OBSERVATIONS OF THE LCROSS IMPACT EVENT FROM THE MCMATH-PIERCE SOLAR TELESCOPE: SODIUM AND DUST Rosemary M. Killen[1,5], Andrew E. Potter[2], Dana M. Hurley[3,5], Claude Plymate[2], Shantanu Naidu[4], [1]NASA Goddard Space Flight Center, Code 695, Greenbelt MD 20771 (Rosemary.Killen@nasa.gov); [2]National Solar Observatory, Tucson, AZ 85721; [3]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723; [4]Dept. of Astronomy, University of Maryland, College Park, MD 20742; [5] NASA's Lunar Science Institute, NASA/Ames Research Center, Moffett Field, CA 94035.

Introduction: A small instrumented payload launched on NASA's Lunar Reconnaissance Orbiter was developed to observe the result of a targeted crash of the upper stage of the launch vehicle into a permanently shadowed lunar crater to look for evidence for water in the ejected material. The Lunar Crater Observation and Sensing Satellite (LCROSS) targeted the crater Cabeus. The impact occurred as planned, with the Centaur upper stage impacting at 11:31:19 UT on Oct. 9, 2009, and the shepherding spacecraft impacting at 11:35:35.05 UT. The Centaur weighed 2350 kg, and the shepherding spacecraft weighed 610 kg. We used the stellar spectrograph on the McMath-Pierce solar telescope at Kitt Peak, Arizona, to observe the ejected sodium gas from these impacts. The purpose of observing sodium is twofold. First, sodium is present in the lunar regolith and is ejected by meteoritic impacts [1-4]. Sodium is present in cometary material and we know the sodium fraction in at least those comets that have been observed. We can constrain the amount of material ejected, and by comparing the relative amounts of water vapor and sodium vapor observed we can constrain the source of the material ejected, whether it is indigenous to the Moon or to comets or of solar wind origin or a combination of the above.

Observations: On Oct. 9, 2009, the seeing was excellent at Kitt Peak and there were no clouds. Sodium was observed with a160 micron slit extending 100 arcseconds. The plate scale was 0.518 km/arcseconds, and the field of view was 0.4574 km across the slit and 193 km along the slit. The impact flash was observed at two slit positions. At the time of impact we observed over the impact point in Cabeus crater, 81.55° S, 43.1° W. A 90 second exposure was begun at the impact time (Figure 1). A 120 second exposure was taken off the limb. We took 6 more exposures off the limb. The sodium emission was weak in exposures taken after the first off-limb exposure (Figure 2). Calibration was obtained by comparing counts in the continuum to a Hapke model of the lunar surface at the point where the continuum was obtained. We saw no sodium above the polar limb prior to the impact.

The maximum emission seen over Cabeus crater (Figure 1) was 150 kR, with a FWHM of 7.3 arcseconds, or about 378 km. Assuming that the emission is isotropic and Gaussian, we integrated the emission with a two dimensional Gaussian of FWHM 3.78 km. Given a g_value of 0.53 photons/atom/sec for the D2 line, we obtained a total number of atoms at this time of 1.26×10^{25}, or 2.4 grams. The emission seen over the limb was integrated along the slit and averaged. We obtained 2×10^{10} atoms cm^{-2}.

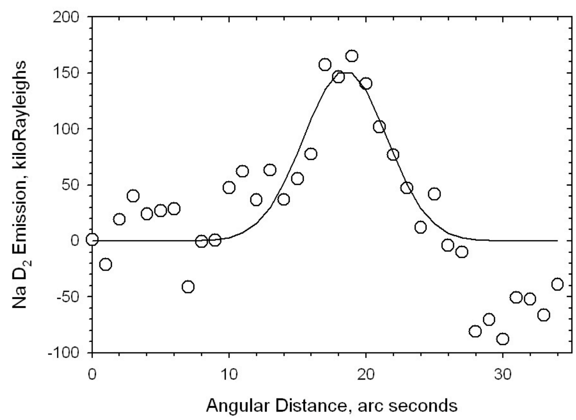

Figure 1. Sodium emission in the D2 line observed above Cabeus crater at the impact time. The plate scale is 1.93 arcseconds/km. The g_value for sodium D2 is 0.53 photons/atom/second.

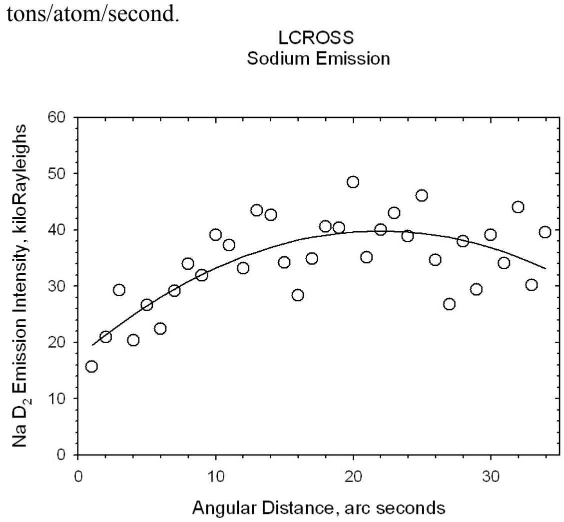

Figure 2. Sodium D_2 emission observed off the limb just above Cabeus crater beginning at 11:35:45 UT, or 4.4 minutes after impact. This was a two-minute integration.

