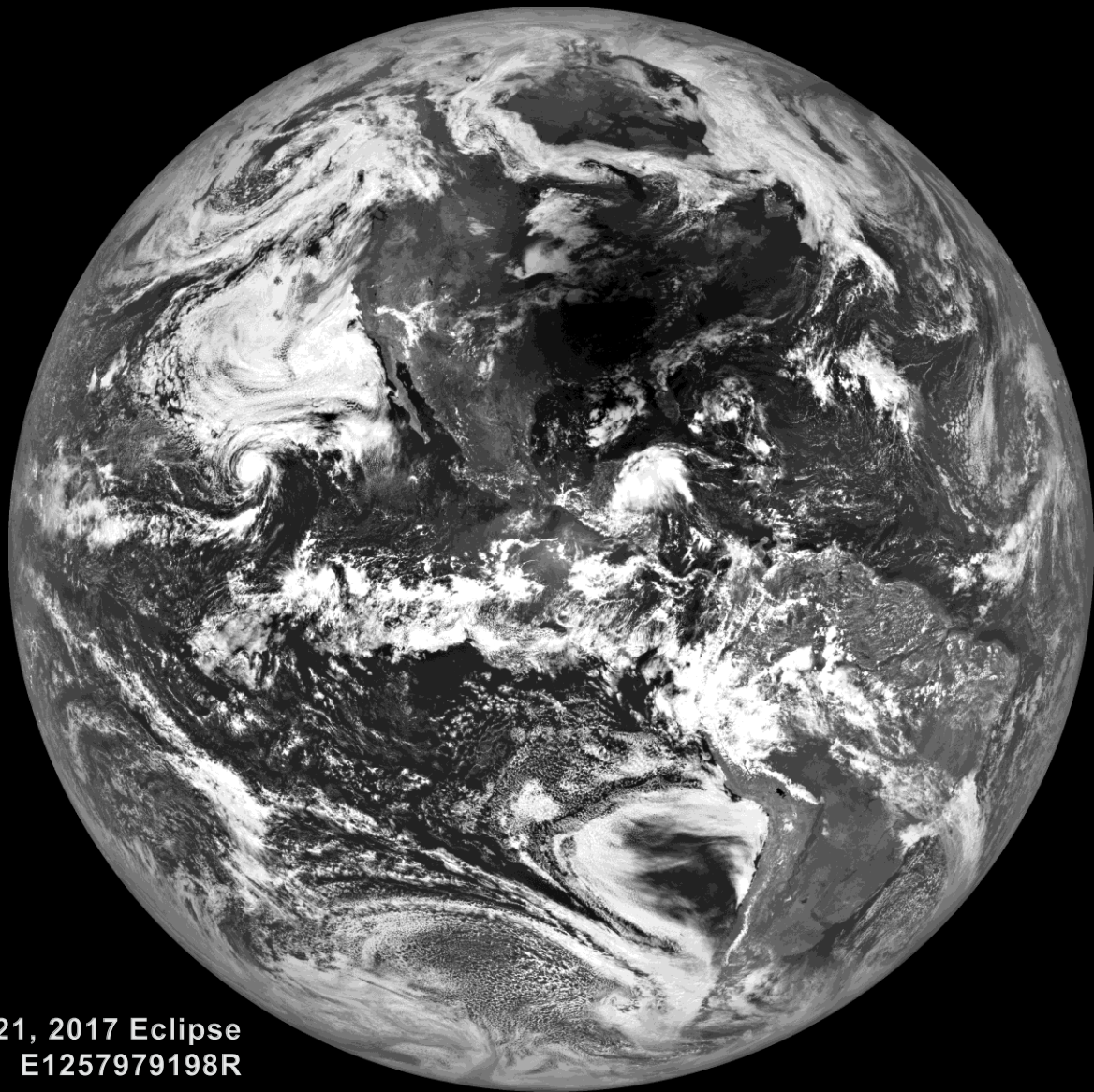
The Lunar Reconnaissance Orbiter: A Focused Study Of Fundamental Solar System Processes at the Moon

Noah Petro - Deputy Project Scientist

John Keller - Project Scientist

LEAG Annual Meeting

October 10th, 2017



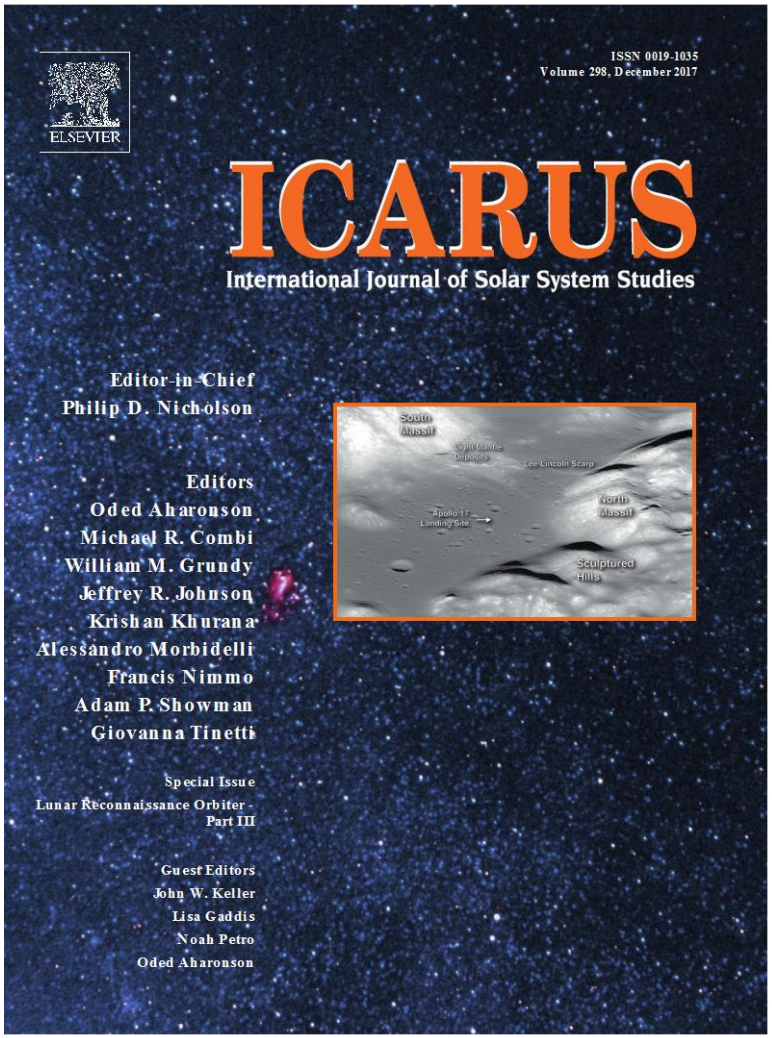
LROC NAC Image of August 21, 2017 Eclipse
E1257979198R

Craig Tooley
LRO Project Manager

Mission Status

- LRO is nominal
- Instruments are nominal
- LRO operations team and instrument operations teams are awesome

- Mini-RF is collecting data with Goldstone, Arecibo is offline
- Volume 3 of the *Icarus* special issue is out, SI of *PSS* is nearly done
- 53% through a two year extended mission – The Cornerstone Mission



