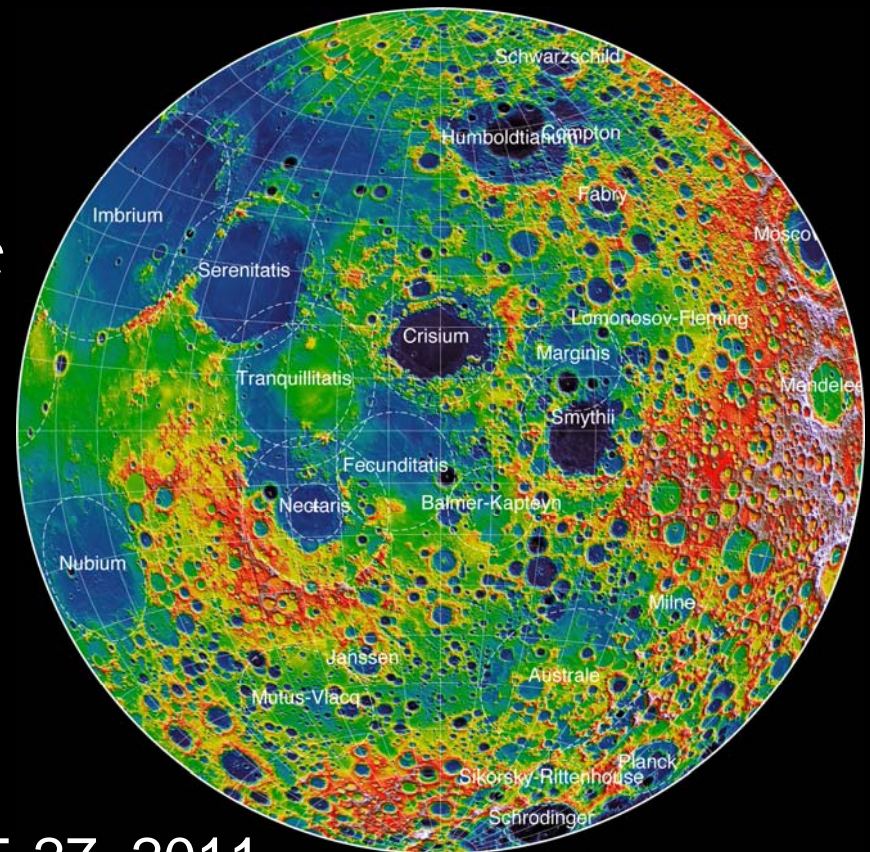


LRO-LOLA: Measurements of Lunar Altimetry and Surface Conditions

*David E. Smith, MIT
Maria T. Zuber, MIT
Gregory A. Neumann, GSFC
Erwan Mazarico, GSFC
and
the LOLA Science Team*

Lunar-Glob Mission
International Workshop #1
Moscow

Jan 25-27, 2011





Lunar Reconnaissance Orbiter (LRO)

Present status:

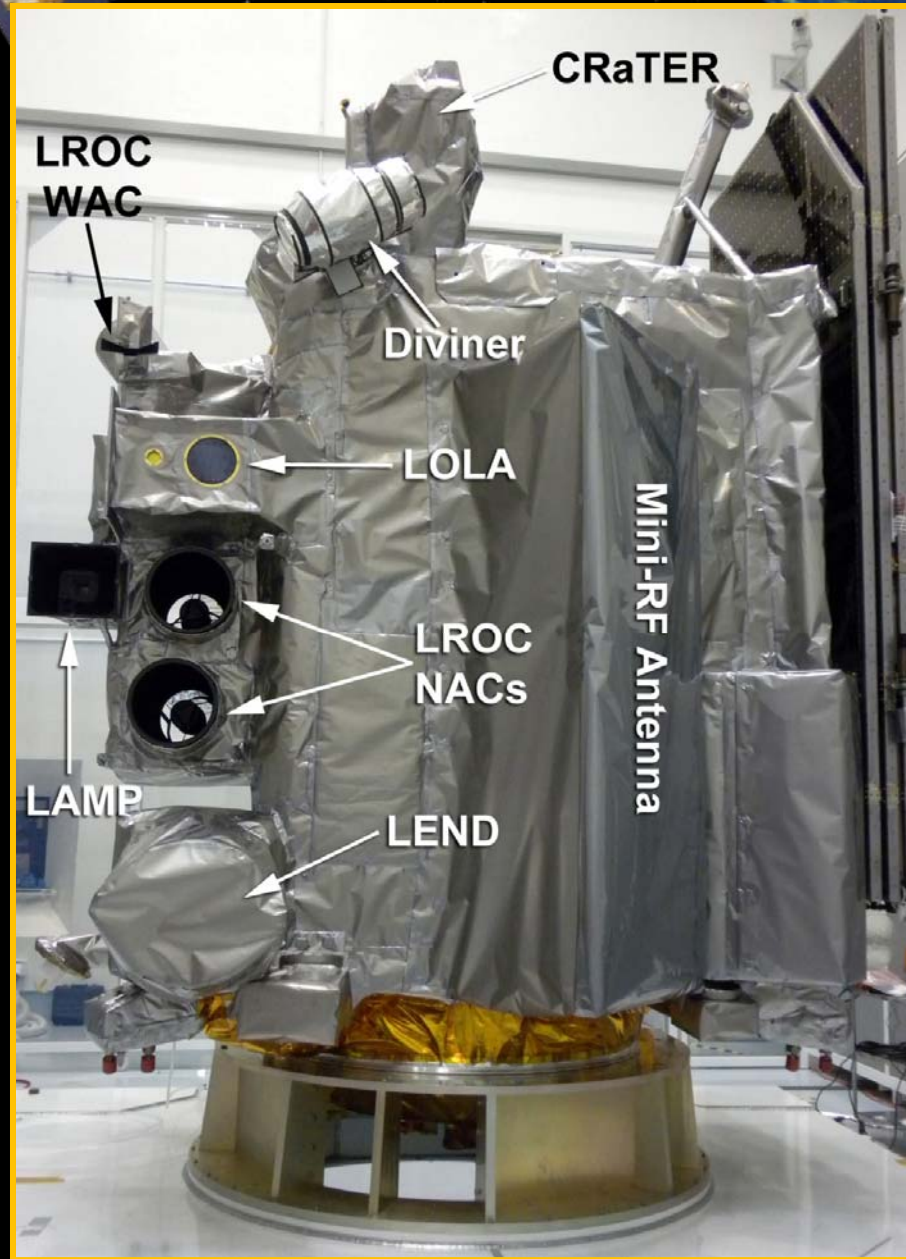
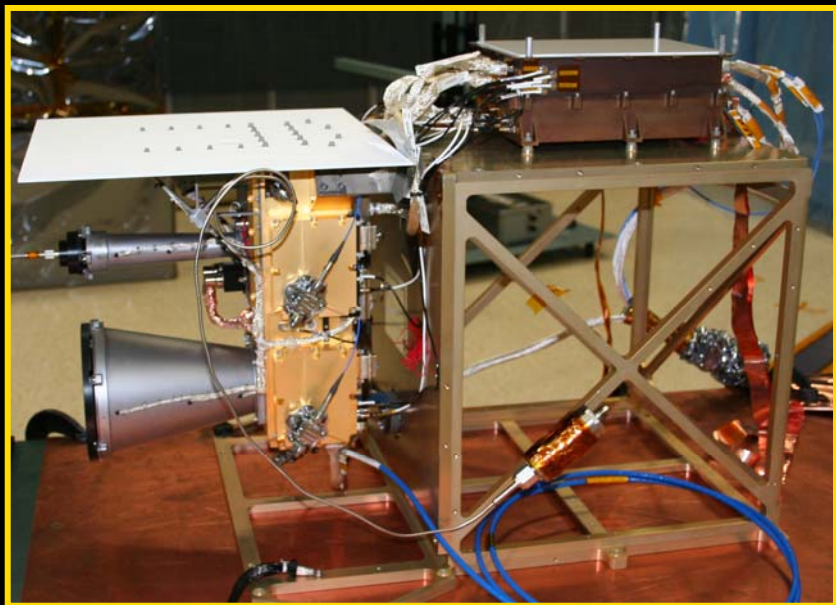
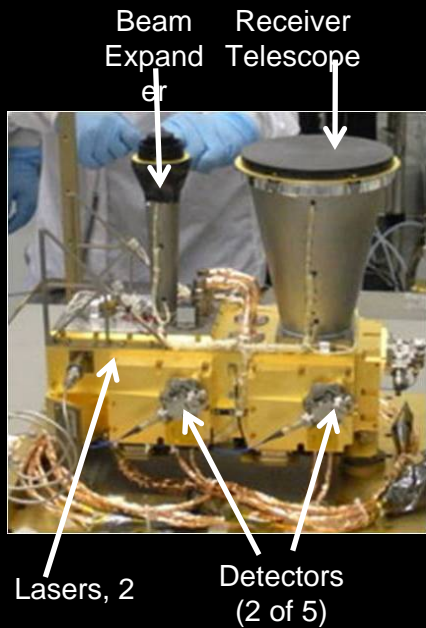
In lunar orbit since June 2009 and operating as planned.

Orbit is an average of 50 km near circular ($\sim\pm 10$ km), polar.

Every month the orbit is adjusted to maintain the altitude.

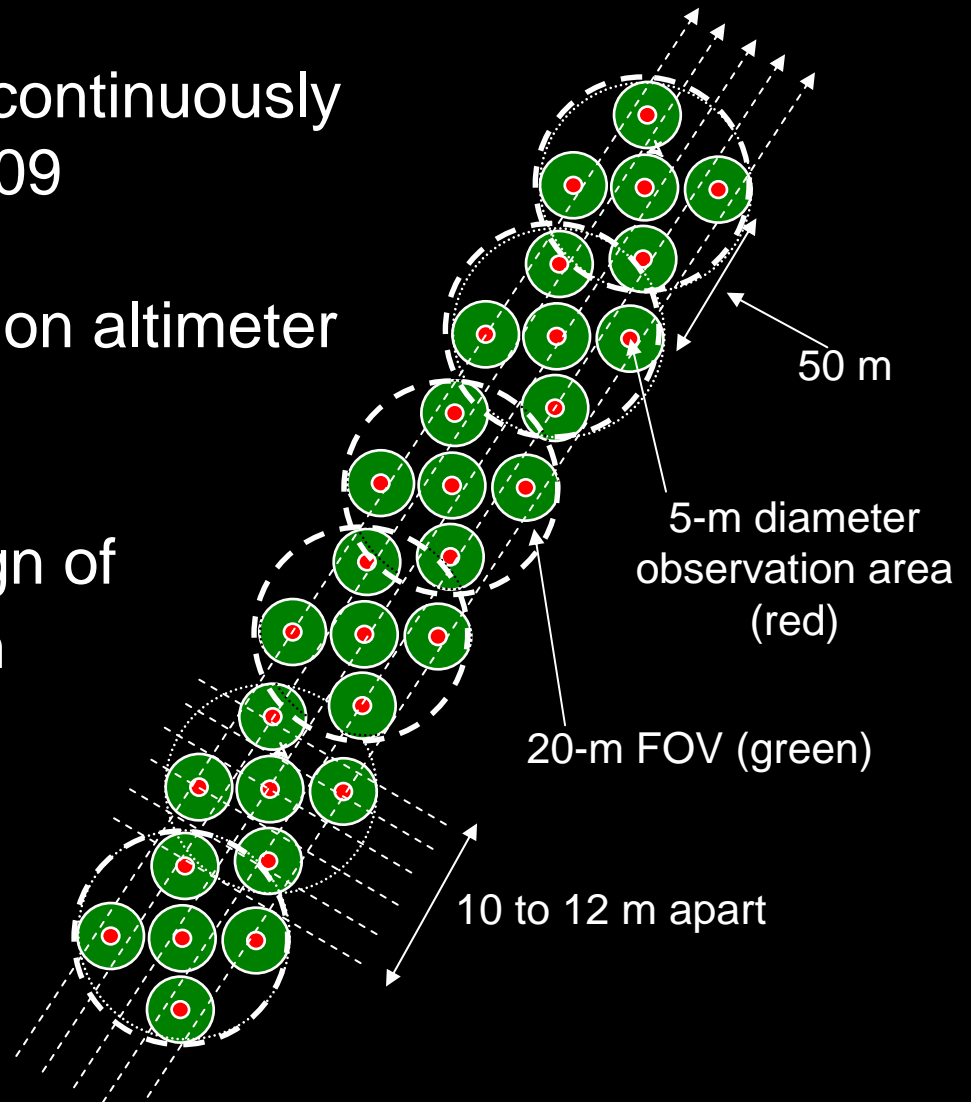
Continued operation expected for another 2 years, maybe longer. Possible orbit change this summer.

LOLA Instrument



LOLA: A Multi-Beam Laser Altimeter

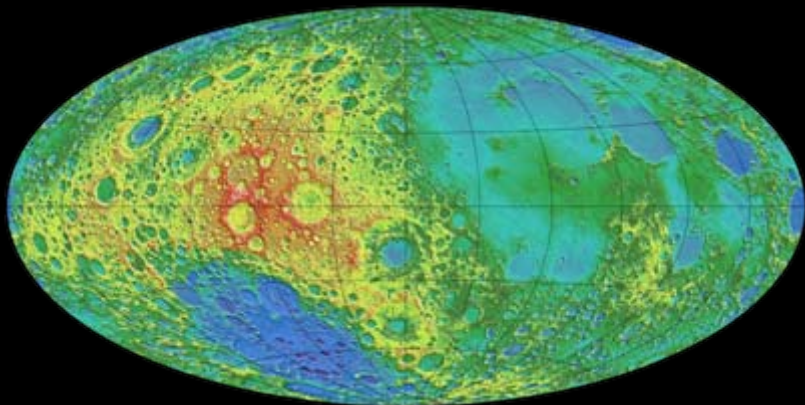
- LOLA has been operating continuously since turn-on July 13, 2009
- LOLA has acquired 3.2 billion altimeter measurements
- The two lasers show no sign of degradation since launch
- LOLA continues to acquire observations at an average of 80/second



Precision of each beam is 10cm; demonstrated 20 cm at the Moon.

