.

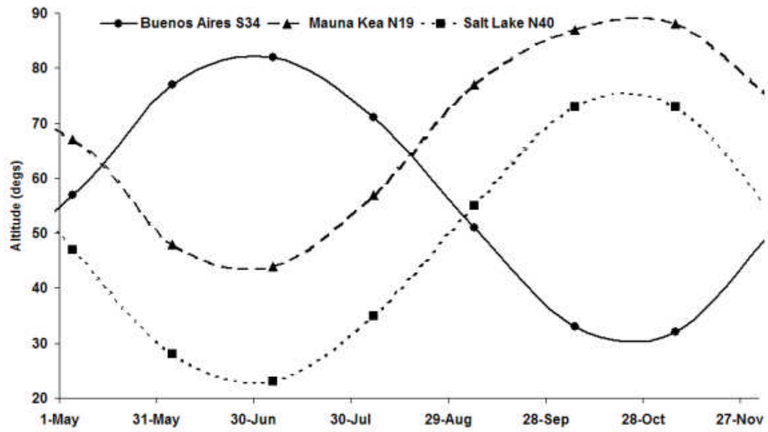


Figure 4 – Daily Altitude of the Moon at Transit for May-Nov. 2009 at three latitudes: S34, N19 and N40.

If the impact occurs between the second week of July and the first week of August 2009, western-southern hemisphere observers near the Pacific Coast will be most favored. For northern hemisphere observers, the tilt of the Earth's axis places the Moon low on the horizon during the July and August, but at a high altitude for southern hemisphere observers.

3.2. South polar candidate area

Location by Earth-based observers and the subtle illumination of the south target Faustini is shown in a December 8 imaging session by amateur Clif Ashcraft of Perrineville, New Jersey, Figure 5, below.

Ashcraft's image was taken on Dec. 8, 2008 at 4:27 UT with a 184mm Schupmann Medial and a DMK31 camera using an effective focal length of approximately 5100mm. South is up and left is east. Dots identify features as follows: Red – Schomberger, Blue – Schomberger A and C; Green – Malapert K; Yellow – the Malapert E "keyhole" crater. The Malapert E "keyhole" consists of two impact craters on the northern flank of south polar mountain Leibnitz Beta. The southern rim of Faustini is seen beyond Malapert E and southern edge of Leibnitz Beta.

The southern target zone around Faustini is shown in a less favorable libration in this Nov. 7, 2008 image taken by LCROSS Team astronomer Diane H. Wooden using the near-IR SpeX spectrometer and imaging camera of the NASA Infra-Red Telescope Facility (IRTF) on Mauna Kea, Hawaii, Figure 6, below.

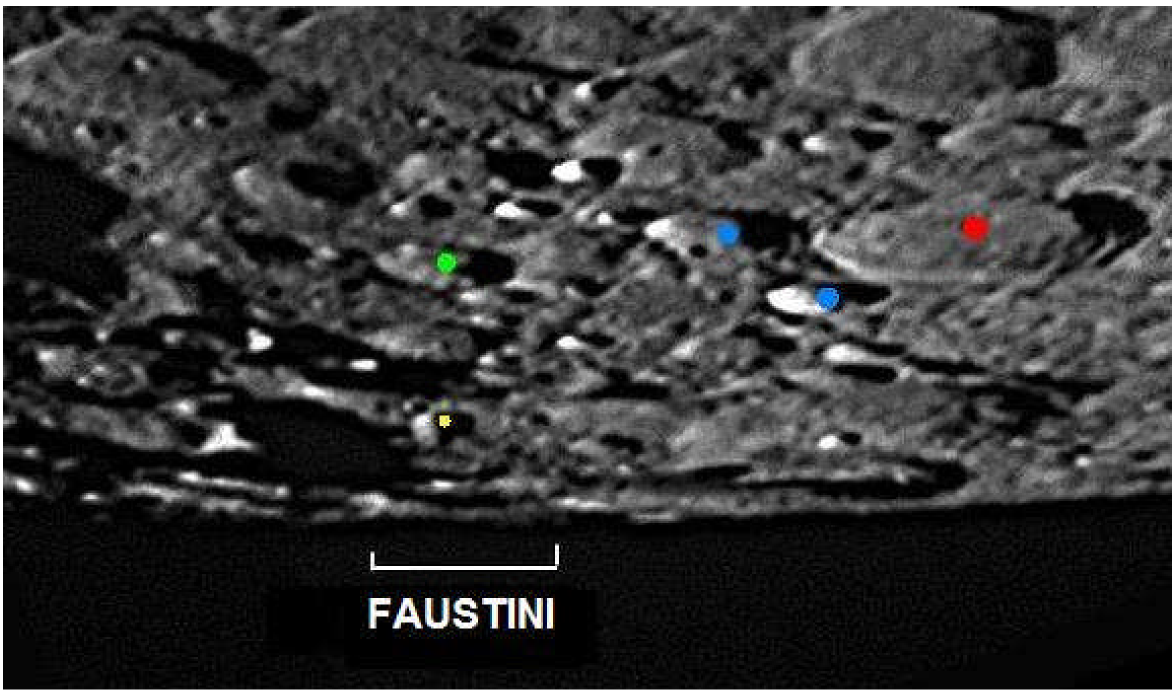


Figure 5 – Faustini and the southern polar area on 8 Dec. 2008. (Color-coded craters are identified in text). Photo courtesy of C. Ashcraft. In the image, lunar north is up and lunar east (celestial west) is to the right.

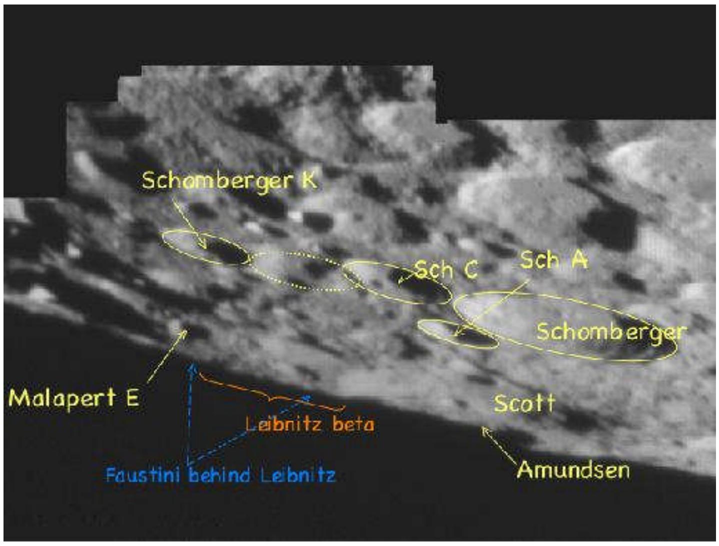


Figure 6 – The southern polar area around Malapert E on 7 Nov. 2008 (Malapert K mislabeled as Schomberger K, *see* USGS Gazetteer of Planetary Nomenclature) (NASA, 2008e). Photo courtesy of NASA and NASA Ames Res. Center. In the image, lunar north is to the upper-right and lunar east (celestial west) is to the right.

The Faustini-Shoemaker area is best found by locating Schomberger and its satellites, Schomberger A and C. Then traverse to Malapert K and proceed south to Malapert E, a small 17 km dia. "keyhole" shaped crater on the flanks of southern mountain Leibnitz Beta. After topographic orientation, observers typically directly locate Malapert E, but the Malapert E landmark becomes increasing invisible towards full Moon illumination.

The Earth-based view is extremely foreshortened and the true nature of the topography is shown in NASA 2008b: a 2007 digital-elevation polar-view model prepared by NASA's Jet Propulsion Laboratory data collected with the facility's Goldstone Solar System Radar. Leibnitz Beta is a massive plateau that Earth-based observers look over to see the far rim of Faustini.

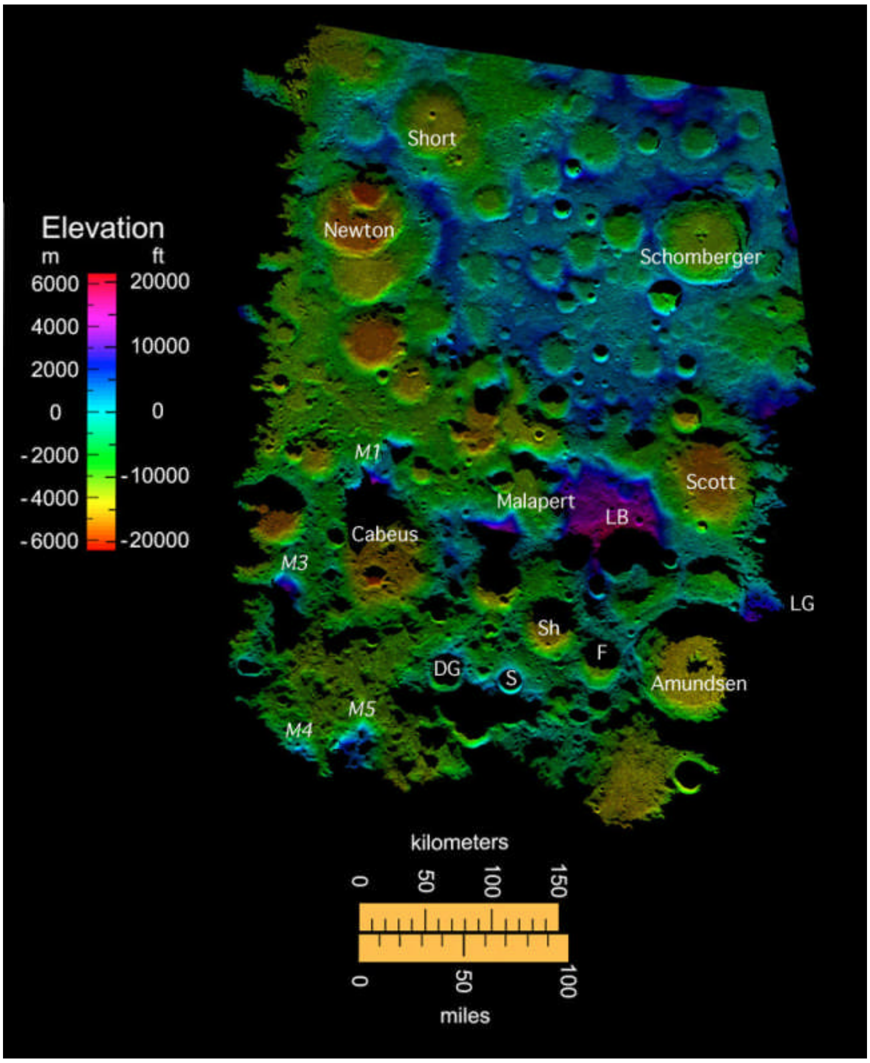


Figure 7 – A polar DEM rendering of the southern polar area prepared from Goldstone radar study (NASA, 2008b). Image courtesy of NASA and NASA Ames Res. Center.

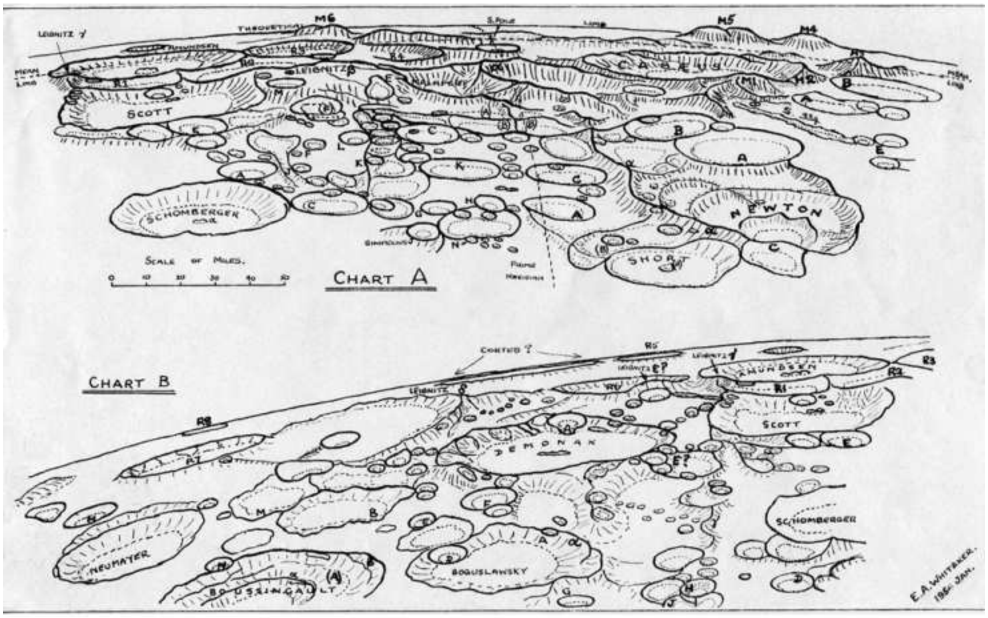


Figure 8 – Whitaker's 1954 Drawing of the South Polar Area (Wood, 2007; Whitaker, 1954). Courtesy of the J. British Astronomical Assoc.

In Figure 7, above, "F" is Faustini; "Sh" is Shoemaker; "S" is Shackleton and "LB" is Leibnitz Beta.

Whitaker's 1954 drawing of the lunar south pole, Figure 8, above, still is a useful reference map to deciphering the extreme limb view of this area (Wood, 2007). Mosher (2008) has prepared a composite image overlaying Whitaker's chart on a modern amateur image of the lunar south pole. On Whitaker's chart, Faustini is labeled "R3" and Shoemaker "R4".

In both Figure 7 and Figure 8 (Chart A), Malapert E "keyhole" feature is convenient landmark to orient oneself to the topography.

Figure 7 and Figure 8 nicely illustrates the technological progress of lunar science over 5 decades between 1954 – the pre-Sputnik era - and 2008 – during the post integrated circuit era.

Cabeus appears on Chart "A" of Figure 8 and is also shown in the following simulated illumination rendering:

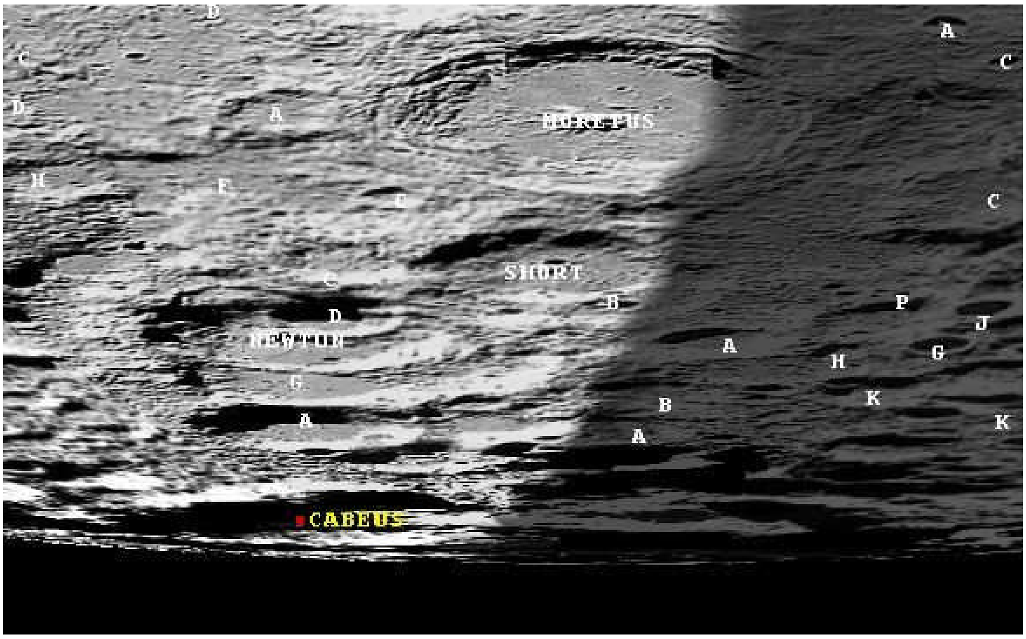


Figure 9 - Simulated view of west half of the southern target area and Cabeus on May 16, 2009 20UT in 3rd Quarter illumination at -2.5 degrees libration in latitude (Chevalley and Legrand, 2009, Virtual Moon Atlas). In the image, lunar north is up and lunar east (celestial west) is to the right.

Spudis et al. (2008) classify massifs in the south polar area, such as Leibnitz Beta, as being associated with the pre-Nectarian 3.9 Gyr South Pole-Aitken (SPA) basin. Faustini is a Nectarian impact. They reclassify Shackleton from the Eratosthenian age to a 3.6 Ga year-old Imbrian age.

3.3. North polar candidate area

The northern target area was more enigmatic during the December 2008 and January 2009 LCROSS Amateur Observing Campaign imaging sessions. Libration on those dates placed the Byrd C-D target zone directly on the apparent limb; Nansen F was on the farside of the apparent limb. A synthetic Earth-based and polar view renderings generated from the Clementine north polar mosaic (USGS, 1996b) using the LTVT software tool identifies navigation landmarks to the Bryd C-D area and the Nansen F area.

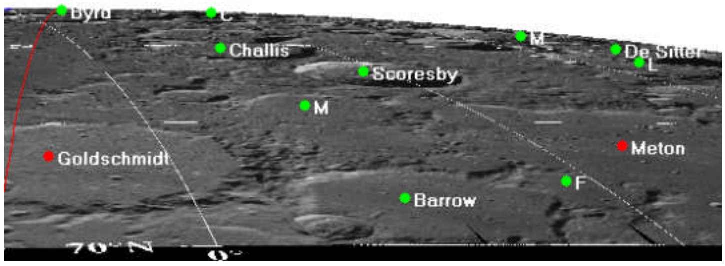


Figure 10 –Earth-based view of the Bryd C target area – east-half of northern pole - on 6 Dec. 2008 (Clementine USGS, 1996b (labeled using LTVT)). Image courtesy of USGS. In the image, lunar north is up and lunar east (celestial west) is to the right.

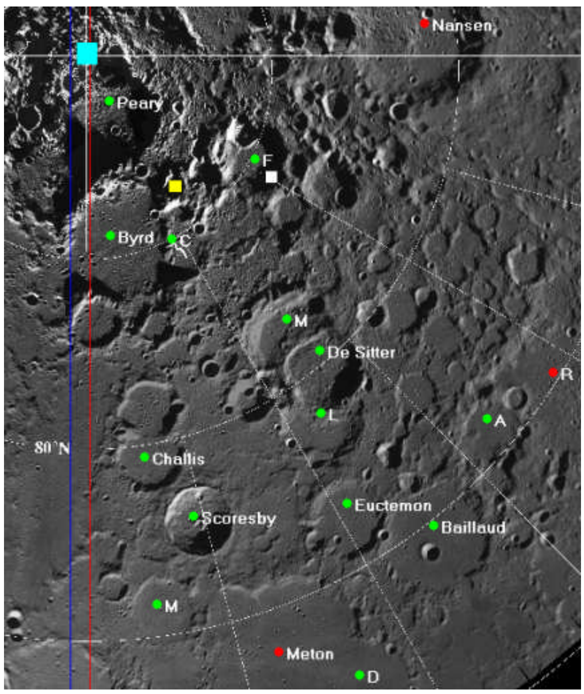


Figure 11 – Polar-view of the Bryd C and Nansen F target area on the east-half of the northern poless (Clementine USGS, 1996b (labeled using LTVT)). Image courtesy of USGS. In the image, lunar east (celestial west) is to the right.

In Figure 11, the white square in the floor of Nansen F is the northern target Region A. The yellow square between Nansen F and Byrd C is the northern target "Crater F". The North Pole is the blue-green square. A close-up of the area with south at the top and east to the left is shown in Figure 13, above.

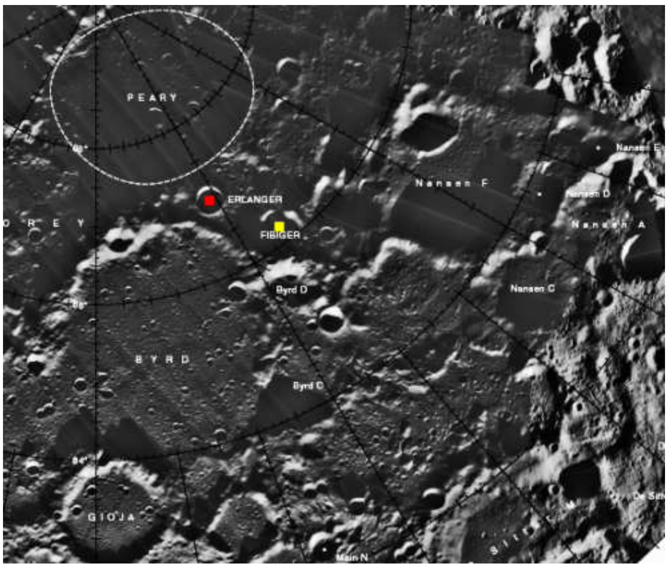


Figure 12- Location of newly I.A.U. craters Fibiger and Erlanger at north lunar pole (USGS, 2009a). Image courtesy of USGS. In the image, lunar east (celestial west) is to the right.

On January 22, 2009, the U.S.G.S. Astrogeology Research Program implemented I.A.U. nomenclature changes to the north polar area, LCROSS F was renamed Fibiger, after Danish Nobel Prize winning pathologist Johannes Andreas Grib Fibiger. The USGS Gazetteer of Planetary Nomenclature lists the coordinates of 17.7 km dia. Fibiger as N86.08, E37.3. Comparison of Fibiger's coordinates to the NASA LCROSS announced coordinates of Crater F at N86.2, E38.4 indicates that Crater F is Fibiger. This is also confirmed by an LCROSS slide presentation that graphically marks Crater F at the same location as Fibiger (Bart (2008), Slide 8; Margot et al., 1999).

A second crater near Fibiger is now called Erlanger, after American Nobel Price winning physiologist Joseph Erlanger (USGS, 2009b). This is same as LCROSS Crater “C”.

These nomenclature changes are reflected in Figure 12, above (USGS, 2009a). In Figure 12, Erlanger is labeled with a red square; Fibiger is labeled with a yellow square.

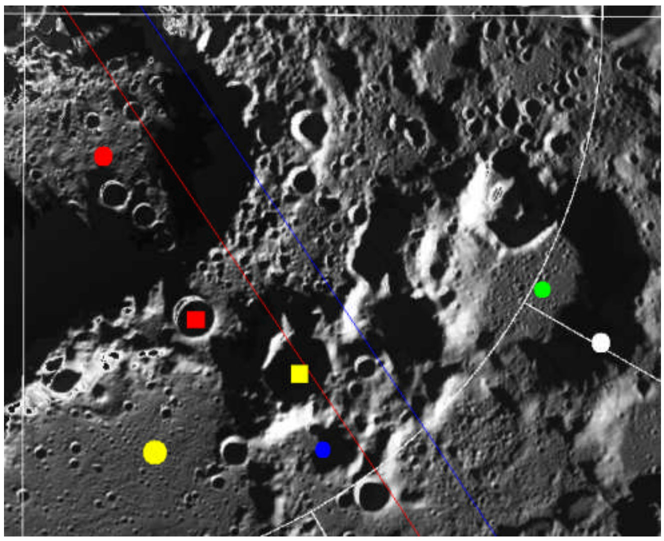


Figure 13 – Close-up polar-view of the Bryd C and Nansen F target areas with Bussey cold-traps (Clementine USGS, 1996b (labeled using LTVT). (Color-coded craters are identified in text). After Bart (2008), Slide 8; Margot et al. (1999). Terminator lines (red-blue) are for the beginning of the favorable libration imaging opportunity on 14 Feb. 2009 12:00UT. Image courtesy of USGS. In the image, lunar east (celestial west) is to the right.

