Lunar Reconnaissance Orbiter: Status, Recent Science Results, and Plans for the Extended Science Mission

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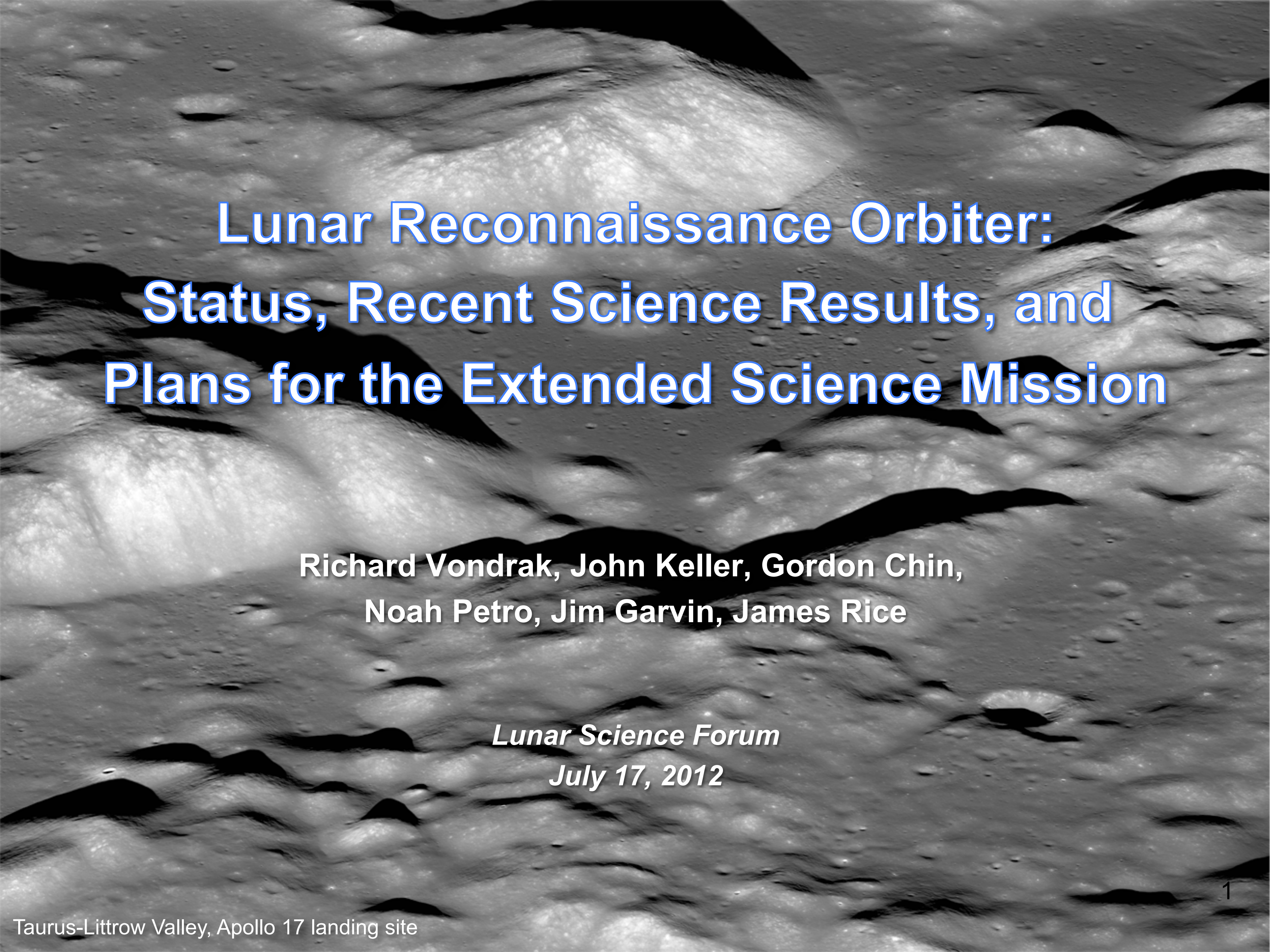
Lunar Science Forum
July 17, 2012



Taurus-Littrow Valley, Apollo 17 landing site

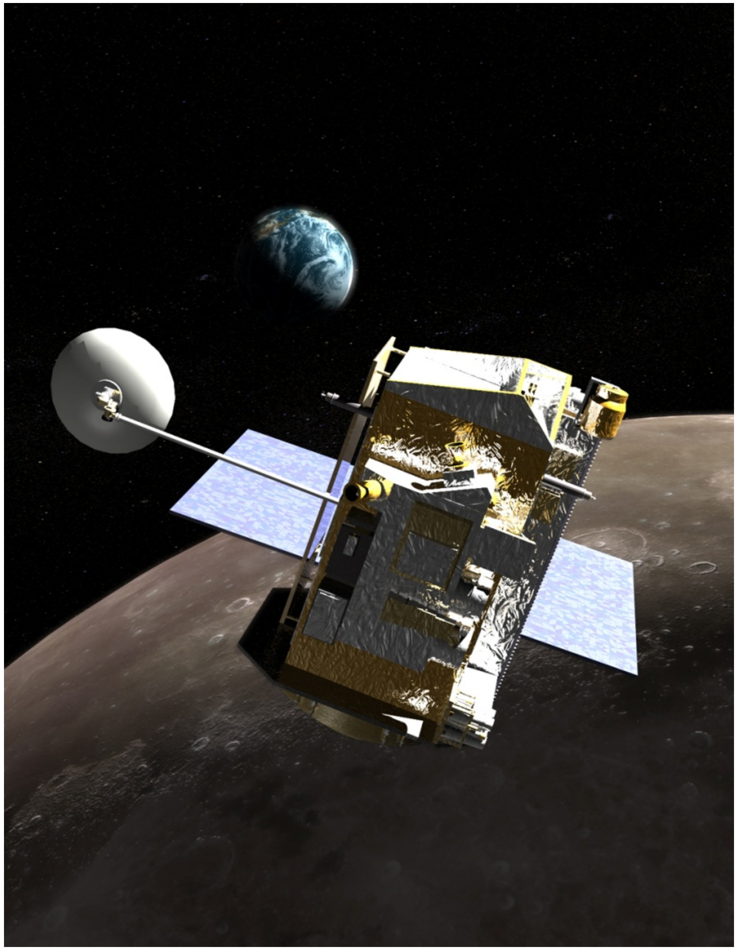
Lunar Reconnaissance Orbiter (LRO)

Seven instrument payload

- Cosmic Ray Telescope for the Effects of Radiation (CRaTER)
- Lunar Orbiter Laser Altimeter (LOLA)
- LRO Camera (LROC)
- Lyman-alpha Mapping Project (LAMP)
- Diviner Lunar Radiometer Experiment (DLRE)
- Lunar Exploration Neutron Detector (LEND)
- Miniature Radio Frequency System (Mini-RF)