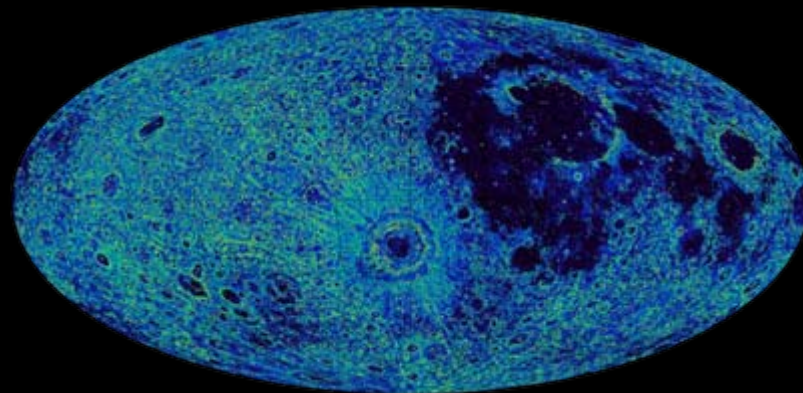
LOLA's 4 Global Data sets

Topography



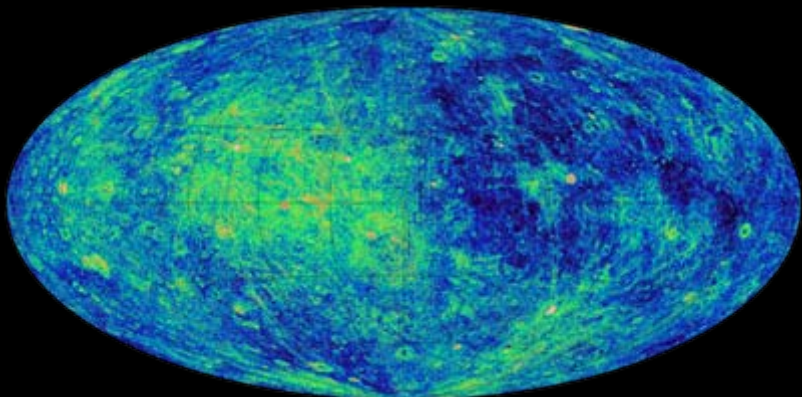
-9 10km

Surface Slope



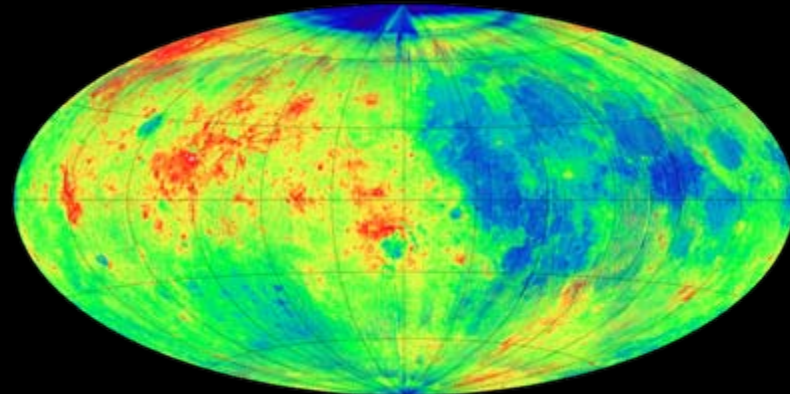
0 30°

RMS Surface Roughness



0.4 1.6m

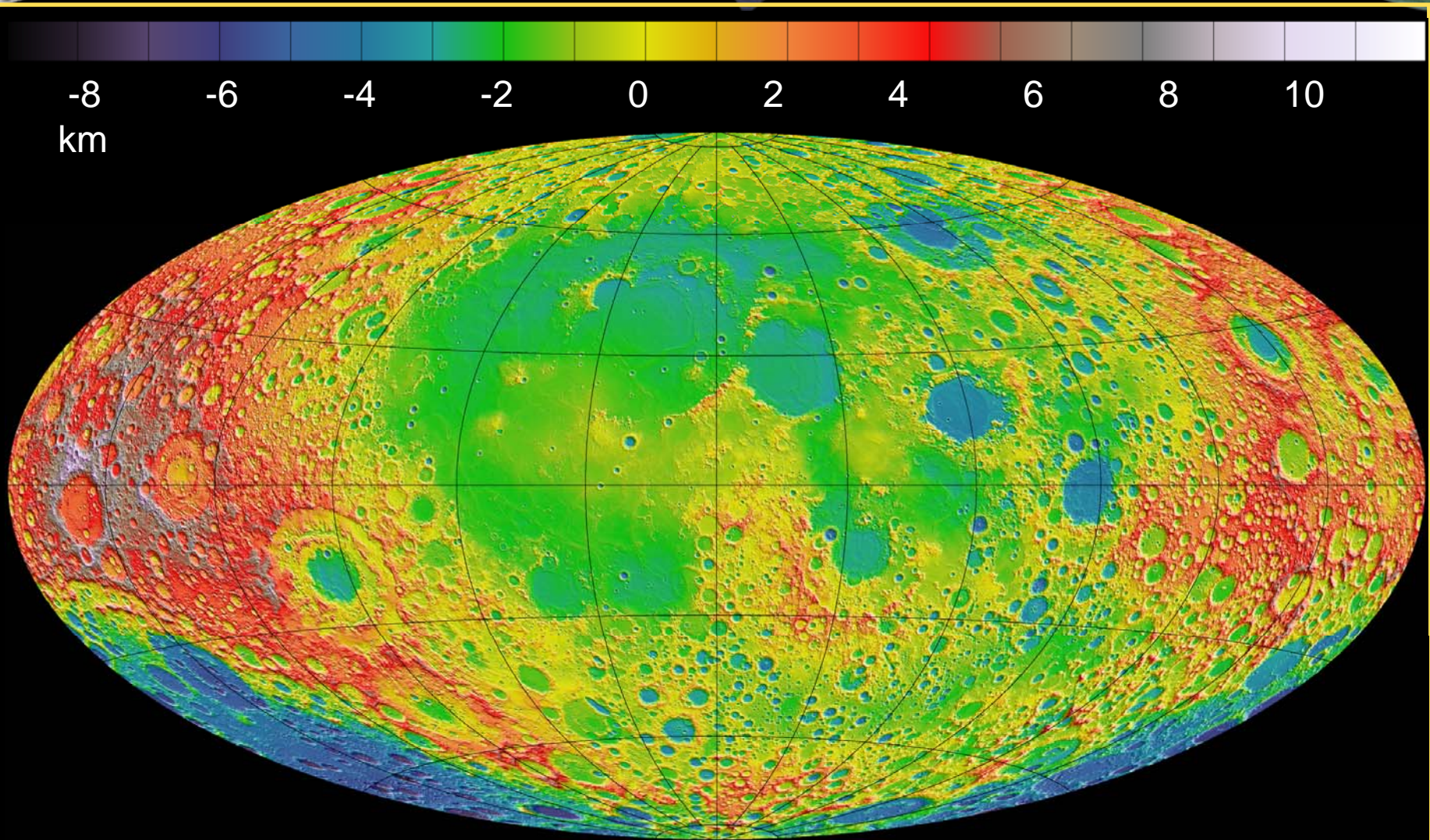
Bi-directional Reflectance



0 0.6

I/F

LOLA Global Topography of the Moon



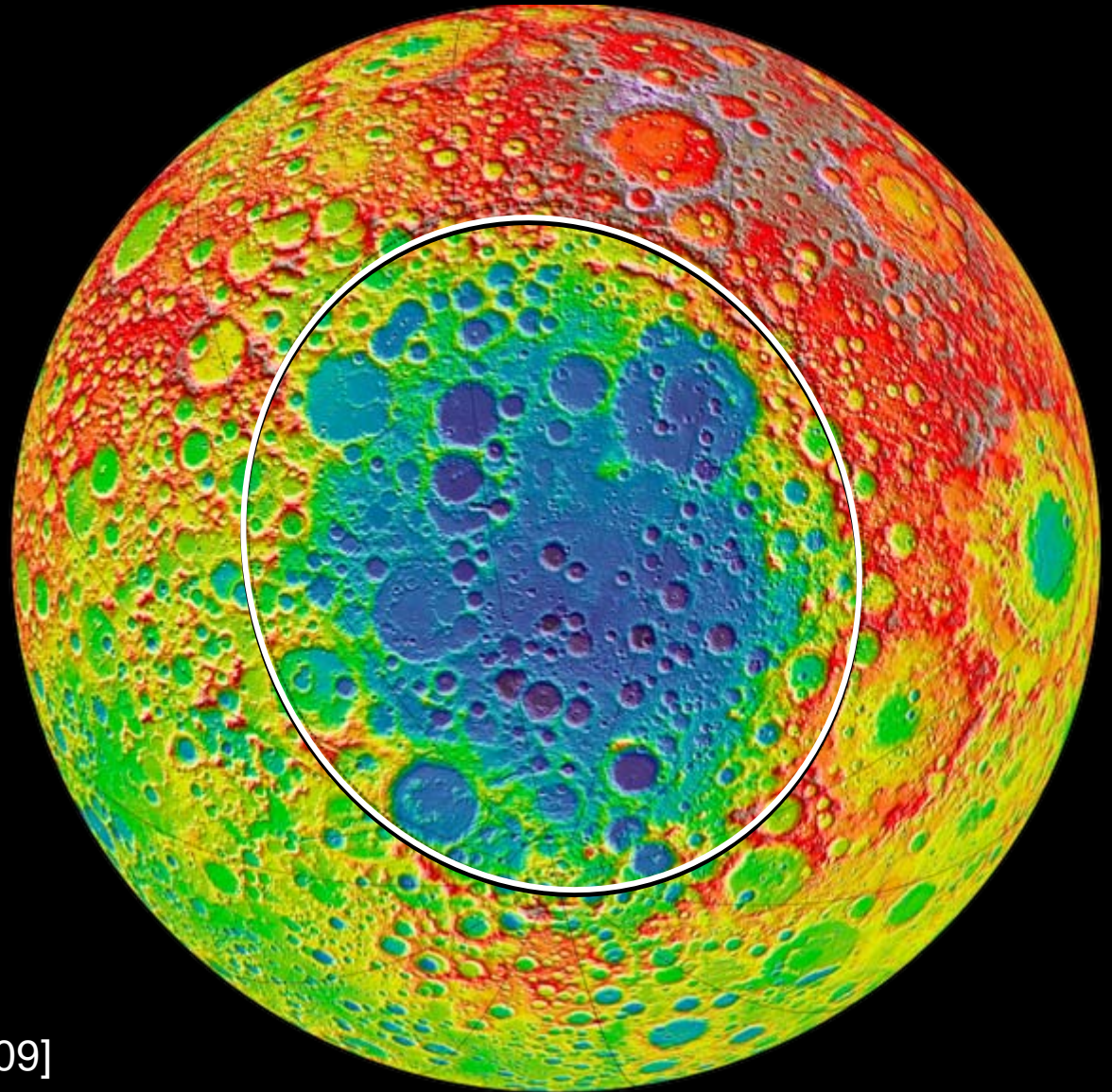
Developed from 2 billion LOLA measurements of lunar topography.

SP-A: Shape and Orientation

Basin center:
55.0° S
191.1° E

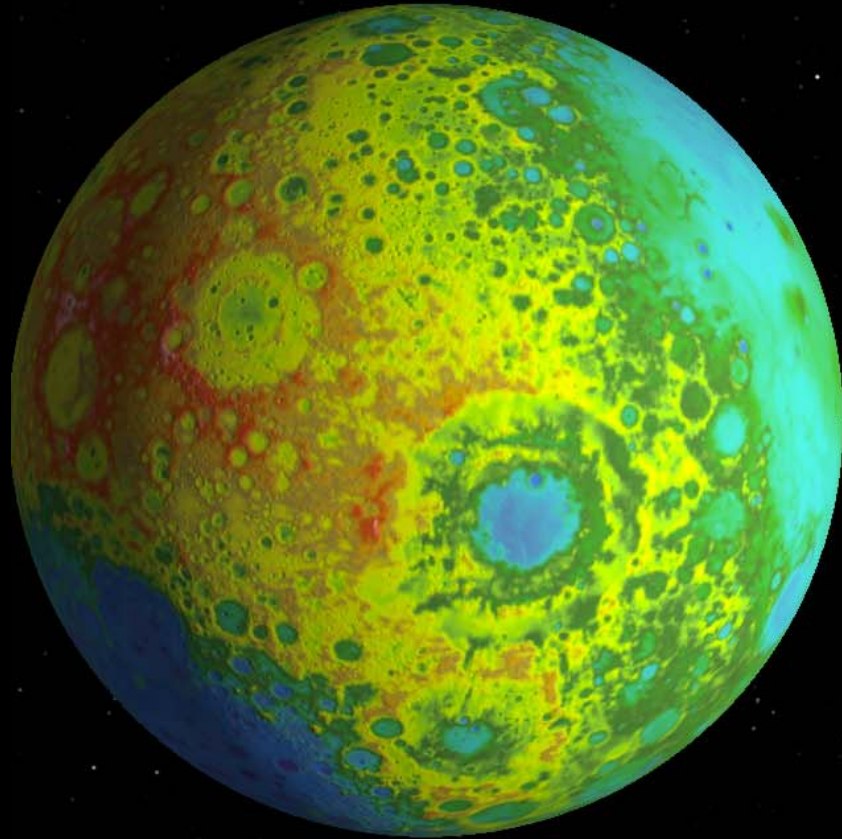
Basin axes:
970 x 720 km

Tilt: -18.8°



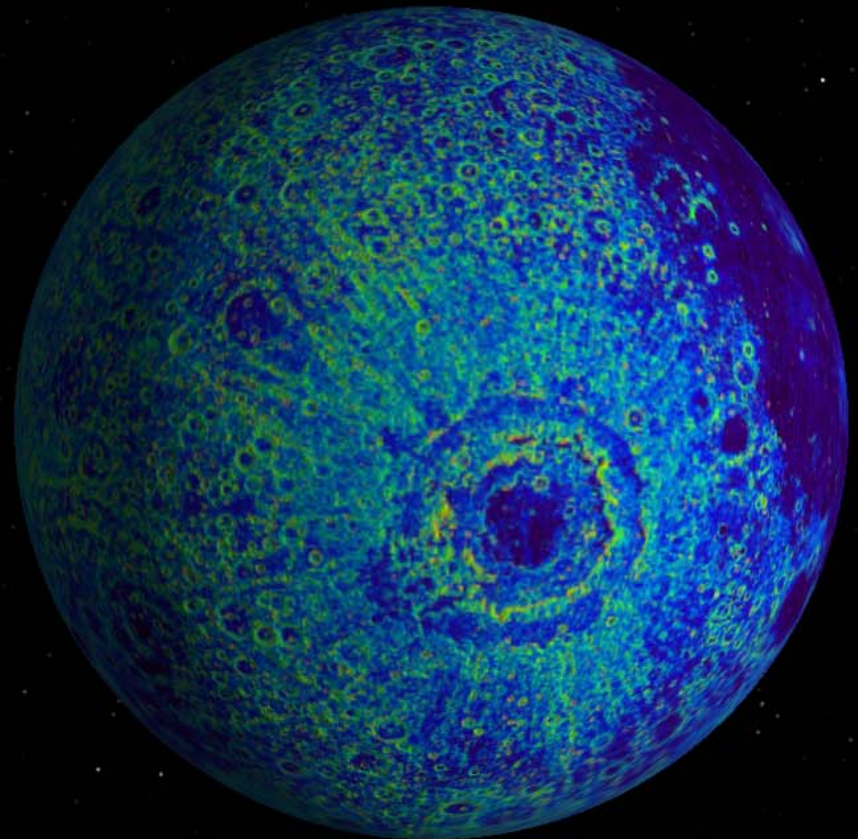
Orientele Basin

Topography



240 meter/pixel

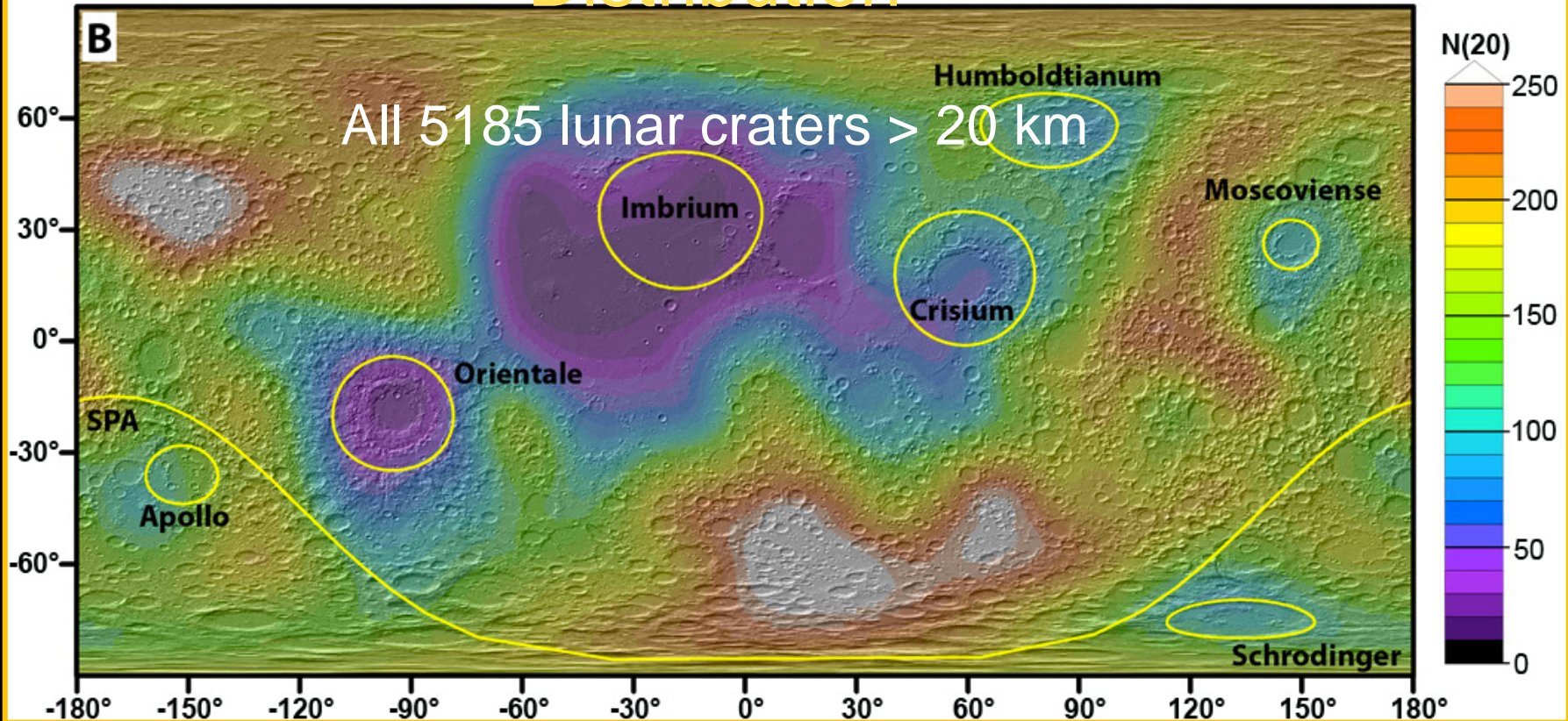
Surface Slopes



50 meter baselines

N-S resolution 20 m, E-W resolution 0.02° (~0.8 km at equator)

