Lunar Reconnaissance Orbiter Data in Support of Characterizing Future Landing Sites

Lunar Science for Landed Missions Workshop

January 10th, 2018

LROC NAC Image of Apollo 16 landing site, M192817484

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Mission Update

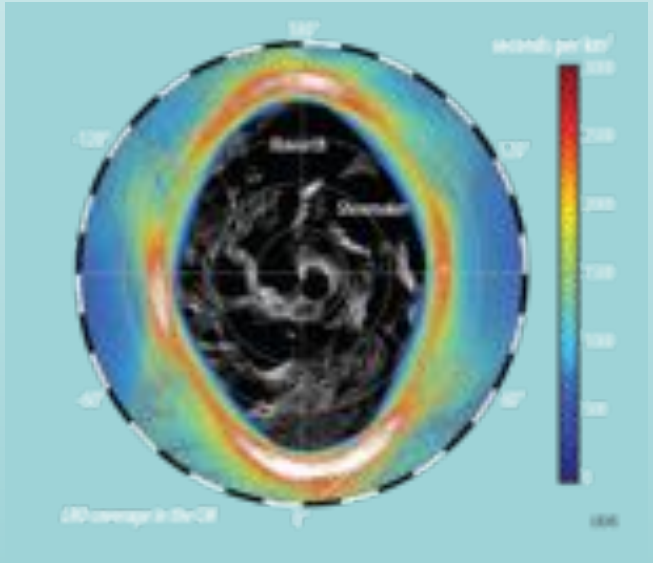
- LRO is nominal
- Instruments are nominal
- LRO operations team and instrument operations teams are exceptional
- 3,039 days of lunar science (103 lunar days)

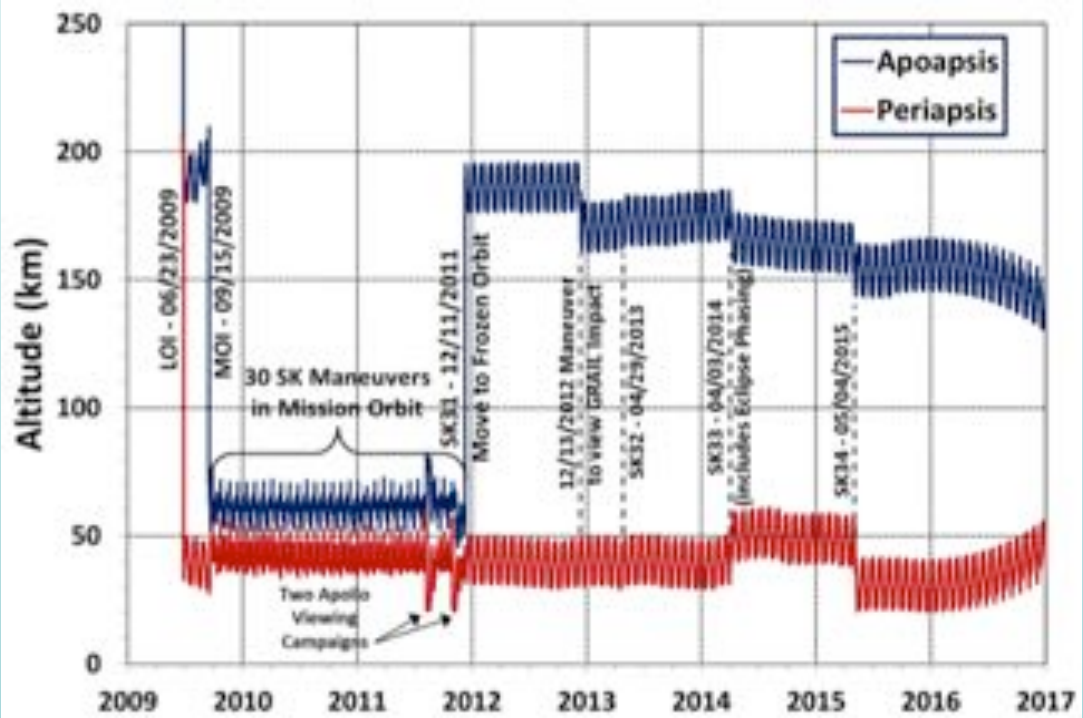
- Mini-RF is collecting data with Goldstone, Arecibo is getting back online
- Lunar eclipse on Jan. 31
- Oct. 20 – International Observe the Moon Night
- 44% through a three* year extended mission – The Cornerstone Mission

Lunar phase and libration, 2018
https://svs.gsfc.nasa.gov/4604

Mission Status - Orbit

- LRO remains in a “quasi-stable” orbit with a periapsis near the South Pole
- GRAIL data have proven invaluable in predicting our orbits
- LRO’s orbit now traces over a latitude ~87.5º



