A VISIBLE AND INFRARED SPECTROPHOTOMETRIC MODEL FOR THE MOON BASED ON ROLO AND CHANDRAYAAN-1 MOON MINERALOGICAL MAPPER DATA. M. D. Hicks[1], B. J. Buratti[1], M. Staid[2], C. Pieters[3], J. Nettles[3], J. W. Boardman[4], J. Sunshine[5] [1]NASA Jet Propulsion Laboratory, California Inst. of Technology, Mailstop 183-501, Pasadena, CA 91109 (Michael.Hicks@jpl.nasa.gov), [2]Planetary Sciences Inst., USA. [3]Brown University, Providence RI, USA. [4]Analytical Imaging and Geophysics, Boulder, CO, USA. [5]University of Maryland, College Park, MD, USA,

Introduction: Much of the variation in specific intensity and spectral albedo on the Moon is not intrinsic but rather due to changing radiance viewing geometry. In order to detect and map subtle spectral features of minerals and volatiles on the lunar surface, such as iron-and titanium-bearing minerals and water ice, a quantitative model describing the directional properties of reflected solar radiation must be developed. The Moon Mineralogical Mapper (M^3), which is an imaging spectrometer launched with the Indian Space Agency's Chandrayaan-1 spacecraft October 22, 2008, provided the motivation to develop a spectrophotometric model for the visible and near-IR. The database used for the model was produced from the USGS's Robotic Lunar Observer (ROLO) dedicated ground-based lunar calibration project [1]. We can now compare our preflight ROLO model with acquired M^3 data to assess calibration wavelength-dependent solar phase functions across 85 spectral channels from 430 to 3000 nm.

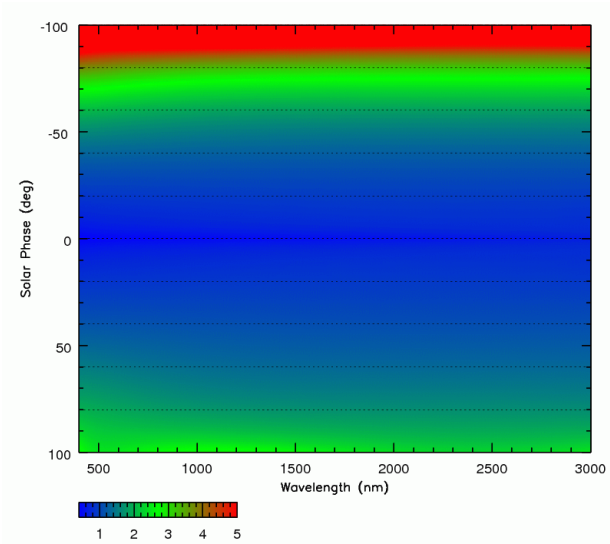

Fig. 1: ROLO derived solar phase correction factor.

Preflight ROLO Model: A multi-year ground-based program to gather photometric data for the Moon over the spectral range attainable from Earth (0.347 – 2.39 µm) and over solar phase angles of 1.55-97 degrees, was initiated by Hugh Kieffer and his colleagues. Extensive measurements have been published [1], and additional data files are available from the USGS. We obtained 36,000 photometric data points from the ROLO observations for each of the 11 reference regions defined in [1], concentrating on the Mare Serentatis and Highland regions isolated by ROLO. The observations were corrected for "limb-darkening" (changes in specific intensity due to changes in the incidence and emission angle) using the well-established $(\mu_o+\mu)/\mu_o$ factor, which defines lunar or "Lommel-Seeliger" scattering behavior, characterized by the cosine of the incidence angle (μ_o), the cosine of the emission angle (μ), and the solar phase angle (α).

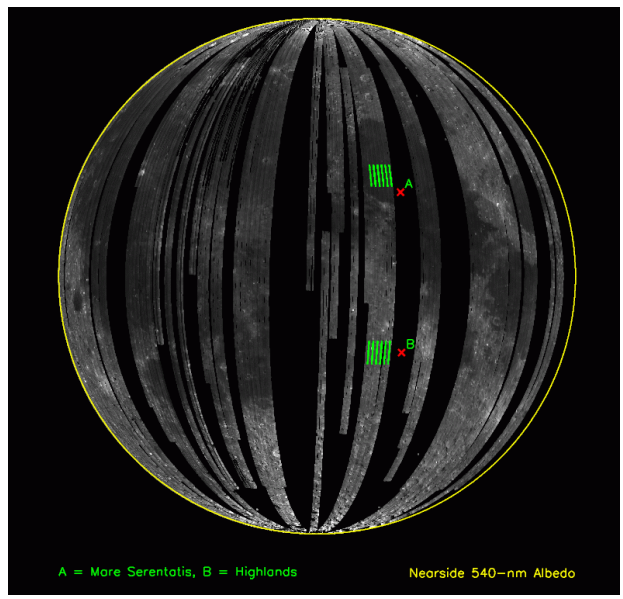

Fig. 2: Lunar nearside 540 nm albedo map obtained by M^3 during OP1. Marked in red are coordinates for the Mare Serentatis and Highland ("A" and "B", respectively) areas modeled in detail using ROLO data. The green areas indicate 5° x 5° regions in the M^3 data extracted for comparison.