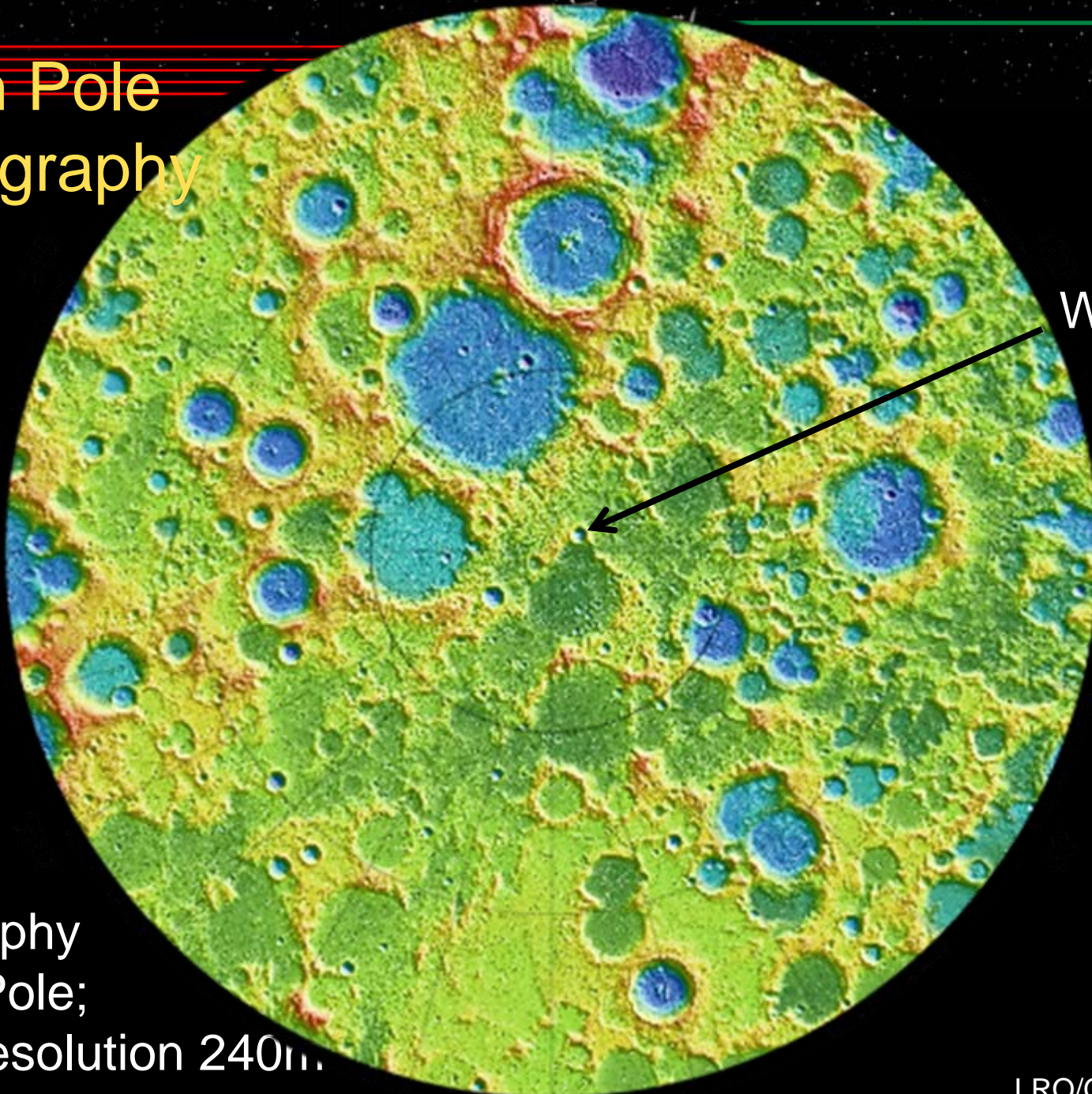
Global Crater Density and Distribution



LOLA data have been used to display all craters larger than 20km in diameter. The crater density distribution reflects the relative age of the surface. The major basins, Imbrium, Orientale, Crisium, etc are younger.

[Head et al *Science*, Sept 17, 2010]