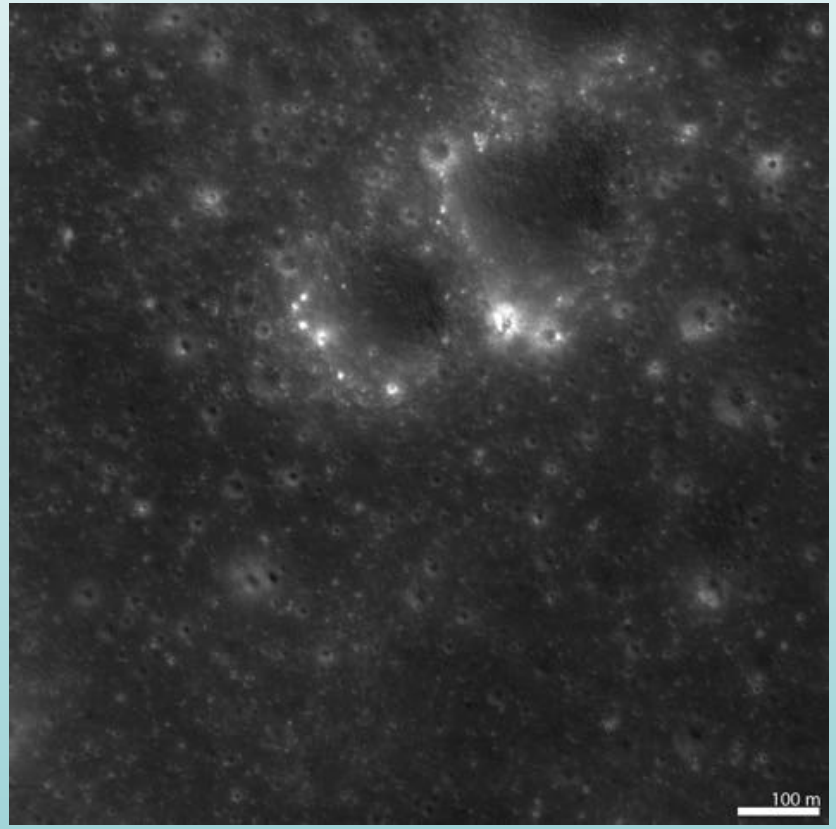


The Benefit of a Long Lived Orbiter

- LRO-era impact craters found by LROC (and others)
- SEP events recorded by CRaTER
- Volatile transport by LAMP, CRaTER, LEND
- High temporal resolution thermal variations by Diviner

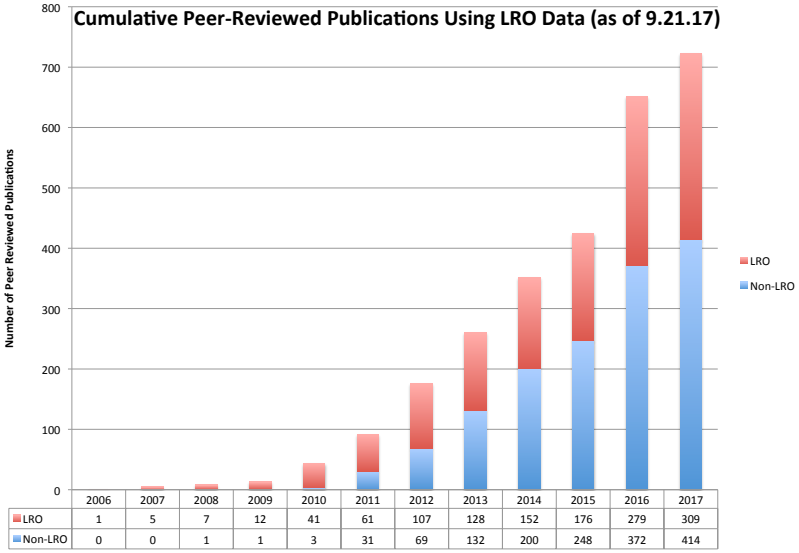
- Synergies with other missions (LADEE, GRAIL, ARTEMIS, etc.)
- New modes of operation for Mini-RF, CRaTER, LOLA, and LAMP

- Operate long enough to see another initiative to return to the Moon!



What is the future of LRO?

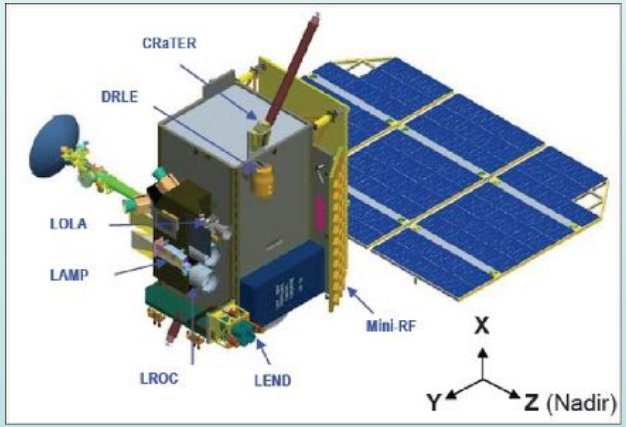
- LRO runs on the four “P’s”
  - Proposals:
    - We are in the midst of our current extended mission, ends on September 15, 2019*
  - Papers:
    - LRO science teams continue to be productive
    - The community uses LRO data



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
LRO	1	5	7	12	41	61	107	128	152	176	279	309
Non-LRO	0	0	1	1	3	31	69	132	200	248	372	414

What is the future of LRO?

- LRO runs on the four “P’s”
  - Propellant:
    - LRO has ~27 kg of fuel remaining (including line loss of 5 kg), and has used ~20 kg in the last 6 years
    - LRO launched with 898 kg of hydrazine propellant
    - 741 kg (82.5%) used to get into orbit
    - 95.75 kg (10.7%) was allocated for orbit maintenance (station keeping and momentum unloads) during our initial quasi-circular Exploration Orbit from 9/15/09–9/15/10
    - 61.25 kg (6.8%) was allocated for the Science Mission and margins.
    - We have more than 47% of the hydrazine propellant that had been allocated for the LRO Science Mission. We expect to continue careful propellant management so that LRO will have a useful lifetime of up to 11 years.
  - Power:
    - LRO’s solar panel provides power to the S/C
    - Continuous monitoring of the power supply



