The Final Minute: Results from the LCROSS Solar Viewing NIR Spectrometer A. Colaprete[1], M. Shirley[1], J. Heldmann[1], D. H. Wooden[1], [1]NASA Ames Research Center, Moffett Field, CA, Anthony.Colaprete-1@nasa.gov

Introduction: In the final moments before itself impacting the moon, the Lunar Crater Observation and Sensing Satellite (LCROSS) Shepherding spacecraft (SSC) descended through the remaining dust, ices and vapors ejected from the impact of the Centaur upper stage. One instrument that was situated specifically to make these late-stage measurements was a solar viewing NIR spectrometer. This spectrometer monitored the solar flux from before impact to the moment signal was lost from the SSC (2-3 km above the surface of the moon). In these data clear evidence for water vapor and water ice is evident with the strongest signature in the final scans. This "late-stage" water ice suggests a level of ice-grain purity in that it had to have lasted 3+ minutes in sunlight to be observed. Fits to the 1.5 micron water ice suggest water ice grains larger than 2 microns.

The LCROSS Mission: The primary objective of LCROSS was to confirm the presence or absence of water ice at the Moon's South Pole. This mission used a 2300 kg kinetic impactor (the spent upper stage of the Atlas V launch vehicle, the Centaur) with more than 200 times the energy of the Lunar Prospector (LP) impact. The Centaur was guided to its target, a site in permanent shadow inside the crater Cabeus, by a Shepherding Spacecraft (SSC), which after release of the Centaur, descended toward the impact plume, sending real-time data and characterizing the morphology, evolution and composition of the plume with a suite of cameras and spectrometers (Figure 1). The SSC made observations from ~4 min until just ~1 sec prior to itself impacting the lunar surface.

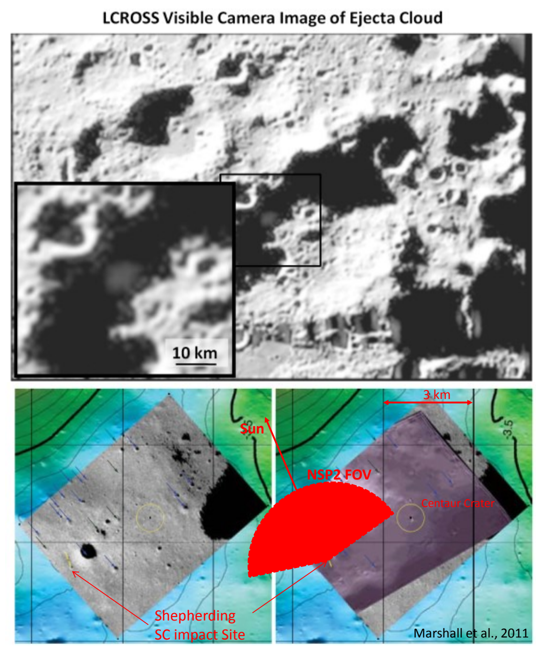

Figure 1. (Top) Image of the LCROSS impact ejecta cloud as seen in the visible context camera at about 20 seconds after impact. Inset shows the ejecta cloud expanding to fill the shadowed region targeted at the bottom of the crater Cabeus. **(Bottom)** Location of the Centaur and Shepherding SC impacts, with the NSP2 FOV and direction to the sun.

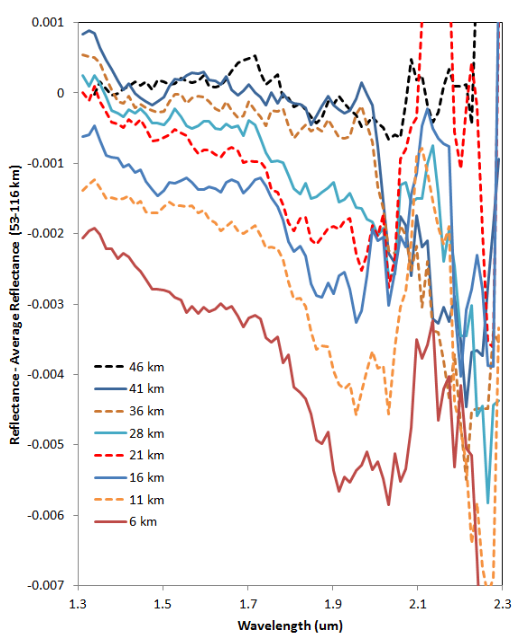

Figure 2. Series of 5-spectra averages differenced from a "high altitude" (70-50 km) average (approximately 15 spectra averaged) centered on the indicated altitude (above the lunar surface).

