LCROSS from the Lunar Diviner Instrument

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Definition

On October 9, 2009, the Lunar Crater Observation and Sensing Satellite (LCROSS) performed a controlled impact into one of the coldest places on the Moon, where several instruments onboard the Lunar Reconnaissance Orbiter (LRO) and ground-based telescopes observed the impact dynamics and subsequent chemistry from the ejecta plume.

Mission Objectives

In 2009, the LCROSS controlled impact event occurred near the center of one of the coldest regions of the Moon, in Cabeus crater (~ -81.5°) (Colaprete et al. 2010; Paige et al. 2010a). LCROSS was designed as a Centaur rocket to strike the Cabeus persistently shadowed region (PSR) of the lunar south pole, ejecting debris, dust and vapor (Hayne et al. 2010). The LRO Diviner and other instruments observed the impact through a suite of instruments, including cameras, radiometers, and spectrometers. Diviner includes two broad-band solar reflectance channels, three mineralogy channels, and four thermal channels (Paige et al. 2010b; Donaldson et al. 2012).

The LRO orbit was modified to mainly observe the impact event at the closest approach at ~ 90 s after impact, but also to protect the spacecraft from the subsequent impacting even (Hayne et al. 2010). LRO also rolled ~81° to allow the Lyman Alpha Mapping Project (LAMP) to view the Cabeus crater lunar limb (Hayne et al. 2010, Hurley et al. 2012). It is noted that the LRO Diviner instrument is independent of spacecraft attitude with instrumental actuators, enabling prime targeting even when in an oblique point of view (with an emission angle of 48° and pixel size of ~ 400 m; Hayne et al. 2010).

The LCROSS target site at Cabeus crater was selected from a variety of criteria (Colaprete et al. 2010). While topographic data and its orientation to the Sun made Cabeus a prime target (Noda et al. 2008; McClanahan et al. 2009; Teodoro et al. 2009), the two main selection site defining criteria were the altitude at which ejecta would be illuminated by sunlight and detection of hydrogen from elevated levels as per previous measurements made by the Lunar Prospector Neutron Spectrometer (LPNS) and the Lunar Exploration Neutron Detector (LEND) (Feldman et al. 1998; Mitrofanov et al. 2010). Based on the comparatively low latitude of Cabeus crater and a cleft in the crater rim topography on the sunward side, the height required for the debris to reach sunlight (and thus start notable spectral and impact dynamic measurements) was 833 m (Colaprete et al. 2010). Another reason for this crater selection was the impact was at the lunar south pole and a PSR with temperatures less than 50 K (average temperature ~37 K from thermal models) (Paige et al. 2010a), which is a prime location for cold-trapped volatiles.

Impact Dynamics

Ejecta dynamics of the impact prior to the designated LCROSS impact event were predicted through scaling laws and computational modeling (Schultz 2006; Heldmann et al. 2007; Shuvalov and

Trubetskaya 2008), and experiments (Schultz 2006, 2010; Hermalyn et al. 2010). From laboratory settings, ejecta velocity decreases with increasing time after impact (Hermalyn et al. 2012, Strycker et al. 2013). From this, slower particles in the high-angle plume are inferred to originate at greater depths than those of faster particles. This is important for determining excavated materials when deciphering Diviner radiometer and spectral measurements.

The Centaur impacted the surface in a rare vertical impact at 85± 5° from horizontal, resulting in a non-standard projectile with an extremely low density and low impact velocity was not a true hypervelocity impact (compared to natural planetary events or the Deep Impact mission) (Hermalyn et al. 2012; Henderson and Blume 2015). The unique aspect of this projectile dynamic was that the peak shock pressures were insufficient to cause shock heating and melting of the target (Hermalyn et al. 2012). From this, it has been noted that the material properties of the lunar surface impact site would further reduce the peak pressure and ejecta dynamics (e.g., more compressible or porous materials).

Ejecta Plume Chemistry from Diviner

Diviner's multispectral thermal infrared measurements of the LCROSS event provided clues into the energy dissipation and cooling during a planetary impact, specifically in a region where there are cold-trapped volatiles (Watson et al. 1961; Zhang and Paige 2009; Hayne et al. 2010).

Diviner observed a layer a few millimeters thick heated to an initial temperature of 1000 K and a hydrogen vapor cloud by LAMP (Gladstone et al. 2010; Killen et al. 2010). From Hayne et al. (2010), these temperatures desiccate the regolith nearly instantaneously, though sublimated water molecules show a more gradual flux as the thermal wave propagates downward. Spectral signatures of hydroxyl radical (OH) were also detected at the initial impact release (Colaprete et al. 2010).

Following the initial plume was a detection of water ice grains and OH that continued to sublime (Colaprete et al. 2010, Hayne et al. 2010). The OH may have been produced through the photodissociation of water vapor or desorption of OH from the water ice grains (Fraser et al. 2001; Noble et al. 2012). Colaprete et al. (2010) notes the interesting chemical ratios in the preliminary analyses of the volatiles to be more abundant than ratios found in predicted gas-gas reactions in the protoplanetary disk (Fegley 2000) and comets. The PSR within Cabeus could enhance such abundances compared with water due to molecular formation on cold grain surfaces, where the reservoir of volatiles that LCROSS impacted may have been partly of cometary (or asteroidal) origin (Colaprete et al. 2010; Sinitsyn 2011; Berezhnoy et al. 2012). The surface temperature measured by Diviner decreased to ~600 K at 90 s after impact, this release temperature (and flux thereof) is also important for the detection of sodium vapors, which was also observed by ground-based telescopes (Killen et al. 2010).

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