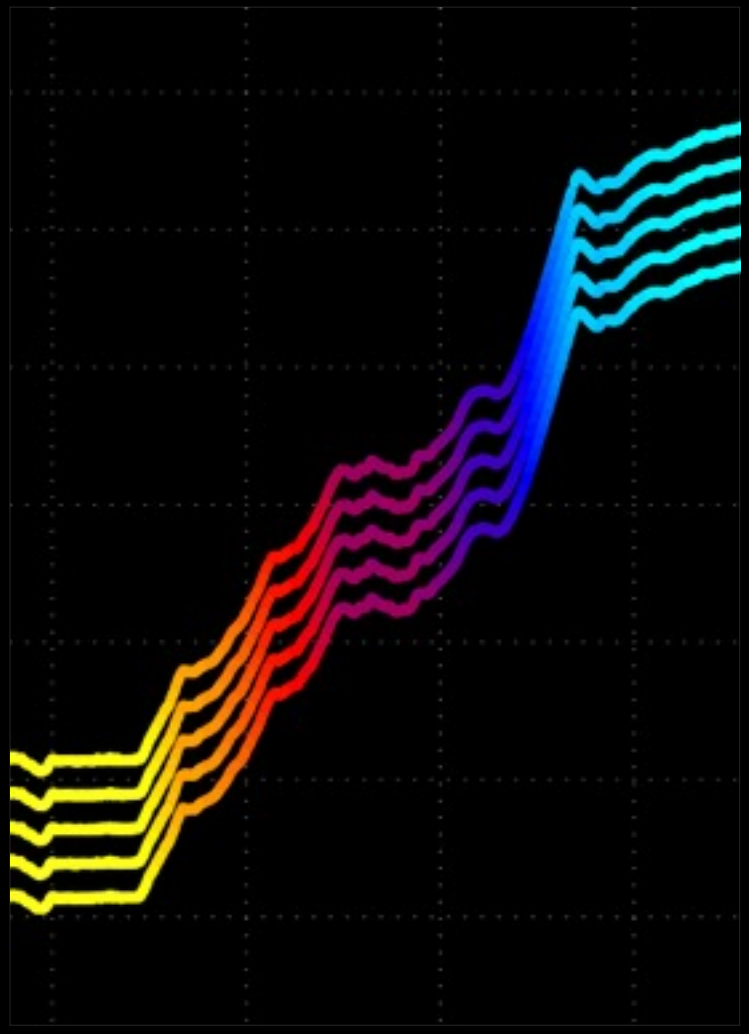
Status Report on the Commissioning of the LRO Laser Altimeter (LOLA) and Laser Ranging (LR) Instruments

David E. Smith, Maria T. Zuber, John F. Cavanaugh, Gregory A. Neumann, Mark H. Torrence, Erwan Mazarico, Jan F. McGarry, Haris Riris, Peter Liiva, Frank G. Lemoine, David D. Rowlands, James C. Smith, Xiaoli Sun, Owen Westbrook

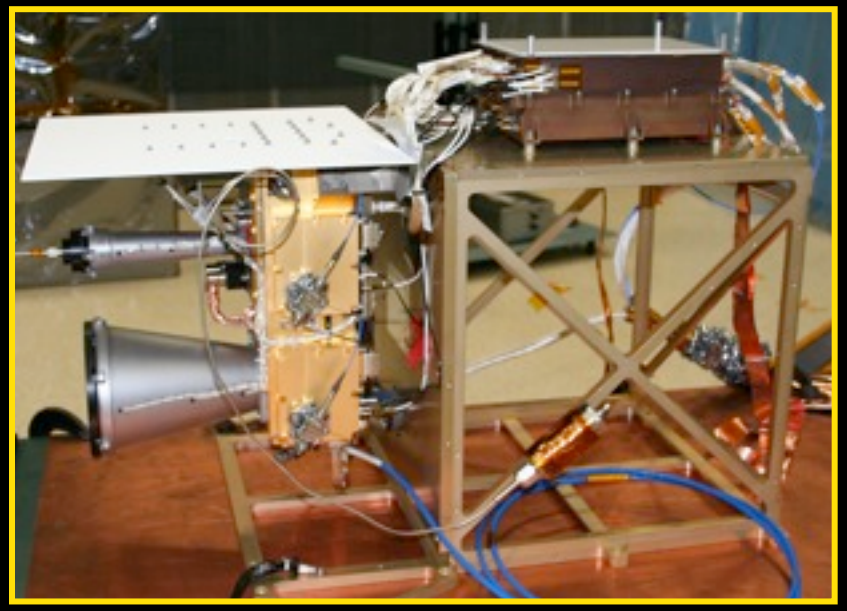
Lunar Science Forum
NASA/Ames Research Center
July 21, 2009



NASA/GSFC/LRO/LOLA

LOLA/LR Measurement Objectives

1. Lunar topography to an accuracy ± 1 m and 10-cm precision.
2. Surface slopes in 2 directions to better than 0.3° on a 25-m scale.
3. Surface roughness to 30 cm.
4. Surface reflectance at 1064 nm to ~ 5%.
5. Establish a global lunar geodetic coordinate system.
6. Improve knowledge of the lunar gravity field via precision orbit determination.



LOLA prior to TVAC

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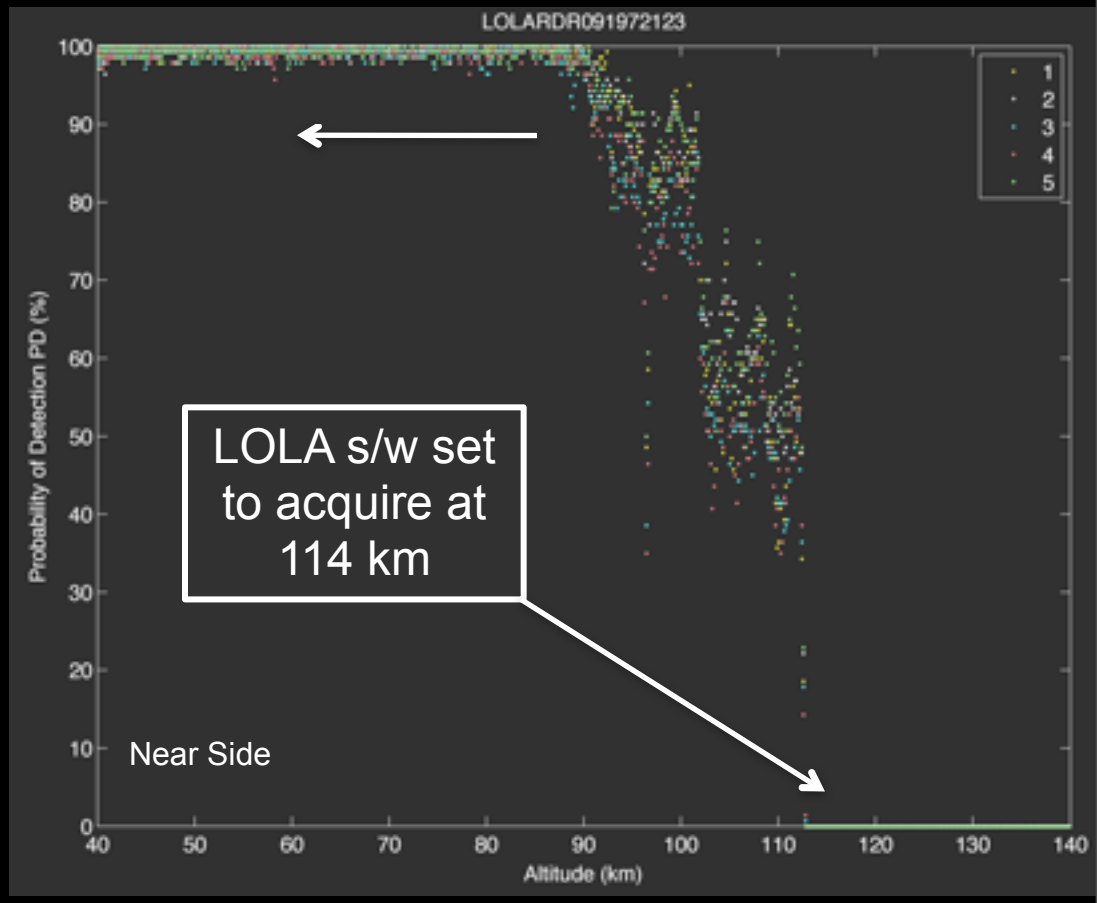
Commissioning Status

- As of July 20, 2009 (~9 days of laser operation):
  - 18,943,055 valid ranges
  - fraction signals acquired
  - 2.8x Kaguya data set [Araki et al., *Science,* 2009 =6.77x10^6] measurements as of 03/31/09
- Continuous ranging at high probability achieved for all 5 channels to altitude of 120 km
  - limited by range gate width
  - designed for 50 km altitude

- Loss of signal crossing terminator being investigated
  - alignment?
  - environment (e.g., thermal, lunar albedo, etc.)?



