Planetary Laser Altimetry; Past and Present

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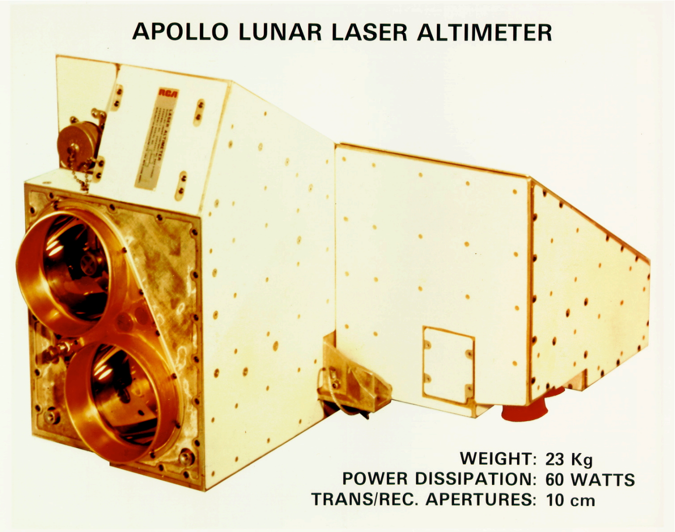
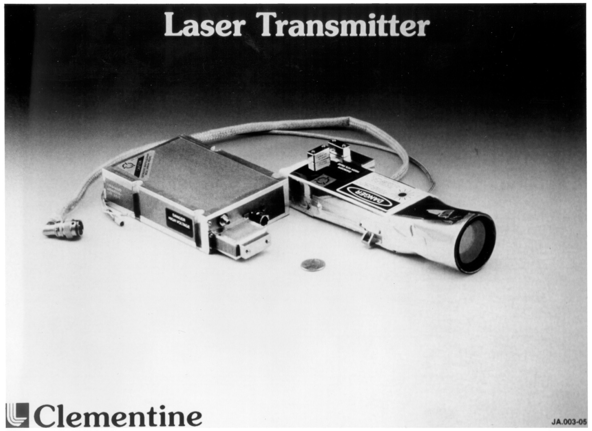
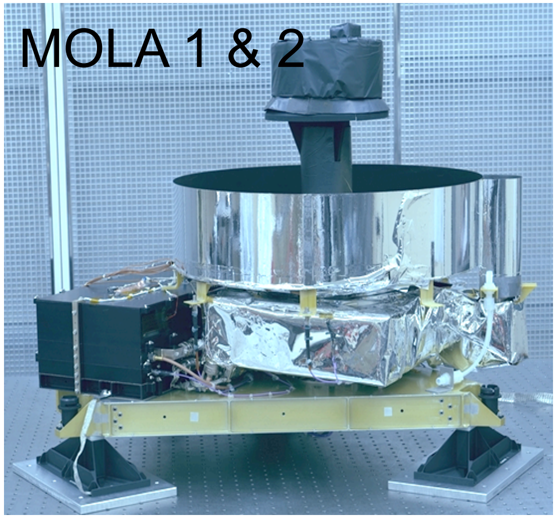
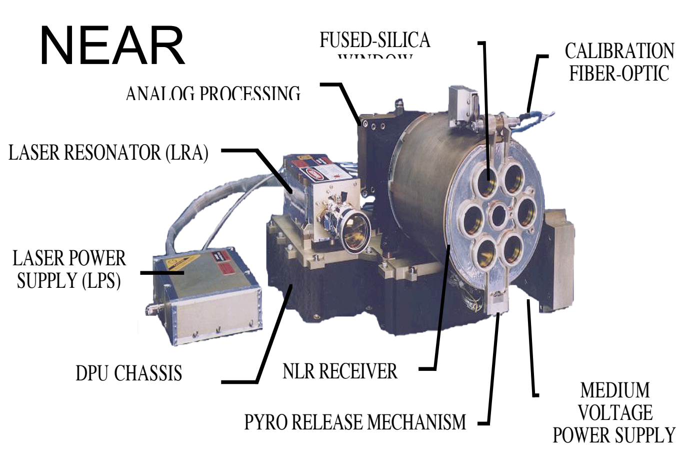
After Apollo, laser altimetry in NASA began with Mars Observer (MOLA-1), launched in 1992 but lost on approach to Mars, and re-flown on Mars global Surveyor (MOLA-2) in 1996. In Jan 1994 the Clementine mission to the Moon carried the second laser altimeter into space that provided the first global shape of the Moon. In 1996 the NEAR spacecraft carrying the NEAR Laser Ranger (NLR) was launched to the asteroid 433 Eros, and in 2004 a laser altimeter was launched on the MESSENGER spacecraft to Mercury and is currently in cruise to the planet. Early next year the LRO spacecraft carrying LOLA will be launched to the Moon. Japan launched the SELENE spacecraft in 2007 carrying the LALT laser altimeter followed by Chang'E by China. Soon India will launch Chandrayaan carrying a laser altimeter. In nearly all the missions todate laser altimeters have been used for mapping of planetary bodies with remarkable success and played major roles in preparing for subsequent lander missions. All of the these missions and their laser instruments have helped make advances in the use of lasers for planetary science and helped convince skeptical space agencies that these kinds of instruments could be used with confidence and reliability on long planetary missions in some harsh environments. Laser altimetry is now accepted, albeit not with the same level of confidence as microwave instruments, and laser tracking of planetary spacecraft will be next challenge.

