SEARCHING FOR LUNAR HORIZON GLOW WITH THE LRO STAR TRACKER CAMERAS.
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Introduction: Our objective is to search for the putative “lunar horizon glow” (LHG) reported during the Apollo-era that was possibly caused by the forward scattering of sunlight by dust in the lunar exosphere [1, 2, 3]. If LHG occurs and it is caused by exospheric dust, then the processes involved are likely common to the many other airless bodies in the Solar System. Determining how dust behaves in the lunar environment has important implications for both science and exploration activities on the Moon [4, 5].

This LHG search was undertaken using one of the star tracker navigation cameras (ST2) on the Lunar Reconnaissance Orbiter (LRO), which is capable of producing images suitable for scientific analysis. In this way, ST2 has become the eight science instrument on LRO. The advantage of using ST2, compared with instruments used in recent searches from orbit [6, 7], is that it offers much better spatial resolution, the ability to probe to lower altitudes, and has a wavelength sensitivity similar to Apollo-era observations. It is also highly complementary to multi-wavelength measurements from other instruments, e.g., the Ultraviolet and Visible Spectrometer (UVS) on the Lunar Atmosphere and Dust Environment Explorer (LADEE), as well as the Lyman Alpha Mapping Project (LAMP) FUV spectrograph and the Diviner radiometer on LRO.

Evidence for LHG: An “excess brightness” – above that expected from known sources, such as coronal and zodiacal light (CZL) – was reported in three coronal photographic sequences taken from orbit during the Apollo 15 and 17 missions [2]. This excess brightness was interpreted as being LHG produced by exospheric dust with radii ≈0.1µm. However, a reanalysis demonstrated that only the sequence taken above lunar sunrise during Apollo 15 showed any significant evidence for LHG [8]. Other optical evidence includes visual observations from Apollo astronauts from orbit [3]; while from the surface, the Lunokhod-II astrophotometer detected a brighter than expected twilight sky [9] and the Surveyor lander TV cameras observed LHG apparently extending <1 m above the post-sunset western horizon [1, 10].

More recent searches for LHG, and any associated population of ≈0.1µm-scale exospheric dust, have so far only been able to produce upper limits for dust abundances [6, 7, 11]. These upper limits are significantly lower than the abundances inferred from Apollo-era measurements.

Possible Reasons for Non-detections since the Apollo-era: It is conceivable that LHG is never there, and that observations indicating its presence were somehow flawed; e.g., the excess brightness in the Apollo 15 coronal photographs taken above lunar sunrise could have been due to some unknown source of stray light contamination. Perhaps more likely is that LHG does occur, but just not very frequently. It has been suggested that meteoroid impact plumes, possibly associated with streams (observed as meteor showers on Earth), may play a significant role in generating abundances of exospheric dust capable of producing LHG [8, 12, 13]. Searches using Clementine star trackers [6] and LAMP [7] did not coincide with any major meteoroid streams, which reduced the chances of detecting the effects of a substantial impact plume.

The LRO Star Trackers: The star tracker cameras have 16.4×16.4° fields-of-view (FOV) and 512×512 pixel CCD arrays that are sensitive at visible and near-IR wavelengths. We use ST2 for the LHG search, while ST1 was kept occulted to maintain attitude performance. Integration times range from 5 to 4000 ms in 5 ms increments. For various reasons we are limited to reading out rectangular images with <3056 pixels (out of 260,100 available) once every 130 s. The typical procedure during a LHG search is to slew (roll and/or pitch) LRO to point ST2 at the limb near the lunar equator (cf. Apollo observing conditions) and take a sequence of seven images, with the seventh image optimized to view the occulted Sun closest to the limb. The pointing accuracy is about ±5 arcsec, so the uncertainties are comfortably sub-pixel.

Preliminary Observation Results: Over 30 operation activities have so far been planned and undertaken in the search for LHG. Some of the early measurements, in particular, were used to learn how the ST2 navigation camera could be re-purposed for science. Many high-quality images were acquired, and in some cases patches of excess brightness were observed just above the limb. These patches were limited in spatial extent to <=3 pixels vertically and <=5 pixels horizontally. A good example of this is image 6 of 7 taken on 25 December 2013 at 02:45:00 UT, as shown in Figure 1. Pixel dimensions on the limb vary between about 200 and 400 m, so the spatial scales appear to be smaller than the km-scales inferred from Apollo-era measurements [2, 3, 8]. Given the near-limb nature of the excess brightness, it is clearly necessary to deter-
mine whether these patches could have been produced by sunlight reflecting from the lunar surface rather than scattering from exospheric dust.

**Preliminary Simulation Results:** A lunar surface illumination model has been adapted to simulate the sunlight reflected from the surface into the ST2 FOV. This model has previously been validated against LROC data [cf. 14] and applied to both the Moon and Vesta [15, 16]. Initial test simulations used a 64 pixel/degree global digital elevation model (DEM) derived from data acquired by the LRO Lunar Orbiting Laser Altimeter (LOLA). Figure 2 shows a test case simulation for the same time and viewing conditions as the image presented in Figure 1. This shows that the simulation predicts an element of surface illumination close to the location of the excess brightness observed by ST2. The simulated limb profile also appears to be a good match to that observed by ST2.

On closer inspection, both the predicted limb profile and surface illuminated element are offset by a few pixels from the observations. This mis-alignment is likely due to the coarse resolution of the DEM. The resolution of the DEM is ≈450 m, whereas the ST2 pixel resolution at the limb for this case is ≈310 m. We would anticipate much better agreement with a higher resolution DEM; e.g., a 512 pixel/degree DEM [17] would have a resolution <60 m.

**Summary:** The initial simulation results shown in Figure 2 suggest that the excess brightness in the image presented in Figure 1 was produced by sunlight reflecting from the lunar surface rather than forward scattered from exospheric dust. However, simulations with higher resolution DEMs, and a more sophisticated comparison, are required in order to provide a greater degree of certainty regarding the source of the observed excess brightness.