In Figure 13, the North Pole is at the cross-hairs. The green dot is Nansen F. Region A is the white-dot labeled in the floor of Nansen F. Colaprete (2009) confirmed that. Region A is a suspected water-rich regolith area within shadowed crater Nansen F. The yellow square is Crater F-Fibiger. The blue circle is Byrd D. The yellow circle is the north end of Byrd. The red circle is Peary. The red square in Figure 13 is Erlanger – Crater “C”. Rükl (2004) shows this area on his chart - Libration Zone II.

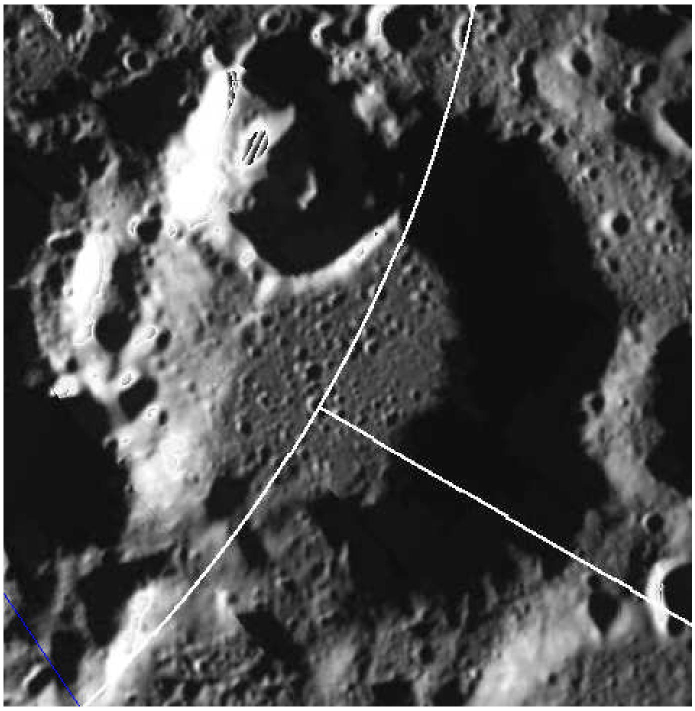


Figure 14 – Small craters on floor of the interior of Nansen F (Clementine USGS, 1996b) Image courtesy of USGS. In the image, lunar east (celestial west) is to the right.

Figure 14 shows a high resolution view of the interior of Nansen F. Any of the numerous small craters on the floor of Nansen F larger than 30 meters can act as a cold-trap (Arnold, 1979). Any such craters in the permanently shadowed areas of the Region A target area might be enhanced shadowed-craters-within-shadowed craters cold traps (Bussey et al., 2003).

Northern candidate targets added by Bart and Colaprete (March 2009) (Table 3) are shown in Figure 15:

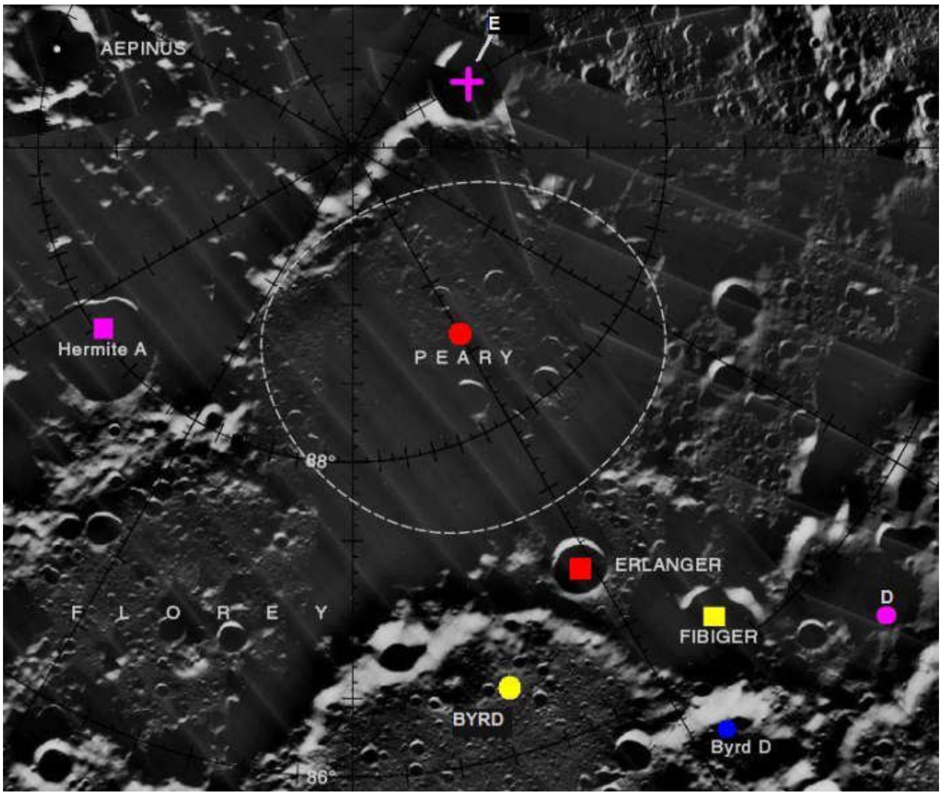


Figure 15 - Close-up polar-view of the Hermite A to Bryd D target area and the west-half of the northern pole (USGS, 2009a). Image courtesy of USGS. In the image, lunar east (celestial west) is to the right.

Color-coding of features in Figure 15 is after Figure 13, with the following additions: the purple square marks Hermite A, Crater E near the North Pole north of Peary is marked with a the purple "+" sign, and permanently shadowed Region D between Fibiger and Nansen F is marked with a purple circle.

Figure 16 is a synthetic image of the northern pole on April 9, 2009 at 11UT. Figure 16 shows the topography west from Nansen F to target candidate Hermite A:

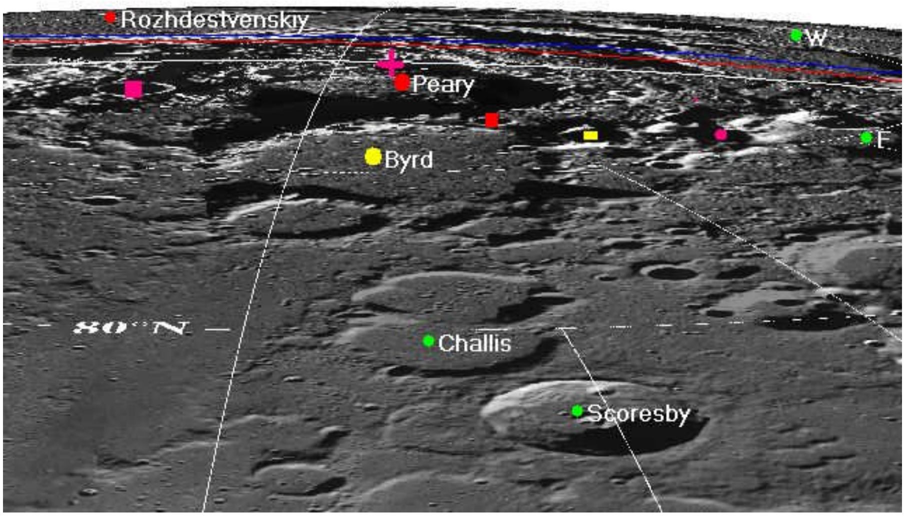


Figure 16 - Earth-based view of the Hermite A to Fibiger target area on 9 Apr. 2009 (Clementine USGS, 1996b (labeled using LTVT)). In the image, lunar north is up and lunar east (celestial west) is to the right.

Color-coding of features follows Figure 13 and Figure 15. Hermite A is the purple square; the purple "+" sign is Crater E, the red square is Erlanger; the yellow square is Fibiger; and the purple circle is Region D between Fibiger and Nansen F.

Images unambiguously showing the northern target areas were not obtained from the December 2008 and January 2009 LCROSS Amateur Observing Campaign sessions.

On Jan. 13, 2009, Adam Block captured this 3rd quarter illuminated image of the north and northeast lunar pole during a more favorable topographic study libration using 600mm of aperture, an effective focal length of 4755mm and an STL1100 camera from Mt. Lemon, Arizona:

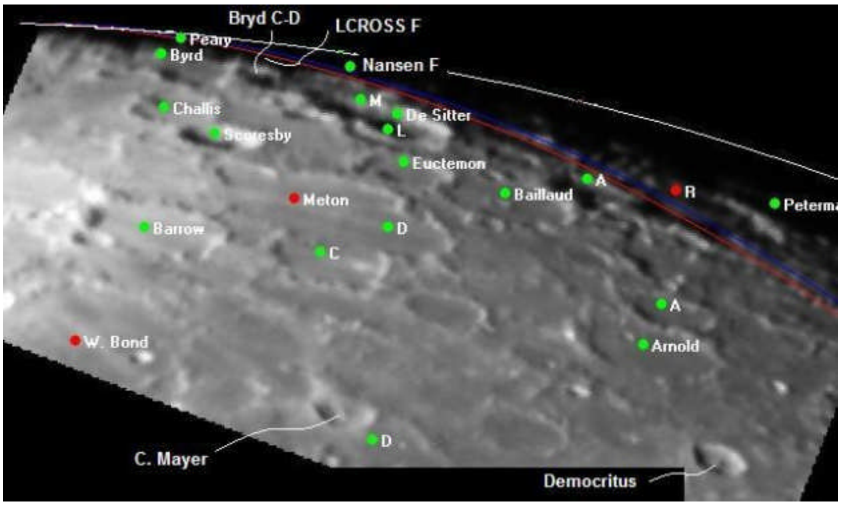


Figure 17 – Byrd C-D Area by Adam Block on 13 Jan. 2009 6:33UT. Photo courtesy of Adam Block/Mount Lemmon SkyCenter/University of Arizona. In the image, lunar north is up and lunar east (celestial west) is to the right.

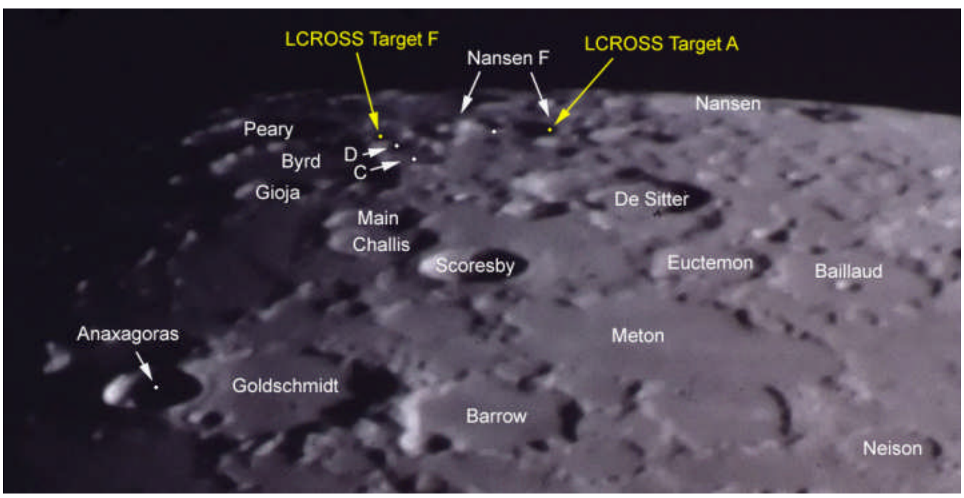


Figure 18 - 1975 Extreme libration image (+6.9 in latitude) by John Sanford. Labeling by J. Mosher. Photo courtesy of J. Sanford. In the image, lunar north is up and lunar east (celestial west) is to the right.

Bryd D is seen northeast of landmark crater Scoresby with the LCROSS target Crater F sitting in a dark well just inside the terminator.

Figure 18 is a 1975 extreme latitude libration image taken by John Sanford. Comparison of Sanford's and Block's images illustrates the need for pre-event practice observing and imaging in order for observers to become familiar with north polar topography under conditions of changing illumination and libration.

Telescopic navigation to these northern polar areas proceeds by locating either Scoresby or Meton and then moving north to locate Main and Challis. The Byrd C-D area lies on the shortest line between the centers of Main and Challis to the northern apparent limb. Nansen F is to the east of that point.

In favorable third quarter illumination, C. Mayer and Democritus are prominent guideposts which can used to locate Scoresby and DeSitter on the terminator. For smaller telescopes, C. Mayer, Democritus and Aristoteles form a large triangular asterism that eases initial orientation.

In first quarter illumination, the Nansen F target area is navigated to by proceeding northeast from DeSitter.

Further target location and navigation information for amateurs can be found at the comprehensive The-Moon-Wiki LCROSS Observing Campaign reference site maintained by LTVT co-creator Jim Mosher (Mosher and Bondo, 2009) and at the Pages section of the temporary official NASA LCROSS Observation Campaign Google Group (NASA, 2008g).

3.4 Final target selections have not been announced and may change

Final target selections have not been announced. Colaprete (2009) and Bart and Colaprete (2009) report that the LCROSS Team is still finalizing target selection based on the most up-to-date imagery from Kaguya and further Arecibo radar studies. Bart and Colaprete (2009) note that the LCROSS Team will use imagery and sensing data gathered by LRO (*e.g.* – mini-RF radar) during LCROSS's three month cruise phase to select the final target. A preliminary announcement as to candidate targets will be made shortly after launch (Kumar, 2009, quoting LCROSS Team member Heldmann). Final target selections will be announced thirty days before impact. Mission launch date is currently set for May 7, 2009 (Tooley, Feb. 12, 2009), a target date slipped from April 25, 2009 0UT (April 24, 2009, 8pm EST) (NASA, 2009b); NASA, 2009c).

Galal (2008), Slide 11, lists three possible mission lengths ending in either a north or south pole impact: 86 days (south pole impact), 100 days (northern impact) and 114 days (southern impact).

This implies probable impact dates of:

Launch Date	Mission Days	Estimated Impact Date	Impact area
24-Apr-09	86	19-Jul-09	Southern
24-Apr-09	100	2-Aug-09	Northern
24-Apr-09	114	16-Aug-09	Southern

Table 4 - Estimated Impact Dates based on Galal (2008), Slide 11.

However, a review of lunar librations in conjunction with the LCROSS mission constraint that the impact be observable by ground-based telescopes favors final selection of targets in the northern pole based on an April 25, 2009 or May 7, 2009 launch date:

No.	Dates	Pole	Description
1	Feb. 9 to Feb. 20	Northern	Libration nod in 3rd-4th Qtrs for Hermite A area. Max latitude libration for Hermite A of 7 degs on Feb. 15.
2	Feb. 25 to Mar. 6	Southern	Libration nod in 2nd Qtr. Max latitude libration of Faustini 5 degs around Mar. 3.
3	Mar. 7 to Mar. 21	Northern	Libration nod in 3rd-4th Qtrs. Nansen F at max. latitude libration approx. 7 degs around Mar. 13 then in shadow. Fibiger at max. latitude libration approx. 6 degs around Mar. 15 then in shadow. Hermite A max libration on 3-14-2009 at 7 degs.
4	Mar. 28 to Apr. 1	Southern	Libration nod in 1st Qtr. Max latitude libration of Faustini 6 degs at beginning of window around Mar. 28.
5	Apr. 2 to Apr. 17	Northern	Libration nod in 2nd-3rd Qtrs. Nansen F and Fibiger at max. latitude libration approx. 7 degs around Apr. 10 then in shadow beg. Apr. 12. Fibiger at max. latitude libration approx. 7 degs around Apr. 10 then in shadow about Apr. 15. Hermite A begins on Apr. 6 with max. latitude libration on Apr. 11 at 7.2 degs.
6	Apr. 29 to May 14	Northern	Libration nod in 1st-2nd Qtr. Nansen F at max. latitude libration approx. 7 degs around May 6 then in shadow beg. about May 10. Fibiger at max. latitude libration approx. 7 degs around May. 7 then in shadow about May 13. Hermite A in 2nd-3rd Qtrs begins on May 4 with max. latitude libration 6.5 degs on May 7.
7	May 26 to Jun. 10	Northern	Libration nod in 1st-2nd Qtr. Nansen F at max. latitude libration approx. 6.5 degs around June 2. Fibiger at max. latitude libration approx. 7 degs around June 3. Hermite A in 2nd-3rd Qtrs with max. latitude libration on Jun. 4 at 7.1 degs.
8	Jun. 9 to Jun. 16	Southern	Cabeus libration nod in 3rd-4th Qtrs. Max latitude libration on Jun. 16 at 7.6 degs.
9	Jun. 25 to Jul. 8	Northern	Libration nod in 1st-2nd Qtr. Nansen F at max. latitude libration approx. 6.3 degs around July 1. Fibiger at max. latitude libration approx. 6.3 degs around July 1. Hermite A in 2nd-3rd Qtrs beginning July 4 with max. latitude libration on July 4 at 5.5 degs.
10	Jul. 7 to Jul. 15	Southern	Cabeus libration nod in 2nd-3rd Qtrs. Max latitude libration on Jul. 15 at 6.4 degs.
11	Jul. 25 to Aug. 4	Northern	Libration nod in 1st-2nd Qtr. Nansen F at max. latitude libration approx. 7 degs around July 28. Fibiger at max. latitude libration approx. 7 degs around July 28.
12	Aug. 4 to Aug. 14	Southern	Brief southern libration nod in 2nd 3rd Qtr. Max latitude libration of Faustini 3 deg around Aug. 6-7, then Faustini is in shadow. Cabeus libration nod in 2nd-3rd Qtrs. Max latitude libration on Aug. 12 at 6.3 degs.
13	Aug. 23 to Sept. 2	Northern	Libration nod in 1st-2nd Qtr. Max Libration of Nansen F at Aug. 25. Fibiger max libration and enters sunlight on Aug. 26.

Table 5 - Libration cycles from February to August 2009 with favorable maximum librations in latitude.

Table 5 lists favorable libration-in-latitude observing windows based on a 40N, western continental United States observing point using United States dates. The topographically favorable windows identify libration nod cycles. A "libration nod" refers to the apparent view of a target area as it is first on the apparent limb. On successive lunar days, an observer will see the target exhibit an apparent motion where it moves off the limb and then returns to the limb. For individual observing points, actual libration in latitude and the date of maximum libration will vary from those shown below due to topocentric libration. Specific dates for individual observing points should be verified using lunar planetarium software.

The implication of the libration nod cycles shown in Table 5 is that there are no favorable libration cycles for the southern polar areas from mid May through early August, except for Cabeus in mid-July. A consequence of that Earth-Sun-Moon geometry is that LCROSS will most likely impact in the northern polar area for a launch date of May 7, 2009 in order for the impact to be visible from Earth-based ground telescopes, although some possible mission schedules allow for a south polar scenario.

The foregoing discussion does not mean that the southern target area is no longer relevant for the pre-event practice and study discussed below. The LRO-LCROSS launch date has been rescheduled several times, *e.g.* - most recently on the April 24, 2009 date. If the May 7, 2009 launch date is scrubbed, a new launch window will be evaluated. That future launch window might dictate a southern polar target.

Again, all this is provisional and will change based on the LCROSS Team’s final target selection announcement thirty days before impact.

Figure 13 of the north polar target area illustrates the theory behind selecting the best crater to target the EDUS on.

The 1999 Lunar Prospector satellite impact into Shoemaker failed to produce a sufficient ejecta plume to return useable data. Lunar Prospector had a mass of 156 kg and impacted

at a low angle at 1.7 km sec^{-1}. At most on impact, Prospector possessed 2.25E+8 Joules of kinetic energy and produced a crater only 1 meter deep.

This top meter of lunar soil is routinely churned by small impacts over the course of 1 billion years. Thus, Lunar Prospector did not have sufficient energy to penetrate to a hypothesized hydrogen or water resource layer beneath a depth of 1 meter. Bart (2008).

At a velocity of 2.5 km sec^{-1}, the 2,000 kg EDUS will impact with a kinetic energy of 6.5E+9 Joules. The EDUS will excavate to 3 meters in depth. Colaprete (2008). It is believed that the higher LCROSS impact force will produce a larger ejecta cloud that will yield a detectable signal.

As noted above, Elphic et al. (2007) produced higher resolution hydrogen resource maps associated with smaller sized craters. Elphic et al. (2007) concluded that in some small craters, "wet pockets" of 10% water by weight are not excluded by available evidence. Similarly, Bussey et al. (2003) suggested that small shadowed craters within other permanently shadowed craters may be the best cold trap candidates.

The smaller northern polar craters like Fibiger may be the final preferred target.

4. Recommendations for pre-event imaging practice

4.1. Generally

Recommended amateur imaging practice dates are grouped into three categories: topographic, exposure calibration, and amateur photometric research. Topographic familiarization is designed to acquaint the amateur imager with the topography of north and south polar areas near target craters. Variations in illumination at the poles makes acquisition of specific targets – that may be completely or almost fully shadowed – difficult for beginner and intermediate imagers. Exposure calibration involves practice imaging to determine the effect of capturing relatively faint 3 to 6 mpsas extended objects against the partially illuminated lunar limb, the dark limb, or backscattered washed-out background sky between 12 to 17 mpsas – conditions similar to the EDUS impact scenarios discussed here. Photometric research concerns better defining the relative and absolute brightness of shadowed crater floors, half-illuminated crater rims, background dark limbs, and backscattered bright night sky above the apparent lunar limb.

Winter weather over much of the continental United States on January 2, 2008 prevented most amateurs from participating in the January session of the LCROSS Amateur Observing Campaign. Clif Ashcraft managed a grainy image during adverse winter weather that illustrates the importance of the topography and subtle contrast changes can have when imaging the July or August 2009 impact.

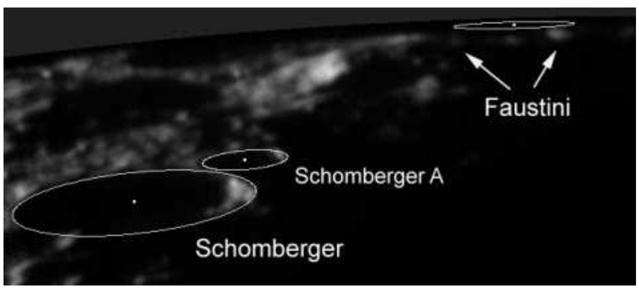


Figure 19 – Faustini on 1 Jan. 2009 at 23:23 UT. Photo courtesy of C. Ashcraft. In the image, lunar *south* is up and lunar east (celestial west) is to the *left*.

Compare Figure 5 with Figure 19. If the actual EDUS impact occurs in illumination conditions similar to December 2008, then the ejecta curtain will rise out of the dark crater floor, pass a half-illuminated crater rim and then be contrasted against the terminator backscatter night sky. If the impact occurs in conditions similar to January 2009 shown in Figure 19, then the ejecta curtain rises directly into night sky and their appears to be less backscatter from the surrounding terrain into the crater floor.

Creating an aesthetic image of the impact will probably require two images – one exposing the fainter ejecta curtain but overexposing illuminated features on the terminator. The second exposure will correctly expose lunar terminator features. As with imaging Venus-Moon conjunctions, the two exposures will have to be combined using digital darkroom techniques.

4.2 Topographic recognition practice

Figure 5, Figure 18 and Figure 19 illustrate the need for pre-event topographic recognition practice before this unique one-shot event. The illuminated topography of the poles changes significantly by both the colongitude of the terminator and libration. Intermediate lunar imagers should not assume ease of target recognition.

Ideally, topographic recognition practice should be done on those dates libration and sun angle at the poles is similar to the libration and sun sun angle as it will be seen at the date and time of the impact. As noted above, final target selections and the date of the impact are not known at this time. Initially, it was thought that libration would be similar to libration over the target area during LCROSS Team Observation Campaign imaging requests of Nov. 2008, Dec. 6-8, 2008 and January 2, 2009. Review of images during those times indicate that may not be a correct assumption. For example, in the Nov. 2008 session image, Figure 6 above, Faustini was obscured behind Leibnitz Beta. On January 2, 2009, the Byrd C-D and Nansen F areas were not on the nearside of the apparent limb.