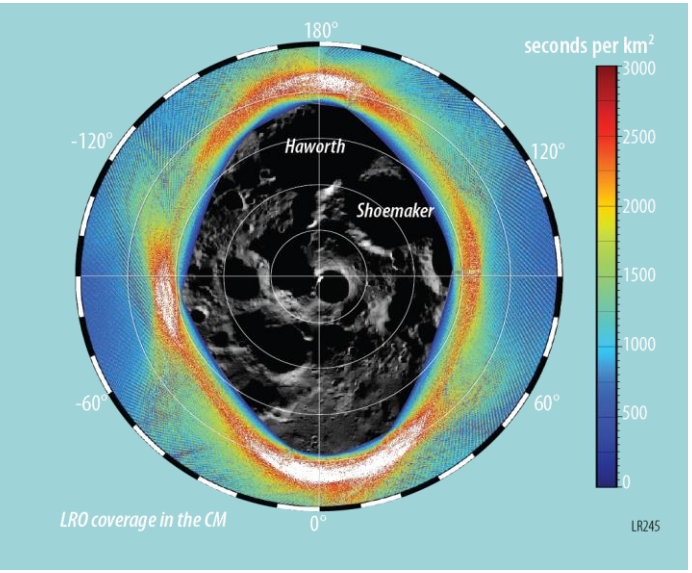
Events of Note

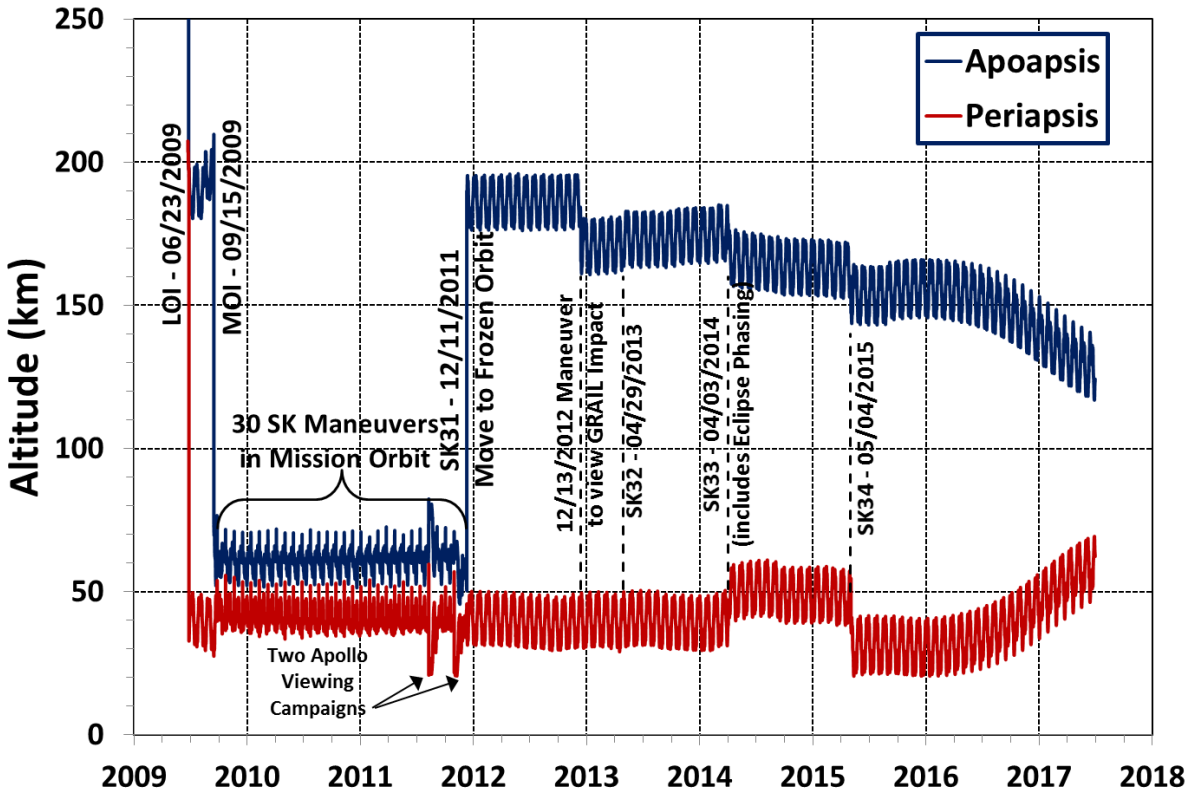
- Last PDS delivery was September 15 (next in December)
- International Observe the Moon Night – October 28

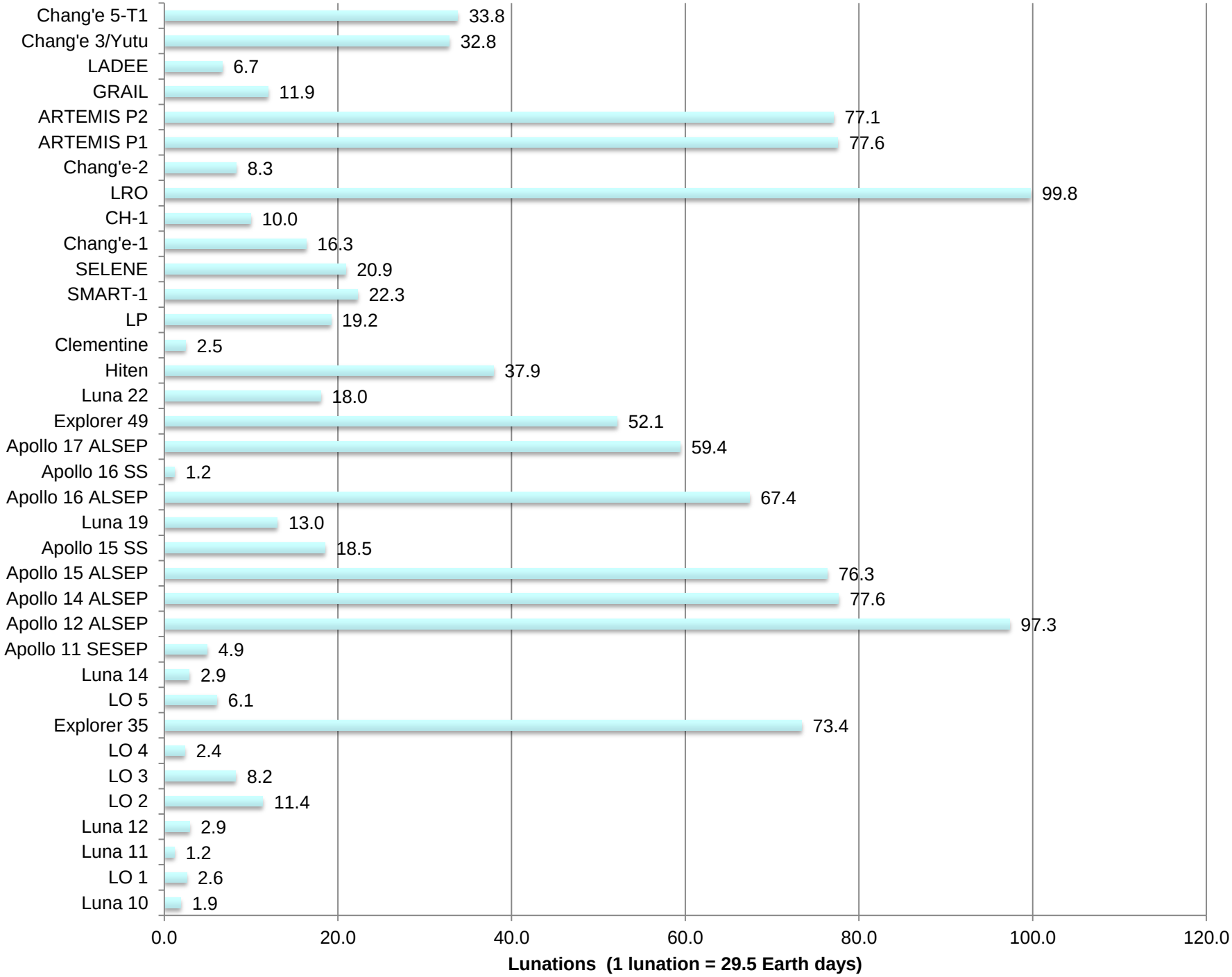
- AGU
  - Sessions on LRO and lunar science:
    - P015. Future Lunar Exploration Enabled by Recent Mission Data and Science
    - P041. The Dynamic Moon: Insights From Apollo Through the Lunar Reconnaissance Orbiter
    - P013. Exploring the Surface Properties of the Moon, Asteroids, and Other Airless Bodies

