Notes on Topographic Masking by M1 of the LCROSS impact plume

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This is amateur work product and in not suitable for citation or reliance on in news reporting.

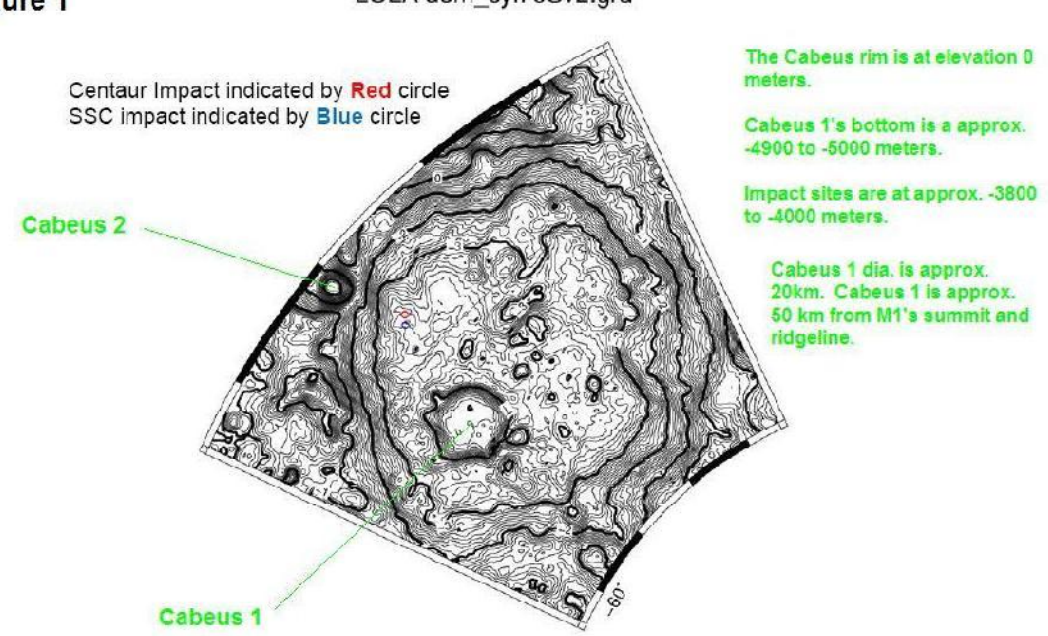
This note applies simple, spacial reasoning to examine the effect of topographical masking by lunar mountain M1 of the LCROSS booster impact on Oct. 9, 2009. The purpose of this exercise was to complete pre-impact analysis of some additional DEM information released by the LCROSS Team on Oct. 2. Work and personal obligations prevented analysis before the impact. Any plume less than 3.5km in height would be completely masked from Earth-based view by lunar mountain M1.

The LCROSS actual plume was substantially less than the predicted 10 km diameter by 5 km tall brightest predicted plume size. Based on an LRO LOLA Team DEM for the Cabeus crater released Oct. 2, 2 009, all but 1.5km to 1.75km of the predicted 5.0 km tall LCROSS plume would have been topographically masked from Earth based views from Palomar (N33 .2) and Salt Lake City, Utah (N40 .8). A less than predicted actual plume "100s of feet high" (P. Schultz reported 10 - 10 - 2009) would be completely masked from Earth view. Quoted USA Today 10-10-2009, url: http://www.usatoday.com/tech/science/columnist/vergano/2009-10-09-nasa-lcross-moon_N.htm (last accessed Oct. 11, 2009).

Figure 1 is an LRO LOLA Team DEM for the Cabeus crater released as part of an October 2, 2009 LCROSS impact target slide presentation by LCROSS Team co - principal investigator Colaprete. url: http://apps.nasa.gov/lcross/observations/files/19/ (last accessed 10-11-2009).