On February 1, 2009, members of the LCROSS Observation Google group informally started to gather a catalogue of images of the northern and southern target areas through one entire apparent libration “nod” for both features – that is when the north or south target area first becomes visible on the apparent limb, through maximum favorable libration, and back again to a position near the apparent limb. Images gathered during that informal project will provide a baseline catalogue to aid visual and photograph amateurs to pre-plan based on the likely topographic appearance of the final selected target area.

Although the position of features during the entire course of a “libration nod” can easily be simulated with planetarium software such as Virtual Moon Atlas, illumination of features on each day of a “libration nod” cannot be simulated well by currently available software.

Observers can learn much from becoming familiar with the target zones when they present at favorable librations. Table 5, above, lists the dates of favorable libration nods and the maximum libration-in-latitude of the current target candidates. Observers should use Table 5 as their primary planning guide for practice imaging at topographically favorable librations-in-latitude. Table 5 presents estimated dates from which observers can do a quick planning assessment can be done, but specific dates and these libration cycles should be checked for an individual observing point using a lunar planetarium program.

Figure 17, above, is an example of a topographic study taken at a favorable imaging libration for the northern target area.

Table 6 is a more defined list of universal dates and times of combined favorable libration and illumination limited to the Byrd C-D Fibiger, Nansen F and Faustini target areas:

Target	Date	Time UT	Qtr	Termin-ator	Lib. Lat.
Faustini	2009/02/28	14:38	1	43E	-5.6
Nansen F	2009/03/13	19:00	3	62E	+7.1
Byrd C-D	2009/03/16	12:00	3	29E	+6.6w
Faustini	2009/03/30	03:59	1	42E	-5.9w
Nansen F	2009/04/12	19:00	3	56E	+6.3
Byrd C-D	2009/04/15	12:00	3	23E	+4.2
Faustini	2009/04/28	16:24	1	42E	-3.3
Nansen F	2009/05/12	03:00	3	58E	+4.3w
Byrd C-D	2009/05/31	14:00	1	00E	+5.2
Nansen F	2009/05/31	14:00	1	00E	+5.2
Byrd C-D	2009/06/27	03:00	1	29E	+4.6
Nansen F	2009/07/25	07:00	1	52E	+5.5w
Byrd C-D	2009/07/27	17:00	1	22E	+6.6

Table 6 - Imaging practice opportunities of selected target areas during topographically favorable librations for Feb. 2009 through 31 July 2009 based on an observing point at W118 41N. Computed using LTVT.

The “w” symbol in the right-hand column of Table 6 indicates events that are observable for Intermountain and Pacific western continental United States observers.

While observers can benefit from pre-event topographic recognition of the polar regions above north 80 degrees latitude, their pre-event practice can be refined by applying the knowledge that the LCROSS impact is also constrained to certain phase ranges. NASA (2008d) and Heldmann (2007) (at Slide 11) notes that "[t]he LCROSS mission plans to impact the moon when the lunar phase is approximately between 76 degrees and 150 degrees [during the 1st and 2nd lunar quarters] and between 210 and 284 degrees [during the 3rd and 4th lunar quarters]." NASA (2008d) use of the term “lunar phase” refers to the *lunar age* of the Moon – that is its orbital position during one revolution around the Earth across 360 degrees beginning at the New Moon as measured from the Earth. These LCROSS lunar orbit constraints create 60 degree exclusion zones centered around the new and full Moon and are designed to “provide sun avoidance for space-based telescopes, such as the Hubble Space Telescope” (NASA, 2008d).

The LCROSS impact target lunar ages correspond approximately to the following terminator positions and lunar days:

Lunar Age	Lunar Day	Terminator longitude	Terminator Type	Illuminated Fraction	Quarter
76 to	6.2	E14	Rising	38%	First
150	12.3	W60	Rising	93%	Second
210 to	17.2	E60	Setting	93%	Third
284	23.3	W14	Setting	38%	Fourth

Table 7 - Lunar ages during which the LCROSS impact will occur

Pre-event topographic practice can focus on those ages of the Moon which coincides approximately to lunar days 6 to 12 and 17 to 23.

Comparing these constraints with libration nod cycles in Table 5, provides guidance to select some representative librations and illuminated fractions for synthetic rendering of the northern polar area at the limits of LCROSS illuminated fraction and age constraints:

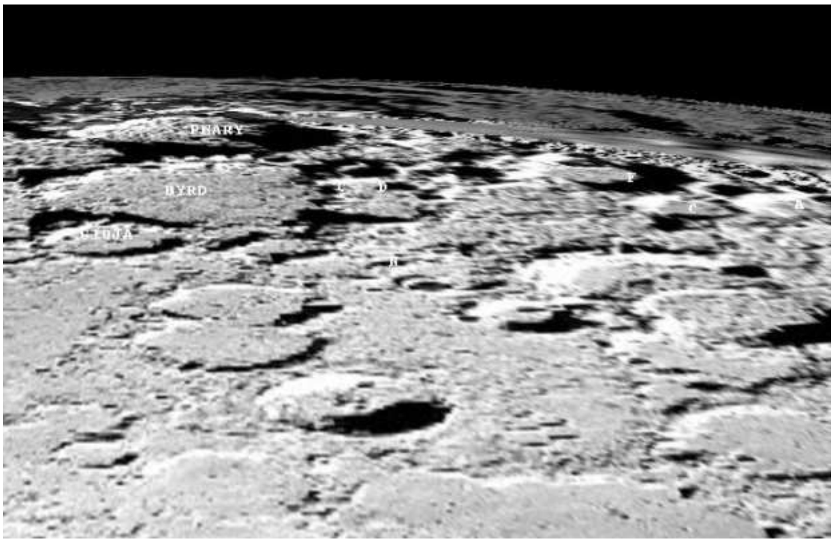


Figure 20 - Simulated view of east half of the northern target area in libration nod practice window no. 3 per in Table 5 on March 12, 2009 in Third Quarter at 93% illumination and +6.2 degrees libration in latitude (Chevalley and Legrand, 2009, Virtual Moon Atlas). In the image, lunar north is up and lunar east (celestial west) is to the right.

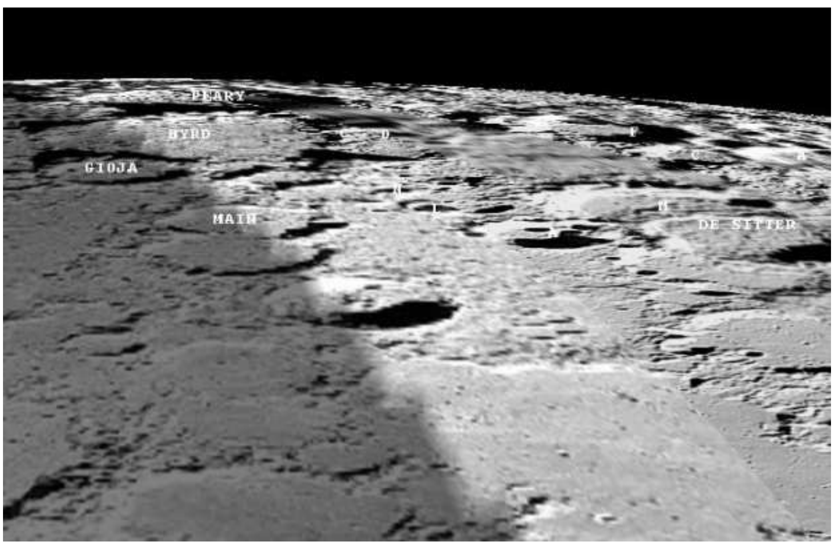


Figure 21 - Simulated view of east half of the northern target area in libration nod practice window no. 7 per in Table 5 on May 29, 2009 in First Quarter at 38% illumination and +3.0 degrees libration in latitude (Chevalley and Legrand, 2009, Virtual Moon Atlas). In the image, lunar north is up and lunar east (celestial west) is to the right.

These illuminated fraction range endpoints are more favorable for imaging, since the backscatter and glare of the Moon's bright limb is less near candidate impact points. But, there is nothing in the LCROSS target age constraints that prohibit conducting the impact in the middle of the range of illuminated fractions instead of at the more favorable endspoints. Comparing these constraints with libration nod cycles in Table 5, above, indicates that there are no 3rd Quarter opportunities to image the Faustini southern area from February through the end of July.

4.3 Exposure calibration practice

Observers can also profit from exposure calibration practice, considering the LCROSS impact is a one-shot event with uncertain brightness.

One strategy for pre-event exposure calibration consists of taking out-field images of faint planetary objects that have similar exposure times to the expected impact. Then image the south and/or north polar areas in order to explore the characteristics of glare and over-exposure on lunar features.

Table 8 lists the brightness of planets in terms of magnitudes per square arcsecs in a range similar to the predicted brightness of the ejecta curtain within 40 to 60 seconds after impact:

Object	Mpsas	Dia. arcsecs	Integrated magnitude
Mars	4.0	3.5-25	-2.9 to 1.8
Jupiter	5.3	30-50	-1.6 to 2.9
Ceres	6.0	0.84 – 0.33	6.7 to 9.3
Saturn	6.7	14-20	0.4 to 1.2

Table 8 - Integrated magnitudes and MPSAS for selected outer planets and minor planets.

Another pre-event exposure practice would be to image the Moon, either out-field or during occultation, as its passes the Pleiades.

The Pleiades contains a good spread of stars between magnitude 0 and 9. Imagers can use those passages to make exposures of the Pleiades that capture various limiting magnitudes of Pleiadean stars and then image the lunar polar target areas at those exposures.

Such practice might enable imagers to explore glare and over-exposure patterns in the target areas at various exposure settings. Lunar grazes by bright stars is another in-field imaging practice opportunity.

Sky & Telescope (1969) reports an example of an in-field lunar graze by the bright star Antares.

Grazes by fainter stars between magnitude 0 and 9 can be identified using software (Occult 4.0) and city-graze lists of the International Occultation Timing Association (IOTA, 2008; Herald, 2008).

Table 9 lists passages of the Moon near selected bright planets, stars and the Pleiades through July 31, 2009.

Date	Time UT	Object	Position
2009/03/03	08:00	Moon	0.8 deg N of Pleiades
2009/03/10	12:34	Ceres	21.2 deg N of Moon
2009/03/11	02:36	Saturn	6.22 deg N of Moon
2009/03/17	05:00	Antares	0.2 deg S of Moon
2009/03/30	14:00	Moon	0.6 deg N of Pleiades
2009/04/04	09:00	Moon	1.7 deg S of M44
2009/04/06	12:36	Ceres	19.3 deg N of Moon
2009/04/07	07:19	Saturn	6.1 deg N of Moon
2009/04/13	13:00	Antares	0.4 deg S of Moon
2009/04/26	21:00	Moon	0.4 deg N of Pleiades
2009/04/29	02:00	Moon	1.8 deg N of M35
2009/05/03	19:22	Ceres	17.2 deg N of Moon
2009/05/04	11:22	Saturn	6.15 N of Moon
2009/05/10	21:00	Antares	0.5 deg S of Moon
2009/05/17	07:49	Jupiter	3 deg S of Moon
2009/05/31	10:08	Ceres	15.8 deg N of Moon
2009/06/07	04:00	Antares	0.6 deg S of Moon
2009/06/28	01:58	Saturn	6.5 deg N of Moon
2009/06/28	07:25	Ceres	14.8 deg N of Moon
2009/07/04	10:00	Antares	0.5 deg S of Moon
2009/07/18	03:00	Moon	0.5 deg N of Pleiades
2009/07/26	09:16	Ceres	14.0 deg N of Moon

Table 9 - Imaging practice opportunities during lunar passages of major open clusters, faint planets and bright star Antares – 1 Jan. 2009 to 31 July 2009 based on a W111 N41 observing point for planets (RASC, 2009; USNO , 2009).

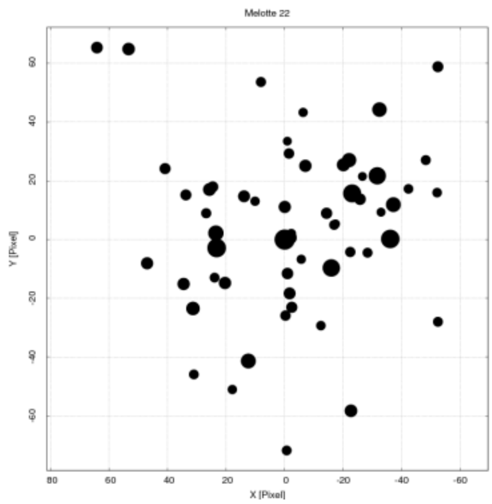


Figure 22 – Magnitude plot of Pleiadean stars between magnitudes 0 and 9 (Mermilliod and Paunzen, 2008). Chart courtesy of Webda Cluster Database/ Institute of Astronomy of the University of Vienna.

Magnitudes of the Pleiadean stars can be plotted by most planetarium programs commonly used by imagers. Figure 22, above, graphically shows the magnitude and position of Pleiadean stars between magnitudes 0 and 9.

The Webda Open Cluster Database is an easily accessible internet database that provides the magnitudes, position and membership of known star clusters (Mermilliod and Paunzen, 2008).

4.4 Spectroscopy

For amateurs wishing to attempt spectroscopy, two images would be required to detect any increased signal from hydrogen or sodium above a solar spectrogram as discussed further, below. Table 6 lists favorable times at which a baseline spectrogram can be taken above the lunar limb in target areas.

4.5 Photometry

Photometry research involves using absolute and differential photometry of the glare features and dark areas in the floor of polar crater Faustini and surrounding other northern target areas.

4.6 Imaging satellite MStar 3 Centaur rocket booster, Int'l. Id. 1999-023B

Imaging an outbound LCROSS-EDUS can be simulated by imaging satellite MStar 3 Centaur rocket booster, International Id. 1999-023B, U.S. Space Command Id. 25725. The MStar 3 booster is a Centaur-class upper stage similar in size to the LRCOSS-EDUS booster. It is in a near-Earth orbit with a perigee of 706km (1.5 mag at 100% illumination), an apogee of 5,148km (3.0 mag at 50% illumination) and an orbital period of 149 minutes. This Centaur booster is a current frequent target of satellite observers; there are more than 150 observations listed in the Heaven's Above observer database, the most recent haven been made on 22 Jan. 2009 (Heaven's Above, 2009).

Satellite overflight opportunities are observing point specific. The reader should consult an online ephemeris such as Heaven's Above or CalSky for favorable overflights at their location.

Table 10 lists favorable overflights above 40 degrees altitude of the Milstar 3 Centaur booster for observing points Salt Lake City, United States, Rome, Italy, Hong Kong and Delhi, India from February 1 through March 31, 2009.

This is an incomplete list of selected opportunities; many other lower altitude opportunities exist at all observing points; and no observing opportunity in the table coincides with a desired observation near apogee:

City	Date	Time UT	V	Dist. km (obs-sat)	Sun alt deg	Moon alt deg
SLC	08-Mar-09	11:38	5.4	3252	-25	4
SLC	09-Mar-09	12:30	5.5	3283	-16	42
Rome	10-Mar-09	03:20	5.3	3176	-25	21
Rome	11-Mar-09	04:12	5.4	3246	-15	14
SLC	11-Mar-09	11:34	5.1	2924	-25	19
SLC	12-Mar-09	12:26	5.2	2558	-15	22
Rome	13-Mar-09	03:16	5.0	2884	-25	28
Rome	14-Mar-09	04:08	5.2	3040	-15	22
SLC	14-Mar-09	11:30	4.8	2666	-25	22
SLC	15-Mar-09	12:22	5.1	2867	-15	25
Rome	16-Mar-09	03:12	4.8	2663	-24	24
Rome	17-Mar-09	04:04	5.1	2900	-15	22
SLC	17-Mar-09	11:26	4.6	2477	-25	22
SLC	18-Mar-09	12:18	4.9	2755	-15	20
Rome	20-Mar-09	04:00	5.0	2831	-14	16
SLC	20-Mar-09	11:23	4.4	2358	-24	13
SLC	21-Mar-09	12:15	4.8	2716	-15	10

Table 10 - Favorable overflights of Milstar 3 Centaur (USSC 25725) for Salt Lake City, Utah and Rome, Italy and above 40 degrees altitude for March 2009. Source: Calsky (2009).

City	Date	Time UT	V	Dist. km (obs-sat)	Obj. alt deg	Sun alt deg
Honolulu	18-Feb-09	14:25	6.6	4587	29	-36
Hong K.	19-Feb-09	20:11	6.5	4451	29	-38
N. Dehli	19-Feb-09	22:43	6.9	5157	23	-36
N. Dehli	20-Feb-09	23:34	6.6	4560	38	-25
Hong K.	21-Feb-09	19:15	6.4	4457	20	-50
SLC	24-Feb-09	11:58	6.9	5248	28	-25
Rome	26-Feb-09	03:39	6.8	5038	28	-25
SLC	26-Feb-09	11:01	6.8	5203	20	-35
Rome	28-Feb-09	02:43	6.6	4969	20	-34

Table 11 - Near apogee overflights of Milstar 3 Centaur (USSC 25725) for selected international locations for February 2009. Source: Calsky (2009).

There is a dearth of photometry observations of Milstar 3 Centaur (USSC 25725) near its apogee at 5,148 km. This probably is because the orbital inclination of Milstar 3 Centaur is 28 degrees and apogee occurs near the most southerly position of the orbit. Thus, apogee is low on most northern hemisphere observer horizons. Table 11 is a list of international imaging opportunities for the Milstar 3 Centaur near apogee during February and March 2009 at low-altitude passes regardless of lunar altitude and phase. Only viable February dates were found. Four cities are included in Table 11: Salt Lake City, Utah; Rome, Italy, New Dehli, India, Hong Kong, and Honolulu, Hawaii.

Two other recently launched Centaur rocket boosters may be viable practice imaging targets. Two Centaur boosters launched in 2007 and 2008 remain in orbit and that have known orbital elements (but no observations): USSPACECMD 32379 (launched 10 Dec. 2007 with an apogee of 16,069 km) and USSPACECMD 32764 (launched 14 Apr. 2008 with an apogee of 4935 km).

4.7 Lunar meteor impact imaging

As discussed below in Section 7.3, analogous lunar meteor impacts flashes have integrated magnitudes between approximately 3 and 8. It is unlikely that the EDUS impact flash will observable from Earth, and if it is visible, that would only occur under very favorable librations. Nonetheless, imaging such flashes may be of related observer interest. ALPO (2005) lists only one favorable lunar meteor impact flash observing opportunity between February and July 2009 – the Capricorn stream peaking on July 30 when the Moon as at a waxing gibbous phase.

5. LCROSS Mission Description

5.1 Purpose

The primary objective of the LCROSS mission is to confirm the presence of water in the regolith in shaded polar craters by detecting the presence of OH- vapor – a by-product of dissociated water (H_2O). Water may be dissociated into OH- and H+ by the force and temperature of the initial impact. Water also may be dissociated into OH- vapor by the action of sunlight on water vapor in the rising ejecta cloud (Crovisier, 1989).

5.2 Spacecraft

The LCROSS satellite is a relatively small collar that connects the LRO to an upper trans-lunar injection stage of an Atlas V rocket built around a hydrazine tank that weighs about 700 kg and is approximately 2 meters in diameter and 2 meters high (Bussey, 2008a) at Slide 2 (weight)).

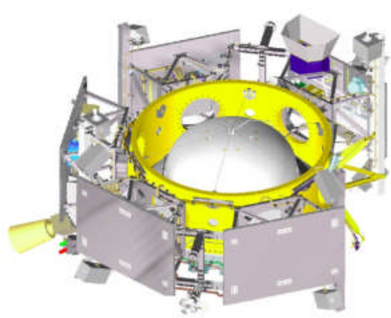


Figure 23 – LCROSS satellite schematic(Ennico, 2008 at Slide 3). Drawing courtesy of NASA Ames Res.Center and Northrop Grumman.

Figure 24 – LCROSS satellite in vacuum chamber testing (Bart, 2008 at Slide 11). Photo courtesy of Northrop Grumman Corp.

The mission design is in the spirit of the better-faster-cheaper NASA philosophy of the Lunar Prospector era. It uses the spent trans lunar insertion booster of the existing LRO mission as an impact probe. The upper stage, called the Earth Departure Upper Stage (EDUS), is 12 meters by 2.5 meters in diameter, is powered by a Centaur booster and weighs about 2,000 kg empty of fuel (Figure 25 and Figure 26). A 12 meter object at a mean lunar distance of 384,400 kilometers only will subtend 0.006 arcsecs.

Figure 25 - EDUS Centaur 3 booster (Ennico, 2008 at Slide 28. Photo courtesy of NASA Ames Res. Center and Northrop Grumman.

Figure 26 - LCROSS–EDUS coupled – schematic (Ennico, 2008 at Slide 22). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

In comparison to analogous Apollo era equipment, a Saturn IVB trans lunar injection booster was 17.8 m long, 6.6 m in diameter and had a mass of about 14,000 kg. The Apollo Command Module-Capsule combination was 11 m long, 3.9 m in diameter and had a mass of about 30,300 kg.

The LCROSS shepherding satellite consists of two main components. First, maneuvering injectors to allow precise targeting of the spent EDUS booster and final precision targeting for impact imaging (Figure 23, above). Second, the observation payload which consists of a bank of visual and infrared cameras will observe the EDUS impact flash and ejecta plume (Figure 27 and Figure 28).

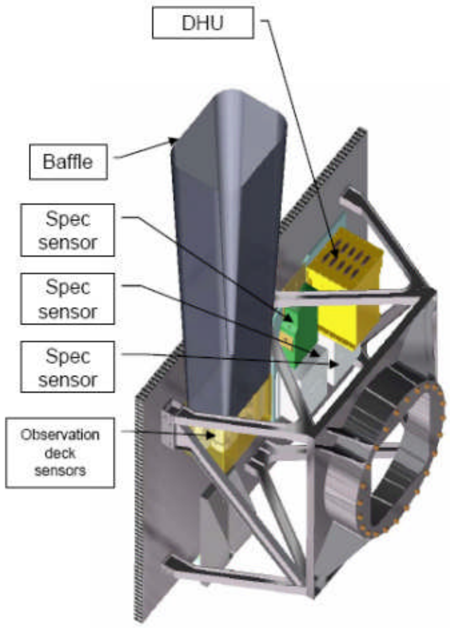


Figure 27 – LCROSS Observation Payload Schematic (Bussey, 2008a at Slide 18). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

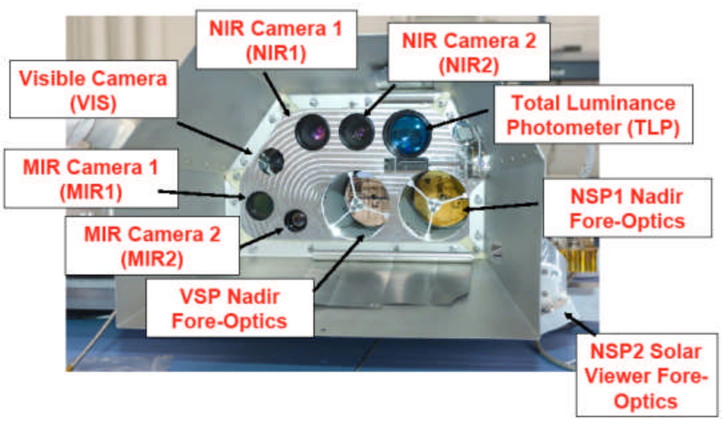


Figure 28 – LCROSS Observation Payload – Imaging Sensors (Colaprete, 2008 at Slide 14). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

5.3 Mission schedule

About nine hours after liftoff, the LRO will disconnect from the LCROSS-EDUS combination. The LRO will continue on directly to lunar orbit and begin collecting imagery and remote sensing data to identify the best LCROSS-EDUS impact site (Bart and Colaprete, March 2009).