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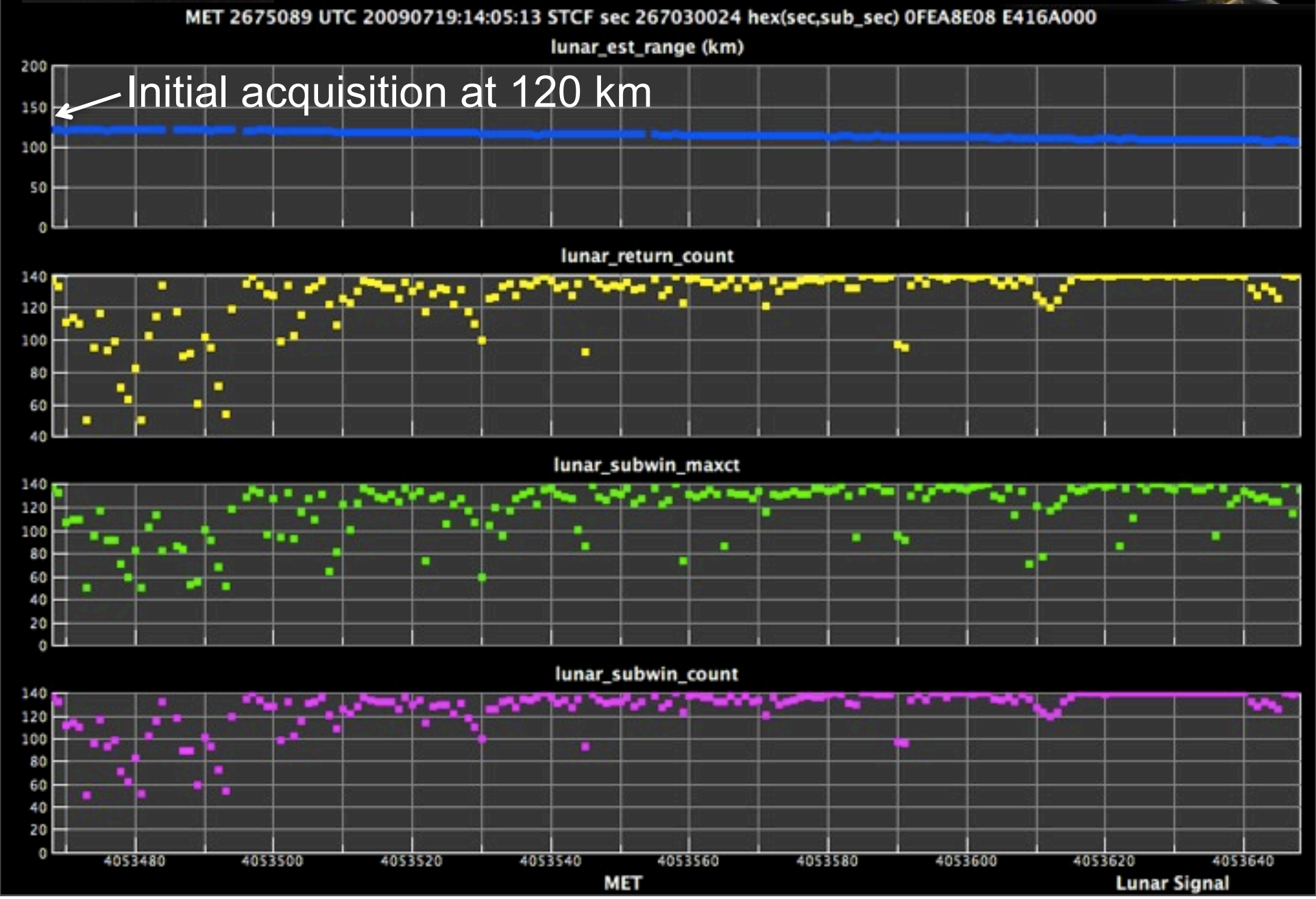
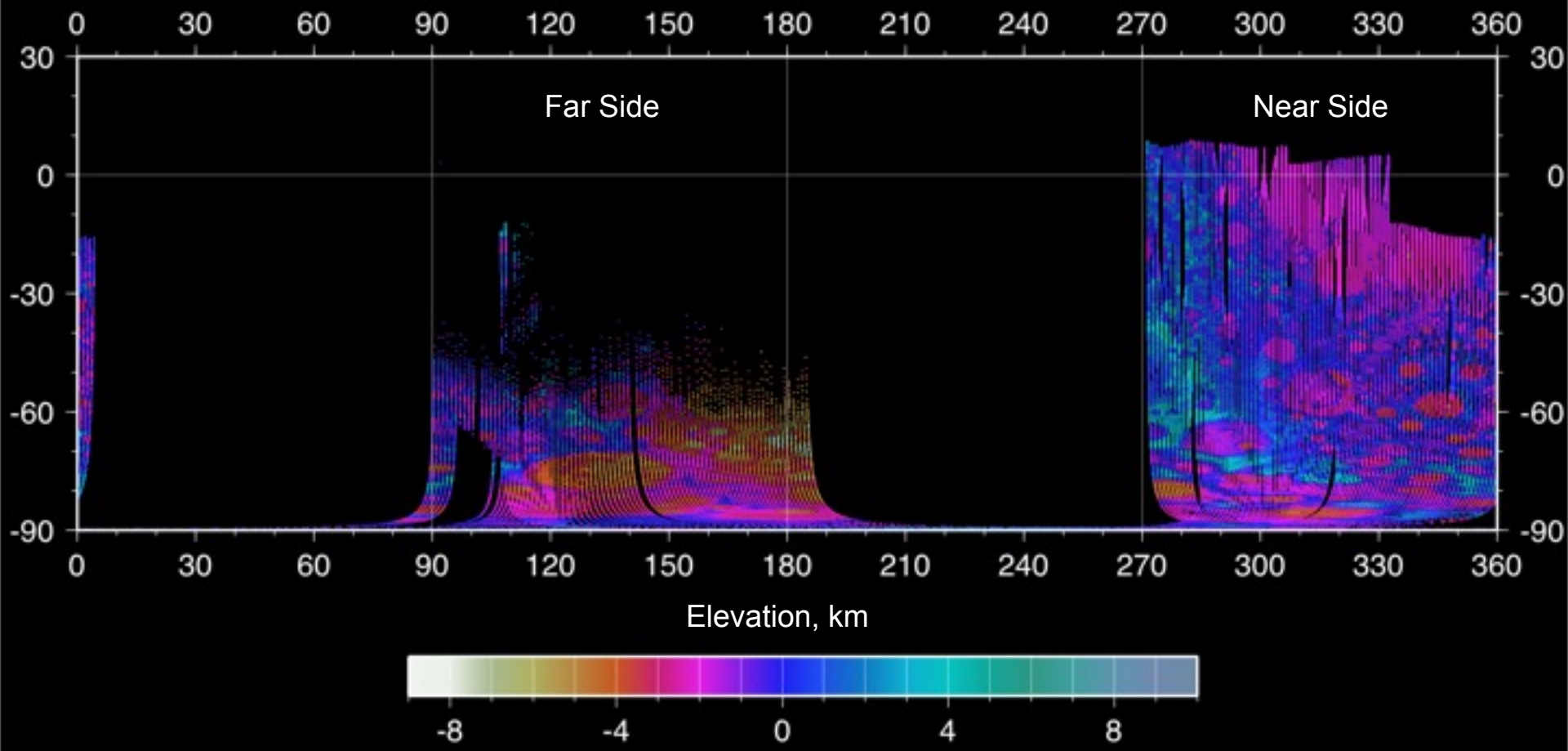
Realtime Display – Ranging Altitude



Data Distribution
Through 20 July 2009



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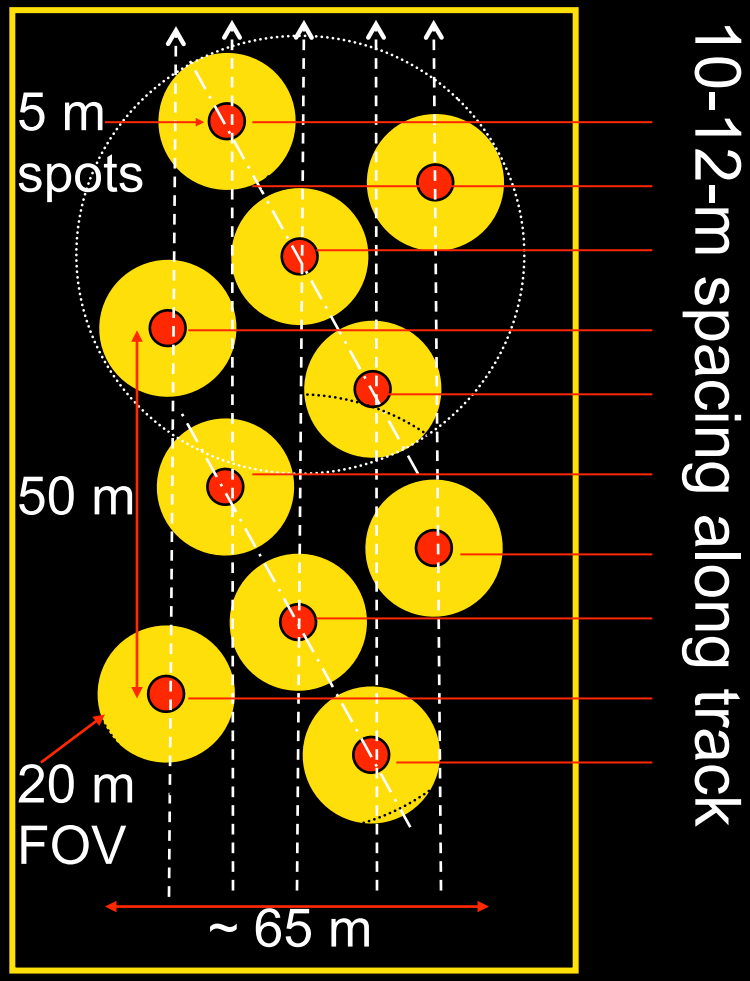
Ground Pattern – 50-km Altitude

- Each 5-m spot provides:
  - range to surface
  - footprint-scale surface roughness
  - 1064-nm reflectance of surface
- Transmitter Energy: 2.7 mJ; ~0.5 mJ/spot
- Diffractive Optical Element: 5 beams each 100-μrad divergence (red spot)
- Receiver: 0.14-m diameter
- FOV: 400-μrad each spot (gold area)
- Detectors: 5 fiber optically-coupled avalanche photodiodes



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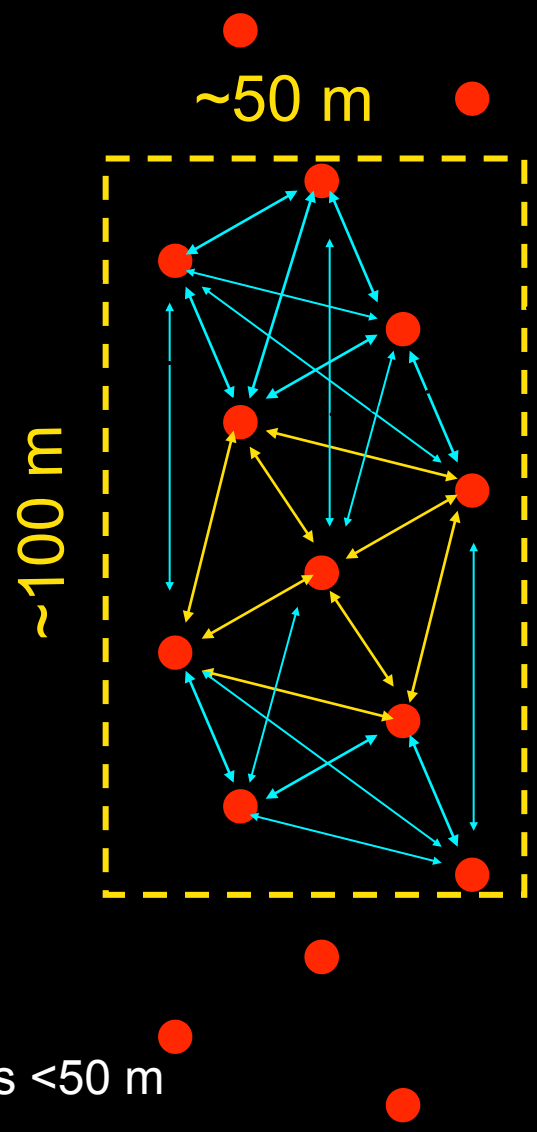
Surface Slopes

- Within a 100-m x 50-m along-track area there are:
  - 10 5-m-diameter spots
  - slopes with baselines ranging from 25 m to 50 m
  - another 23 slopes with baselines of >50 to <100 m

- For slopes < ± 3° in a 5-m spot, height precision will be < ± 10 cm and slope accuracies will be ± 0.3° to 0.15°.