North Pole Topography



7 km

Whipple

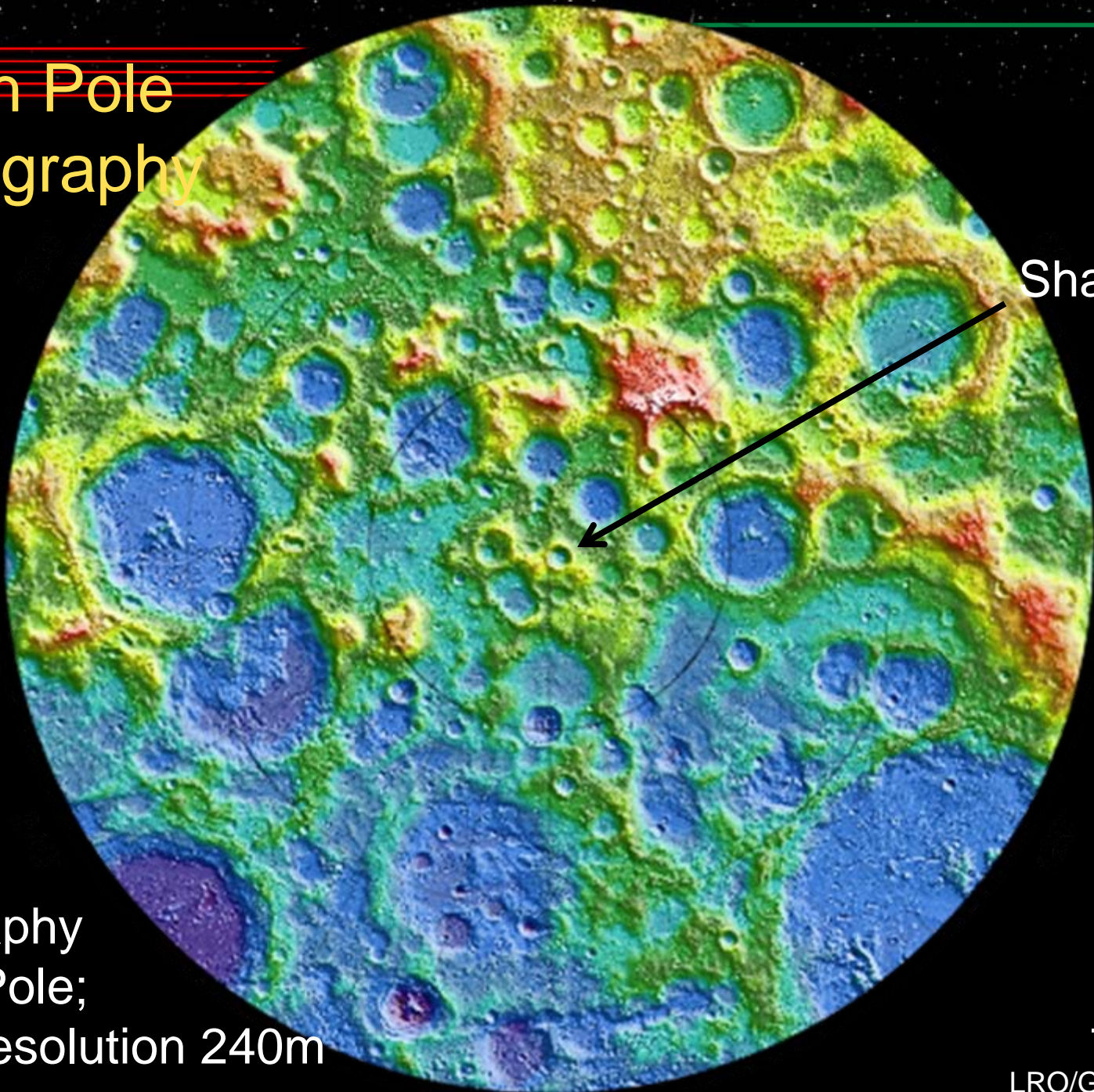
0

-7 km

LRO/GSFC/MIT/LOLA

Topography
75N to Pole;
Image resolution 240m

South Pole Topography



7 km

Shackleton

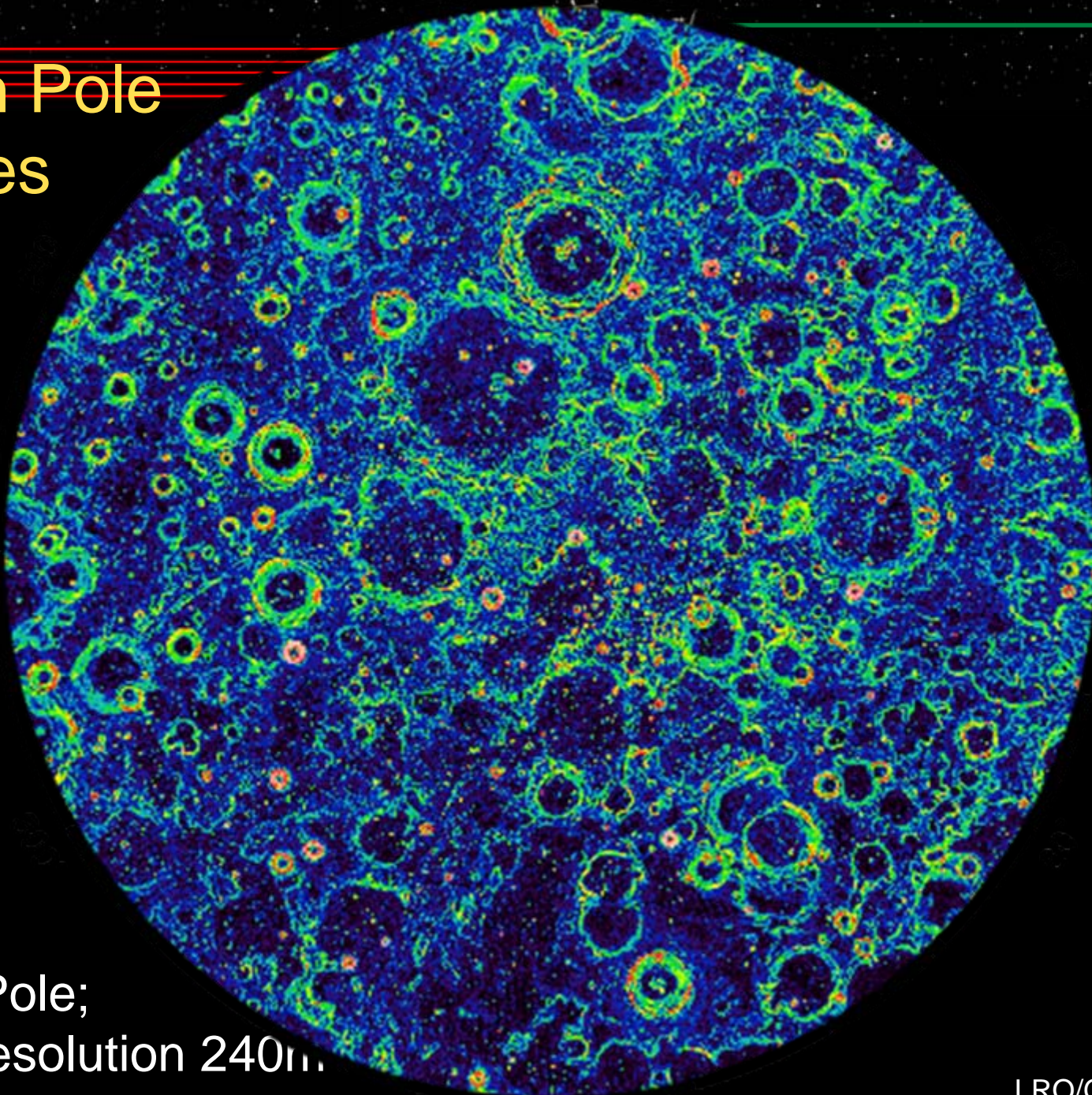
0

-7 km

LRO/GSFC/MIT/LOLA

Topography
75S to Pole;
Image resolution 240m

North Pole Slopes

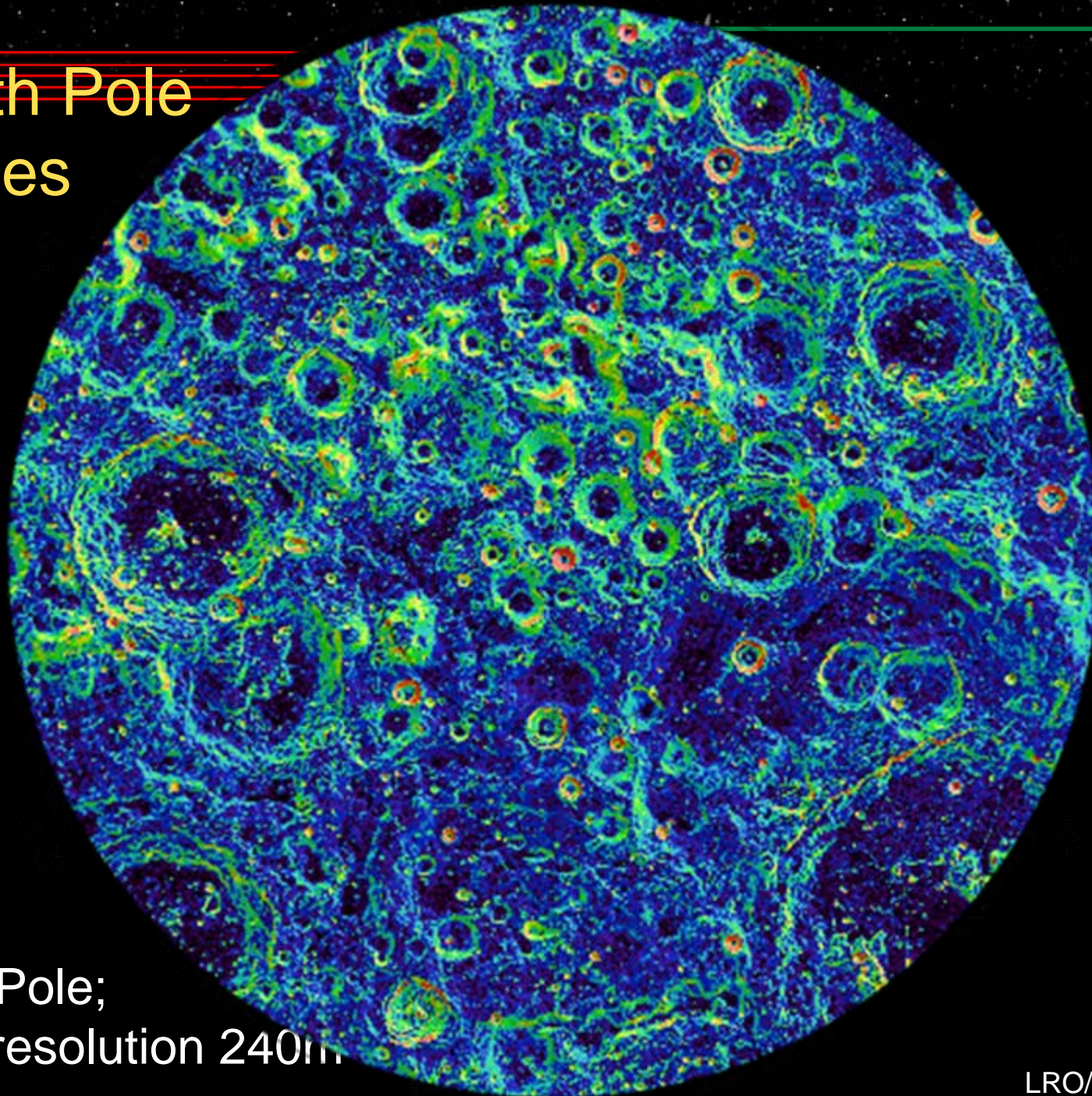


Slopes
75N to Pole;
Image resolution 240m

35°

0

South Pole Slopes

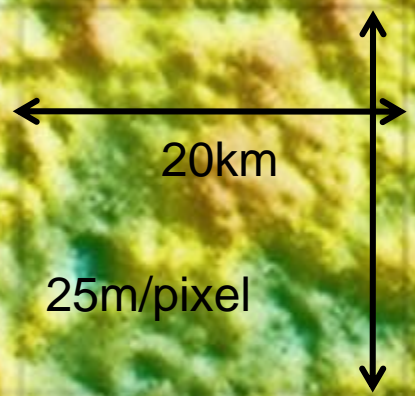


Slopes
75S to Pole;
Image resolution 240m

100x80 km² Centered on North Pole

Image resolution 25m

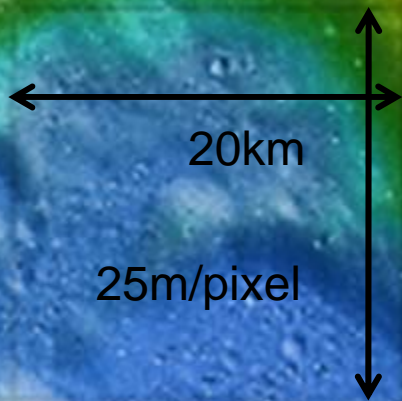
Whipple



100x80 km² Centered on South Pole
Image resolution 25m



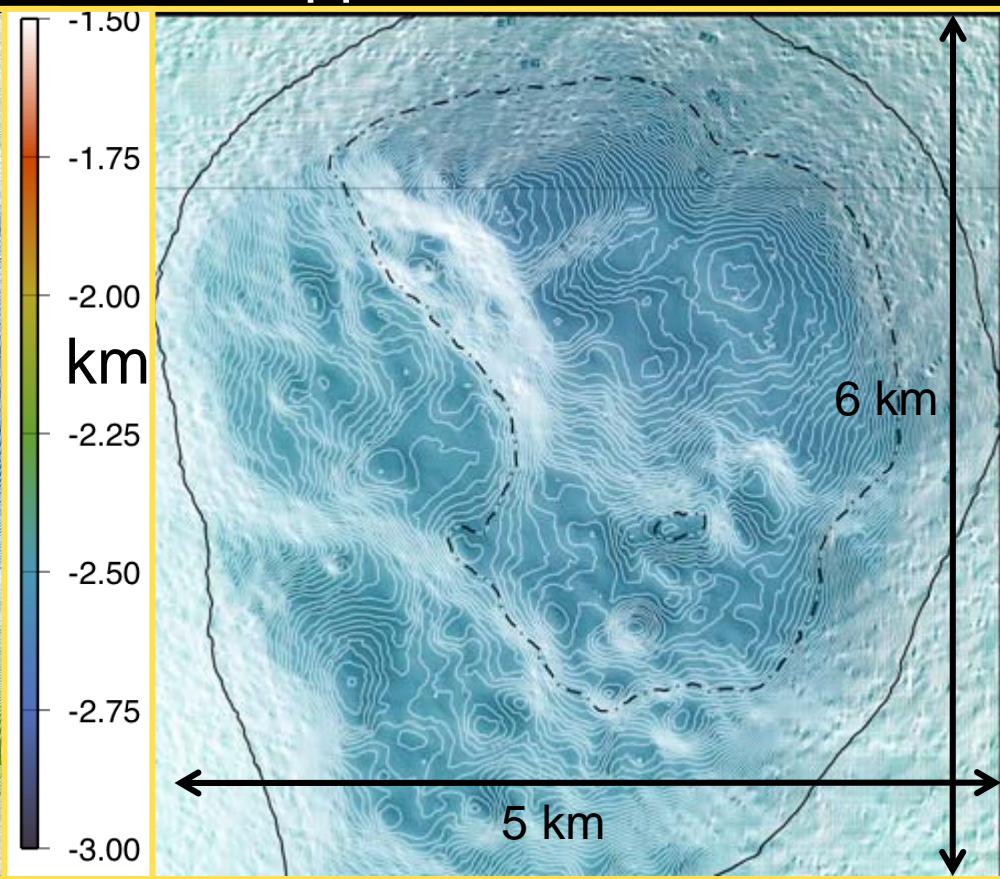
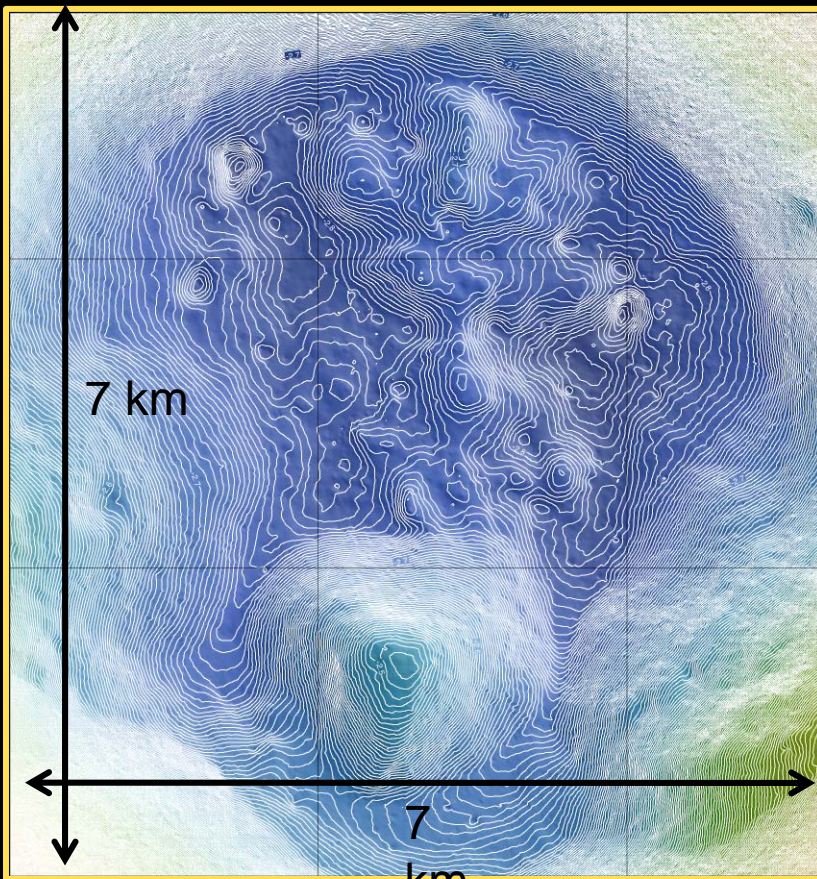
← Shackleton



Crater Floors at 5-Meter Contours

Shackleton, Lunar South Pole

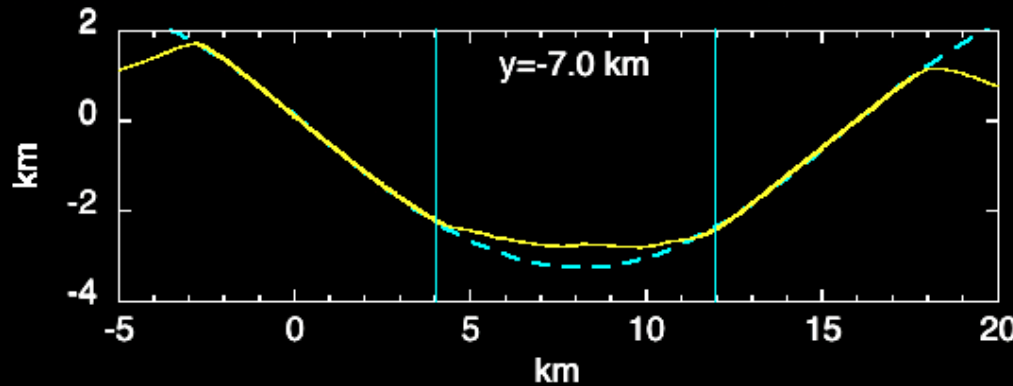
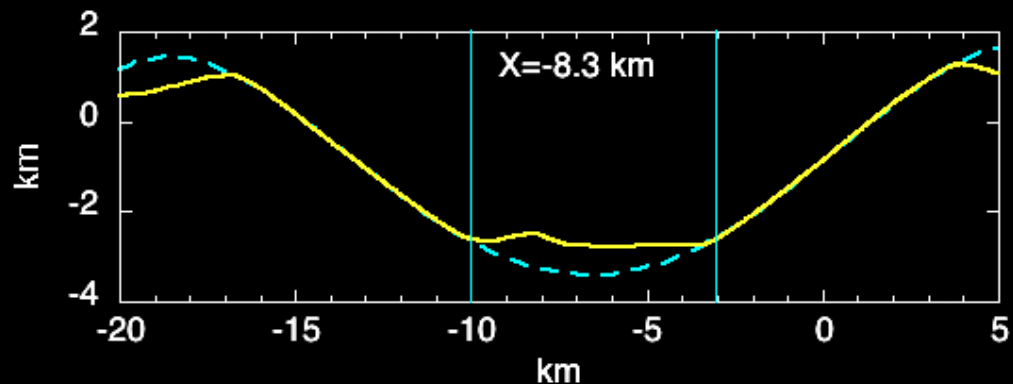
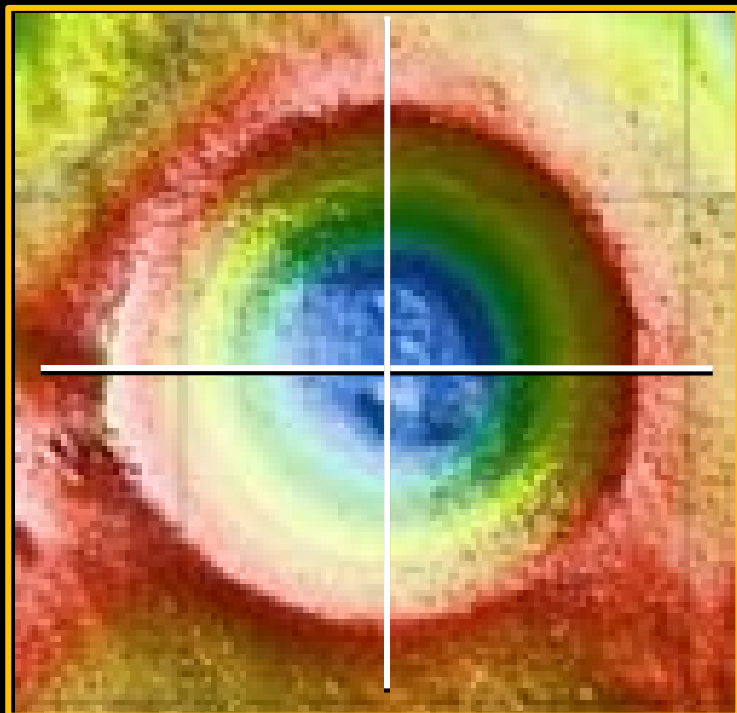
Whipple, Lunar North Pole



Topography on the floor of both craters is a few hundred meters.

Both floors are entirely in shadow. Sides of both craters are

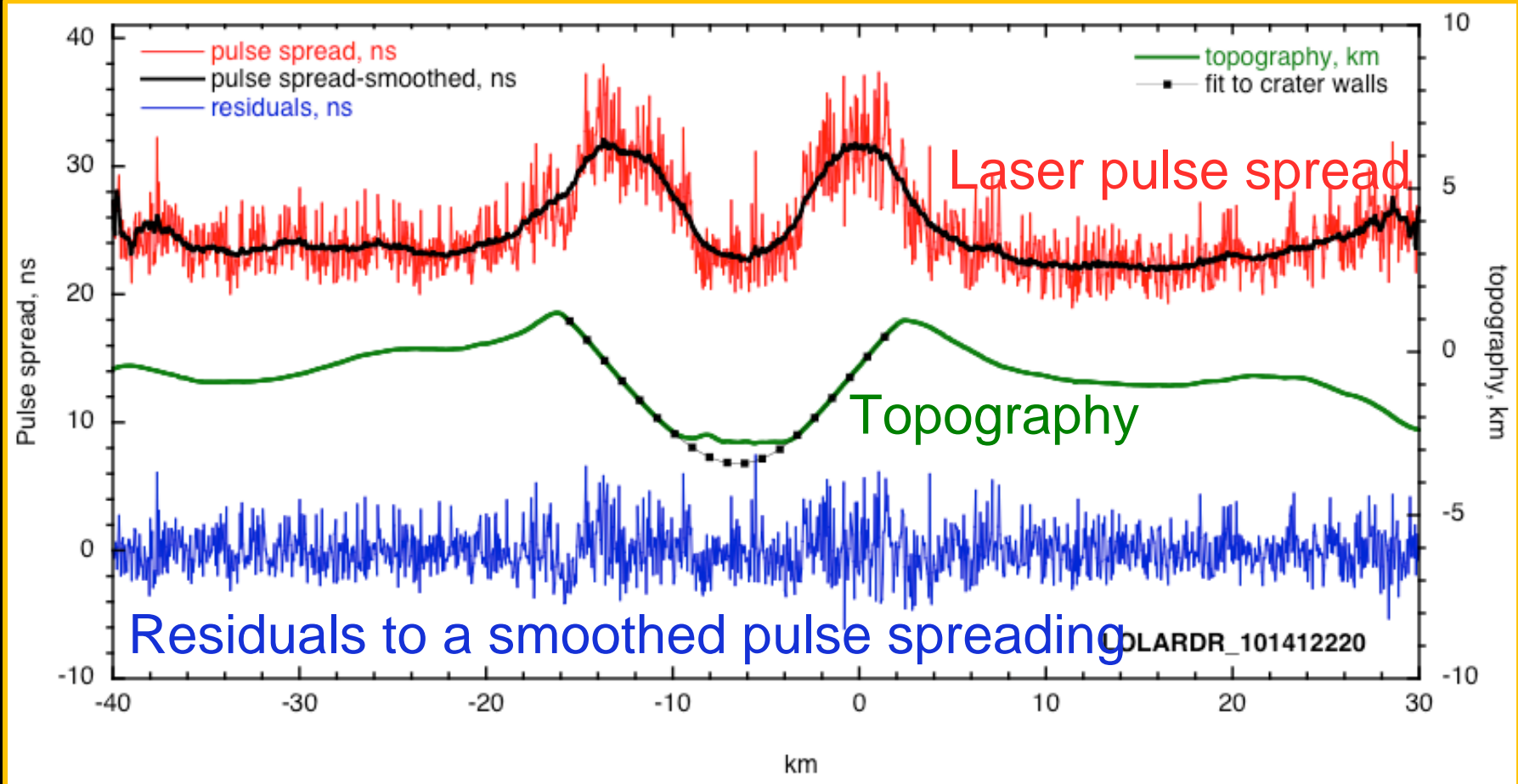
Shackleton Crater Walls and Fill



	Original cavity depth, km	Thickness of fill, km	% error in measured depth due to fill
X	3.41	0.67	8.03
Y	3.24	0.54	8.33

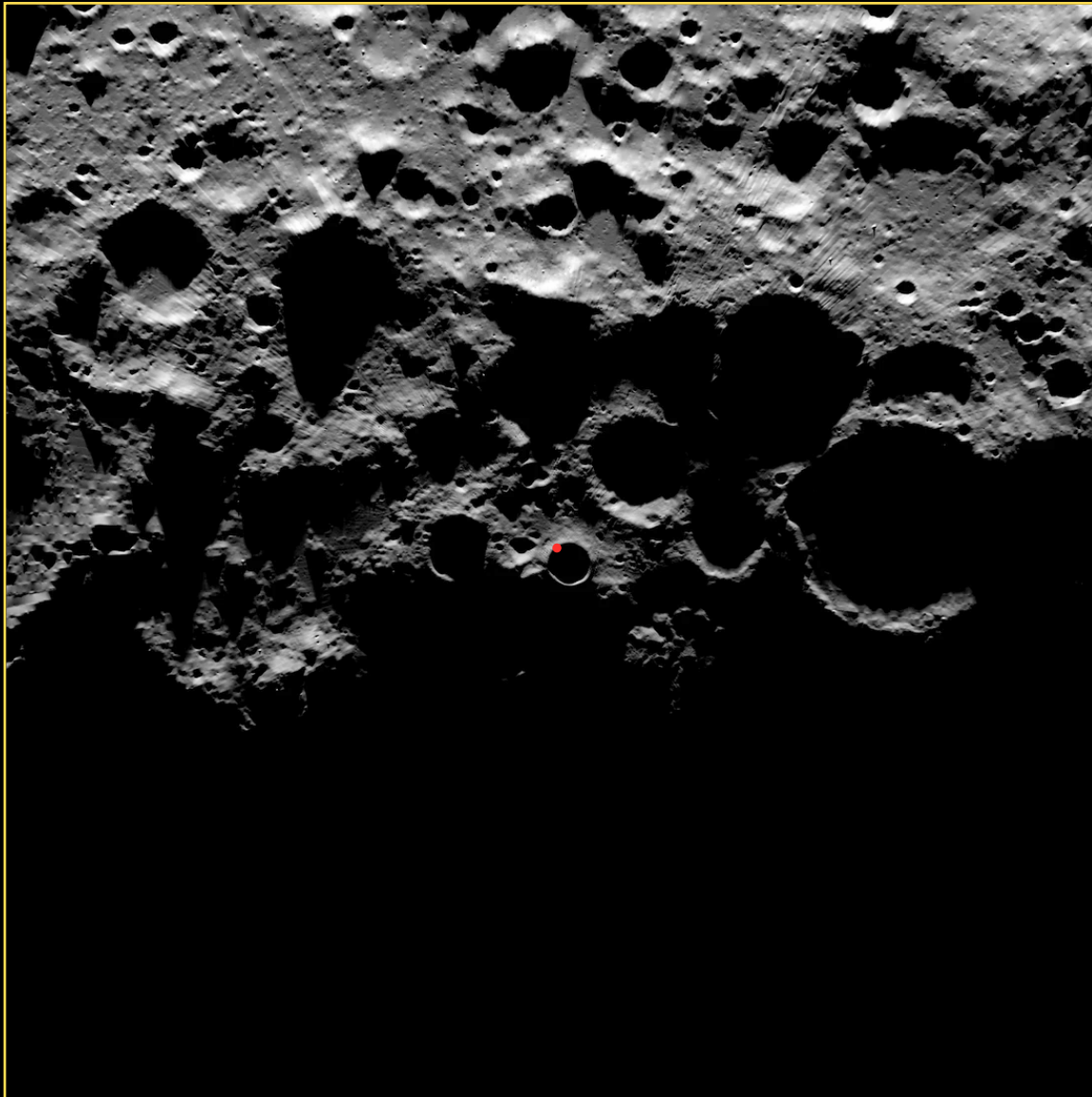


5-Meter Surface Roughness in Shackleton Crater



The spreading of the laser pulse on a profile across the Shackleton crater indicates an **rms roughness of 53 cm** outside and inside the crater **on a horizontal scale of < 5 meter**

South Pole Shadowing



Polar illumination model derived from topography.