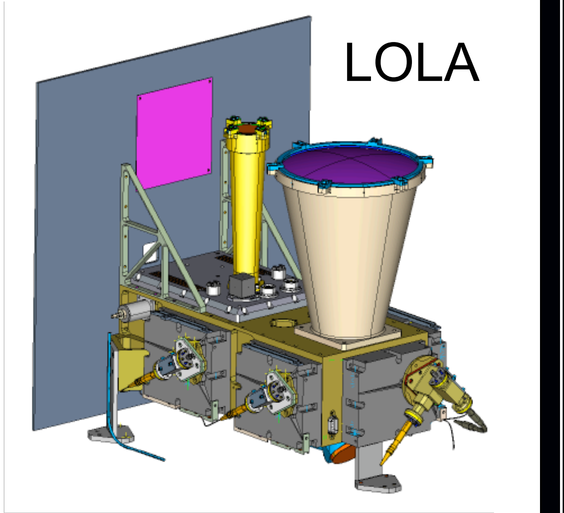
US Planetary Laser Altimeters
1969 - 2009



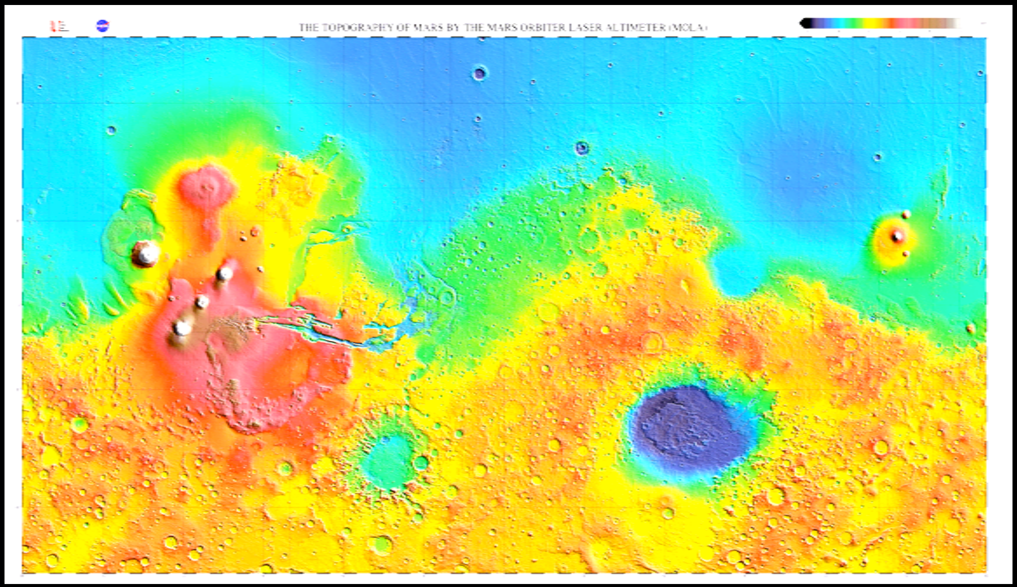


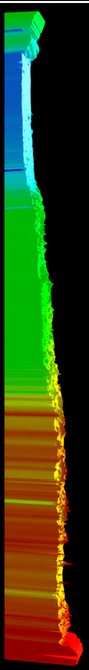




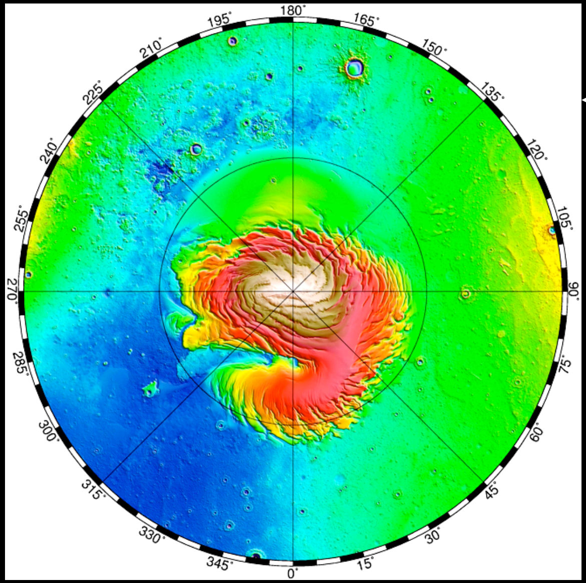


