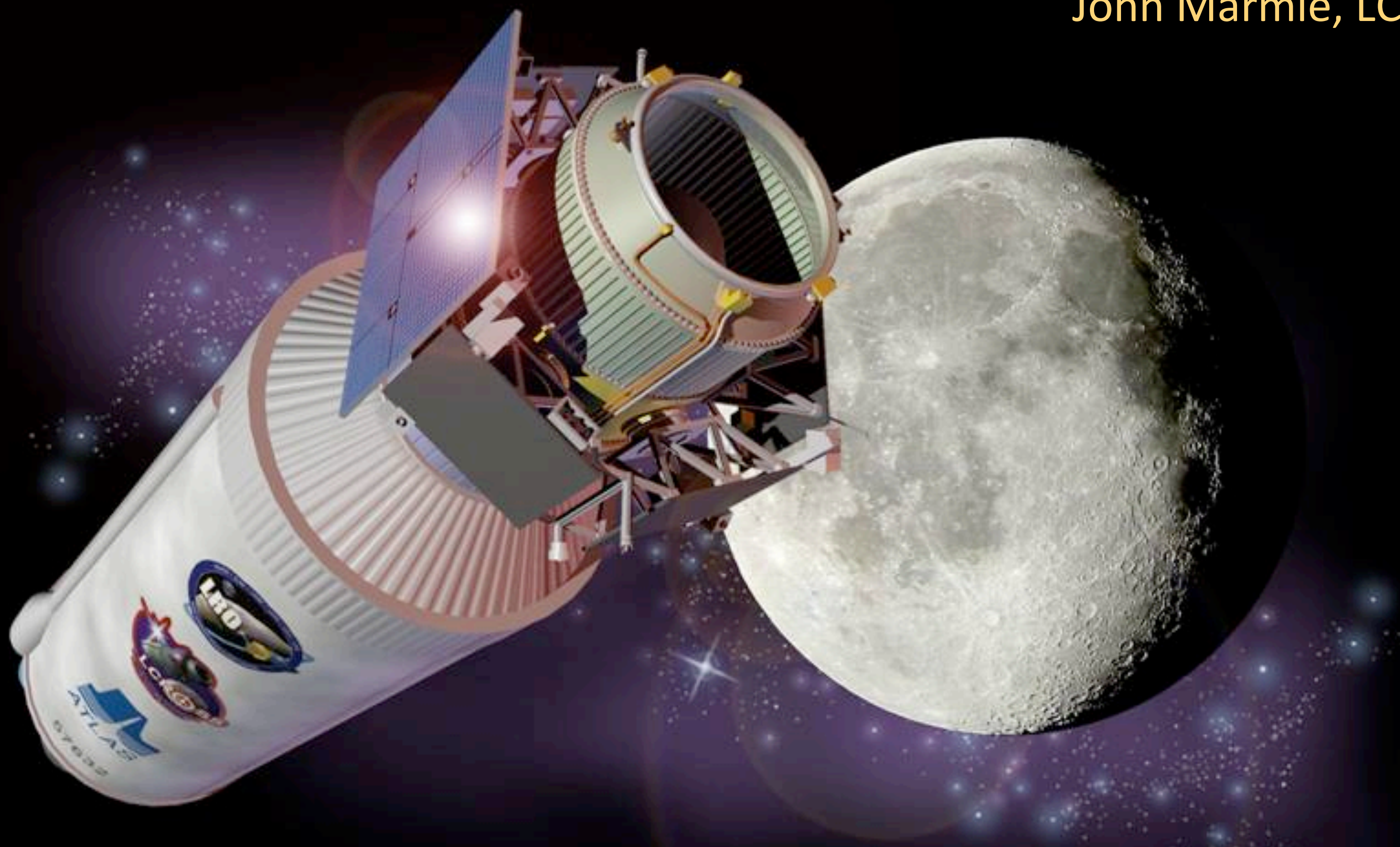
LCROSS

Lunar CRater Observation and Sensing Satellite Project

LCROSS

John Marmie, LCROSS dPM

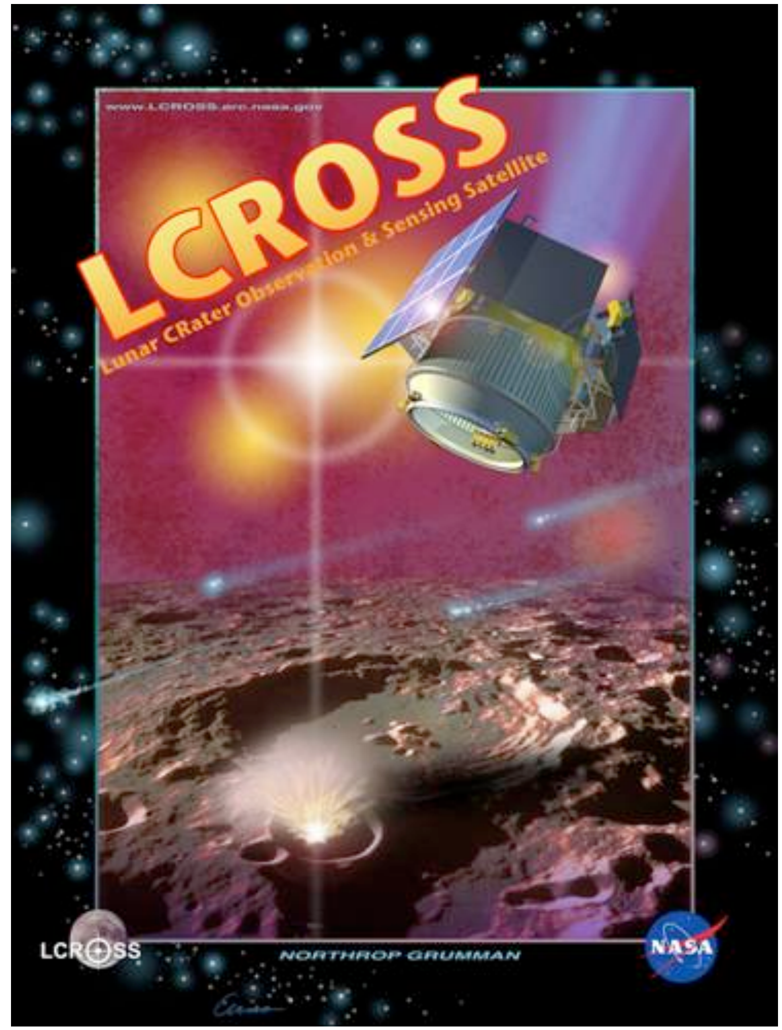


INTERNATIONAL SPACE DEVELOPMENT CONFERENCE 2010

LCROSS: A Mission of Opportunity

- January 2006: ESMD announces a "small secondary payload" opportunity to be launched with LRO
  - *"Given schedule & cost constraints, NASA encourages concepts that have history and heritage… concepts that leverage existing hardware, have high TRL components or that are well studied and documented will be more attractive than concepts that do not"*

- April 2006: ESMD selected the lunar water hunter "LCROSS" from (19) proposals!

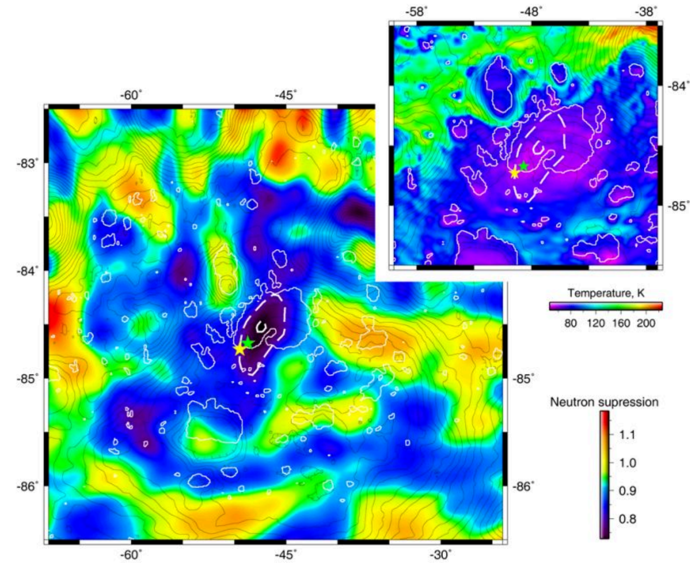


Mission Rationale and Science Goals

The LCROSS mission rational:

- The nature of lunar polar hydrogen is one of the most important drivers to the long term lunar exploration architecture
- Need to understand Quantity, Form, and Distribution of the hydrogen
- The lunar water resource can be estimated from a minimal number of “ground-truths”
- Early and decisive information will aid future ESMD missions

LEND Neutron Depletion



Mitrofanov et al, 2010

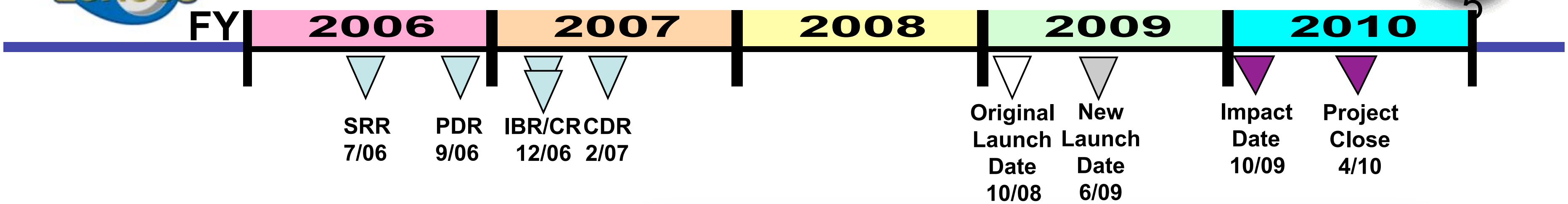
The LCROSS mission science goals:

1. Confirm the presence or absence of water ice in a permanently shadowed region on the Moon
2. Identify the form/state of hydrogen observed by at the lunar poles
3. Quantify, if present, the amount of water in the lunar regolith, with respect to hydrogen concentrations
4. Characterize the lunar regolith within a permanently shadowed crater on the Moon

Project Constraints

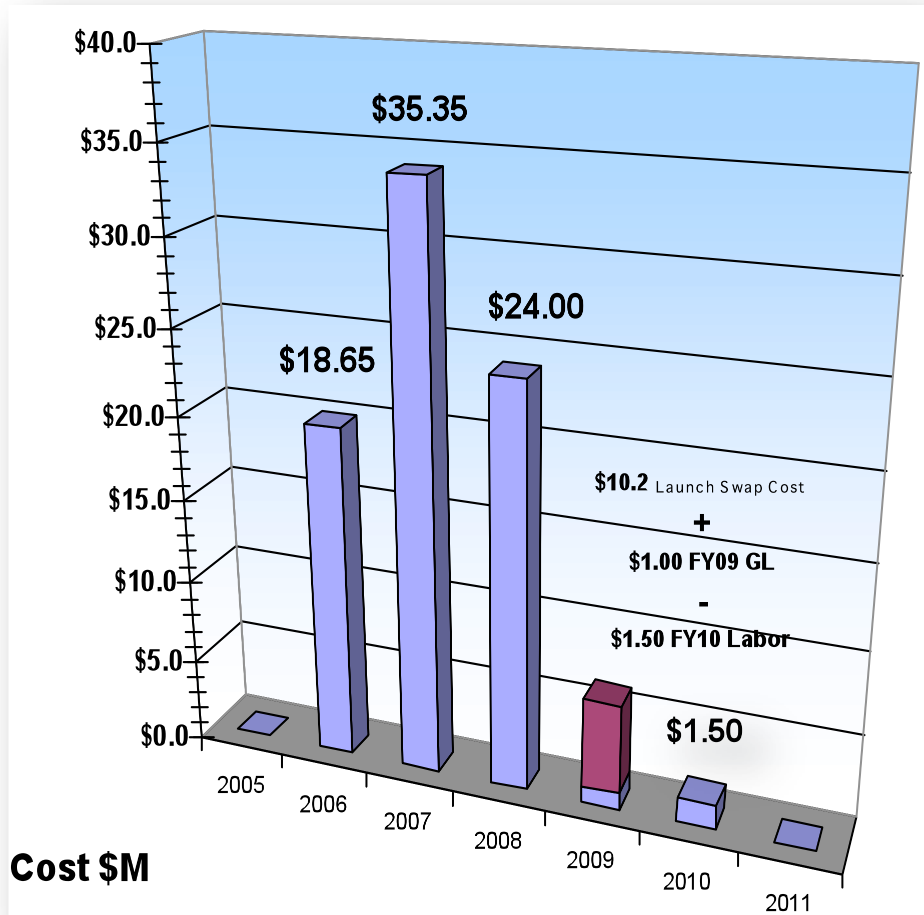
- LCROSS Project Constraints
  - Independent variables:
    - **Safety:** Same as Class A, per NPD 8700.1
    - **Cost-Capped:** $79M cost cap (including margin)
    - **LV Mass-limited:** 1000kg *(including adaptor)*
    - **Schedule-Constrained:** 31mo development)
  - Dependent variables:
    - **Scope:** Full vs. Minimum Success Criteria
    - **Risk Position:** Class D (NPR 8705.4), Category III (NPR 7120.5C)
      - NPR 8705.4 states, "Medium or significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted"
    - **Testing:** Qualification, Acceptance, and Proto-flight Testing
      - NPR 8705.4 states, "Testing required only for verification of safety compliance and interface compatibility". Acceptance test program for critical performance parameters

Annual Dollar Guideline



Guideline by Center

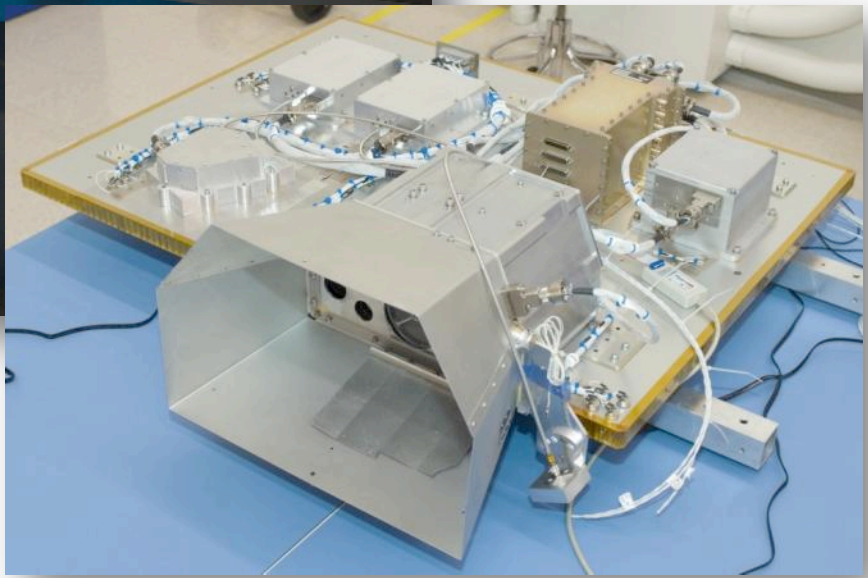
ARC	$8.0M
MSFC	$0.003M
JPL	$ 2.5M
GSFC	$ 3.6M
NG	$64.9M
Total GL	$79.0M
Launch Swap Cost	$10.2M
New GL	$89.2M



LCROSS Photo Album

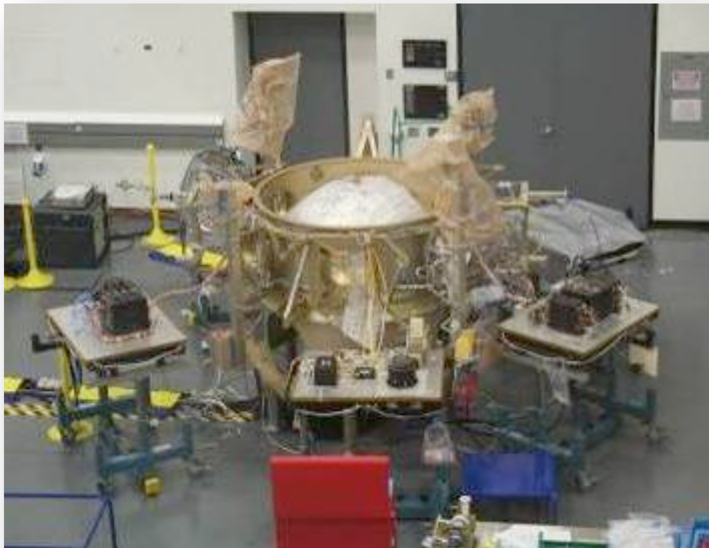
LCROSS Photo Album:
NASA-Ames developed payload

Final cleaning
(Jan 2008)



Finished Payload Panel

LCROSS Photo Album:
NG developed spacecraft



Assembly
(March 2008)

Acoustic
Test
(May 2008)

TVAC Test
(June 2008)

LCROSS Photo Album:
Astrotech payload processing

Astrotech processing. Titusville, FL
(2/9/2009)

LCROSS Photo Album:
Vertical Integration Facility

Lifting atop the Atlas-V Rocket
(5/2009)