Solar phase functions ($f_\lambda(\alpha)$) were extracted for each of the 11 ROLO sites and equations (4th-order polynomial and an exponential term) were fit to $f_\lambda(\alpha)$ for each region at each ROLO wavelength. Interpolations were done to produce fits at one nanometer resolution and extrapolated to M^3 wavelengths. Our model of the solar phase behavior of the Moon allowed a normalization of M^3 observations to 30° reference phase and a first-order correction for phase-dependent reddening and absorption band attenuation. The resulting ROLO derived solar phase correction is shown in Fig. 1. Our phase correction model is not symmetric about 0° phase. Although the Moon is quite spherical, concavities and shadow-causing topographic structures at all spatial scales cause a branching in the observed solar phase function into

"waxing" ($\alpha>0°$) and "waning" ($\alpha<0°$) phases. This effect can be understood simply. For each point on a spherical Moon if the emission angle and the incident angle are both equal or greater than the solar phase angle then the Sun is effectively behind the observer and shadows at all spatial scales are preferentially hidden from the observer ("waxing"), else the shadows are preferentially exposed to the observer ("waning"). Lommel-Seeliger scattering remains valid: this effect reflects the inability of μ and μ_o computed for a spherical Moon to reflect the localized pixel-by-pixel topography.

Comparison with M3 data: Wavelength-dependent radiance for the M^3 observations obtained adjacent to the ROLO "Mare" and "Highlands" regions, as shown in Fig 2, were extracted from data collected during the spacecraft's first Optical Period (OP1). Radiance was converted to relative reflectance by correcting for geocentric and heliocentric distance and dividing by the solar spectrum and Lommel-Seeliger term. Fig. 3 and Fig. 4 show M^3 data at three representative wavelengths as compared with the pre-flight ROLO "Mare" and "Highland" photometric models, respectively, with remarkable agreement at all wavelengths.

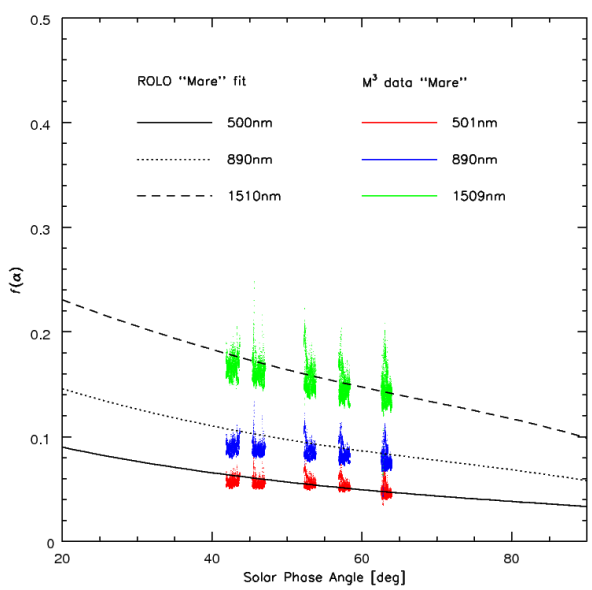

Fig. 3: Comparison of M^3 (colored symbols) and ROLO photometry for the Mare Serentatis regions

Discussion and Future Work: Although preliminary, we have verified the calibration of M^3 at the wavelengths in common with the ROLO model, which agree to within 5% for both regions. We are in initial stages of a detailed analysis of the complete dataset obtained in both OP1 and OP2 (the Chandrayaan mission ended in August 2009). This additional data incorporates a much wider range of solar phase angles and will allow us to characterize $f_\lambda(\alpha)$ using the M^3 data itself. The M^3-derived $f_\lambda(\alpha)$ will be used to generate a new self-consistent phase correction table. This is required because the M^3 solar phase behavior appears slightly more shallow than the $f_\lambda(\alpha)$ as measured by ROLO, as seen in Figures 3 and 4. The more shallow $f_\lambda(\alpha)$ manifests itself as systematic cross-track gradients in M^3 image mosaics, which should be much improved with a second-generation $f_\lambda(\alpha)$ model. We note that the shallow M^3 $f_\lambda(\alpha)$ observations appears to be similar to the solar phase behavior as obtained by Clementine [2].

Phase 1 of our $f_\lambda(\alpha)$ studies will utilize empirical fits in order to describe the solar phase behavior. Phase 2 shall include detailed Hapke modeling and analysis as a function of selenographic latitude and longitude and will include nearside and farside albedo maps and correlations with geologic units. We will also investigate the role of multiple scattering.

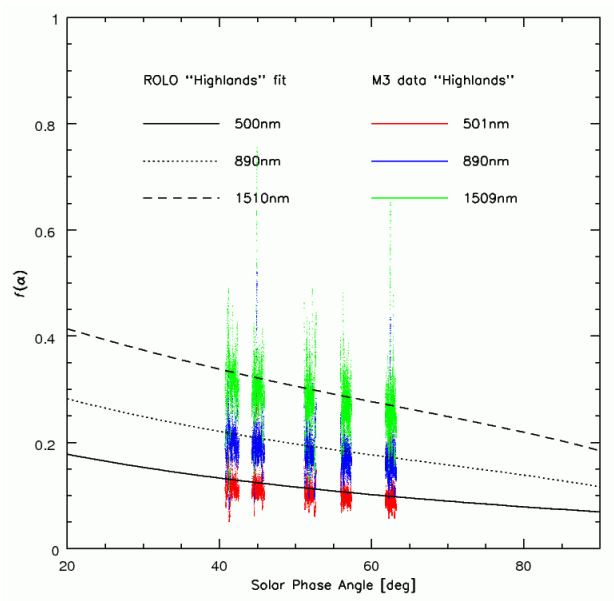

Fig. 4: Comparison of M^3 (colored symbols) and ROLO photometry for the Highlands region.

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References: [1] H. H. Keiffer and T. S. Stone (2005). *A. J.* 129, 2887-2901. [2] J. K. Hillier, B. J. Buratti, and K. Hill (1999) *Icarus* 141, 295-225.