PREDICTIONS FOR THE OPTICAL SCATTERING AT THE MOON, AS OBSERVED BY THE LADEE UV/VIS SPECTROMETER.
T. J. Stubbs[1,2], D. A. Glenar[2,3], D. T. Richard[4,5], and A. Colaprete[5]. [1]University of Maryland, Baltimore County, [2]NASA Goddard Space Flight Center, [3]New Mexico State University, [4]San Jose State University, [5]NASA Ames Research Center. Correspondence to: Timothy.J.Stubbs@nasa.gov.

Introduction: When viewing the lunar exosphere there appear to be three major sources of optical scattering that are typically observed: atomic line emissions from the exospheric gases [1]; the relatively bright coronal and zodiacal light (CZL) background [2]; and the putative scattering of sunlight by exospheric dust, which is also referred to as "lunar horizon glow" (LHG) [3]. The lunar exospheric environment has not been well characterized, and there is still much to discover about the various physical processes taking place. This was recognized in the NRC SCEM report by "Concept 8: Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state" [4].

In response, NASA is going to fly the Lunar Atmosphere and Dust Environment Explorer (LADEE) to address these goals [5]. LADEE will carry a neutral mass spectrometer, a dust detector, and an ultraviolet/visible (UV/Vis) spectrometer. It will be placed in a near-circular retrograde equatorial orbit at an altitude of ≈50 km, and is due for launch in 2011.

Here we focus on the modeling necessary for the analysis of the UV/Vis spectrometer data. We have developed an adaptable code that can simulate the optical scattering processes that can be observed at UV and visible wavelengths from an orbiter within the shadow of the Moon. The predictions presented here indicate that the LADEE UV/Vis spectrometer will be able to readily distinguish between atomic line emissions and CZL, as well as LHG.

Lunar Exospheric Environment Overview:

Atomic line emissions. The lunar exosphere consists of various elements (e.g., H, He, Na, K, Ar, Rn), which are continuously sourced from the lunar surface and are either lost to space or recycled back to the surface [1]. Although only trace elements in the lunar exosphere, the bright emissions from sodium (Na) and potassium (K) with scale heights H ~ 100 km have been extensively used to study the variability of the exosphere from ground-based observatories [6,7]. The Na-D lines, at wavelengths λ_{D1} = 589.6 nm and λ_{D2} = 589.0 nm, are particularly bright in the visible with intensities up to several kiloRayleighs.

Coronal and Zodiacal Light. This refers to both sunlight scattered by the solar corona, and that scattered by interplanetary dust in the inner solar system. The Zodiacal dust population is distributed about the ecliptic plane and produced by asteroids and comets [2]. A formulation for the spatial and spectral characteristics of CZL was developed [8], and later refined by fitting to spectral broad measurements from the Clementine Star Tracker cameras [2].

Lunar Horizon Glow. Observations of a glow along the lunar horizon suggest that there is a greater abundance of lunar exospheric dust than is expected to be produced by meteoritic ejecta alone [9]. Therefore, it has been proposed that electric charging of the lunar surface by plasma and solar UV could result in the electrostatic transport of dust [e.g.,10].

The Surveyor landers observed LHG along the local western horizon after sunset, which indicated that micron-scale dust grains (radii a ~ 5 μm) were "levitating" within ≈1 m of the surface. Direct detection of highly-charged lunar dust moving at ~100 m s^{-1} was likely provided by the Apollo 17 Lunar Ejecta and Meteorites (LEAM) experiment [10]. The LEAM dust counts peaked around the terminator, which strongly suggests a connection with LHG [11].

Evidence for exospheric dust "lofted" to higher altitudes came from Apollo astronaut observations and coronal photography from orbit while within lunar shadow [3,12]. These observations indicated that the high-altitude dust was submicron (a ~ 0.1 μm) with H ~ 10 km [13]. Further evidence from the astrophotometer aboard the Soviet Lunokhod-II rover revealed a brighter than expected lunar twilight sky [14], while the Apollo 16 Far-Ultraviolet Camera/Spectrograph possibly detected LHG during the lunar daytime [15].

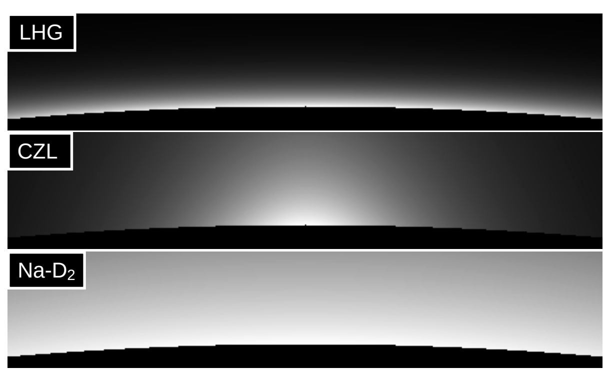

Figure 1. Predictions for the spatial distributions of optical scattering at $\lambda \approx$ 589 nm from: lunar horizon glow (LHG); coronal and zodiacal light (CZL); and the exospheric sodium D_2 atomic line emission (Na-D_2).

It has also been tentatively suggested that the Clementine Star Tracker might have observed LHG [16].

NMSU Light Scattering Code for Lunar Exospheric Dust: A brief overview of the model.

Dust Model Distribution. We use the simple Murphy and Vondrak radius-altitude distribution for exospheric dust above the lunar terminator [17], which is based on McCoy's model "0" [12], as well as Apollo astronaut [13] and Lunokhod-II observations [14].

