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

Anthony Colaprete

NASA Ames Research Center, Moffett Field, CA,
Anthony.Colaprete-1@nasa.gov

KISS: New Approaches to Lunar Ice Detection and Mapping

7/22/2013

LCROSS – A Mission to Search for Ice

- 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 Spacecraft and Impactor

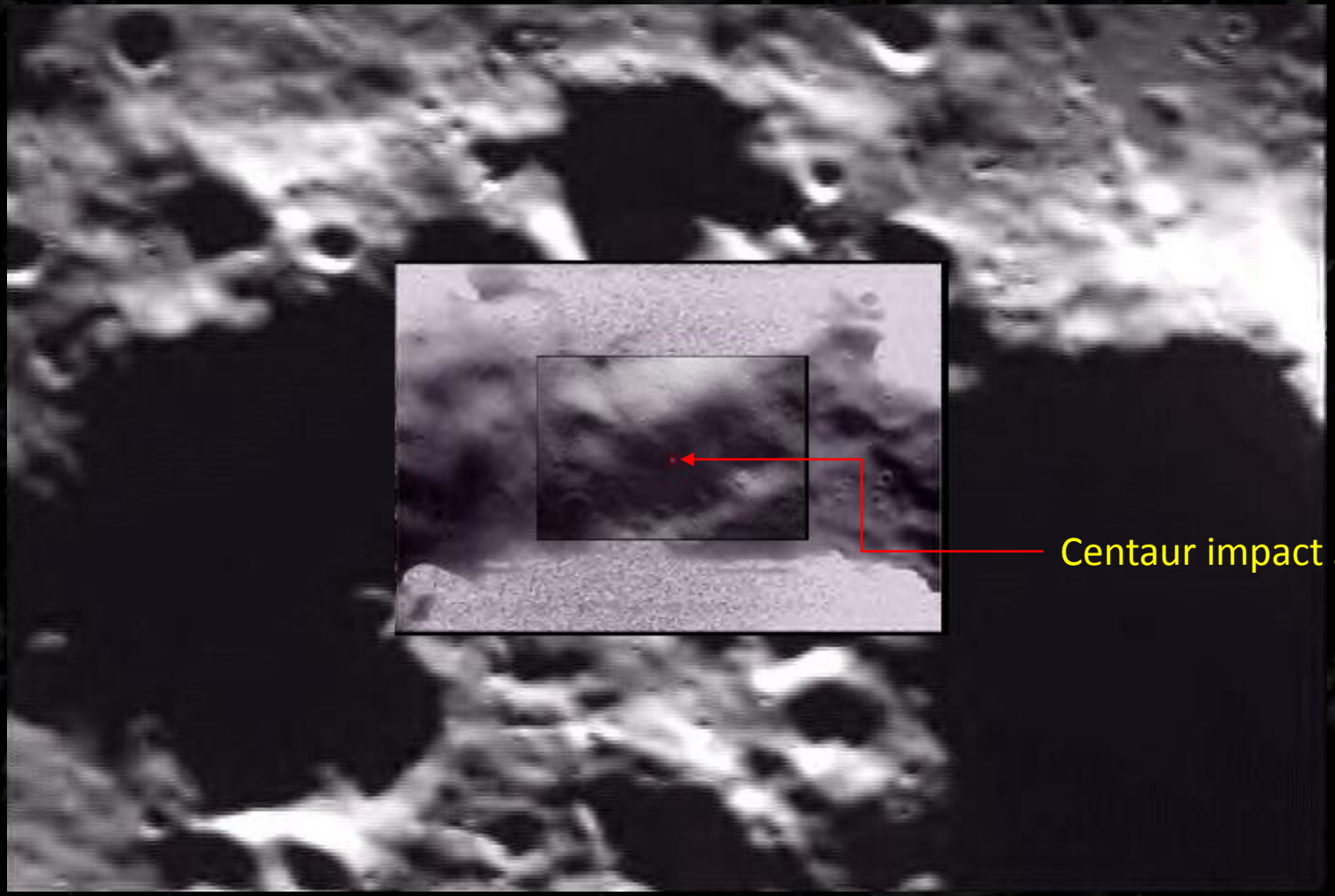
The LCROSS Impact Site

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

The LCROSS Impact Site

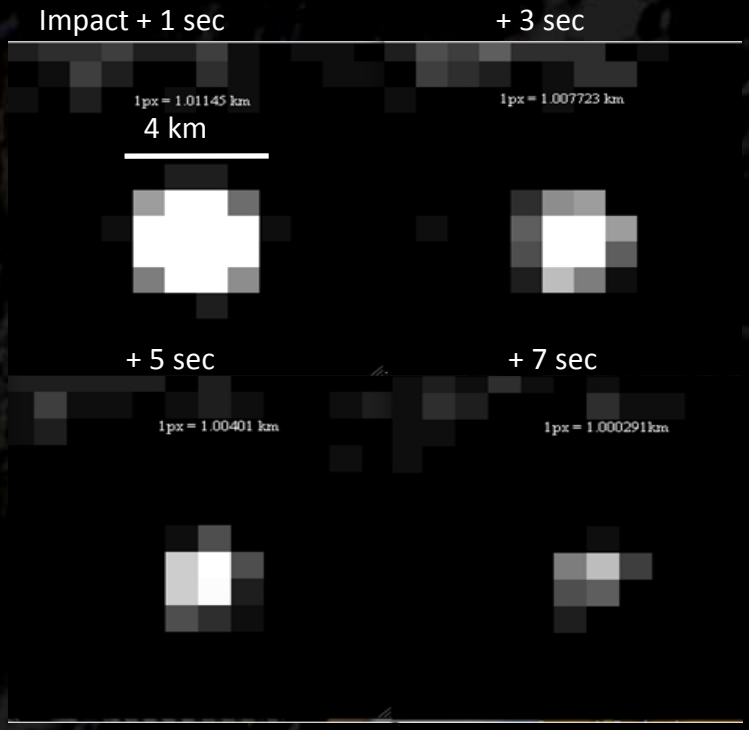
LCROSS NIR Observations of Cabeus

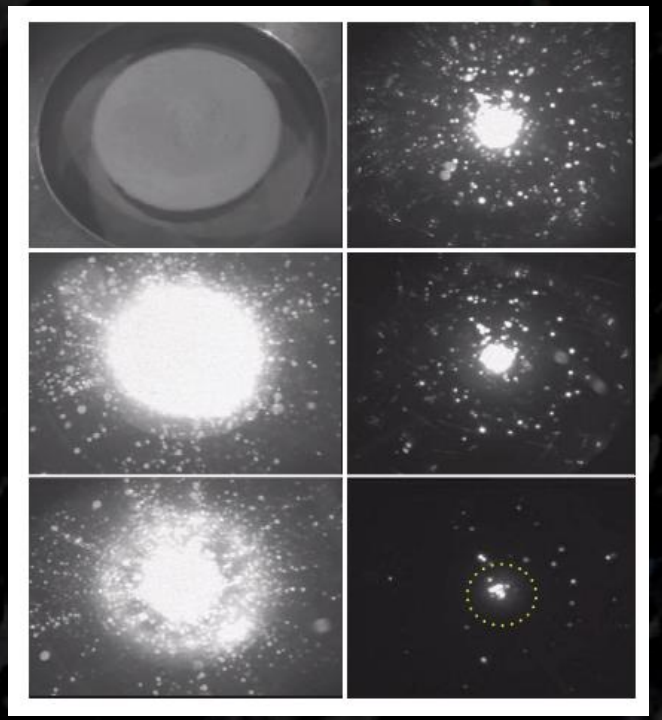


LCROSS Observations

1 sec ≤ Impact ≤ 3 sec

- First ejecta seen in UV-Vis and NIR spectra
- Fastest eject moving at ~800 m/sExtensive thermal signature