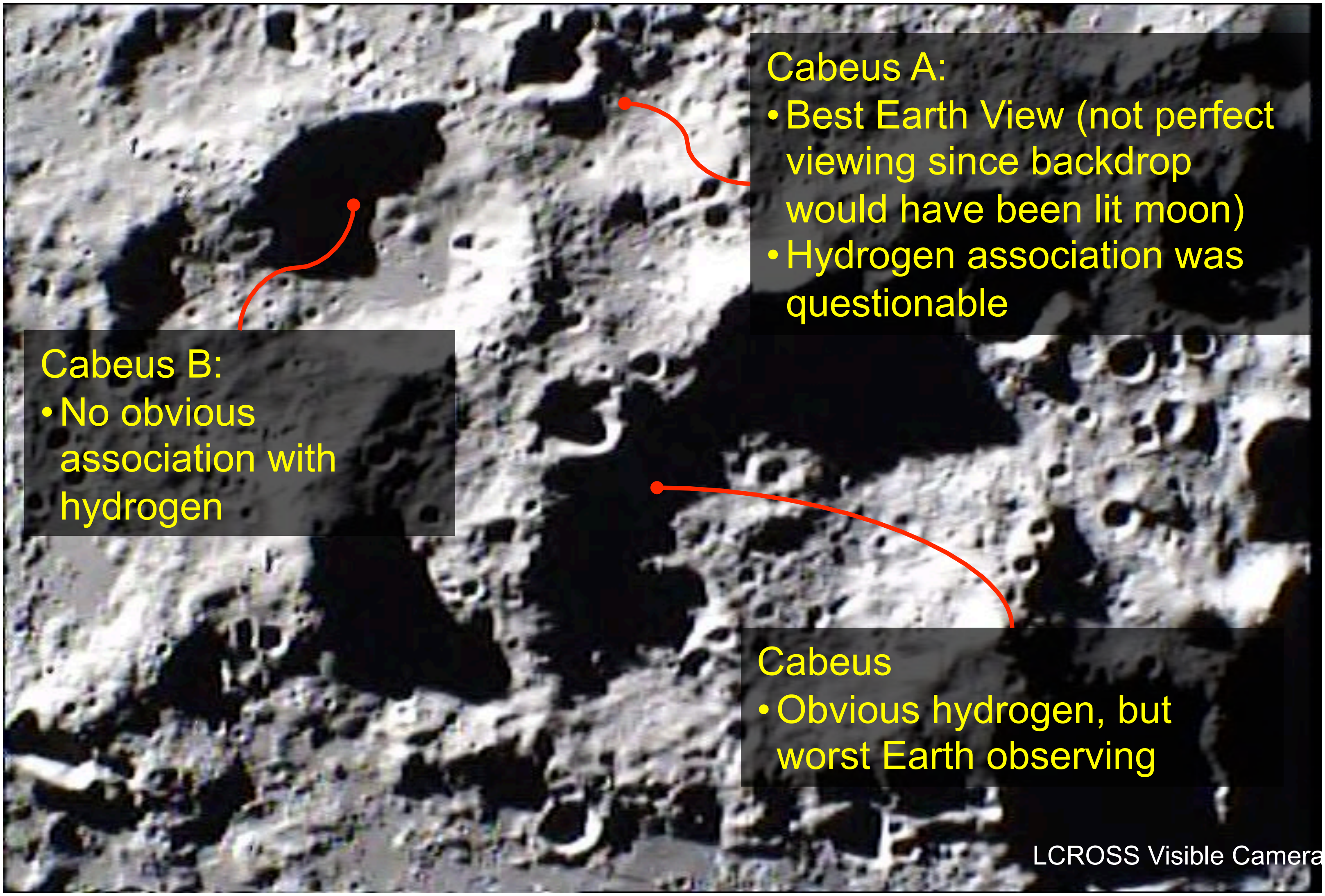
LCROSS Photo Album:
Rollout to pad

SLC-41, Cape Canaveral, FL
(6/17/ 2009)

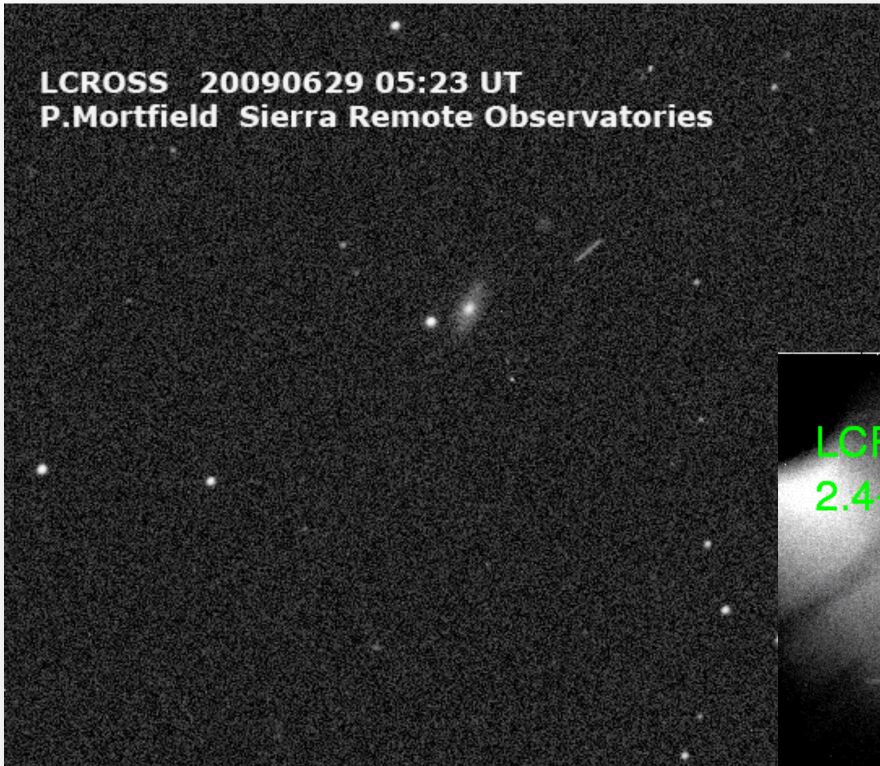
LCROSS Photo Album:
Launch

LRO/LCROSS Launch
(6/18/2009, 5:32pm EDT)

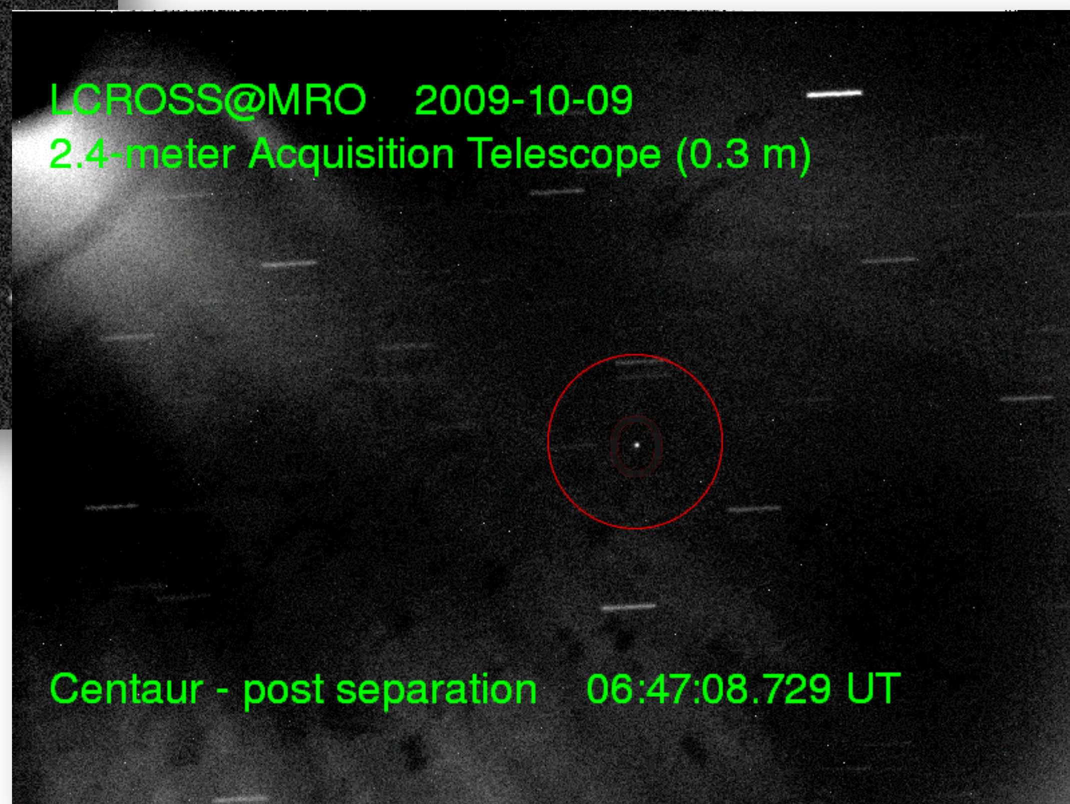
Impact Target Selection



LCROSS Photo Album:
LCROSS Spotted in Flight



LCROSS (still attached to Centaur)
(6/29/2009)



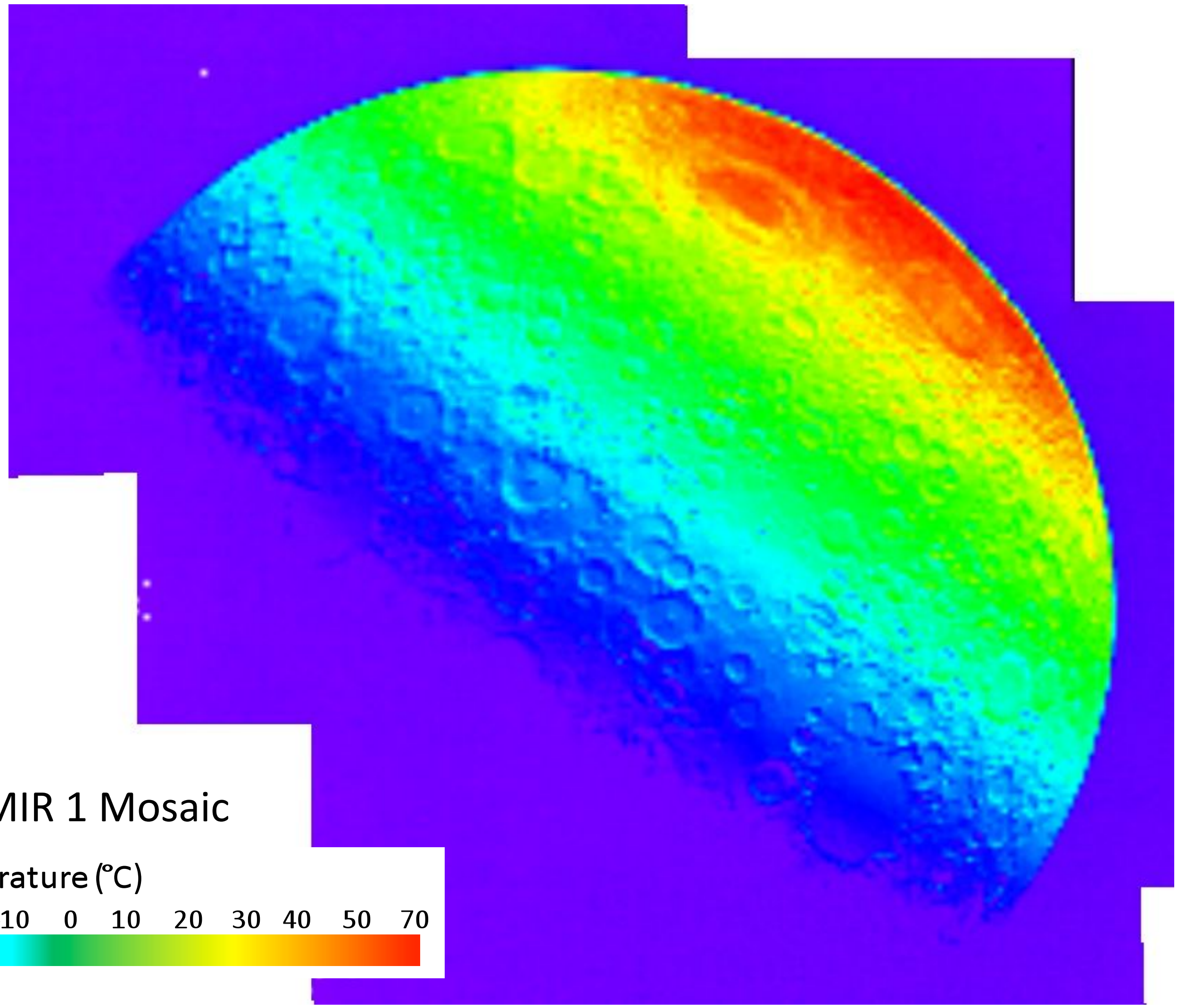
Centaur (post-separation)
(10/9/2009)