The EDUS will be maneuver for a gravity assist lunar orbit and most of its remaining fuel will be vented, in part, to reduce contamination of the eventual impact readings (Ennico, 2008 at Slides 20-21). After 5 days, the LCROSS-EDUS will swing by the Moon and, using a gravity assist, will settle into a lunar orbital inclination of about 76 degrees with a nominal lunar orbit diameter of 500,000 - 700,000 km – an orbit large enough to encompass both the Earth and Moon (Figure 29; Ennico, 2008 at Slides 20-21; Galal, 2008 at Slide 11).

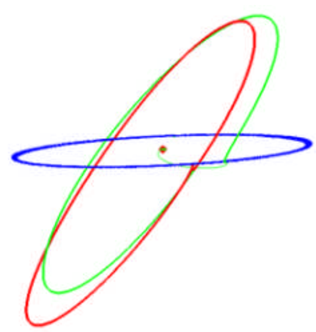


Figure 29 – LCROSS-EDUS cruise orbit with lunar gravity assist turn to high inclination (Bussey 2008a, Slide 8). Earth is at center. Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

The LCROSS-EDU will remain in a cruise orbit for another 3 to 4.5 months (nominal 85 days) and make 2 to 3 perigee passes within 4,000 km of the Moon (Galal, 2008 at Slide 11).

7 hours before impact on about the 86th mission day, the LCROSS shepherding satellite will make a final targeting adjustment for the EDUS, will separate from EDUS, and then

make a deceleration burn such that shepherding satellite will trail the spent EDUS by about 10 minutes but in the same impact-bound orbit path (Figure 30; Ennico, 2008 at Slides 20-21).

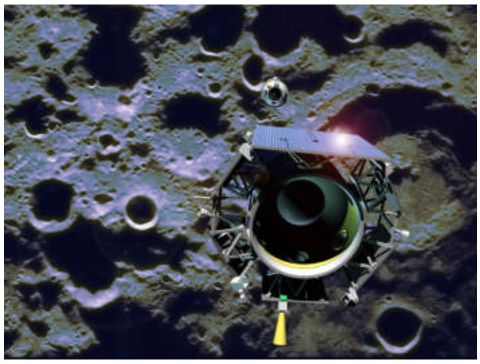


Figure 30 – LCROSS Shepherding satellite trailing EDUS (Colaprete, 2008, Slide 11). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

The LCROSS shepherding satellite can target the EDUS to an accuracy of 3 km (Bussey 2008a at Slide 9). The EDUS descends first (Figure 31) and impacts (Figure 32) at a velocity of 2.5 km sec^{-1} (Bussey, 2008a at Slide 2).

Figure 31 – EDUS descending to impact (Bussey, 2008a, Slide 2). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

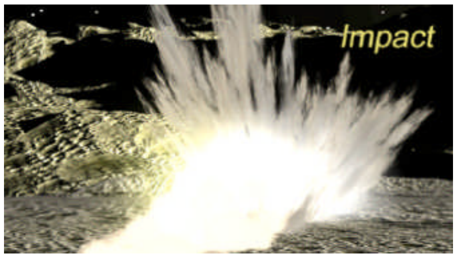


Figure 32 – EDUS Impact – Artist Impression (NASA, 2008c). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

Figure 33 – EDUS Impact – Impact flash from NASA Ames high velocity gun experiment. Clip from LCROSS First-Step video (NASA, 2008f). Image courtesy of NASA Ames Res. Center and Northrop Grumman.

Korycansky et al. (2008) modeled the maximum temperatures at the point of impact have been modeled at about 1230K. Shuvalov and Trubetskaya (2008) modeled that the heat of impact should melt between 10 to 50% of water frozen in the regolith at temperatures between -35C deg and -200C degs. But Schultz (2007) notes that the waste heat of impact is insufficient to release significant water vapor.

During the first sixty seconds, an ejecta cloud will rise from the lunar surface (Figure 34 and Figure 35).

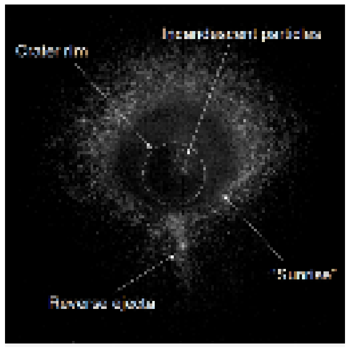


Figure 34 – EDUS simulated impact, satellite or top view of ejecta cloud (Colaprete, 2008 at Slide 18 (from Peter Schultz, Brown Univ.) Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

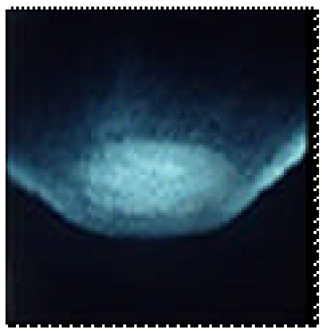


Figure 35 – EDUS simulated impact, side view of ejecta cloud (Colaprete, 2008 at Slide 33) from NASA Ames Vertical Gun Range). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

The impact will create a crater approximately 20 meters in diameter and about 3 meters deep (Bussey, 2008a at Slide 2; Colaprete, 2008 at Slide 9; Heldmann, 2007 at Slide 22). The impact will excavate approximately 200,000 to 250,000 kg of lunar regolith, but most of this mass will be deposited within 3 crater radii of the impact crater (Bussey, 2008 at Slide 2; Colaprete, 2008 at Slide 3; Schultz, 2007). The LCROSS shepherding satellite follows transmitting infra-red images and spectrometry data back to Earth. Figure 36. During its key 60 seconds of observing, the LCROSS shepherding satellite will attempt to detect the OH- signature caused by temperatures from the initial impact in the near-infrared at 1400 and 1900 nm (Heldman, 2006a at Slides 23-24; Heldmann, 2006b at Slide 23-26. Spacecraft target frequencies for water content are in near-infrared areas not observable from Earth at 1400 and 1900 nm. *Id.*

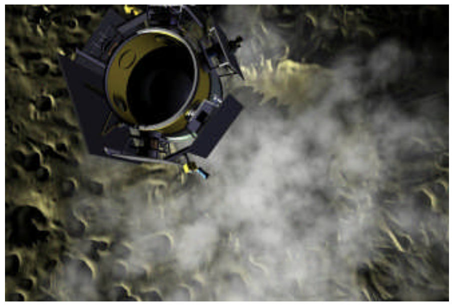


Figure 36 – LCROSS observing the ejecta cloud (Colaprete, 2006 at Slide 8). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

The ejecta curtain will rise above the crater rim – perhaps one or two kilometers above the impact site – and into the sunlight and direct Earth-view.

Figure 37 – EDUS impact, schematic of ejecta cloud rising into sunlight (Colaprete, 2008 at Slide 7). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

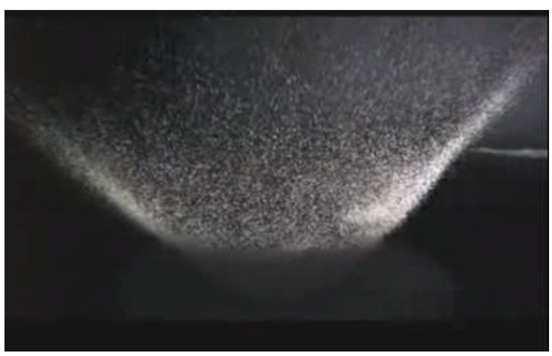


Figure 38 – Simulated EDUS impact, ejecta curtain rising from shadowed area during NASA Ames high velocity gun experiment. Clip from LCROSS First-Step video (NASA, 2008). Image courtesy of NASA Ames Res. Center and Northrop Grumman.

Ice, water and vaporized water that rises into sunlight will be heated and dissociated by sunlight, not the impact energy (Schultz, 2007). Figure 35 and Figure 38 illustrate a key feature of the ejecta cloud that will be the focus of professional astronomers who will use spectroscopy to detect vaporized water in the cloud. On the left and right sides of the “lampshade” cloud illustrated in Figure 35 and Figure 38, there are bright edges that are the result of zones of concentrated reflection. These zones are sub-arcsec features of the ejecta cloud in which major Earth ground-based observatories like Keck and NASA’s IRTF hope to detect vaporized water using multi-meter apertures.

Bart and Colaprete (March 2009) report that the LCROSS Team is evaluating final target candidates based on a detailed shadow analysis of a crater at the time of impact and Earth-Moon geometry. The goal of that analysis is to assure that the ejecta curtain will rise into sunlight and reflect light, as shown in Figure 37.

For Earth-based amateurs using 10” to 12” apertures, all of Figure 38, if the actual ejecta cloud conforms to the LCROSS Team’s predicted 5” x 2.5” dimensions, will probably be captured as a small set of pixel squares. At smaller apertures, the details in Figure 38 that professionals hope to capture in multi-meter telescopes, will not be captured on amateur CCD images.

A smaller fraction regolith may rise to 30 km, under ideal conditions (Bussey, 2008a at Slide 13; Schultz, 2007). Of the 200,000 to 250,000 kg of ejecta, 100,000 kg may reach 2 km above the surface; 10,000 may reach 5km; and 1,000 kg may reach 25km above the surface (Bussey, 2008a at Slide 12).

The observation payload on the LCROSS shepherding satellite will collect key spectrometry data during this key first 60 seconds after impact. Then, Apollo era-Ranger style, the shepherding satellite will fly through the ejecta cloud and crash within 100 meters of the EDUS impact site (Bussey, 2008a at Slide 9; Figure 46, below re: analogous Ranger 7 impact crater).

As noted above, NASA (2008f) is a four minute NASA-LCROSS Team video that includes an animation of an ejecta plume, somewhat larger than the high-bound estimate discussed here, can be seen via the internet. Helpful impact visualizations of the top and side views of the impact process can be found in NASA Ames Vertical Gun Range high-speed photography made for the Deep Impact mission by Univ. of Maryland and NASA

(2008a) and Univ. of Maryland and NASA (2008b). The animation in NASA (2008f) also includes an image of a high-velocity gun experiment showing a bottom shaded ejecta cloud.

As a back-up to any observation payload failure and to collect corroborating measurements, ground-based telescopes in Hawaii, Chile and the United States will also image the impact including the NASA InfraRed Telescope Facility (IRTF), a 3 meter telescope optimized for infrared on Mauna Kea, Hawaii, Keck, and major Chilean observatories. On Feb. 2, 2009, NASA (2009d) announced its selection of four investigators using six observatories to assist the team in ground-based observations of the impact. Space-based telescopes will also follow the impact including Hubble, LRO, Chandrayaan-1, and Kaguya (Colaprete, 2008 at Slide 26; Heldmann, 2006a at Slide 7; Heldmann, 2006b at Slide 37). The time of impact will be set so that the Moon will be well-positioned over major Earth ground-based observatories in Hawaii and/or Chile (Galal, 2008 at Slide 6; *see* NASA, 2008e).

If water (H_2O) is present at the impact site and in that portion of the regolith ejected high above the lunar atmosphere, either the high temperature of the initial impact or the subsequent Sun's rays may dissociate vaporized water into OH- molecules (Heldmann, 2007 at Slide 8; Heldmann, 2006a at Slide 21; Schultz, 2007).

For 24 hours after the EDUS impact, the space-based and Earth-based observatories mentioned above will seek to monitor the formation of the OH- vapor cloud caused by solar disassociation at 308 nm and 3000nm (Heldmann, 2006a at Slide 20).

5.4 Mission observation wavelengths

Other than making a visual light curve at about 500nm, the wavelengths that the LCROSS Team is focused on detecting to achieve experiment objectives are beyond the spectral response curve of amateur CCD equipment.

Typical amateur CCDs and spectrographs have a spectral response curve between 350nm and 1100nm (Tonkins, 2002). Specialty CCD chips that are more sensitive in the near-ultra-violet (NUV) exist. The spectral response curve of commercial spectrographs commonly owned by amateurs, such as an SBIG DSS-7 spectrograph, is between 400 nm and 750 nm (Santa Barbara Instr. Group, 2009). Cousins-Bessel U through I filters span 340 nm to 1100 nm (Optec, 2008). Even where a sufficiently sensitive instrument is used, the exposure would still have to be made at high-altitudes in order to not have the Earth's atmosphere block a key wavelength at 308nm.

LCROSS Team member Heldmann has summarized the LCROSS target observation wavelengths (Heldman, 2006a at Slides 19-27; Heldmann, 2006b at Slides 23-26; Heldmann, 2007 at Slides 11-16). Those wavelengths, and whether they are observable with amateur equipment, include the following:

Visual brightening at 500nm: The dust ejecta plume size and growth will be monitored in the visual range by the shepherding spacecraft and ground based telescopes to corroborate the model of the ejecta cloud and calibrate other measurements (Heldmann, 2007 at Slide 9). It is this visual ejecta cloud that is expected to grow to 10 km by 5 km. Table 1, above.

OH vapor cloud at 308nm and 3000nm: Ground based telescopes and shepherding satellite will look for OH traces in the initial impact near 308nm. Ground based telescopes will look for OH bands at 3000nm (Heldmann, 2007 at Slides 11 and 16). Amateur class spectrometers typically cannot reach either wavelength.

One counterintuitive characteristic of the OH vapor cloud is its size. The OH vapor cloud could grow to 100km in the first hour (Heldmann, 2007 at Slide 8). The OH vapor is created from sunlight disassociation of H_2O vapor. The vapor cloud will be much larger than visual range dust ejecta cloud because the mass of water molecules is lower than 100 micron dust particles. The water molecules quickly reach a much greater altitude than the dust.

Summy et al. (2009) modeled the radiant emittance of the expected OH cloud between approximately 100 and 1000 Rayleighs at 50 seconds after impact depending on the altitude above the surface.

Eventually, the OH vapor cloud expands and becomes a lunar OH exosphere.

Planning for the 1999 Lunar Prospector mission provides an instructive comparison. For the Lunar Prospector impact, Goldstein et al. (1999) expected the impact OH exo-lunar atmosphere eventually to expand to a thin 1000 km radius. This 1000 km OH exosphere would form from just 18kg water ice. Barker et al. (1999) and Goldstein et al. (2001) reported that the 1999 Prospector attempt was unsuccessful probably due to the difficulty of detecting the faint signal from such a small amount of the material.

Organic molecules at 380nm: The shepherding satellite will look for organic molecules like CN at 380nm (Heldmann, 2007 at Slide 16).

Ionized water H_2O + at 619nm: The shepherding satellite will look for ionized water at 619nm (Heldmann, 2007 at Slide 16). Summy et al. (2009) modeled the density of the expected H_2O between 25 to 100 seconds after impact.

In contrast to the 18kg of water mass expected by the 1999 Lunar Prospector team, the LCROSS Team planning assumption for OH production is that a water content of 1% of 200,000 kg of ejected regolith also will raise about 100kg water vapor and 1000kg of water ice over 35km above the lunar surface (Heldmann, 2007 at Slide 23).

OH cloud at overtone wavelengths between 1400nm and 1900nm: The shepherding satellite will look for overtone wavelengths for water ice: "Broad minima at 1.5 and 2.0 microns [are] indicative of water ice." "A sharper minimum at 1.65 microns shows that the ice is crystalline in structure, rather than amorphous" (Heldmann, 2007 at Slide 13).

In conclusion, most of the wavelengths of interest to the LCROSS Team are either beyond the range of amateur spectroscopy equipment or CCD camera spectral response. The main exception is the visual component of the dust ejecta plume with a maximum emittance around 500 nm.

5.5 Other wavelengths of interest to amateurs

Other wavelengths that are not part of official LCROSS observing frequencies may be of interest to amateurs.

Sodium (Na) vapor at 589nm: Neutral sodium vapor strongly emits at 589nm and may be of interest to amateurs. Since elemental sodium emits at the same wave length as light polluting sodium street lamps, the opportunity to observe any enhanced sodium lines with amateur spectroscopy equipment or filters from an suburban location probably is small for most amateurs.

LCROSS Team publications do not discuss experiments to observe enhanced sodium lines in the ejecta curtain.

There is an extensive history of sodium vapor detection in the lunar exosphere and with respect to the Lunar Prospector mission.

Returned Apollo 14 lunar soils averaged 0.42% elemental sodium, principally in the mineral Na_2O. Na_2O averaged 0.57% by weight (Apollo 14 Preliminary Science Report at Table 5-IVI, p. 120; NASA, 1971). Apollo 16 highland rock samples also average about 0.5% Na_2O by weight (Apollo 16 Preliminary Science Report at Table 7-III, p. 7-5; NASA, 1972b).

Since the LCROSS impact is expected to excavate 200,000 kg of soil, that volume of soil could contain 1,000 kg of Na_2O that includes 800kg of elemental sodium.

The Moon has a thin exosphere that consists in part of vaporized elemental sodium. The source of the sodium gas is the lunar regolith. The gas is liberated by meteor impacts and solar radiation (Lucey et al., 2006 at 199-201).

In a 1998 serendipitous discovery, Smith et al. (1999) and Wilson et al. (1999) observed neutral sodium gas at the antisolar point. The source of the sodium vapor was the vaporization of lunar soils during the November 1998 Leonid meteor shower. The excess vapor collected at the Moon's antisolar point was observed by a simple amateur class all-sky camera: a Minolta 16mm f/2.8 lens, a sodium narrowband filter, and a CCD camera.

Smith and Wilson were using the all-sky camera to conduct long-term monitoring of how gravity waves effect sodium in the Earth's upper atmosphere. The sodium vapor cloud concentration from the Moon was an accidental capture on their nightly all-sky runs. Both Smith et al. (1999) and Sky & Telescope (1999) include black & white images captured by their CCD camera showing the sodium cloud.

In 1999, the Lunar Prospector Team planned to, but failed to, detect a neutral sodium vapor exosphere (Goldstein et al., 2001).

Also of note was the 1959 use of several pounds of sodium vapor artificially dispersed by Soviet scientists to mark the position of Luna 2 during trans lunar orbit, as discussed in Section 8.2, below. At 113,000 km, the dispersed sodium vapor cloud reflected sunlight at maximum of 4 or 5 magnitudes.

Available LCROSS Team documents do not analyze whether the impact or solar radiation on the ejecta curtain will produce enough sodium vapor to emit a detectable signal. But this may be another area that expert-level amateurs in spectroscopy may want to consider further. Edmund Scientific sells a 589nm narrowband filter, Part No. NT62-164.

Ionized hydrogen (H) vapor cloud: If the OH cloud cannot be observed, what about a hydrogen vapor cloud at H-alpha and H-beta wavelengths?

Twenty-five minutes after impact, the LCROSS Team estimates an OH molecule production rate of 82,000 sec and a solar flux at 308 nm of 1E20 photons m^{-2} sec^{-1} mm^{-1} str^{-1} (Colaprete, 2008) at Slide 8). As noted above, the predicted OH molecular cloud may reach 100km (Heldmann, 2007 at Slide 8).

While the cycle of creation and destruction of OH from solar disassociation is known, what is the fate of the excess H+ ion? *See* Crovisier (1989) with respect to the photo dissociation of water in comet halos. Crovisier notes that on photo-dissociation, some of the energy of dissociation is converted into motion. The OH molecular has a velocity averaging 1.3 km sec^{-1}. Due to its lower mass, the H+ ion has a higher velocity of 20 km sec^{-1}. This occurs in the low-gravity field of interplanetary space.

The differential velocity photo-dissociated molecules might be the cause of the colored layers observed in the outer halo and extended outer halo of Comet 17P Holmes seen by this author and other amateurs in late Nov. and Dec. 2007. Comet Holmes had a green OIII emitting outer halo surrounded by an even larger red extended outer halo.

Speculatively, after the EDUS impact, it is possible that as the OH cloud forms a H ion cloud may form further from the lunar surface.

This speculation should be tempered with Goldstein, Austin and Barker et al. (2001)'s conclusion that the dark limb of the Moon acts as a cold sink quickly traps most of the measurable volatiles from an impact.

Available LCROSS Team publications do not analyze the fate of the H ion byproduct of H_2O photo-dissociation, thus the possible occurrence of an H ion cloud remains speculative.

5.6 Public education and amateur astronomy participation

NASA's Stockman and Day (2008) are planning an LRO and LCROSS public participation website based on the social networking model used in the Deep Impact and Mars Rover missions (Day, 2008) and public school children education activities typical of NASA missions. The currently operating LCROSS Twitter site (NASA, 2009e) and NASA LCROSS Quest Challenge education activities are illustrative of those models.

The nature of amateur observing participation in public outreach program has not been finalized.

Public outreach during the 2005 Deep Impact mission included a website for the general public to post observations (McRobert, 2005; Univ. of Maryland and NASA, 2009), a small telescope sciences program ("STSP") with observing campaigns (Univ. of

Maryland, 2007a; Univ. of Maryland 2007b), and an inbound STSP amateur image site (Univ. of Maryland 2007c). Registration was required to participate in the STSP.

Mention has been made of preliminary plans to include undefined amateur astronomer observation participation beginning with mission launch (Day, 2008). The LCROSS Team also has considered a public observing campaign proposal built around replicating the imaging of the EDUS Centaur booster during its gravity assist cruise orbit. The proposal was based on the accidental reacquisition and imaging of a Saturn V booster in Earth-Lunar orbit in 2002 (Britt, 2002a; Britt, 2002b).

The many satellites sent to the Moon between Lunar Orbiter in the 1960s to the current Kayuga flight have produced vast catalogues of images showing the Moon's surface illuminated from a high or low lunar orbital viewpoint.

Kuiper et al.'s 1967 *Consolidated Lunar Atlas* ("CLA") still represents one of the best professional catalogues of lunar images taken by Earth-based telescopes.

Representative plates of the polar regions taken at favorable librations include A10 (north, +3.4 latitude libration), HII (south, -3.0 latitude libration), and H7 (south, -4.8 latitude libration). Figure 39 is a representative example of a CLA polar image that shows Peary (red circle) and Byrd (yellow circle):

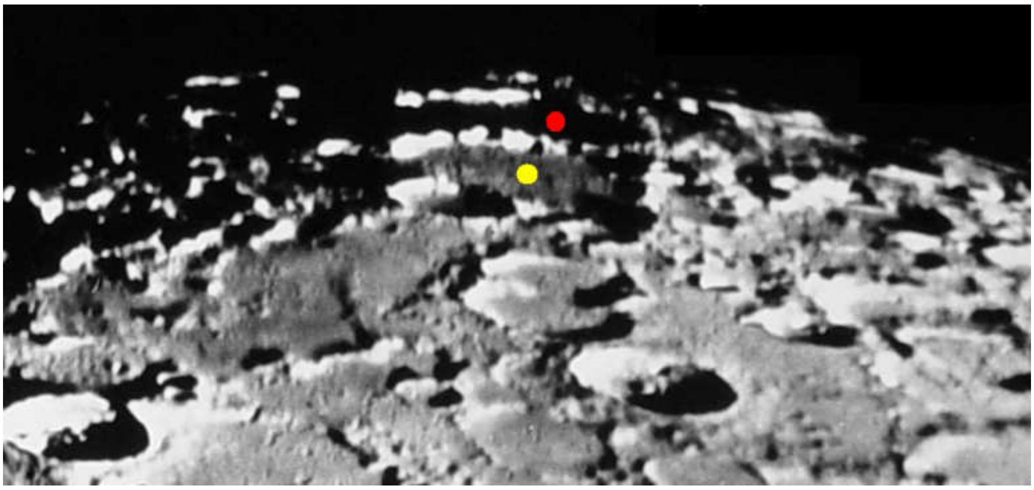


Figure 39 – North lunar pole - excerpt from Consolidated Lunar Atlas Plate A10 at +3.4 latitude libration (Kuiper et al., 1967). Image courtesy of Lunar and Planetary Institute. In the image, lunar north is up and lunar east (celestial west) is to the right.