22 measured baselines <50 m

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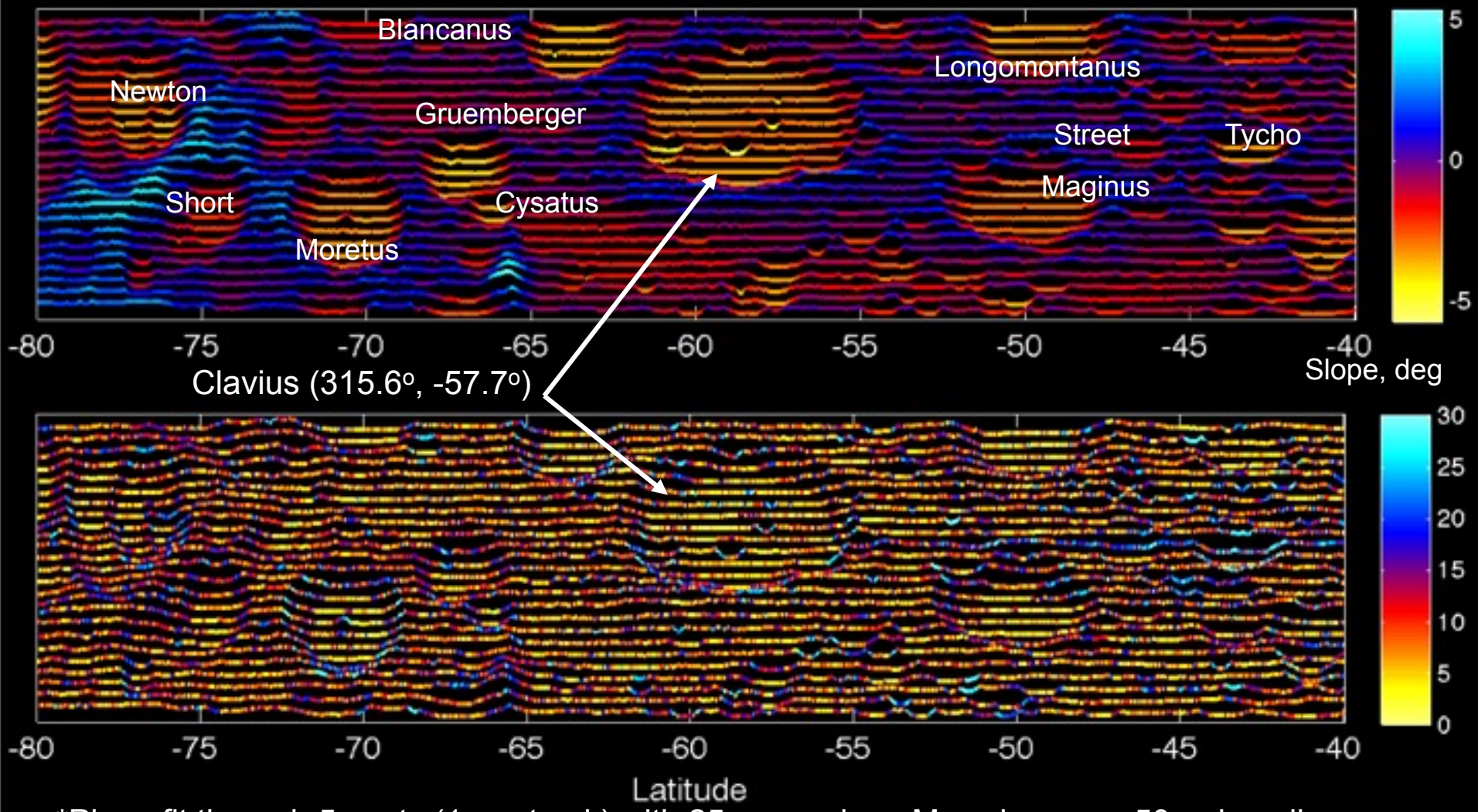
Topography and Slopes*

2 days of data

Orbit track spacing= 1° ~15 km at 60S.



*Plane fit through 5 spots (1 per track) with 25 m spacing . Max slopes on 50-m baselines.

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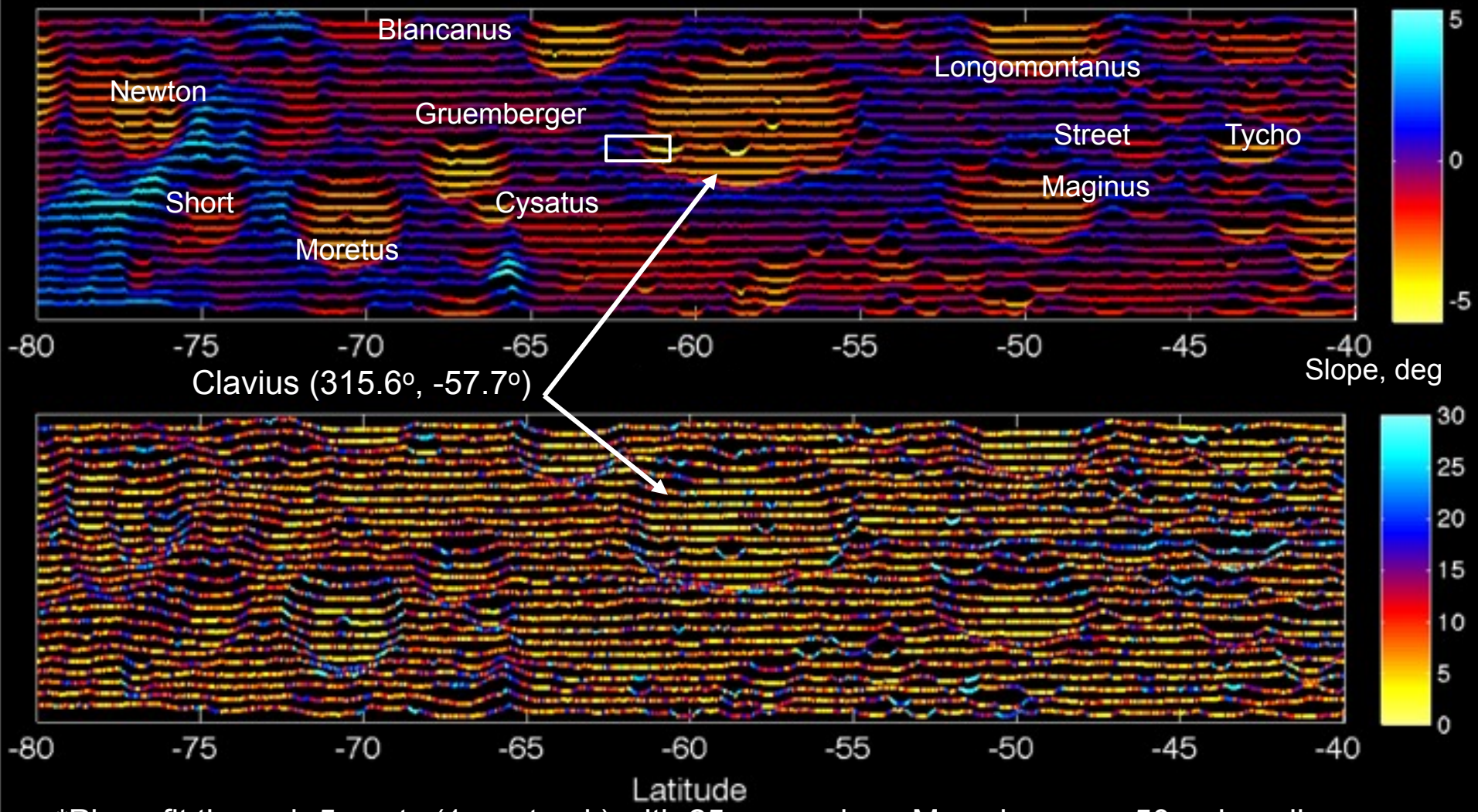

*Plane fit through 5 spots (1 per track) with 25 m spacing . Max slopes on 50-m baselines.

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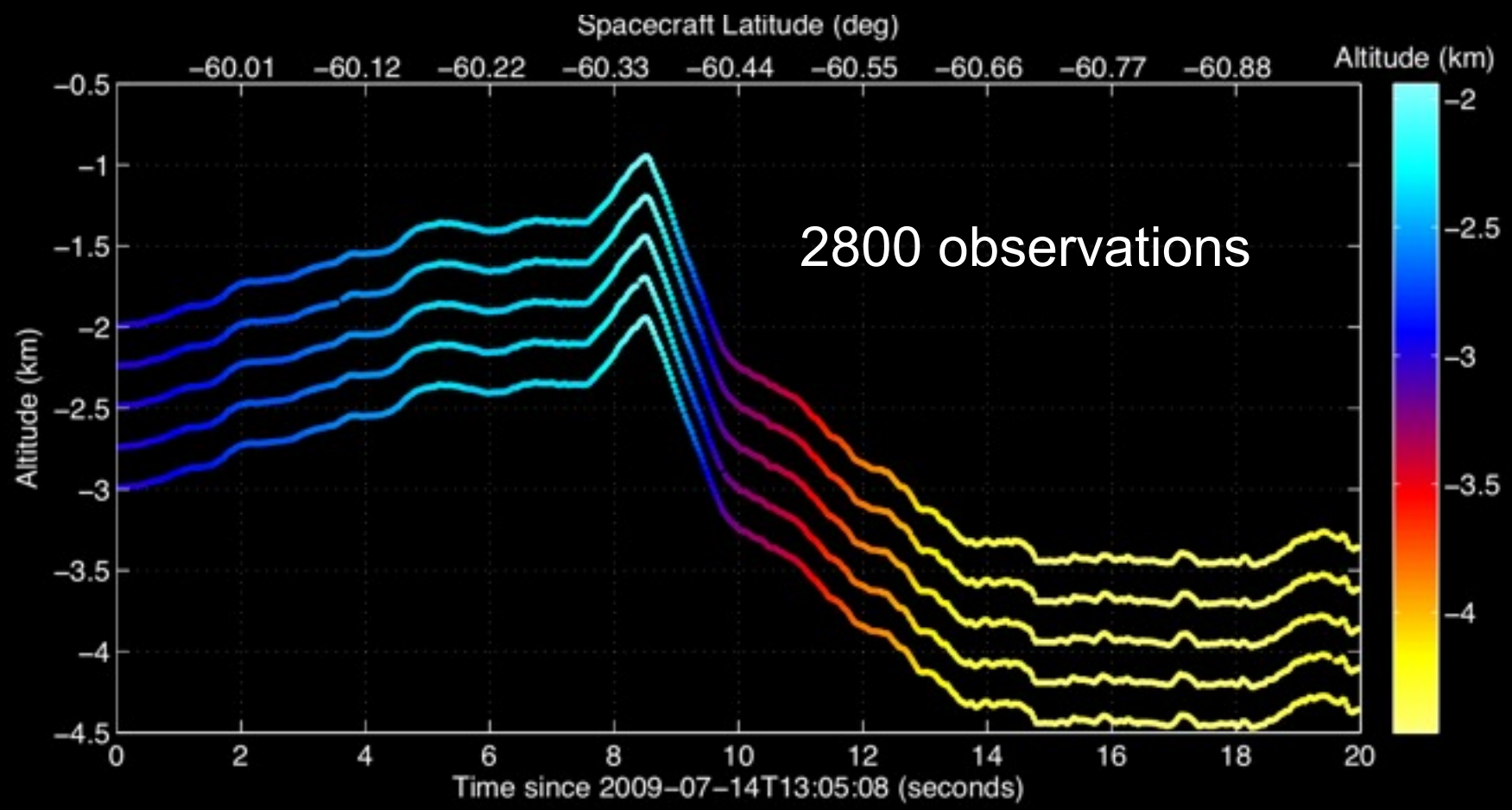
20 seconds of Topography and Slopes