Payload Performance

- All instrument performed very well through entire mission:
  - Quicklook (June 20)
  - Starfield (June 22)
  - Swingby (June 23)
  - Earth Look1 (August 1)
  - Earth/Moon Look-MIR calibration (August 17)
  - Earth Look 3 (September 18)
  - Impact (October 9)

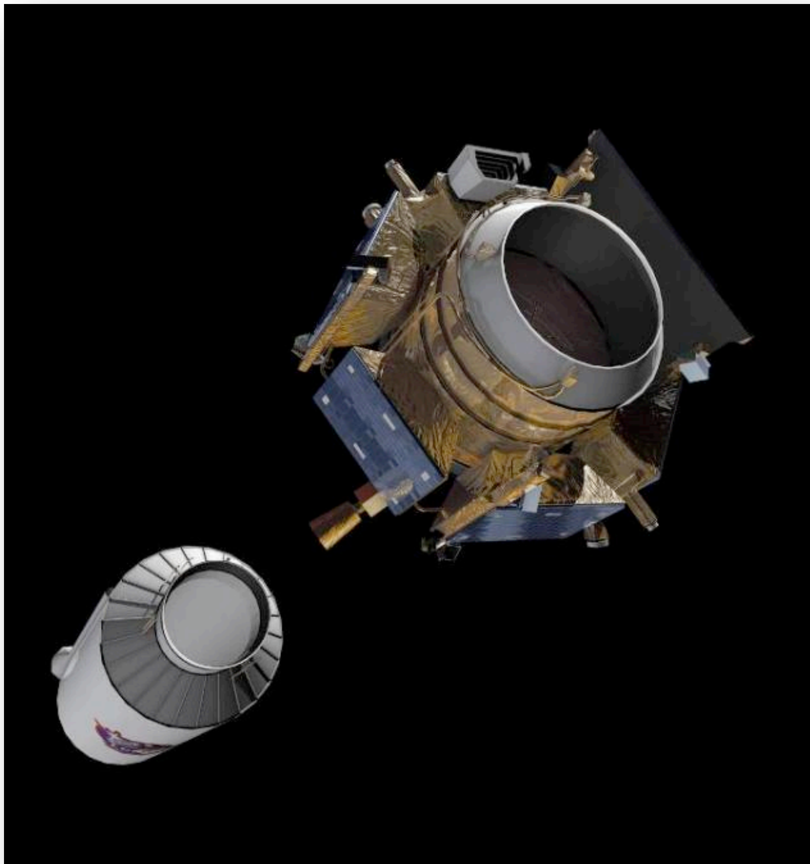
- Lessons Learned / Looking Forward:
  - COTS Instruments can work for extended periods in space
    - Nine (9) instruments + DHU for 110 days, >10 hours operation
  - COTS component screening accomplished via acceptance testing
    - Screening via acceptance testing requires flexible, accommodating schedule
  - Distributed and overlapping measurements across instrument suite lowered overall risk and enabled discovery
    - Enabled by use of COTS: nine (9) instruments at a cost of about $3.5M.
  - Ground testing of unique, single event CONOPS was difficult
    - Swingby was critical as a practice run
    - More could have been done on the ground to establish instrument performance

Payload Performance
From Beginning…



Swingby MIR 1 Mosaic

LCROSS Photo Album:
LCROSS Separation



"Goodbye Centaur", post-separation image
(10/9/2009)

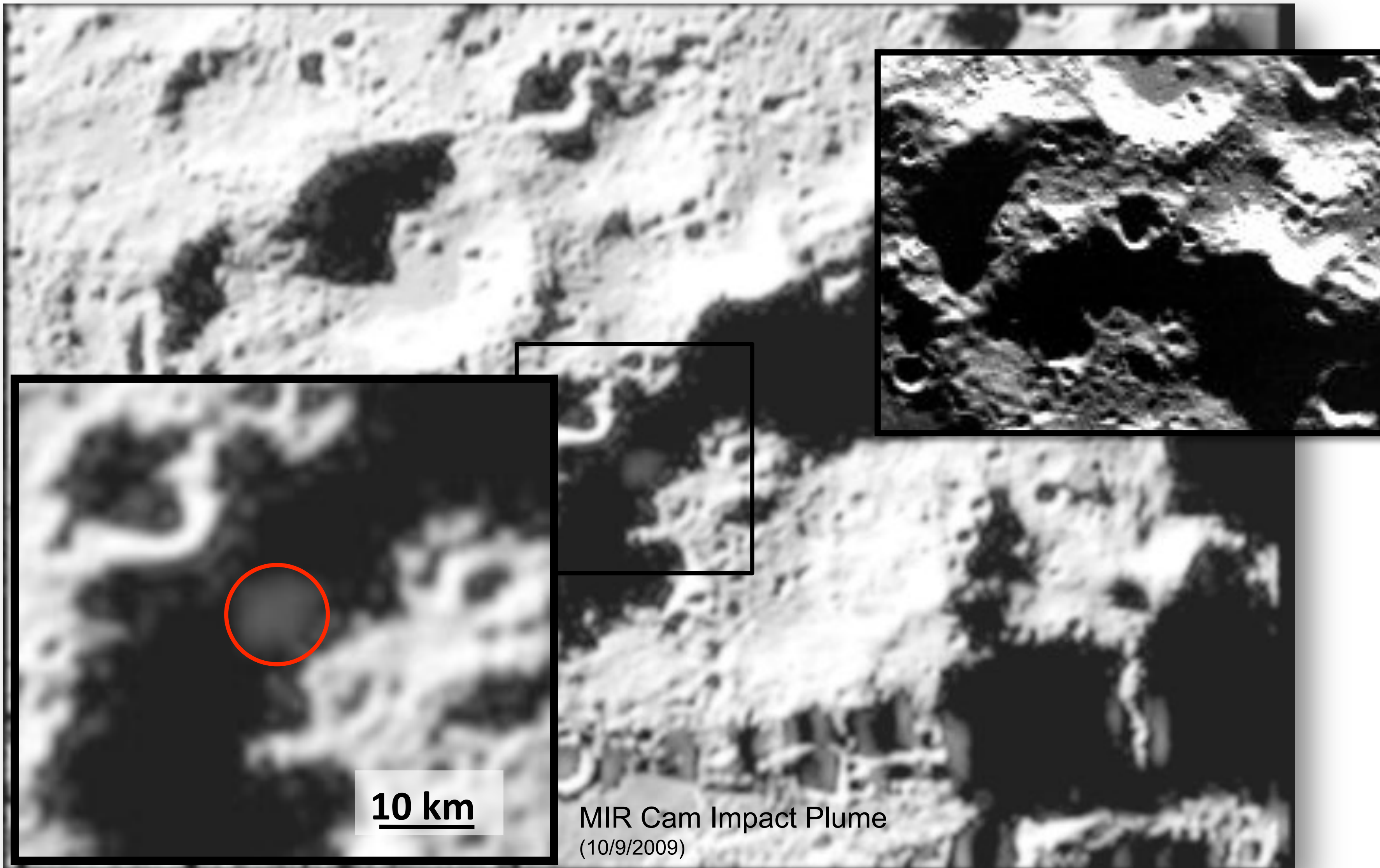
LCROSS Photo Album:
Mission Operations: NASA-ARC

Impact Night, NASA-Ames MMOC & SOC
(10/9/2009, 4:30am PDT)