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

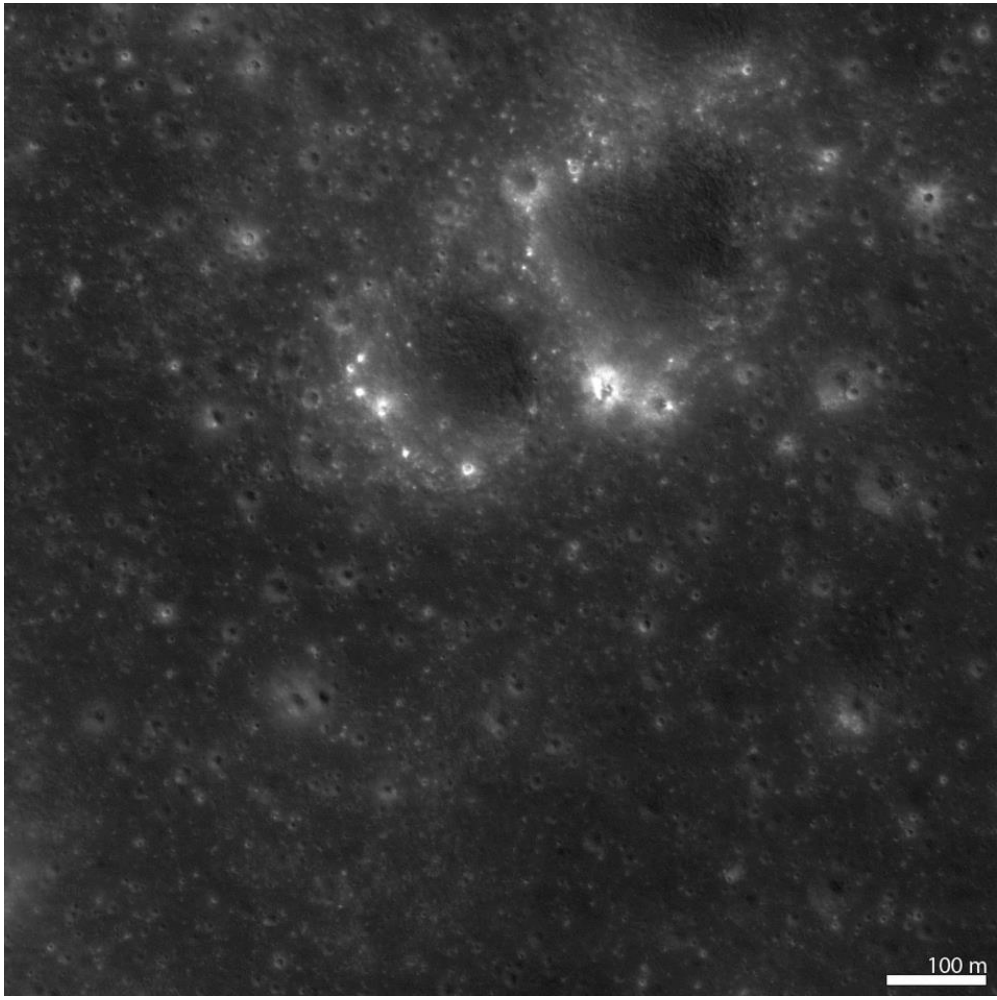





Chang'e 5-T1 33.8
Chang'e 3/Yutu 32.8
LADEE 6.7
GRAIL 11.9
ARTEMIS P2 77.1
ARTEMIS P1 77.6
Chang'e-2 8.3
LRO 99.8
CH-1 10.0
Chang'e-1 16.3
SELENE 20.9
SMART-1 22.3
LP 19.2
Clementine 2.5
Hiten 37.9
Luna 22 18.0
Explorer 49 52.1
Apollo 17 ALSEP 59.4
Apollo 16 SS 1.2
Apollo 16 ALSEP 67.4
Luna 19 13.0
Apollo 15 SS 18.5
Apollo 15 ALSEP 76.3
Apollo 14 ALSEP 77.6
Apollo 12 ALSEP 97.3
Apollo 11 SESEP 4.9
Luna 14 2.9
LO 5 6.1
Explorer 35 73.4
LO 4 2.4
LO 3 8.2
LO 2 11.4
Luna 12 2.9
Luna 11 1.2
LO 1 2.6
Luna 10 1.9
0.0
20.0
40.0
60.0
80.0
100.0
120.0
Lunations (1 lunation = 29.5 Earth days)

The Benefit of a Long Lived Orbiter – A New Moon

- LRO-era Impact Craters by LROC
- SEP events recorded by CRaTER
- Solid-body tides measured by LOLA
- Volatile transport by LAMP, CRaTER, LEND
- High temporal resolution thermal variations and eclipse measurements 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”