The 5 tracks are ~ 12 m apart; shown separated by 250 m in altitude



altitude label corresponds to bottom profile

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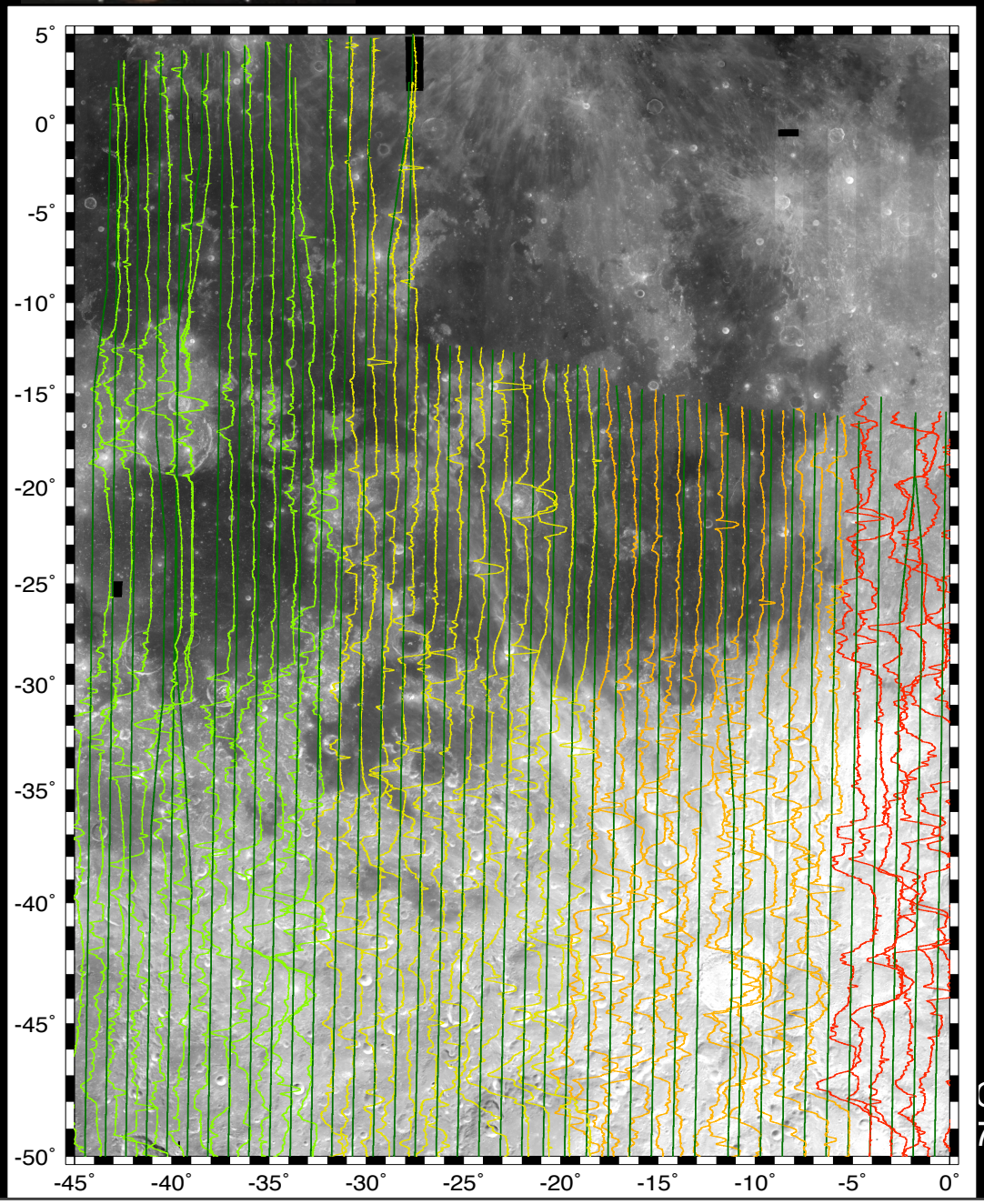
LOLA Detector 3



- 4 days of data
- 1° track spacing
- Each orbit track contains 5 profiles
- Chart shows changes in acqusition altitude

Clementine USGS 750-nm mosaic

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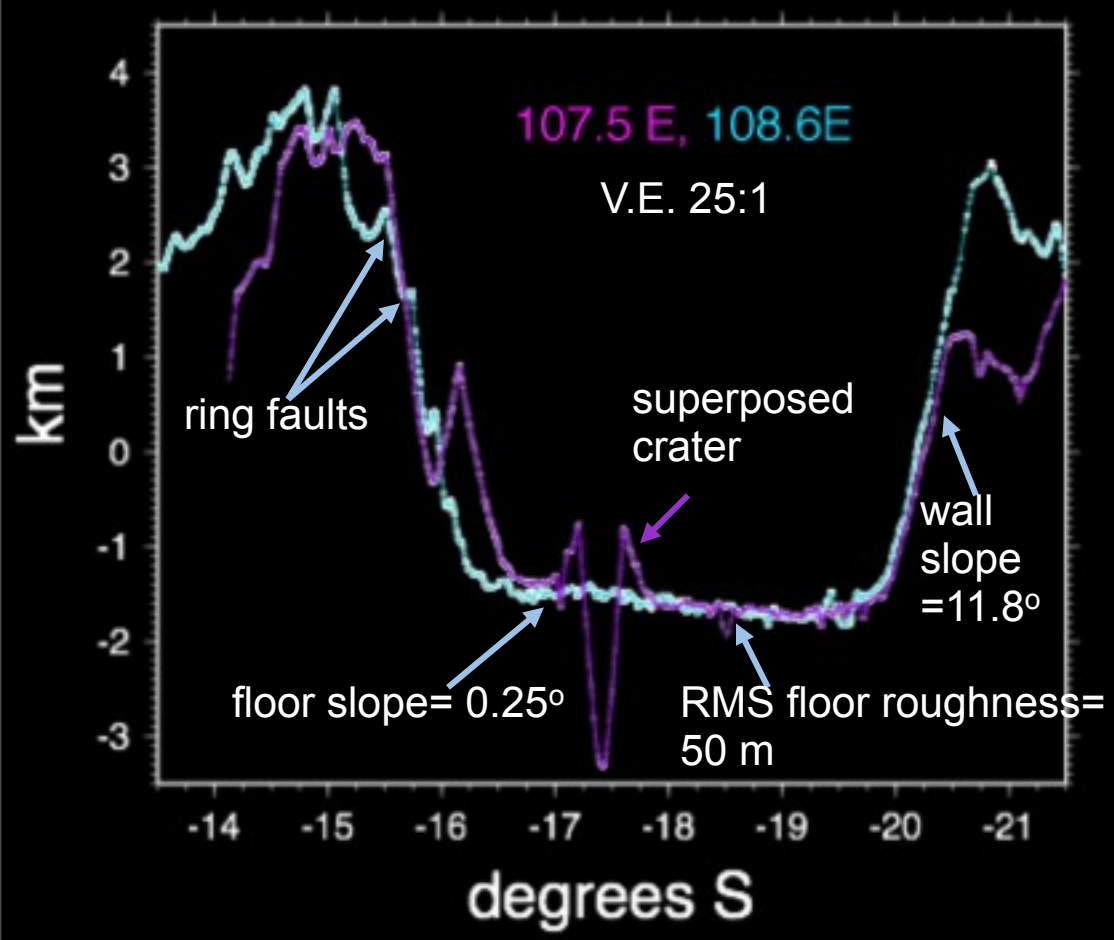
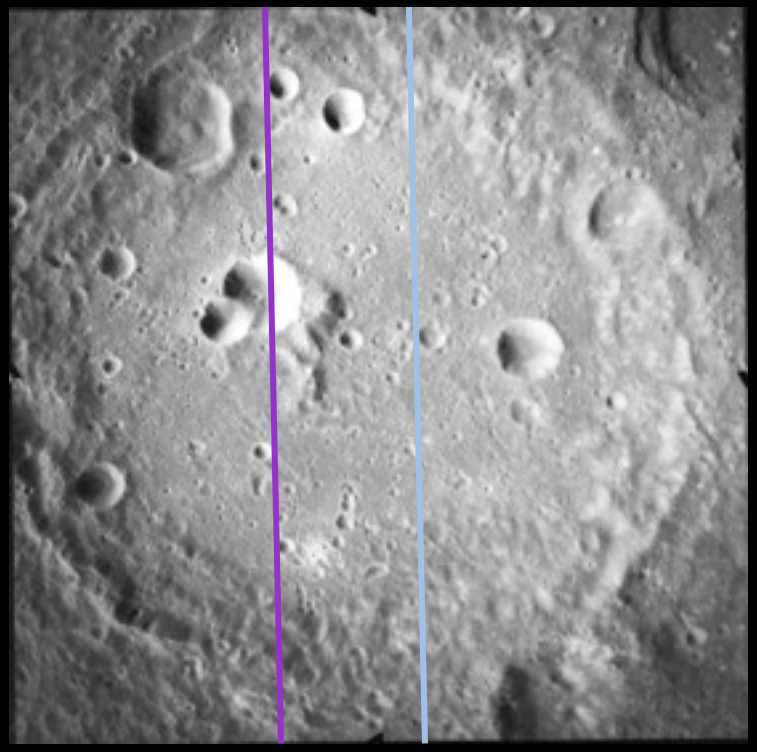
Structure of Hilbert Basin





NASA/Apollo 15
AS15-M-1729

- Salient aspects of structure:
  - ring faults
  - floor tilt and roughness
  - superposed craters

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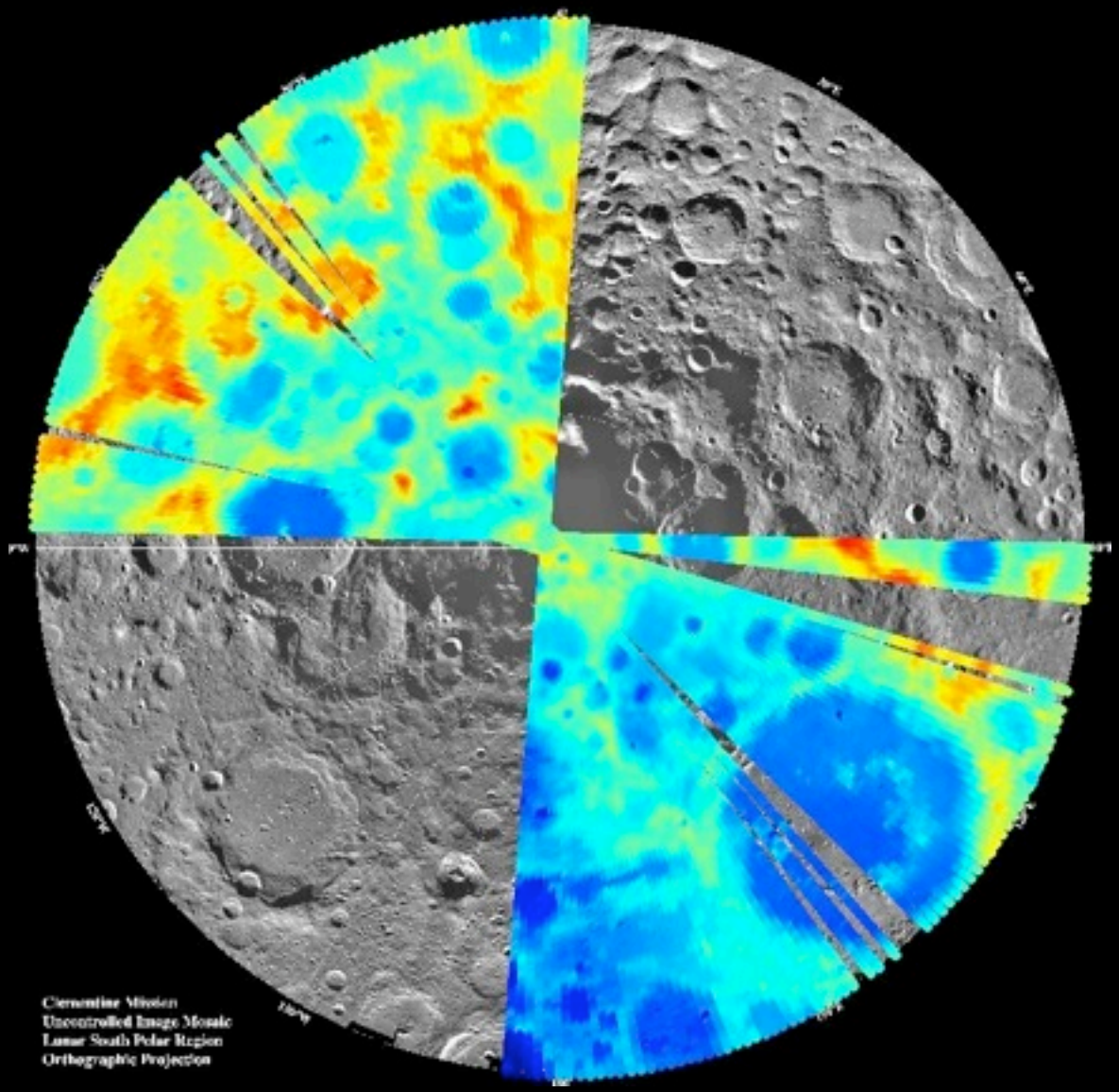
South Polar Topography, 70S-Pole