Improving as more data acquired

Shackleton Illumination



Average lighting of Shackleton over a lunar day derived the altimeter data.

Computed for the month of the LCROSS landing, Oct 2009.

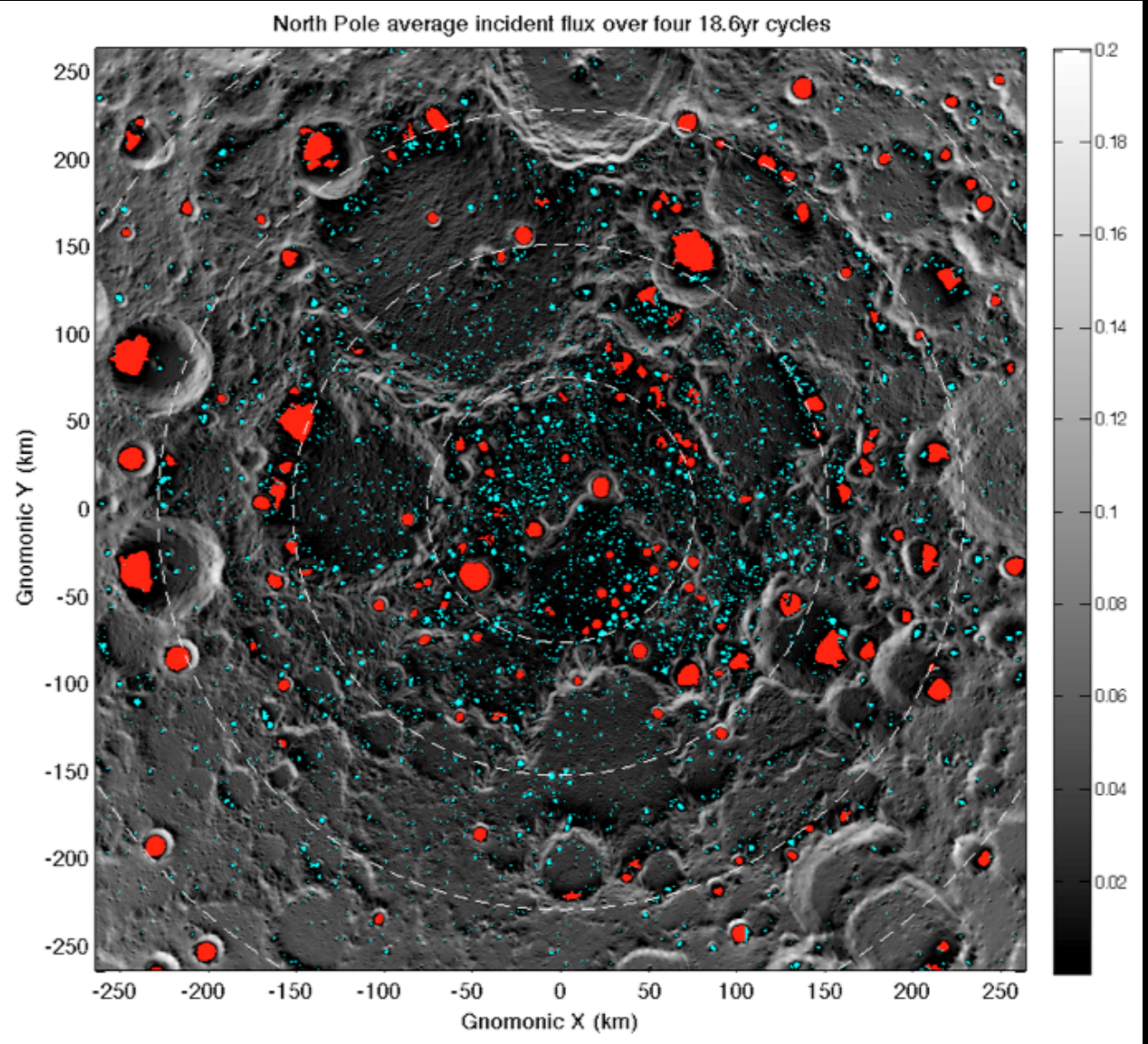
Shackleton: 21 km in diameter, 4 km deep

Mazarico

Permanent Shadow Regions - North

Less PSR in north than south.

540 km (18 deg)

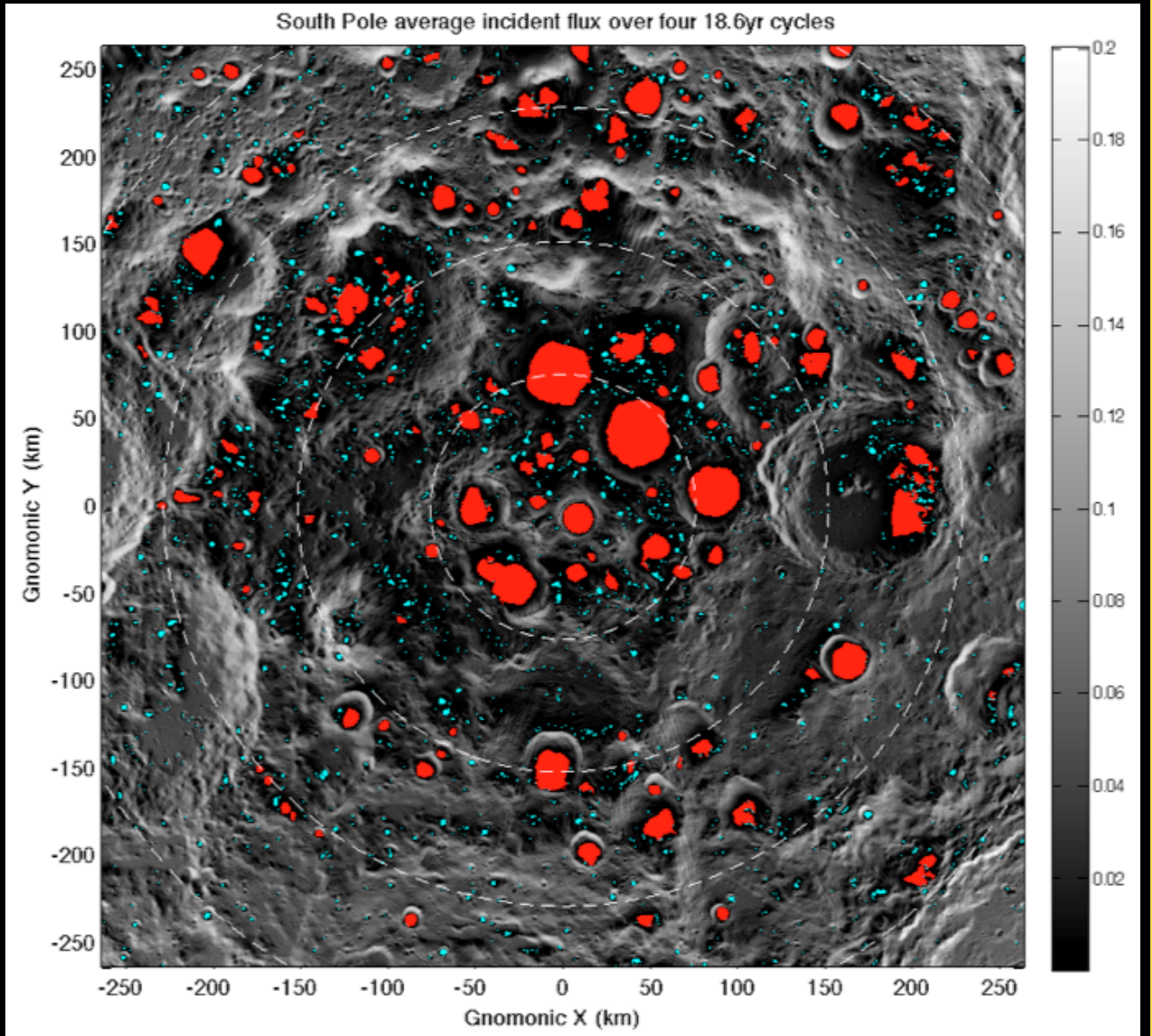


Permanent Shadow Regions - South

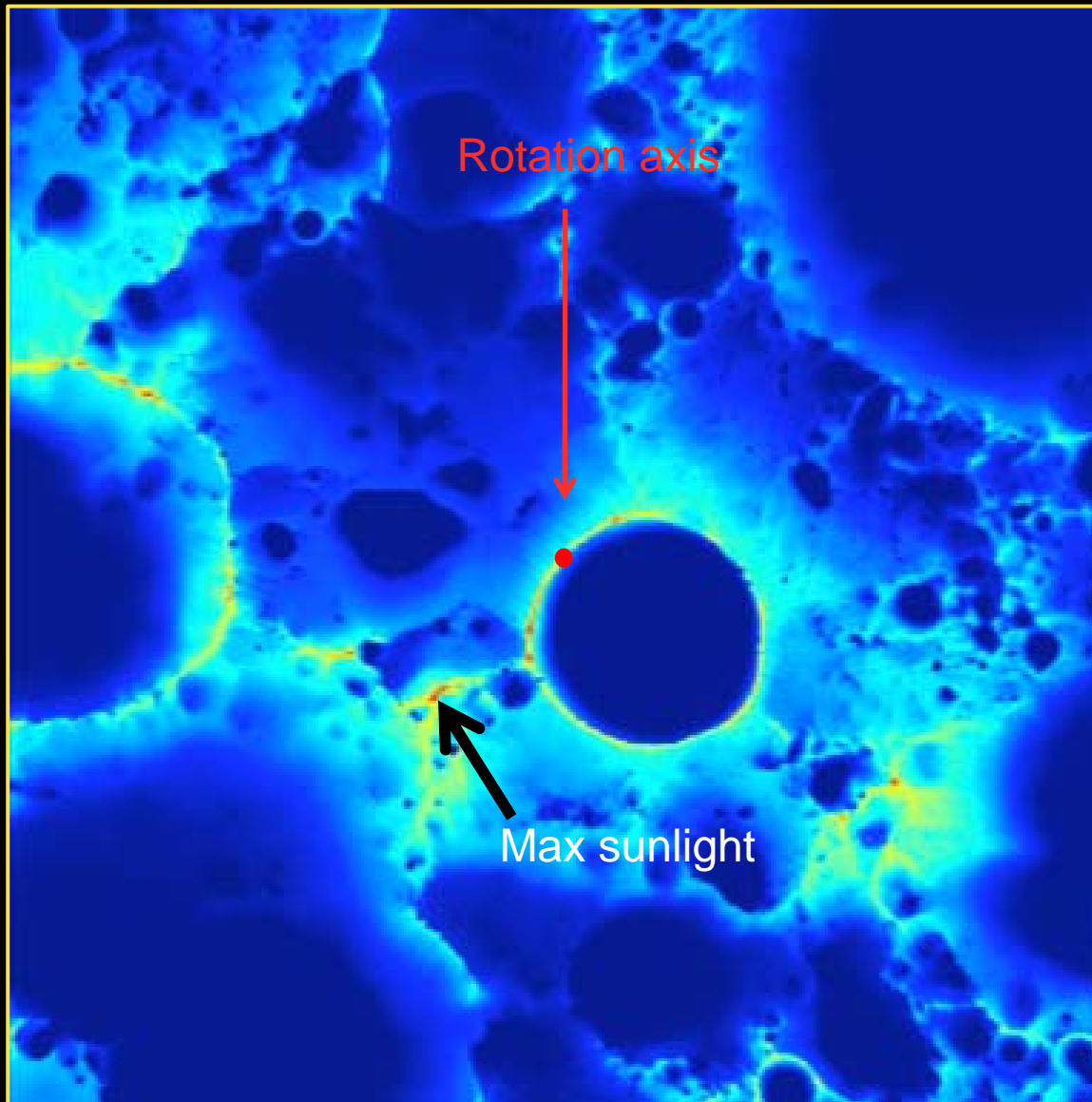
More total PSR area than previously observed.

540 km (18 deg)

No PSR areas over several thousand years when reflected sunlight and earthshine included.



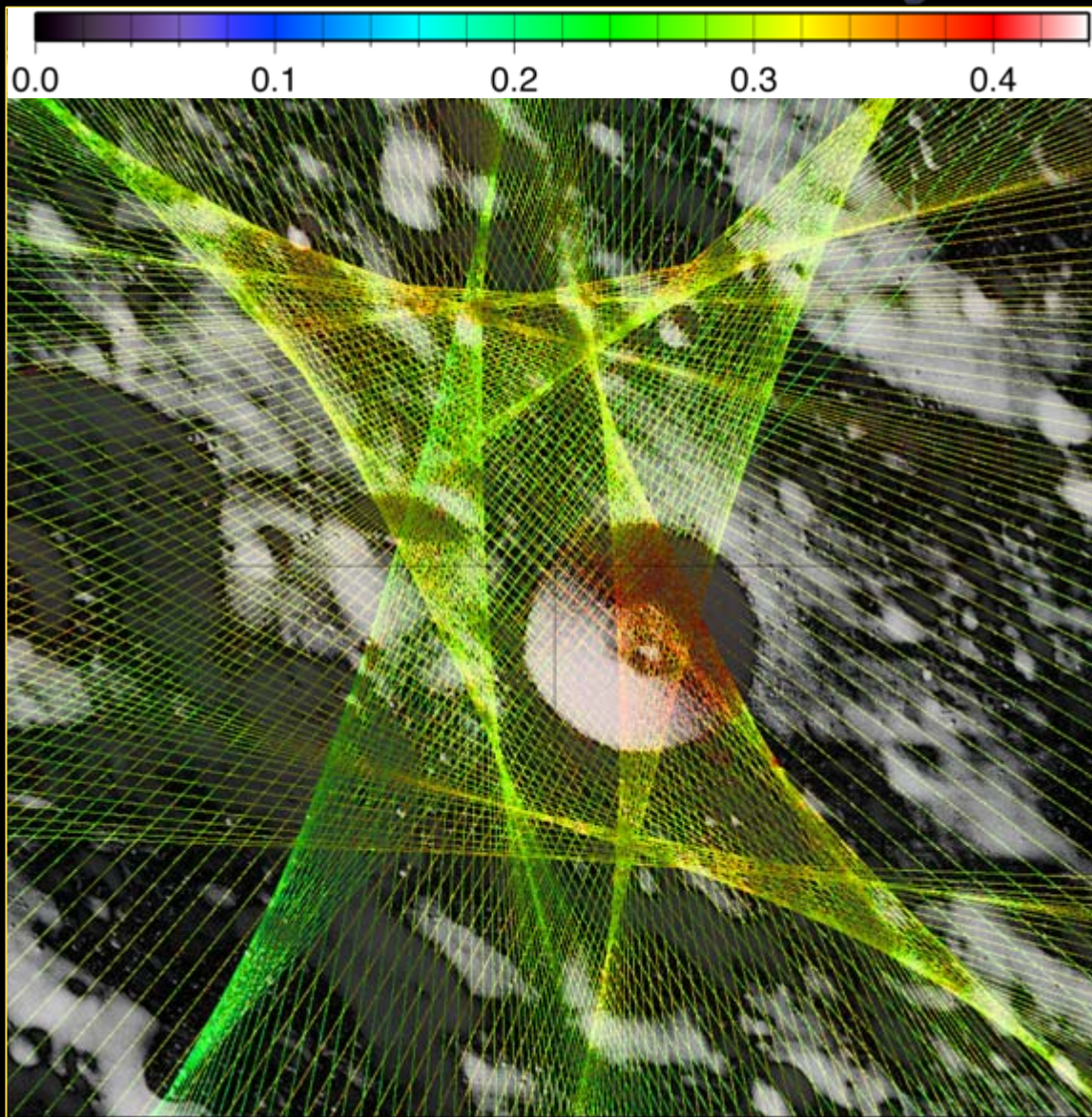
South Pole Regions of "Eternal Light"



Several small areas close to the south pole are in sunlight for most of the month.