Modern amateur imaging equipment can produce images that exceed the resolution of professional images in the CLA.

A Nov. 26, 2008 NASA LCROSS Team press release (NASA, 2008d) solicited amateur imaging, in part, for subsequent use by professional astronomers to “refine new protocols for observing the moon . . .” Creation of an atlas of the lunar poles at varying librations and illuminations was suggested:

> The Lunar Crater Observation and Sensing Satellite (LCROSS) Observation Campaign is seeking assistance from amateurs to develop a library of digital images of the lunar poles under varying phase and librations. . . . . Amateur astronomers have the opportunity to create a useful reference imaging data set for the LCROSS impact. They can be helpful in the development of an amateur astronomer atlas of the lunar poles at different lighting and libration conditions. Images taken under different phases produce subtle shifts in crater shadows that affect determination of "crater centers" in images. This can affect the determinations in the offsets between these reference craters and a target crater. Furthermore, images taken during phases on the opposite side of full moon may reveal subtle features that are useful in refining the pointing accuracy.

In a January 2009 email to amateur Jim Mosher, principal co-investigator Heldmann clarified the purpose of the requested activity (Heldmann, 2009):

> Due to the libration of the Moon, the appearance of surface features (particularly near the limb, where LCROSS will be impacting) can visually look different from Earth at different times of year. Professional astronomers have already been testing out their pointing of large telescopes and this is proving to be a non-trivial task. Therefore additional information regarding these lunar areas is desirable.
>
> . . . .
>
> To point large telescopes to 0.5 arcsec a process has been developed by D. Wooden to use "guide craters", as opposed to guide stars. This approach makes use of relatively small craters near the target site. The appearance of these craters changes with illumination and view angle (phase and libration), so having reference images [from amateurs and professionals] for various phases and librations helps identify and pre-plan these "guide craters" and gives the telescope operator a visual queue/key.
>
> . . . .
>
> The amateur images will give different types of information than the DEMs, particularly in terms of albedo variations (key for "crater-hopping" and pointing) and variations in the appearance of lunar landscapes & craters from Earth (particularly near the limb).
>
> We have used the Goldstone DEMs as well as Kaguya DEMs for generating illumination maps, but the products are not very satisfactory (certainly not as satisfying as some ground based images we have seen).
>
> Amateur astronomers are encouraged to image the north and south poles of the moon.
>
> The goal is to obtain images that determine the scale of recognizable features observed in the wider field of view on amateur telescopes when compared the higher spatial resolution of professional telescope images.

NASA (2008k) includes an animation of a NASA south polar DEM used to simulate illumination.

In the fall of 2008, a NASA LCROSS sponsored a temporary LCROSS Amateur Observing Campaign regarding amateur imaging of the southern and northern target areas in December 2008 and January 2009, simultaneous with imaging by the NASA ITRF on Mauna Kea, Hawaii (NASA, 2008d; NASA, 2008e). That temporary campaign used the free Google Group service as an image depository and community selfcoordination point. NASA LCROSS Observation Campaign Google Group, above.

By January 2009, the LCROSS Observation Google Group became one internet focal point for amateurs to contribute images of the lunar poles at various librations and illuminations. The Geologic Lunar Research Group (GLRG) similarly is collecting a set of polar images.

A final pre-mission of the NASA LCROSS public participation website will be forthcoming, modeled on a NASA Deep Impact template.

6 Amateur imaging opportunities before impact

6.1 Hydrogen and oxygen fuel dumps within the first 10 hours

LCROSS team public education member Brian Day mentioned that the team was considering unspecified amateur participation shortly after mission liftoff (Day, 2008).

About 9 hours after liftoff, the LRO will disconnect from the LCROSS-EDUS combination. The EDUS will be targeted for a gravity assisted lunar orbit and its remaining fuel will be vented to reduce contamination of the eventual impact readings (Ennico, 2008 at Slides 20-21).

Based on historical experience but depending on the timing of the event, the fuel dump event can be imaged by amateurs of all aperture classes.

A Sky & Telescope back issue from the Apollo era revealed an interesting amateur observed event (Sky & Telescope, 1971). On Jan. 31, 1971, the Apollo 14 Saturn-IVB third stage dumped its excess hydrogen load. Three hours later, the S-IVB dumped its excess liquid oxygen. The possible fuel dump was pre-announced by NASA and many amateurs attempted to observe and image the event. John Bortle and other amateurs observed the hydrogen dump as a 1 degree diameter, 1st magnitude object. Many amateur observers reported to Sky & Telescope that the H cloud was between 1 and 2 degrees in diameter and 0 to 1 magnitudes. The volume of hydrogen dumped is not described in the article but the distance to the event is stated at 18,000 miles or about

29,000 km. The Apollo 14 launch and first 10 hours of flight occurred at 21:03 GMT on Jan. 31, as night began to fall across the eastern United States (NASA, 1972; Apollo 14 Mission Report at Table 6-I).

On Dec. 10, 2007, a defense Atlas V Centaur rocket booster (USSC 32379, Int'l Designator 2007-060-B for satellite USA 198) made a fuel dump that was widely imaged and observed as a bright naked-eye object (Fetter, 2007 (video); Spaceweather.com, 2007). USSC 32379 is still in orbit and observable.

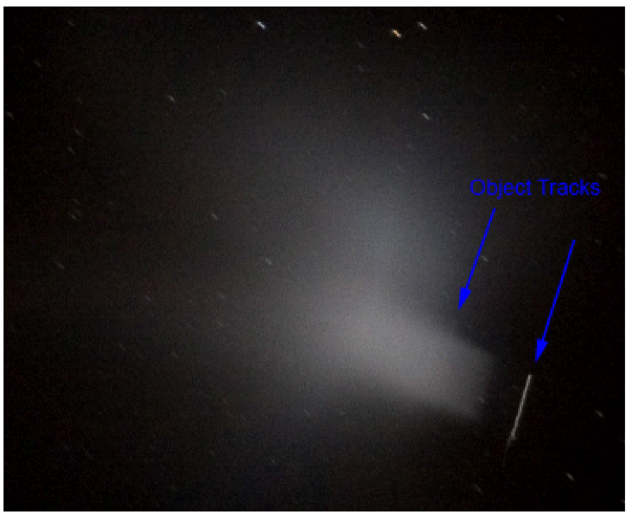


Figure 40 – USSC 32379 Atlas 5 Centaur booster fuel dump on 10 Dec. 2007 (Spaceweather.com, 2007). Photo courtesy of Chris Schierer.

Later on February 21, 2008, failed defense satellite USA 193 was destroyed in orbit in a missile defense test.

Debris and residual hydrazine fuel (maximum of 400 liters) produced a molecular cloud in low-Earth orbit that may have been imaged by Hawaiian amateur Rob Ratkowski using a DSLR camera.

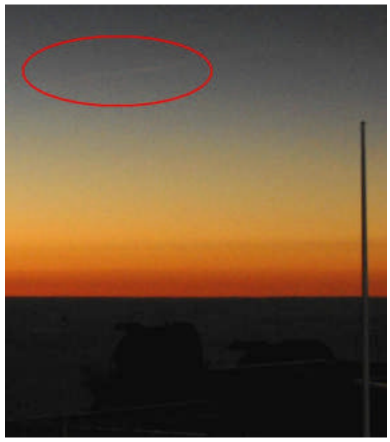


Figure 41 – USA193 satellite debris and hydrazine field imaged from Mauna Kea, Hawaii, 28 Feb. 2008. Photo courtesy of R. Ratkowski.

The visibility of the LCROSS-EDUS-LRO trans lunar injection and fuel dump will depend on the time of launch and the observer's location. For example, the last slipped scheduled launch for the LRO-LCROSS (NASA, 2009c) reported that LRO-LCROSS was set for April 25, 2009 00UT (April 24, 2009 at 8:00pm EDT). A noon Eastern Daylight Time launch might favor observations by Asian or European observers. A dusk launch might favor United States observers. Final launch and orbital parameters have not been announced by the LCROSS Team as of this writing.

Lessons learned from prior experience during the 1971 Apollo mission and from the 2005 Deep Impact are the need for contemporaneous dispersed short-wave or cell phone updates of the timing of a launch or impact. Contemporaneous impact progress reports will help imagers to precisely time the taking of images.

While observing the Apollo 14 mission from a dark-sky site, John Bortle reported to Sky & Telescope that he observed for several hours waiting for launch. He was unaware that mission launch had been delayed for several hours. While unsuccessfully observing the 2005 Deep Impact and 2006 SMART-1 impact at a local astronomy club, this author noted that whether either impact could be detected was uncertain because the exact timing of the actual impact could not be determined. Some club members offered to remain at home and watch NASA-TV online and then make a cell phone call when the impact occurred.

While cell phone service reaches most of the continental United States and Europe, there are significant dark sky regions in the western continental United States that do not have cellular service. Conversely, local amateur ham radio operators can broadcast into such regions.

The above implies that observers of the LCROSS impact could benefit from more organized cell phone trees and/or a cooperative effort with their local ham radio operator clubs. Local ham radio operator clubs could monitor the impact progress on NASA channels and broadcast updates to dispersed amateurs at dark sky sites.

6.2 Trans lunar orbit imaging within first 30 hours

Another event that could be observed within a short time frame after liftoff is the Centaur-LRCOSS combination, while the spacecraft is within 125,000 kilometers of Earth. Based on historical experience and first-order differential magnitude modeling, such an event can be imaged by amateurs using ordinary 10 to 12 inch apertures.

Figure 42 – LCROSS and EDUS spacecraft (Colaprete, 2008 at Slide 3). Drawing courtesy of NASA Ames Res. Center and Northrop Grumman.

Modern amateur imaging of a Centaur booster to a distance of 10,000 km at magnitude 6 have been reported on the SeeSat observing list. Hatton (undated). In October 1997, amateur Gorden Garradd imaged the Centaur booster of the outbound Cassini probe at 26,000 km using a 25cm f/4.1 Newtonian at 17 seconds exposure and hypered Kodak

Gold III 400 ISO (Hunt, 2008). At 26,000km, geosynchronous satellites are an ordinary amateur astrophotography challenge using 106mm of aperture, *e.g.* - Misty Mtn. Obs. (2006).

On January 14, 2009, Patrick Wiggins imaged the gravity-assist flyby of the Stardust Next bus spacecraft, a 1.7 meter long object, at 35,000 km and 16.5 magnitudes using a Celestron 14" SCT and a ST-10XME camera at an effective focal length of 3900 mm with 10 sec. exposures taken at 1 minute intervals (NASA, 2009a; Spaceweather.com, 2009; Wiggins, 2009). The 16.5 magnitude estimate from differential photometry of Wiggins' images is by this author.

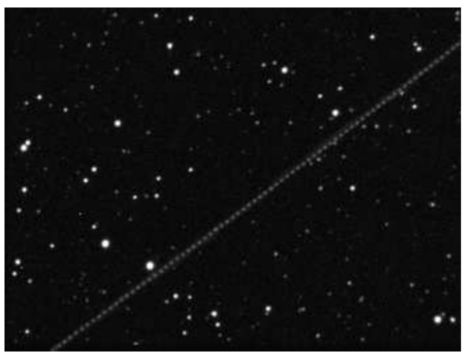


Figure 43 – Stardust Next Bus Earth flyby imaged by P. Wiggins 14 Jan. 2009 05:14UT. FOV ~ 11'x17'; composite of images at approx. 1 minute intervals. Processing by H. Jackman. Photo courtesy NASA Solar System Ambassador to Utah Patrick Wiggins.

On January 29, 2009, amateur Roberts (2009) reported on the SeeSat satellite observing list, his animation of images tracking of the Astra constellation of geosynchronous satellites using a 6 inch reflector and Meade DSI Pro II camera. The Astra constellation is a group of 6 geosynchronous satellites that provide telecommunications services to Europe. A satellite in geosynchronous orbit is 35,786 km in altitude above mean sea level. The Astra 5 satellite, with solar collectors deployed, has a cross-section of 27.3m by 2.8m (SES Astra, 2009). A 12 m by 2.5m Centaur booster is smaller.

Differential magnitude modeling of Centaur booster visibility suggests that imaging of that class of booster using apertures of 10 to 12 inches can reach 100,000 km to 125,000 km from Earth.

A search of Centaur boosters satellite records in CalSky.com returned 25 historical and current boosters similar to the LCROSS-EDUS Centaur. Of those 25, two are complete records in that the CalSky and corresponding Heaven's Above.com data records include (a) the size of the booster; (b) orbital elements including apogee and perigee; (c) an apparent magnitude estimate at perigee and 100% illumination; (d) an apparent magnitude estimate at apogee and 50% illumination; and (e) a record of actual amateur observations of the object. Two of 25 possible Centaur targets meet those criteria. The characteristics of those two targets are listed in Table 12 through Table 14:

Object	**USSPACE-CMD Id**	**Int'l ID**	**Status**	**No. Heaven's Above ob-serv.**
MStar 3 Cent Rocket	25725	1999-023B	Current	>150
USA 136 Cent Rocket	25035	1997-068B	Decayed?	16

Table 12 - Characteristics of two Centaur boosters with observed magnitude distance data. Source: CalSky (2009).

Object	Dia. major m	Dia. minor m	Perigee km	Apogee km	Inclination deg
M Star 3 Cent Rocket	10	2.5	706.8	5148.8	28.3
USA 136 Cent Rocket	8.6	3.0	87.7	23274	63.5

Table 13 - More characteristics of two Centaur boosters with observed magnitude distance data. Source: CalSky (2009).

Object	Magnitude at perigee 100% illumination	Magnitude at 1000km 50 % illumination	Period minutes
M Star 3 Cent Rocket	1.5	3.0	706.8
USA 136 Cent Rocket	-2.5	3.5	87.7

Table 14 - Further characteristics of two Centaur boosters with observed magnitude distance data. Source: CalSky (2009).

(CalSky and Heaven's Above list different magnitude estimates at perigee-100% illumination and at 1000 kilometers-50% illumination.)

Using the two magnitude estimates at perigee (100% illuminated) and at 1,000km (50% illuminated), the distance modulus formula (Equation 1 and Equation 2), and the

Steavenson-Sigdwick light-grasp equation for simple telescopic limiting magnitude (Equation 3 and Equation 4), a model of the Centaur booster distance from the observer, magnitude and minimum apertures needed to view that magnitude was constructed.

$m_2 - m_1 = 5 * \log10(d_2/d_1)$

Equation 1 - Distance modulus formula

$m_2 = 5 * \log10(d_2/d_1) + m_1$

Equation 2 - Distance modulus formula solved for m_2

$m_2 = 1.8 + 5 * \log10(D\_mm)$

where m_2 is Telescopic Limiting Magnitude.

Equation 3 - Steavenson-Sigdwick simple telescopic limiting magnitude (TLM)

$D\_mm = 10^{(m2-1.8)/5)}$

where m_2 is Telescopic Limiting Magnitude.

Equation 4 - Steavenson-Sigdwick TLM solved for minimum aperture to observe a magnitude.

Figure 2, above, shows the results of the model and the estimated magnitude of the Centaur booster at various distances from the observer in kilometers. Figure 44 chains the magnitude estimates of Figure 2. Equation 2 is the input for Equation 4 and yields a rough first-order estimate of the minimum aperture needed to view and image the Centaur at a given observer satellite distance:

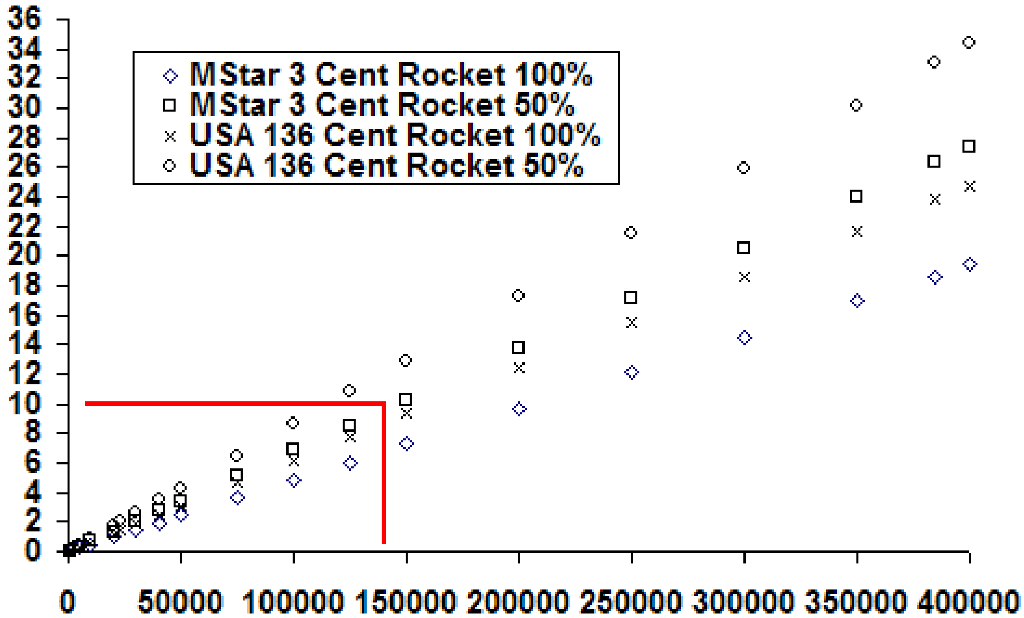


Figure 44 – Estimate of minimum aperture needed to view the LCROSS-EDUS at various observer-satellite distances. y in aperture inches; x in kilometers.

Distance km	Mag	Min D_mm	Min D_in
1000	3	1.7	0.06
5000	6.4	8	0.3
5148.8	6.5	8	0.3
10000	8	17	0.6
20000	9.5	34	1.3
30000	10.3	52	2
40000	11	69	2.7
50000	11.4	86	3.4
75000	12.3	130	5.1
100000	13	173	6.8
125000	13.4	217	8.5
150000	13.8	260	10.2
200000	14.5	347	13.6
250000	14.9	434	17.1
300000	15.3	521	20.5
350000	15.7	608	23.9
384400	15.9	668	26.2
400000	16	695	27.3
450000	16.2	782	30.7
500000	16.4	868	34.2

Table 15 - Simple differential magnitude estimate of EDUS Centaur booster - MilStar 3 Centaur booster 50% illumination baseline.

A supplemental spreadsheet of supporting computations is available at Fisher (2009a). For more background on the Steavenson-Sigdwick TLM and Schaefer TLM models, *see* Fisher (2006b).

Using the MilStar 3 Centaur 50% illumination magnitude as the planning baseline, differential magnitude analysis suggests that amateurs using 10 to 12 inch telescopes should be able to image the LCROSS-EDUS to observer-satellite distances between 100,000 to 150,000 kilometers.

As the launch event nears, observers may wish to update their personal visibility estimate using a Schaefer TLM calculator. *See* Fisher (2006a) for a javascript implementation updating Larry Bogan's 1998 code for the Schaefer TLM algorithm.

The primitive model above relies on the Steavenson-Sigdwick light-grasp telescopic limiting magnitude formula. The Steavenson-Sigdwick TLM model has been superceded by the more complex Schaefer TLM model. The earlier Steavenson-Sigdwick TLM formula is based on the assumption of good magnitude 6.0 ZLM (zenithal limiting magnitude) skies and the observer using the maximum theoretical magnification for a given aperture.

Modern observers typically view from semi-light-polluted suburban locations. The Schaefer TLM model incorporates the observer's local ZLM into the model's TLM estimate.

Light-pollution may not be the only source of sky wash-out on the expected mission launch date in May. The last scheduled LCROSS-LRO launch date was for April 25, 2009 0UT (Spaceflightnow.com, 2009, NASA, 2009b; NASA, 2009c). This launch date has been rescheduled and has been slipped on five prior occasions, most recently to May 7, 2009 (*id.*; Tooley, Feb. 12, 2009).

On April 25, 2009 0UT, the Moon will be at 4.8 lunation days with an illuminated fraction of 19%. Considering that the LCROSS-EDUS will initially travel and skim the Moon in a low orbit for a gravity-assist pass, partial sky washout from a near-first quarter Moon is possible during its first Earth-Moon transit. Similar constraints may exist for the rescheduled May 7, 2009 launch date.

In conclusion, balancing sky-washout against the increased limiting magnitude reach achievable through CCD imaging (typically 1 to 1.5 magnitudes), the LCROSS-EDUS booster conservatively should be visible or detectable by imaging using 10 to 12 inches of aperture to a distance of 100,000 km to 125,000 km from Earth. Observers should update their personal estimates on the launch date using a Schaefer TLM calculator (Fisher, 2006a).

This trans-lunar orbit booster visibility estimate is consistent with historical records.

A historical search of Sky & Telescope issues during the Apollo era revealed some amateur and professional observations of Apollo trans lunar orbit insertions and the outgoing and returning Command Modules. Sky & Telescope (April 1971) reports how the "Moonwatch Division" of the Smithsonian Astrophysical Observatory distributed predicted locations of the outbound Apollo Command Module and Saturn IV booster. Pulliman (Oct. 2007) gives background on Project Moonwatch.

Observations reported in the 1971 Sky & Telescope article include the following. On Jan. 31, Fernbank Science Center imaged the Command Module and two 33 ft Saturn IV adapter panels at 18,000 miles (29,000km) using 36 inches of aperture. A Center scientist also visually observed the Command Module and the adapter panels in a 6 inch refractor finder scope at magnitude 10 or 11. On Jan. 31, F.J. Eastman visually observed the 11 magnitude Command Module in a 12 1/2 inch Newtonian. On Feb. 1, 1971, the Fernbank Science Center imaged the Command Module as a magnitude 13 object and the engine plume during a mid-course burn correction using a 36 inch aperture. No distance is stated in the article, but the Apollo 14 Mission Report at Table 6-III indicates that the first mid-course correction burn occurred about 30 hours into the flight and at about 118,000 miles (190,000km) from the Earth (NASA, 1972).

On Feb. 7, 1971, University of Oregon researchers, using a 24 inch aperture, imaged the returning Command Module at 177,830 miles (286,000km).

On Feb. 8, 1971, amateur observers were reported to have visually seen the Command Module in an 8 inch reflector when the CM was about 106,000 miles (170,000km) from

Earth.

For fuel dumps to be observable within the first 10 hours or to track the outbound booster during the initial trans lunar orbit during the first 30 hours, timely orbit element and position data will be necessary. Ordinarily, amateur satellite trackers use orbital elements provided on a delayed basis from the United States Airforce (Spacetrack.org, 2009). One way that LCROSS public outreach efforts can aid amateur involvement is to create a conduit for such positional data between amateurs the Ames Mission Operations Center and/or the Flight Dynamics Center at Goddard Space Flight Center (*see* Heldmann , 2006b at Slide 38). The existing satellite ephemeris service providers are a preexisting network that can distribute such information, *e.g.*, Heaven's Above, CalSky and/or the Jet Propulsion Laboratory's Horizon web application.

6.3 Cruise phase imaging opportunities

LCROSS team public education member Brian Day mentioned that the team was considering supporting amateur imaging of the EDUS stage based on the 2002 amateur detection of an Apollo era Saturn V booster at an Earth Lagrange point (Day, 2008).