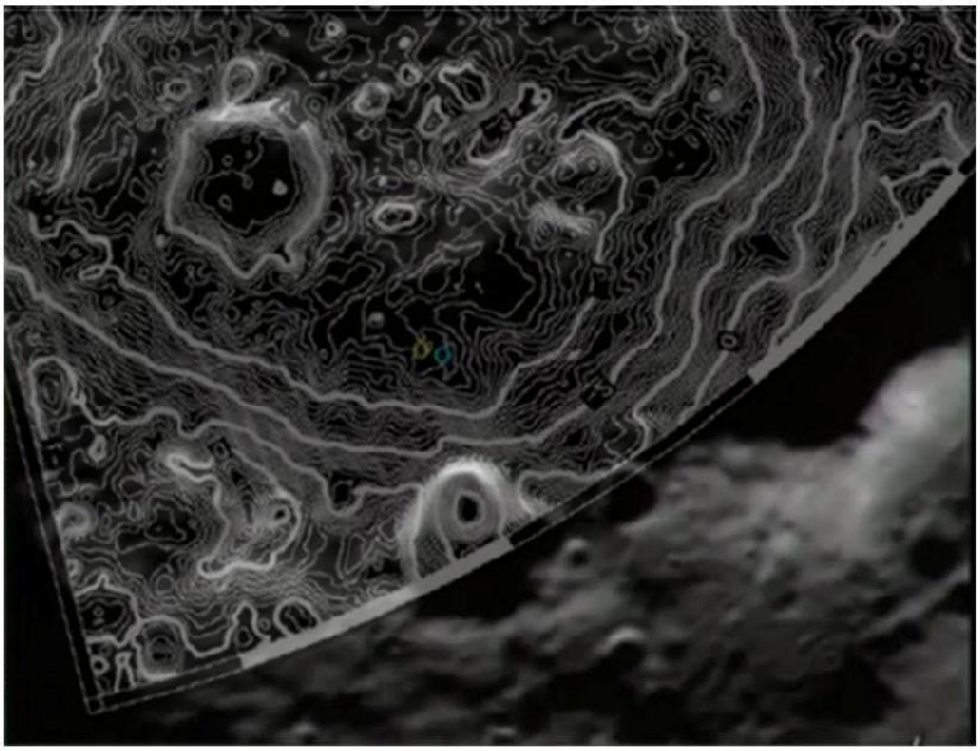
Figure 2 rotates and overlays this LOLA DEM over a frame clipped from the final moments of the LCROSS shepherding satellite on board visual camera. (Composite image courtesy of S. Lammel.) Figure 3 shows the raw frame clip from the LCROSS shepherding satellite video. url: Video at http://www.nasa.gov/mission_pages/LCROSS/multimedia/index.html (last accessed 10-11-2009).

Figure 1



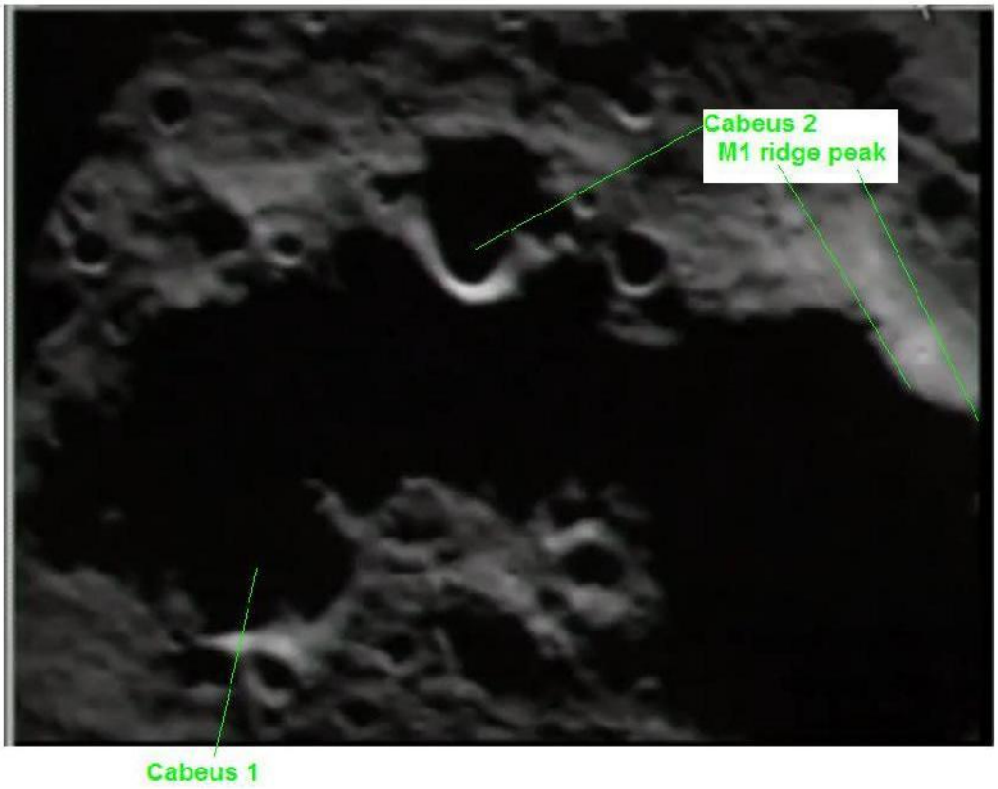
Source: A. Colaprete. 10-2-2009. "Targeting Coordinates, Timing, and Finder Charts for the LCROSS Centaur and SSC Impacts" Slide presentation, Slide 4. (Green is added matter to original). Added feature names are arbitrary.
url: http://apps.nasa.gov/lcross/observations/files/19/ (last accessed 10-11-2009).