Lunar Dust Scattering Properties. Mie theory is used here since it provides a good estimate for the radiative transfer properties of exospheric dust ($a \leq \lambda$). We have assumed a dust refractive index of $n_r = 1.58$ and $n_i = 0.03$ [17], with a size parameter range from 0.7 to 6.0. The model keeps track of both polarizations, which can also provide important dust information [18], and will be measured by LADEE. Solar spectral irradiance data is provided by NASA's Solar Radiation and Climate Experiment (SORCE).

Path Integration Geometry. We use a spherical coordinate framework, which requires the spacecraft altitude z and solar zenith angle χ, as well as the instrument field-of-view (FOV), pixel FOV, spectral resolution $\Delta\lambda$, observational wavelengths λ.

Coronal and Zodiacal Light and Atomic Line Emissions. The CZL predictions are based on a modified Hahn et al. model [2] with color information [19]. We also include the sodium D-line emissions [6,7].

Predictions for LADEE UV/Vis Spectrometer: The predictions in Fig. 1 show the spatial distribution of the optical scattering produced by lunar horizon glow, coronal and zodiacal light, and the sodium D_2 atomic line emission, as viewed from lunar shadow. In each panel the predictions are for wavelengths $\lambda \approx 589$ nm (Na-D_2 line), and the intensities have been normalized. The viewing position is at $z = 50$ km and $\chi \approx 115°$. The nominal FOV was chosen to be 5° × 26° in order to be able to show the differences in spatial distribution, with 5° corresponding to a vertical height of ≈40 km at the limb. Figure 1 clearly demonstrates that it should be possible for LADEE UV/Vis to spatially distinguish between the horizon-hugging LHG, the bright CZL peak centered on the Sun, and the near-uniform glow from the Na-D_2 emission. The differences shown between LHG and Na-D_2 line emission are due largely to the differences in scale height.

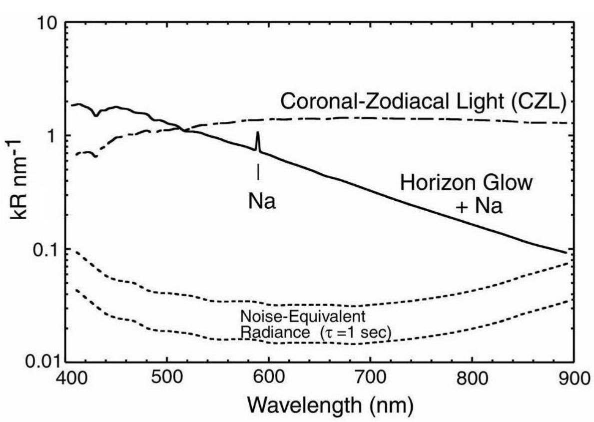

Figure 2. Predictions for the spectral behavior of the scattering light sources, as seen by the LADEE UV/Vis spectrometer looking just above the limb.

Figure 2 shows predictions for the intensities of the optical scattering observed at the Moon as a function of wavelength. In this case, the ≈1° FOV of LADEE UV/Vis is pointed just above the lunar limb. This clearly shows that LHG has a "blue" slope and CZL has a "red" slope, and that it is likely better to search for LHG at blue wavelengths (~400–550 nm). At a spectral resolution of $\Delta\lambda \approx 1.5$ nm and solar elongation angle $\varepsilon \approx 9°$, the significant contribution from the Na-D_2 line at $\lambda \approx 589$ nm is easy to identify and distinguish from LHG, which is an important objective for LADEE. The optical scattering intensities should also all be above the Noise Equivalent Radiance (NER) produced by the instrument itself.

Conclusions: These predictions show that LHG, CZL and atomic line emissions can be distinguished on the basis of spatial morphology alone. LHG intensities are comparable to (or exceed) those of CZL, given a spatial resolution of a few km or less above the limb and solar elongation angles less than ≈15°. The photometric colors of LHG and CZL are distinct, with LHG having a "blue" slope and CZL a "red" slope. LHG is most readily identified at blue wavelengths and small tangent heights. The Na-D_2 line emission is comparable in intensity to LHG and CZL at $\lambda \approx 589$ nm $\Delta\lambda \approx 1$–2 nm, in which case it can be readily identified. Based on our predictions, if LHG is present then it should be easily detectable by the LADEE UV/Vis spectrometer.

References: [1] Stern (1999), *Rev. Geophys.*, 37. [2] Hahn et al. (2002), *Icarus*, 158, 360. [3] McCoy & Criswell (1974), *Proc. LSC 5*, 2991. [4] The Scientific Context for Exploration of the Moon (2007), *NRC*. [5] LADEE SDT Report (2008), *NASA*. [6] Potter & Morgan (1994), *GRL*, 21, 2263. [7] Potter & Morgan (1998), *JGR*, 103, 8581. [8] Giese & Dziembowski (1969), *PSS*, 17, 949. [9] Rennilson & Criswell (1974), *The Moon*, 10, 121. [10] Colwell et al. (2007), *Rev. Geophys.*, 45. [11] Stubbs et al. (2007), ESA SP-643, 185. [12] McCoy (1976), *Proc. LSC 7*, 1087. [13] Zook & McCoy (1991), *GRL*, 18, 2117. [14] Severny et al. (1975), *The Moon*, 14, 123. [15] Page & Carruthers (1978), *NRL Report 8206*. [16] Zook, et al. (1995), *Proc. LPSC* 26, 1577. [17] Murphy & Vondrak (1993), *Proc. LPSC 24*, 1033. [18] Richard & Davis (2008), *A&A*, 483, 2. [19] Pitz et al. (1979), *A&A*, 74, 15.