Hermalyn et al, 2012

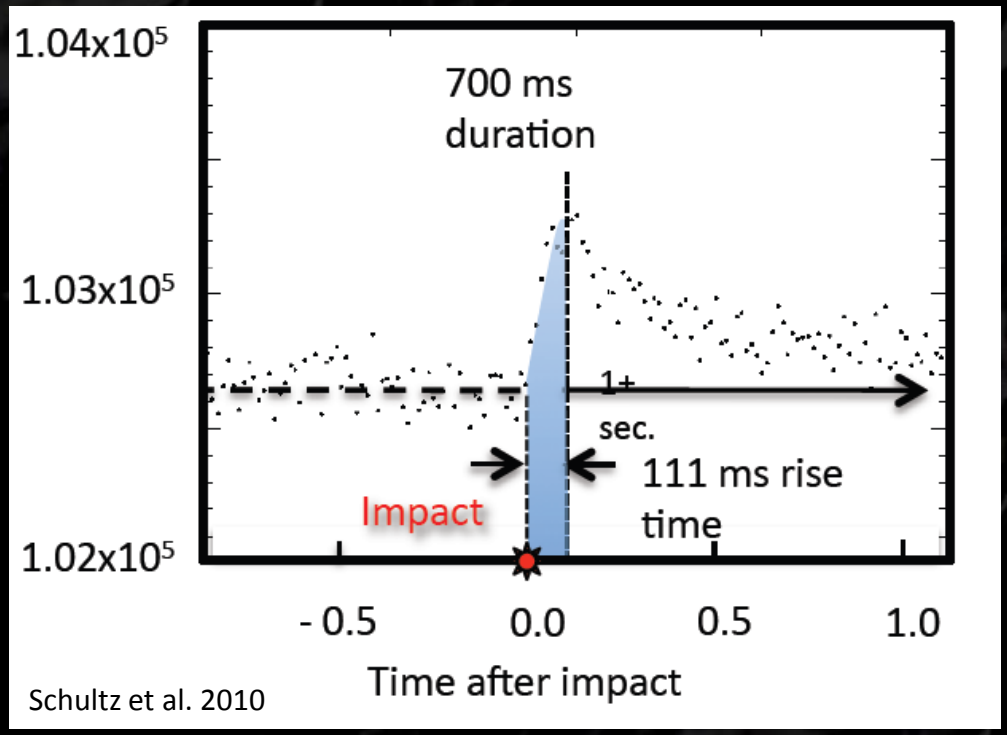
Schultz et al. 2010

LCROSS Observations

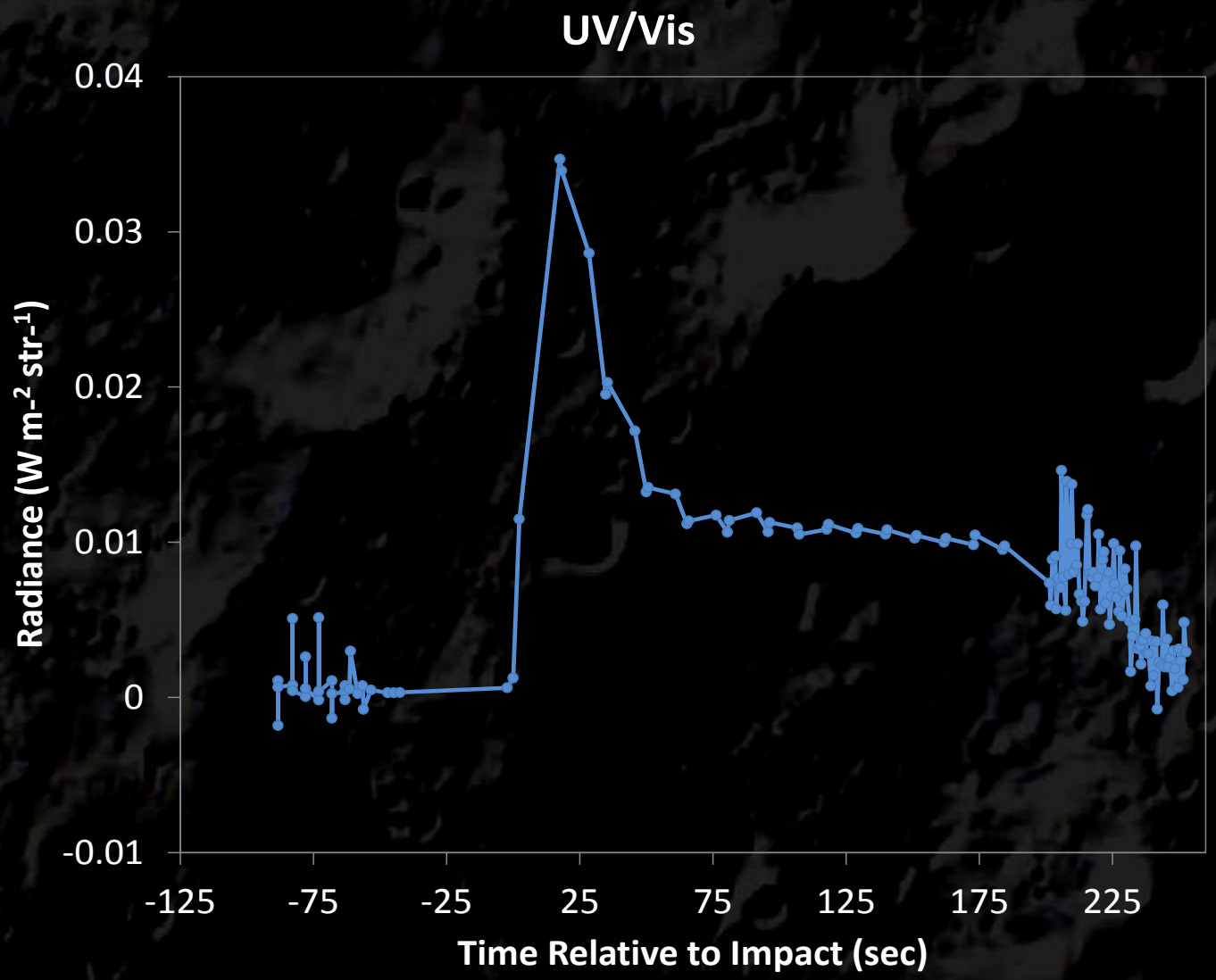
Impact + 3 sec

- 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



LCROSS Observations

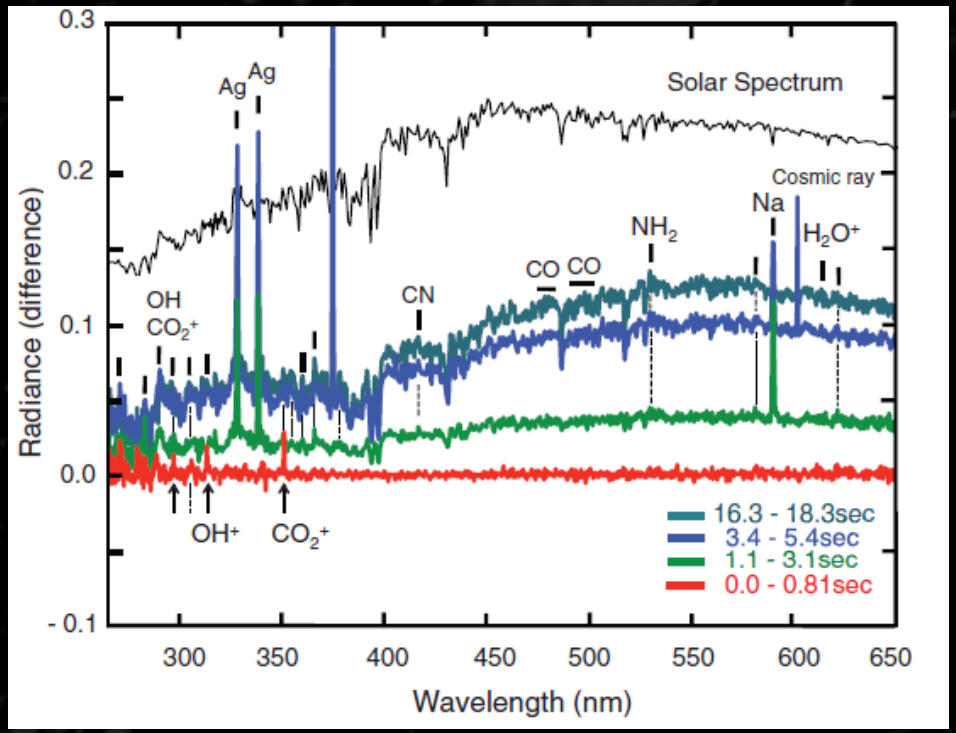


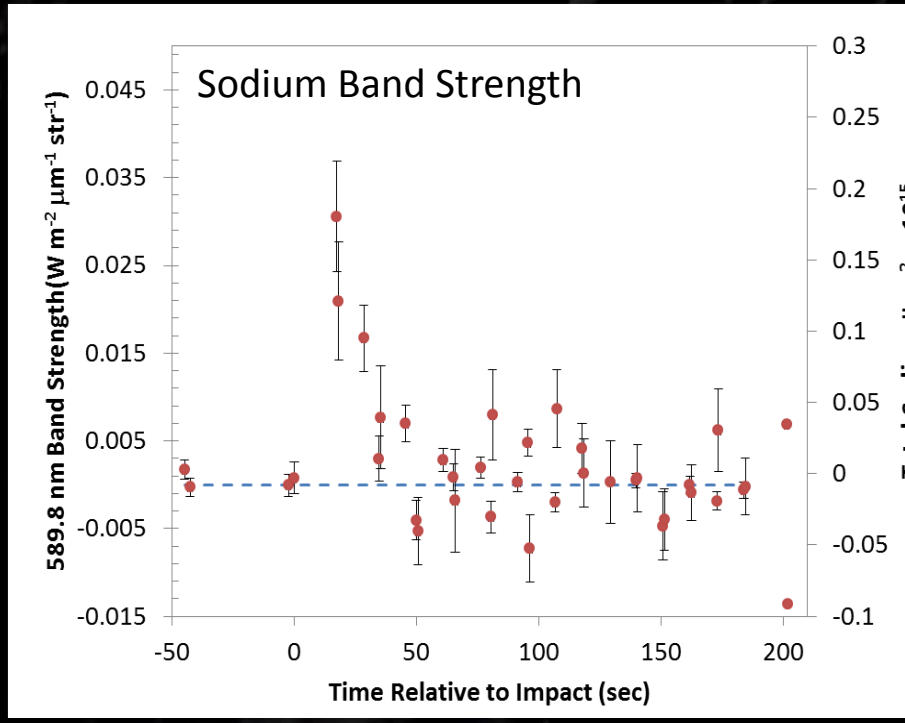