Global Topography of Mars from MOLA



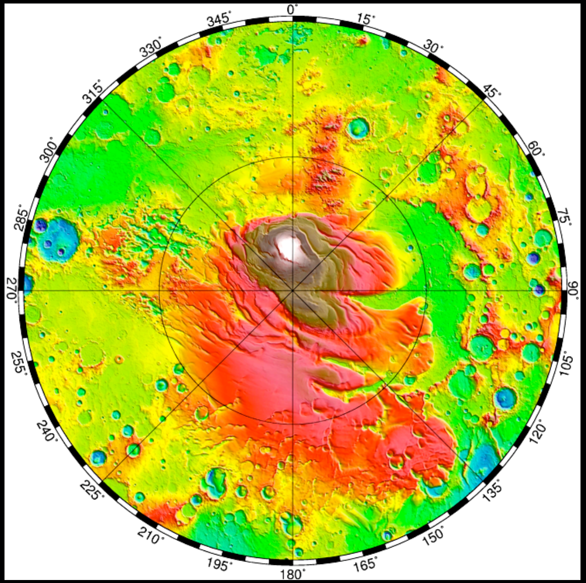


Equatorial topography and South to North slope



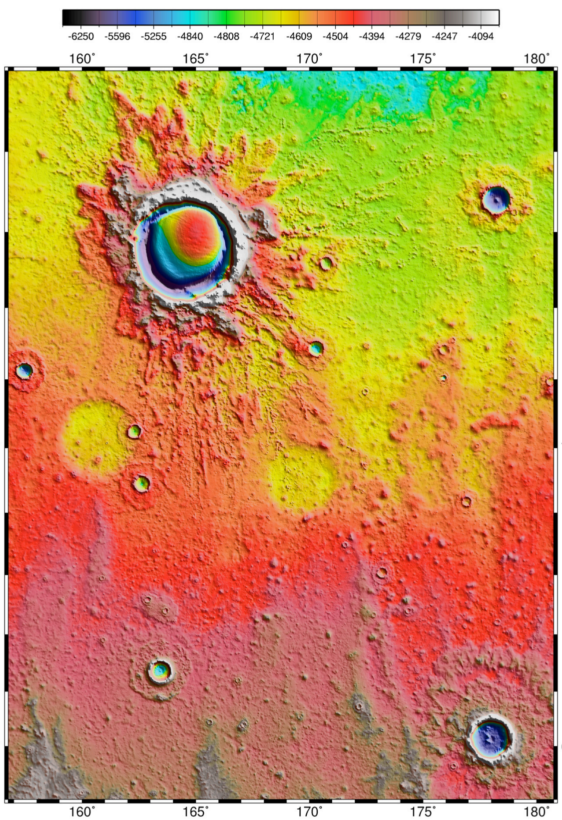
North Pole