- South polar coverage:
  - only detector 1 shown
  - 1,416,540 observations
  - navigation orbits
  - 9 days of data

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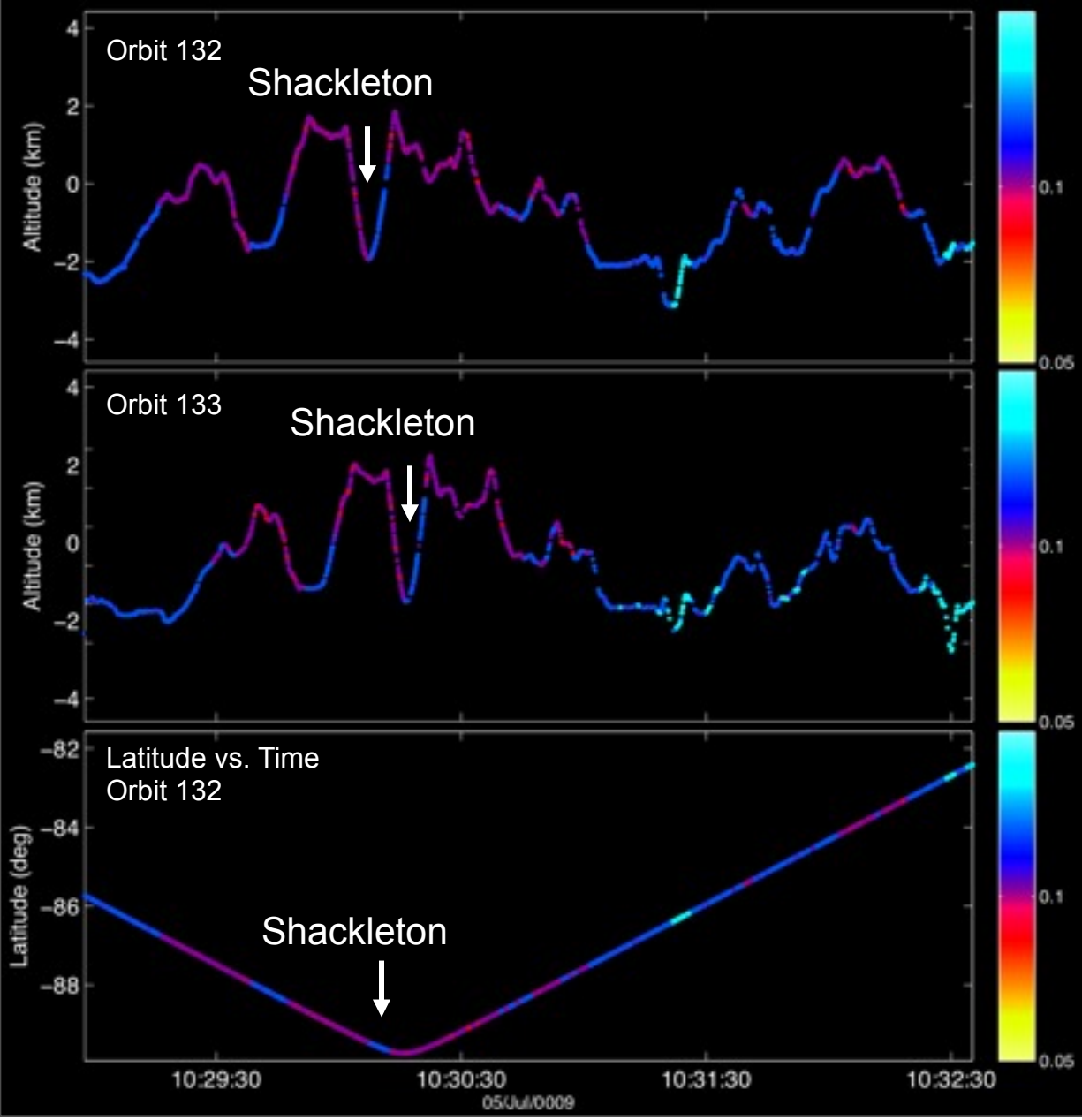
Returned/Transmitted Energy



- Ratio of returned/ transmitted laser pulse energy indicative of surface reflectance @ 1064 nm.
  - brightening of surface in some craters
  - observed in successive orbits
- Energies uncalibrated

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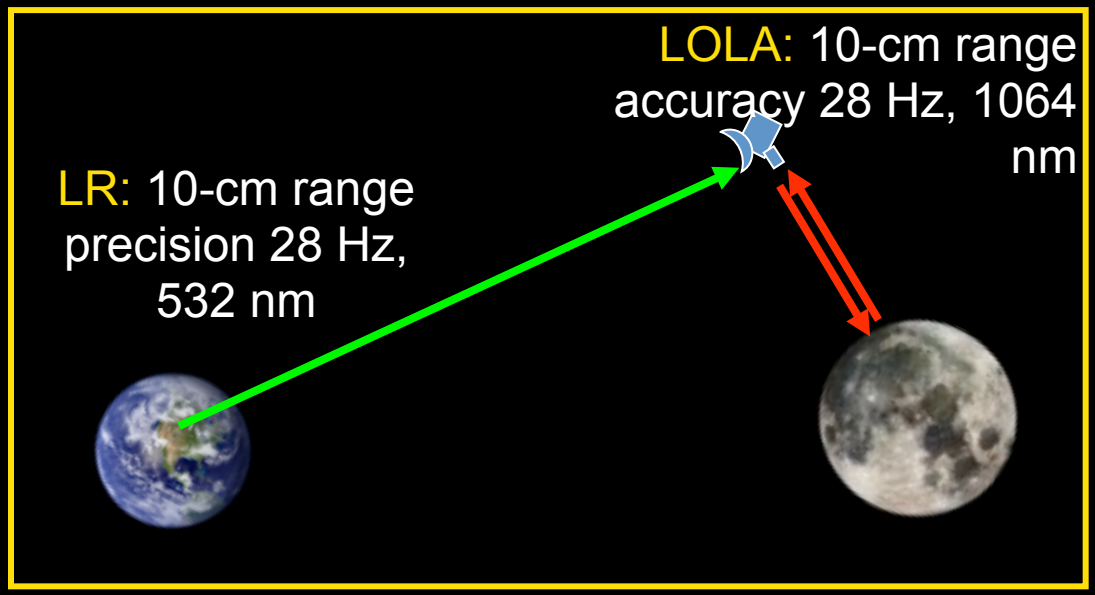
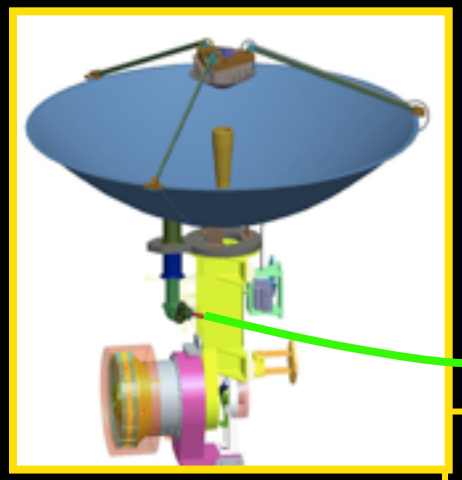
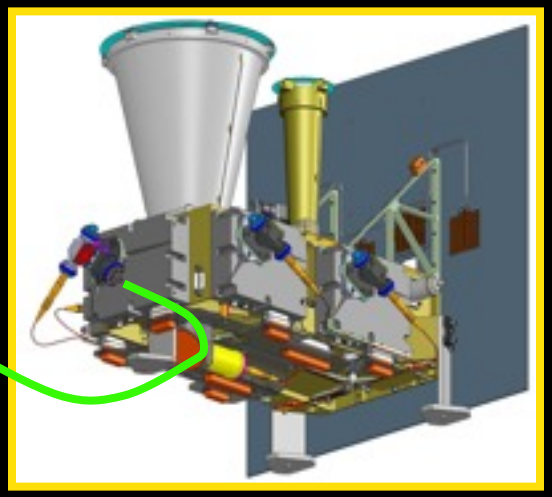
Laser Ranging to LRO

Earth-based laser tracking stations are successfully ranging to LRO via LOLA for improved LRO timing and orbit determination.





10-m fiber optic bundle transmts LR Earth laser signal to LOLA channel-1 detector



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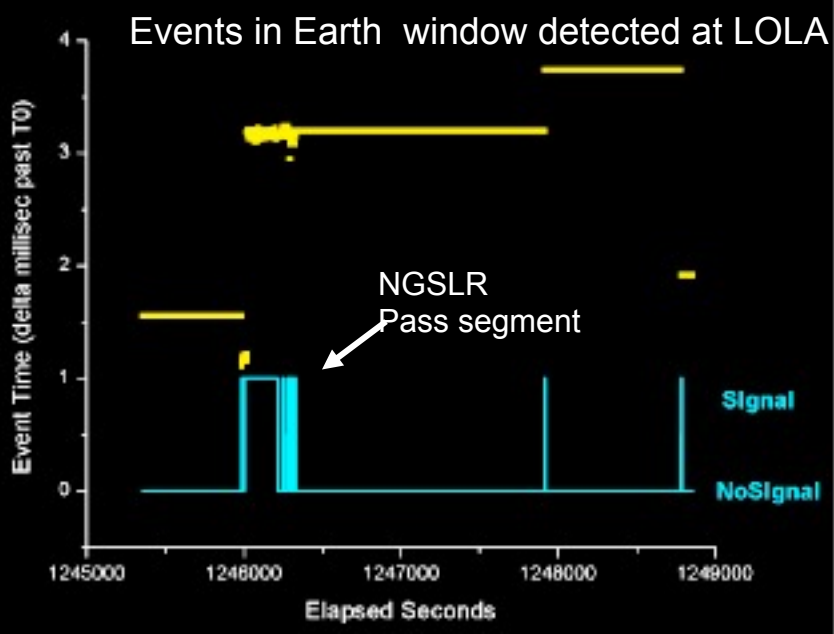
Laser Ranging Status

- Routinely ranging to LRO from NASA Next Generation Satellite Laser Ranging (NGSLR) station in Greenbelt, MD.
- Also successfully ranged to LRO from:
  - Mobile Laser station MOBLAS-7 @ Greenbelt.
  - Herstmonceaux laser ranging station, UK.
- Other approved participants from International Laser Ranging Service (ILRS) preparing to participate.