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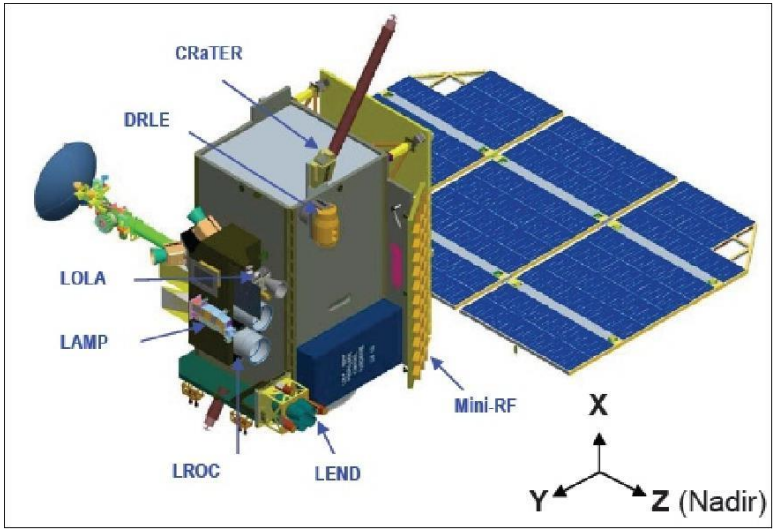
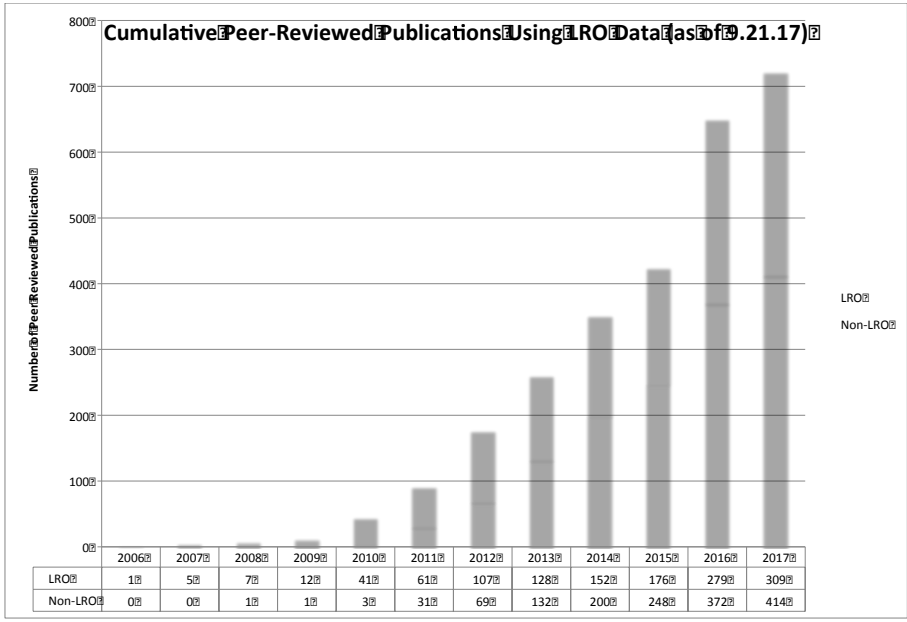
  - Propellant:
    - LRO has ~23 kg of fuel remaining, and has used ~20 kg in the last 6 years.
    - With no major Station Keeping maneuvers we could last ~11 years, with one SK a year ~5 years
    - We use fuel to unload momentum (2.23 kg/yr)
  - Power:
    - LRO’s solar panel provides power to the S/C
    - Continuous monitoring of the power supply



What is the future of LRO?

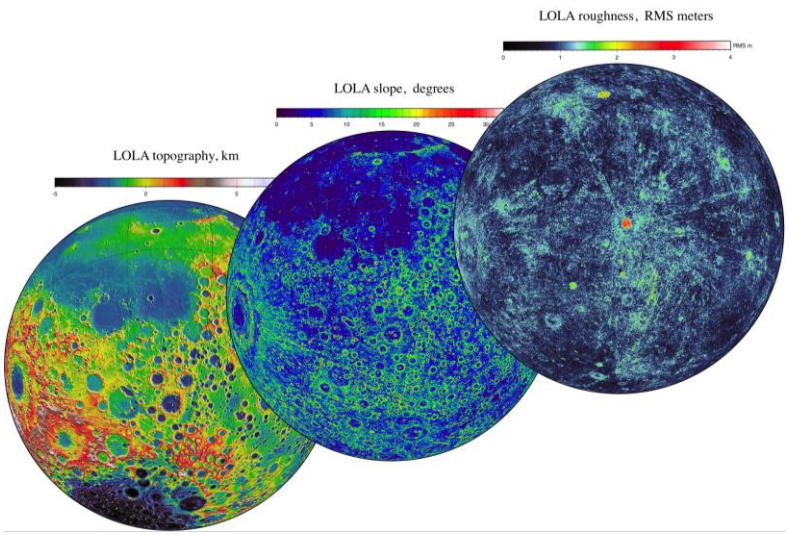
- LRO runs on the four “P’s”
  - Proposals:
    - We are in the midst of our current extended mission, ends on September 15, 2018*
    - May have to submit a proposal in April 2018
  - Papers:
    - LRO science teams continue to be productive
    - The community uses LRO data



	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

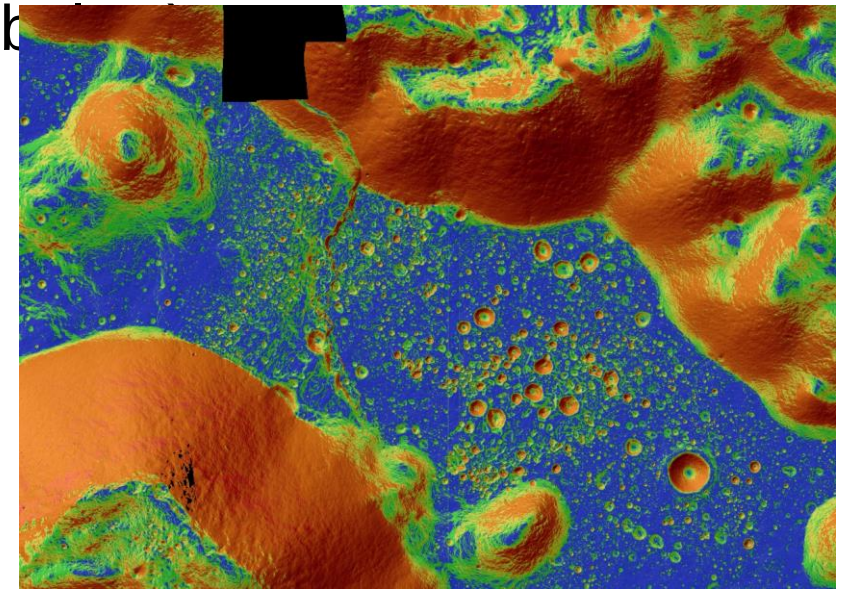
LRO Resource Products

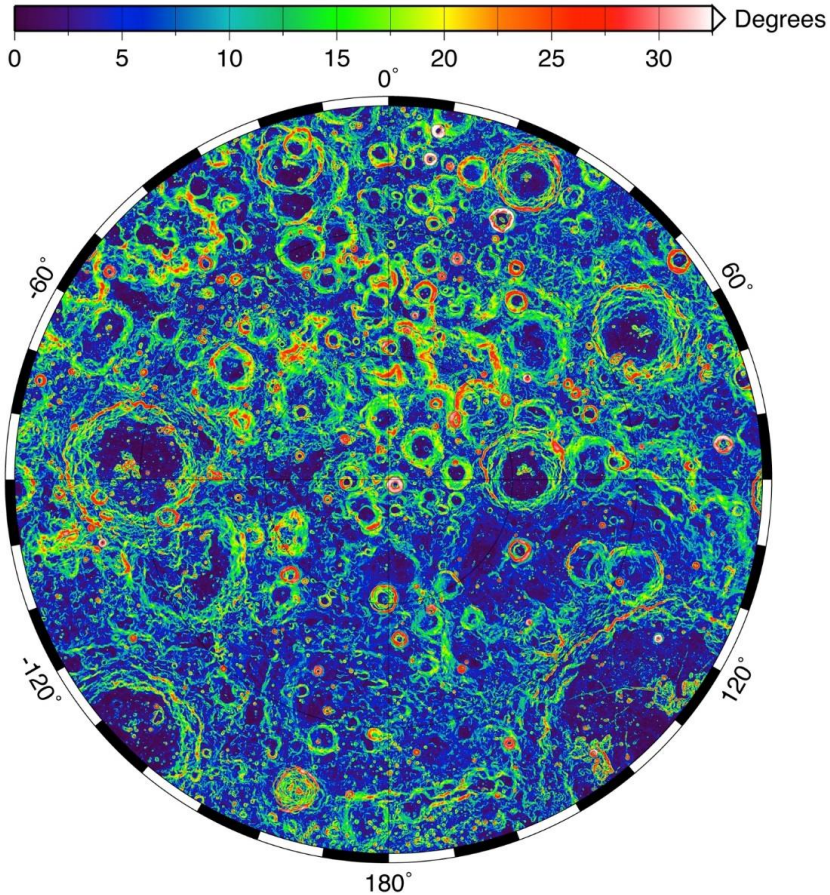
- All products are archived in the PDS and at the instrument team webpages
  - LROC at http://wms.lroc.asu.edu/lroc/rdr_product_select
  - LOLA at http://imbrium.mit.edu
  - Diviner at http://www.diviner.ucla.edu/data
  - Main PDS archive: http://pds-geosciences.wustl.edu/missions/lro/default.htm
    - LAMP polar products, Mini-RF polar mosaics, etc.



