The LASP Lunar Albedo Measurement and Analysis from SOLSTICE (LLAMAS)

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Introduction

The SOLar-STellar Irradiance Comparison Experiment (SOLSTICE) [1] on the SOLar Radiation and Climate Experiment (SORCE) [2] has been observing the lunar irradiance in the ultraviolet on a routine basis since June 2006. SOLSTICE is a two channel grating spectrometer that monitors the solar irradiance from 115 to 300 nm and uses an ensemble of bright stars to track instrument degradation. The far ultraviolet (FUV) channel measures from 115 to 180 nm, while the middle ultraviolet (MUV) channel measures from 180 to 300 nm. The large dynamic range of the instrument allows us to also measure the lunar irradiance with good signal-to-noise over a wide range of phase angles.

Photometric measurements of atmosphereless solar system bodies provide information on the textural and topographic properties of their surfaces. Near zero phase, the disk-integrated reflectance rises sharply. This phenomenon is commonly known as the opposition surge. The amplitude of the rise and its width in phase angle provide information about the porosity, grain size distribution, and the physical mechanism of reflection [3]. Disk-integrated measurements at large phase angles provide information on topographic surface roughness [4]. SOLSTICE observations of the Moon are well-suited to such photometric studies as they span a wide range of phase angles ($\sim 0° – 170°$). The ultraviolet wavelength range of SOLSTICE may provide unique information on these photometric properties of the Moon.

Unlike previous ultraviolet albedo measurements, the SOLSTICE instrument observes both the lunar and solar irradiances. As described in Snow et al. [5], this observing technique removes uncertainties due to instrument cross-calibration in the measurement of the disk-integrated lunar albedo. An additional advantage to using SOLSTICE to observe the Moon is that we have solar spectra taken shortly before or after the lunar spectrum (usually less than an hour). This is particularly important in the FUV band where the Sun is highly variable compared to the visible.

Observations

During the daylight portion of each orbit, SOLSTICE measures the solar irradiance at 0.1 nm spectral resolution. When the spacecraft is in eclipse, the instrument exchanges the small solar entrance and exit slits for much larger stellar apertures. With the increased throughput, SOLSTICE can measure the irradiance from the Moon over the entire 115-300 nm range. The spectral resolution of the lunar observations is 1.1 nm in the FUV and only 2.2 nm in the MUV.

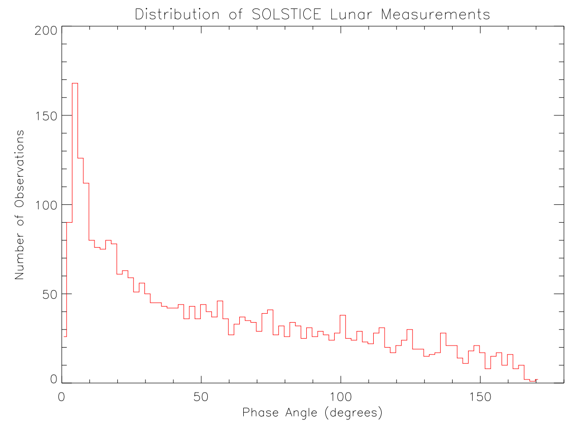

Figure 1: Histogram of SOLSTICE lunar observations.

Figure 1 show the distribution of phase angles that have been observed so far in the program. Lunar observations compete with the stellar calibration observations for spacecraft time, but we have averaged about one spectral scan of either the FUV or MUV band per day. We have purposefully weighted the scheduling priority of lunar observations towards small phase angles to improve sampling of the phase curve near full Moon. Starting in 2009, we also began increased observing frequency at large phase angles, so in the future these histograms will also show a peak near 170°, the limit of spacecraft pointing restrictions.

Preliminary Results

The SOLSTICE measurements of both the Sun and Moon are disk integrated irradiances, therefore the natural quantity to compute from these two datasets is the disk-equivalent albedo as defined by Kieffer and Stone [6]:

$$A_M(\alpha) = \frac{E_M/\Omega_M}{E_\odot/\Omega_\odot}, \quad (1)$$

where E_M and $E_\odot$ are the irradiances of the Sun and Moon respectively, and Ω is the solid angle subtended by each object. The disk-integrated albedo at 0° phase is also known as the geometric albedo.

