SEARCHING FOR LUNAR HORIZON GLOW WITH THE LUNAR ORBITER LASER ALTIMETER. M. K. Barker[1], E. Mazarico[2], D. E. Smith[3], X. Sun[2], M. T. Zuber[3], T. P. McClanahan[2], G. A. Neumann[2], M. H. Torrence[4]. [1]Sigma Space Corp., 4600 Forbes Blvd. Lanham, MD 20706 michael.barker@sigmaspace.com, [2]Solar System Exploration Division, NASA Goddard Space Flight Center 8800 Greenbelt Rd. Greenbelt, MD 20771, [3]Dept. of Earth, Atmospheric and Planetary Sciences, MIT, 77 Massachusetts Ave. Cambridge, MA 02139, [4]Stinger Ghaffarian Technologies, Inc., 7701 Greenbelt Road, Suite 400, Greenbelt, Maryland 20770, USA.

Introduction: The origin and cause of the lunar horizon glow (LHG) observed by the Apollo astronauts [1,2] has been a source of intrigue and interest since it was first reported. A number of more recent attempts [3,4,5] have been made to observe LHG from lunar orbit and none has been successful. Furthermore, the predicted effect, based upon these observations and models of lunar dust, suggests an LHG signal two orders of magnitude smaller than that seen by the astronauts. Here we describe experiments conducted by the Lunar Orbiter Laser Altimeter (LOLA) onboard the Lunar Reconnaissance Orbiter (LRO) spacecraft to observe LHG by using the instrument's laser ranging (LR) telescope to observe the lunar limb immediately prior to lunar sunrise.

Instrument: LOLA is a time-of-flight laser altimeter operating at a firing rate of 28 Hz [6]. The instrument has 5 separate detectors, or channels, dedicated to each of the 5 laser spots that collectively comprise the LOLA footprint on the lunar surface [7]. However, as part of the one-way LR experiment between Earth stations and LRO [8], channel 1 is also connected via a fiber optic cable to another telescope mounted on, and co-aligned with, the LRO high gain antenna (HGA). The light collected by this LR telescope is fed through a 0.3-nm bandpass filter centered on 532 nm.

Method: In the current search for the LHG, LRO's HGA is held fixed in the -*Z* direction while LRO slews so that the -*Z* axis and LR telescope are pointed at the limb for several minutes before and after sunrise. The advantage of using the LR telescope to look for LHG contrary to nadir deck instruments is that it can point arbitrarily close to the Sun for long periods of time. As of the end of 2015, 3 such slews have been conducted, on Day of Year (DOY) 351, 352, and 364.

Initial Results: The results of the third slew are shown in Fig. 1 as a function of seconds of orbit on the *x*-axis. The left-hand *y*-axis is the angle above the spherical limb, and the right-hand *y*-axis is the logarithm of the count rate measured by the LR telescope (red line). The black line shows the angular height of the topography from LRO's perspective at the tangent point along the LR boresight vector. It is only an approximate representation of the topographic horizon, because it only applies to a single spatial point at each time step. It does not, for example, account for topographic variation along the line of sight and over the whole field-of-view (FOV), but it is sufficient for illustrative purposes.

The LR telescope, which has a 1.75° diameter FOV shown by the blue lines, was pointed at the dark surface before sunrise, and gradually moved closer to the horizon until a time labeled in Fig. 1 as t_0 when the LR telescope just peeked above the horizon. We use the time before t_0 to estimate the dark current mean level and standard deviation (σ) in the count rate shown in red, which gives the detection limit in counts/sec. The dark current is due to thermal electrons in the detector assembly.

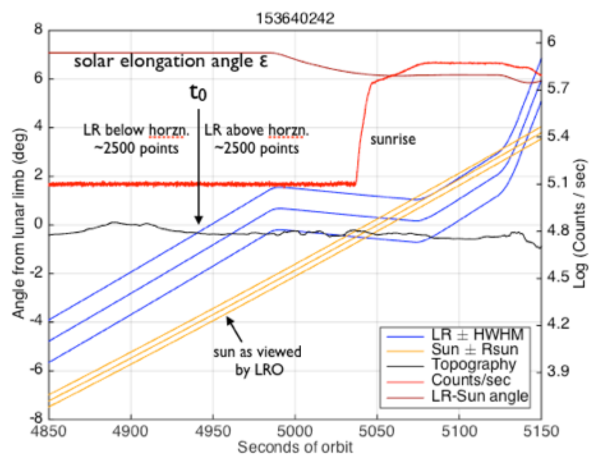

Figure 1. Results of 3rd test to search for the LHG, conducted on 2015 DOY 364. The count rate measured by LOLA/LR is shown as the red line while the other lines show the vertical offset of the LR field-of-view (blue), Sun (orange), and topography (black).