KISS: Lunar Ice Detection & Mapping

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



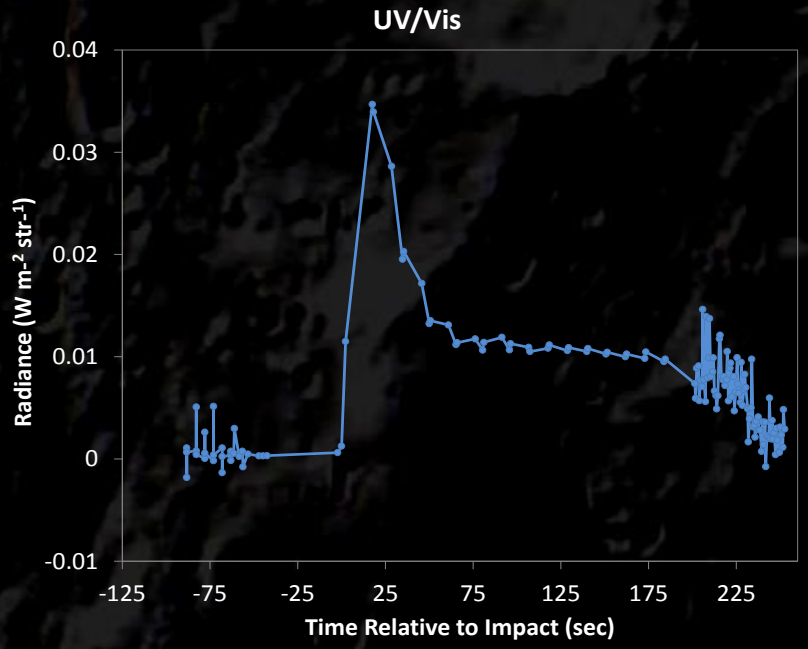


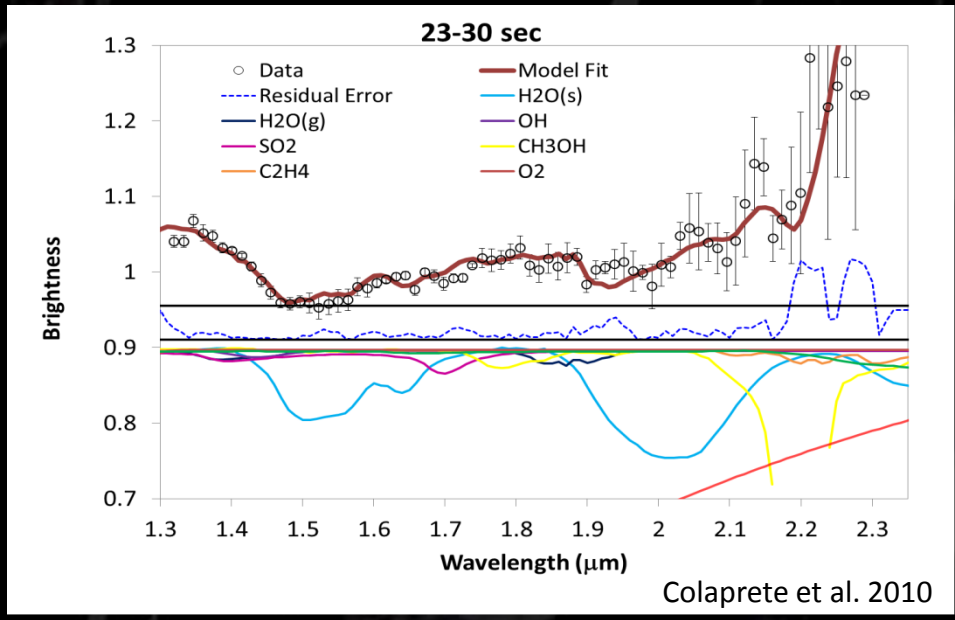
Schultz et al. 2010

LCROSS Observations

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



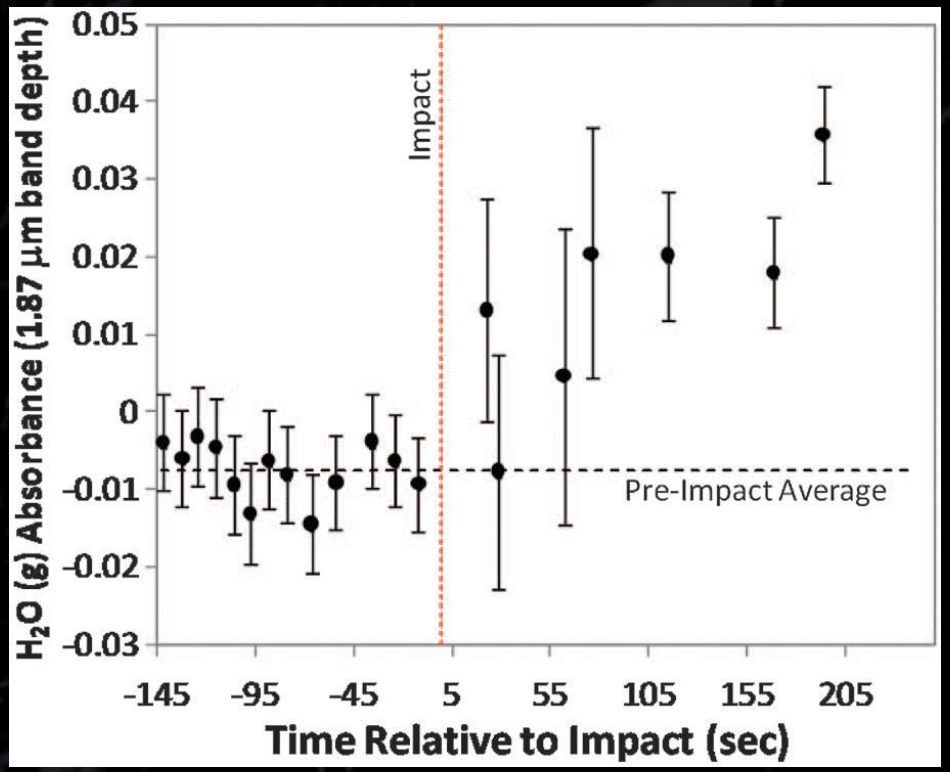