Figure 2



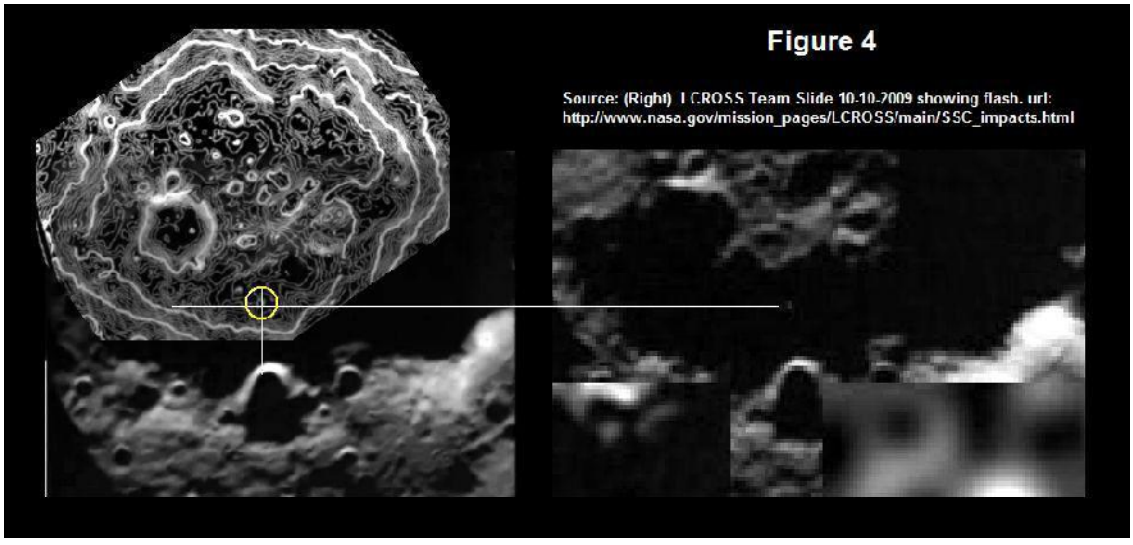
Source: LRO LOLA Dem overlain on LCROSS spacecraft impact video frame. (Image overlay by S. Lammel at request of K. Fisher 10-11-2009). LCROSS Spacecraft video: http://www.nasa.gov/mission_pages/LCROSS/multimedia/index.html

Figure 3



Source: Raw frame excerpt from LCROSS spacecraft video, above. Green is added matter.

Figure 4 is a similar DEM rotation and overlay prepared by this author. In the right - side of Figure 4, an LCROSS Team shepherding spacecraft camera frame showing the Centaur impact flash is scaled. Right side of Fig. 4 url: url: Video at http://www.nasa.gov/mission_pages/LCROSS/multimedia/index.html (last accessed 10-11-2009). Alignment lines relate the DEM, the raw spacecraft video clip and the LOLA DEM.



Figures 1 through 4 stand for the unremarkable proposition, previously announced by the LCROSS Team, that the Centaur impacted where and when the LCROSS Team intended to impact.

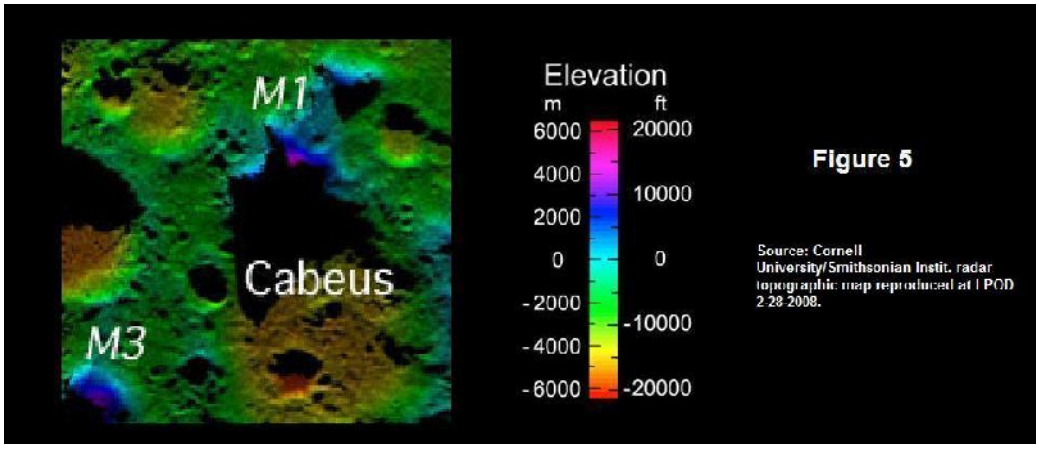
Figures 1 and 4, however, add new topographic DEM information for depths below and relative to the rim of Cabeus. The unnamed 20 km diameter crater within Cabeus is the lowest elevation within Cabeus and bottoms out at 4900 to 5000 meters below the rim. The rim of this unnamed crater is at about 4000 meters below the Cabeus rim. The Centaur impact site is at approximately 500 meters higher than the rim of unnamed crater, at about 3500 to 3600 meters below the Cabeus rim. The impact site sits on a downslope that pitches 500 meters over approximately 20 kilometers, or a downpitch of about 1.4 degrees, to the rim of the unnamed crater in the floor of Cabeus -

```
N[ArcTan[-500 / 20000] / Degree]
```

```
-1.4321
```