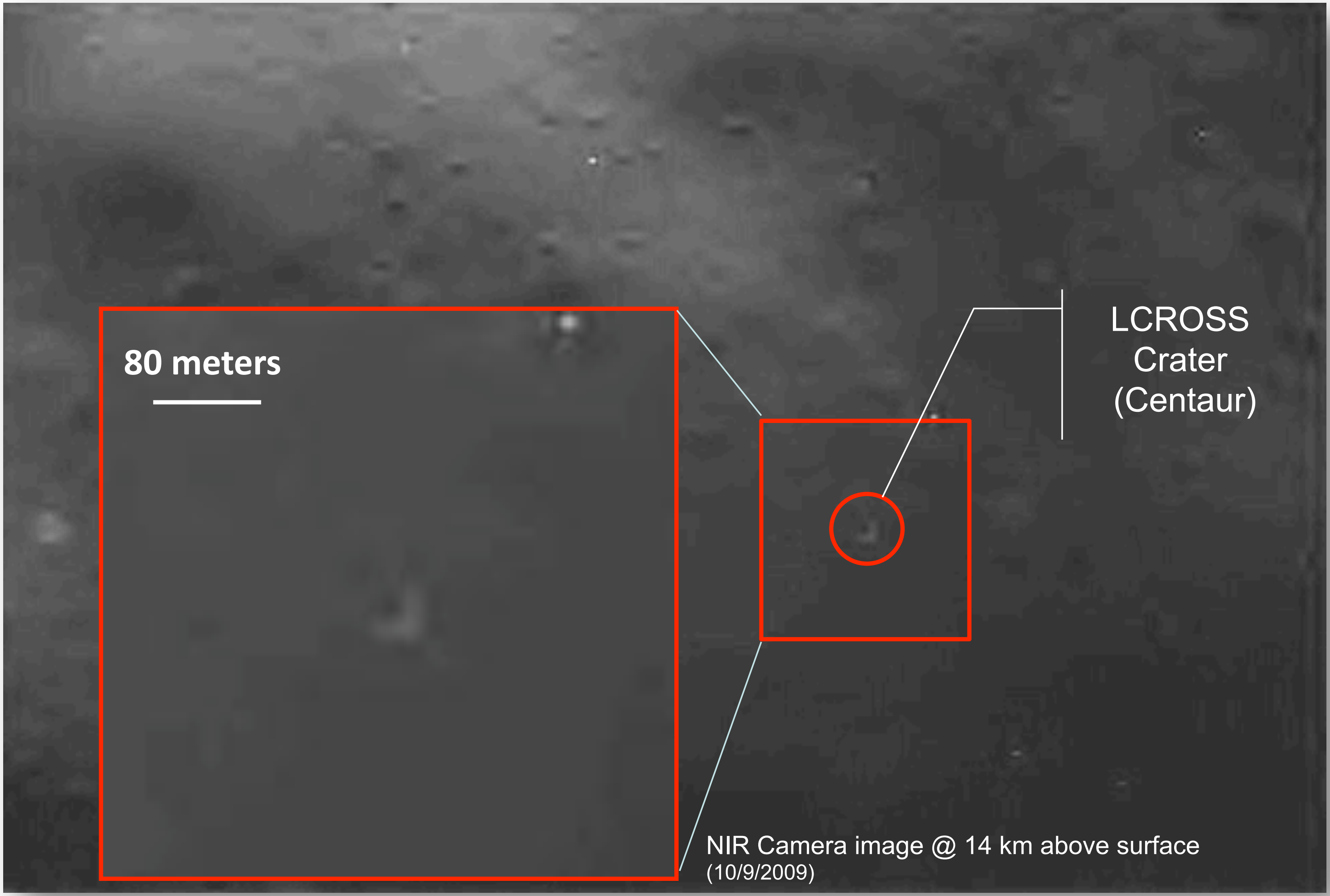
LCROSS Photo Album:
Impact Night

Impact Night, NASA-Ames
(10/9/2009, 4:30am PDT)

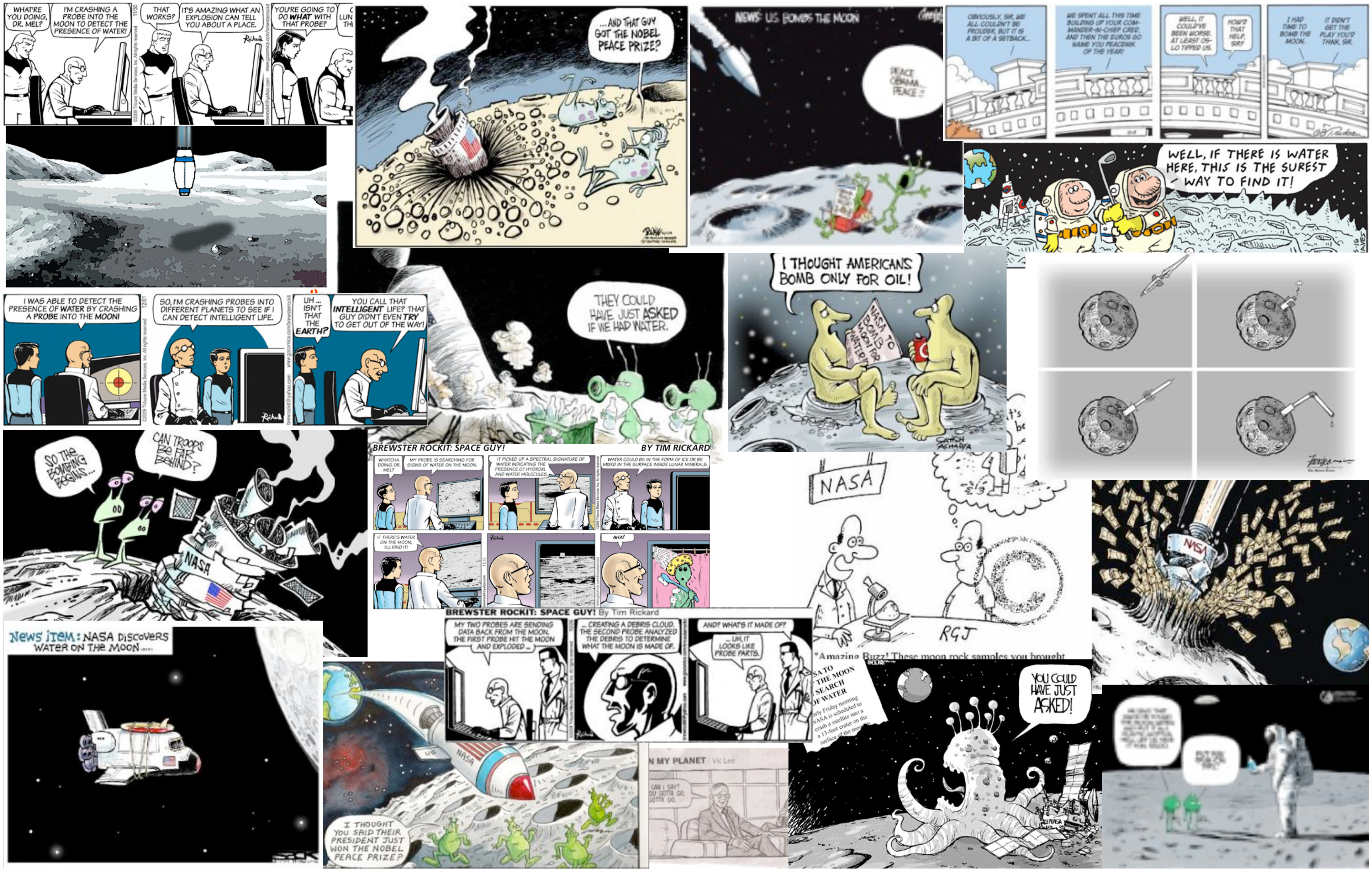
LCROSS Photo Album:
Centaur Impact plume in Cabeus



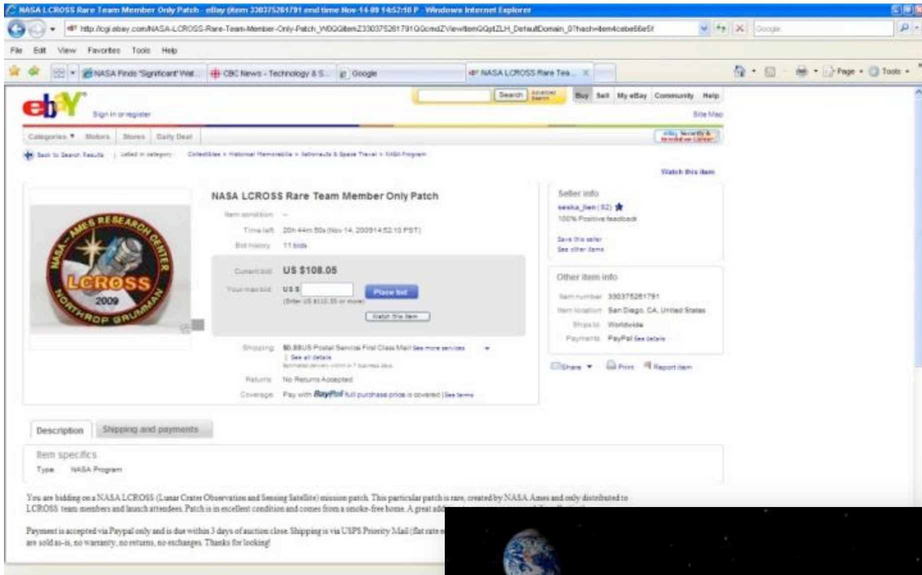
LCROSS Photo Album:
Centaur Impact crater