NGSLR



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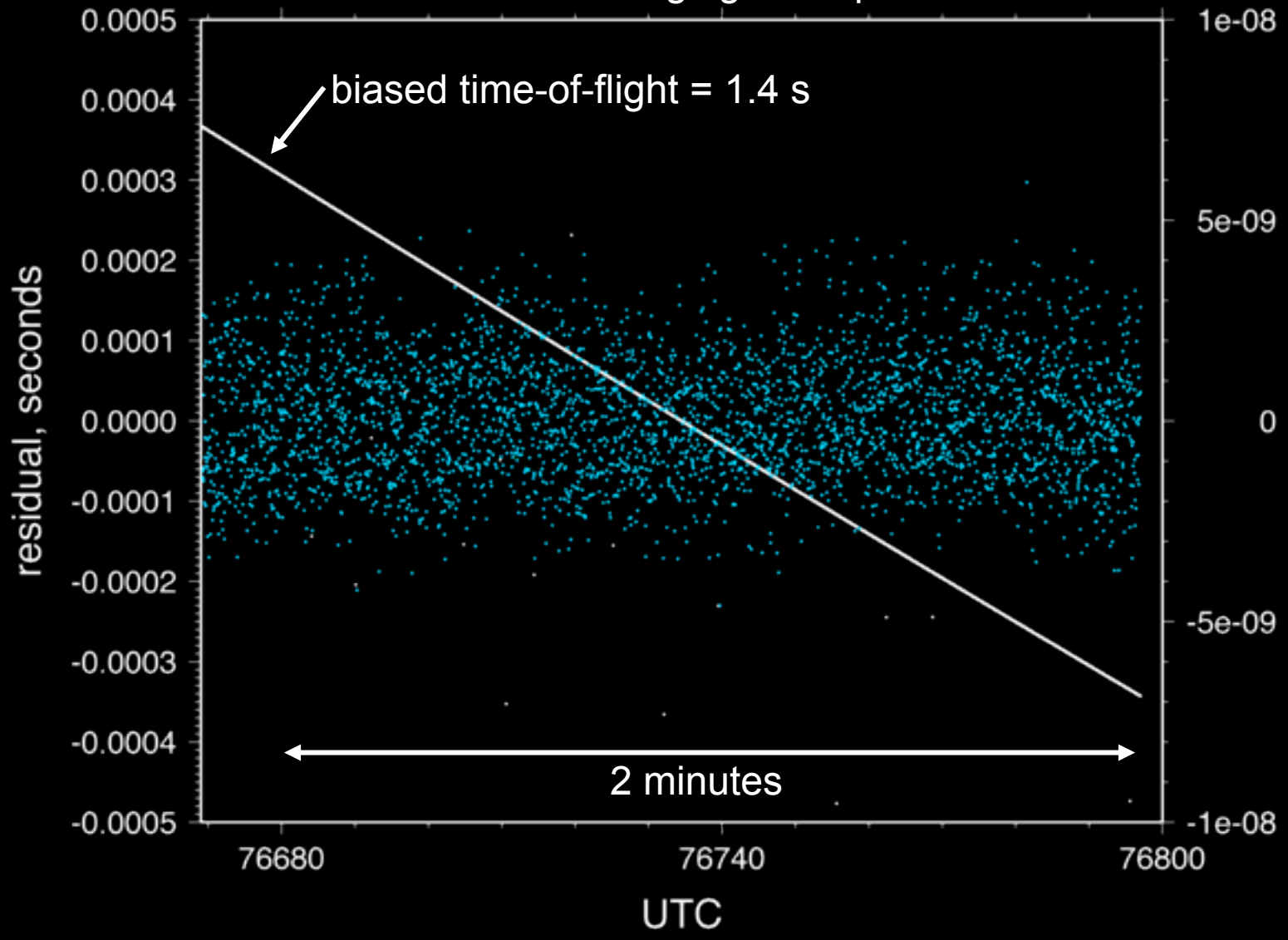
Laser Ranging Performance

Raw Range Residuals Day 181 (30 June 2009)
First Ranging Attempt

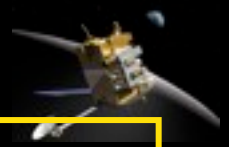


single shot RMS = 1.6 ns = 48 cm (1-way; 2-way value for altimetry = 24 cm)

5-s averages should produce ~10x improvement

NASA/GSFC/LRO/LOLA

Summary



- LOLA is successfully operating during LRO commissioning orbit.
  - all 5 signal channels returning observations
  - signal detection altitude exceeds design specifications
  - signal loss across terminator under investigation
  - 19 million valid elevations collected as of 20 July 2009.
- Laser ranging to LRO is being used to improve spacecraft timing and orbit determination.
  - first operational optical tracking of a spacecraft orbiting a planetary body beyond Earth.
  - demonstrated 48-cm precision at 28 Hz (1-way) on first attempt.
- At the end of commissioning expect to have complete coverage of the southern hemisphere, equator to pole.

End

Investigation Team

Investigation Team			
David E. Smith	GSFC	PI	lunar coordinate system
Maria T. Zuber	MIT	DPI	exploration and altimetry
Oded Aharonson	Caltech	Co-I	surface roughness
James W. Head	Brown	Co-I	landing sites, geology
Frank G. Lemoine	GSFC	Co-I	orbit and gravity
Greg A. Neumann	GSFC	Co-I	altimetry, radiometry
Mark Robinson	ASU	Co-I	polar ice, landing sites
Xiaoli Sun	GSFC	Co-I	instrument performance
Haris Riris	GSFC	IS	instrument performance
Paul Lucey	Hawaii	PS	surface reflectivity
Tom Duxbury	JPL	PS	geodetic positioning
Olivier Barnouin-Jha	APL	PS	impact cratering

Instrument Team		
John Cavanaugh	GSFC	system engineering
Peter Liiva	GSFC	bench check equipment
Erwan Mazarico	GSFC	orbit analysis, altimetry
Jan McGarry	GSFC	laser ranging, software
David Rowlands	GSFC	orbit analysis, gravity
Mark Torrence	GSFC	orbit analysis
Owen Westbrook	MIT	altimetry analysis

Geodetic Measurement Objectives of NASA's Lunar Precursor & Robotic Program

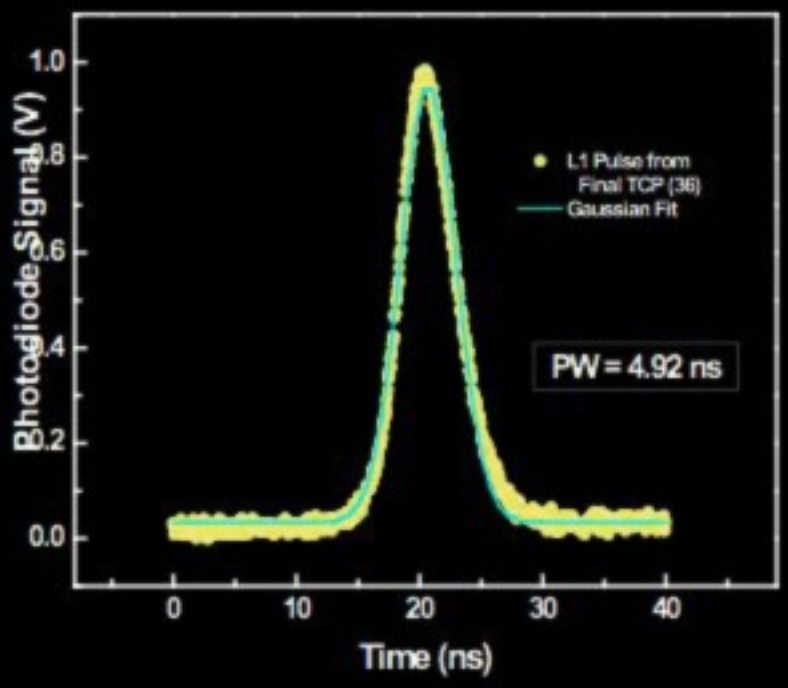
1. Determine the topography of the Moon to geodetic quality from global to landing-site-relevant scales.
2. Image the lunar surface in permanently shadowed regions on landform scales.
3. Characterize the illumination of the polar region environment at relevant temporal scales.
4. Identify the locations of appreciable surface water ice in the permanently shadowed regions of the Moon's polar cold traps.
5. Assess meter- and smaller-scale features to facilitate safety analysis of potential future lunar landing sites.

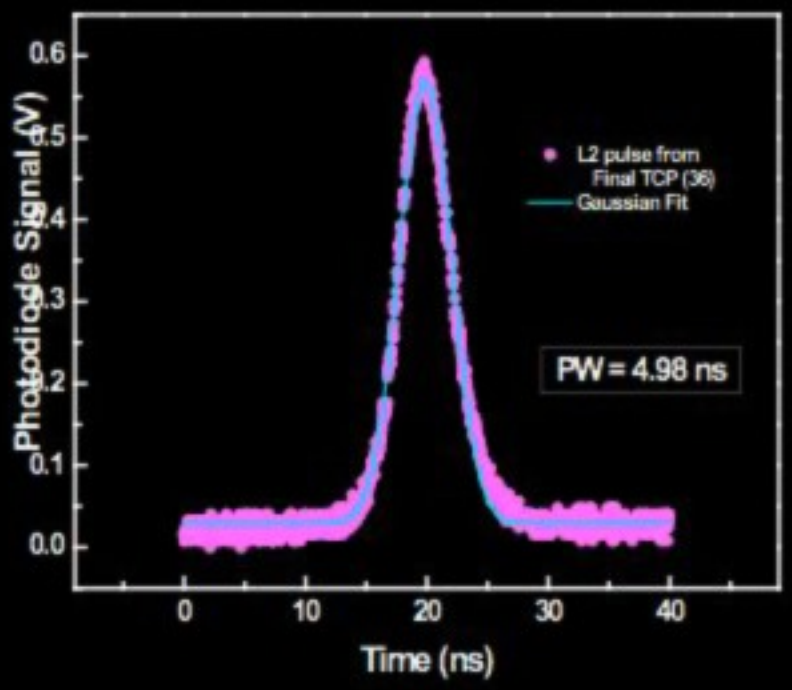
NASA/Apollo 17

NASA/GSFC/LRO/LOLA

Laser Pulse Width

Outgoing pulse width is < 5 ns for lasers 1 and 2





Timing resolution 30 ps; accuracy 100 ps (3 cm)