The best area appears to be approx. 10km west of the rim of Shackleton.

Shackleton Crater: Bidirectional reflectance



1064-nm reflectance
in crater interior
greater than
surroundings

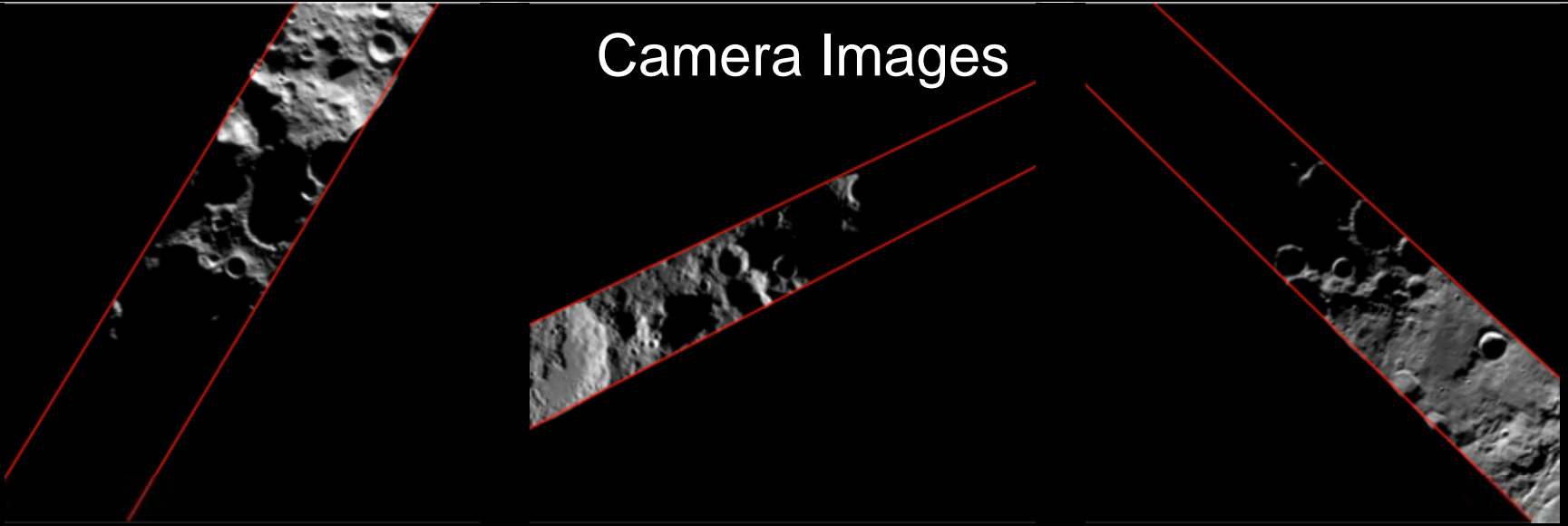
- ~0.25 0.35
- $-61 < \beta \text{ angle} < -38$
- day 127-150

Interpretation:

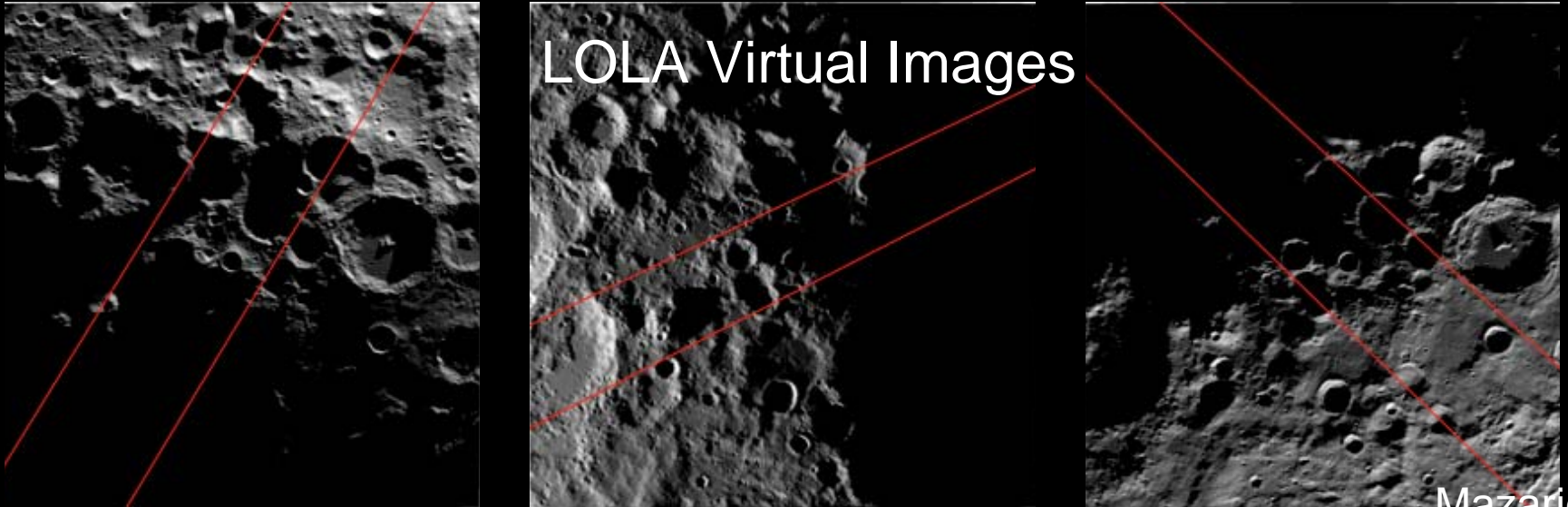
- 20% Surface ice?
- Composition?
- Surface roughness?
- Surface age?

Camera & Altimeter Shadow Model

Camera Images



LOLA Virtual Images



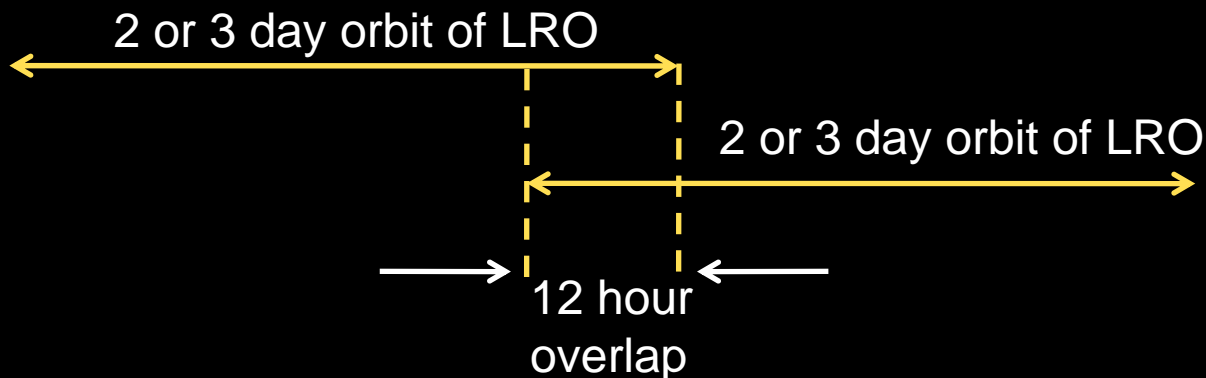
LOLA comparison with lunar laser ranging

LOLA DEM (~59 m/pixel) vs. LLR (M.E.)

Lon	Lat	<i>H</i> Refl. (km)	<i>h</i> LOLA (km)	LOLA-Refl. (meters)	Refl. Array
324.99350	38.31598	-2.4713	-2.4748	-3.5	Lun. 1
30.92201	25.83223	-2.7615	-2.7608	0.7	Lun. 2
23.47293	0.67337	-1.9269	-1.92747	-0.6	A11
342.5212	-3.64421	-1.0646	-1.0640	0.6	A14
3.62837	26.1333	-1.9223	-1.9235	-1.2	A15

Orbital Quality from Overlap Data

July 2009 through November 2010 (17 months)



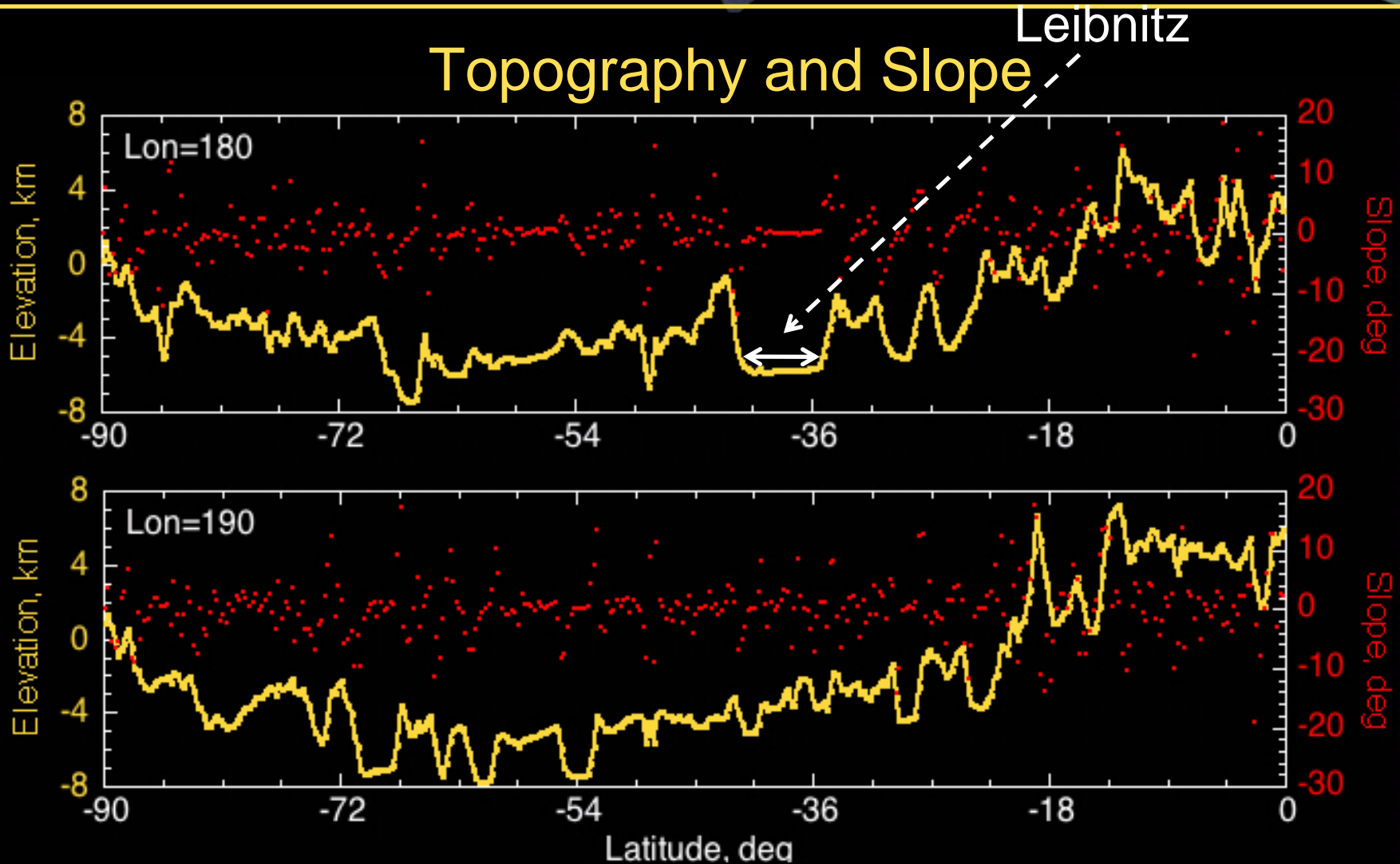
Average rms orbital differences during 12 hr overlap periods for 17 months of LRO:

Long Track	Across Track	Radial	
TOTAL			
(meters)	(meters)	(meters)	(meters)
8.5	8.3	1.6	

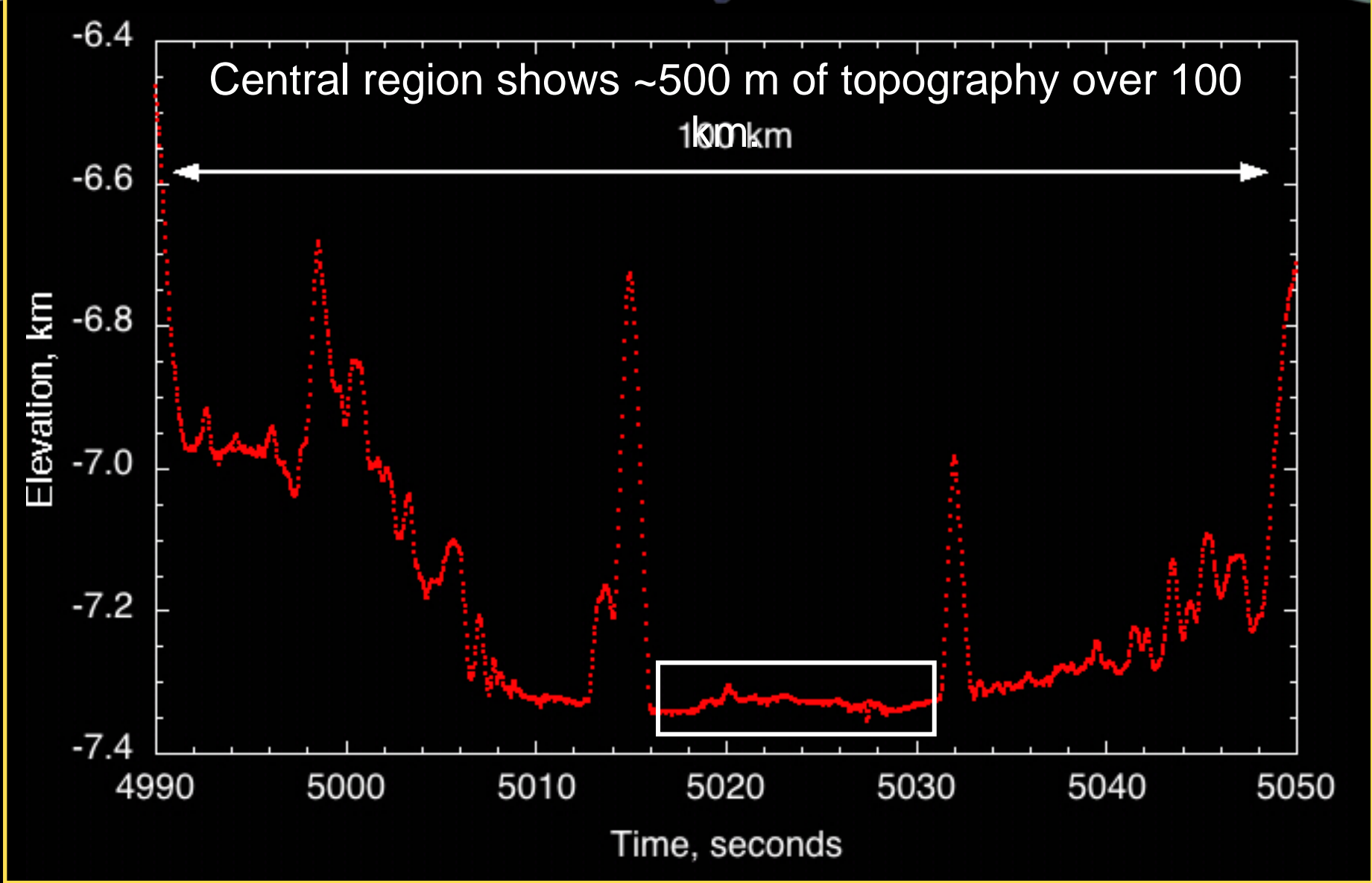
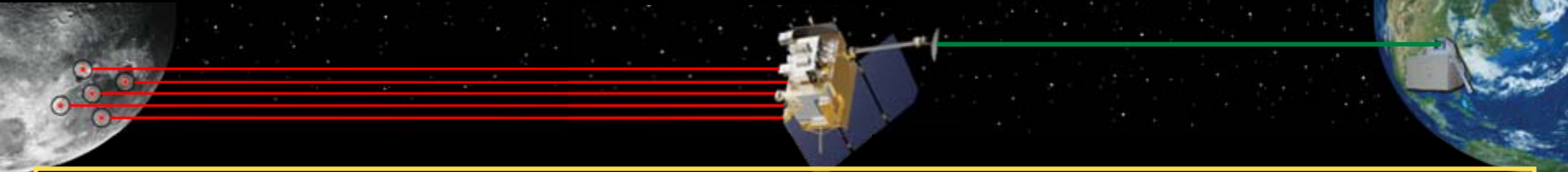


