The Final Minute: Results from the LCROSS Solar Viewing NIR Spectrometer

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KISS: New Approaches to Lunar Ice Detection and Mapping
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On October 9, 2009 the Centaur (2300 kg) impacted at 2500 km/sec inside of Cabeus.
- Was a secondary, mission of opportunity launched with LRO.
- Used four-month cruise to bake-out and “decontaminate” Centaur.
- Impacted within 100 meters of planned target.

Impact observed by an armada of observatories.
- Two best seats in the house were LCROSS Shepherding SC and LRO.
- Final impact site and high levels of terrestrial water (over Hawaii) made Ground-based observations difficult.
The LCROSS Impact Site

Key Characteristics of the LCROSS Impact Site

• **Dark**: In Persistent Shadow

• **Cold**: Diviner places temperature around 40 K (annual average around 70 K)

• **Significant neutron depression**: One of the strongest (if not the strongest) at the south pole

• **Topography**: Possibly “double-shaded” - NIR images and LOLA topography shows depression which corresponds to low temperatures

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The LCROSS Impact Site

LCROSS NIR Observations of Cabeus

Centaur impact Site

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1 sec ≤ Impact ≤ 3 sec

- First ejecta seen in UV-Vis and NIR spectra
- Fastest eject moving at \(\sim 800 \text{ m/s} \)
- Extensive thermal signature

Impact + 1 sec

Impact + 3 sec

Impact + 5 sec

Impact + 7 sec

Hermalyn et al., 2012

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Schultz et al., 2010
Impact + 3 sec

- No visible flash seen in flash radiometer or UV-Visible Spectrometer
- NIR flash had a slow rise time
- Consistent with LRO LAMP observations

Total NIR Radiance vs. Time

Schultz et al. 2010

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LCROSS Observations

UV/Vis

Radiance (W m^-2 str^-1)

Time Relative to Impact (sec)

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LCROSS Observations

Impact + 3 sec

- First ejecta seen in UV-Vis and NIR spectra (eject speeds ~800 m/s)
- Compounds seen in florescent emission in near-UV/Vis, including Na, OH, and Ag

Schultz et al. 2010

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3 sec ≤ Impact ≤ 180 sec

- Curtain expansion and peak of visible radiance: A tale of two plumes
- Peaking brightness marked by bluing of spectra
- Early water ice detection
- Continued evolution of volatiles, water vapor band begins to strengthen

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Colaprete et al. 2010
Summary of Observations

Long lasting and sustained water

- Nadir water measurements show strengthen water band with time suggesting persistent water cloud
- Ultraviolet OH emission more “prompt” rather than “florescent” emission
The Solar Viewing NIR Spectrometer

• LCROSS had two NIR spectrometers: a nadir viewing (NSP1) and a solar viewing (NSP2)
  ➢ Had identical wavelength ranges and resolutions
  ➢ Solar viewer used a diffusor to observe sun during the descent to the surface

• Diffusor was very lambertian so could support a range of angles to sun (since exact impact date was not constrained by LCROSS)
  ➢ For the actual impact date the angle between sun and diffusor was relatively small (~ 14 deg) and constant during final moments (changed <3 deg)

• By viewing the sun the spectrometer had very high SNR (>1000)

• Intent was to look for any occultation of sunlight by ejecta cloud

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The Solar Viewing NIR Spectrometer

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The Impact Plume(s)

The High Angle Impact Plume

- Two curtains seen in UV/vis spectrometer (VSP)
- Dust seen at altitudes >4 km by observed by Apache Point Observatory (Strycker et al., 2012)
- Would have to have reach ~12 km to still be falling at Impact+4 min
- Possible dust clouds seen NIR camera images (Schultz et al., 2010)
NSP2 Observation Geometry

- Shepherding SC came down ~3km from Centaur impact site
- Sampled spectra once every 0.6 seconds

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NSP2 Observations

The final moments

- Averaged 5 scans in time and across 11 pixels (moving average) to build SNR
- Ratioed averaged scans to “reference” scan made from spectra taken about 30-40 sec prior to impact

Spectra vs. Altitude Above Surface

Linear Fit to 6 km spectrum

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NSP2 Modeling

- Monte Carlo Simulations of Solar Viewing NIR Observations
- Modeled hemispherical cloud of dust, water ice and water vapor

Fit against water gas column

Fit against ice grain radius

Fit against water ice OD

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Summary of Observations and Modeling

- NSP2 Observed dust + water (ice and gas) cloud in final ~20 seconds of its descent
- Linear and Monte Carlo fits identify water ice and vapor and constrain grain size to > 1 μm
- Water ice grains are relatively pure (ice-to-dust ratio) to persist ~4 min in sunlight
- Total water gas measurements consistent with nadir measurements: A persistent surface source, maybe sublimation from exposed ice?
- The high angle plume likely consisted of material closer to the surface (top 1-2 meters?) compared to low angle plume (Hermalyn et al., 2012)
A Model for the LCROSS Site

One Interpretation:

• A variety of compounds (e.g., Na, Ag, H2, Hg) “plate” out near surface as frost or bound in pour space (e.g., H2)

• Along with water and lack of a thermal cycle (Metzger) these volatiles create a highly porous frost

• At depths below this, water becomes more dominant, but not exclusive

• The concentrations of [H] bearing compounds suggest a non-uniform lateral distribution (Elphic et al., 2010)
  - Ice-rich deposits may be controlled by local conditions, including topography and temperatures on scales of < 1km

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Thank You
NSP2 Linear Fits

1.375225014

3.618636747
NSP2 Linear Fits

0.234409627

0.261712635
The LCROSS Payload

- NIR Spectrometer
- UV/Visible Spectrometer
- MIR Cameras
- NIR Cameras
- Flash Radiometer
- Visible Color Camera
- Solar NIR Spec
- MIR Cameras
- UV/Visible Spectrometer
- NIR Spectrometer