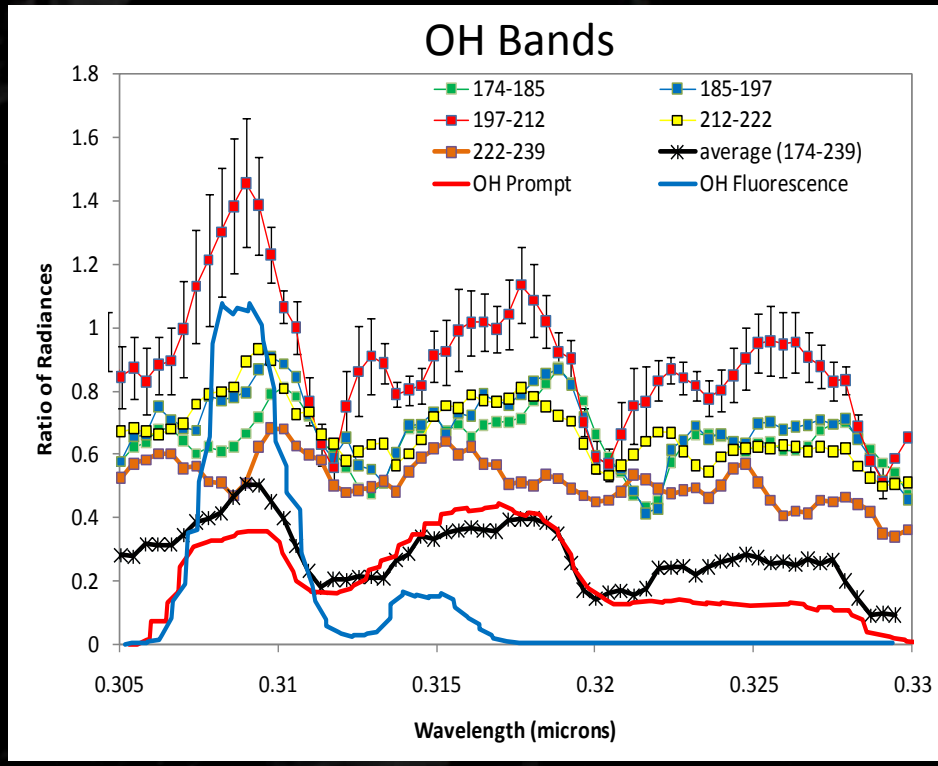
Colaprete et al. 2010

Summary of Observations

Long lasting and sustained water

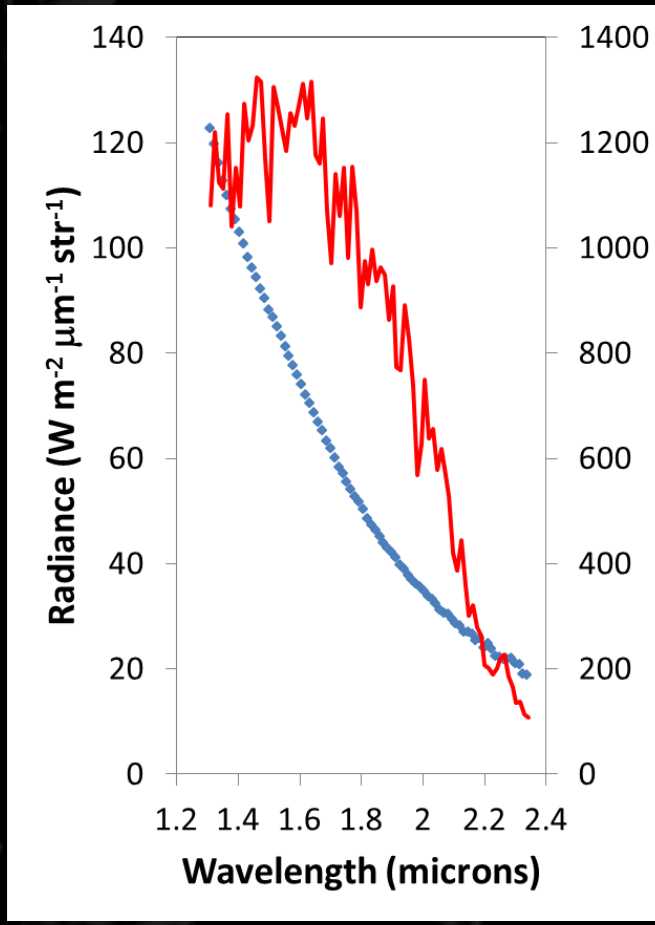
- Nadir water measurements show strengthen water band with time suggesting persistent water cloud
- Ultraviolet OH emission more “prompt” rather than “florescent” emission