Maps of Regional Slope

- 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 b





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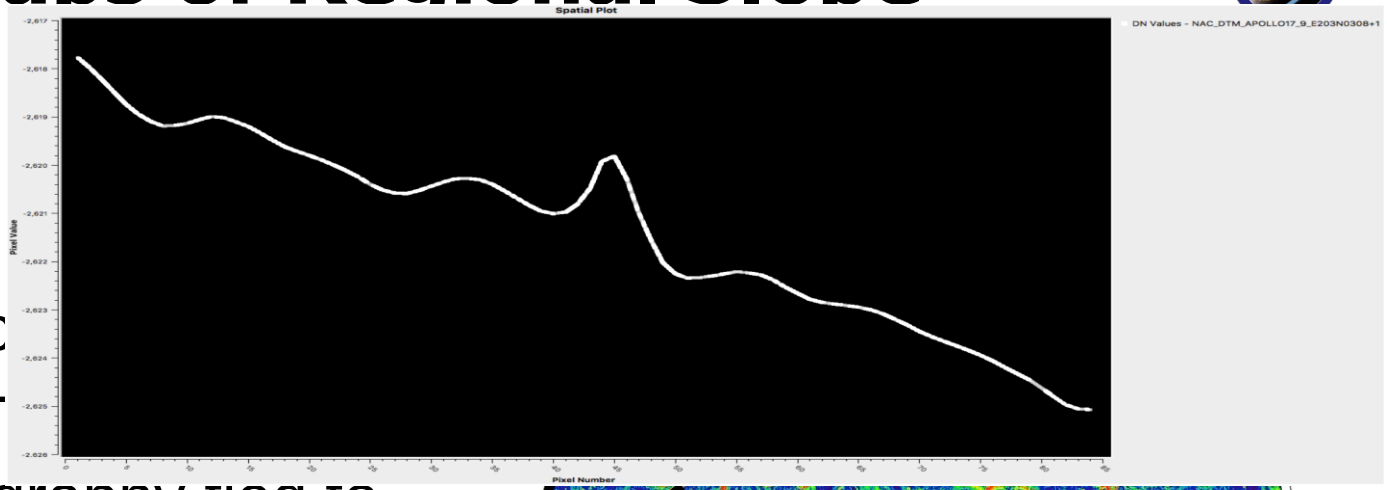
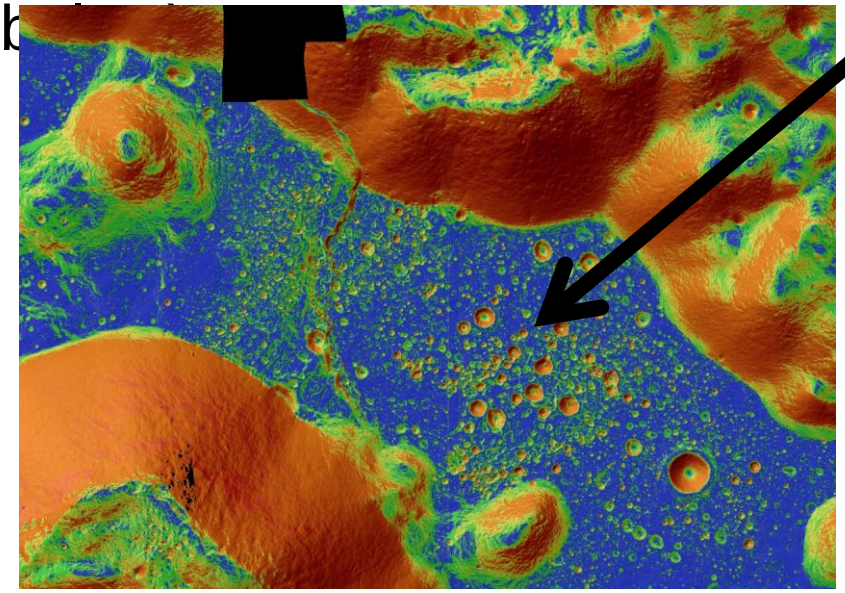
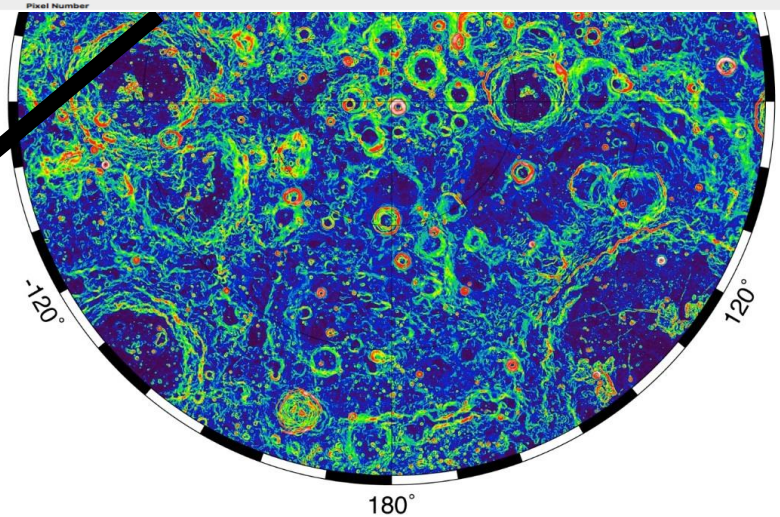