Profiles Through South Pole - Aitken

Topography and Slope

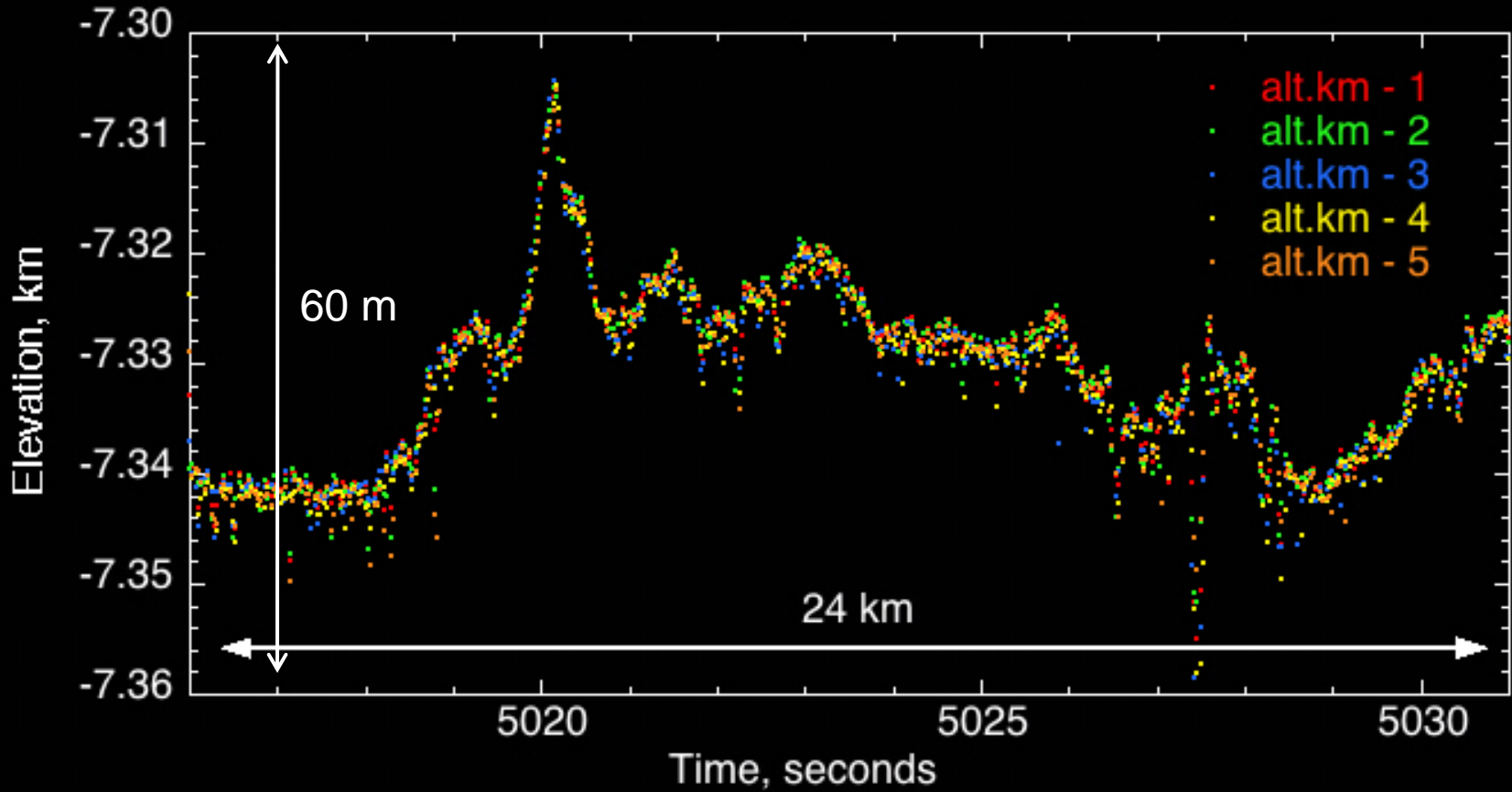
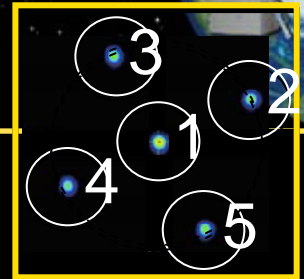


Profile data has ~10 to 20 m resolution along track



Center of Leibnitz

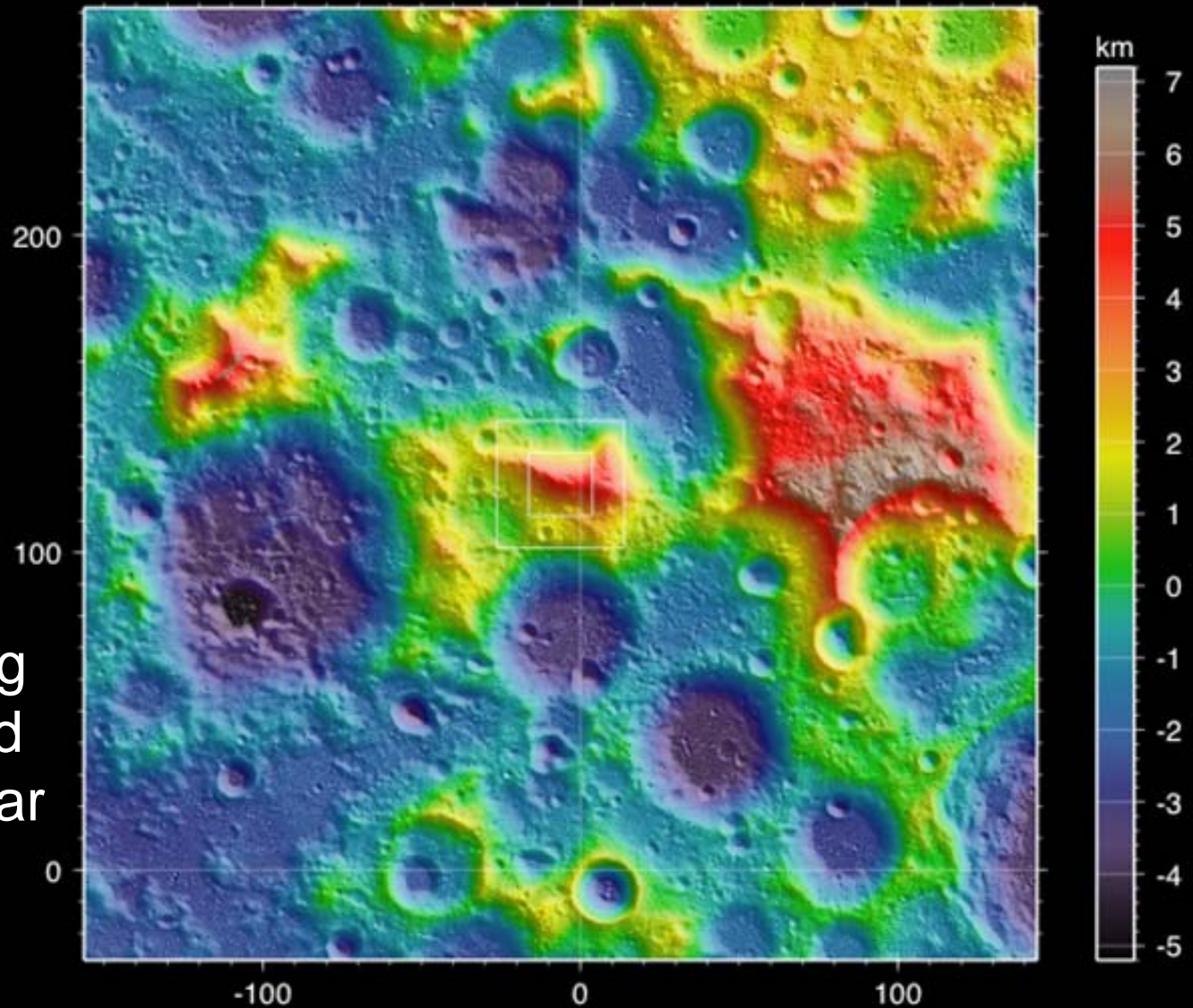
15 seconds of LOLA data



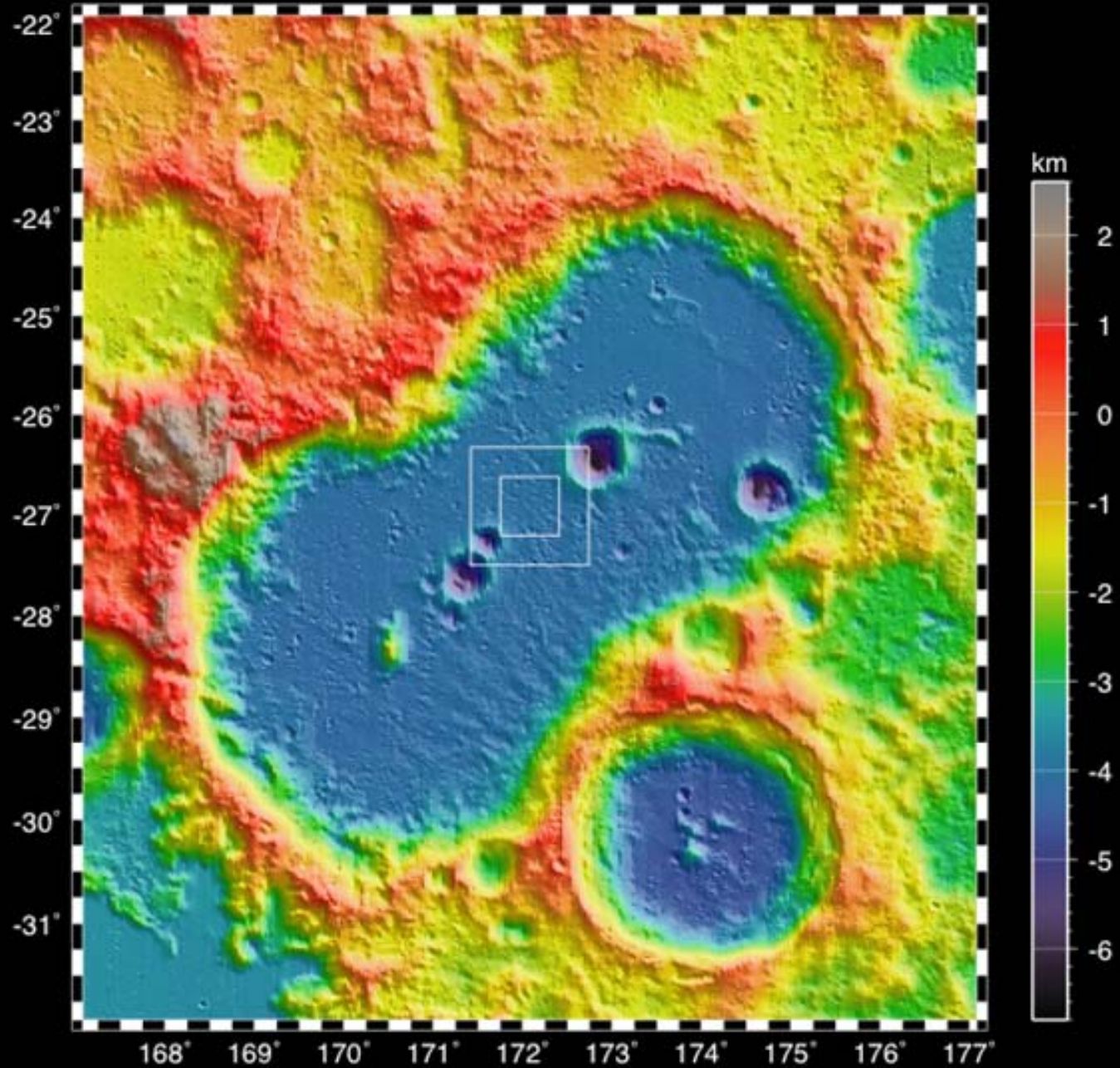
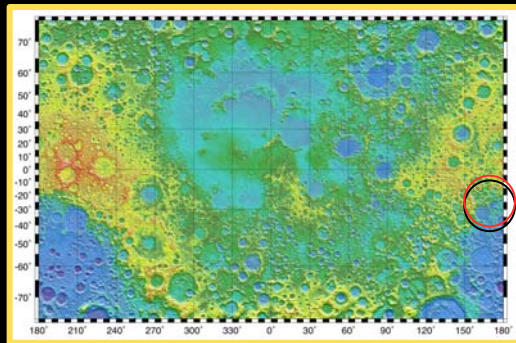
Malapert Mountain (86.0S, 5.0E)

120 m/pixel
context
topographic
image of
Malapert
Mountain.

One of the
potential landing
sites considered
by NASA's Lunar
Exploration
Program

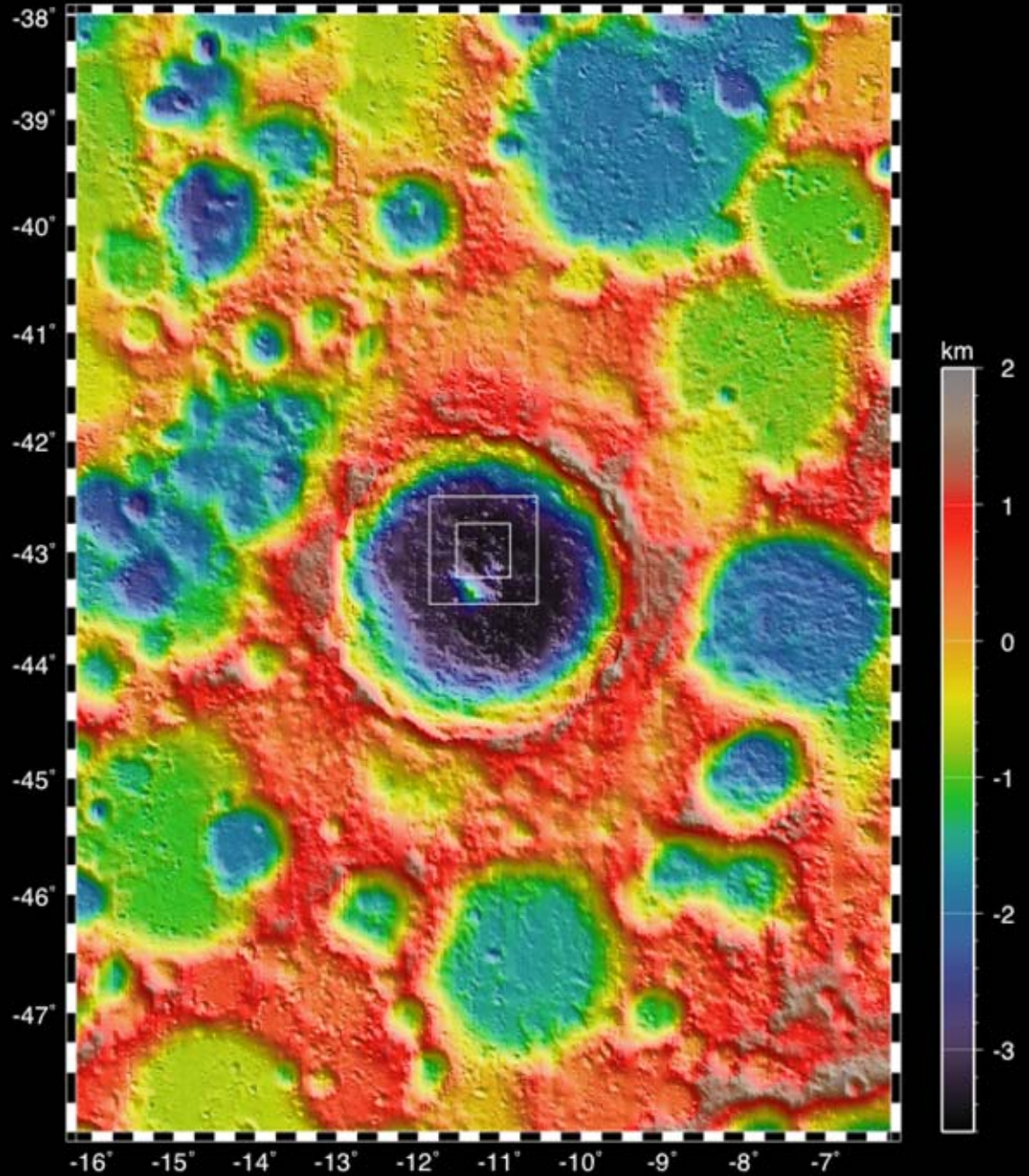
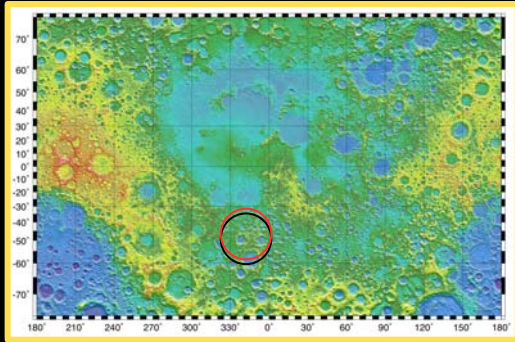