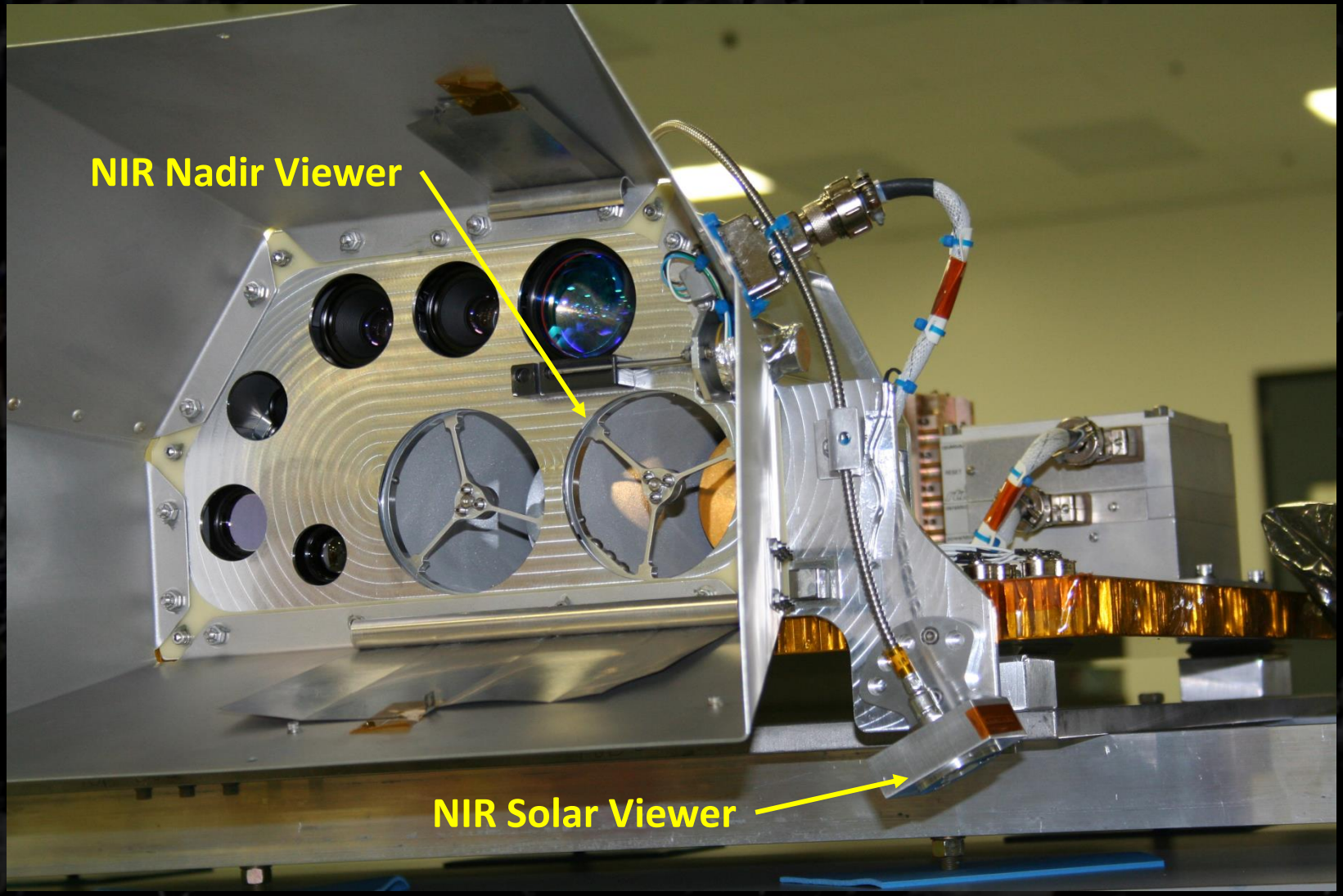


The Solar Viewing NIR Spectrometer

- 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



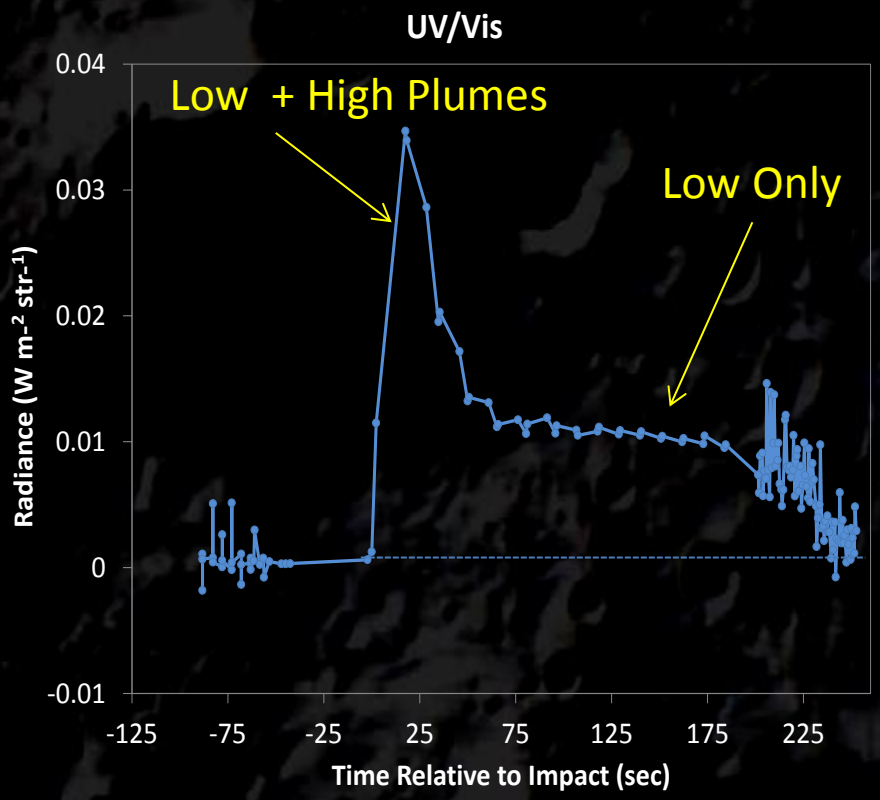
The Solar Viewing NIR Spectrometer



The Impact Plume(s)