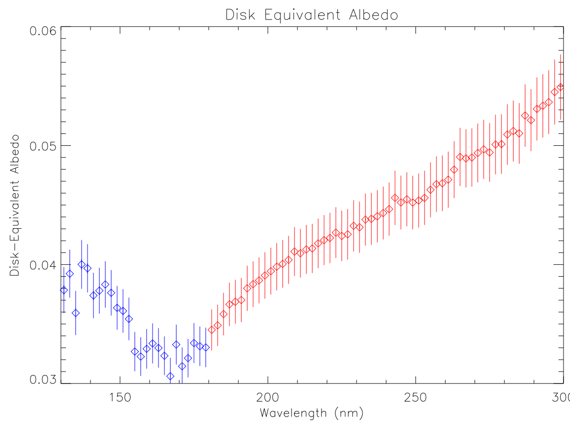

Figure 2: Lunar disk-equivalent albedo at phase angle of 10 degrees. Blue and red points are from the FUV and MUV channels respectively. Error bars are due to systematic and statistical sources [5].

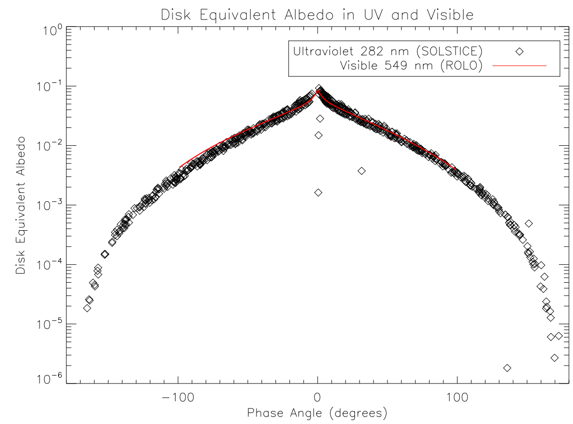

Figure 3: Phase Curve of the Moon at a wavelength of 282 nm. Negative angles correspond to waxing phase, positive to waning phase.

Using only the observations near 10 degrees phase angle, the disk-equivalent albedo as a function of wavelength is shown in Figure 2. This plot shows only wavelengths longer than 130 nm. Since the SORCE spacecraft is in low Earth orbit, observations in the neighborhood of Lyman alpha (121.6 nm) are impacted by geocoronal airglow emission. We are still in the process of modeling this contribution to estimate the lunar albedo at Lyman alpha.

Figure 3 shows the disk-equivalent albedo for a single wavelength (282 nm) as a function of phase angle. One of the unique properties of the LLAMAS dataset is the coverage of phase angle from near zero to over 170 degrees. This will allow us to study both the opposition surge well as surface roughness.

For comparison, we have included the phase curve for visible wavelengths from the Robotic Lunar Observatory (ROLO) [6]. Both phase curves show asymmetry between the waxing and waning phases (positive and negative angles, respectively). In the visible part of the spectrum, mare appear darker than highlands terrain, thus the waning moon is on average darker than the waxing moon due to a larger abundance of maria in the western hemisphere. Preliminary indications are that the asymmetry in the ultraviolet is in the opposite sense than in the visible. This is consistent with observations by Lucke et al. [7] that showed the relative brightness of highlands and mare are reversed in the ultraviolet, i.e. that mare is bright and highlands are dark.

Although we have a catalog of lunar observations starting in 2006, we have only recently acquired resources to analyze this dataset. The results that we will present at this meeting are therefore preliminary.

References

[1] W. E. McClintock, G. J. Rottman, and T. N. Woods. Solar-Stellar Irradiance Comparison Experiment II (Solstice II): Instrument Concept and Design. *Solar Phys.*, 230:225–258, August 2005. doi: 10.1007/s11207-005-7432-x.

[2] G. Rottman. The SORCE Mission. *Solar Phys.*, 230:7–25, August 2005. doi: 10.1007/s11207-005-8112-6.

[3] B. Hapke. Bidirectional reflectance spectroscopy. IV - The extinction coefficient and the opposition effect. *Icarus*, 67:264–280, August 1986. doi: 10.1016/0019-1035(86)90108-9.

[4] B. Hapke. *Theory of reflectance and emittance spectroscopy*. 1993.

[5] M. Snow, G. Holsclaw, W. E. McClintock, and T. Woods. Absolute ultraviolet irradiance of the moon from SORCE SOLSTICE. In *Proc. of the SPIE*, volume 6677, October 2007. doi: 10.1117/12.732498.

[6] H. H. Kieffer and T. C. Stone. The Spectral Irradiance of the Moon. *AJ*, 129:2887–2901, June 2005. doi: 10.1086/430185.

[7] R. L. Lucke, R. C. Henry, and W. G. Fastie. Far-ultraviolet albedo of the moon. *AJ*, 81:1162–1169, December 1976. doi: 10.1086/112000.