A positive detection of horizon glow would be an enhancement in counts above the dark current sometime between t_0 and sunrise, an interval of about 100 seconds. At sunrise, the counts increase dramatically, and eventually settle to a level that we use to estimate the radiance calibration and convert counts/sec to radiance units. At no time is the Sun within the field of view -- the elongation angle ranges from about 6° to 7°, but the telescope has a non-zero off-axis transmission curve, which was measured in pre-flight testing. During this slew, LRO had an altitude of ~40 km above the sphere, and was located at 170° E and 60° S.

The distance to the horizon was ~350 km and the field-of-view was ~10 km at the horizon.

All 3 slews conducted so far give a similar mean dark current level and 3σ detection limit of ~0.02 W/m^2/μm/sr, and a radiance conversion of 1 count/sec ~ 10^{-13} W/m^2/μm/sr for the 35.7 msec integration time. This detection limit is about 10 times higher than the brightest Apollo 15 measurement [1,2]. Therefore, we could detect any LHG as bright as the Apollo 15 measurement by averaging over the LR data with a time baseline of a few seconds.

In the 3 slews performed thus far we have yet to find any clear indication of horizon glow, but that is not surprising given the large elongation angle (6° – 7°) and recent limits placed on the dust column density [3,4].

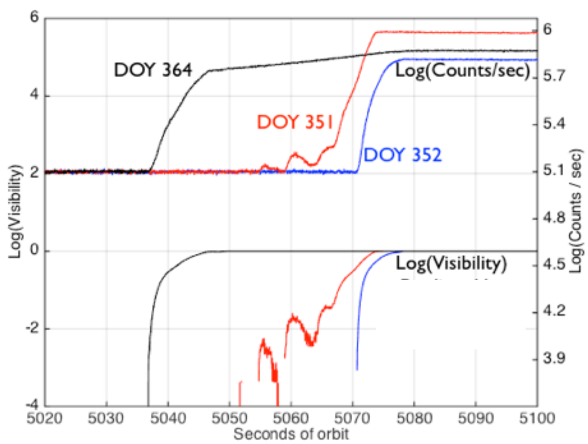

Figure 2. Comparison of measured count rate during all 3 slews and predicted Sun visibility.

Figure 2 compares, for all 3 tests, the Sun visibility (lower 3 curves) to the LR count rate (shown in the upper 3 curves). The Sun visibility is the fraction of the Sun's disk visible from LRO predicted by an illumination code [9] that accounts for topography along hundreds of sightlines sampling the limb-darkened solar disk. There is good agreement between the models and observations in the timing and duration of sunrise. This dataset will be useful to further estimate the LR detection limit and radiance calibration. The most interesting observation thus far is the small positive enhancements above the dark level in the red line (DOY 351) at the beginning of sunrise. These are caused by the varying topography along the line of sight that partially obscures the Sun. These features demonstrate that one must be careful about interpreting any brightness enhancements immediately before sunrise, but we can at least model the effects of topography to aid in interpreting any enhancements. We will also look for any LHG signal at times earlier than shown in Fig. 2, when the Sun is still well below the topographic horizon.

In the red line in Fig. 2, the smallest enhancements apparent to the eye have a visibility of order 10^{-3}, which, when multiplied by the off-axis attenuation factor of 10^{-6}, yields a brightness sensitivity of ~ 10^{-9} B_{sun}, consistent with our other estimates of the detection limit. Of course, this estimation must be better quantified to determine the significance level to which these particular enhancements correspond.

Summary: The experiments conducted so far have enabled the calibration of the detector at the new operating detector thresholds and helped develop the methodology for LOLA lunar limb measurements. Refinements are still needed to make the planned weekly observations as non-intrusive as possible to the other instruments on LRO. As observations accumulate, and the observing strategy is optimized, our chances of detecting LHG will increase such that if it is presently occurring at the levels seen by the Apollo astronauts, we are optimistic it will be detected.

References: [1] McCoy J. E. (1976) *Proc. Lunar Sci. Conf. VII,* 1087-1112. [2] Glenar D. A. et al. (2011) *Planet. Space Sci. 59,* 1695-1701. [3] Feldman P. D. et al. (2014) *Icarus 233, 106-113.* [4] Glenar et al. (2014) *J. Geophys. Res. Planets* 119, 2548-2567. [5] Stubbs T. et al. (2015) *AGU Fall Meeting*, PB53-2125. [6] Smith D. E. et al. (2010) *Space Sci. Rev. 150,* doi:10.1007/s11214-009-9512-y. [7] Smith D. E. et al. (2010) *Geophys. Res. Lett. 37,* doi:10.1029/2010GL043751. [8] Zuber M. T. et al. (2010), *Space Sci. Rev., 150,* doi:10.1007/s11214-009-9511-z. [9] Mazarico E. et al. (2011) *Icarus, 211,* doi:10.1016/j.icarus.2010.10.030.