In Figures 1 through 4 and for discussion purposes here, the lowest feature - the unamed crater in the floor of Cabeus - is designated artibrarily as Cabeus 1. A small crater on the rim adjacent to LCROSS impact site is artibrarily designated Cabeus 2.

The LOLA DEM (Fig. 1) does not include or provide elevation data for M1, a large lunar mountain that masks the LCROSS impact site from Earth - based observers. Figure 5 shows an excerpt from an earlier Cornell University/Smithsonian Institution Earth - based radar DEM that also covers Cabeus and M1. url: http://lpod.wikispaces.com/February+28,+2008 (last accessed 10-11-2009). The index difference between the LOLA and Cornell DEM is 1000 meters, e.g. the bottom of Cabeus 1 is 6000 meters relative elevation in the Cornell DEM and is at 5000 meters in the LOLA DEM.

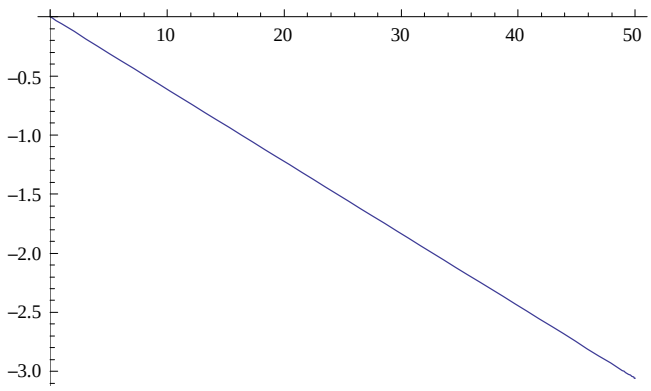


The Cornell Smithsonian DEM shows the relative elevation between the peak of M1 and the bottom of Cabeus 1 as about 9000 meters (9 km = 3000 meters - -6000 meters). The ridgeline on the Earth site line between a Utah or Palomar observing appears about 1000 meters lower, or a gain of about 8 km above the floor of Cabeus 1. The relative elevations of key features in kilometers are, therefore, roughly:

Cabeus 1 floor	-1.5	0.0
Cabeus 1 rim	-0.5	1.0
LCROSS impact site	0.0	1.5
Cabeus rim	3.5	5.0
Top of 5 km plume	5.0	6.5
M1 ridgeline	6.5	8.0
M1 peak	7.5	9.0

Virtual Moon Atlas reports libration on latitude at the time of the impact for Salt Lake City, Utah at - 3.50 degrees. For Palmor in California, libration in latitude was -3.61 degs. The impact point appears to be roughly 50 kilometers from the M1 ridgeline along a siteline from an Earth-based observer at those locations. Therefore, for an Salt Lake observer looking 50 km behind the M1 ridgeline, he or she could see vertically beneath the ridge -

```
Plot[Tan[-3.5 Degree] × x, {x, 0, 50}]
```




```
Tan[-3.5 Degree] × 50.0 km
```

```
- 3.05813 km
```

- and for Palomar -

```
Tan[-3.61 Degree] × 50.0 km
```

```
- 3.15449 km
```

The LCROSS plume is running downslope at an angle of -1.43 degrees from the original impact site and also away from the M1 ridgeline. The 5km top of the predicted LCROSS plume gets lower relative to the M1 ridgeline the further its moves away from the ridgeline. 5km downslope, the top of the plume would be lower than the intial impact point by -

```
Tan[(-1.43) Degree] × 5.0 km
```

```
- 0.124817 km
```