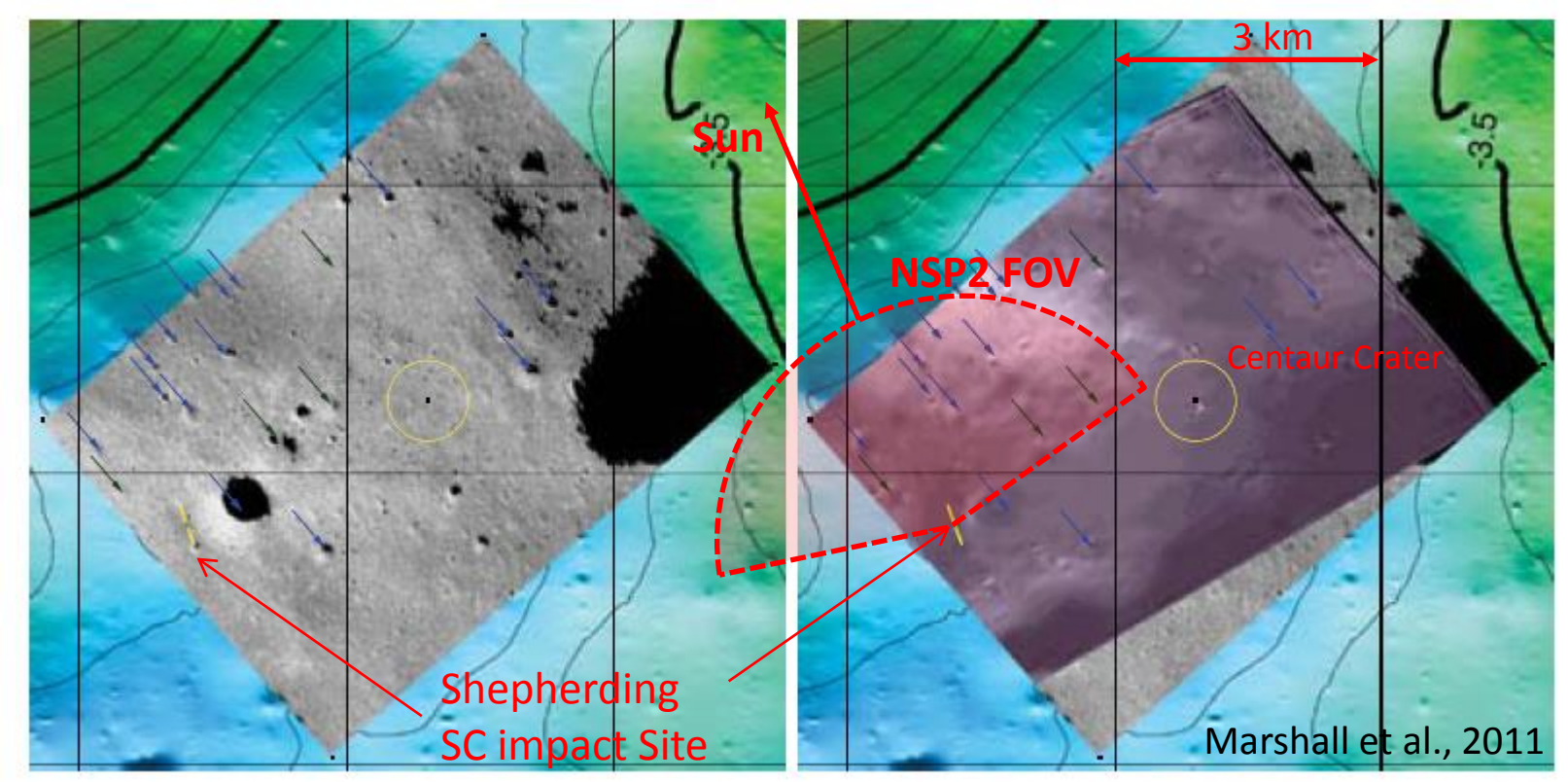
The High Angle Impact Plume

- 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

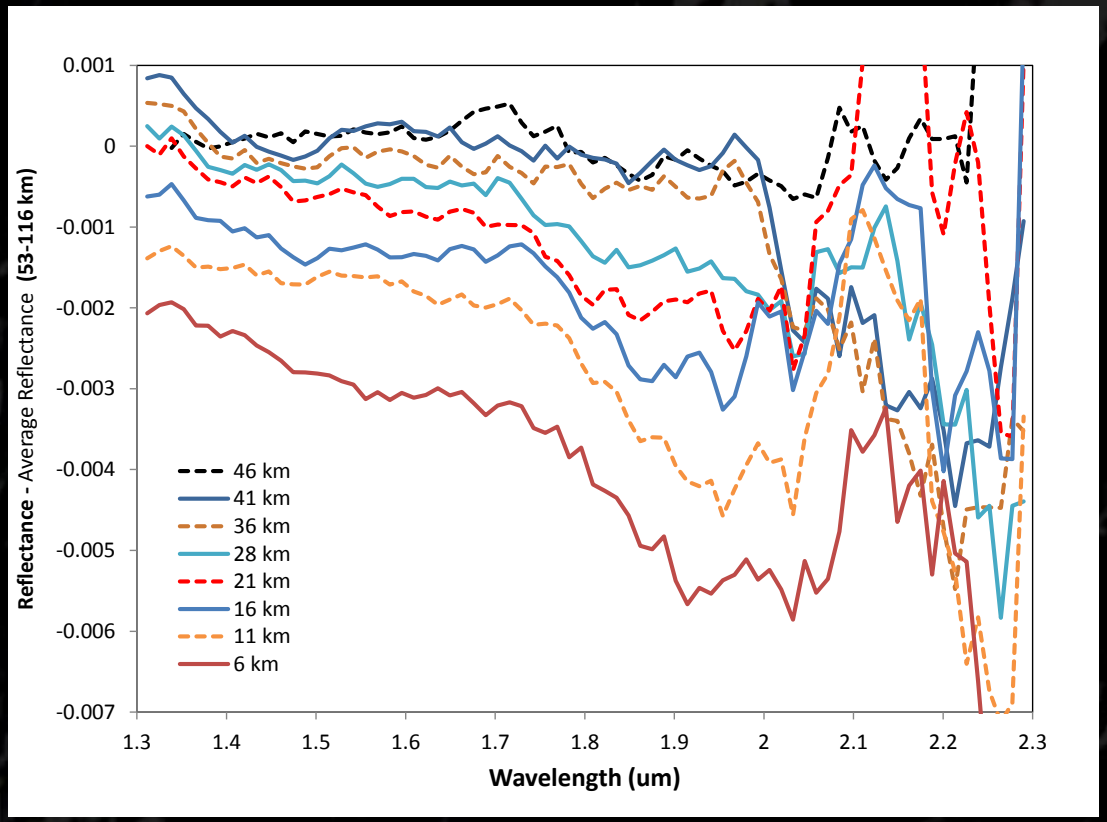


NSP2 Observations

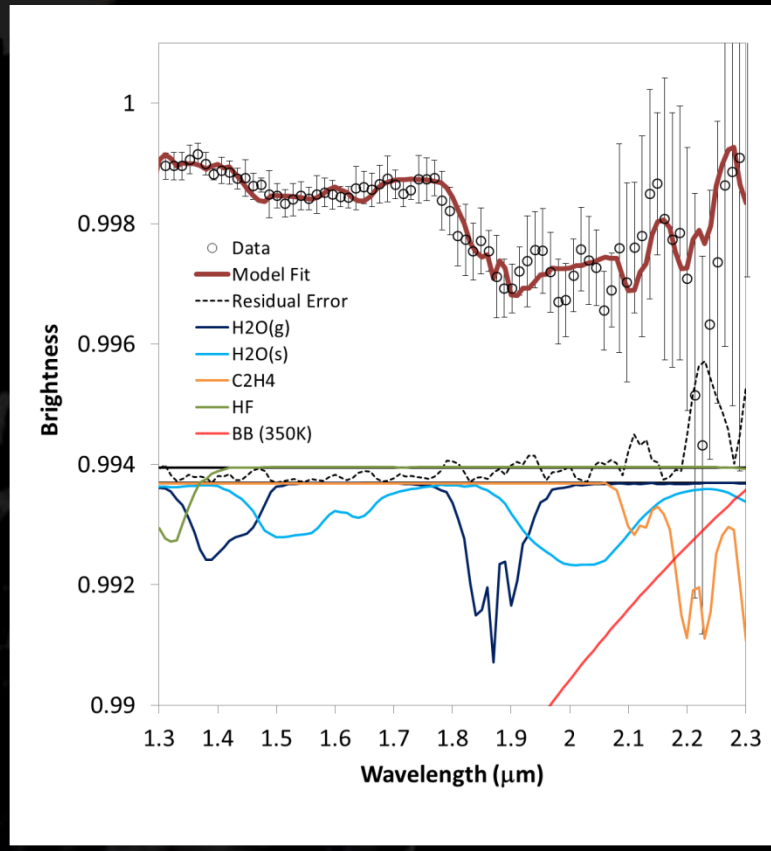
The final moments

- Averaged 5 scans tin 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

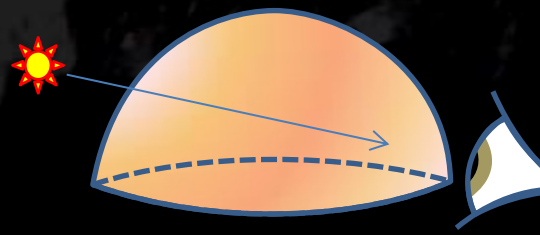


Linear Fit to 6 km spectrum

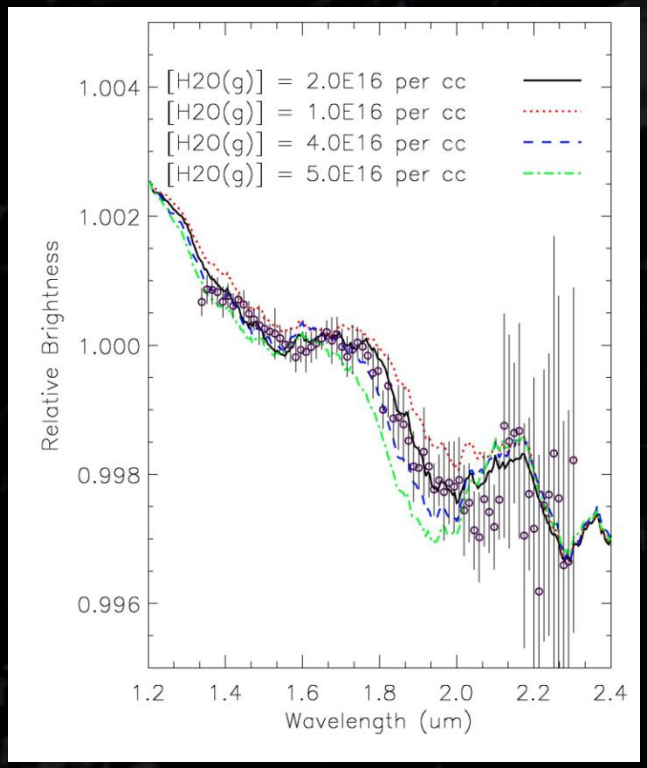


NSP2 Modeling

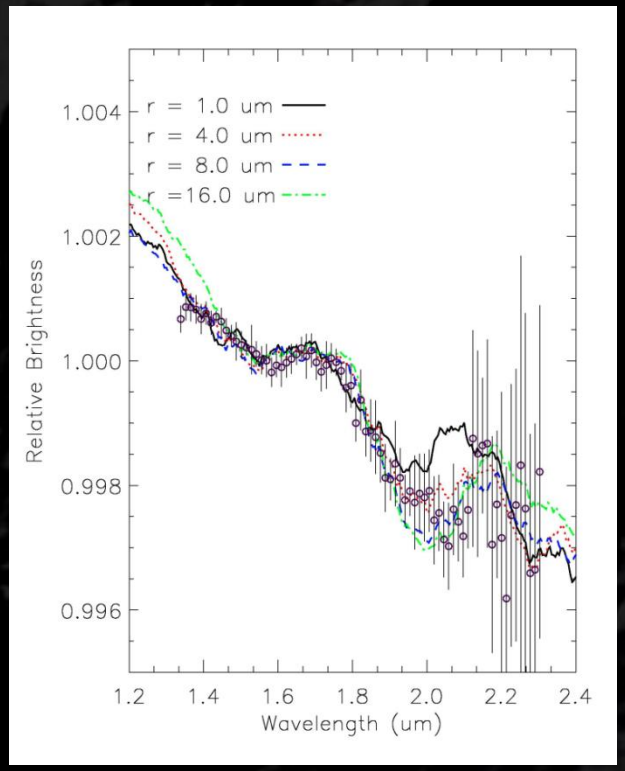
- Monte Carlo Simulations of Solar Viewing NIR Observations
- Modeled hemispherical cloud of dust, water ice and water vapor