Model: The sodium emission has been modeled using a Monte Carlo model [5], giving the sodium density per kg of sodium released as a function of time and distance from the impact. From a comparison of our results obtained over the limb at the impact time plus

4.4 minutes to impact time plus 6.4 minutes, with the simulation for a 1000 K omnidirectional impact at 3.5 – 5.5 minutes after impact (Figure 3), we estimate that approximately 2 kg of sodium was released time-integrated over the entire impact and outgassing event.

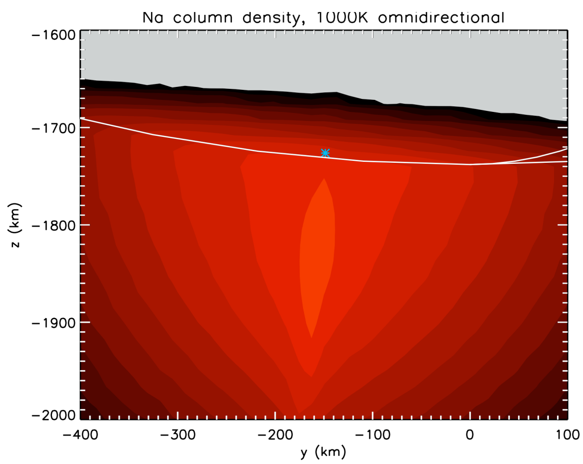

Figure 3. Monte Carlo simulation of the sodium emission from the impact, giving the emission per kg if sodium released in the impact. This simulation assumes an omni-directional vapor source. We will also discuss the implication of release preferentially at a 45° angle from the zenith direction.

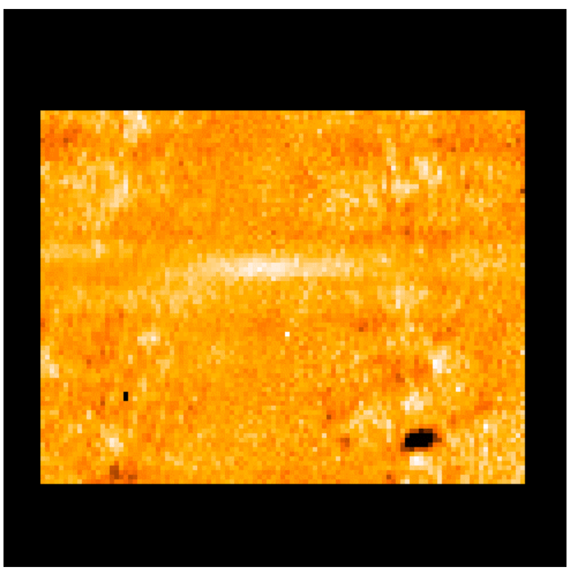

Figure 4. Image showing the impact site at the time of the impact seen by the East Auxiliary telescope. The broad white area just above center is the impact site. Other bright areas are peaks that are in sunlight. A neutral density filter and polarizing beam splitter were used.

Polarization Measurement: We attempted to observe dust ejected from the impact by observing the lunar surface and limb with a polarizing prism at two orthogonal orientations. For this we used the East Auxiliary telescope at the McMath-Pierce solar telescope. An occulting disk alternately obscured one or the other beam. The field of view was 100"x100", or about a square 212 km on each side. The CCD was on a rotating stage so that the orientation of the moon was stationary with respect to the successive images. We used a neutral density filter to reduce the intensity of the lunar surface. We saw no change in the relative intensity of the two orthogonal beams after the impact, indicating that if dust is present it is below our detection limit.

Results: The impact flash was observed both in the CCD images with the East Auxiliary telescope (Figure 4) and with the stellar spectrograph observing the sodium D_2 emission. The spectrograph slit was over the impact point at the time of impact (Figure 1). Sodium emission was observed above the impact point and off the lunar limb until 6 minutes after impact. The sodium emission seen over the impact during the first 90 seconds after impact is bright but confined to an area with FWHM of 3.78 km. The amount of sodium seen in this time was about 2.4 grams or 0.1 mole, indicating a release rate of 0.027 g/s of sodium gas. However, a comparison of our observed sodium above the limb with simulations indicates that 2 kg of sodium was released by the LROSS impact. The very large discrepancy between the sodium seen above the impact site and that seen off the limb could be due to the fact that the emission is due to resonance scattering of the solar flux. If most of the sodium was still in shadow during the first 90 seconds after impact then it would not have been observed; however, we estimate that 14% of the sodium was in shadow during the first 90 seconds. Further analysis will be performed to resolve this issue.

There are water lines in the region of our observations but we saw no change in the water absorption lines before, during or after the impact. Likewise there was no evidence of a dust cloud. We saw no change in polarization before, during or after the impact.

References: [1] Barbieri, C., et al. (2001) *EM&P.*, *85*, 479-486. [2] Hunten, D.M. (1991) *Journ. Geophys. Res.*, *18*, 2101-2104. [3] Hunten, D.M. et al. (1998), *Icarus*, *136*, 298-303. [4] Verani, S, et al. (2001), *MNRAS*, *327*, 244-248. [5] Crider, D. and R. Vondrak (2000), *Journ Geophys Res. 105*, 26773-26782.