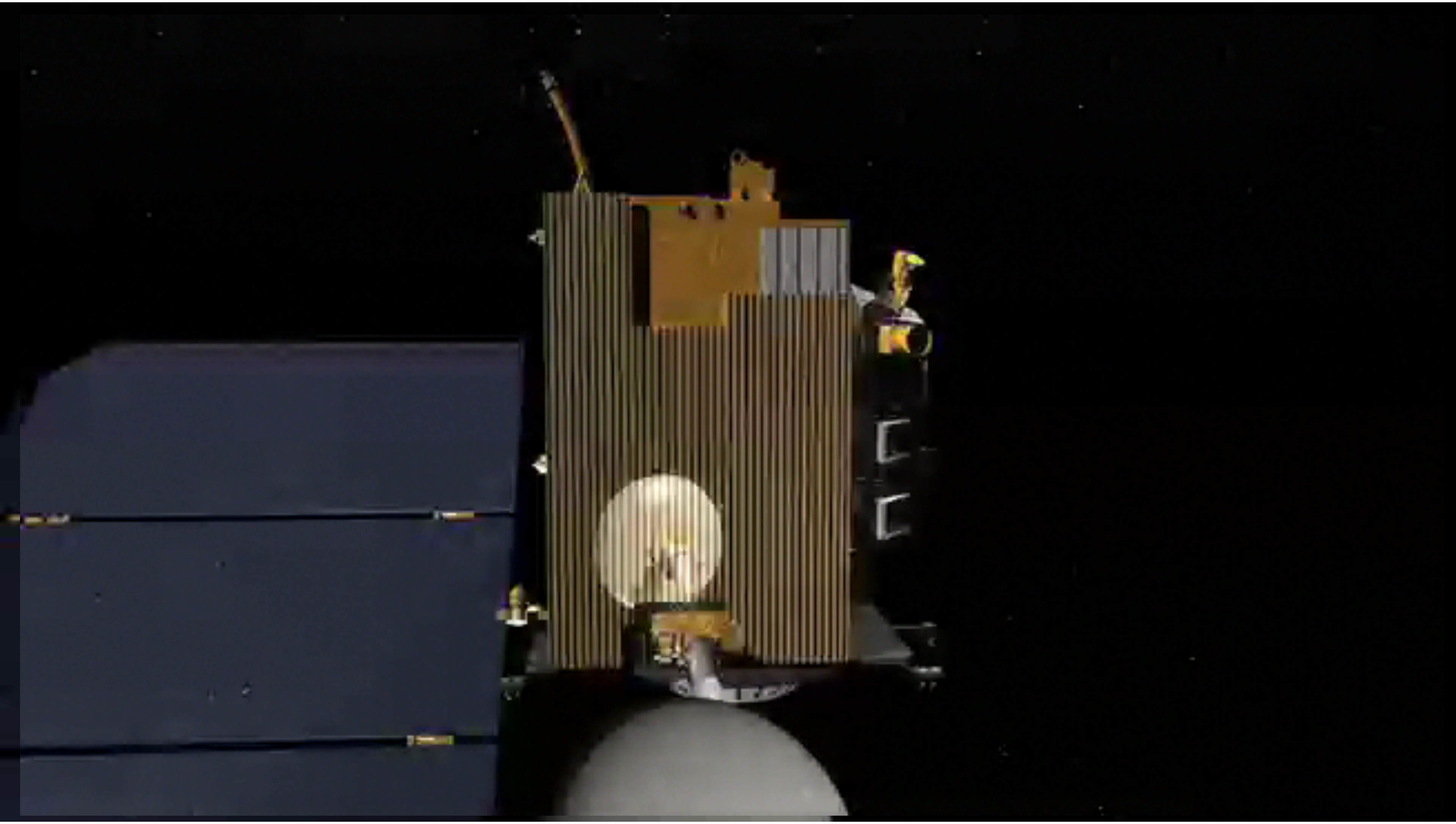
LRO is returning

- Global day/night temperature maps (DLRE)
- Global high accuracy geodetic grid (LOLA)
- High resolution monochrome imaging (LROC)
- High resolution local topography (LOLA, LROC)
- Global far ultraviolet albedo map (LAMP)
- Polar observations both in shadowed and illuminated areas (LEND, LROC, LOLA, DLRE, Mini-RF, LAMP)
- Ionizing radiation measurements in the form of energetic charged particles and neutrons (CRaTER, LEND)



LRO was launched June 18, 2009 and entered mapping orbit September 15, 2009

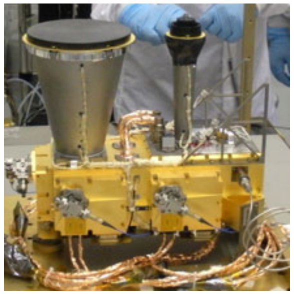
LRO has 7 Instruments



LRO Instruments and Investigations

LOLA: Lunar Orbiter Laser Altimeter

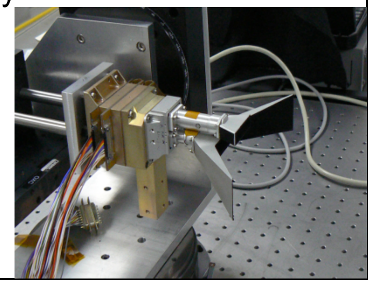
- Topography
- Slopes
- Roughness



5-spot altimeter
10 cm vert.
25 m horizontal resolution

LROC/WAC: Wide-Angle Camera

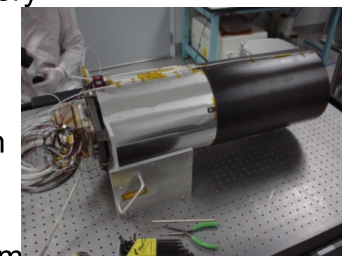
- Global Imagery
- Lighting
- Resources



7-band UV/Vis
~100 m resolution from 50 km altitude

LROC/NACs: Narrow-Angle Cameras

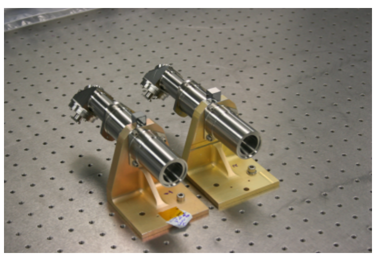
- Targeted Imagery
- Hazards
- Topography



50 cm resolution
2 NACs with 5 km combined swath from 50 km

LR: Laser Ranging

Precision Orbit Determination



Uses LOLA detector to range from Earth to LRO

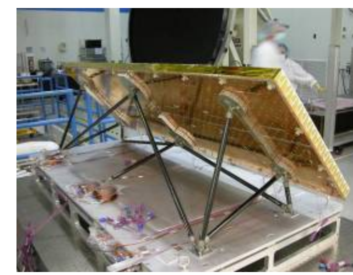
Diviner Lunar Radiometer

- Thermal State
- Volatile Stability
- Rocks&Regolith
- Composition

0.35 to 400 μm in 9 channels
~150-500 m res.

Mini-RF: Synthetic Aperture Radar

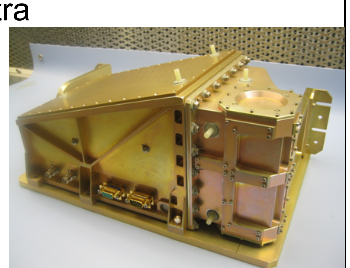
- Resources
- Topography
- Hazards



Bistatic radar measurements
30 m S & X SAR imagery

CRaTER: Cosmic Ray Telescope…

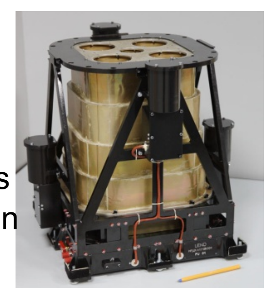
- Radiation Spectra
- Tissue Effects



LET spectra
Behind tissue Equiv. plastic
0.9 keV/μm to 2.2 MeV/μm

LEND: Lunar Explr. Neutron Detector

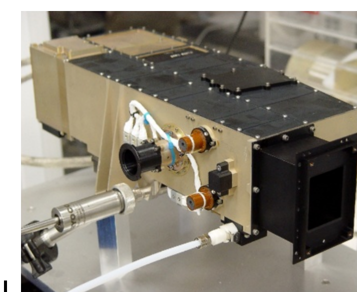
- Neutron Albedo
- Hydrogen Maps



Thermal, epithermal and energetic neutrons
10 km spatial resolution from 50 km

LAMP: Lyman-Alpha Mapping Project

- Water-Frost
- PSR Maps

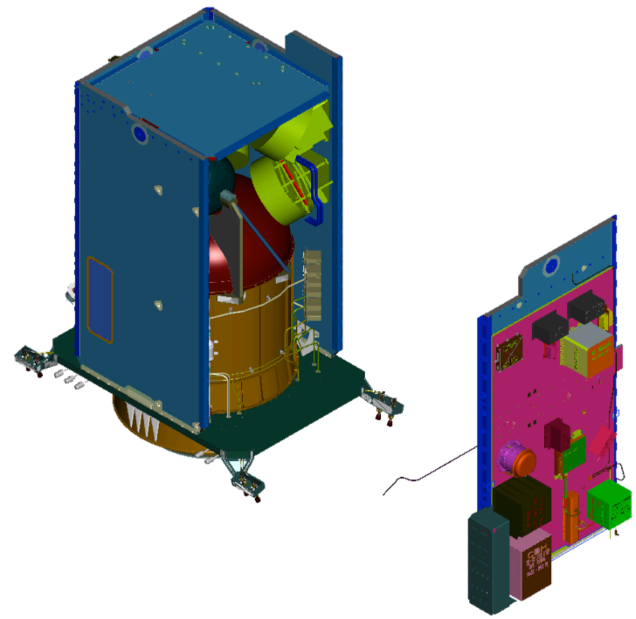


UV imaging
57 to 196 nm
0.18 nm spec. resolution
~300 m spatial

Half of LRO Mass is Propellant
LRO's Data Volume is Enormous

LRO Orbiter Characteristics

Launch Mass	**1916 Kg**	Dry: 1018 kg, Fuel: 898 kg (1313 m/sec)
Orbit Average Power	**681 W (2 kW array)**	
Data Volume, **Max Downlink rate**	**459 Gigabits/day,** **100 Megabits/sec**	



LRO has deposited 325 Terabytes of data into the PDS through June 2012.