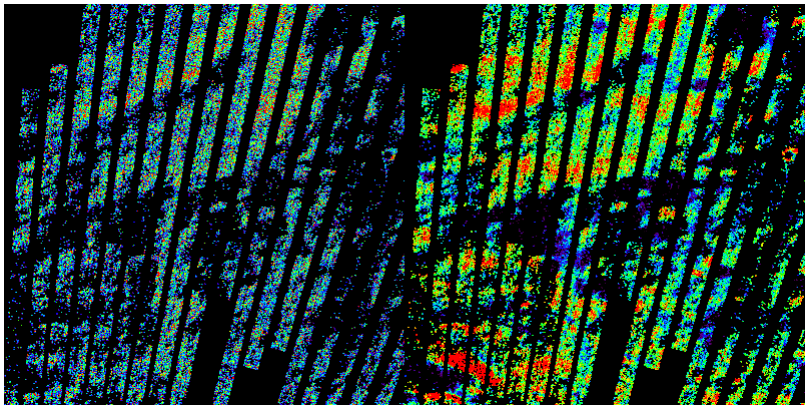




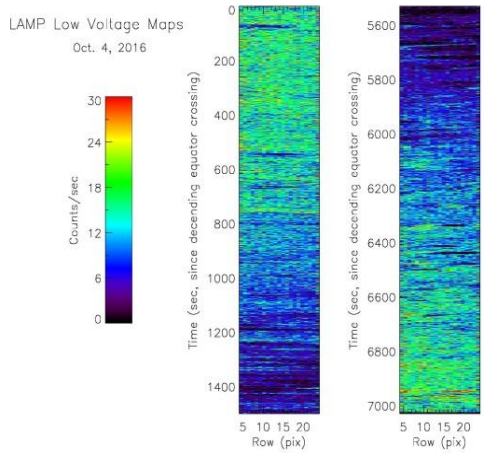
New LAMP Failsafe Door Open Mode:
A new emphasis on dayside dirunal variations

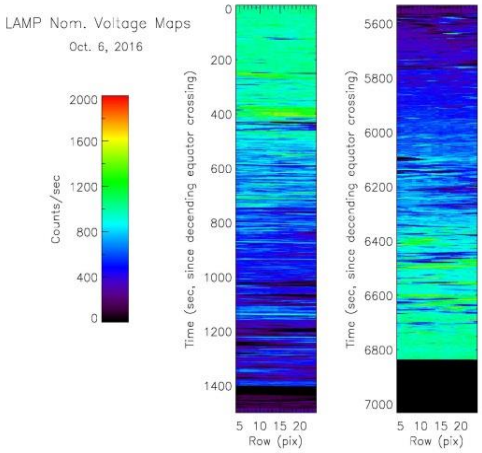
- LAMP's new mode improves dayside spectral imaging data quality by increasing typical UV photon detection rates of 600-3000 counts/sec up to 50,000 counts/sec (x15 to x80).
- **Searches for variability that otherwise would require trending months of data for statistics may be performed with individual LRO orbit strips like those displayed here.**

Maps: Before After (Prediction)



Orbit Strips: Before After (Real Data)





- Previous data quality at left is noisy with sparse coverage in individual orbit tracks; right shows much improved map quality for th new mode.
- Comes at the cost of increased calibration efforts, and faster detector gain degradation.

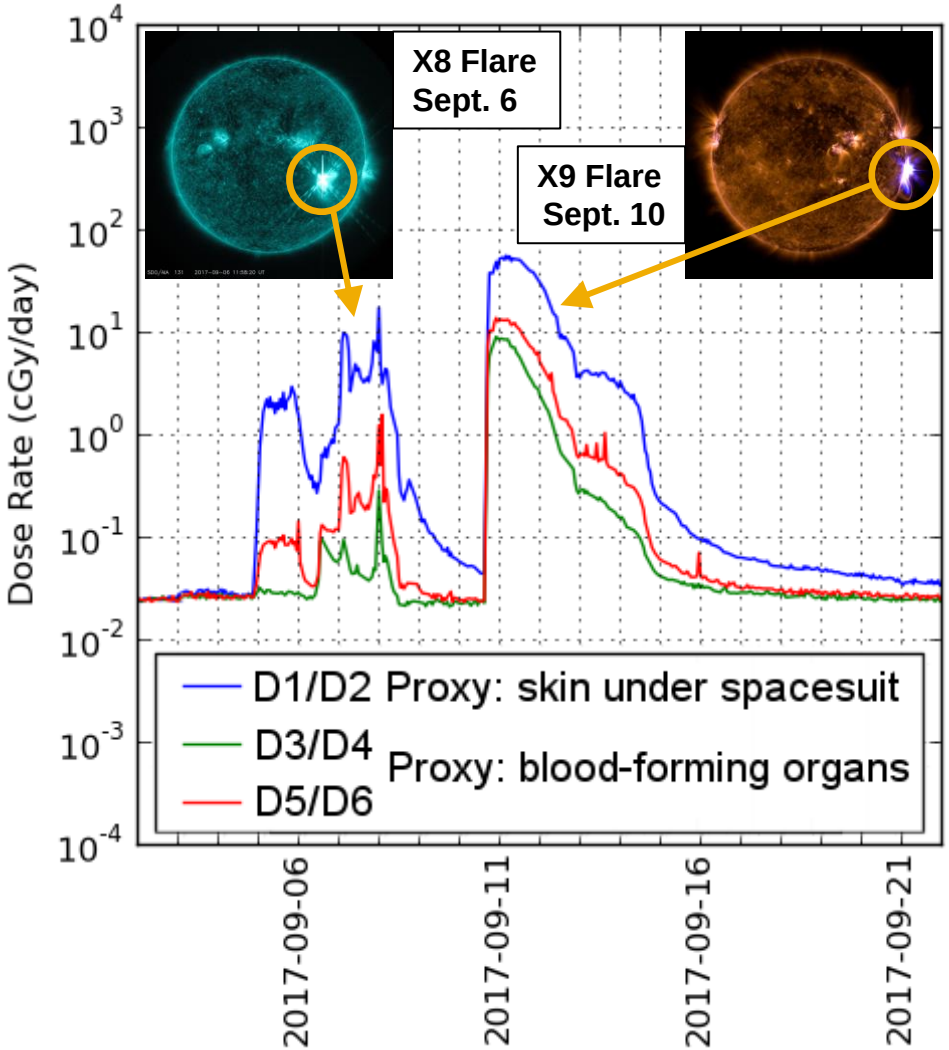
CRaTER Measures Back-To-Back Solar Energetic Particle Events Following X-Flares

Following two X-class solar flares in September 2017, solar energetic particle fluxes were high enough to create short-term effects associated with high radiation doses

September 6: An X8 solar flare was accompanied by a gradual increase in solar energetic particles that peaked early on September 8. The radiation dose rate peaked at 0.11 Gray per day.

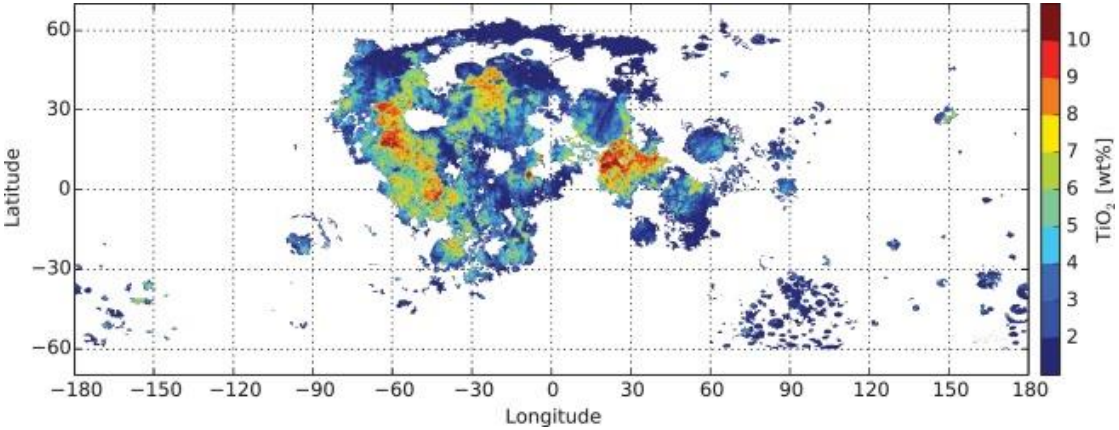
September 10: An X9 solar flare from the same sunspot (which had rotated away from the Earth) produced an immediate steep spike in energetic particles, and radiation dose rates almost reached 1 Gray per day, the limit at which an unprotected astronaut might suffer from temporary nausea.

