LRO/LAMP CAMPAIGN TO DETECT A LUNAR NANODUST EXOSPHERE. **C. Grava[1*]**, T. J. Stubbs[2], D. A. Glenar[3], K. D. Retherford[1], [1]Southwest Research Institute, San Antonio, TX, USA, [2]NASA/Goddard Space Flight Center, Greenbelt, MD, USA, [3]University of Maryland, Baltimore County, Baltimore, MD, USA. *Corresponding author: cgrava@swri.edu

Introduction: The Lyman Alpha Mapping Project (LAMP) UV spectrograph [1] onboard the Lunar Reconnaissance Orbiter (LRO) [2] was used to conduct a campaign to observe the Moon's nanodust exosphere, evidence for which was previously provided by the Lunar Atmosphere and Dust Environment Explorer (LADEE) Ultra Violet Spectrometer (UVS) [3]. These LADEE/UVS observations occurred during the 2014 encounter with the Quadrantid meteoroid stream (QUA), which suggested that the nanodust exosphere was modulated by meteoroid impact rates.

Observations: LRO performed off-nadir maneuvers around the peak of the January 2016 QUA (Figure 1), in order to reproduce, as closely as possible, the observing geometry of LADEE/UVS in 2014 [4]. Observations during the December 2015 Geminids (GEM) were also performed.

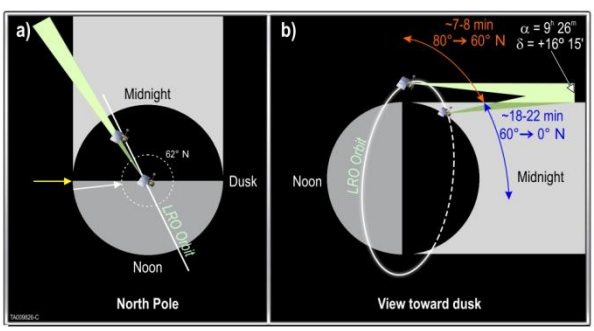

Figure 1 Geometry of LRO/LAMP observations during the 2016 QUA.

LRO was in a polar orbit moving from high to low latitudes in the northern hemisphere close to the dawn terminator, during which time LAMP performed inertial stares, i.e. the RA and Dec of the target on the sky was fixed throughout the six orbits. The solar elongation angle, i.e. the angle between the LAMP-Sun direction and the LAMP-target direction, was 143°, so any dust detection would arise from the backscattering of sunlight by nanodust grains, in the long wavelength of the instrument (140–190 nm). A consequence of LRO's polar orbit was that the path along the LAMP line-of-sight (LOS) crossed into the Moon's shadow near the North Pole, at about LRO's apoapsis (~150 km). The portion of the orbit with a fully illuminated LAMP LOS lasted 7-8 min, with LRO at ~12:40 Local Time (LT). After entering the Moon's shadow (near the North Pole), LAMP observed with a partially shadowed LOS for 18-22 min, with LRO at ~03:20 LT (Figure 2).

Spectra: By comparing spectra before and after the LAMP LOS intersects lunar shadow, it is possible to search for changes in brightness attributable to dust in the shadowed portion of the LOS. A search for backscattering of sunlight from nanodust grains was accomplished by comparing observations when the path along the LAMP LOS was fully illuminated and partially shadowed by the Moon.

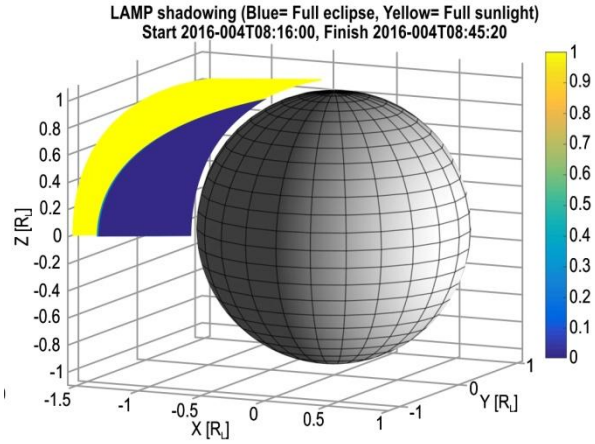

Figure 2 LAMP LOS color-coded between yellow and dark-blue to indicate the fraction fully illuminated and fully shadowed, respectively, during the 2016 QUA.

The six observations during the 2016 QUA are shown in Figure 3. Orange lines are fully illuminated spectra, while blue lines are spectra partially in shadow. Most of the long wavelength upturn in these spectra has previously been attributed to grating scattered Lyman-alpha in the spectrograph [5]. However, we cannot rule out the possibility of a significant contribution from dust scattering, which would also brighten at long wavelengths due to rapidly rising solar radiance. Nevertheless, no difference signal is observed between the illuminated and the partially shadowed spectra.

Modeling: To estimate dust upper limits, we utilize two slightly different methods, both similar to that used by [5] and [6]. A grid of per-grain scattering intensities is first computed as a function of wavelength and grain radius at the 143° scattering angle observed by LAMP. The first method assumes that all the increase in radiance at long wavelength is caused by nanodust, and not from internal scattering of Lyman-alpha photons. Therefore, for the fully illuminated spectra, upper limits for the LOS dust column abundance N_{LOS} (cm^{-2}) at one grain radius are obtained by defining a trial grain scattering model and adjusting N_{LOS} so that the spectral average of the simulation

matches that of the measured spectra. In the second method, average model intensities are equated to the difference in the fully illuminated and the shadowed spectra. In this way, the derived N_{LOS} refer to a column of dust from LRO to the point where the shadow ends, and it is typically a factor of 10 smaller.