Lunacy
Political Cartoons

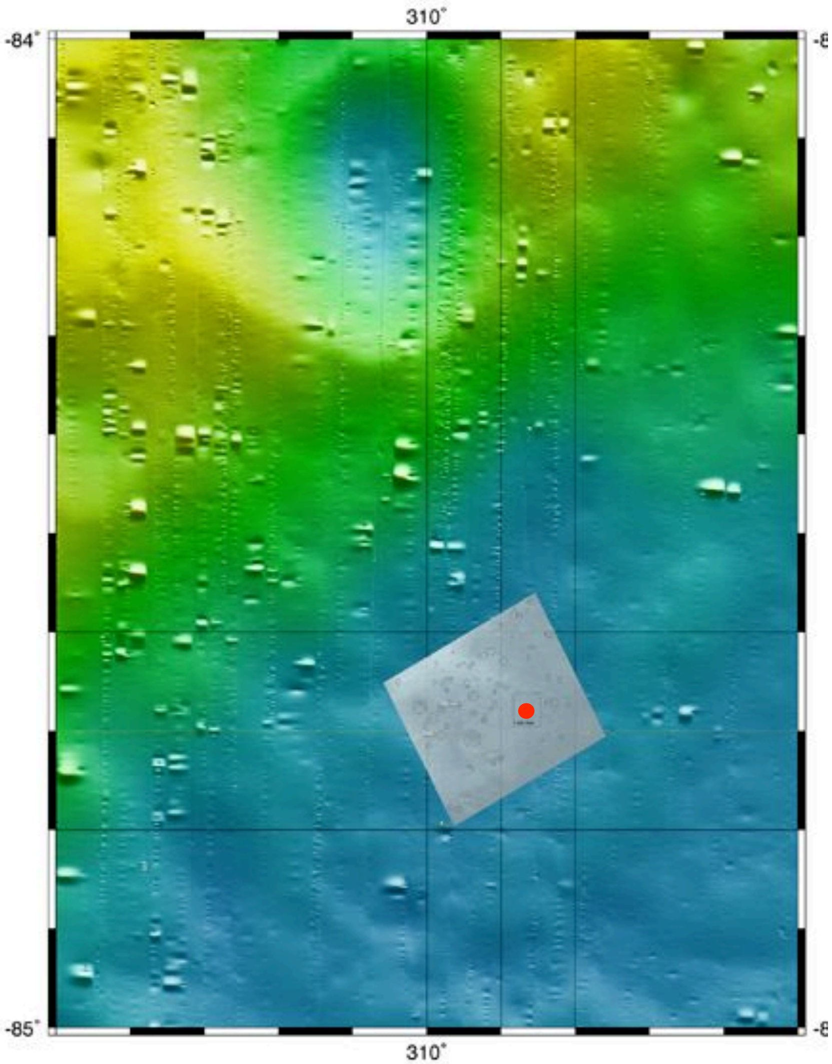


Lunacy
Pop Culture

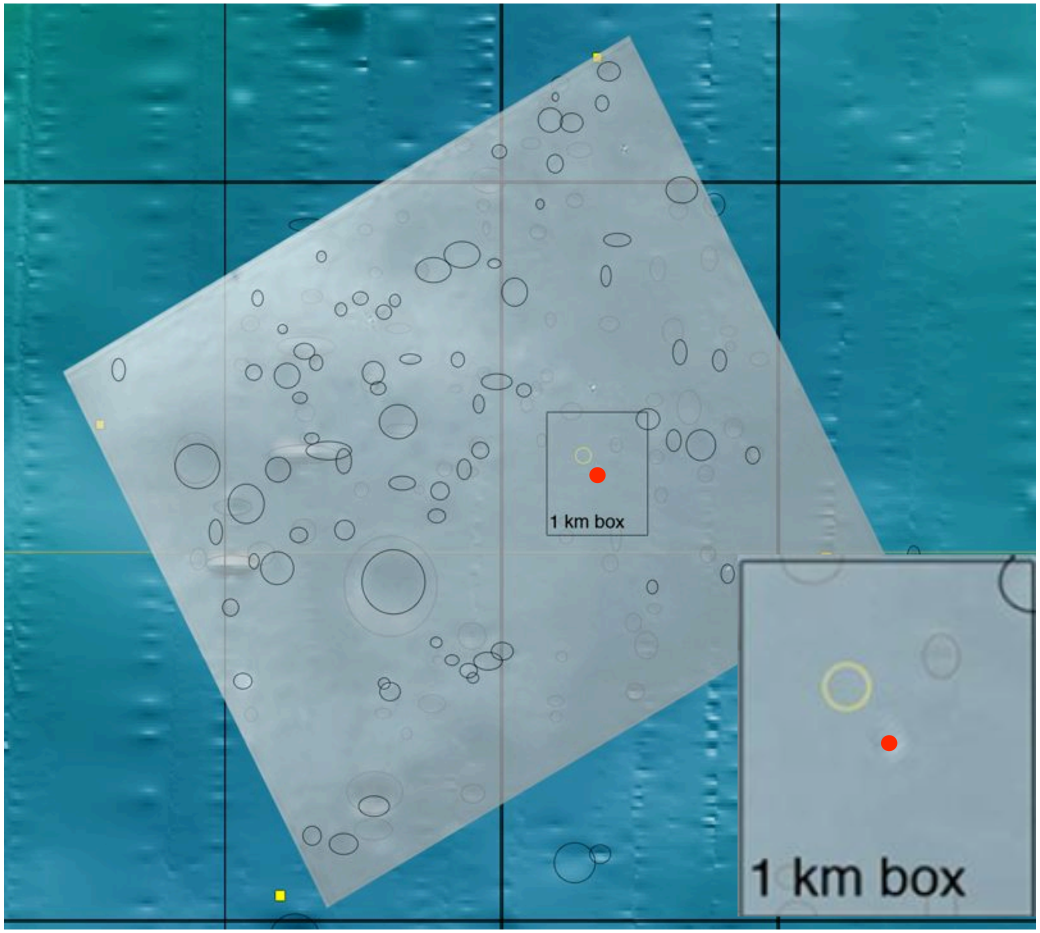


Lunacy
After the water was found…

Impact Targeting



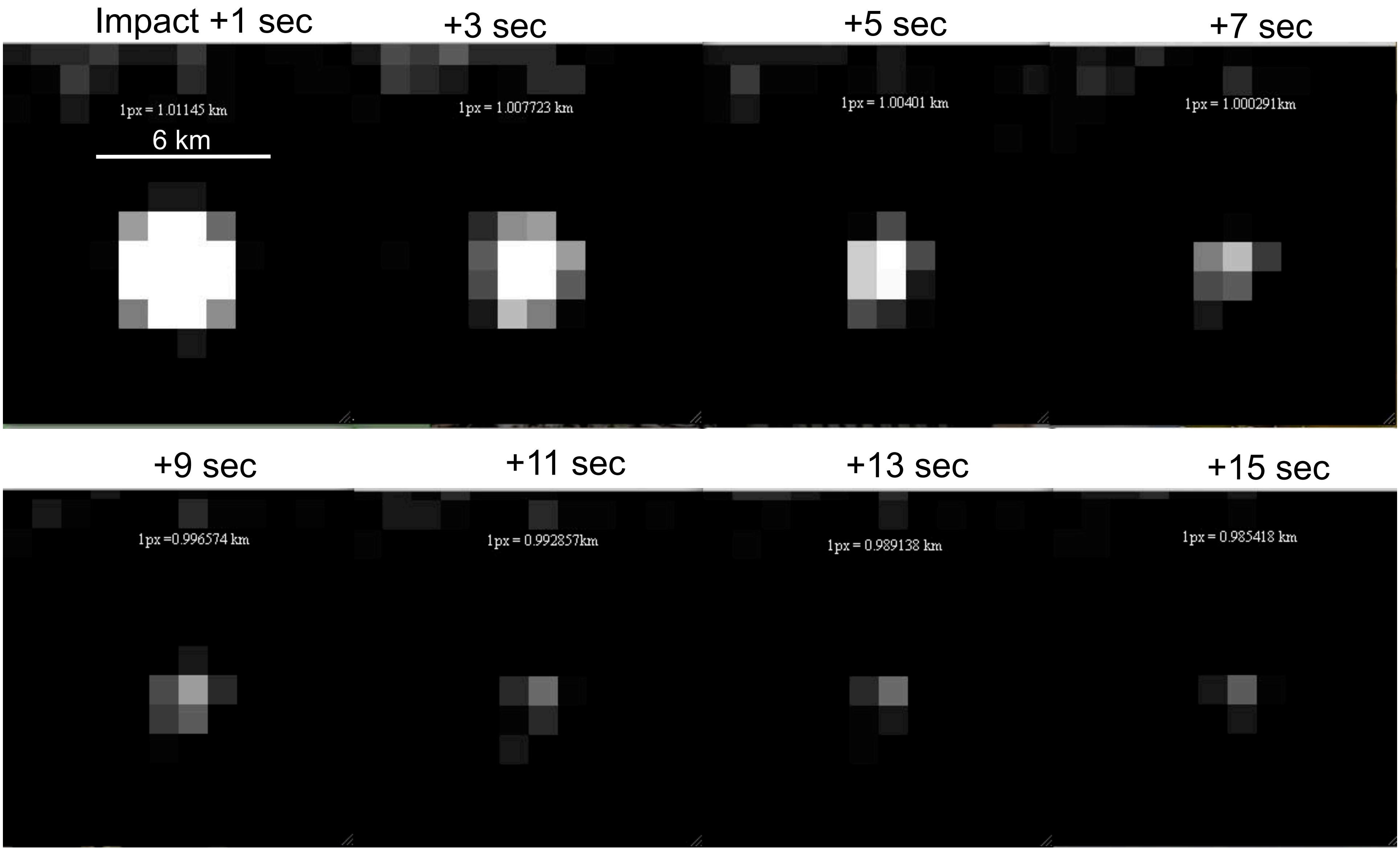
NIR2 image registered to LOLA



Hit within 83 m ±66 m (1s) of planned target

Payload Performance

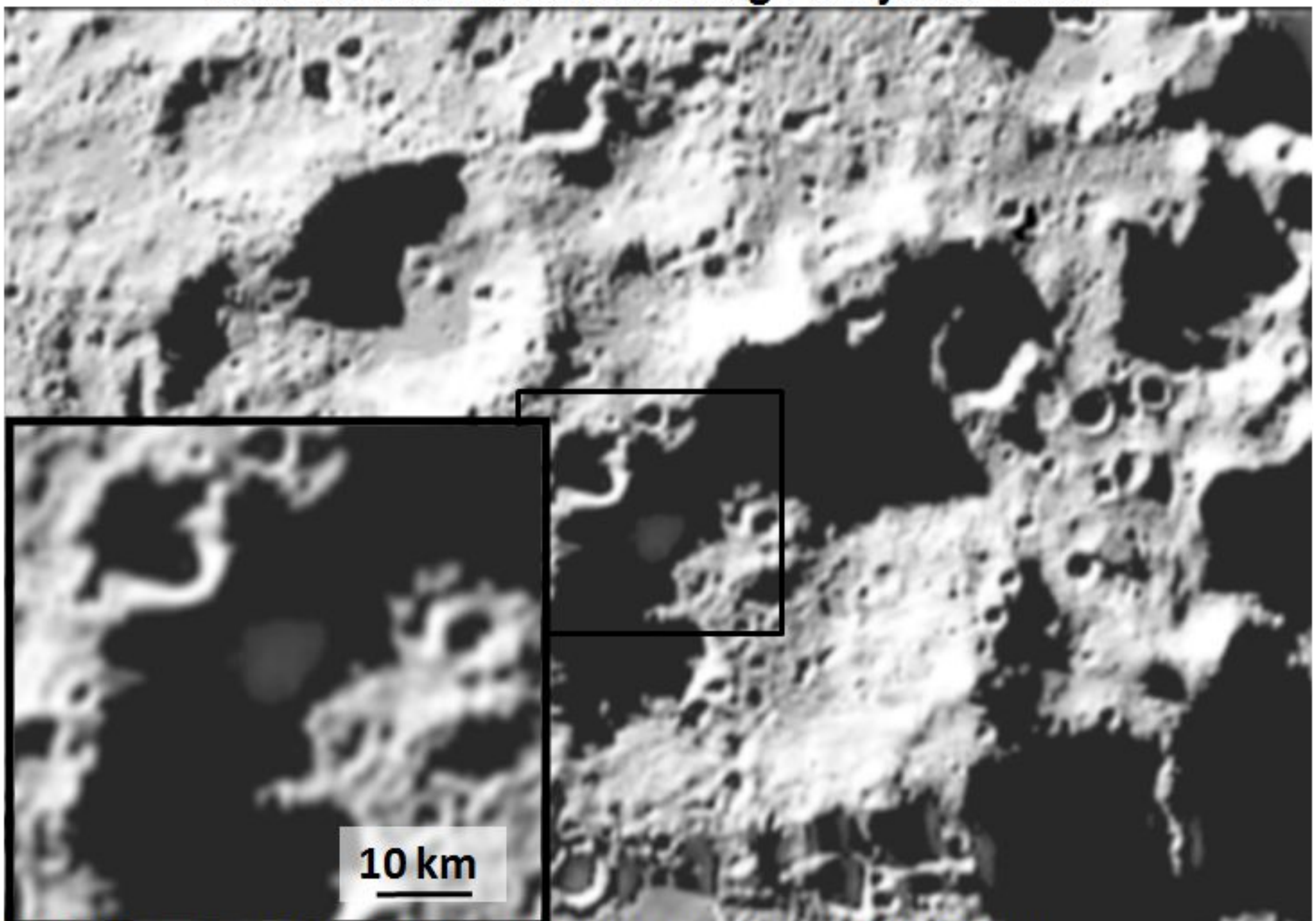
Thermal Camera (MIR2) images of Impact



Payload Performance

(…as it appeared on cover of NY Times)

LCROSS Visible Camera Image of Ejecta Cloud



LCROSS/NASA ARC B. Hermalyn (Brown University), A. Colaprete (NASA Ames)

Science Summary

LCROSS confirmed the presence of water within a permanently shadowed region on the moon

- Water vapor and Ice identified in NIR spectra
- Hydroxyl (OH) measured in UV spectra

The estimated concentration of water in the regolith at the LCROSS impact site is 7.4wt% ± 5.4wt%