LRO Flexible Mission Operations Enabled New Discoveries

Mission phases:

- **LRO was launched on June 18, 2009**

  - Spacecraft and instruments commissioned in a 30 x 200 km elliptical orbit

- **Exploration Mission: 9/16/09 - 9/16/10**

  - a one-year mapping of the Moon to search for resources, identify safe landing sites, and measure the radiation environment

  - quasi-circular polar orbit (50 +/- 15km)

- **Science Mission: 9/17/10 - 9/16/12**

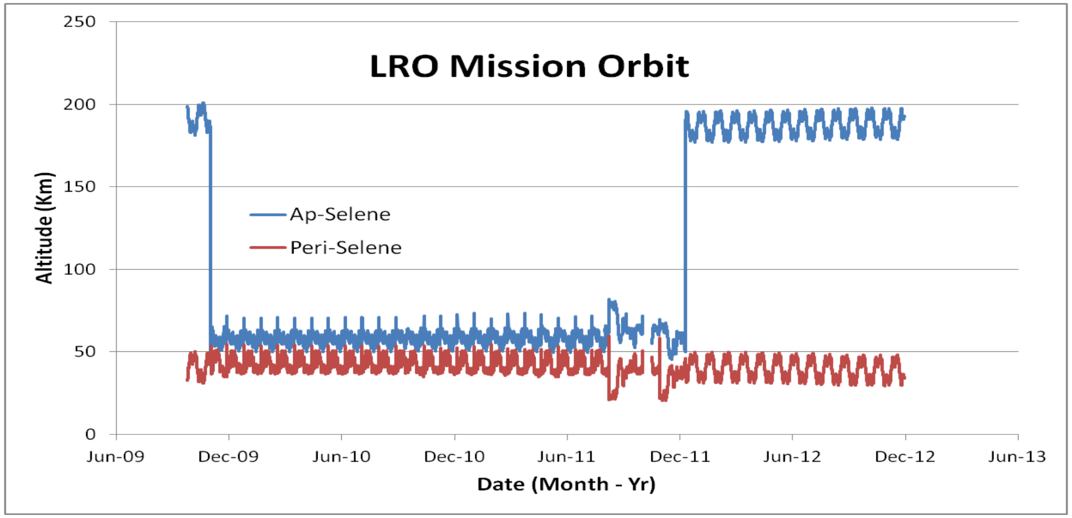
  - more flexible operations for Planetary Science objectives

  - quasi-circular orbit (50 +/- 15km) until December, 2012

  - now in a 30 x 200 km orbit

- **Extended Science Mission: 9/17/12 - 9/16/14**

  - Proposed to PSD



New Measurements in the ESM

- **Increased global mapping coverage and quality:**
  - More than double the narrow angle imaging from 35% to 75% areal coverage
  - Improved coverage near the south pole and smaller gaps near the equator
- **Improved sensitivity for integrating instruments:**
  - Improved spatial resolution and statistical significance by more total counts
  - Refined UV spectra to characterize better the surface within PSRs
- **Unique new measurements:**
  - First measurements of Galactic Cosmic Rays and large Solar Energetic Particle events at the Moon during the active solar cycle
  - First planetary bistatic radar images acquired through a range of β angles

The LRO ESM provides new observations that enable new science and fill strategic knowledge gaps for future exploration planning.

New Science in the ESM

- **New science for the ESM is organized around four themes aligned with Planetary Decadal Survey priorities:**

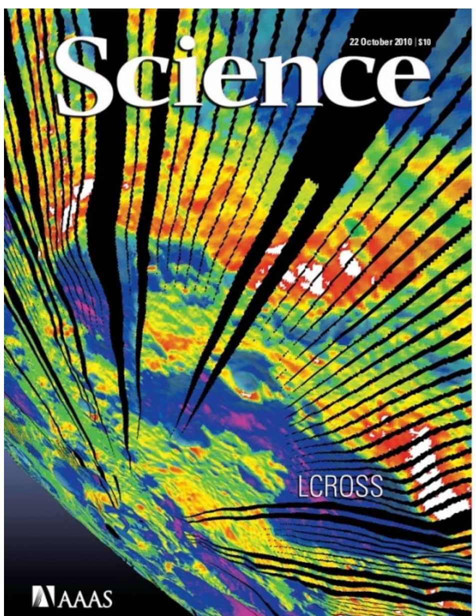
  1. *The Nature of Volatiles Deposited in the Moon's Polar Regions*
  2. *Terrestrial Planet Differentiation and Early Evolution*
  3. *The Lunar Impact Record and its Relation to Solar System History*
  4. *The Moon's Interactions with its External Environment*

The Moon is a natural laboratory for solar system processes and the ESM is optimized to increase our understanding of them.

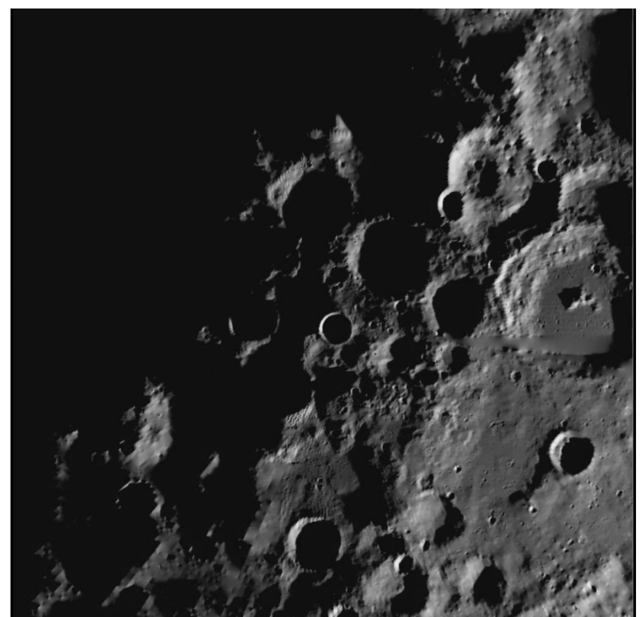
1. The Nature of Volatiles Deposited in the Moon's Polar Regions

In the Science and Exploration Missions LRO:

- Confirmed that polar regions are sufficiently cold to sequester volatiles
- Measured the lighting conditions in the polar regions
- Developed a high-resolution topographic model to predict illumination conditions forward and backward in time
- Measured volatiles released from Cabeus crater by the LCROSS impact



Paige et al., Science, 2010

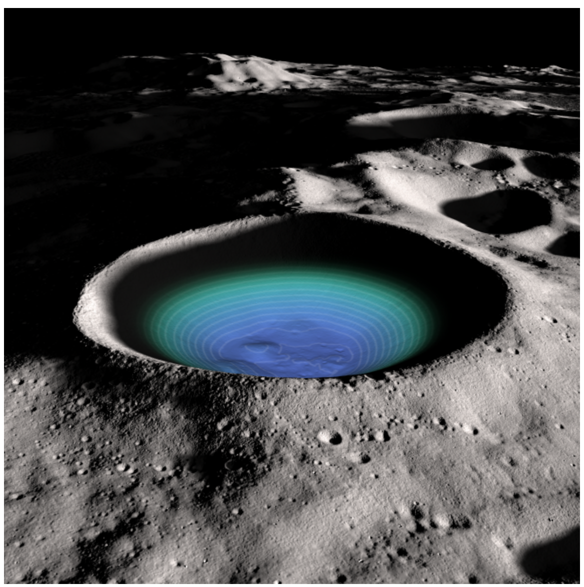


Simulation of polar lighting through the lunar day based on LOLA topography

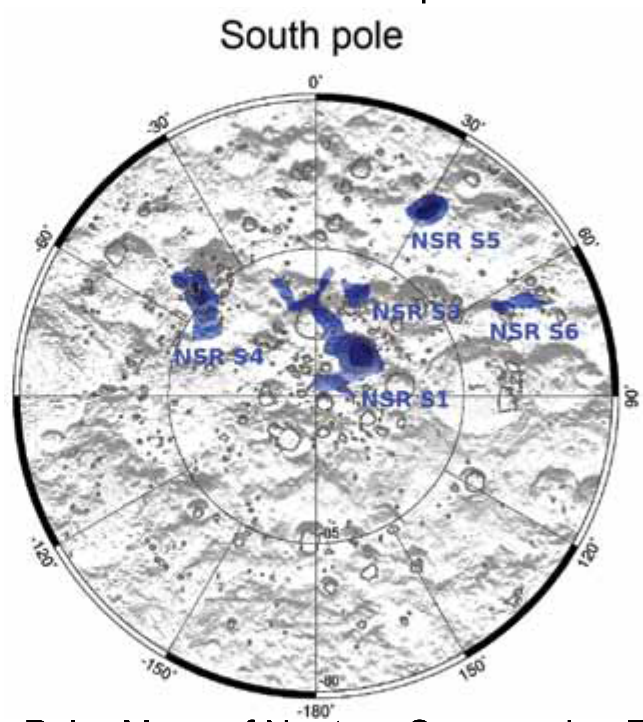
1. The Nature of Volatiles Deposited in the Moon's Polar Regions

In the Science and Exploration Missions LRO:

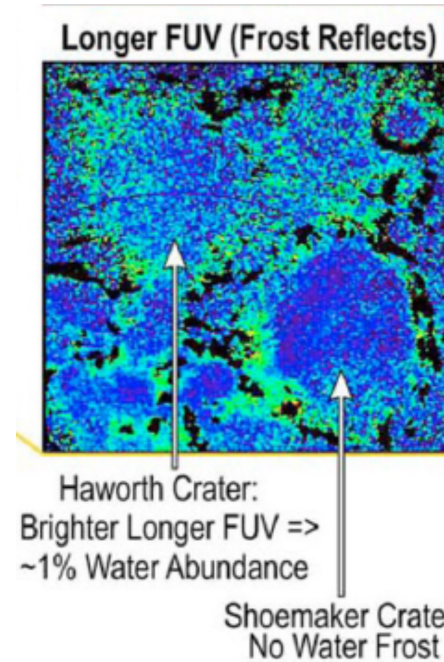
- Found evidence for hydrogen deposits in some, but not all PSRs
- Found evidence for hydrogen deposits outside of the PSRs.
- Found anomalous radar reflections in some polar craters consistent with ice
- Measured ultraviolet and infrared reflectance of some polar craters as consistent with water frost