South Pole



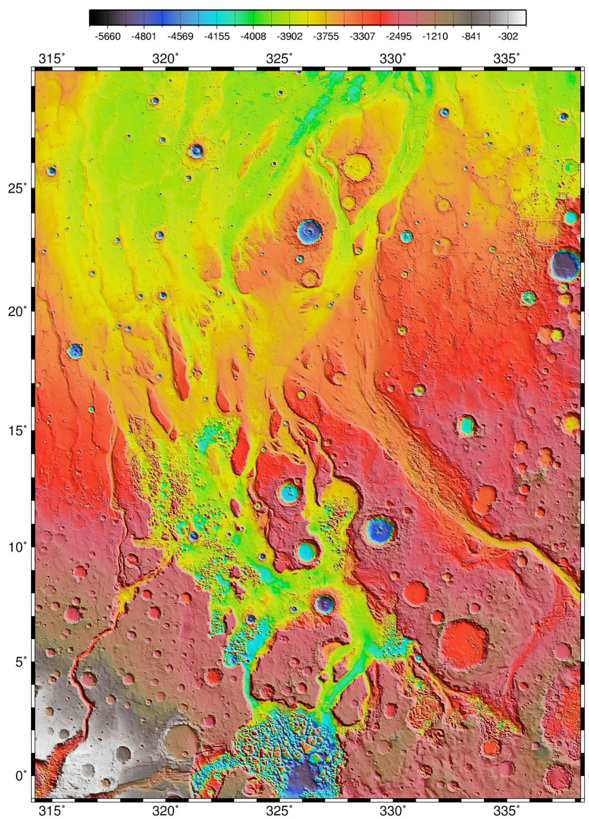
Topographic Images from Altimetry

Ice filled crater



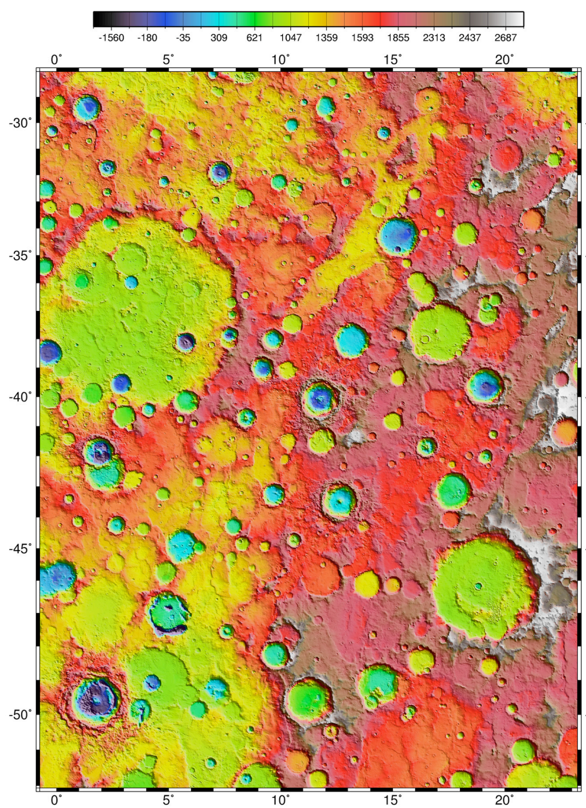
660 x 430 km

Outflow channels