About mission day 5, the LCROSS-EDUS will swing by the Moon into a gravity assist orbit with a nominal lunar orbit diameter of 500,000 - 700,000 km inclined at about 76 degrees to the lunar equator (Ennico, 2008 at Slides 20-21). Depending on a final north or south polar target selection, the LCROSS-EDU combination will remain in a cruise orbit for another 3 to 4.5 months and make 2 or 3 perigee passes within 4,000 km of the Moon (Galal, 2008 at Slide 11). Since a final target selection has not been made, the parameters and timing of this cruise portion of the LCROSS-EDU orbit are not known at this time.

The proposal for Centaur acquisition during the cruise phase is based on imaging experience surrounding minor planet object J002E3 in 2002 and 2003. In 2002, a Saturn V third stage, probably from Apollo 12, was discovered by amateur Britt (2002a) at magnitude 16.5 at Earth's L1 LaGrange Point with 18 inch of aperture (Britt, 2002b).

The object was designated minor planet J002E3. The target distance was not stated, but L1 and L2 points are approximately 1.5 million kilometers from Earth. Jorgensen et al. (May 2003) conduct follow-up spectral imaging and confirmed that J002E3 was an artificial man-made object.

Rick Baldridge imaged J002E3 on March 29, 2003 using a 16 inch f/5 Newtonian using a StellaCam EX at a distance of 446,706 km:

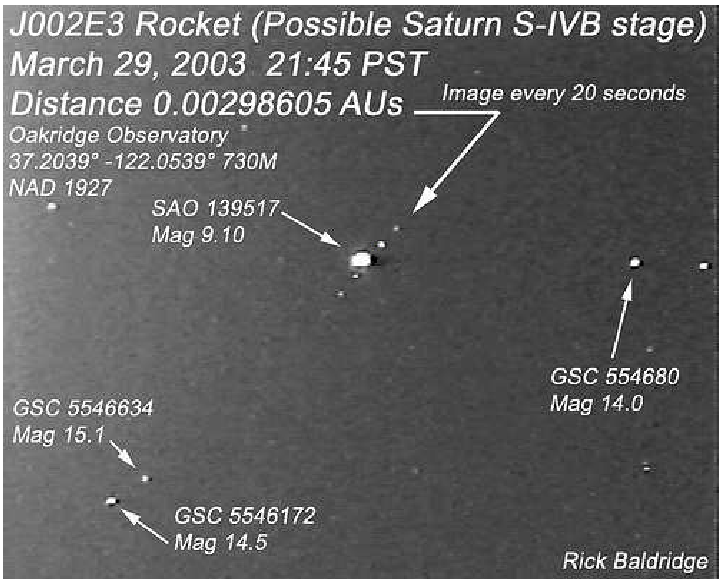


Figure 45 – J002E3 imaged on March 29, 2003. Photo courtesy of R. Baldridge.

For other images of J002E3 in 2002 using 12", 14" and 24" of aperture and 30 to 60 second exposure times, *see* Spaceweather.com (2002).

In conclusion, imaging of the Centaur booster during its three-month cruise phase appears possible.

6.4 Lunar orbit bright-limb transits probably not cannot be imaged

Modeling above indicates that the albedo of a Centaur probably is insufficient to recover the object against a 12 to 15 magnitude per square arcsec dark limb.

The visibility of Centaur as it crosses the bright limb is governed not by its albedo, but by its occulting disk size, *e.g.* as occurs for asteroids occulting stars. Since a 12 meter long object at a distance of 384,400 kilometers only subtends 0.006 arcsecs, it is not probable that amateurs will be able to image the two or three transits of the bright limb of the Moon during the cruise phase. Reported prior experience, described as follows, raises questions about this conclusion.

The matter warrants further consideration by the amateur imaging community.

With respect to near-Earth objects, Lena (2008b) captured the bright and dark lunar limb transit of the debris field from Chinese satellite FENGYUN 1C DEB (1999-025-UX) where the highest concentration of debris was estimated at 850 km. The image capture involved 2 pixel flashes on sequential AVI frames.

Lena (2008b) also imaged the ISS transiting the dark limb of the Moon at a distance of 957 km from an Earth-based observer.

Whether the experience with near-Earth satellites can be extrapolated to a lunar orbiting satellite at a distance of 384,400 kilometers warrants further discussion.

7. At lunar impact, it is unlikely that the impact flash will be visible.

7.1 Generally

Theoretically, the EDUS impact flash could be visible from Earth if the point of impact occurs in those limited portions of permanently shadowed regions that do not receive visible light, but into which Earth-based radar has penetrated. Margot et al. (1999) (at Fig. 3) identifies cold-traps at the north and south poles which are (a) permanently shadowed and not visible to Earth-base radar and (b) permanently shadowed and visible to Earth-based radar. In theory, if an impact occurred in areas that are permanently shadowed and visible to Earth-based radar, the impact flash would be visible.

Inspection of Margot's Figure 3 and the candidate target indicates this is unlikely. Small bowl shaped craters, like northern candidates Fibiger and Erlanger, have crater size to depth relationship that prevented Margot et al.'s radar waves from reaching their floors (*see* Pike, 1977). The Nansen F region and Faustini do have sizeable areas that could have been seen by Margot et. al. radar. But for Faustini, current "sweet spot" coordinates are not within an area that is both shadowed and visible to radar. For the Nansen F region, it remains to be determined whether Nansen F will be selected, or if selected final targeting be in such a light-dark but radar-visible area.

It is more likely that the impact flash will not be visible to Earth-based amateurs principally because the impact will occur below the rim of a shadowed crater. The rim will block a direct view of the impact flash.

No reference to the expected impact flash brightness was found in LCROSS Team publications beyond an indirect flux value of 0.001 to 1 W m^{-2} $micron^{-1}$ at a shepherding satellite distance of 1000 km (Bussey, 2008a at Slide 14). This limited information did not include the size of the initial flash. Thus, it was not possible to formulate a magnitude estimate for the flash as seen by Earth-based observers.

Analogous artificial and man-made impact flashes have been observed in a variety of contexts.

7.2 Analogous artificial impacts flashes

McRobert (2005) and Univ. of Maryland and NASA (2008d) report that the 2005 Deep Impact flash was not observed by amateurs, but the resulting sunlit ejecta cloud was observed and imaged by many amateurs using 10 to 16 inches of aperture.

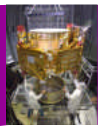
Amateur Lipscomb (2007) makes a credible report that he captured the September 2, 2006 flash from the 276.5 kg SMART-1 impact at 2.0 km s-2. Lipscomb used a Meade LX90 of 8 inches of aperture and under cloudy conditions (Lipscomb, 2006a; Lipscomb, 2006b; Beatty, 2006). The flight mass of Smart-1 was 366.5 kg including 82kg of Xenon fuel and 8kg of hydrazine (ESA, 2003). There is insufficient independent confirmation of the Lipscomb capture as a real flash. The afterglow could just to be a random peak of the background noise (Lena, 2007).

Formal amateur observing campaigns and other advanced imagers failed to capture the flash or ejecta curtain, principally due to unfavorable weather conditions (Astronomia Observacional's Net-REA, Lunar Section, 2006; Wood, 2006b).

Professionals Velliet and Foing using an infra-red webcam with 10 second exposure and an H2 narrow-band filter at 2122 nanometers with a 32 nanometers bandwidth coupled to the Canada-France-Hawaii Telescope with 3.6 meters of aperture imaged both the SMART-1 impact flash and ejecta dust cloud (Velliet and Foing, 2007; Velliet, 2006). Luckily, the flash occurred during one of the 10 second exposure intervals and not during CCD read-out.

The 1999 impact of the 158 kg Lunar Prospector satellite at 1.7 km sec^{-1} at a highly oblique angle failed to produce a detectable flash or plume (Goldstein, 1999 re: spacecraft mass and velocity). Barker et al. (1999) concluded that observation was hampered by scattered light from the bright lunar limb.

A historical search of Sky & Telescope issues around the time of lunar impacts by Apollo LEMs and Saturn IV boosters was done. NASA (2008a) provides a list of LEM and Saturn IV-B impacts was used as a guide. Each Sky and Telescope issue for three



months following a Saturn booster impact was examined. Apollo preliminary science reports were reviewed. No references to Earth-based observations of flashes or ejecta curtains at the time of impact were found. As with the impact flash, it is unlikely that the EDUS and LCROSS post-impact craters will not be observable from Earth because the artificial impact craters will be obscured from direct view by the one to two kilometer high natural crater rim.

Post-impact, several historical artificial lunar impact craters have been imaged. Whitaker (1972) (Apollo Saturn IV) and Moore (1972) (Ranger series) inventoried known images of Ranger and Apollo era impacts using Apollo 16 lunar orbit panorama images (Moore, 1978). Whitaker (1972) lists three impacts that occurred at high angles similar to the proposed EDUS and LCROSS impacts (*id*. at Tables 29-II and 29-III).

Spacecraft	Mass kg	Impact velocity km sec^{-1}	Impact angle	Measured crater dia meters
Ranger 7	365.6	2.616	64	14.5
Apollo 13 Saturn IVB	13,925	2.58	76	41
Apollo 14 Saturn IVB	14,016	2.54	69	39.5

Table 16 - High angle Ranger and Apollo era impacts and resulting craters from Whitaker (1972) and Moore (1978).

Spacecraft	Selenographic coordinates	Apollo panorama image
Ranger 7	S2.45 W43.22	AS16-P-5435
Apollo 13 Saturn IVB	S2.54 W27.79	AS14-69-9656
Apollo 14 Saturn IVB	S8.17 W25.95	AS16-P-5451, 5453, 5444

Table 17 - Apollo images related to Whitaker (1972) and Moore (1978) impacts in preceding table.

Figure 1, above, is of the Apollo 14 Saturn IVB impact crater and ejecta blanket from AS16-P-5451. Note the dark ejecta blanket extends to the southeast and two light ejecta rays exit to the northeast. Although most of the ejecta curtain is confined to within 1 kilometer of the impact, but the longest light ejecta ray extends for 5 km (Whitaker, 1972).

Figure 46, below, is of the Ranger 7 impact crater and ejecta blanket from AS16-P-5435. The crater's gross appearance is similar to LCROSS team models for the 2,000 kg EDUS impact.

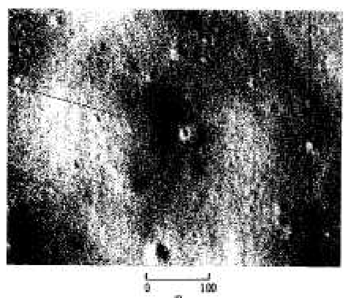


Figure 46 - Ranger 7 impact crater (14.5m) and ejecta blanket from Fig. 29-48 in Whitaker (1972). Scale bar is 100m. Photo courtesy of NASA.

On February 20, 1965, professional astronomers Alika Herring and Chuck Wood attempted unsuccessfully to observed the flash of the impact of Ranger 8 using Kitt Peak's 84" of aperture (Wood, 2008b).

Schultz (2007) concluded that the size of craters produced by the 370 kg Ranger (14.5 m) and 13,900 to 14,920 kg Saturn IV impacts (41 m) can be used to bracket the likely size of the impact crater that will be left by the 2,000 kg EDUS and 700 kg LCROSS shepherding satellite.

7.3 Analogous natural impact flashes

Naturally occurring dark limb meteoroid impact flashes currently are the subject of intense professional research and pro-amateur cooperative observing campaigns (NASA, 2008h, soliciting amateur observations of lunar meteor impacts).

A review of limited available mass-to-magnitude data for lunar meteoroid impact flashes weighs in favor of the conclusion that the impact flash, if not obscured from Earth observers, would be visible. A minimum integrated flash magnitude for amateur planning purposes is 7 or 8 magnitudes.

Again, the LCROSS mission profile is to target the EDUS impact deep in the permanently shadowed portion of lunar polar crater. It is unlikely that the flash will be seen, absent targeting error or uncertainty, by the target crater's rim from Earth-based direct-view. There is small chance that the EDUS impact will strike in those portions of PSRs that receive no sunlight but that are visible to Earth-based radar. The targeting accuracy of the EDUS is 3km (Bussey, 2008a at Slide 9).

For an analogy to the integrated magnitude of the EDUS impact, we look to the minimum kinetic energy before impact of known lunar meteor impacts that produced a flash detectable on the Earth.

As of Nov. 7, 2008, NASA's Space Environments Team and Meteoroid Environment Office at the Marshall Space Flight Center has catalogued 138 probable and confirmed lunar impact flashes (Moser, 2008).

Of these 138 detected flashes, the Meteoriod Environment Office has published data on the magnitude of the impacts for 20 events (Cooke et al., 2007 at Table 1; Cooke et al., 2006). For the 20 events with published magnitudes, 9 are confirmed and associated with meteor streams with known average velocities. Of those 9 observations, 6 impacts were brighter than magnitude 9. NASA (2006) lists characteristics of a seventh event (Meteriod Office Id 2) that occurred on May 2, 2006.

The characteristics of these limited 7 impact observations still are instructive as to the minimum kinetic energy that an object must possess in order to produce a lunar impact flash that can be observed from the Earth.

Meteoriod Office ID	Date	Approx. mag.	Associated stream	Average stream velocity km sec^{-1}
1	7 Nov 05	7.3	Taurid	27
2	2 May 06	6.9	Sporadic	38
11	17 Nov 06	8.2	Leonid	70
15	14 Dec 06	8.5	Geminid	33
16	14 Dec 06	8.6	Geminid	33
19	14 Dec 06	8.7	Geminid	33
20	14 Dec 06	7.5	Geminid	33

Table 18 - Characteristics of seven lunar meteor impact flashes from Moser (2008), Cooke et al. (2007) and NASA (2006).

Meteoriod Office ID	Date	Moon phase	Impact lat.	Detection aperture mm
1	7 Nov 05	Waxing	39.5W	254
2	2 May 06	Waning	19.6W	254
11	17 Nov 06	Waning	80.3E	355
15	14 Dec 06	Waning	46.4E	355
16	14 Dec 06	Waning	84.0E	355
19	14 Dec 06	Waning	71.6E	355
20	14 Dec 06	Waning	28.2E	355

Table 19 - More characteristics of seven lunar meteor impact flashes from Moser (2008), Cooke et al. (2007) and NASA (2006).

Sources for Table 18 and Table 19 are: Id, date, approx. mag., and probable stream are from Cooke et al. (2006) and NASA (2006). Moon phase and impact latitude and detection aperture are from Moser (2008). Average stream velocity at Earth above atmosphere is from Cox (2001), Table 13.10 at p. 333.

This sample of seven flashes is biased for lower-velocity, waning phase meteor impacts from the Geminid streams, which itself has an average lower velocity relative to the Earth as compared to the Leonids.

Suggs et al. (2008) notes that there is population bias in their sample of 138 probable detections related to the phase of the Moon. Detections are less frequent (0.09 hr-1 vs. 0.17 hr-1) and have a lower average velocity (25 km sec^{-1} vs. 55 km sec^{-1}) near the third quarter waning phase of the Moon. At that first-quarter waxing phase, the Moon follows the Earth in its orbit around the Sun and the Earth-observable dark limb of the Moon is exposed to impacts from meteors travelling from the apparent apex of Earth's travel, from the antihelion direction and from the toroidal (north-south z plane of the ecliptic) directions. Meteors approaching from the Earth's apparent apex of motion have a higher average velocity due in part to the relative orbital motion of the Earth and Moon.

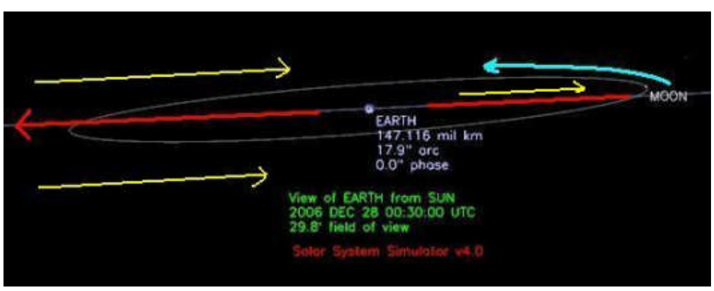


Figure 47 - Apex meteors striking visible face of the First Quarter Moon. Yellow = meteors from the apparent apex. Red = Earth orbital direction. Graphic courtesy of NASA JPL Solar System Simulator.

At the third quarter waning phase, the Moon leads the Earth in its orbit around the Sun and dark limb of the Moon exposed to higher velocity apex impacts faces away from the Earth.

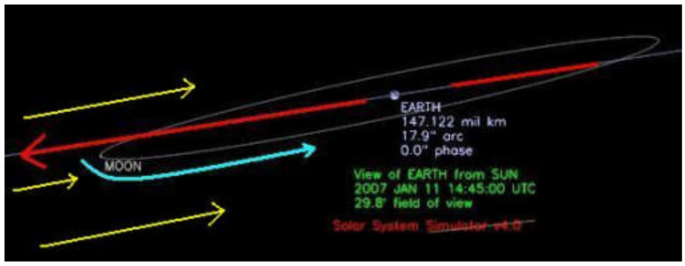


Figure 48 - Apex meteors striking hidden face of the Third Quarter Moon. Yellow = meteors from the apparent apex. Red = Earth orbital direction. Graphic courtesy of NASA JPL Solar System Simulator.

Compare Figs. 3 and 2 in Suggs, Cooke and Suggs et al (2008).

This sample of 7 impact flashes listed above are biased towards the waning phase impacts from the moderate velocity Geminid meteor stream on a single date. As a sample to be used to define the constraint on the minimum kinetic energy that an impactor must possess in order to produce an impact flash visible to Earth-based observers, this bias is helpful.

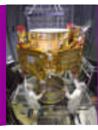
The Earth-based view angle of these 7 impacts is also relevant to their impact energy. Three of the seven samples are occurred at lunar latitudes greater than 80 degrees; three occurred at latitudes less than 50 degrees.

In experiments with the NASA Ames Velocity Gun Range, a hyper-velocity gun, Ernst and Schultz (2008) found the brightness of simulated lunar impact flash was nine times fainter when viewed from the side as opposed when viewed from above. “An impact near the edge of the lunar disk will appear to have far less luminous energy than an identical impact near the sub-Earth point.” *Id.*

Bellot-Rubio et al. (2000) provide an analytic model for determining the luminous energy reaching the Earth from lunar meteor impacts viewed at various angles.

The brightness ratio of 9-to-1 found by Ernst and Schultz implies a differential integrated magnitude of about 2.4v (2.5 x log10(9/1)).

The three impacts in Table 18 near the lunar limb would have to have more impact



energy in order to produce flashes of approximately the same apparent magnitude – about 8.5v – as those impacts that occurred closer to the center of the lunar disk.

The three impacts in Table 18 at lunar latitudes greater than 70 degrees suggest a minimum constraint on the impact energy necessary to produce an impact flash at the Moon's north or south poles that would be observable from the Earth:

ID	Appx mag.	Impact lat.	Velocity km sec^{-1}	Kinetic energy J for 1kg meteor before impact
11	8.2	80.3E	70	2.45E+09
16	8.6	84.0E	33	5.45E+08
19	8.7	71.6E	33	5.45E+08

Table 20 - Minimum impact energy of Earth-observable lunar meteor impacts – kinetic energy at Moon implied from three lunar impact flashes from Suggs et al. (2008).

Appx mag.	Est. Mass kg	Velocity km sec^{-1}	Kinetic energy J before impact	Detection aperture mm
3	4.9	72	1.27E+10	200
4	1.9	72	4.92E+09	200
5	0.77	72	2.00E+09	200
6	0.3	72	7.78E+08	200
7	0.12	72	3.11E+08	200

Table 21 - Earth-observable impact energies at Moon for six lunar impact flashes observed by Bellot-Rubio et al. (2000).

Object	Est. mass (kg)	Velocity km sec^{-1}	Kinetic energy before impact J
Deep Impact sat. - comet	370	10.2	1.92E+10
Sporadic mag 6.9	23.5	38	1.7E+10
Leonid mag 3	4.9	72	1.27E+10
EDUS – predicted	**2000**	**2.5**	**6.25E+09**
Leonid mag 4	1.9	72	4.92E+09
Leonid mag 8.2	1	70	2.45E+09
LCROSS - predicated	**700**	**2.5**	**2.19E+09**
Leonid mag 5	0.77	72	2.00E+09
Leonid mag 6	0.3	72	7.78E+08
SMART-1 (oblique)	276.5	2.0	5.38E+08
Geminid mag 8.6	1	33	5.45E+08
Geminid mag 8.7	1	33	5.45E+08
Leonid mag 7	0.12	72	3.11E+08
Lunar Prospector (oblique)	156	1.7	2.25E+08

Table 22 - Kinetic energy before impact of satellites and lunar meteor impacts with known magnitudes and EDUS-LCROSS predicted kinetic energies.

Suggs et al. (2008) suggested the meteors in the Meteoroid Environment Office impact list to be "on the order of 1 kg." Table 20 ignores the unknown angle of impact relative to the lunar surface for each meteor.

Bellot-Rubio et al. (2000) reported observed magnitudes and estimated velocities and masses for five Leonid meteor flashes that occurred at an oblique angle between 30-55 degrees on Nov. 18, 1998. Table 21.

Table 22 summaries the kinetic energies of natural and artificial impactors are described in Table 18 through Table 21. With respect to the May 2, 2006 Meteoriod Office Id. No. 2 impact, the mass is estimated from information in NASA (2006).

The kinetic energies before impact in Table 20, Table 21 and Table 22 were computed using the simple kinetic equation:

$$E = \frac{1}{2}mv^2$$

Equation 5 - Kinetic energy equation

Colaprete (2008) (at Slide 17) estimates for the impact energy of the 2,000 kg EDUS is 6.5E+9 Joules. (6.25E+9 J = ½ x 2,000 kg x (2.5 km/sec)^2). This is consistent with the energy in Earth observable meteor impacts and is about 11 times the kinetic energy of observed 8.6-8.7 magnitude Geminid meteor impacts near the lunar limb.

If the luminous efficiencies for the EDUS impact and the Geminid impacts are similar, this implies an EDUS impact brightness of about 6 magnitudes. (6.0 = 8.6 + 2.5*Log10 (1/11)).

Bellot-Rubio also computed a luminous efficiency constant for these 72 km sec^{-1} impact of 0.002, that is two-thousands of the impact's kinetic energy was converted to light between 400 and 900nm. The luminous efficiency of the slower 2.5 km sec^{-1} LCROSS-EDUS impact has not been reported.

The radiant efficiency of the LCROSS-EDUS impact is not known and therefore the impact kinetic energy of impacts at these different velocities are not directly comparable.

Nonetheless, the above suggests that if the EDUS impact is not obscured from the direct view of an Earth-based amateur, the event will be visually observable.

Again, the LCROSS mission profile is to target the impact of the EDUS into a permanently shadowed portion of a polar crater that will be obscured from direct viewing by an Earth-based observer.

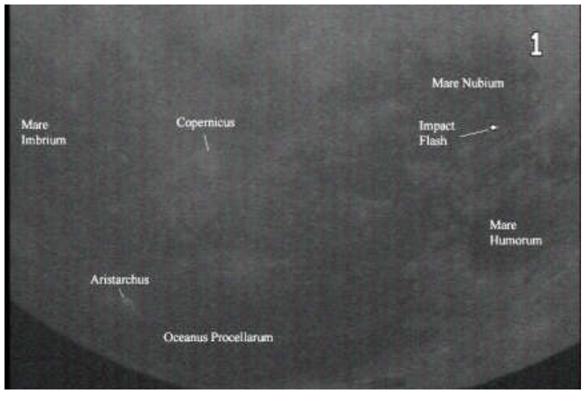


Figure 49 - A magnitude 6.9 lunar impact flash on May 2, 2006 recorded by the NASA Meteoroid Environment Office (NASA, 2006). Photo courtesy of NASA and NASA Marshall Space Flight Center.