Oblique view of the south pole derived from LOLA showing Shackleton crater with lower interior artificially illuminated (Zuber et al., Nature, 2012)



Polar Maps of Neutron Suppression Regions Consistent with subsurface hydrogen Mitrofanov et al., JGR, 2012

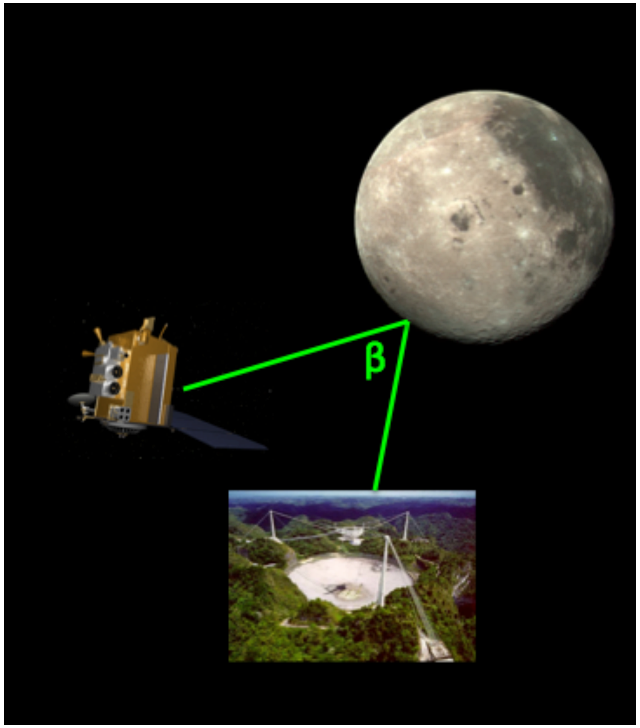


Gladstone et al., JGR Planets, 2012

1. The Nature of Volatiles Deposited in the Moon's Polar Regions

In the extended mission LRO will:

- Search for spatially extensive or blocky water-ice deposits with unique bistatic radar measurements
- Image the interior of Permanently Shadowed Regions (PSRs) using Earthshine and reflected light
- Increase diurnal and seasonal coverage of the dynamic illumination environment and temperature response of PSRs
- Continue neutron absorption measurements to improve accuracy of hydrogen abundance estimates and fill observational gaps at lower latitudes
- Determine the surface characteristics of the PSRs by FUV and IR measurements

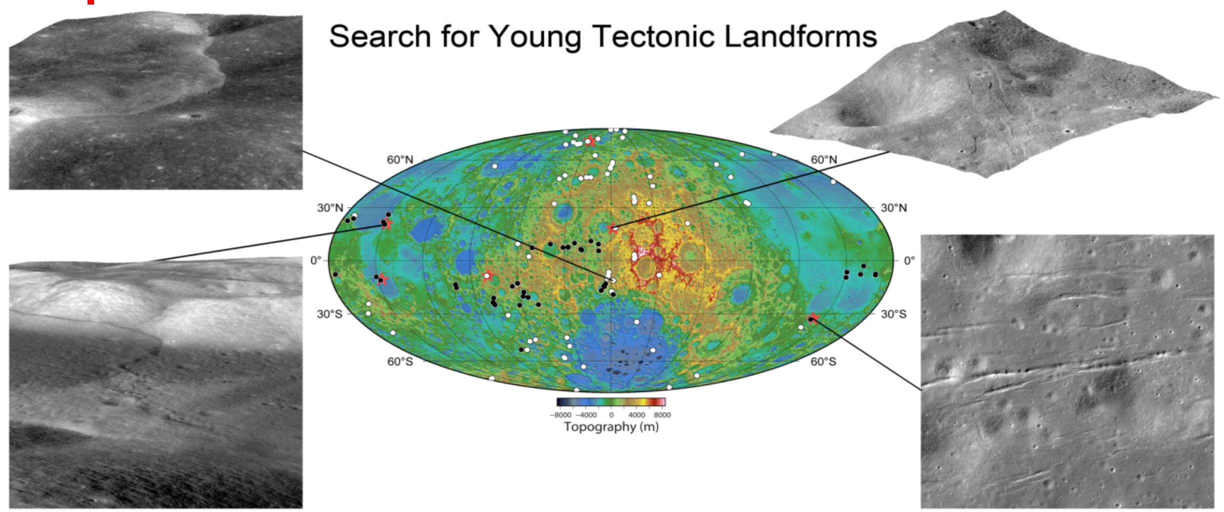


- Arecibo transmits & Mini-RF receives
- Can distinguish between rock and ice as signal changes through range of beta

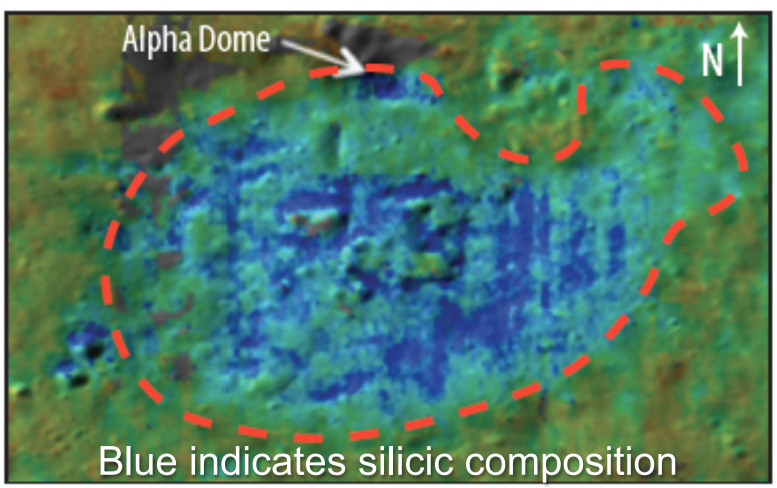
2. Terrestrial Planet Differentiation and Early Evolution

In the Science and Exploration Missions LRO:

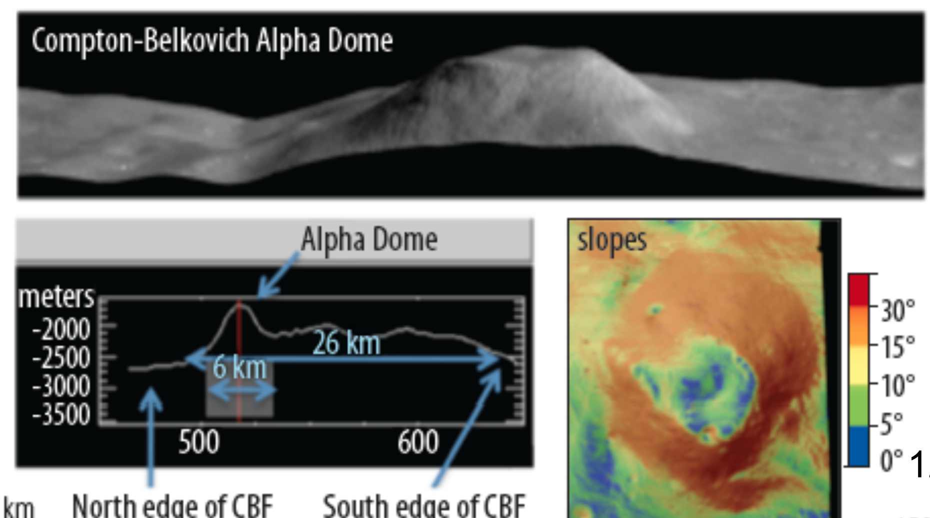
Discovered global population of small-scale, relatively young contractional and extensional structures that show the Moon is in a recent general state of low level global contraction.



Studied emplacement mechanisms for volcanic domes, by characterizing compositions, morphologies, slopes, flows, and volumes.