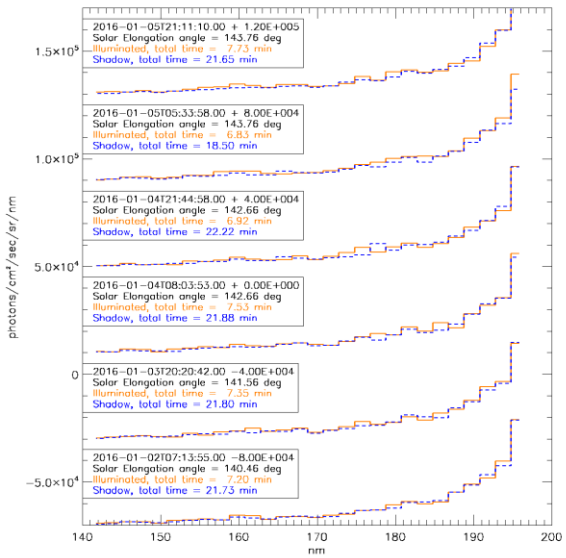

Figure 3 The spectra for the six observations during the 2016 QUA. Orange: fully illuminated path. Blue: partially shadowed path. If a detectable lunar nanodust exosphere exists during these intervals, then a steeper increase of radiance at the longest wavelength is expected for the orange spectra, but this is not observed.

Discussion: Figure 4 summarizes the full suite of upper limit estimates for line-of-sight dust abundance as a function of grain radius, derived for the six LAMP observations during the 2016 QUA. The derived upper limits for path concentrations are nearly proportional to r_{gr}^{-3}, and therefore they conform reasonably well to lines of constant dust mass, as shown in the plot as dashed light-gray lines.

The solid red line in the plot of Figure 4 shows the recent estimate for the nanodust abundance during the 2014 QUA, observed by LADEE/UVS in the anti-Sun direction [3]. Grain radius in that study was constrained by UVS to < 20-30 nm based on the measured spectral slope. Within that size range, the UVS results are at least two orders-of-magnitude larger than the LAMP-derived upper limits.

Conclusions: No brightness enhancement attributable to dust, of any size, was observed. Upper limits for dust column concentration and mass were determined to be: ~10^5 cm^{-2} for grains of radius ~25 nm, and ~10^{-11} g cm^{-2} for radii <100 nm. These limits are about two orders of magnitude smaller than the dust abundances inferred by the UVS measurements, although this disparity reduces to a factor as low as ~10 if larger grain sizes are considered (red dashed line in Figure 4). Two contributors to these conflicting results could have been a decrease in meteroroid impact rate (QUA flux was about a factor of two weaker in 2016 than 2014), and a difference in the viewing geometry (LADEE orbited the Moon in an equatorial orbit, while LRO was in a polar orbit). However, they cannot account for the factor of >~100 disagreement in nanodust abundance reported here.

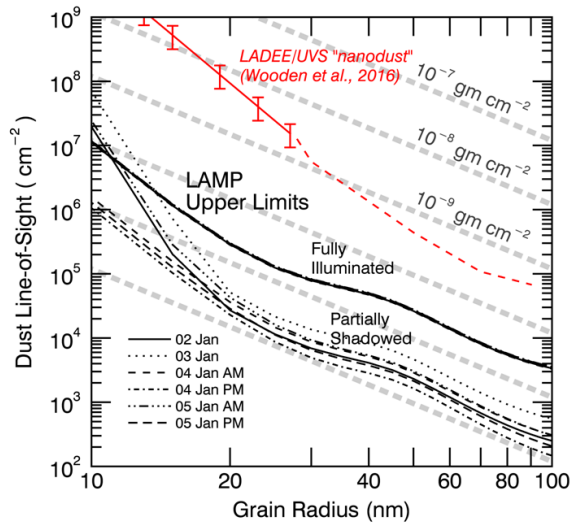

Figure 4 Upper limits for line-of-sight dust abundance as a function of grain radius, derived from the six LAMP observations during the 2016 QUA.

Excluding problems with the UVS calibration, one possible explanation could be the solar wind conditions: charged nanodust grains can have charge-to-mass ratios sufficient to be significantly affected by the Lorentz force, such that their spatial-temporal distribution would be dependent on recent plasma conditions in near-lunar space [3]. Therefore, it is conceivable that this effect could have significantly contributed to the disagreement between the LAMP and UVS observations, under otherwise similar conditions. Finally, we obtained the same N_{LOS} for the December 2015 GEM observations [7].

References: [1] Chin G. et al. (2007), *Space Science Reviews, 129(4)*, 391-419. [2] Gladstone G. R. et al. (2010) *Space science reviews, 150(1-4)*, 161-181. [3] Wooden D. H. et al. (2016) *Nat. Geo.*, 9, 665–668. [4] Grava C. et al. (2017) *GRL*, submitted. [5] Feldman P. D. et al (2014) *Icarus*, 233, 106-113. [6] Glenar D. A. et al. (2014) *JGR*, 119(12), 2548-2567. [7] Grava C. et al. (2016), *AGU*.