Data Driven Lunar Exploration

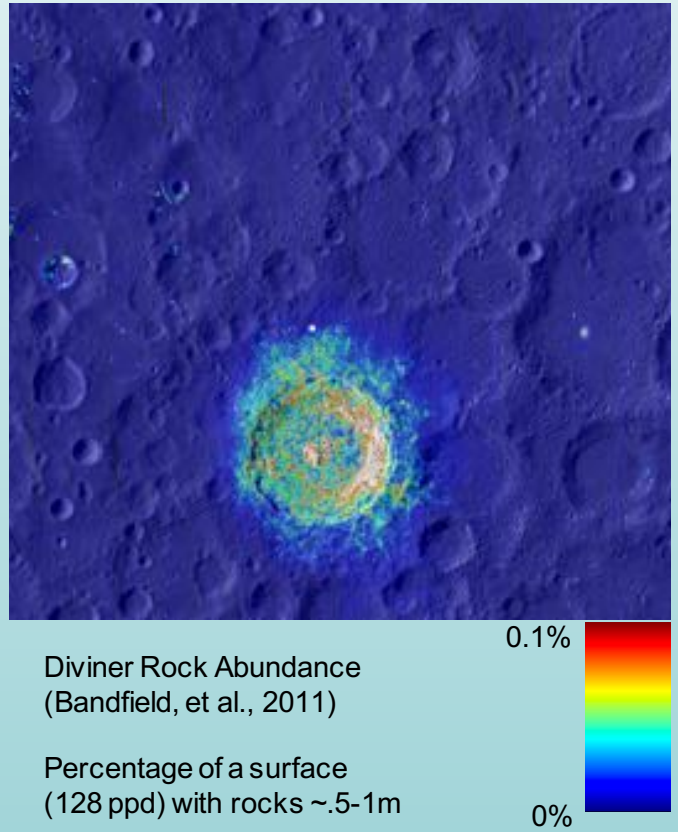
- "Science Enables Exploration, Exploration Enables Science"
- LRO is collected an array of lunar data characterizing
  - Properties of the regolith
  - Rock abundances
  - Location of volatiles, esp. the polar regions
  - Lighting conditions including permanently shadowed regions (PSRs)
  - Temperatures including inside PSRs
  - Composition
  - Topography and slopes

- While individually valuable, taken together the data enable comprehensive planning for a lunar landed mission
  - Location of resources
  - Landing site identification
  - Traverse planning

Ernie Wright (NASA/GSFC/SVS)

What Data Does LRO Produce to Support Landing Site Characterization

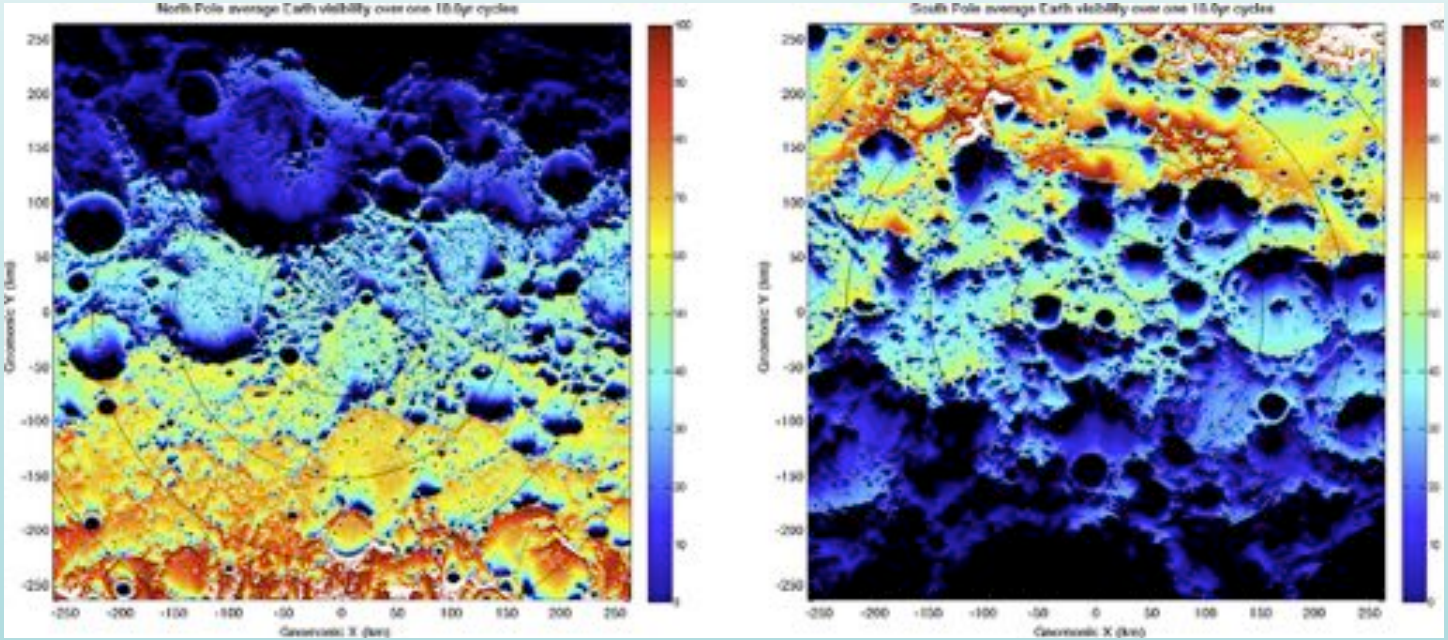
- Surface characterization:
  - LROC NAC (50 cm per pixel from 50 km orbit)
  - LROC WAC 100 mpp (morphology, albedo, composition)
  - Diviner Rock Abundance (Bandfield et al., 2011) and H-parameter (Hayne et al., 2018) at 128 ppd
  - Diviner temperature
- Topography
  - LROC NAC DTM (2 mpp)
  - LOLA DTM (512 ppd)
  - SLDEM
  - The above provide:
    - Slope
    - Terrain Ruggedness Index
    - Illumination
    - Earth line-of-sight



Diviner Rock Abundance (Bandfield, et al., 2011)