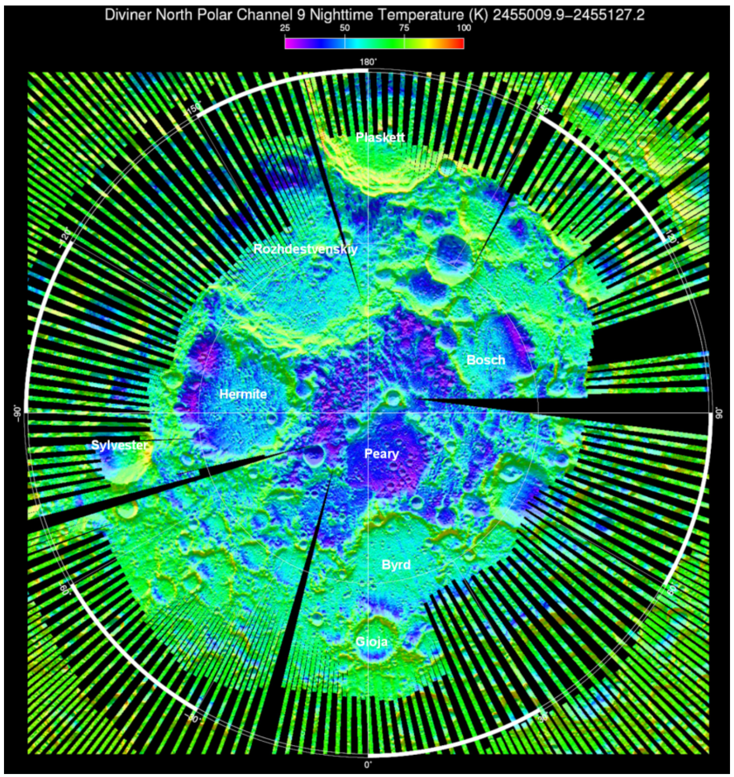
Compton-Belkovich Volcanic Complex, combined Diviner and WAC data, width view ~50 km



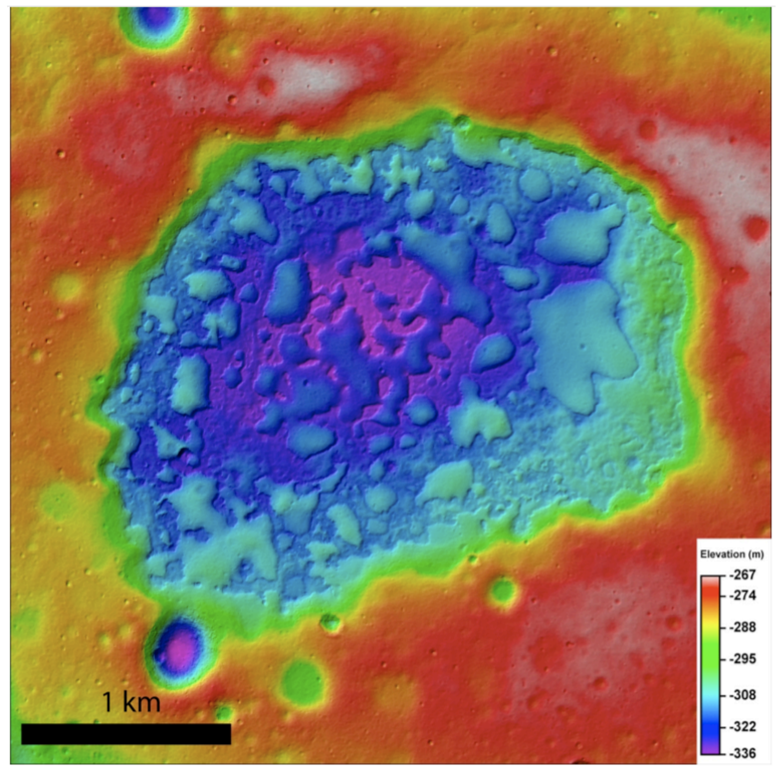
2. Terrestrial Planet Differentiation and Early Evolution

In the extended mission LRO will:

- Set new constraints on lunar heat flow by high resolution polar temperature measurements
- Characterize global distribution and composition of lunar volcanic constructs & deposits



Repeated Diviner measurements of the coldest surfaces on the Moon can be used to constrain lunar heat flow.

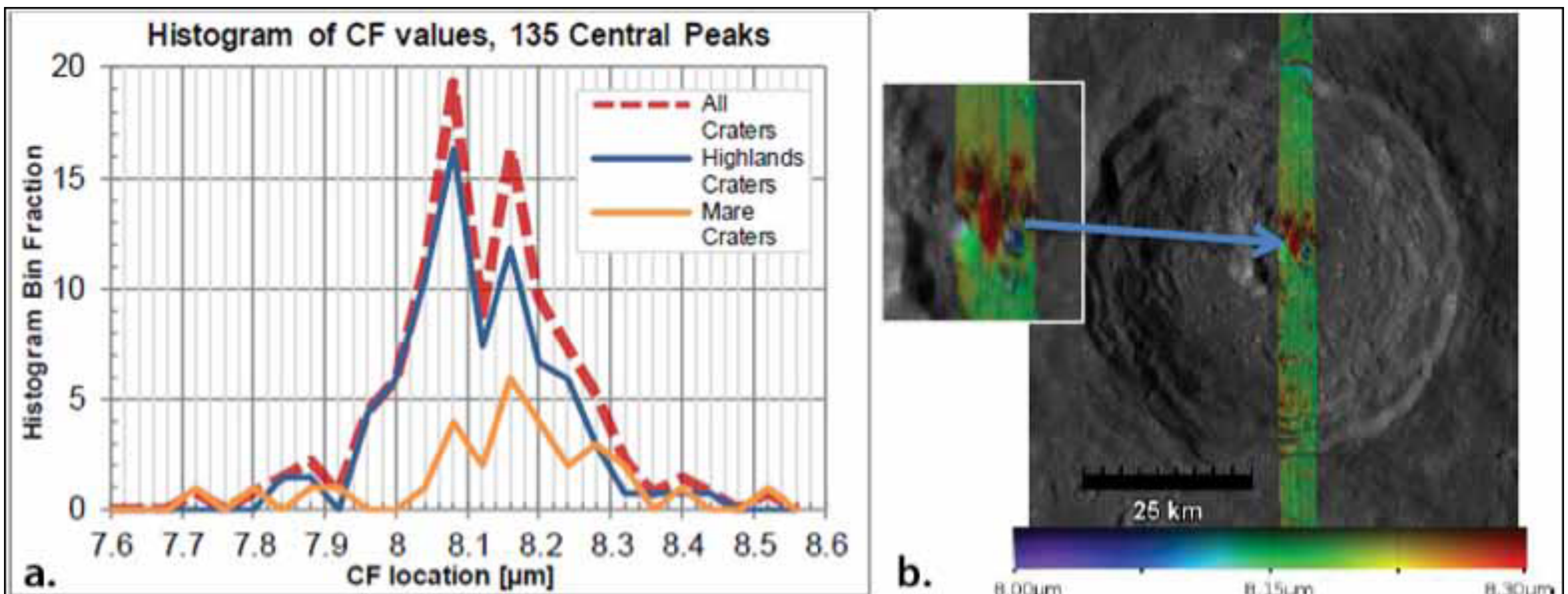


Ina-D caldera is an unusual depressed area in the center of low-relief volcanic dome that may be among the youngest volcanic features on the Moon. Topography derived from NAC geometric stereo.

2. Terrestrial Planet Differentiation and Early Evolution

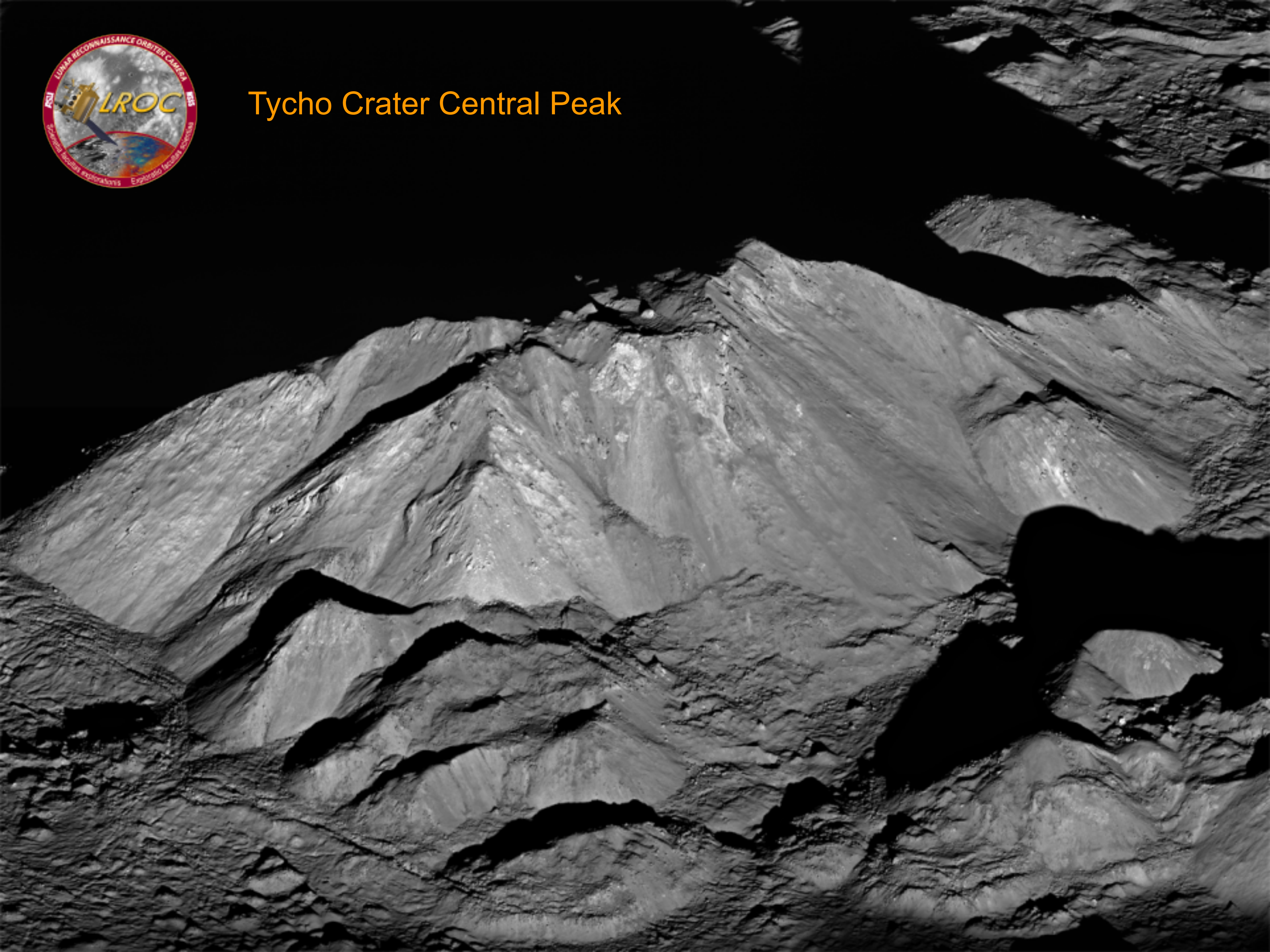
In the extended mission LRO will:

- Determine the global inventory of small-scale tectonic features and their relative ages by using high-resolution imaging and topographic data
- Determine the silicate mineralogy in and around impact features
- Determine the degree of heterogeneity of the lunar crust through enhanced global and targeted coverage of crater central peaks



Bulk silicate mineralogy of rocks in 135 crater central peaks, using the thermal-IR Christiansen Feature (CF) wavelength to indicate composition

Tycho Crater Central Peak



3. The Lunar Impact Record and its Relation to Solar System History

In the Science and Exploration Missions LRO:

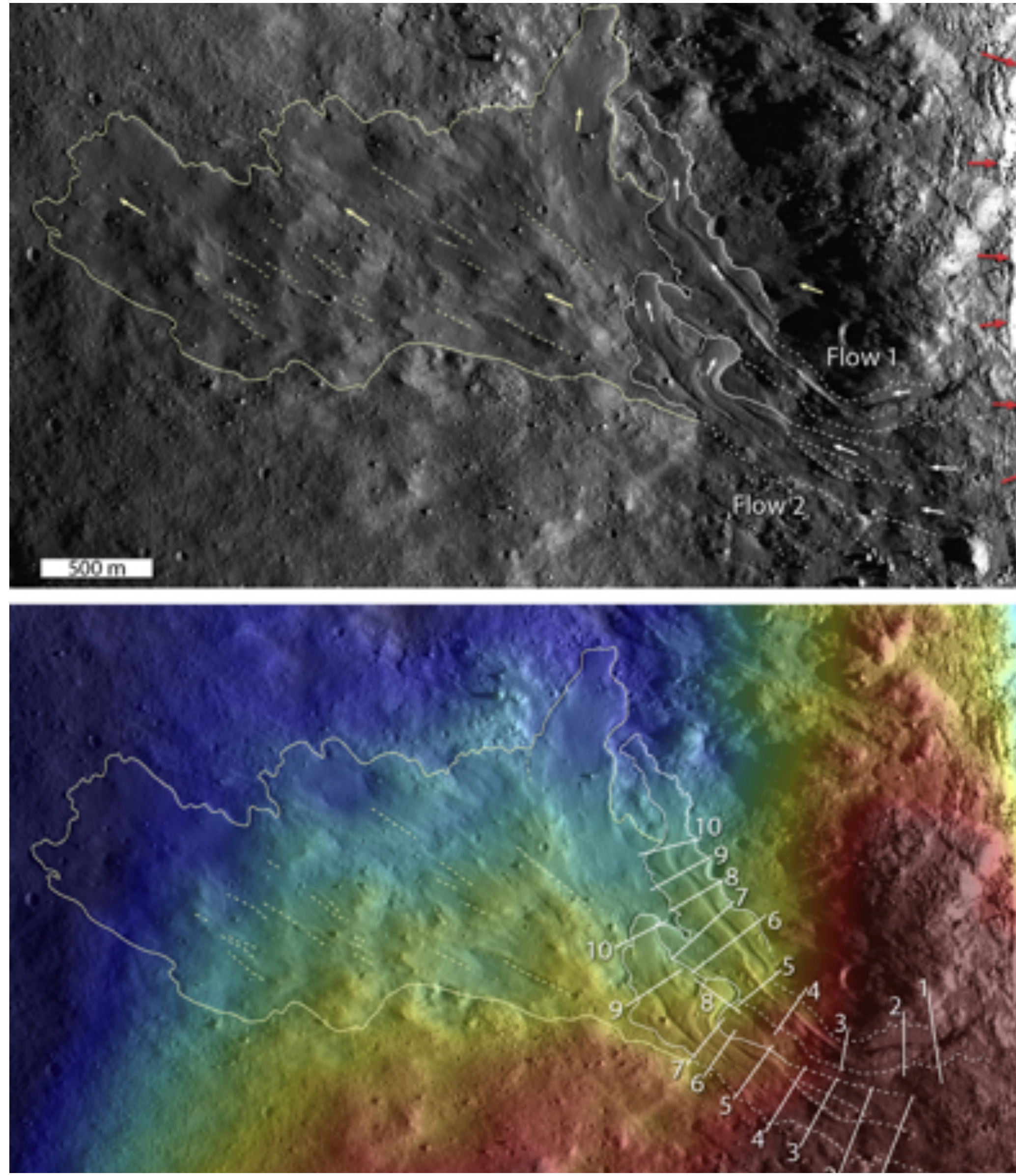
- Assessed the relative ages of the impact basins on the Moon, with detailed examination of topographic evidence for possible or proposed basins
- Developed an improved understanding of the ancient impactor population that affected all of the planets of the inner Solar System
- Improved the age dating of landforms by using crater counts from the new high-resolution images with Sun angles and illumination geometry optimized for morphology

Head et al., Global Distribution of Large Lunar Craters: Implications for Resurfacing and Impactor Populations, Science, 329 (5998), 1504 (2010)

3. The Lunar Impact Record and its Relation to Solar System History

In the extended mission LRO will:

- Expand stereo coverage to characterize and better understand the impact cratering process
- Calibrate models of impact melt volume and impact ejecta for simple and complex craters



Impact melt flows at crater Mandel'shtam F:

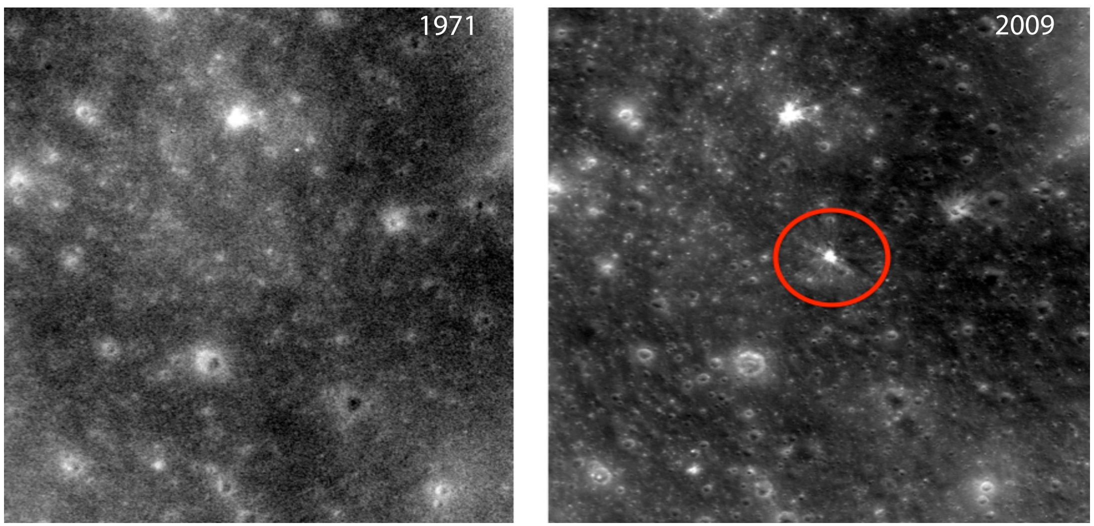
Top: Flows 1 and 2 outlined in white, arrows show flow direction. A sheet-like flow of melt is outlined in yellow, with arrows indicating flow direction and dotted lines showing streamlines within the flow. Red arrows indicate crater rim.

Bottom: NAC derived DTM overlain on orthorectified NAC image showing topographic control of flow down flanks of parent craters (blue to red indicates lower to higher elevation).