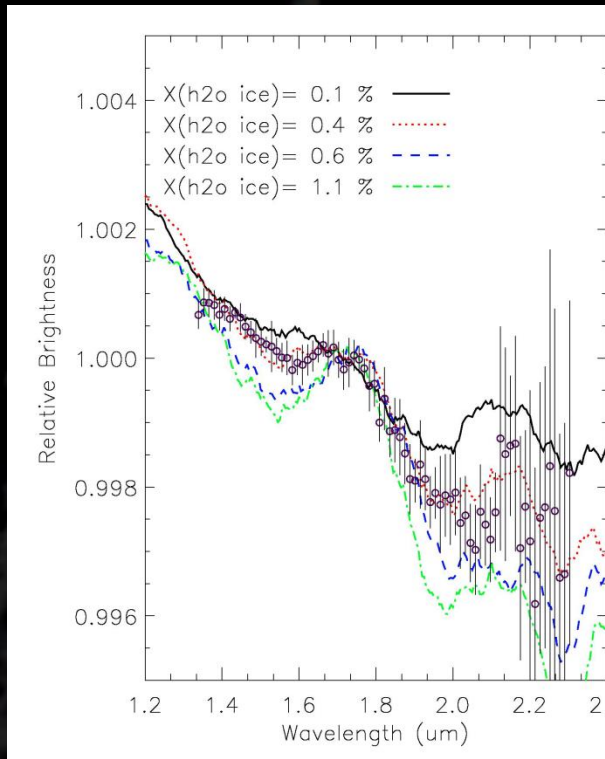
Fit against water gas column



Fit against ice grain radius



Fit against water ice OD



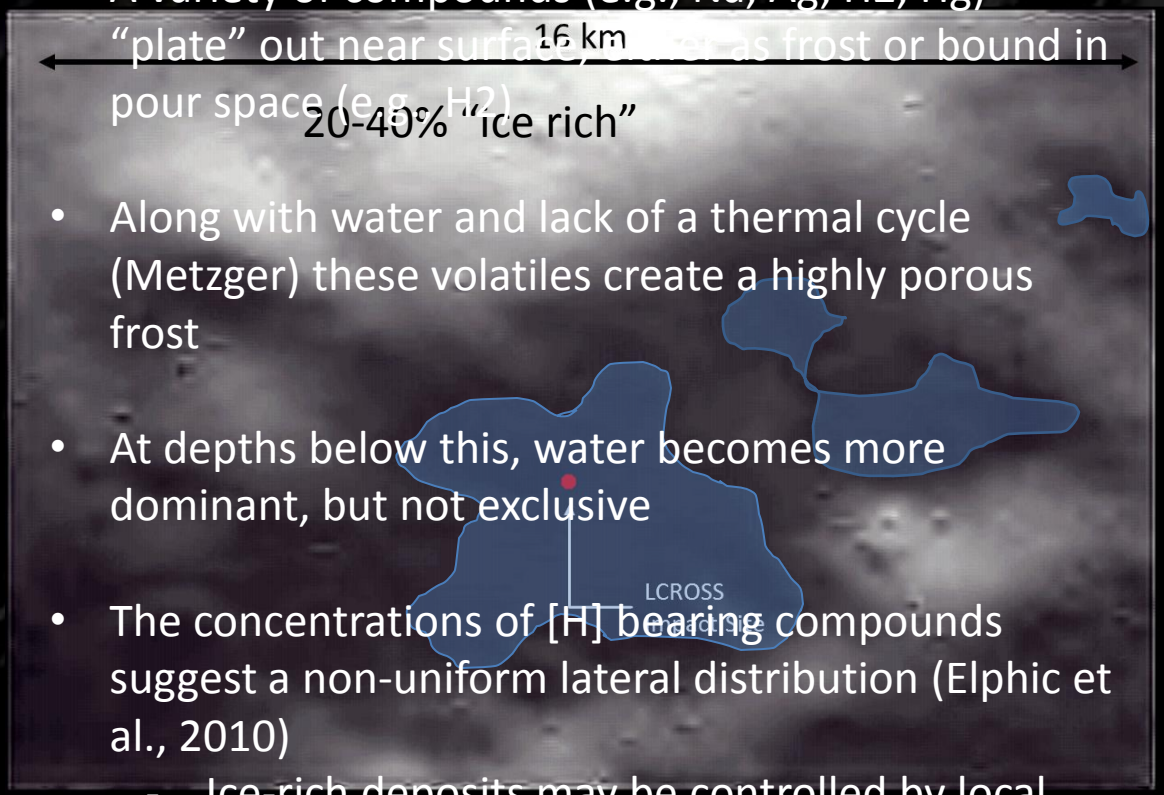
Summary of Observations and Modeling

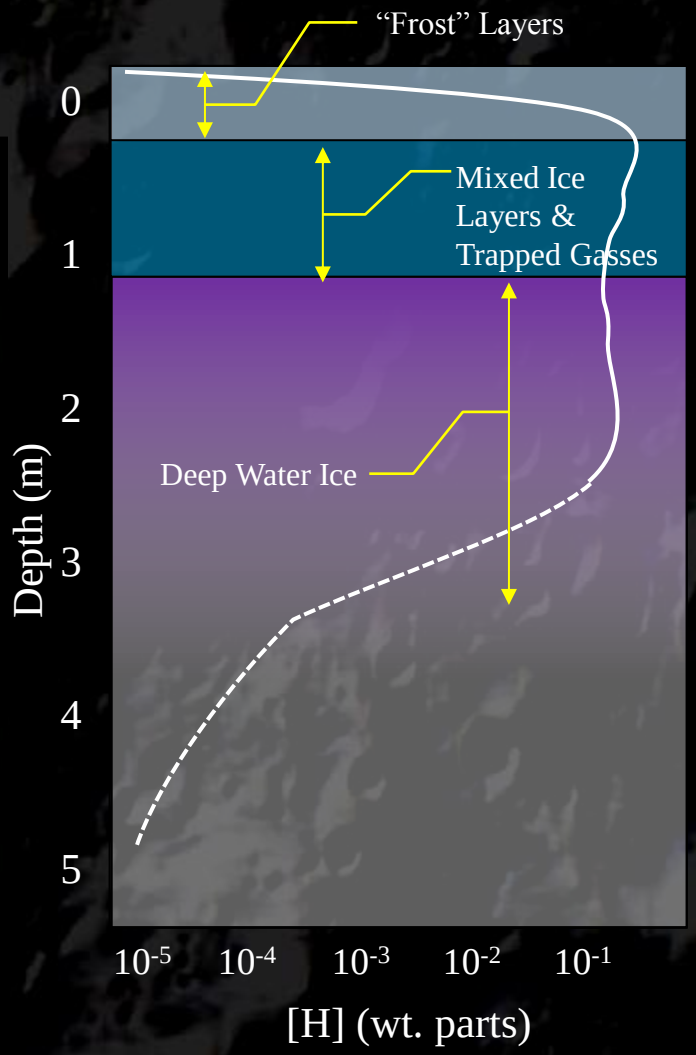
- NSP2 Observed dust + water (ice and gas) cloud in final ~20 seconds of its descent
- Linear and Monte Carlo fits identify water ice and vapor and constrain grain size to > 1 μm
- Water ice grains are relatively pure (ice-to-dust ratio) to persist ~4 min in sunlight
- Total water gas measurements consistent 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, either 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

