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 any 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 (about 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 1-2 microns.

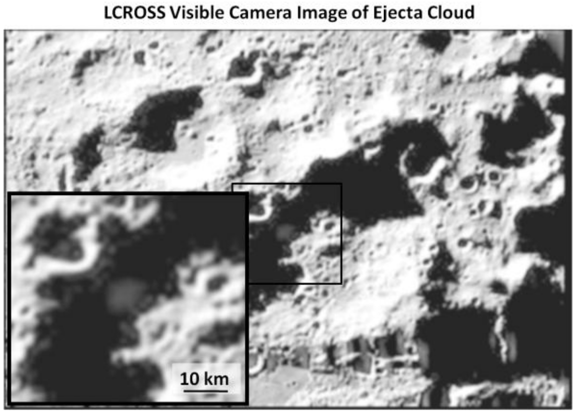

Figure 1. Image of the LCROSS impact ejecta cloud as seen in the visible context camera. Inset shows the ejecta cloud expanding to fill the shadowed region targeted at the bottom of the crater Cabeus.

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 up to ~4 min until just ~1 sec prior to itself impacting 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] in terms of wavelength coverage and spectral resolution. However, the solar viewing NIR spectrometer was fitted with a solar viewing 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 allowed 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

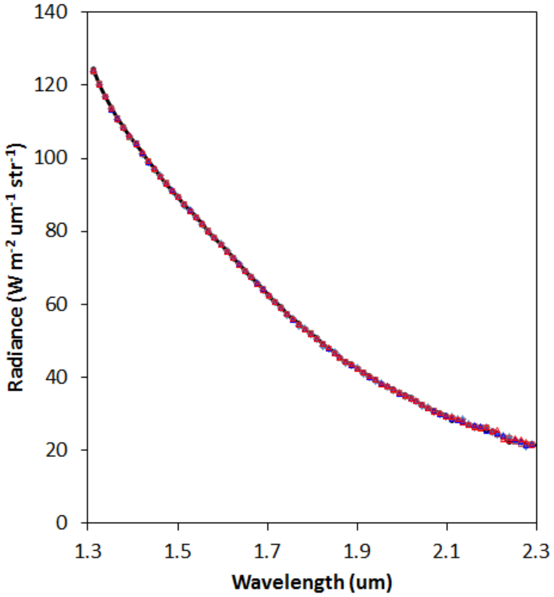

Figure 2. The last five LCROSS Solar Viewing NIR Spectometer spectra collected before the SSC impacted into the floor of Cabeus. Viewing the sun allowed for signal-to-noise ratios greater than 1000/

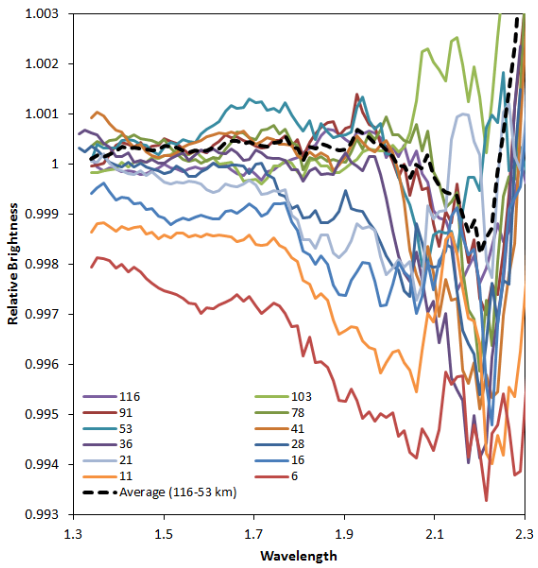

Figure 3. Series of 5-spectra averages centered on the indicated altitude (above the lunar surface). Each spectrum is the ratio(relative brightnes) made from a reference spectrum generated from 15 scans prior to the earliest scan shown in the figure (approximately 50 sec prior to the SSC impact).

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 (see figure 2), SNR is further increased by successive averaging of five scans. Figure 3 shows ratios (relative brightness) for 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 and change in slope of the spectrum across its entire range. Fits to this data (Figure 4). 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.

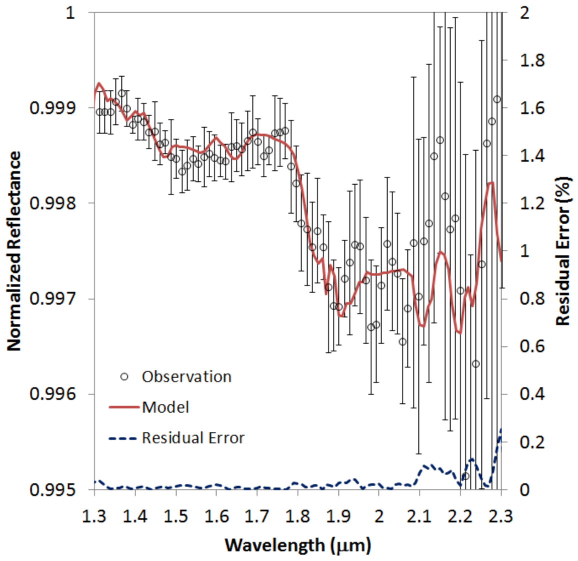

Figure 4. Initial linear fits to a 5-scan average of the last 5 scans prior to the SSC impact. The 5-scan average is referenced to a 15 scan average (made froms cans approximately 50 seconds earlier). Water vapor and ice, and C_2H_4.