Figure 49 shows a magnitude 6.9 flash from a lunar impact captured in May 2006 by the NASA Meteoriod Environment Office. In NASA (2006), Bill Cooke of the Meteoriod Office estimated the resulting impact generated a crater 3 meters deep and 14 meters in diameter. This is similar in size to the predicted crater to be created by the EDUS impact.

For the techniques of imaging and modeling lunar impact flashes by professionals and amateurs, *see* Swift, Cooke and Suggs (2008), Lena and Evans (2008) and Lena (2008a).

8. Ejecta curtain imaging opportunities and brightness

8.1 LCROSS team CBEIM estimate for the ejecta curtain

Amateurs are principally interested in event visibility in the visual range of 480nm to 700nm. Table 1, above, summarizes the results of the LCROSS Team's thinking on what the likely size of the ejecta cloud will be.

As noted in the Introduction, the LCROSS Team has not issued estimates of the integrated magnitudes of the LCROSS-Centaur impact ejecta curtain for amateur imaging purposes.

Magnitude estimates that have been made are for single wavelength spectral radiance and irradiance at Earth with emphasis on predicting the magnitude of the impact as seen through a sub-arcsec slit of the near-IR SpeX spectrograph and imaging camera at the

NASA Infra-Red Telescope Facility (IRTF) on Mauna Kea, Hawaii (Univ. of Hawaii, 2009).

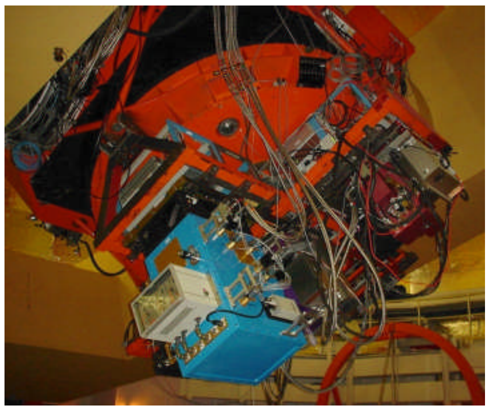


Figure 50 - SpeX spectrograph (blue box) at IRTF (Univ. of Hawaii, 2009). Photo courtesy of IRTF, Univ. of Hawaii.

What has been published by the LCROSS Team as 25 Jan. 2009 is the following: Bart (2008) stated that the ejecta cloud “[s]hould be quite visible (Mag 9-10 per [quarter arcsec]) from Earth in the Pacific (including west coast)” coupled with charts (Slides 19-20) showing the irradiance (brightness) of the ejecta cloud when observed from Earth would be around 1 x 10^{-9} Watts meter^{-2} micron^{-1} (Bart, 2008, Slides 17-20). The best available LCROSS statement regarding the apparent magnitude of the ejecta curtain at Earth is a peak brightness of 6 magnitudes per [quarter arcsec] field-of-view (FOV) at 555nm at 40 secs after impact (Bart, 2008 at Slide 20). (Author’s note: bracketed quarter arcsec figure corrected based on LCROSS Team communication.)

These values are stated in irradiance and spectral irradiance units at a single frequency typically used by professional astronomers and not full spectrum visual or photometric magnitudes usually used by general amateurs. As noted above in Section 2.2, the LCROSS Team and independent researchers have devoted significant effort to modeling the physical ejecta cloud that will result from the EDUS impact and the likely brightness of that ejecta cloud, both from an Earth and spacecraft viewpoint.

LCROSS team estimates of the impact ejecta plume's irradiance at Earth at a visual wavelength of 550nm were developed through three analytical steps. Jutzi and Benz (2006, 2008) and Korycansky and Asphaug (2008) prepared smooth particle hydrodynamic (SPH) computer models. Wooden (2008) took the dust-grain-particle computer models and extended them to predict ejecta cloud brightness based on the radiant efficiency of hypothetical dust particles 30 and 100 microns in diameter. Summy et al. (2009) modeled the dust cloud density (but no dust grain radiant emittance) at 25 to 100 seconds after impact and reported ejecta cloud sizes consistent with Wooden (2008).

Radiant efficiency means, in this context, the percentage of radiant emittance from the Sun that is reflected off the ejecta cloud and back towards the Earth. Dust grains absorb some sunlight and scatter some sunlight away from the Earth. The net balance is reflected towards an Earth based-observer.

An estimate of irradiance at Earth in a single 550nm wavelength is an incidental by-product of the LCROSS Team's activities. However, as a single wavelength prediction, it is not useable by amateurs for making exposure estimates. That requires full spectrum irradiance at Earth values.

As noted above, for Earth-ground-based observations the LCROSS Team is focused on other spectral wavelengths that are outside the spectral response curves of typical amateur CCDs and spectrograph equipment – a fact reflected in the professional focus of their published estimates.

8.2 Prior analogous ejecta curtains

As discussed under Section 7 above, neither impact flashes nor ejecta clouds were observed during the Ranger missions or for Apollo era Saturn IV and LEM impacts.

The Deep Impact ejecta cloud was observed by amateurs with 8 to 12 inches of aperture. *See* discussion Section 2.1, above. The SMART-1 impact cloud was only clearly captured by large professional telescopes. (As noted above, amateur Peter Lipscomb claims an unconfirmed detection.) *See* discussion Section 7.2, above.

In 1959, a vapor cloud from a specially designed Luna 2 rocket booster was observed. The Luna 1 and Luna 2 boosters included several pounds of sodium metal surrounding a thermite charge. The purpose of the packet was to temporarily increase the brightness of the spacecraft to allow Earth-based optical telescopes to determine its position during trans lunar orbit. The thermite charge was electronically detonated at 113,000 km from the Earth and dispersed sodium into a vapor cloud that was optically observed expanding out to a 400 kilometer diameter before it became too faint to see visually (Christy, 2009, including cloud photographs). The cloud reached a maximum brightness of 4 to 5 magnitudes.

8.3 A reasonable interval for exposure calibration testing to capture the ejecta curtain

In the absence of a published model that provides a predicted full spectrum integrated and mpsas value for the ejecta curtain, amateurs are forced to rely on a reasonable range of magnitudes method for deciding on what magnitudes to exposure calibration at the difficult near terminator dark feature poles anticipated at the time of impact.

The upper bound of this reasonable range of magnitudes is based on the compacted, optically opaque, lunar regolith. Montañés-Rodríguez and Goode (Sept. 2007) report that features on the bright limb vary from 4 to 6 mpsas based on Earth-Moon-Sun geometry (Montañés-Rodríguez and Goode, Sept. 2007). The faintest extended object detectable against a background of 4 to 6 mpsas is given by the method of Clark (1990) and Covington (1998):

$$CI = -0.4 * (\text{Object\_mpsas} - \text{Background\_mpsas})$$

Equation 6 - Contrast index formula (Clark, 1990).

Assuming, based on experience, that a contrast index of 1 as a reasonably detectable minimum contrast, the preceding equation reduces to:

$$\text{Object\_mpsas} = \text{Background\_mpsas} - 0.4$$

Equation 7 - Contrast index forumla solved for an object's mpsas at a contrast index of 1.

Against a 4 to 6 mpsas background, a 3.4 to 5.4 mpsas object is the faintest that will generate sufficient contrast to be visible. Applying the method of Covington (1998) and Clark (1990) to convert mpsas of an extended-object to an integrated magnitude, suggests for a 10 km x 5km curtain (5" x 2.75") will need to have an apparent brightness of 0.9 to 2.9 integrated magnitudes to be detectable visually.

0.9 to 2.9 integrated magnitudes is the recommended upper end of the interval for exposure calibration practice.

Anecdotal evidence from amateurs who specialize in lunar occultation indicates that with 12” of aperture and an IR sensitive camera, magnitude 7 stars can be detected to within 5 arcsecs of the bright limb before they disappear into glare.

The lower bound of this reasonable range of magnitudes for imaging calibration testing is the faintest extended object that has sufficient contrast to be visible against the upper range of the dark limb of the Moon.

Montañés-Rodríguez and Goode (Sept. 2007) also report a mean albedo value of 15.44 mpsas for the dark limb at a standardized distance with a variance between 12 to 17 mpsas depending on changes in Earth-Moon geometry, phase, and Earth’s albedo. Assuming a contrast index of 1 as the minimally detectable CI and a 10 km x 5 km ejecta curtain, 12 to 17 mpsas implies 8.9 and 13.9 integrated magnitudes as the minimum brightness of an ejecta curtain that has a sufficient contrast to be detected. The methods of Covington (1998) and Clark (1990) was applied used to compute a contrast index and convert to integrated magnitudes.

8.9 integrated magnitudes is the recommended lower end of the interval for exposure calibration practice.

Anecdotal evidence from amateurs who specialize in lunar occultation indicates that with 12” of aperture and an IR sensitive camera, magnitude 11 stars can be detected before they disappear against the dark limb.

A supporting spreadsheet of computations can be found at Fisher (2009b).

9. Conclusion

A legitimate amateur question concerning EDUS impact imaging may be, to paraphrase Shakespeare, “much ado about nothing?” For the amateur imager, the LCROSS-EDUS ejecta curtain simply may end up as a 5 x 2 arcsec line, invisible in the overwhelming brightness of the lunar terminator and under poor seeing conditions when the Moon is only 20 or 30 degrees above a 40 North latitude observer’s horizon.

LCROSS is so much more than that.

The LCROSS impact experiment represents the best of science. The experiment seeks to settle an important unresolved question on which planetary experts reasonably disagree. The result is a robust scientific debate that in and of itself warrants close following by lunar enthusiasts.

The LCROSS impact will be a once-in-a-lifetime event of uncertain brightness. It may be much larger and brighter than the LCROSS Team CBEIM low-bound prediction. Pre-event practice for this one-shot imaging opportunity will best assure amateurs of capturing a useable image in July or August 2009.

The impact event and suggested pre-event practice provides the hobby astronomer-scientist with many opportunities to use the sky as your personal laboratory. The many pre-impact practice events suggested here also provide amateurs with many opportunities to gain or improve a wide-range of skills, *i.e.* – imaging for details in small features at the extreme polar limbs, topographic recognition at the lunar poles, exposure calibration for high-contrast imaging with filters, lunar grazes and occultation, satellite tracking, spectroscopy, and aesthetic image processing by combining short exposure and long exposure images.

If the LCROSS experiment’s results are negative, this only will mean that 2 of the 1,379 potential cold traps identified by Bussey et al. (2003) will have been tested – or 0.1% of the candidates. If stated in terms of square kilometers, Bussey et al. (2003) identified 7,500 km^2 of permanently shadowed regions. Lunar Prospector and the planned EDUS impact combined at best will excavate a surface area of 600 m^2 or 0.0006 km^2, thus sampling about 0.000008% of PSRs. For a population of 1,379 randomly chosen PSRs (a condition admittedly not present for tests for lunar polar ice) and a desirable significance level of 95%, a sample size of 19 craters would need to be tested. Testing two craters may be not enough to definitively resolve the question of polar ice. Chandrayaan-1 and Lunar Reconnaissance Orbiter are equipped with miniaturized ground-penetrating radar, the mini-RF experiment. If another experiment is needed, these remote sensing instruments will be used to improve identification of future cold trap candidates.

Regardless of the LCROSS experiment's outcome, the lunar poles will continue to be central to the future of human exploration of the Moon. The poles are energy minimum landing points, they have abundant continuous solar power, and the poles experience relatively moderate environmental temperatures compared to the low latitudes of the lunar disk (Bussey, 2008b).

Recommended animations

Lunar Crater Observation and Sensing Satellite (LCROSS) First Steps. url: http://www.nasa.gov/mission_pages/LCROSS/multimedia/LCROSS_First_Step_mp.html and http://www.nasa.gov/mp4/219670main_ARC-LCROSS-FirstStep.mp4 (This animation visualizes the impact. 4 minutes)

LCROSS Overview Video (Northrop Grumman Corp.). url: http://www.st.northropgrumman.com/media/presskits/mediaGallery/LCROSS/videos/media2_1_24476_25754.html (Best explanation of mission; best ejecta plume animation)

Deep Impact: Pumice Impact Test (Side View). url: http://deepimpact.umd.edu/gallery/vid4.html

Deep Impact: Pumice Impact Test (Top View). url: http://deepimpact.umd.edu/gallery/vid3.html

A 6.9 magnitude flash from a May 2006 lunar impact. url: http://www.spaceweather3.com/swpod2006/14jun06/movie450.gif

New Spacecraft to Search for Water on the Moon (NASA-LCROSS). url: http://wm.nasa-global.speedera.net/wm.nasa-global/LCross.wmv (Best spacecraft in cruise animation)

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Heaven's Above Online Satellite Ephemeris Service. url: http://www.heavens-above.com/ .

National Aeronautics and Space Administration (various images).

NASA's Astrophysics Data System. url: http://www.adsabs.harvard.edu/ .

NASA-JPL Horizons Ephemeris Service. url: http://ssd.jpl.nasa.gov/horizons.cgi .

NASA JPL Solar System Live Simulator. url: http://space.jpl.nasa.gov/ .

Webda Open Cluster Database maintained by E. Paunzen of the Institute of Astronomy of the University of Vienna.

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MAPPING FAUSTINI CRATER

by Raffaello Lena, Koksis Antal, KC Pau, George Tarsoudis, Carmelo Zannelli, Stefan Lammel and Paolo Lazzarotti

At the present four south-pole regions are currently candidates for the LCROSS impact, including the region around Faustini crater (87.3° S, 77.0° E, 39 km diameter). Several north pole craters are currently under consideration as well.

Hi-resolution images carried out from a GLR group survey, displaying the southern polar region including Faustini are shown in the following report (cf. first figure for the location of Faustini crater).

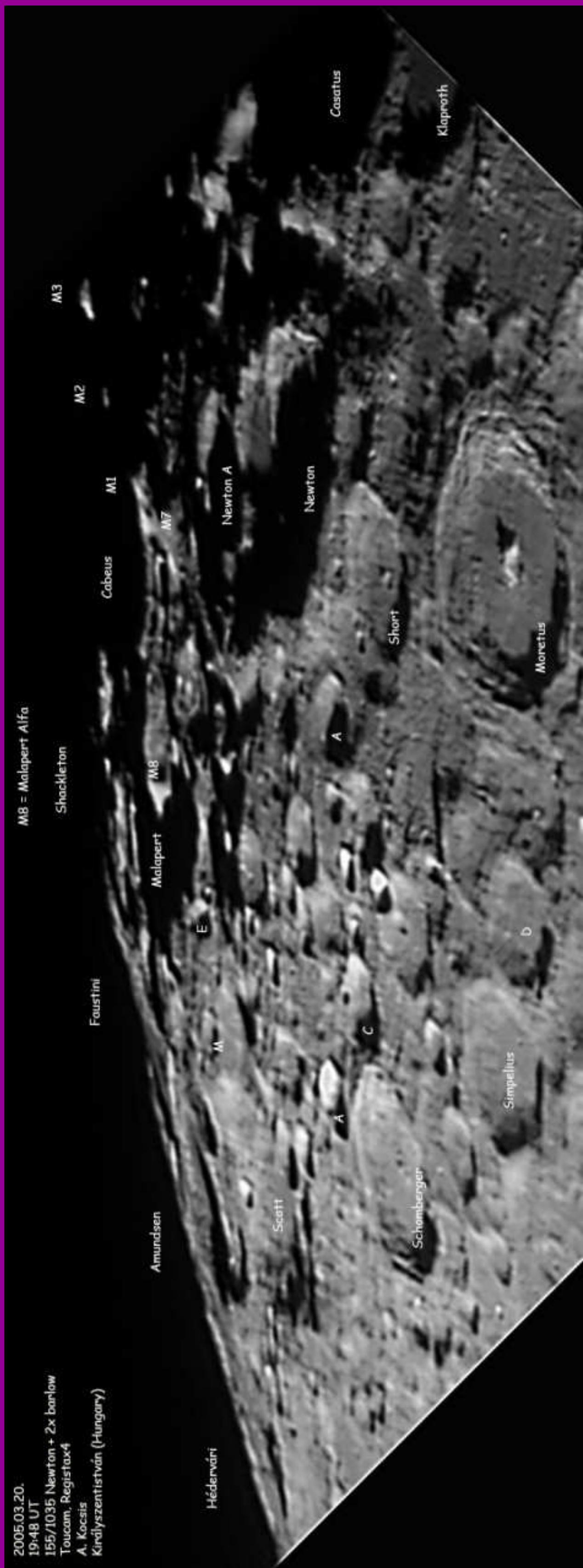
The images show the south polar region imaged with several telescopes from 155 mm to 400 mm in diameter.

For each image is reported the date-time (UT), instrument, the Earth's selen. latitude (L), % of illumination (%), the Sun's colongitude (Col.) and the Moon's age (Age) in days.

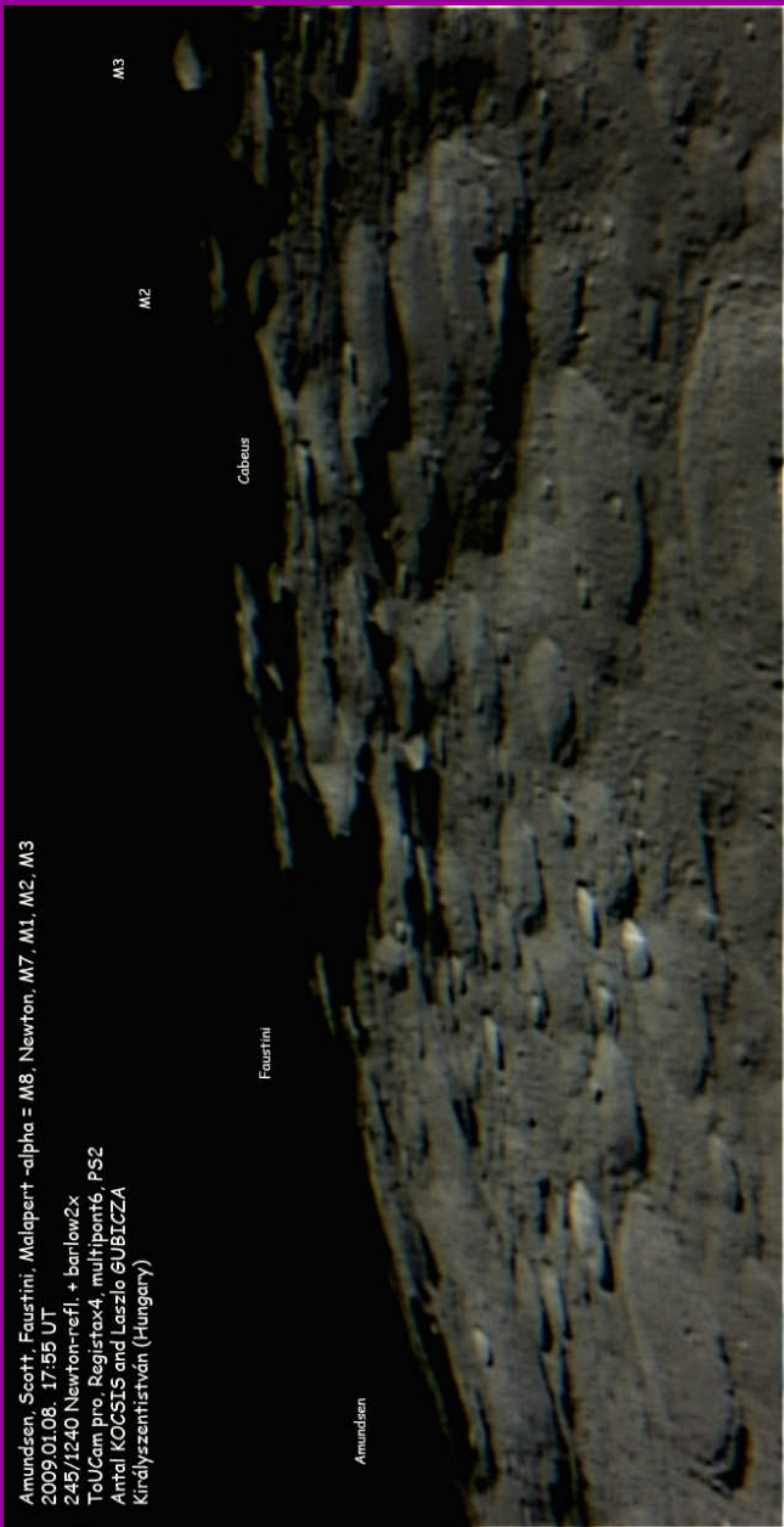
The comparison of modern images with some plates from the Consolidated Lunar Atlas (1950-1960) is interesting.

Representative plates of the polar regions taken at favorable librations include H11 (south, -3.0° latitude libration), and H7 (south, -4.8° latitude libration). The contrast would illustrate advances in amateur imaging capabilities.