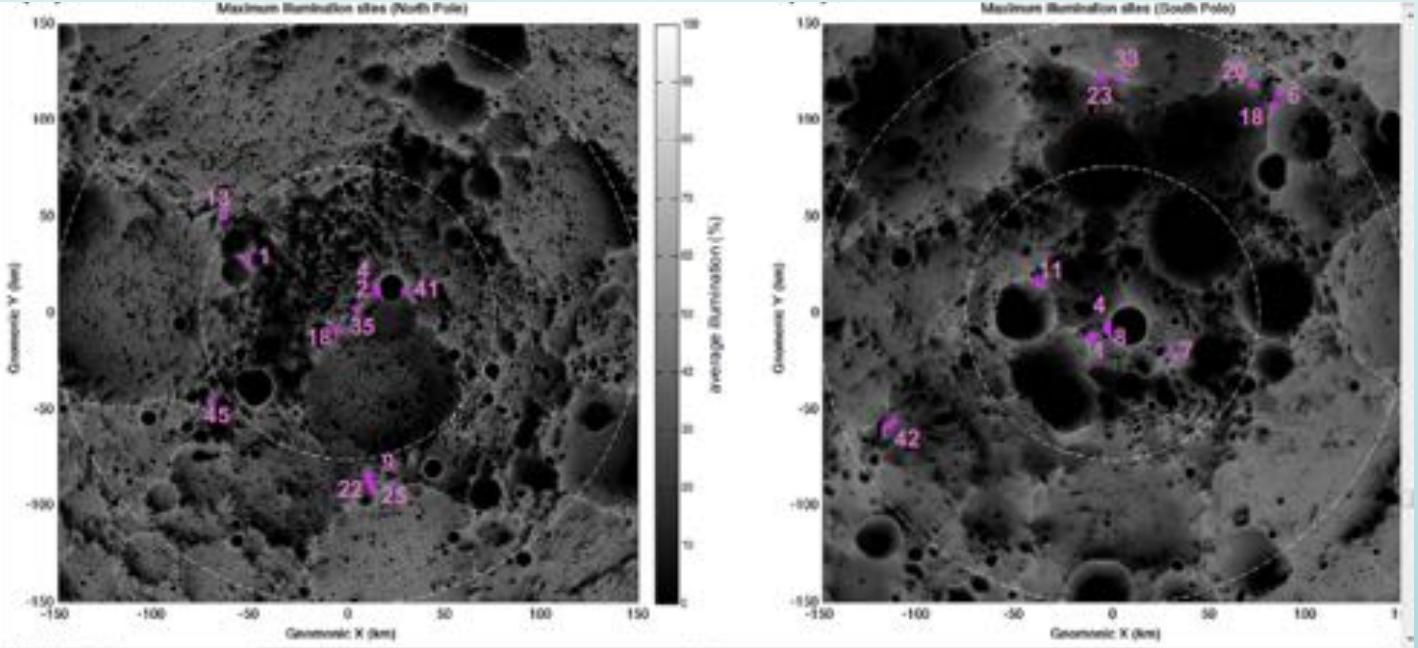
Percentage of a surface (128 ppd) with rocks ~.5-1m

Earth Visibility Maps – Access to Direct Earth Communication



The average visibility of Earth (in percent of a full 18.6 year cycle) for the north (left) and south (right) polar regions.
Full visibility and total lack of visibility are indicated by white and black respectively.

Lighting Maps - Access to Near Continuous Illumination



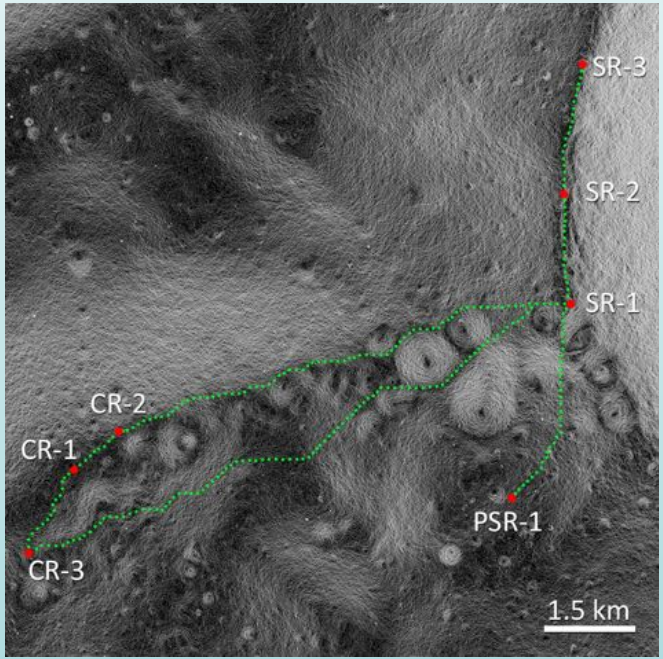
Sites of maximum illumination in the north (a) and south (b) polar regions, over a grayscale map of average sun illumination. The numbers indicate the rank at surface level found in table 3 of Mazarico et al. / Icarus 211 (2011) 1066–1081
For example, site #1 in the South is illuminated 89% of the time.