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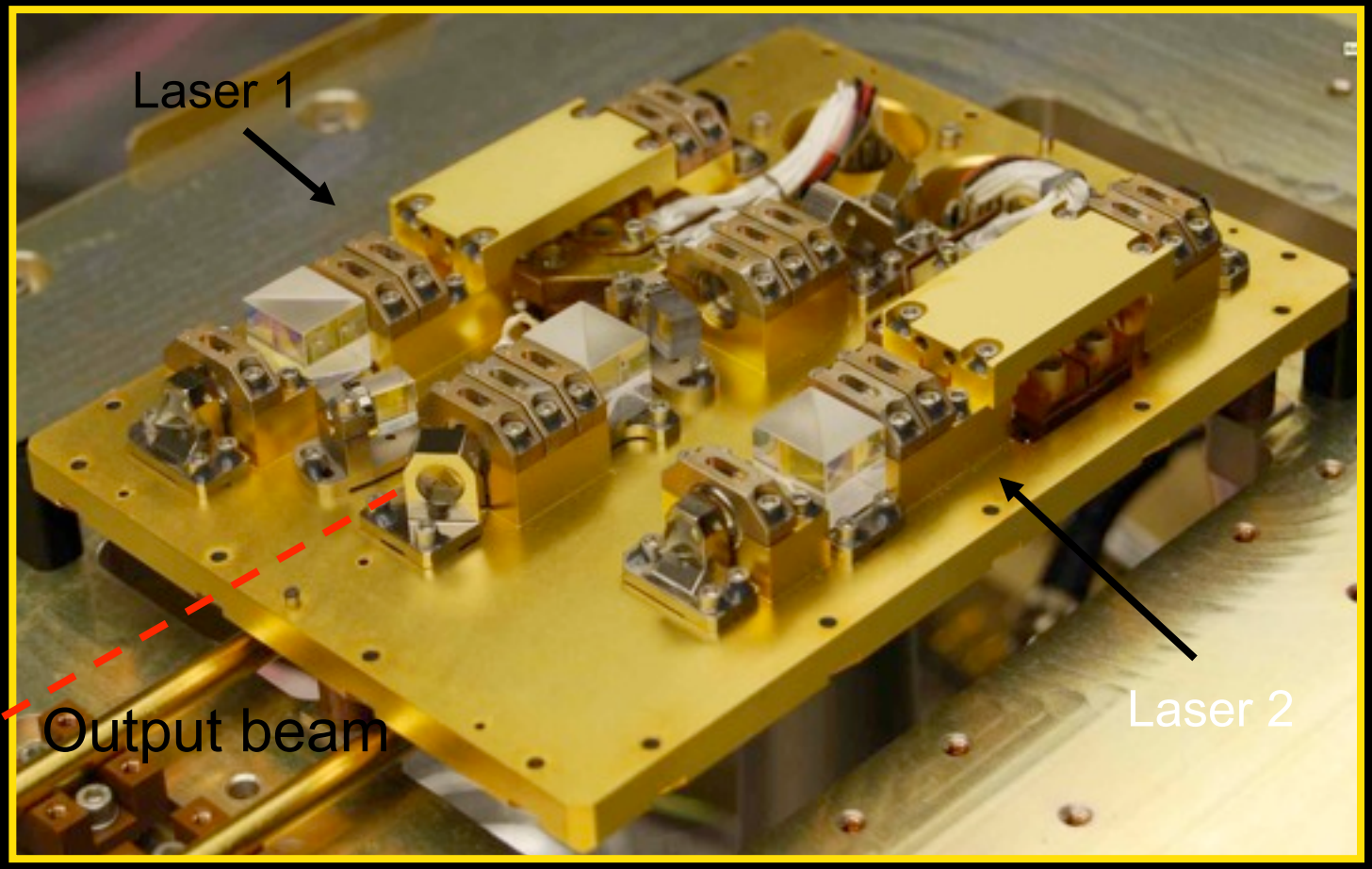
Flight Model Laser



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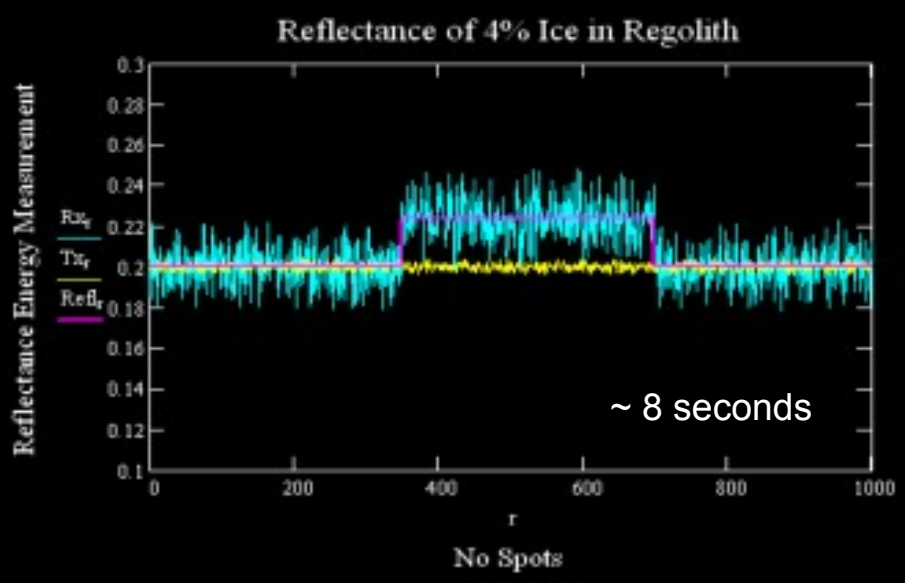
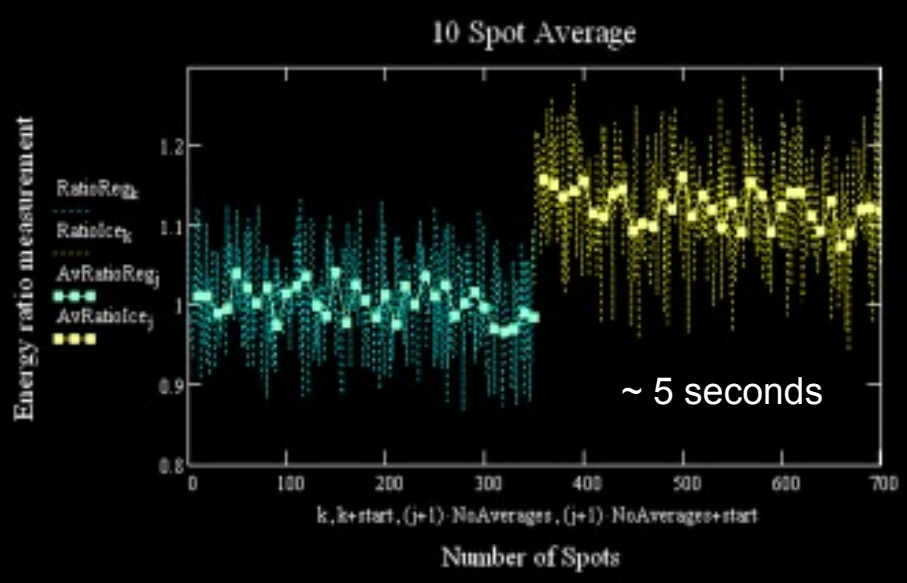
Surface Reflectance Measurement

- LOLA will measure surface reflectance to laser light via ratio of transmitted (Tx) and echo pulse energies (Rx) to search for ice in permanently shadowed regions.
- Mixtures of ice crystals in regolith (4% ice) will exhibit a higher surface reflectance (b = 80% ice, b = 20% regolith) than surrounding areas.





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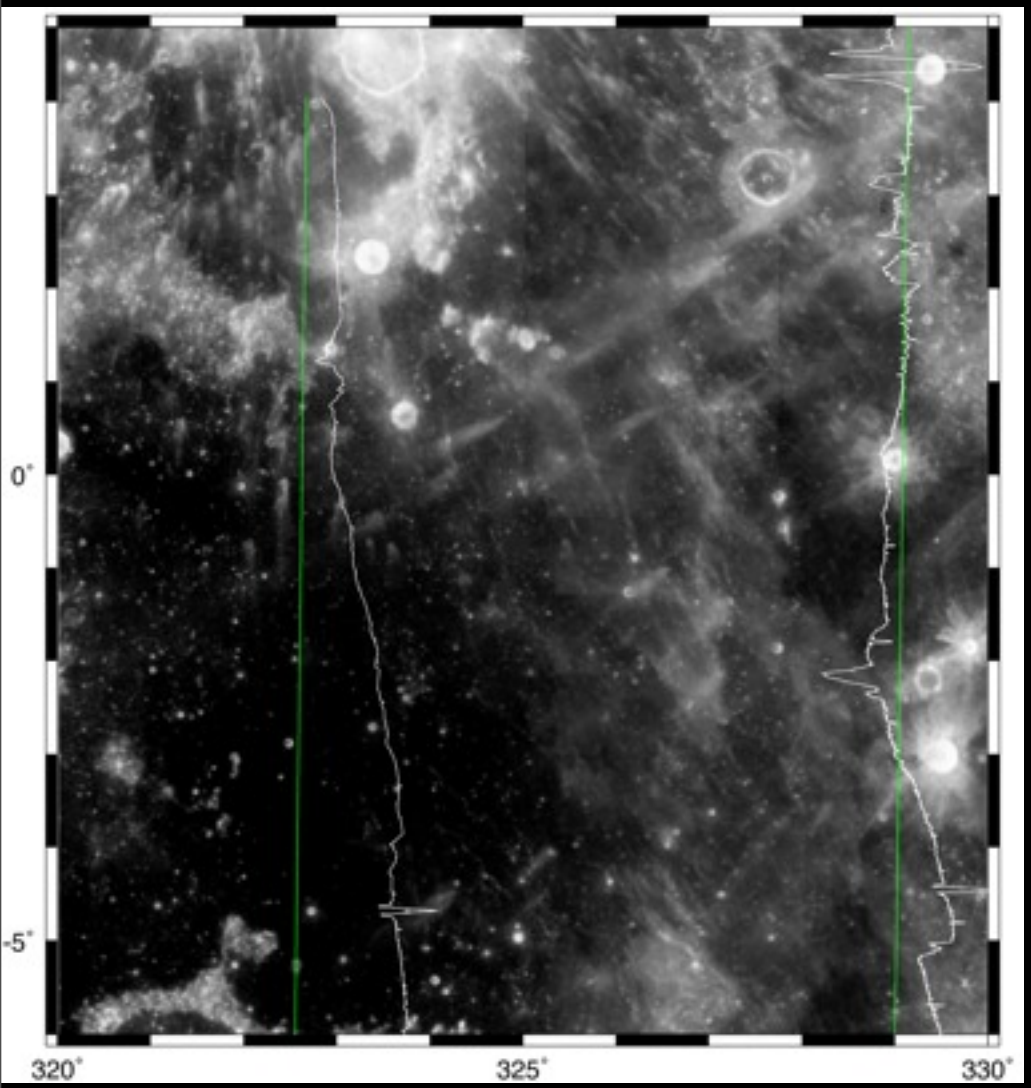
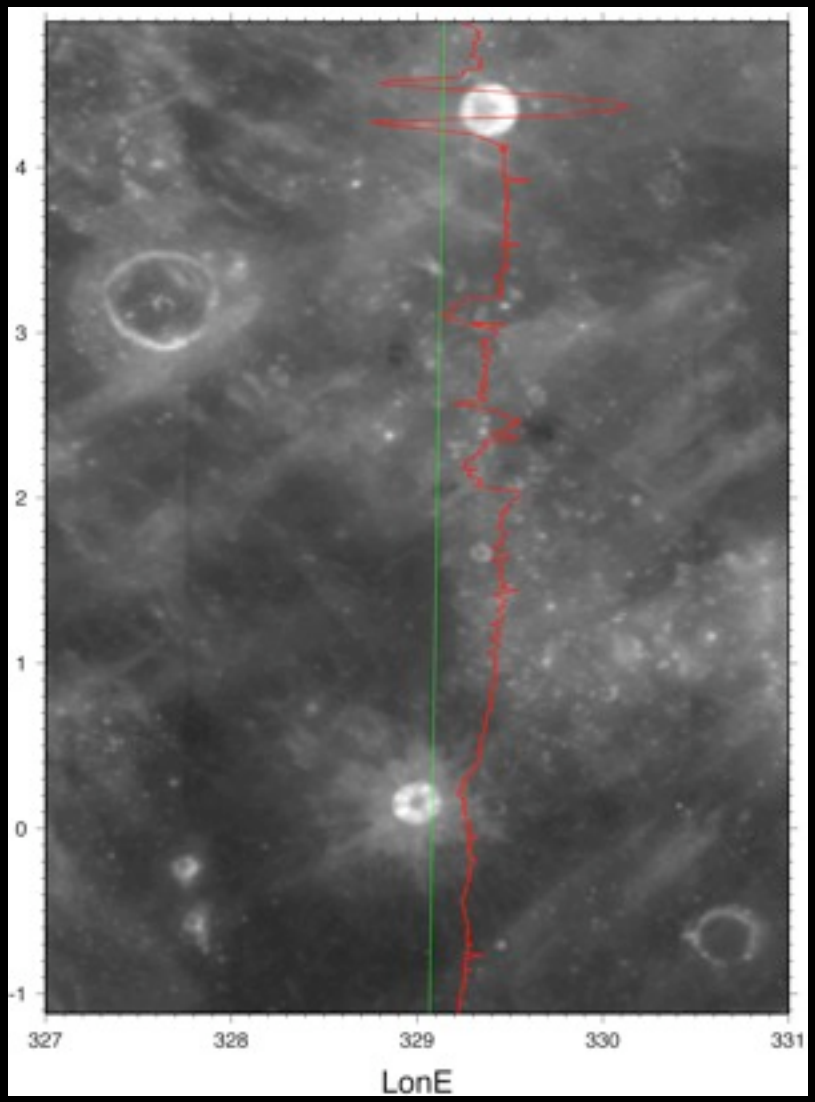
Development of Geodetic Grid





Clementine USGS 750-nm mosaics

*Need to update or delete?