Solar Viewing NIR Spectrometer: The solar viewing NIR spectrometer was identical to the nadir NIR spectrometer which observed the impact from above [1, 2] in terms of wavelength coverage and spectral resolution. However, the solar viewing NIR spectrometer was fitted with a diffusor and positioned such that it could monitor the solar flux during the entire descent of the SSC. The intent of the instrument was to measure any extinction of sunlight caused by attenuation by ejecta debris and/or vapor as the SSC descended through any remnants of the ejecta cloud. The solar viewing diffusor used a 135° FOV Spectralon diffusor sandwiched between two sapphire windows which al-

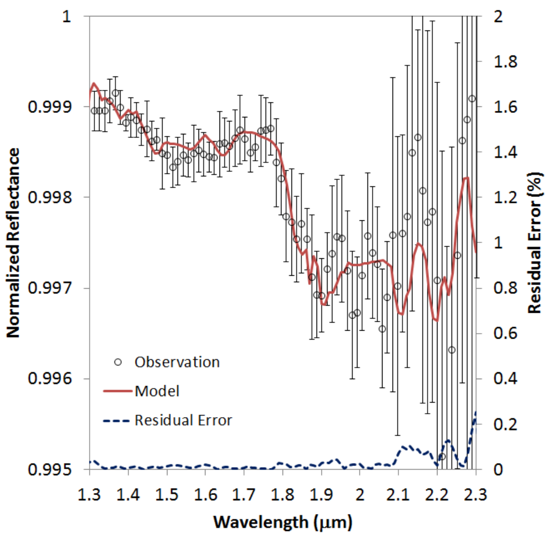

Figure 3. Initial linear fits to a 5-scan average of the last 5 scans prior to the SSC impact. The 5-scan average is referenced to a 15 scan average (made from cans approximately 50 seconds earlier). Included in the fit are water vapor and ice, and C_2H_4.

lowed for a fixed mounting of the entrance optics. The effect of solar incident angle on the diffuser was calibrated inflight before impact with several calibration operations of the instrument with different solar viewing angles. The viewing angle during impact was relatively constant and changed only approximately 4° between from just prior to Centaur impact to the SSC impact. The instrument response has been corrected for the incident solar angle as well as the radiances corrected for scattering from the terrain onto the diffusor.

Water in the Late Time Ejecta: To look for absorption caused by any late-remaining ejecta the NIR spectra are compared to spectra taken at earlier times. By ratioing spectra to earlier reference spectra absolute calibration is not necessary (although absolute calibration is greatly assisted given the source is the sun). While the SNR of each scan is very good (typically SNR>1000 at wavelengths <2 μm), SNR is further increased by successive averaging of five scans. Figure 2 shows the difference in radiance from an average made at "high altitude (50-75 km above the surface). Each spectrum is made from moving sets of 5-scan averages. Each spectrum is centered at an approximate altitude indicated in the figure key. The first signs of the ejecta cloud appear at scans centered at an altitude of 25 km, where absorption features consistent with water vapor and ice appear as well as a broader overall decrease (increasingly negative values) and change in slope of the spectrum across its entire range. A linear

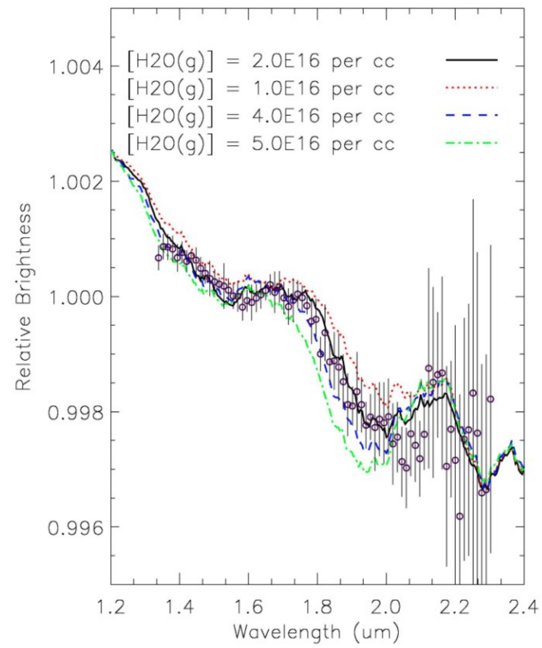

Figure 4. Monte Carlo scattering model fits to the 6 km spectrum shown in Fig. 2. The total amount of ice was held constant and the total water vapor in the scattering cloud varied.

fit to the final 5-scan average (6 km spectrum in Figure 2) is shown in Figure 3. The two primary components of this fit are water ice and vapor. To better understand the total concentration of water ice and vapor a Monte Carlo scattering model was used. This model assumed a hemispherical cloud of dust, water ice and water vapor 10 km across with the observer (the NSP2 solar viewer) on the side opposite the sun. The sun source is modeled as an extended source 0.52 deg across. A surface albedo of 0.3 was assumed. Figure 4 shows an example result from this model where the total number of ice grains and dust grains were held constant and the water vapor concentration varied. For wavelengths between 1.3 and 2 um, the signal-to-noise is greater than 1000 so the contribution of water vapor and ice to the absorption spectrum is strongly constrained with a high confidence level (greater than 3sigma).

How these observations fit into the broader set of observations of the impact event and their possible implications for the distribution of water ice at the Centaur impact site will be presented.

References: [1] Colaprete et al., Science, 2010. [2] Ennico et al., SSR, 2011.