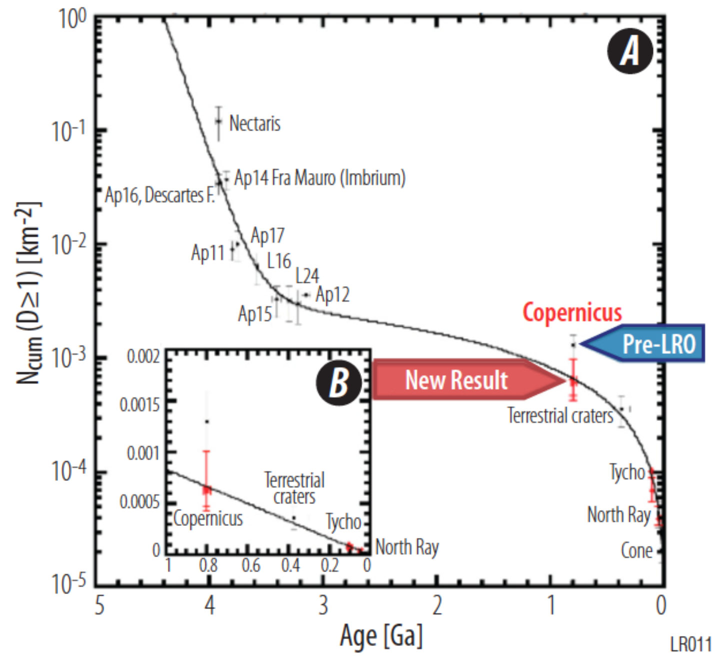
3. The Lunar Impact Record and its Relation to Solar System History

In the extended mission LRO will:

- Complete an inventory of Copernican and Eratosthenian craters and extend the coverage of older and more degraded craters
- Reimage Apollo era and earlier NAC observations to constrain models of meteor fluxes in the ~20 cm to 200 cm range



Multi-temporal NAC observations enable the search for new impact events to constrain current rates of small impacts.



Revision of the age of Copernicus improves the lunar impact crater chronology (from Hiesinger et al., 2012).

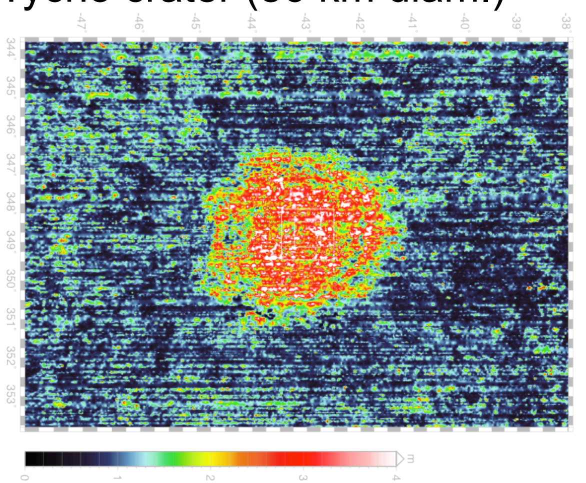
3. The Lunar Impact Record and its Relation to Solar System History

In the extended mission LRO will:

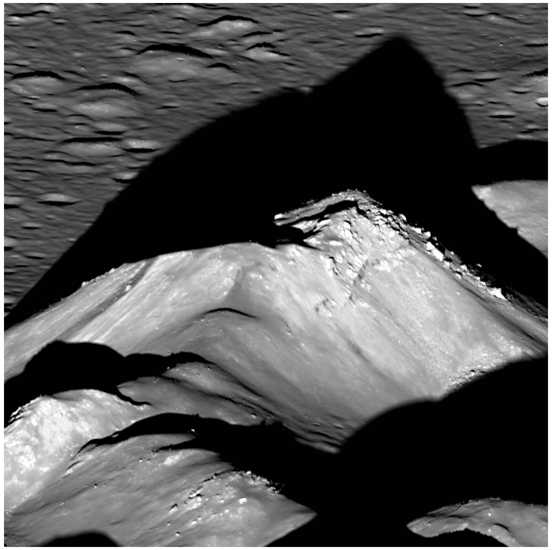
- Obtain surface roughness at a variety of scales and characterize the distribution of surface and subsurface blocky materials for a wide variety of impact craters

Copernicus Crater (93 km diameter)

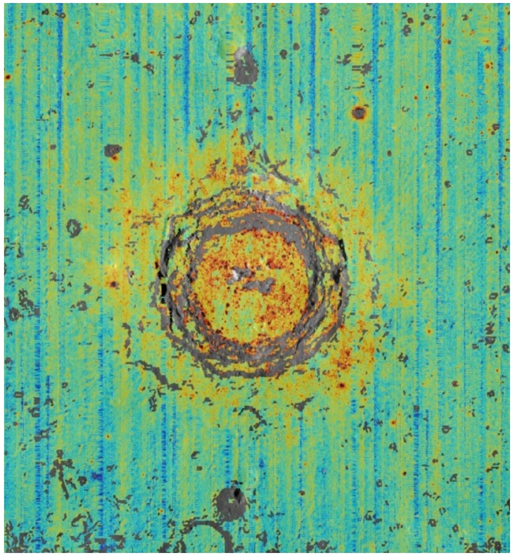
Tycho crater (86 km diam.)



LOLA roughness at 5-m horizontal scale inside the Tycho crater



NAC image of Copernicus crater central peak

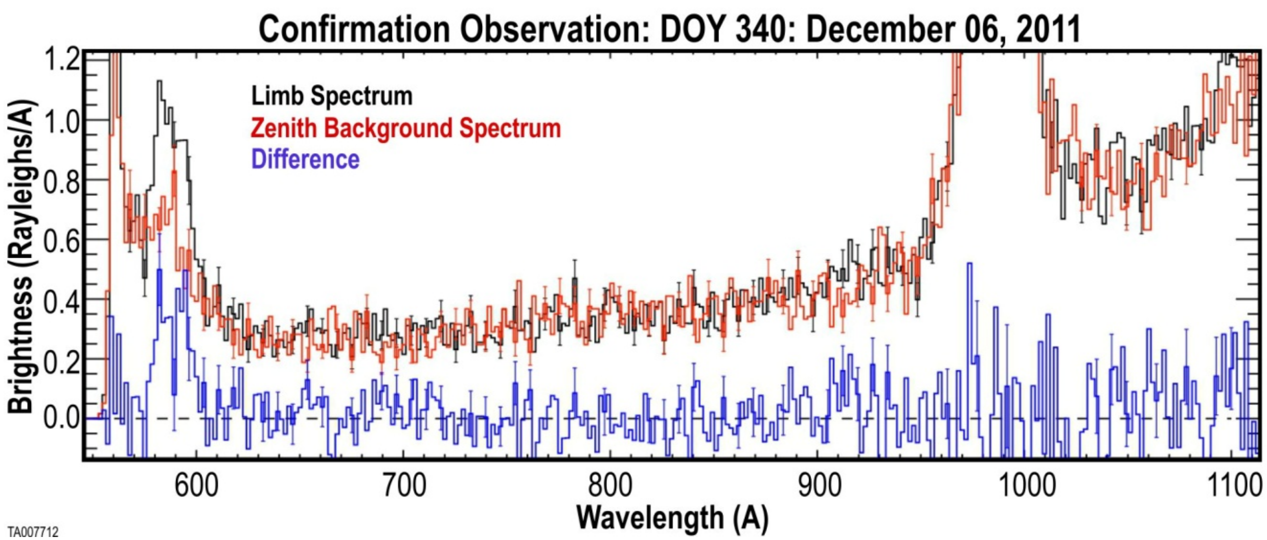


Diviner map reveals blocky proximal ejection buried 1 to 10 cm beneath regolith materials.

4. The Moon's Interactions with its External Environment

In the Science and Exploration Missions LRO:

- Measured Galactic Cosmic Ray (GCR) interactions with the Moon during a period with the largest space-age cosmic ray intensities.
- Created the first proton albedo map of the Moon
- First detection of the lunar helium atmosphere using remote sensing and upper limits for other species and exospheric dust layers
- Uncovered evidence of unusual porosity at the surface of the regolith inside PSRs

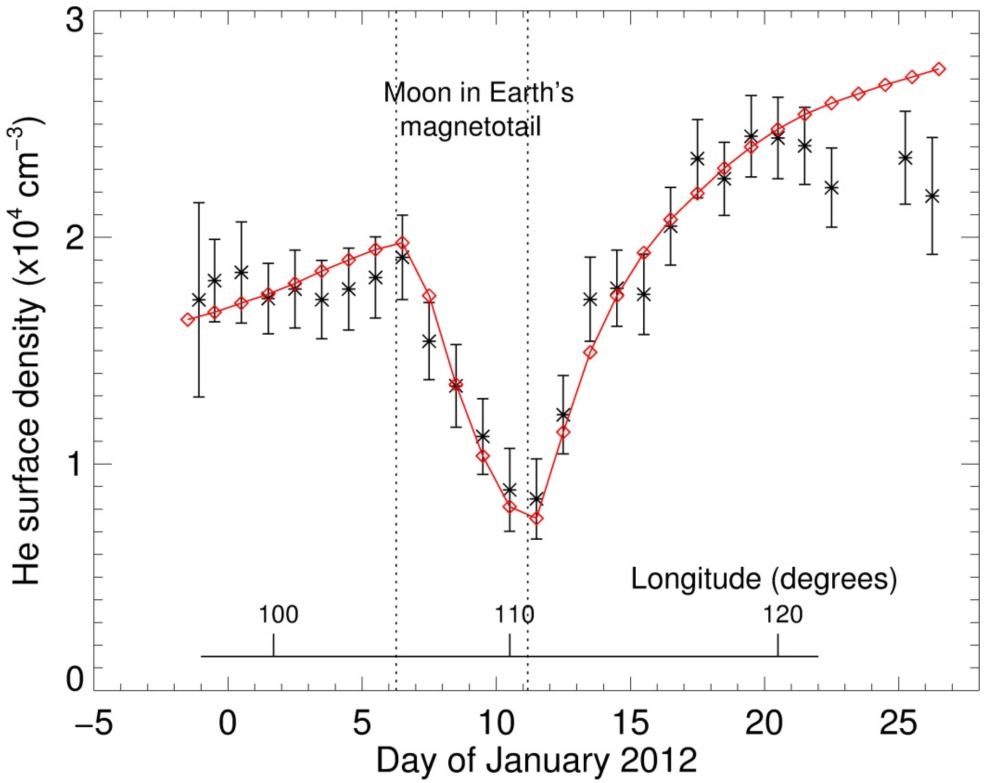


First remote detection of the lunar helium exosphere, Stern et al., GRL, in press.