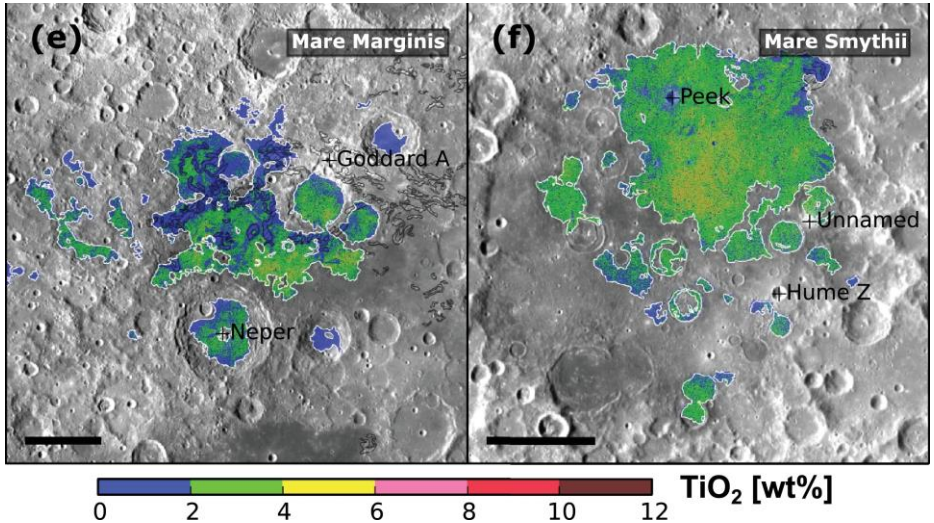
Radiation Dose in Space over 20 Days



LROC WAC TiO_2 Estimates

- Sato et al. (2017) in Icarus now!
- Using a ratio of the 321 and 415 nm bands to estimate TiO_2 content of basalts
- WAC multiband mosaic available at





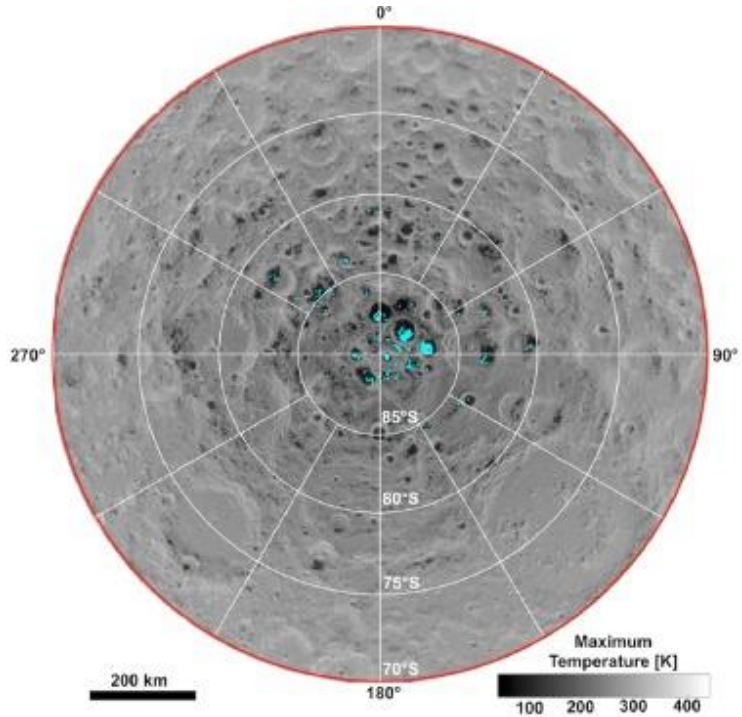
http://lroc.sese.asu.edu/archive/popular_downloads

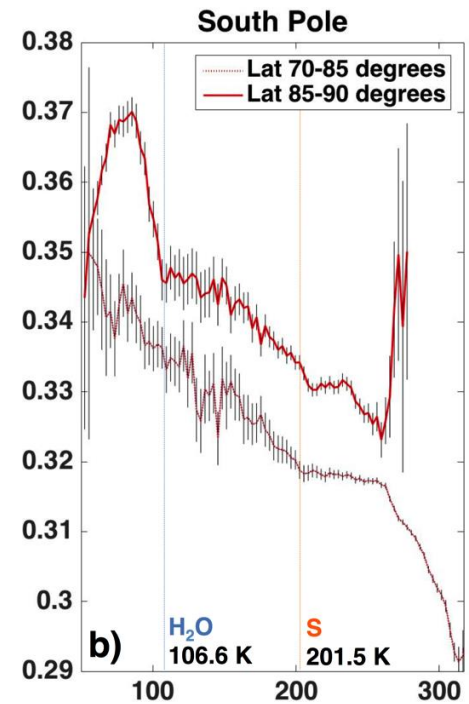
LRO's LOLA and Diviner Find Potential Frosts at the Lunar Poles

Using LOLA-derived albedo and Diviner temperature data, areas of possible surface frost have been identified.

Small regions within 5º of the both poles are identified (in cyan at right for the south pole) that are both flat, bright, and cold. These smooth areas are expected to be free of bright debris flows and are cold enough to contain stable volatiles.

Near the south pole, regions that are brighter than the surrounding smooth surfaces also have temperatures below the stability of both water ice and elemental sulfur (right plot). These very bright surfaces near the south pole are likely to be part of an ice-rich surface and are consistent with observations by other instruments.





Left: Detection map of bright region near the south pole. Cyan pixels show the locations of surfaces that are brighter than the mean of the "cold" pixels, and have maximum temperatures less than 110 K and slopes less than 10˚. At both poles there are concentrations that indicate a common brightening process and are unlikely to be part of the background ice-free population. **Right:** Plot of the average 1064 nm albedo as a function of maximum temperature for flat areas near the south pole, illustrating spatial heterogeneity in polar reflectance-temperature relationships. Volatility thresholds for elemental sulfur and water ice are included for comparison.