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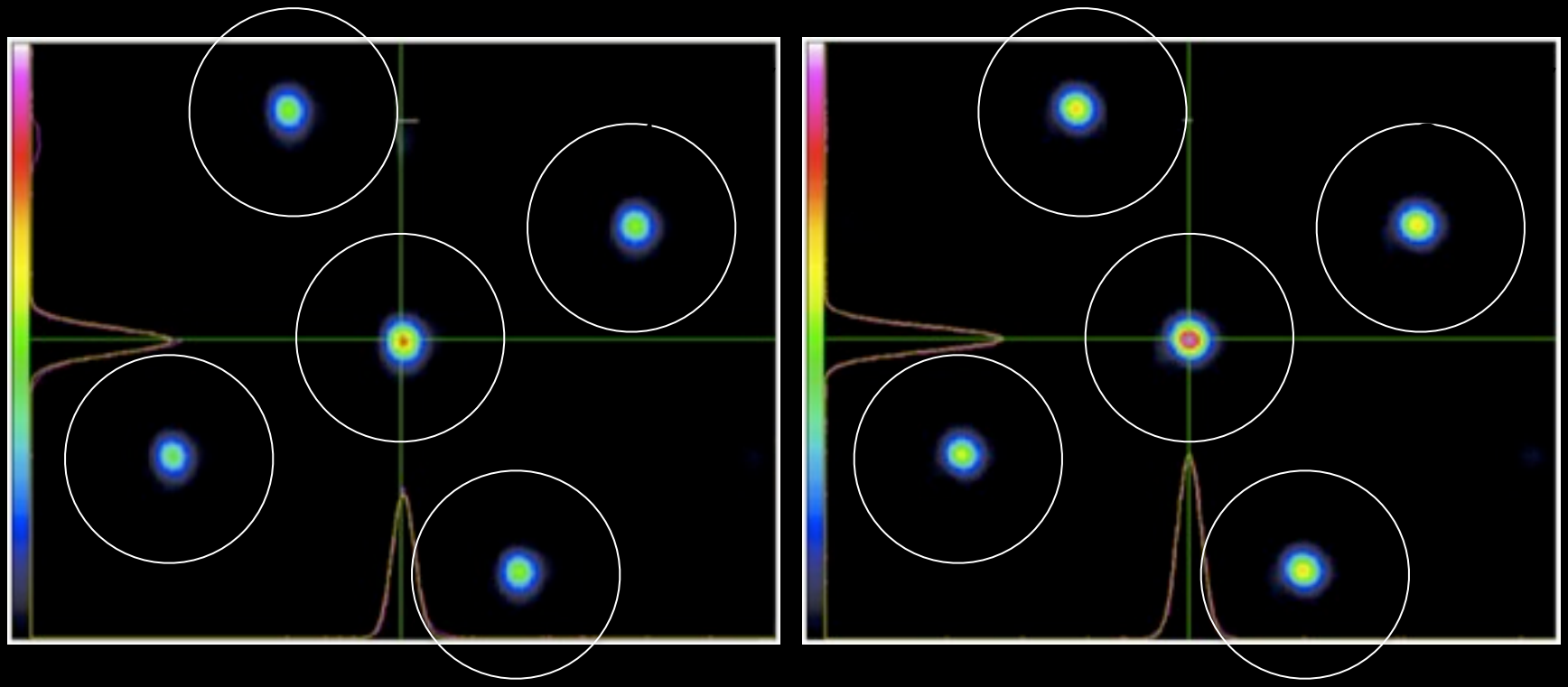
5-Spot Laser Beam Pattern



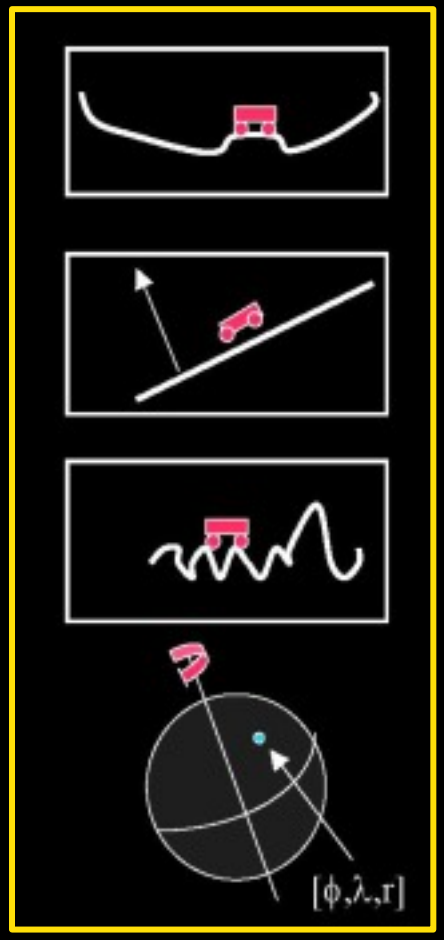
- Laser far-field beam patterns showing 5 spots, energy profiles, and approximate receiver FOV.
- Center spot has slightly more energy than outer 4 spots.
- Spot diameter ~100 mrads; FOV = 400 mrads.

NASA/GSFC/LRO/LOLA

LOLA Measurement Accuracy/Precision

For “flat” surfaces:

- Range to surface: <10 cm
- Surface roughness: 15-30 cm
- Surface reflectance (1064 nm): ± 0.02
- Slopes, 2 directions: ± 0.3^{o}, 25-m baseline
- Orbital altitude knowledge: < 0.5 m
- Along-track positional knowledge: ~ 25 m



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- At the end of commissioning expect to have complete coverage of the southern hemisphere, equator to pole.

Ground Pattern – 50-km Altitude

- LOLA lays down 5 parallel profiles 10 to 12 m apart
- From 50-km orbit altitude:
  - observation area is 5 m in diameter
  - adjacent spots are 25 m apart
- Green areas are FOV of detector, 20-m diameter

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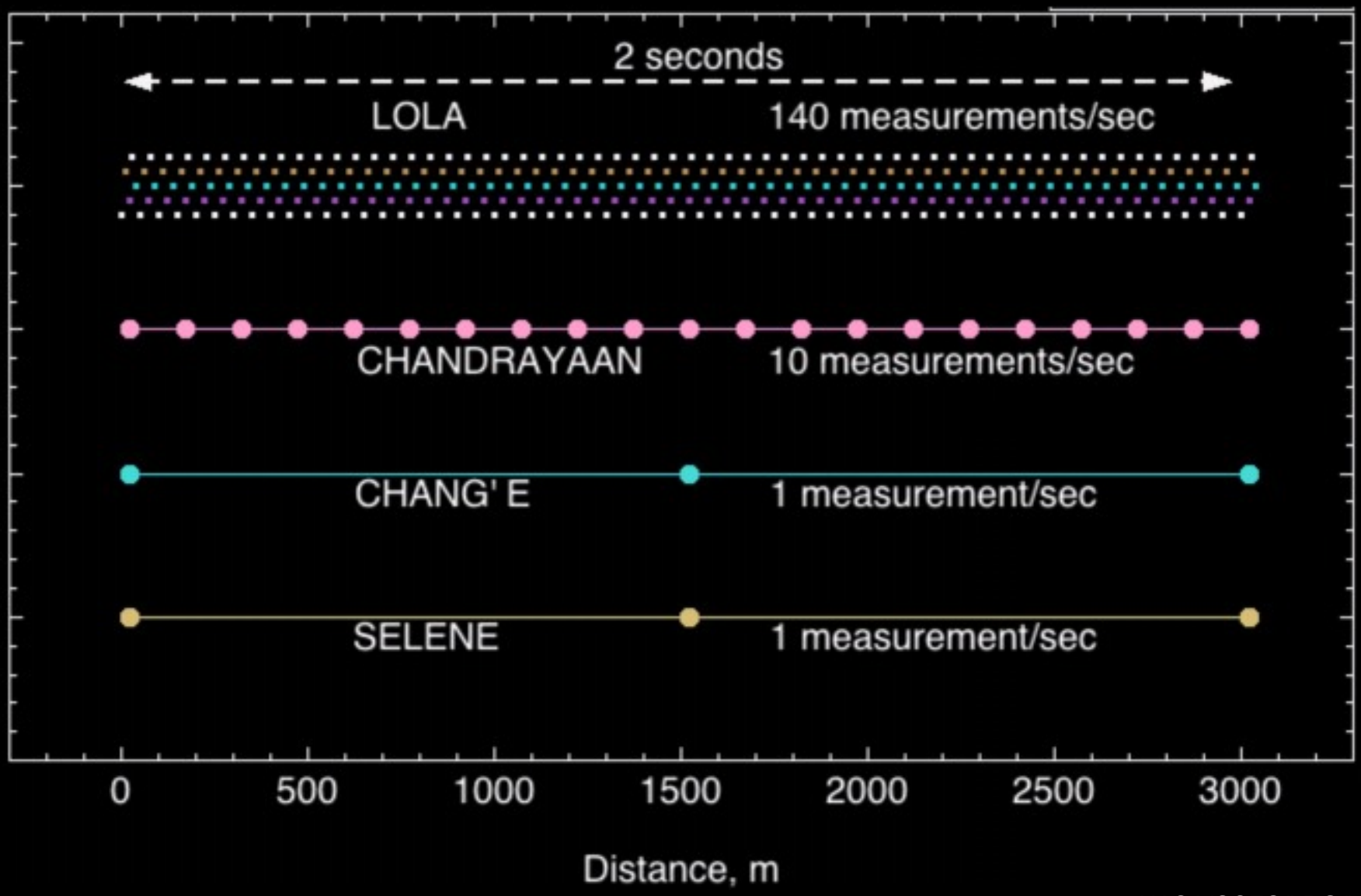
Lunar Laser Altimeter

Surface Shot Comparison



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