Surface Navigation/Trafficability

- LRO data, such as topography models from the Narrow Angle Camera and LOLA as well as temperature data derived from the Diviner, has enabled the development of a tool for use in surface traverse planning

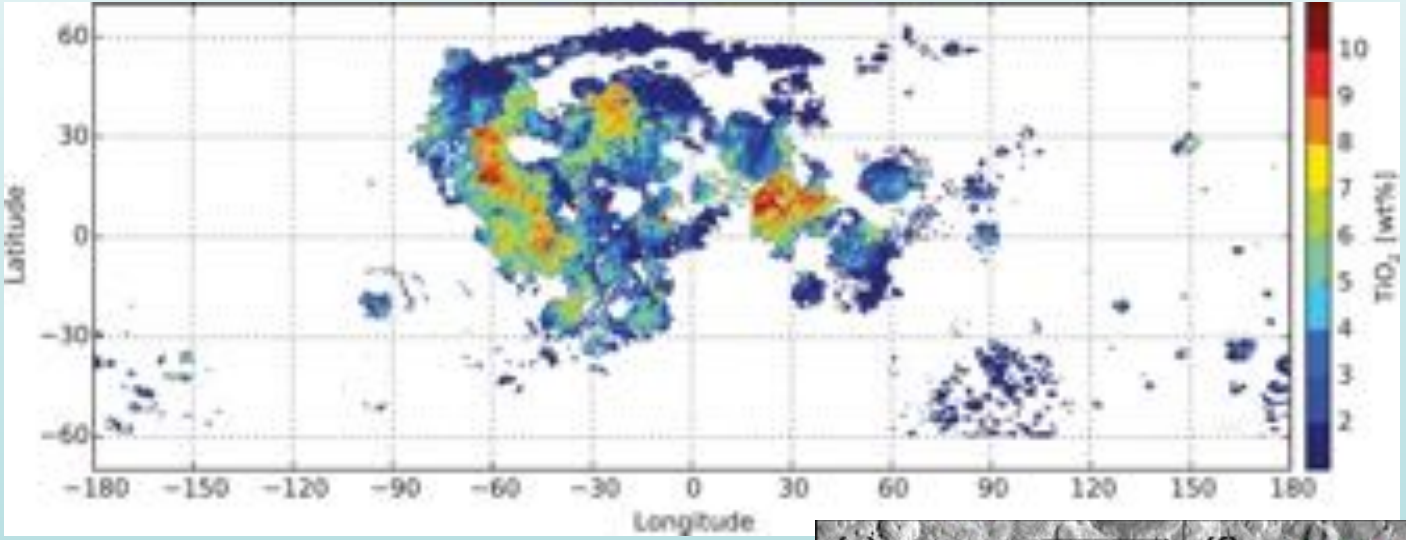
- Based on topography from NAC and LOLA and known surface properties, one can estimate the energy required to traverse between different targets using a terra-mechanics model

- We can calculate the illumination conditions along the traverse at any point in time

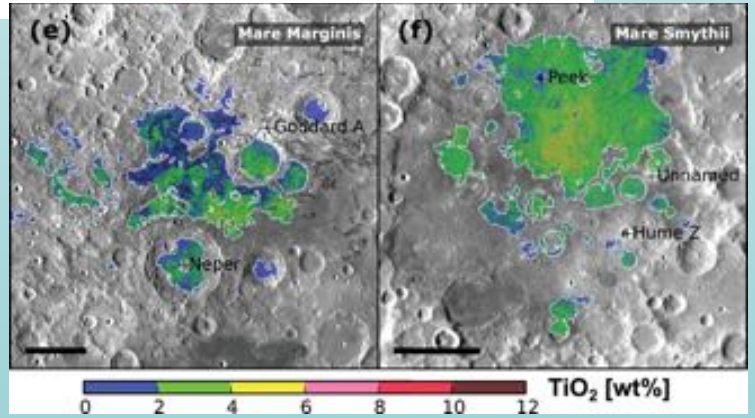


Example of an optimized traverse located along nearly persistently illuminated points on the rim of Shackleton crater (SR-1, SR-2, and SR-3) and the connecting ridge between Shackleton and de Gerlache crater (CR-1, CR-2, and CR-3). **(Speyerer et al., 2016).**