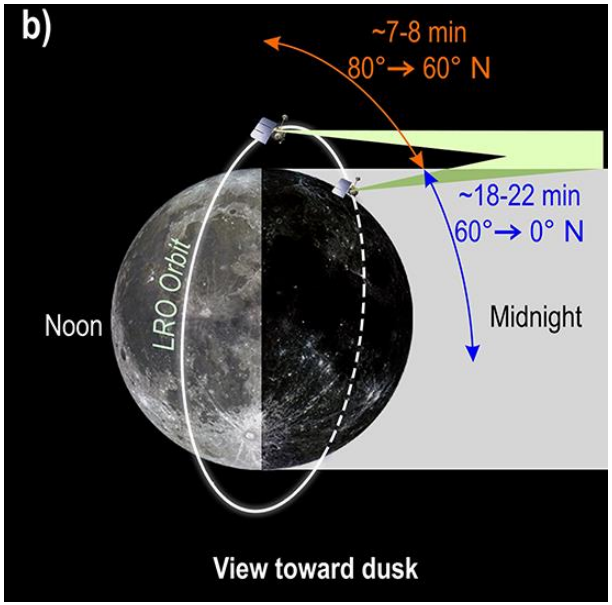
Fisher, E., et al., (2017) Evidence for surface water ice in the lunar polar regions using reflectance measurements from the Lunar Orbiter Laser Altimeter and temperature measurements from the Diviner Lunar Radiometer Experiment, in press, *Icarus*

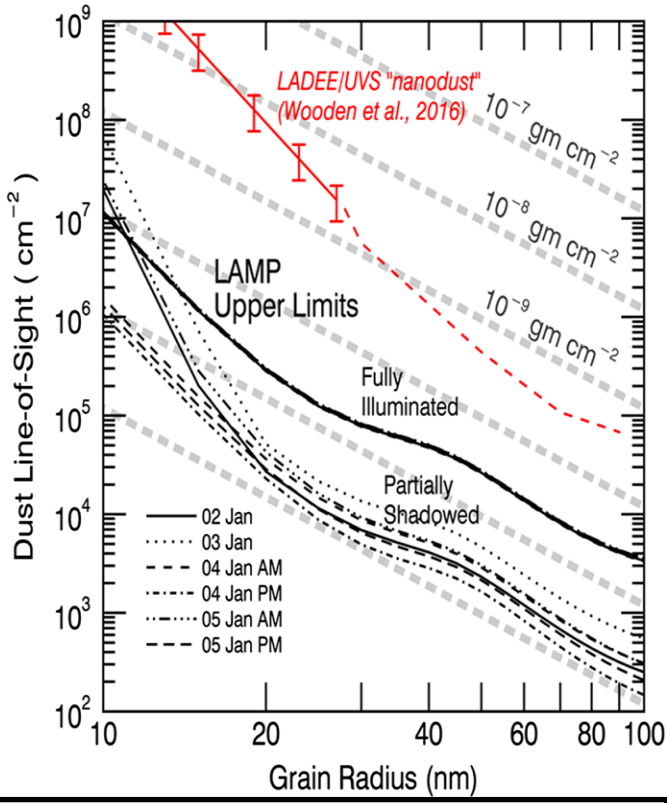
New LRO/LAMP Instrument Constraints on the Fine-Grained Dust in the Lunar Exosphere

LRO LAMP observations of the lunar exosphere during special off-nadir observations constrain the grain-size distribution of lunar exospheric dust.

The LAMP observations are consistent with there being at least 2 orders of magnitude less nanodust during the 2016 Quadrantid meteor shower than inferred by LADEE during the 2014 Quadrantid shower.

The disparate results between LAMP and LADEE UVS may be explained by: differences in the two meteor streams, viewing geometry, solar UV conditions, or an unidentified process responsible for the signal detected by LADEE/UVS.

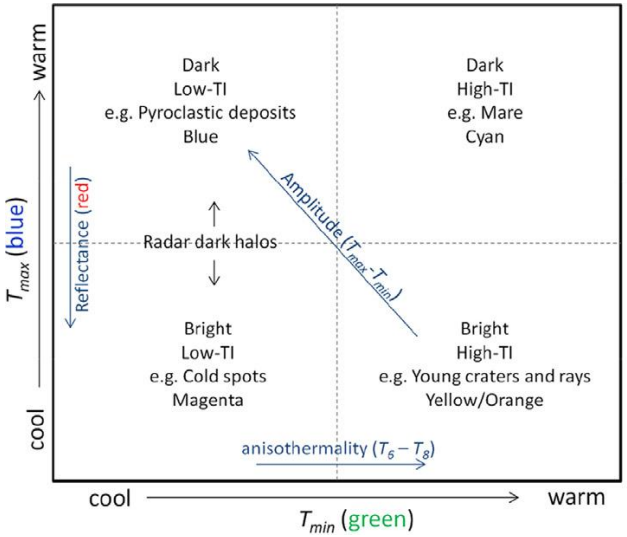


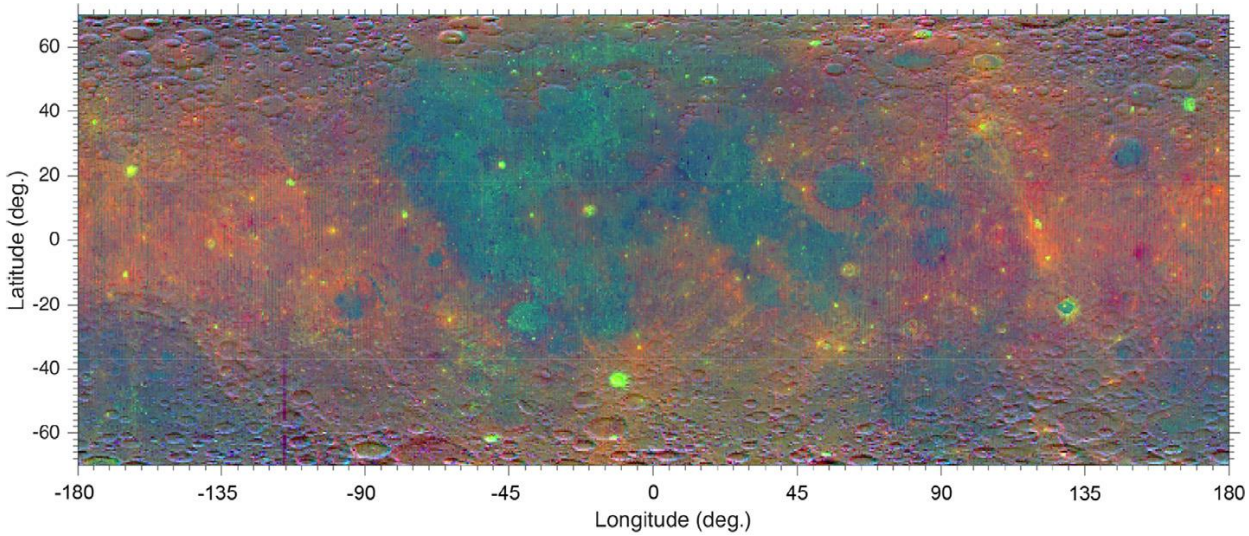


Left: Viewing geometry of LAMP during special observations, where LAMP's line of sight is fully illuminated by sunlight, its duration, and the latitude range spanned. Similarly, the blue portion indicates the portion of the trajectory with LAMP in shadow. The LAMP pointing is fixed on a region of the sky with little or no contamination from stars. **Right:** Upper limits abundance as a function of grain radius, derived from the six LAMP observations (black lines). Each LAMP measurement yields an upper limit well below the observation reported by Wooden et al. (red line). Lines showing constant dust mass are included on the plot (light gray dashed lines), assuming a mass density of 2.0 g cm^{-3}.

Grava, C., T. J. Stubbs, D. A. Glenar, K. D. Retherford, and D. E. Kaufmann (2017), Absence of a detectable lunar nanodust exosphere during a search with LRO's LAMP UV imaging spectrograph, *Geophys. Res. Lett.*, 44, 4591–4598, doi:10.1002/2017GL072797.

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

LRO – The Gift that keeps on giving

- Planning is underway for ESM4, possibly due next year
- We are evaluating multiple orbit options that enable new science
- Looking forward to cooperating with future lunar missions of any size