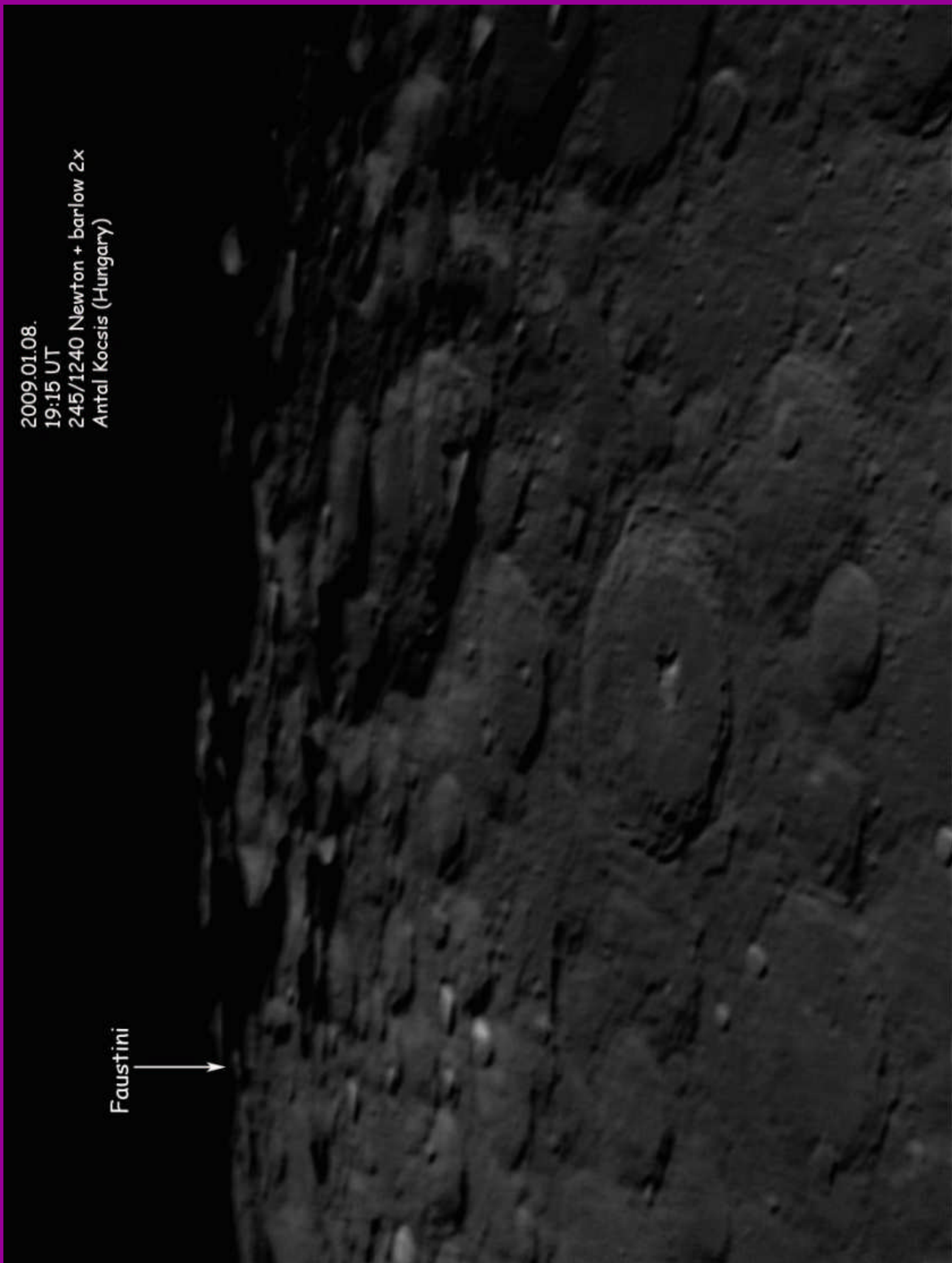
Koksis Antal L= -6.68° %=77.2 Col.= 33.53° Age=10.44



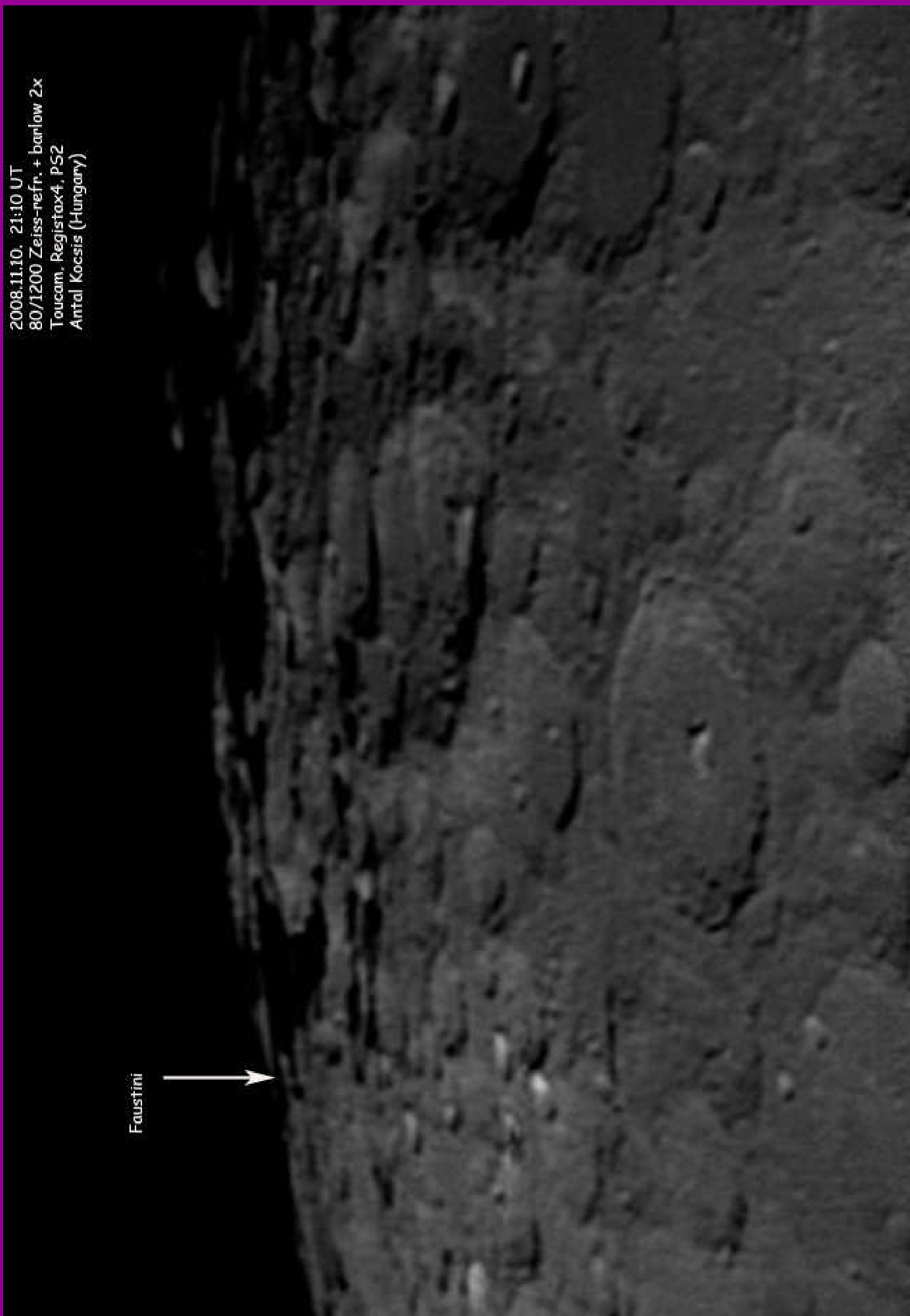
Koksis Antal L= -5.52° %=91.4 Col.= 59.28° Age=12.23



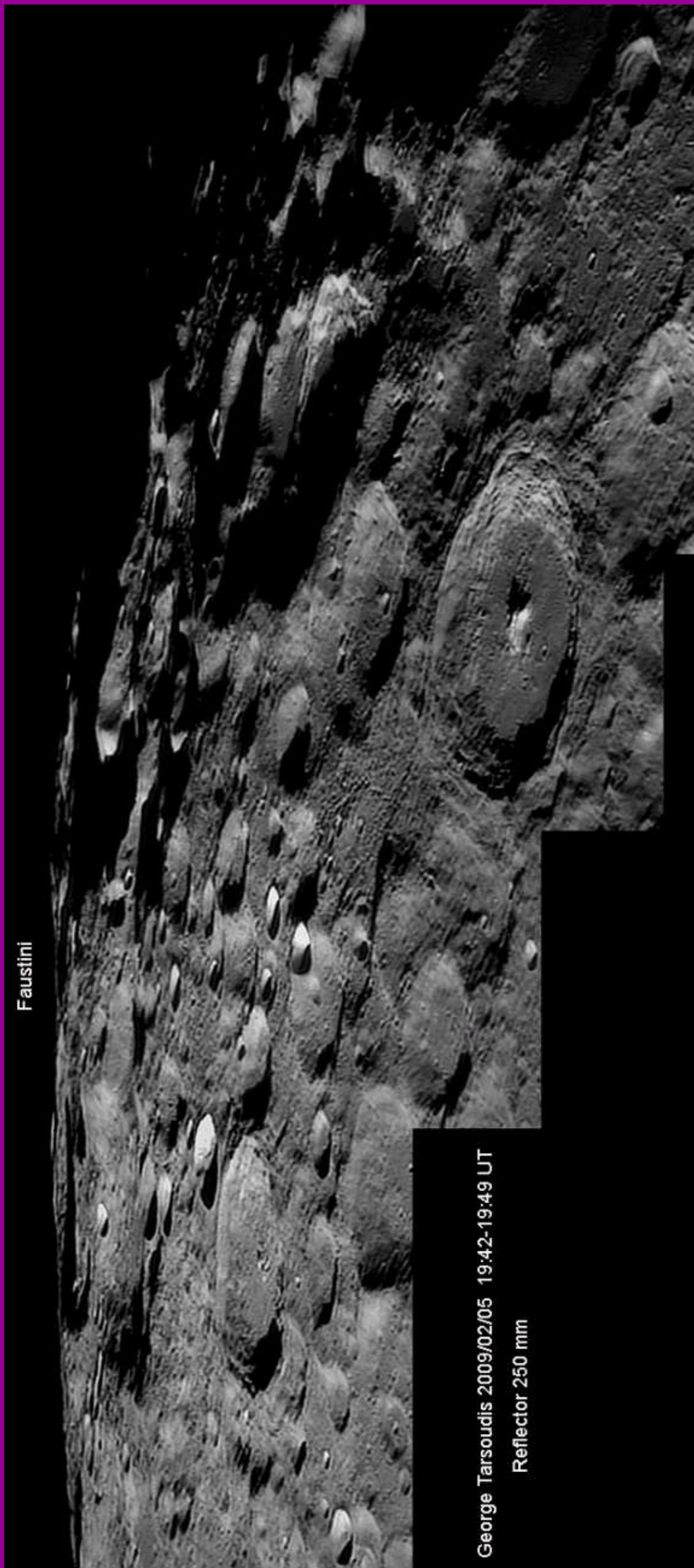
Koksis Antal L= -5.47° %=91.8 Col.= 59.96° Age=12.28



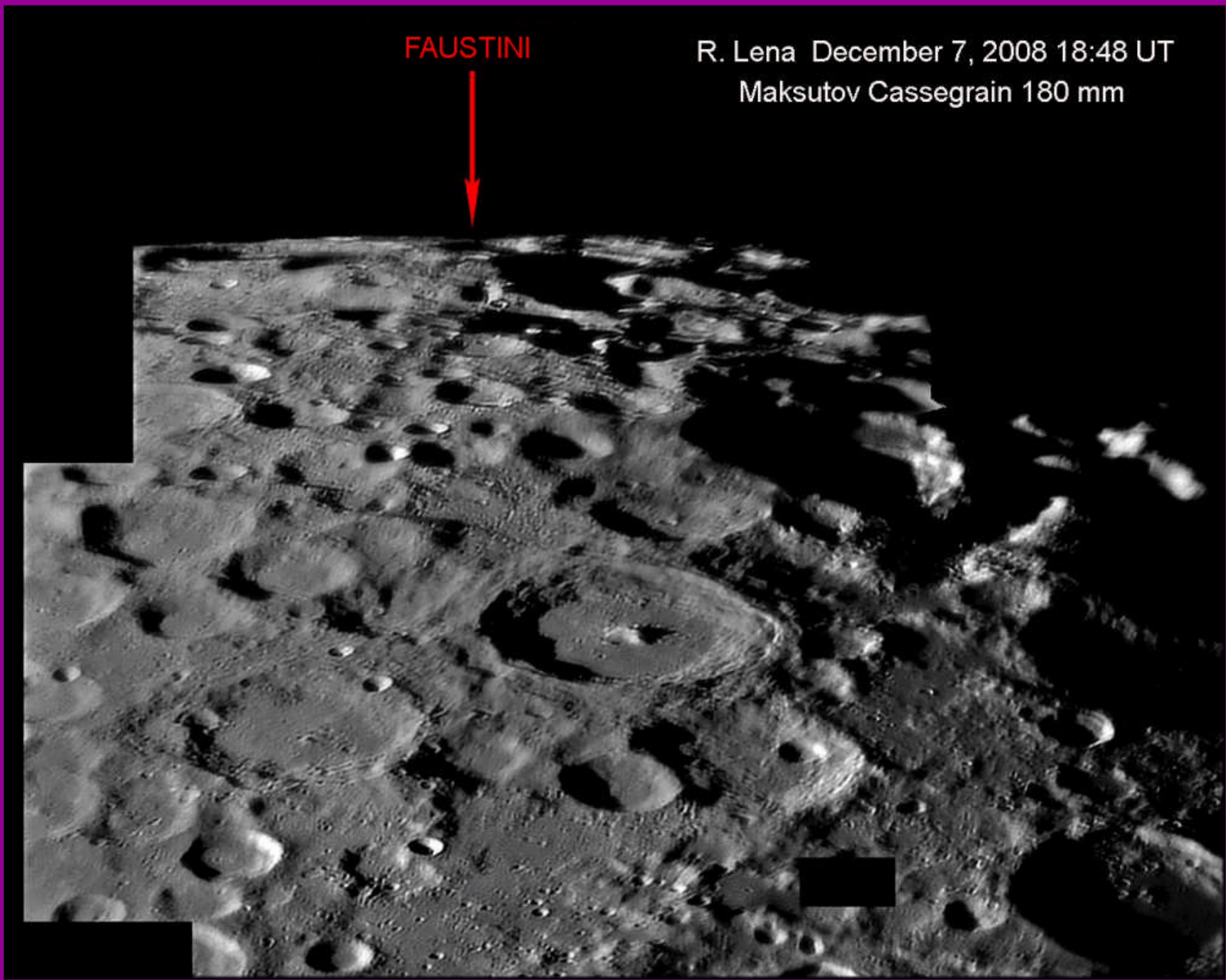
Koksis Antal L= -5.77° %=92.0 Col.= 63.68° Age=12.91



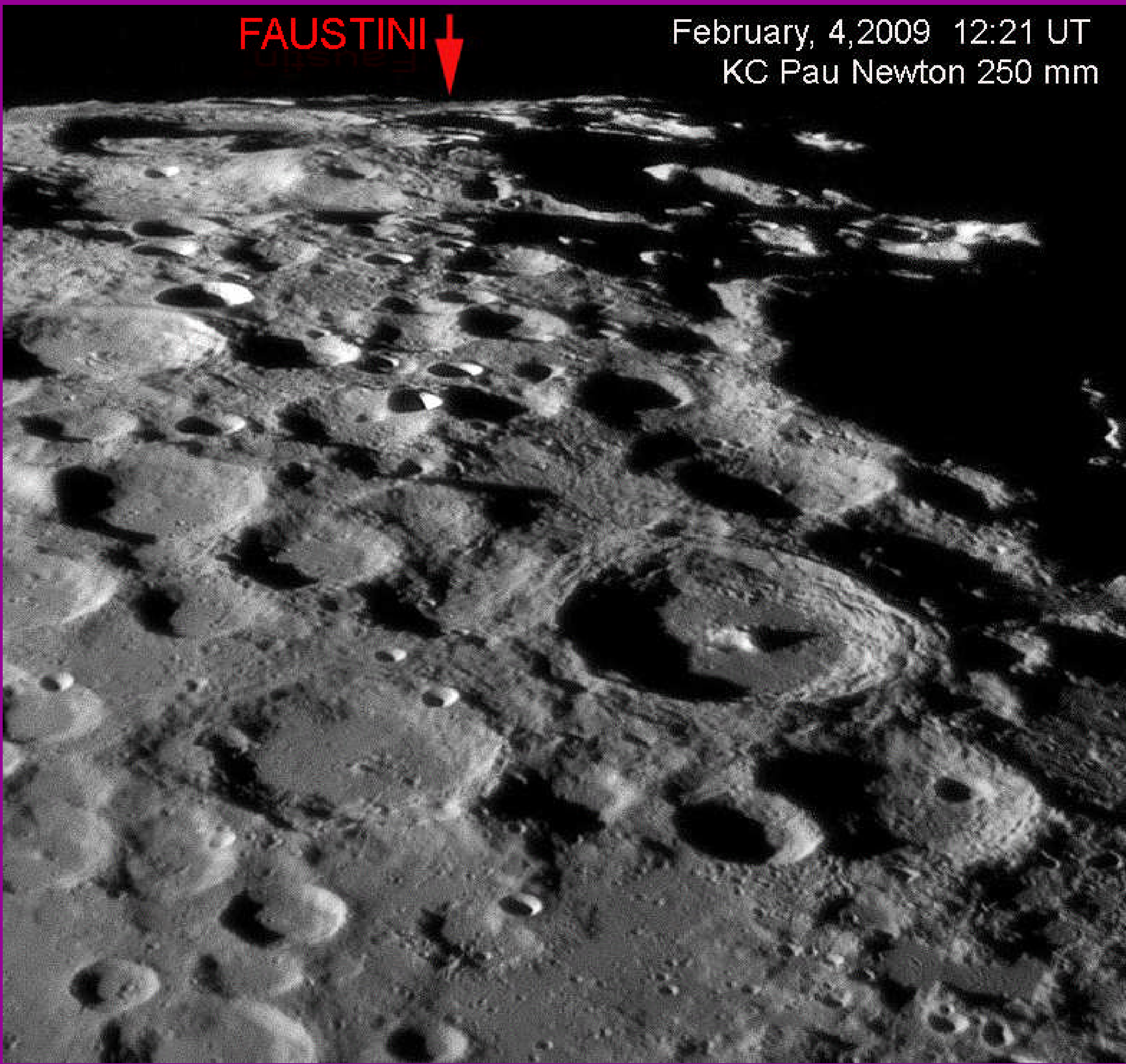
George Tarsoudis L=-4.74° %=80.6 Col.= 40.71° Age=10.49



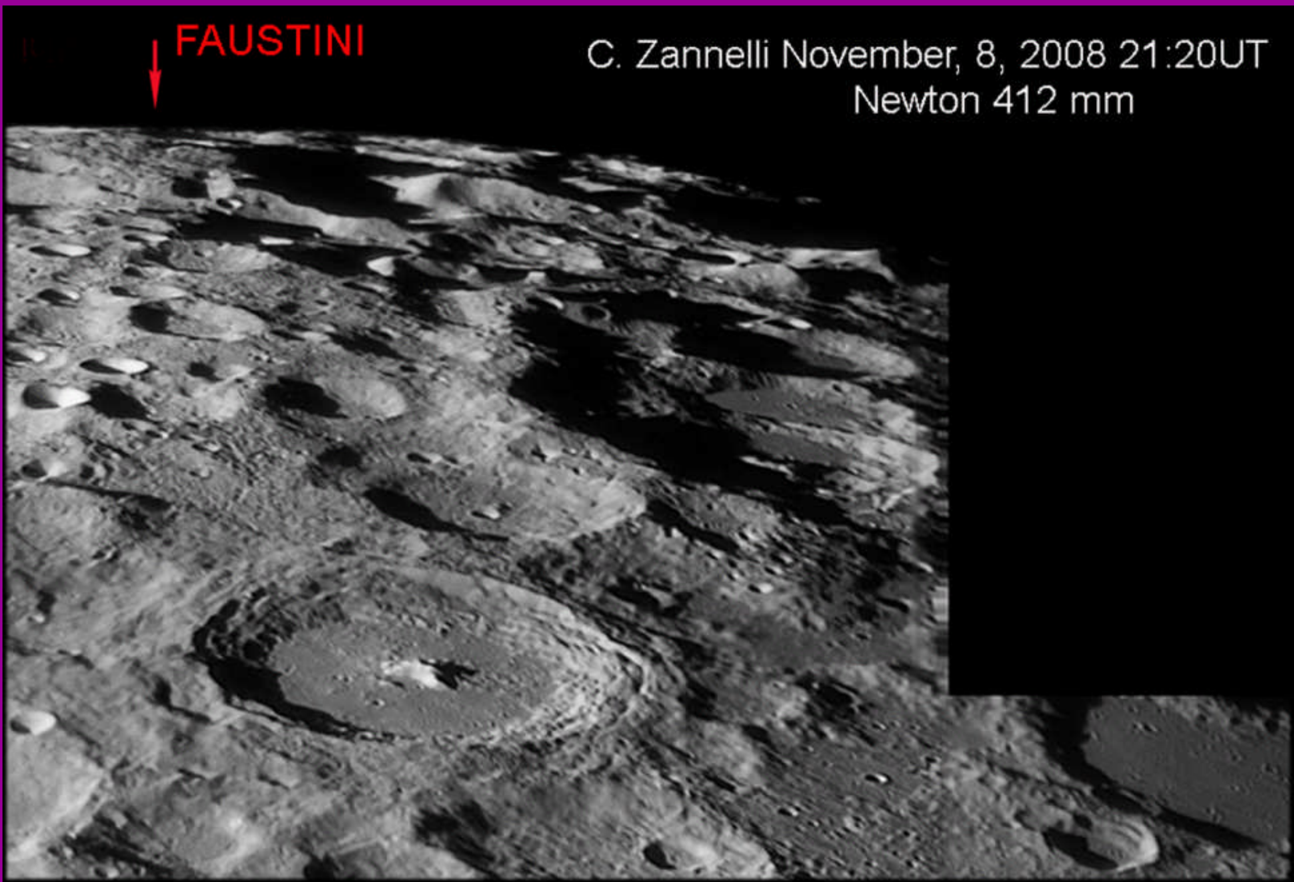
Raffaello Lena L= -5.59° %=69.5 Col.= 30.71° Age=10.01



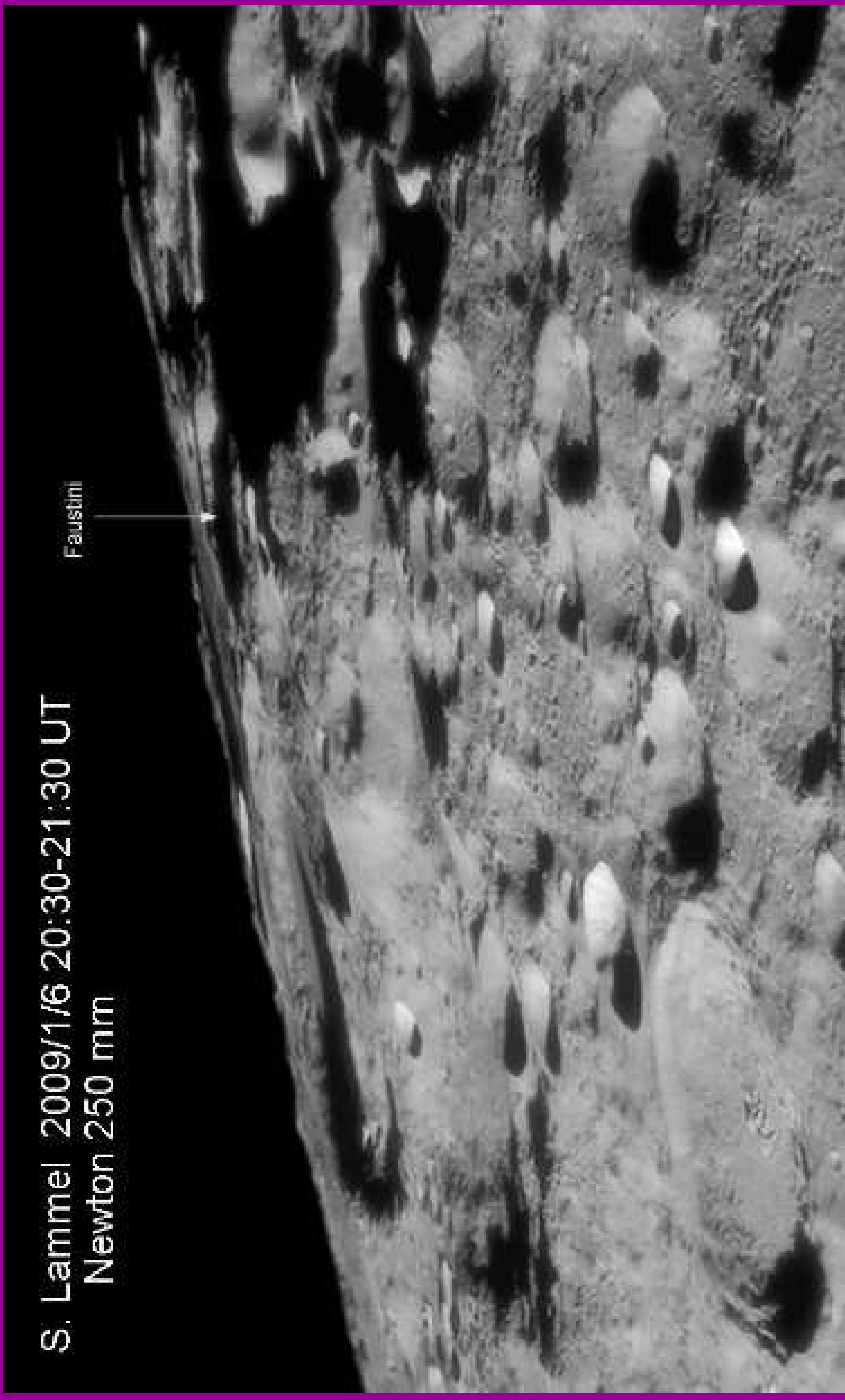
KC Pau L= -6.06° %=67.3 Col.= 24.84° Age=9.18



Carmelo Zannelli L= -3.72° % =76.4 Col.= 39.72° Age=10.92



Stefan Lammel L= -6.69° %=75.3 Col.= 36.58° Age=10.36



Paolo Lazzarotti L= -4.88° %=74.5 Col.= 27.70° Age=9.27