4. The Moon's Interactions with its External Environment

In the Extended Mission LRO will:

- Identify the processes that control the dynamics of the surface-bounded exosphere by measuring the spatial and temporal variability of the lunar helium exosphere
- Expand the search for trace components of exospheric species and dust

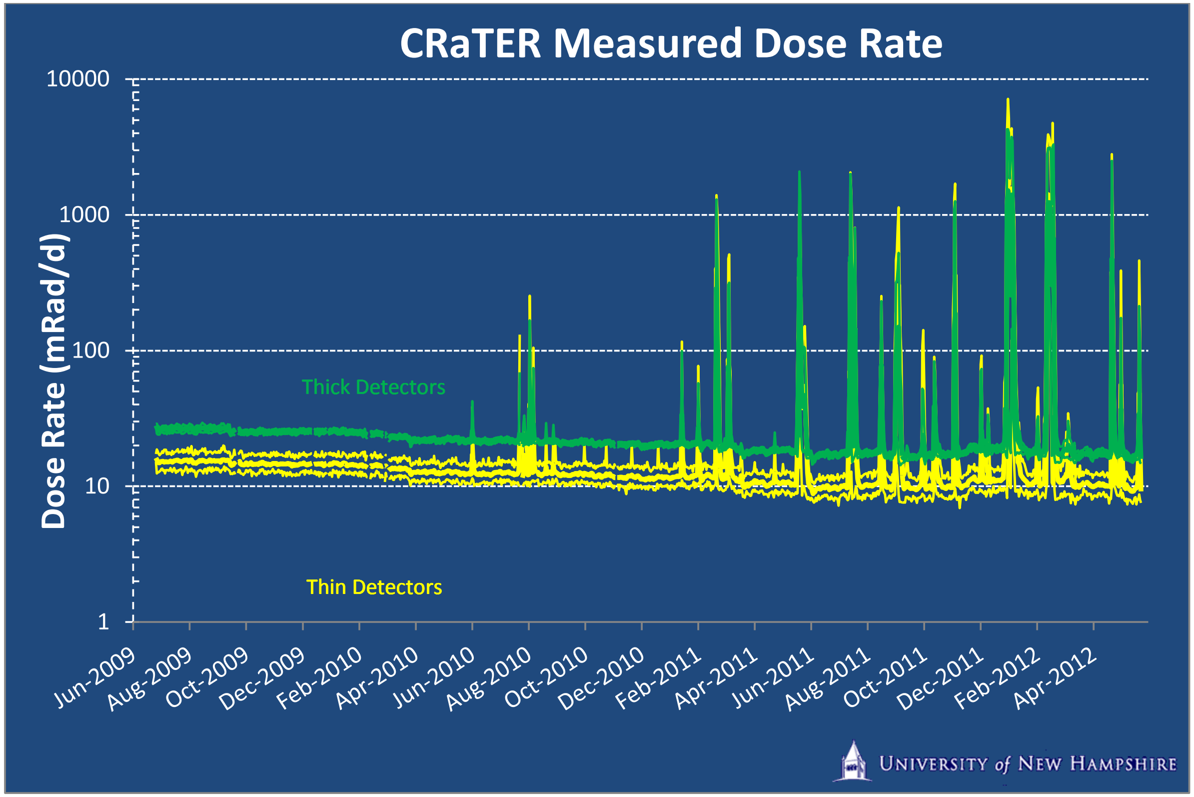


A clear decrease in He is observed during passages into the Earth's Magnetotail; Feldman et al., *submitted to Icarus*, 2012.

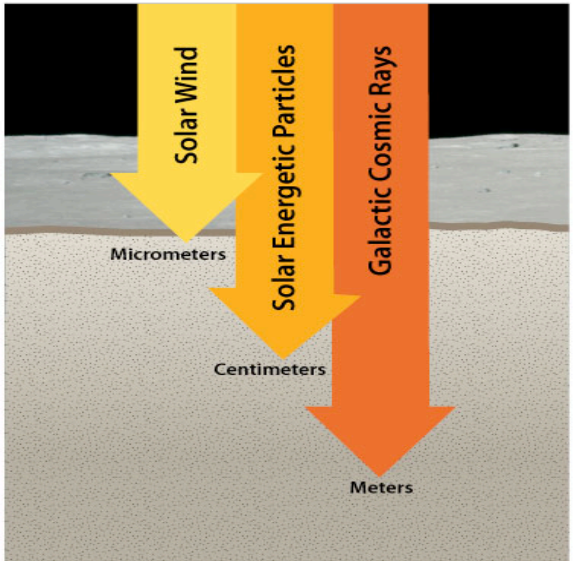
4. The Moon's Interactions with its External Environment

In the Extended Mission LRO will:

- Measure the GCR and SEP flux and radiation dose during the maximum phase of the solar cycle



LRO began the mission with the largest space-age cosmic ray intensities on record and is entering a phase with a more active Sun.

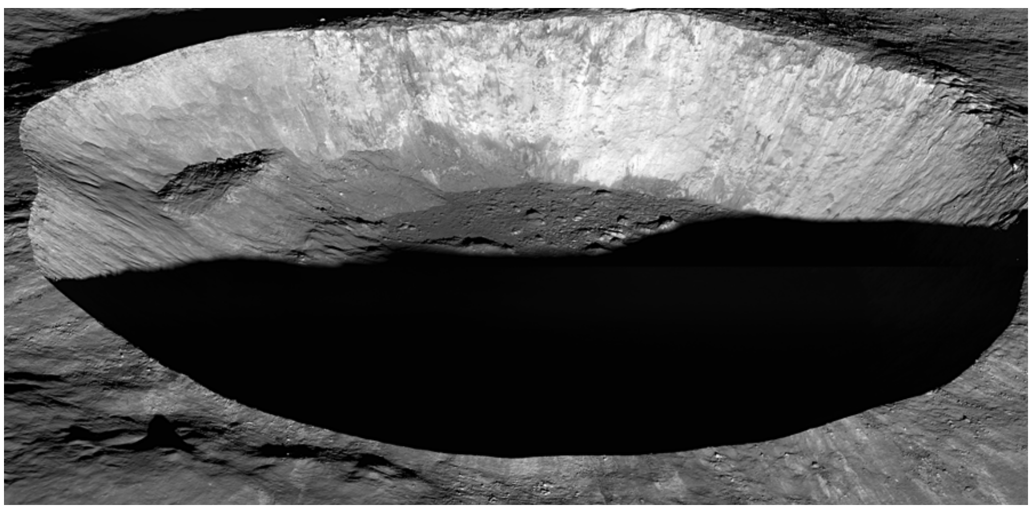


ESM measurements will reveal how SEP events & GCRs contribute to subsurface space weathering

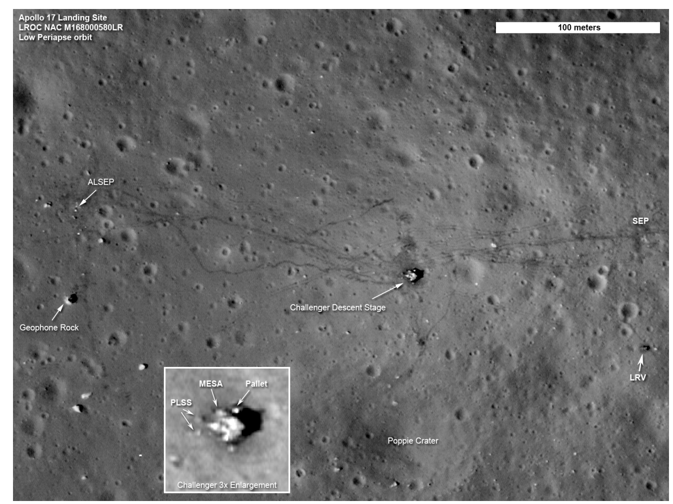
Public Impact of LRO

- LRO has outstanding Education and Public Outreach (EPO) and Public Affairs programs
- Internet utilization
  - The LRO Project and all instruments have web pages, with numerous images and visualizations
  - LRO results frequently highlighted on nasa.gov
  - Social networking (Facebook, Twitter, YouTube)
- Frequent media interactions: 39 Press releases; 11 press conferences; Numerous interviews
- Professional Development Workshops for educators
- Museum exhibits; Science on a Sphere visualizations
- Public events: Live broadcast of lunar orbit insertion on NASA TV; International Observe the Moon Night

LRO observations are a wonderful source of public inspiration!



Sunset over Giordano Bruno



Apollo 17 site