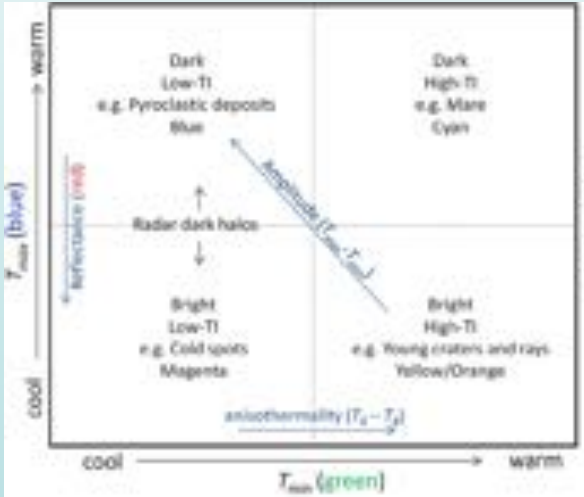
LROC WAC TiO_2 Estimates

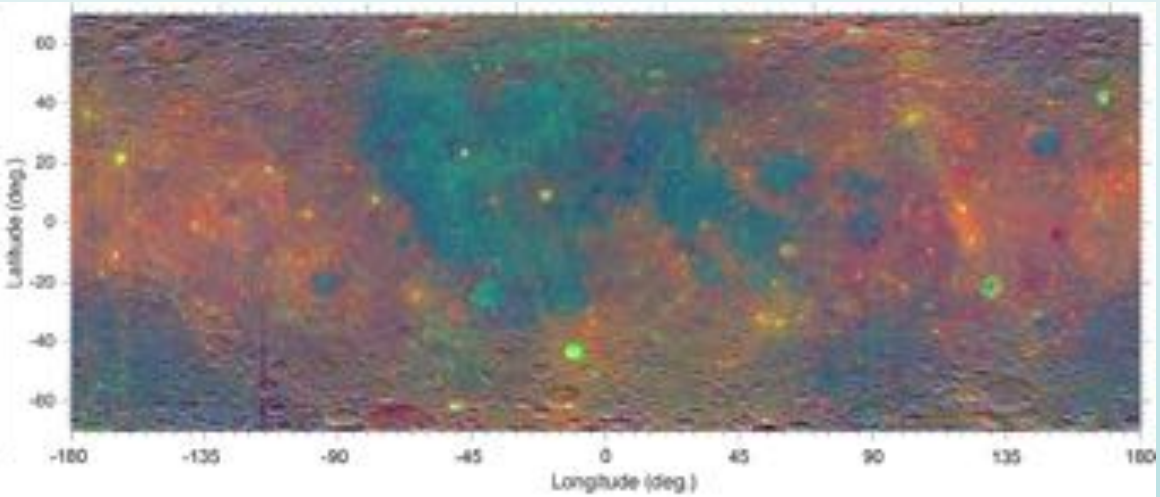


- Sato et al. (2017) in Icarus
- Using a ratio of the 321 and 415 nm bands to estimate TiO_2 content of basalts
- WAC multiband mosaics available at http://lroc.sese.asu.edu/archive/popular_downloads



Global Surface Temperatures



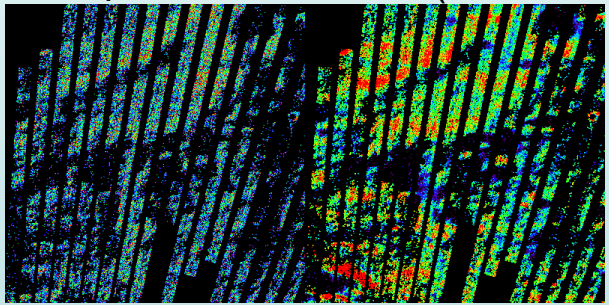


- Williams et al., (2017, Icarus) used the extended temporal baseline of surface temperatures to illustrate the thermal response of the surface
  - Red = brightness in Channel 1 (0.35–2.8μm)
  - Green = minimum bolometric temperature
  - Blue = maximum bolometric temperature

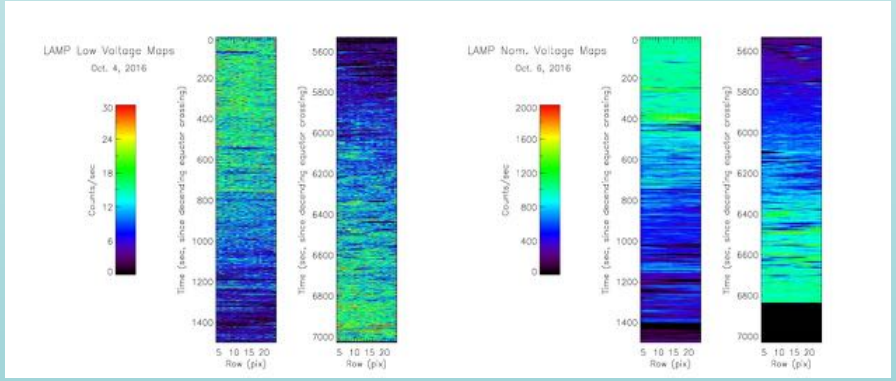
New LAMP Failsafe Door Open Mode:
A new emphasis on dayside dirunal variations

- LAMP's new mode improves dayside spectral imaging data quality by increasing typical UV photon detection rates of 600-3000 counts/sec up to 50,000 counts/sec (x15 to x80).
- **Searches for variability that otherwise would require trending months of data for statistics may be performed with individual LRO orbit strips like those displayed here.**
- Previous data quality at left is noisy with sparse coverage in individual orbit tracks; right shows much improved map quality for the new mode.
- Comes at the cost of increased calibration efforts, and faster detector gain degradation.

Maps: Before After (Prediction)



Orbit Strips: Before After (Real Data)



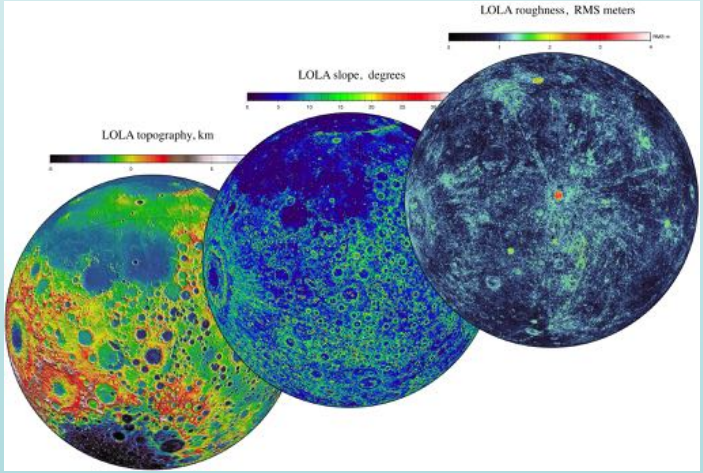
LRO Data Products

- All products are archived in the PDS and at the instrument team webpages
  - LROC at http://wms.lroc.asu.edu/lroc/rdr_product_select
    - Quickmap: quickmap.lroc.asu.edu

LROC NAC Oblique (OBL)
Highly oblique images acquired with large spacecraft slews will allow stratigraphic relationships to be more readily distinguished.

LROC NAC Stereo (3D)
Stereo image pairs acquired by slewing the spacecraft on adjacent orbits will enable derivation of high-res local topography of features of interest.