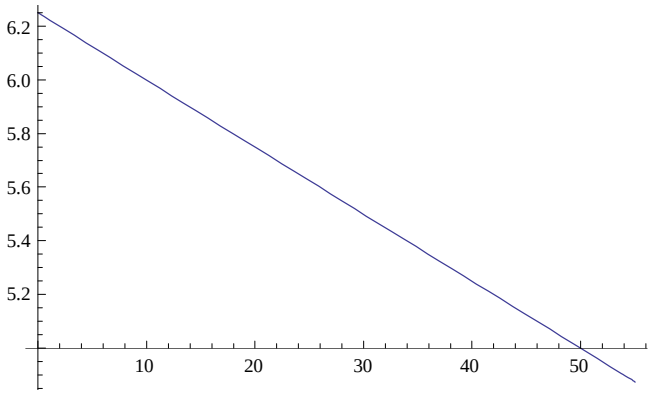
This occurs at a point 50 km along the Earth - M1 - impact sight line. The point - slope equation for a line in the plane of the top of the 5 km high LCROSS predicted maximum brightness impact plume is 5.0 = Tan[(-1.43) Degree] * 50.0 + b or -

```
b = 5.0 - (Tan[(-1.43) Degree] × 50.0)
```

```
6.24817
```

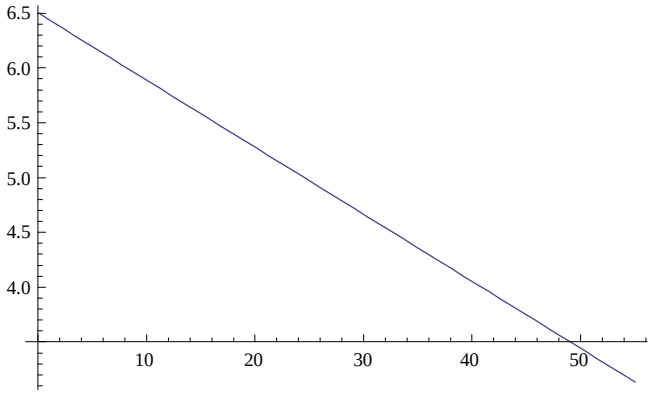
- which plots as -

```
Plot[Tan[-1.43 Degree] x + 6.24817, {x, 0, 55}]
```



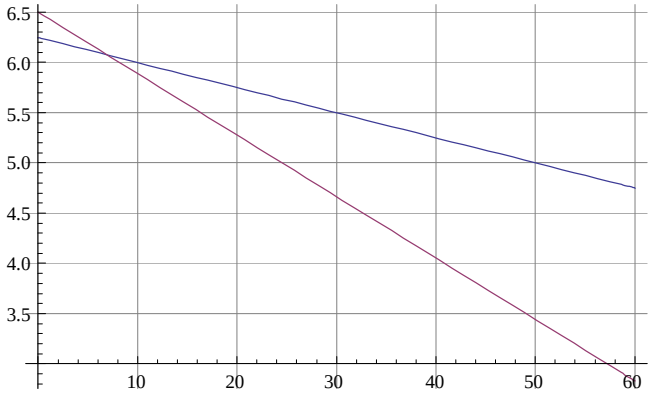
The point - slope form of the Earth - M1 ridgeline sight line, using the M1 ridgeline as the zero point is y = Tan[-3.5 Degree]*x + 6.5 km - which plots as -

```
Plot[Tan[-3.5 Degree] x + 6.5, {x, 0, 55}]
```



Overplotting the two planes in a Cartesian grid relative to the M1 ridgeline gives -

```
Plot[{(Tan[-1.43 Degree] x) + 6.24817, (Tan[-3.5 Degree] x) + 6.5},
 {x, 0, 60}, GridLines → Automatic]
```



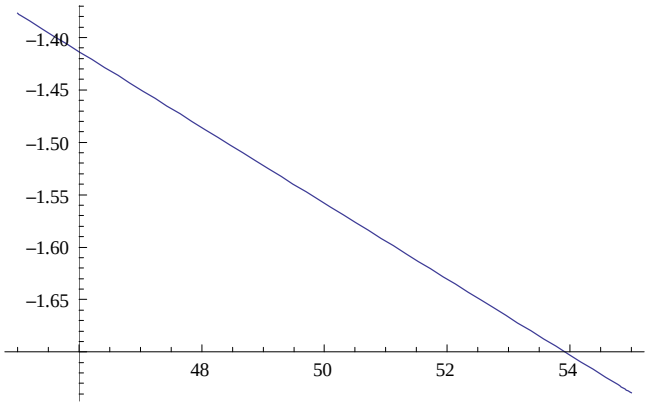
And the difference bewteen the two lines gives the observable plume height between the key distances between the M1 ridgeline line and the plume edges at 45 km and 55 km from the M1 ridgeline -

```
Simplify[(Tan[-3.5 Degree] × x) + 6.5 - (Tan[-1.43 Degree] × x) - 6.24817]
```

```
0.25183 - 0.0361992 x
```

which plots for 45 km to 55 km as -

```
Plot[0.25183 - (0.036199228298241 × x), {x, 45, 55}]
```




```
At the maximum distance, the height of the maximum observable plume would be -
```

```
0.25183 km - (0.036199228298241 × 55 km)
```

```
- 1.73913 km
```