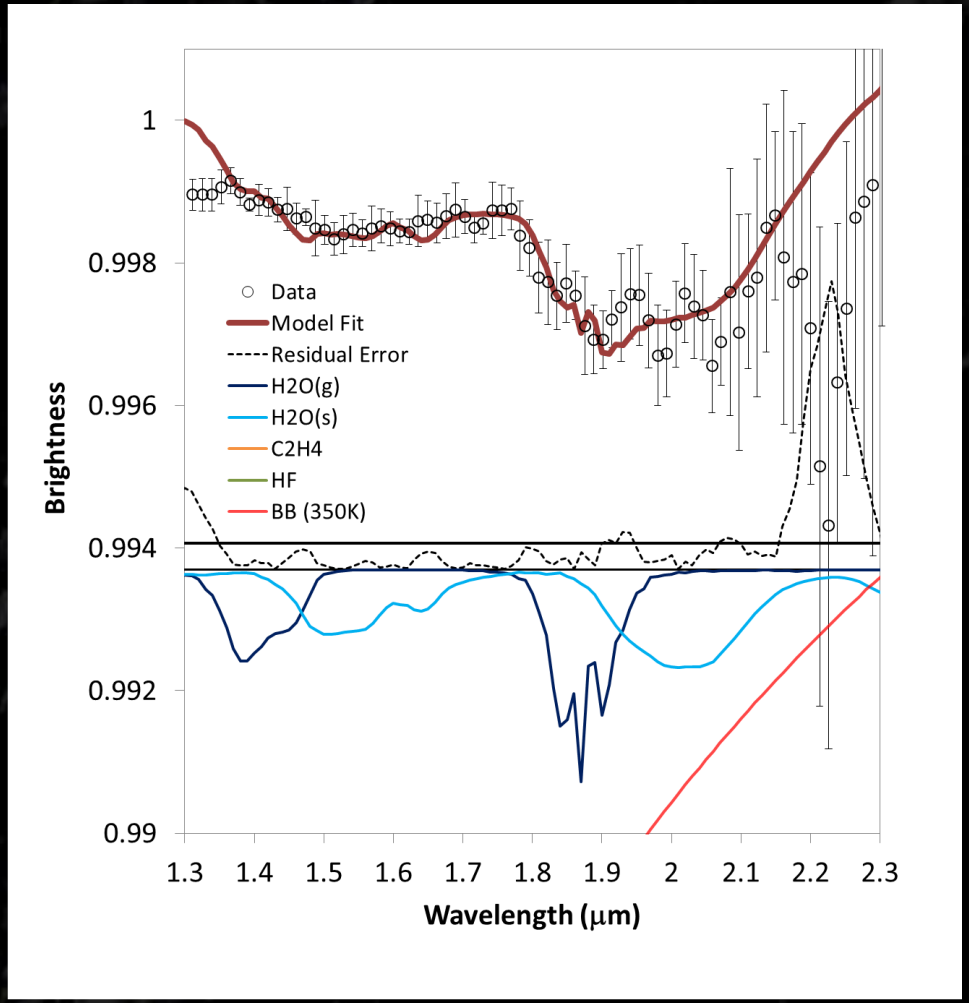




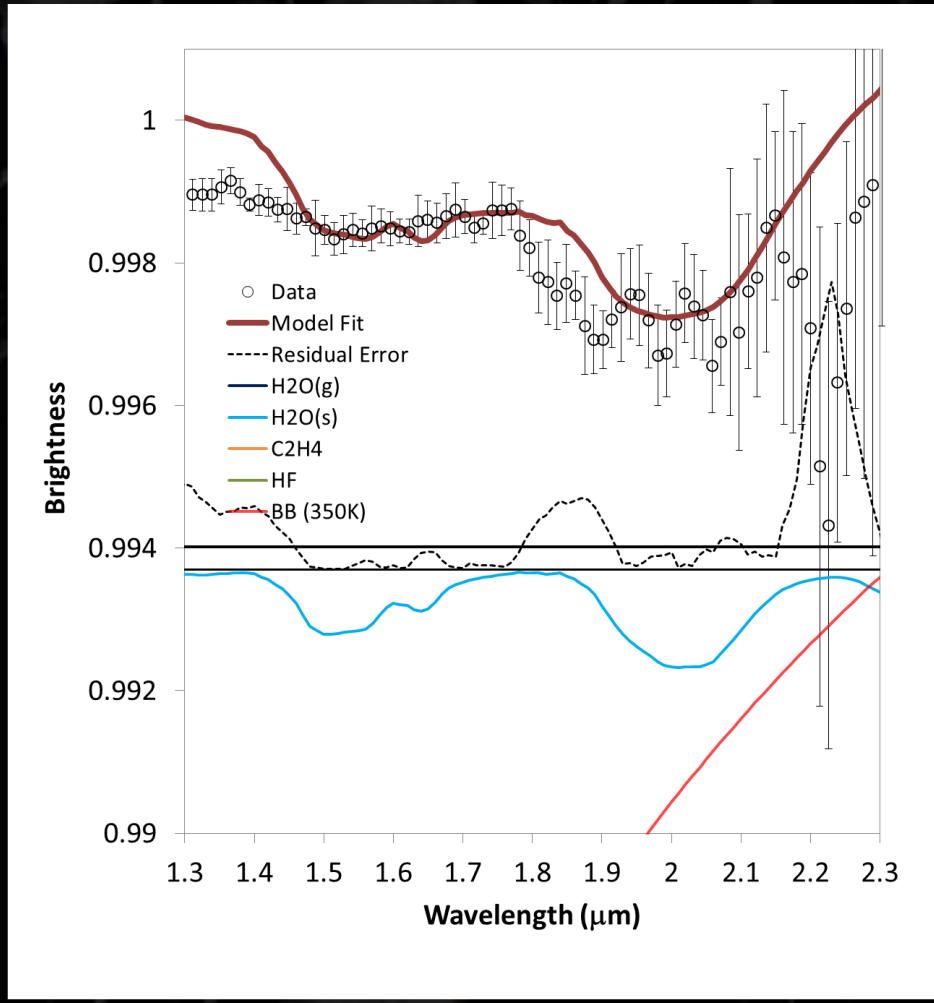
Thank You

NSP2 Linear Fits

1.375225014

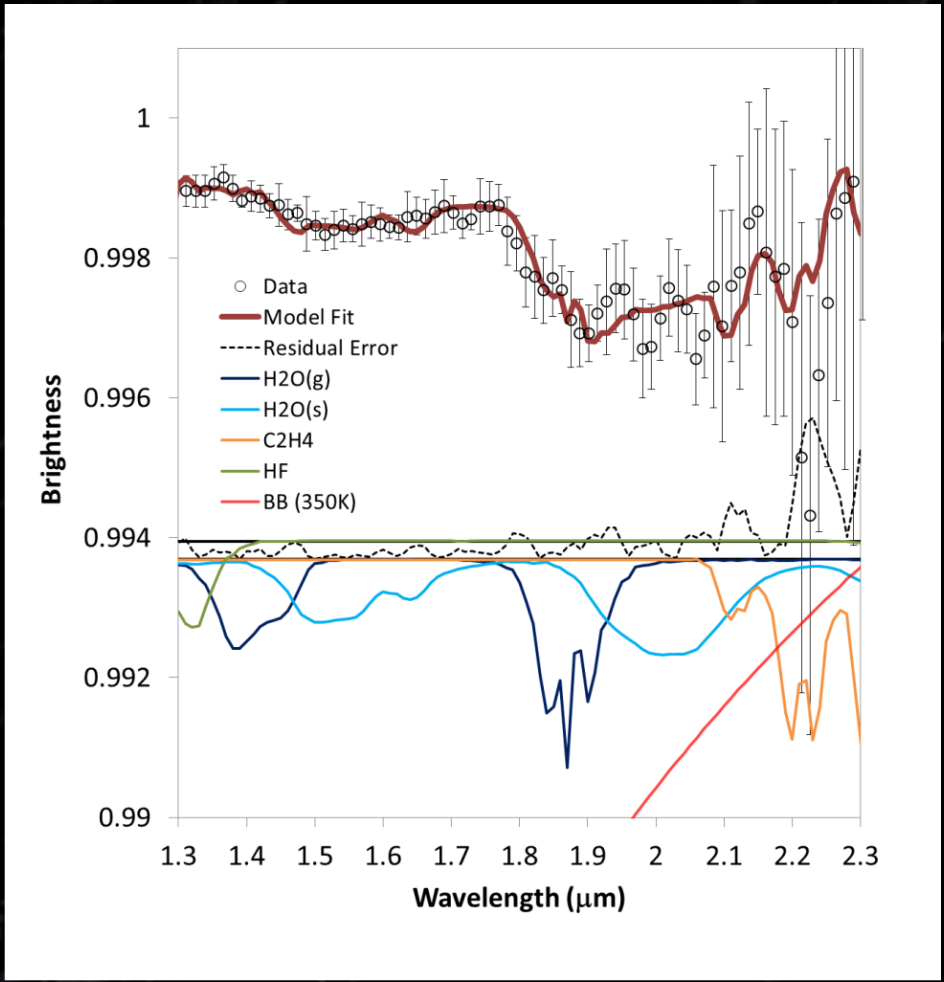


3.618636747

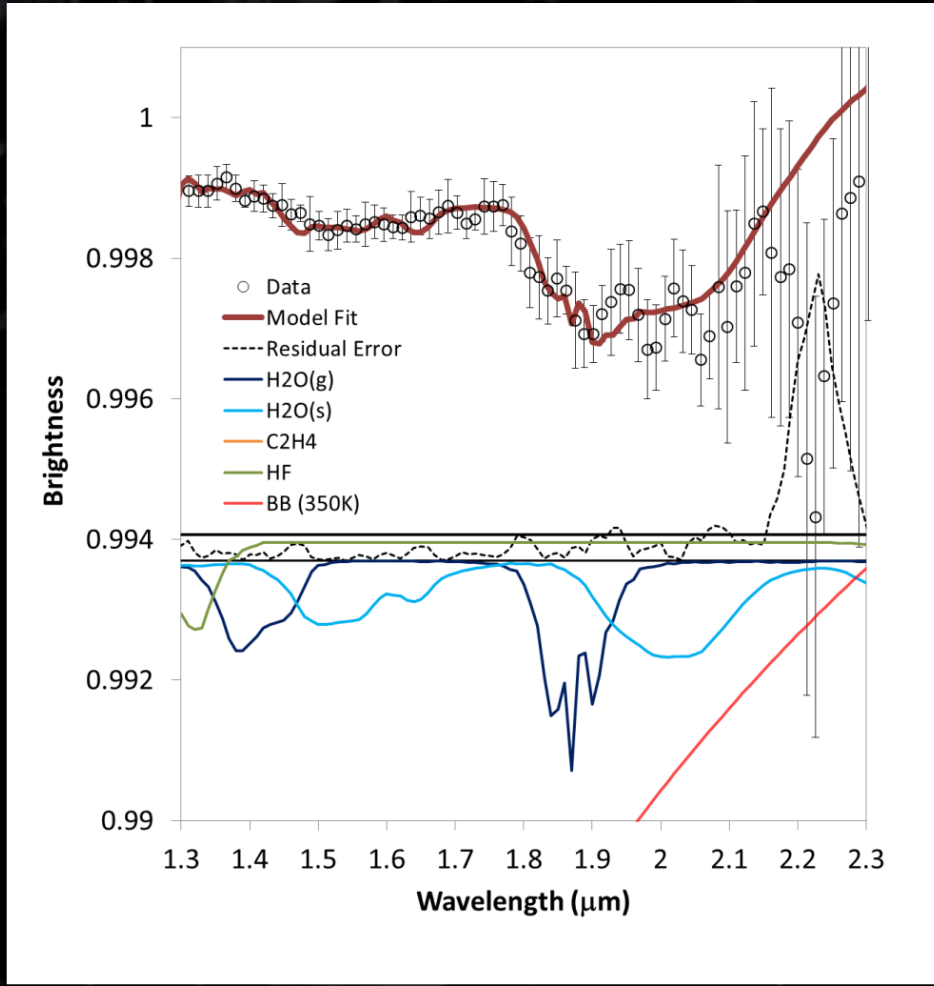


NSP2 Linear Fits

0.234409627



0.261712635



The LCROSS Payload