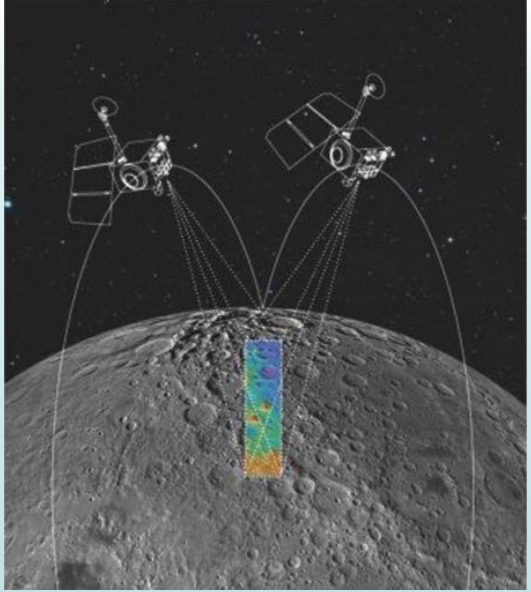
LROC Featured Mosaic (FM)
Mosaics of many NAC images acquired with uniform illumination over several consecutive orbits will enable consistent geologic analyses of complex sites larger than a single NAC pair.



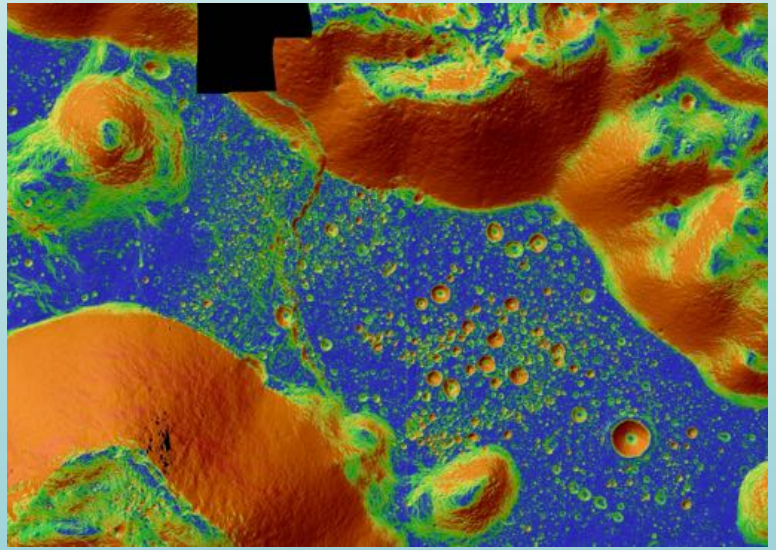
  - LOLA at http://imbrium.mit.edu
  - Diviner at http://www.diviner.ucla.edu/data
  - Main PDS archive: http://pds-geosciences.wustl.edu/missions/lro/default.htm
    - LAMP polar products, Mini-RF polar mosaics, etc.

Topography

- Data from the LOLA and LROC instrument provides local and regional slope data.
- LROC NAC DTM's provide localized topography tied to the LOLA frame (Apollo 17 below)



Henriksen et al., 2017



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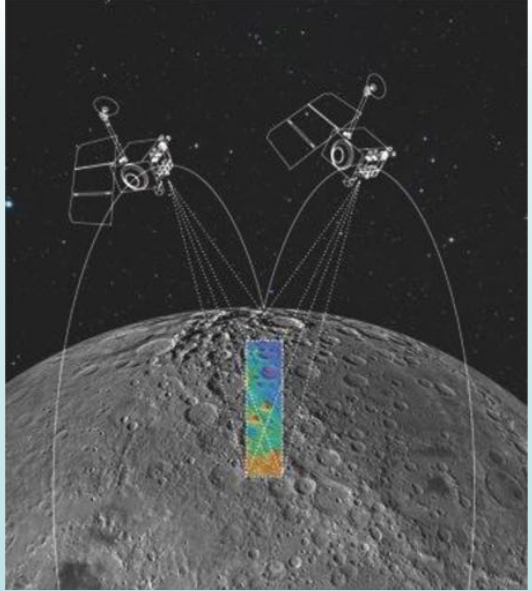

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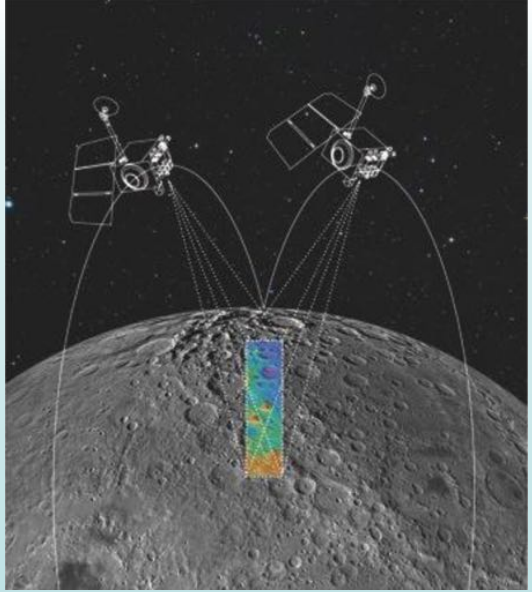

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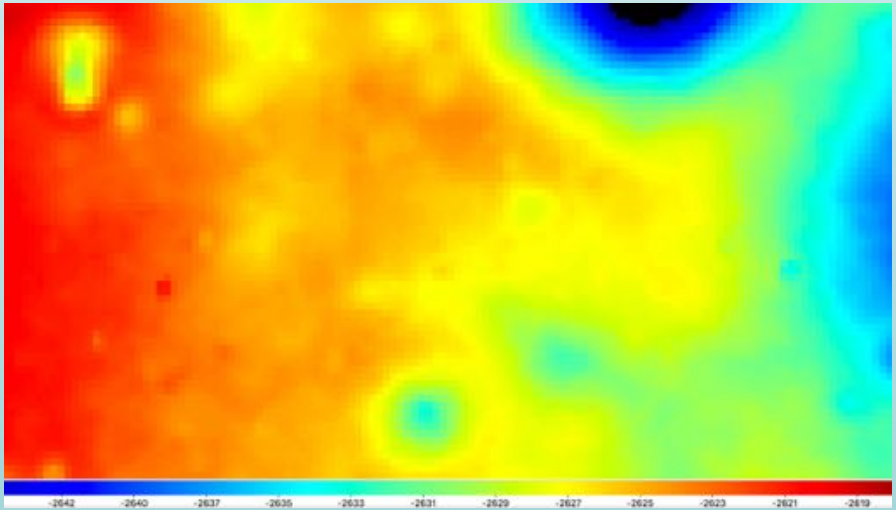