An Earth observer in Utah or at Palomar would see vertically down 3.0 km below and behind the M1 ridgeline to about a relative 3.5 km to elevation above the impact site. About 1.5km to 1.7 km of the predicted 5 km brightest plume would be visible above the sightline of the M1 ridge. This represents 1.5km of the maximum brightness plume that would stick above the level of Cabeus rim.

In conclusion and based on the above, Earth based observers of the predicted LCROSS plume might at best have been able to view a 1.5km to 1.75 km line of one - side of the brightest part of the predicted plume as it ran down-hill from the impact site towards Cabeus 1 and away from the M1 ridgeline , due to topographical masking by that ridge. The actual plume appears to have been much smaller and thus would be completely topographically masked by M1. Any plume lower in height than 3.5 km would be completely masked by the M1 ridgeline.

Cabeus 1 floor	-1.5	0.0
Cabeus 1 rim	-0.5	1.0
LCROSS impact site	0.0	1.5
Cabeus rim	3.5	5.0
Palomar - Utah M1 mask limit	3.5	5.0
Top of 5 km plume	5.0	6.5
M1 ridgeline	6.5	8.0
M1 peak	7.5	9.0

On the date of the LCROSS impact, the Moon was at about 375, 000 km from Salt Lake City, Utah. A 1500 meter tall line object would have had a very small angular size, per the half - angle formula -

```
2.0 × ArcTan[1.7 / (2.0 × 375 000)] × 206 265 arcsecs
```

```
0.935068 arcsecs
```

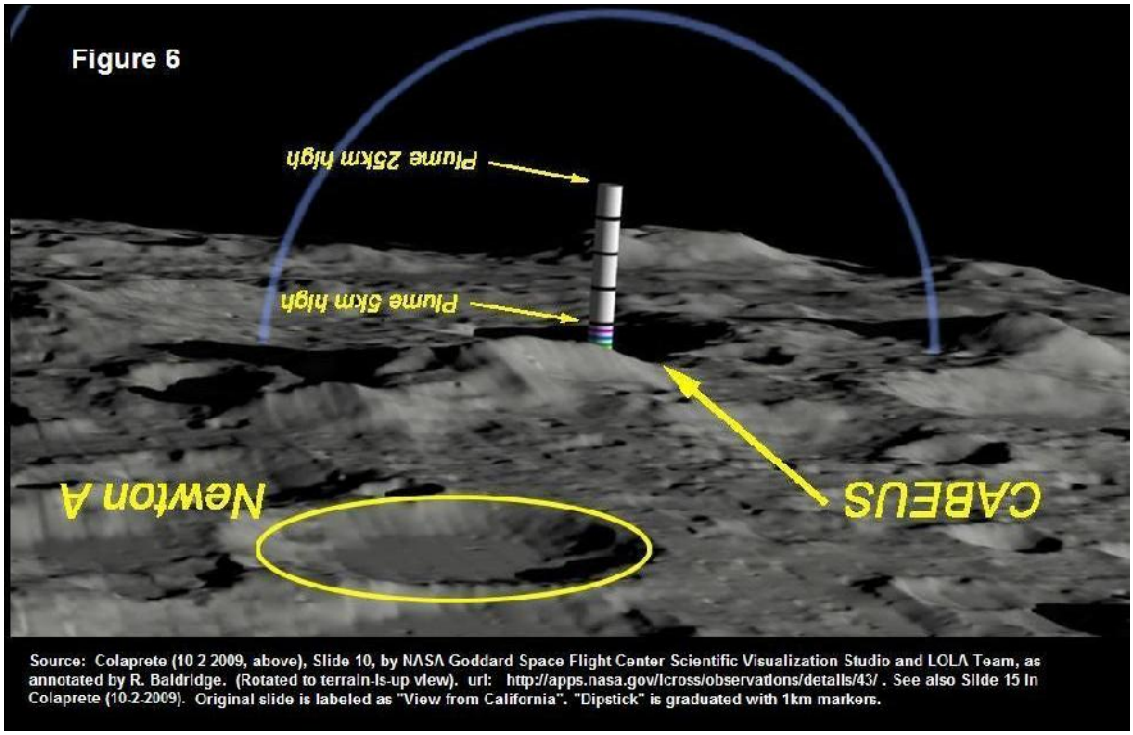
and slightly adjusted for a south 86 degree lunar latitude -

```
N[% × (Cos[ 90 Degree - 86 Degree])] arcsecs
```

```
0.928251 arcsecs
```