- ~150 kg total water vapor and ice in NIR and UV-Visible spectrometer FOV (24 gallons)

Grain size, porosity and composition are subjects of ongoing work

- The low strength and delay in impact flash, and the size of the resulting Centaur crater suggest a very porous regolith with significant amounts of intermixed volatiles

SCIENCE RESULTS

Identify the form/state of hydrogen observed by at the lunar poles

Have identified with high confidence:

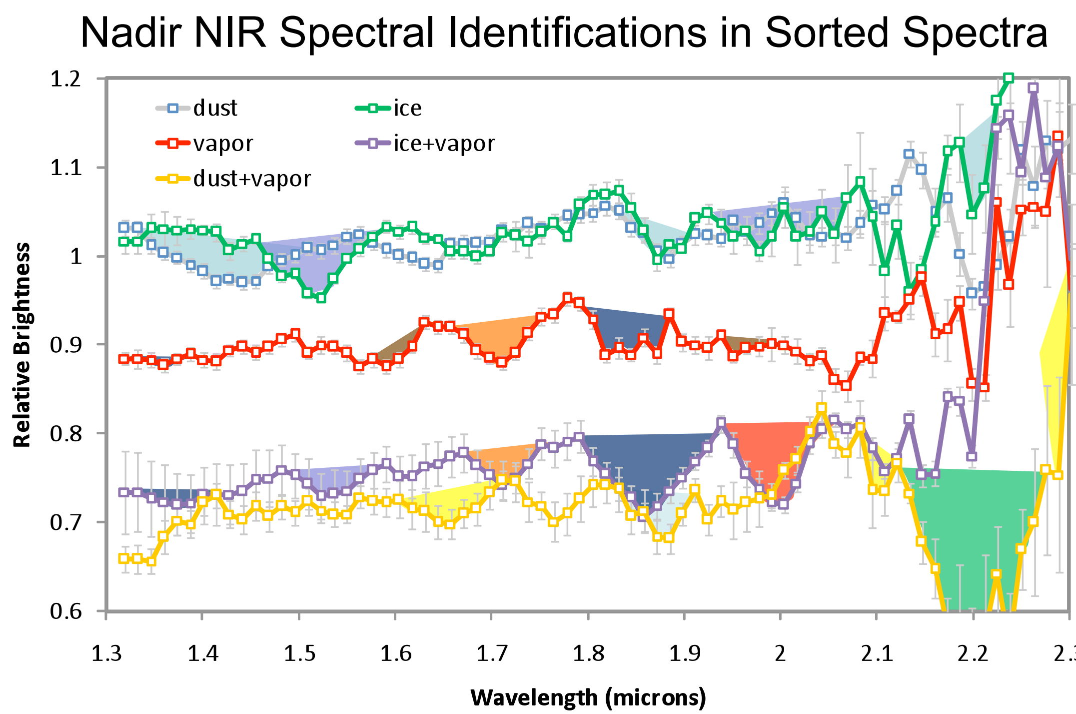
- H_2O (ice and vapor)
- OH (bound)
- H_2S
- H_2 (LRO LAMP)

Have moderate confidence:

- CH_4
- CH_2O
- C_2H_4
- NH_2

Also have strong evidence for:

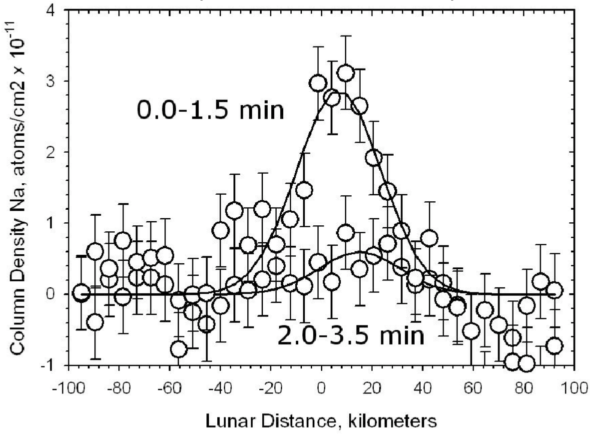
- SO_2
- CO_2
- CN
- CO
- Na
- Mg
- Ca
- Fe



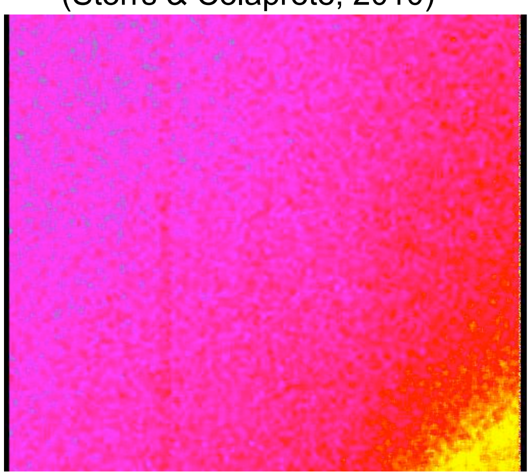
Earth Based Observations

More than 25 Observatories Successfully Observed

Na Observations from Kitt Peak
(Killen et al., 2010)