VDG 172.08 -26.92

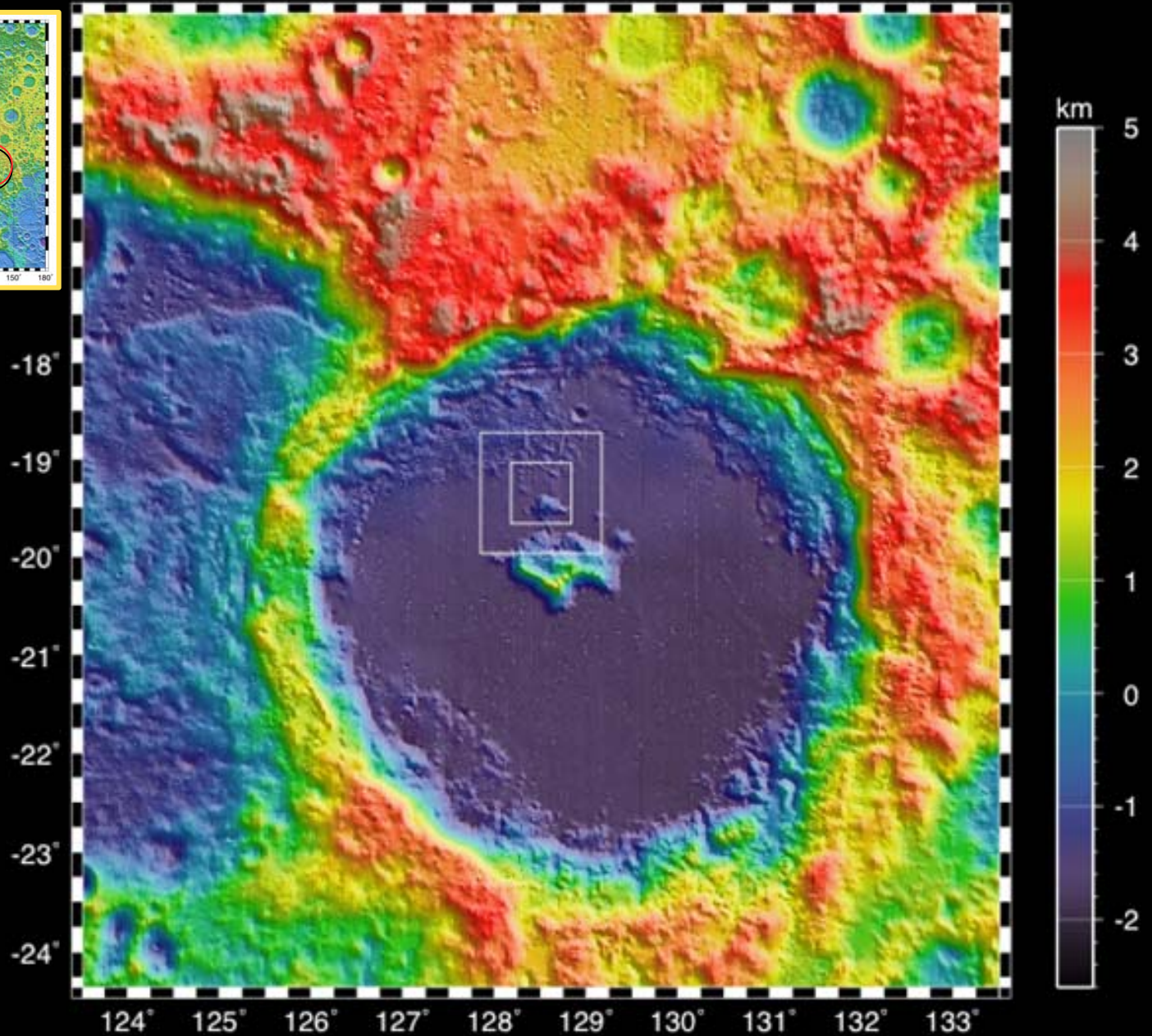
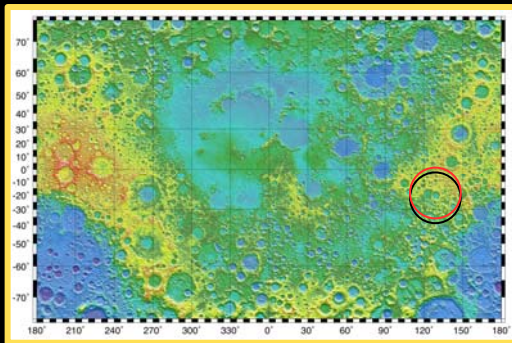


Tycho

TYC 348.80 -42.99

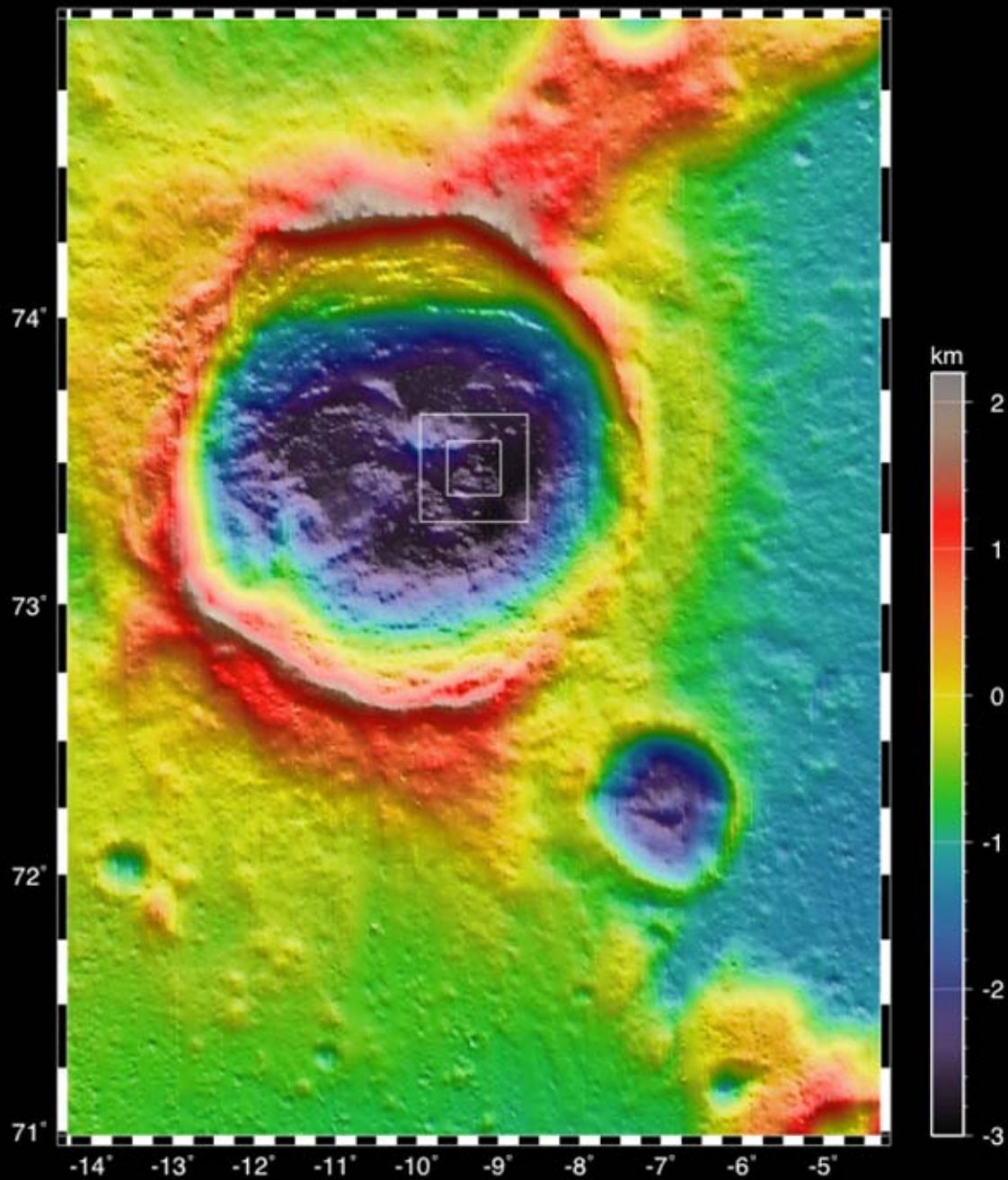
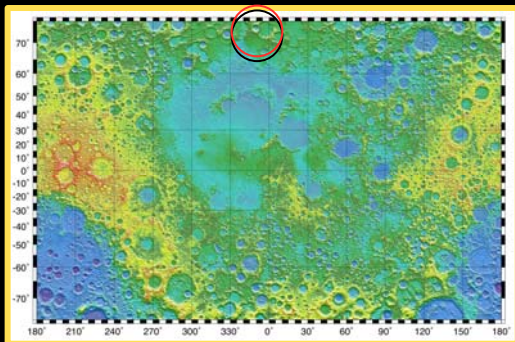


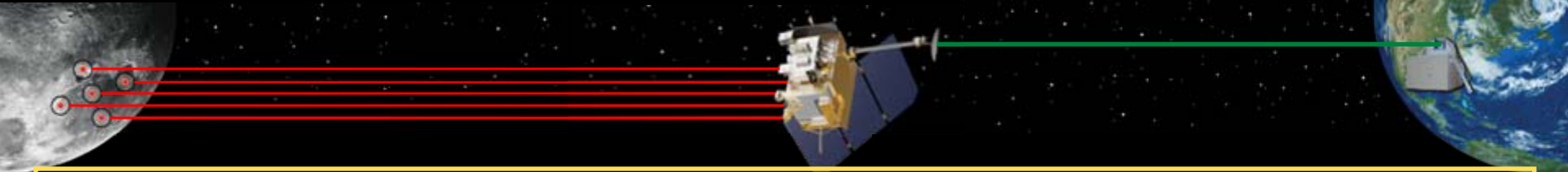
TSK 128.51 -19.35



Anexagoras

ANX 350.70 73.48



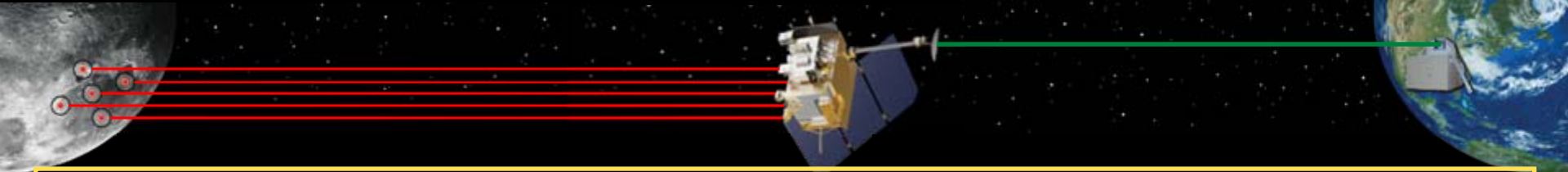


LOLA can provide measurements of:

- elevation (radius)
- surface slopes
- surface roughness over a range of horizontal scales
- surface reflectance

LOLA data can be used to derive accurate positions on the lunar surface and topographic context images of potential landing sites

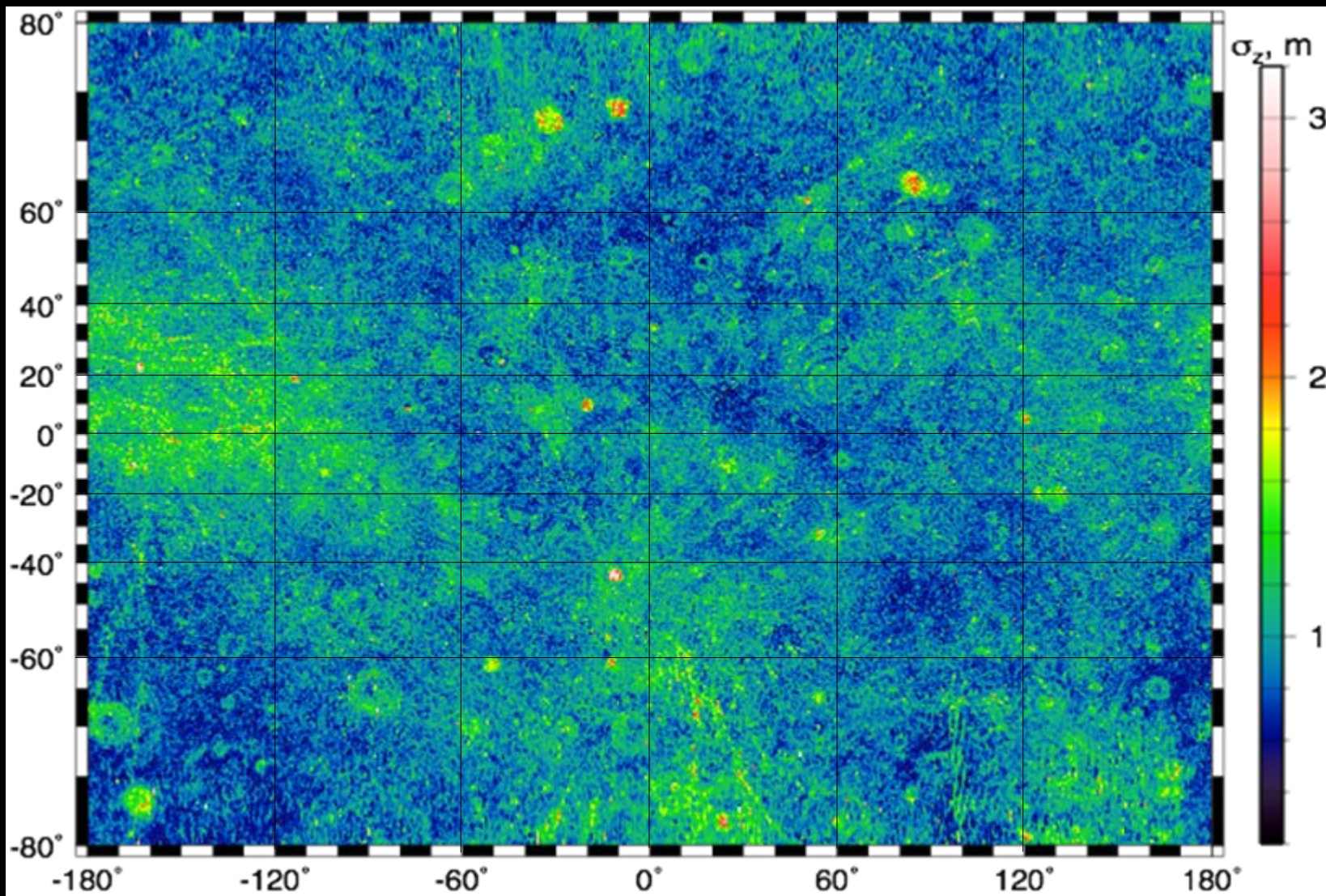
LOLA has developed a self consistent coordinate system for all LRO measurements by all instruments



STOP

Surface Roughness on 50 meter Baselines

Small scale roughness highlights recent impacts



Absolute Positioning: a profile near Apollo 15

ABSOLUTE LUNAR GEODETIC CONTROL

Tie LOLA to NAC
Tie NAC to Apollo

10 m

● Apollo 15

725 meters (0.5 seconds)