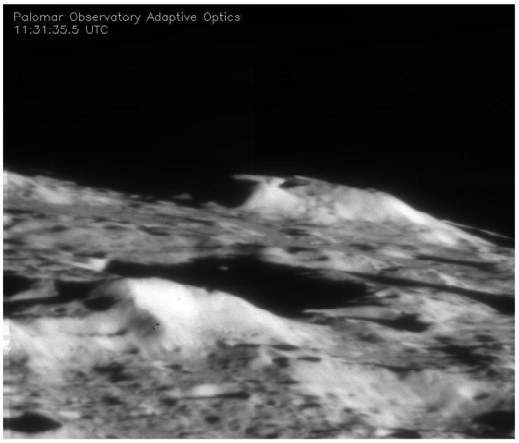
This is slighty less than the Airy disk size of a 254 mm (10 inch) aperature telescope (1.1 arcsecs) and slightly more than the Rayleigh (0.6 arcsecs) limit for visual detection for that aperature seen with 550 nm light. This would probably would have been undistinguishable from the M1 ridgline itself both visually and photographically.

A plume elevation simulation prepared by the Marshall Goddard Scientific Visualization Unit and the LOLA Team (Figures 6 and 7) shows somewhat more than 1.5 to 1.75 km protruding above the ridgeline.Slide 15 in Colaprete presentation at url http://apps.nasa.gov/lcross/observations/files/19/ (last accessed 10-11-2009); Baldridge markup at url: http://apps.nasa.gov/lcross/observations/details/43/ (last accessed 10-11-2009, rotated). Commonly referred to by the LCROSS Team as the "dipstick" graphic, it shows a 3.8km wide "dipstick" with color coded 1/2 kilometer bands separated by 1/2 kilometer white space. Id. The graphic was included in the Colaprete Oct. 2, 2009 targeting slide presentation and was widely distributed to the amateur community on the LCROSS Citizen Science website.

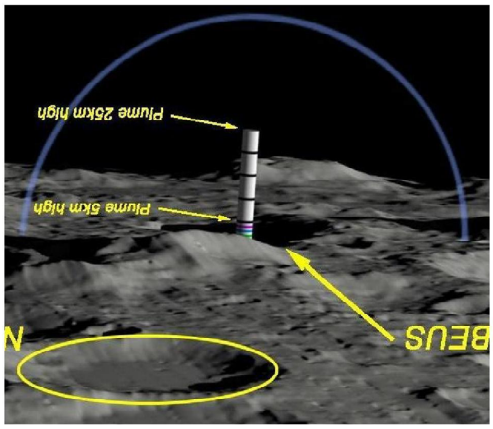


The Marshall-LOLA simulation accurately depicted libration in latitude and longitude. This can be confirmed by comparing a Palomar image of M1 and Cabeus taken at the time of impact with the pre-impact "California view" simulation. Figure 7.

Figure 7 - Palomar actual libration to NASA Goddard-LOLA Team predicted visualization



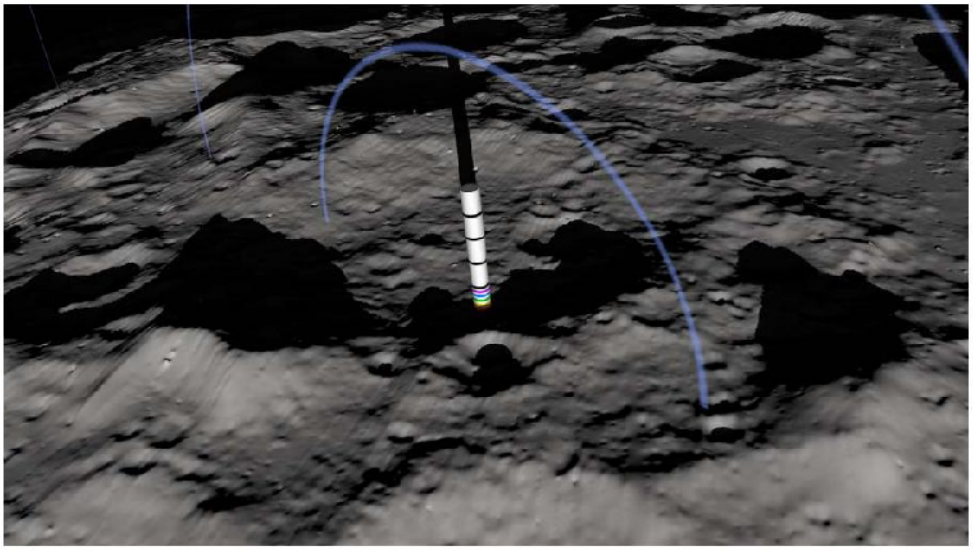
NOT FOR REDISTRIBUTION - A USE RELEASE FOR PALOMAR IMAGE HAS NOT BEEN OBTAINED. - K. Fisher 10-11-2009



The scaling "dipstick" extrudes about 2.5km to 3km above the M1 ridgline. This appears inconsistent with a 5km plume height and an impact site that is 3.5 km below the rim of Cabeus.