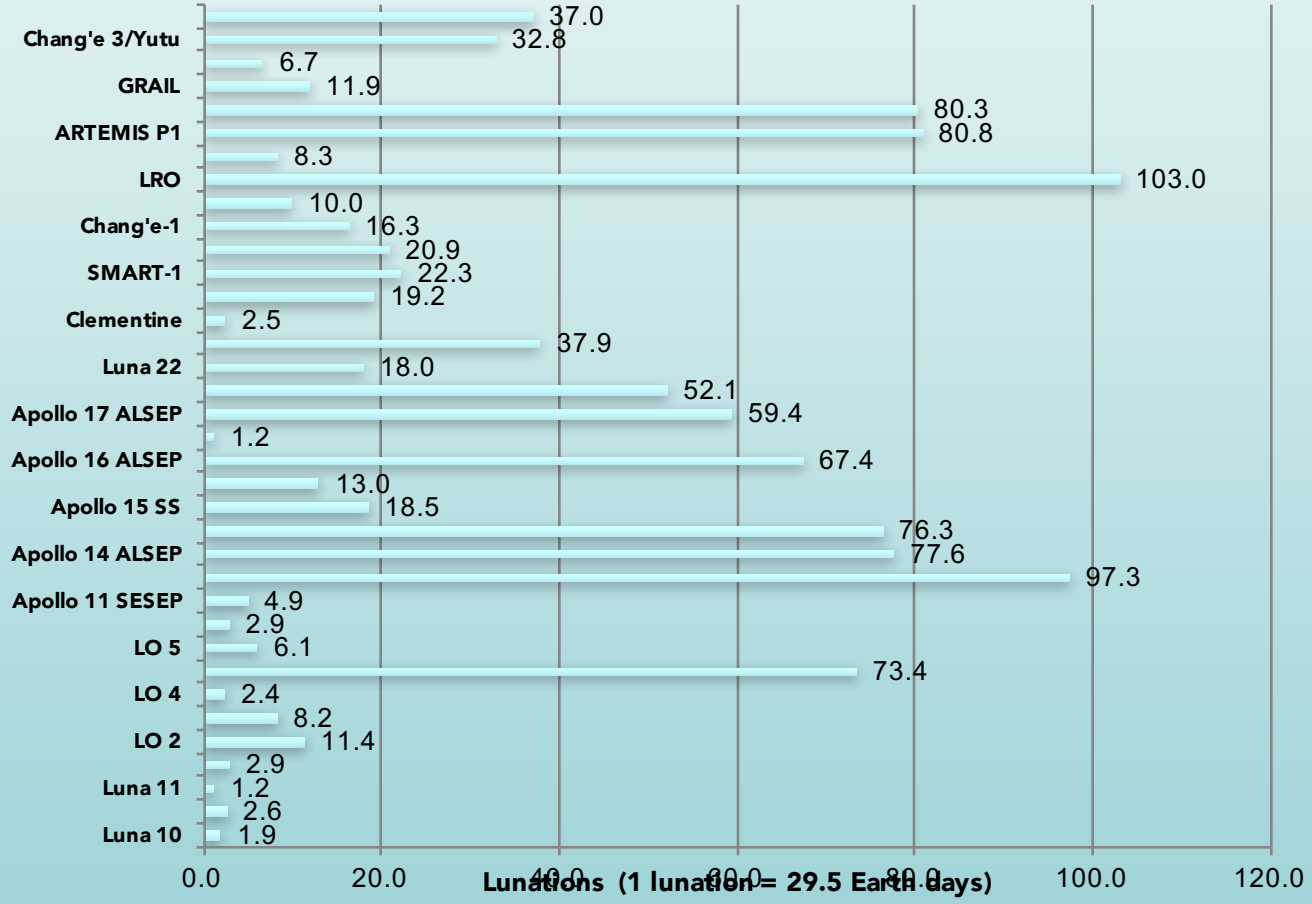
Elevation (m)

LRO – The gift that keeps on giving

- Planning is underway for ESM4
- We are evaluating orbit options that enable new science
- Eager to support future lunar landed missions

Portion of Jackson Crater central peak
http://lroc.sese.asu.edu/posts/992
Imaged area is 10 km from top to bottom
M1117602006LR

LRO: A Long Lived Mission



LROC Shapefiles

- Anthropogenic Features
- Constellation Targets
- NAC DTMs
- Stereo Observations
- Featured Mosaic Observations
- IMP Locations
- Swirls
- Wrinkle Ridges
- Lobate Scarps
- Polar Lobate Scarp Locations
- Mare

- Hiesinger (2011) Mare Age Units
- Hiesinger (2011) Mare Count Areas
- Copernican Craters
- Craters 5 to 20 km Diameter: 0° to 90° E
- Craters 5 to 20 km Diameter: 0° to 90° W
- Craters 5 to 20 km Diameter: 90° E to 180° E
- Craters 5 to 20 km Diameter: 90° W to 180° W
- Craters 5 to 20 km Diameter: North Pole
- Craters 5 to 20 km Diameter: South Pole

- http://lroc.sese.asu.edu/posts/978