OH Observations from HST
(Storrs & Colaprete, 2010)



Moon

Initial Results:

- Imaging of plume was difficult due to diffuse cloud (as apposed to confined curtain)
- However, there are hints of water in some spectra
- Two observatories observed Sodium flash
- HST measured OH exosphere (preliminary finding)

Observatories	
Canada-France-Hawaii (CFHT)	Lick Observatory
Apache Point Observatory	IFA Haleakala
IRTF	Kitt Peak, solar telescope
MMT	Kitt Peak 2.1 m
MRO (Magdalena Ridge)	Palomar
Keck	Table Mt
Gemini North	Faulkes Telescope North
Subaru	VATT
Korea Astronomy & Space Science Institute	LRO
Mt Wilson	Odin
Air Force AEOS Telescope	Hubble Space Telescope
Allen Telescope Array	IKONOS, GeoEye-1
Large Binocular Telescope	EO-1
Tortugas Mtn Observatory	

Presentations / Publications

The data is rich and publications are prolific

- 85 LCROSS specific conference abstracts or papers since 2006
- 110 conference abstracts or papers since 2006 that include LCROSS as subject
- 22 papers on the LCROSS impact were presented at this years Lunar Planetary Conference (LPSC)
- Six companion papers describing initial results from the LCROSS impact where submitted to Science for joint publication (currently all in review):
  - Colaprete et al., *The Detection of Water in the LCROSS Plume*
  - Schultz et al., *The LCROSS Cratering Experiment*
  - Mitrofanov et al., *Spatially-distributed Hydrogen at the Lunar South Pole: Orbital Mapping by the LRO LEND Experiment in Support of the LCROSS Mission*
  - Hayne et al., *Diviner Lunar Radiometer observations of the LCROSS impact*
  - Paige et al., *Diviner Observations of Cold Traps in the Lunar South Polar Region: Spatial Distribution and Temperature*
  - Goldstone et al., *LRO-LAMP Observations of the LCROSS Impact Plume*

In addition a ground based observation paper has also been submitted to Science:

- Killen et al., *Observations of the lunar impact plume from the LCROSS Event*

Metrics

Metrics

Public Events: 34,500 general public
Student Activities: 16,600 students
Educator Training: 1,850 educators

Amateur Astronomers:
Societies Involved: 320+
Workshop Participants: 173
Online Discussion Group: 295
Citizen Science Site: 155

Museums:
Institutions Involved: 200+
LCROSS Museum Tour
Presentation Audience: 4,900

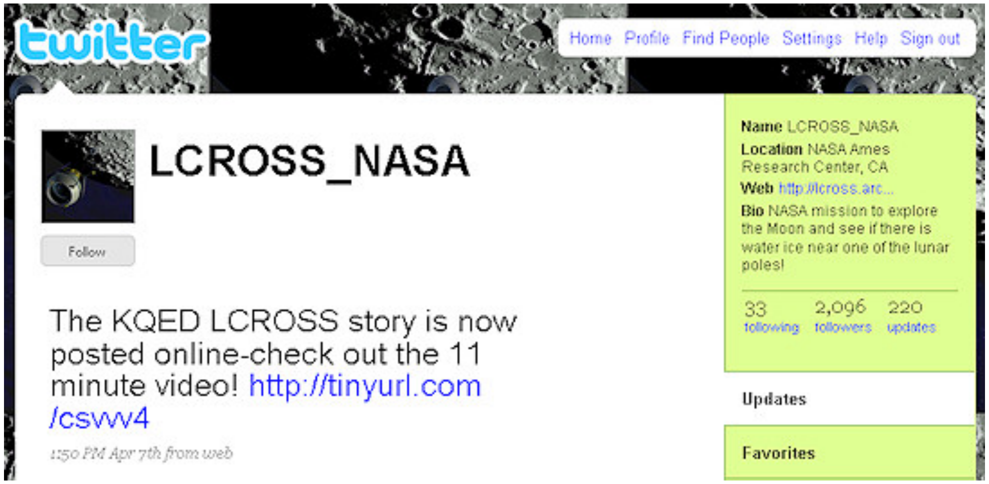
Dissemination Cohorts: Solar System Ambassadors, Night Sky Network, Museum Alliance, AESP

Web:
Impact Webcast: 391,000 streams
Flyby Webcast: 23,100 streams
PBS Webcast: 3,303 streams
Facebook Fans: 11,064
Twitter Followers: 13,144

Metrics

Exceptional public engagement demonstrated by huge volume of Internet traffic.

- LCROSS impact stream was the 3rd most watched event on www.nasa.gov, after RTF launch (438,000) and landing (394,000).
- LCROSS provided the fifth most watched live Internet event in the history of the Web; the 2008 NCAA Tournament and AOL's Live 8 concert scored just over 400k viewers.
- On the Friday afternoon following impact, LCROSS was number 1 in Yahoo searches, beating out President Obama's Nobel Peace Prize and the anniversary of John Lennon's death.
- Twitter activity surrounding impact placed NASA, Moon, and LCROSS into the Trending Topics (top 10 sites on Twitter).

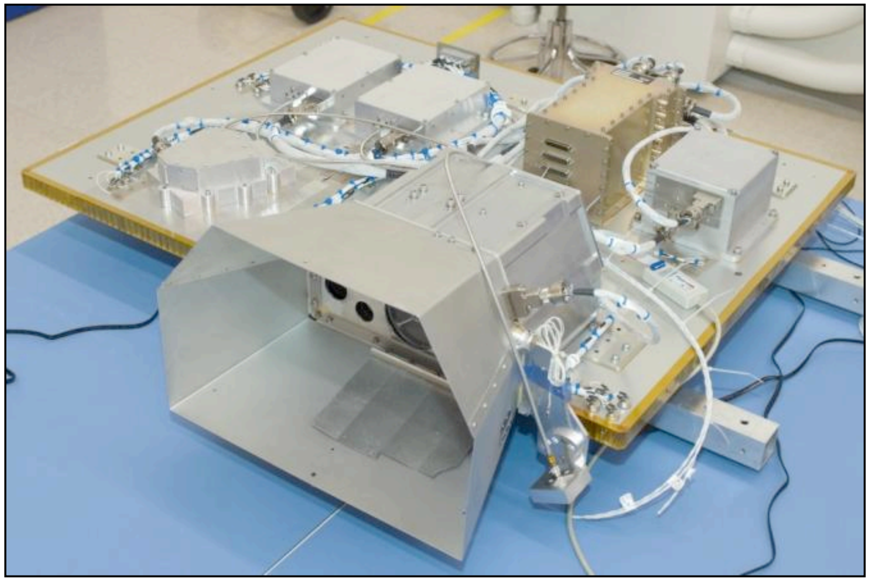


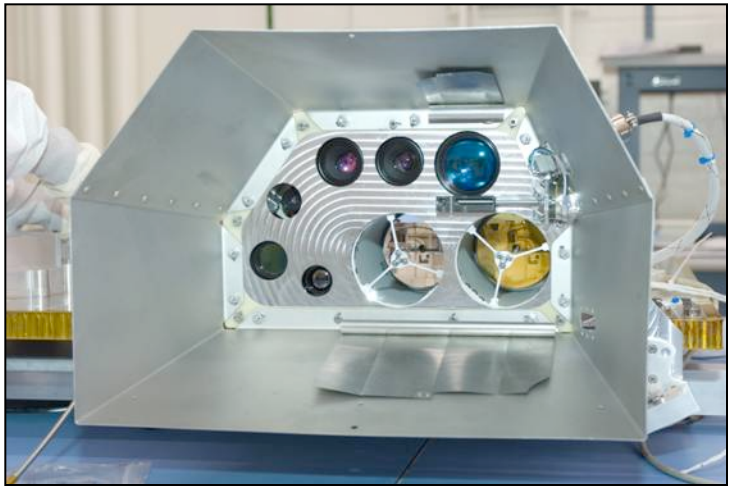
LCROSS was a Smashing Success!

BACKUP SLIDES

The Payload Instruments

- The Instruments:
  - (9) instruments make-up a robust measurement suite
    - Near & Mid IR spectrometry
    - IR & Visible cameras
- The Purpose:
  - Water-ice / Water-vapor detection & concentration
  - Ejecta grain properties
  - Crater and general imagery
- The Heritage:
  - Proven, existing instruments
    - Spaceflight / Space-proven
    - Military / Airborne applications
    - Ocean Floor exploration
    - Industrial monitoring applications
    - Motor sports applications





What is Minimum and Full Mission Success?

- LCROSS Minimum Mission Success
  - Centaur, with or without LCROSS spacecraft, impacts targeted crater
    - Spacecraft survives cruise phase & establishes final trajectory for impact site
    - No premature separation of Centaur
  - No "impact event" data is relayed to ground station

- LCROSS Full Mission Success
  - Centaur separates and impacts targeted crater
  - LCROSS spacecraft…
    1. Points instruments at impact target/Centaur,
    2. Flies through ejecta plume minutes after Centaur impact
    3. Retrieves and relays instrument data of impact site & ejecta plume characteristics to ground station

Note: Observation of impact may also occur by ground and/or space-based observatories. This capability is not the responsibility of the LCROSS Project; however, the presence of these observatories drives LCROSS minimum mission success