In the Marshall - LOLA dipstick graphic, the impact site and the small rim crater arbitarily designated Cabeus 2 for this note, are about equidistant from a hypothetical Earth observer. In such a view, if the bottom of dipstick is positioned at the intended impact site, the 3.5 km marker on the dipstick scale should appear to be nearly level with the rim of Cabeus 2 and the rim of Cabeus generally. Fig. 7.

But the dipstick marking for 3.5 km appears to be set about 1.5 km to 2.0 km above the level of the rim. Fig. 7, see also Fig. 8.



Perspective view showing the level at which ejecta meets sunlight
NASA/Goddard Space Flight Center Scientific Visualization Studio and the LOLA Team

Figure 8. Source : Colaprete Targeting Slide Presentation, 10 - 2 - 2009, above.

Some amateurs who viewed the impact via the pre - view capture from their imaging cameras reported seeing "pixel bouncing" off the M1 ridgeline both before, at and after the impact event. These effects were discounted as atmospheric turbulence seeing smears of photons emanating from the M1 ridgeline. Any LCROSS induced signal would be indistinguishable from this atmospheric noise. For those imagers who recorded at high efls and imprinted a KIWI OSD time signal may wish to reexamine their video captures for (a) periodicity in seeing variations and (b) whether an anomalous aperiodic "pixel bounce" occurs at the M1 ridgeline about 40 seconds after the impact time (11 : 30 : 19 UT 10 - 9 - 2009). If the variations in seeing have a periodicity, it may - speculatively - be possible to tease out an LCROSS impact associated signal from the background noise. However, given that the actual plume was less in density and or size than the predicted plume, searching imagery for such an effect should be considered to have a low-probablity of success given topographical masking by M1.

A early uncalibrated LRO Diviner image release (10 - 9 - 2009) of the ejecta plume 90 seconds after impact appears to show a linear ray in the ejecta pattern. url : http://www.diviner.ucla.edu/blog/?p=184 (last accessed 10-12-2009). This image probably was taken before the ejecta curtain had fully settled back to the surface.

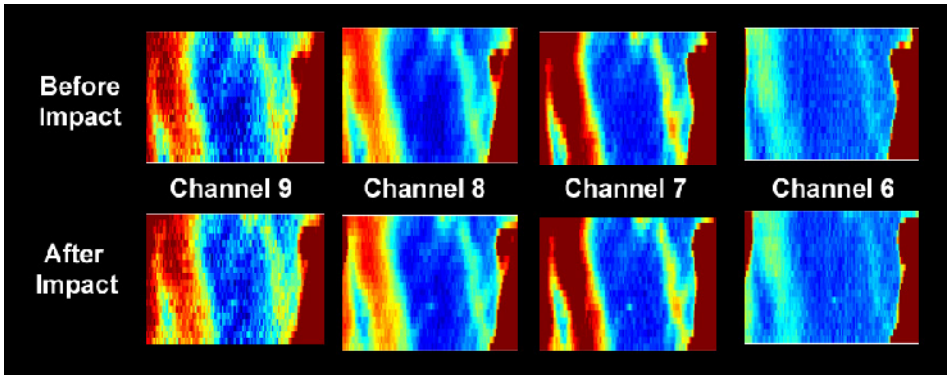


Figure 9. Source : LRO Diviner Early Release Image 10 - 9 - 2009 (2 hours before and 90 seconds after impact in Channels 7 and 8).

The ray pattern evokes the ray seen at an Apollo 14 Saturn IVB highly oblique impact site.

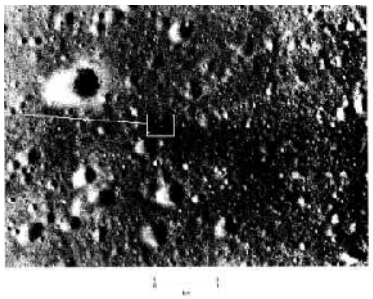


Figure 10. Apollo 14 Saturn IVB impact crater and ejecta blanket from Fig.29 - 52 in Whitaker (1972) (modified).Photo courtesy of NASA.

- End -