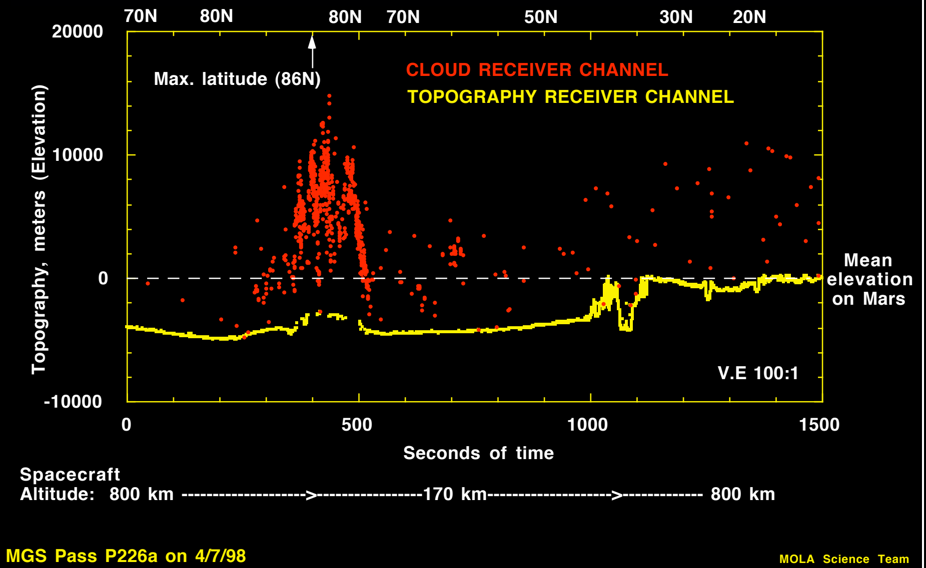
1800 x 1400 km

Cratered highlands

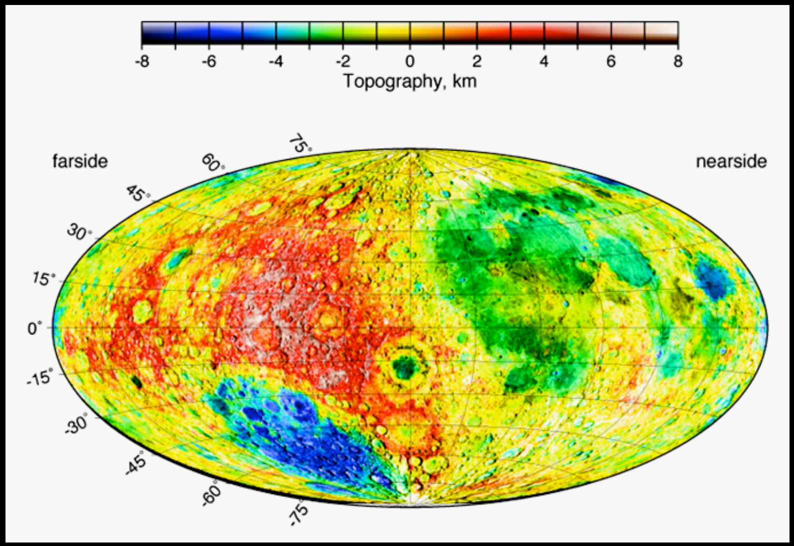


1800 x 1000 km

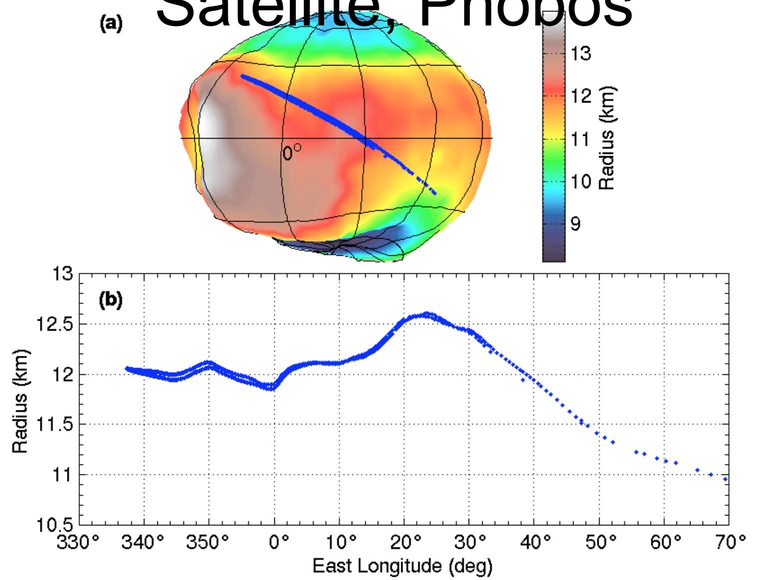
Clouds over Mars' North Pole



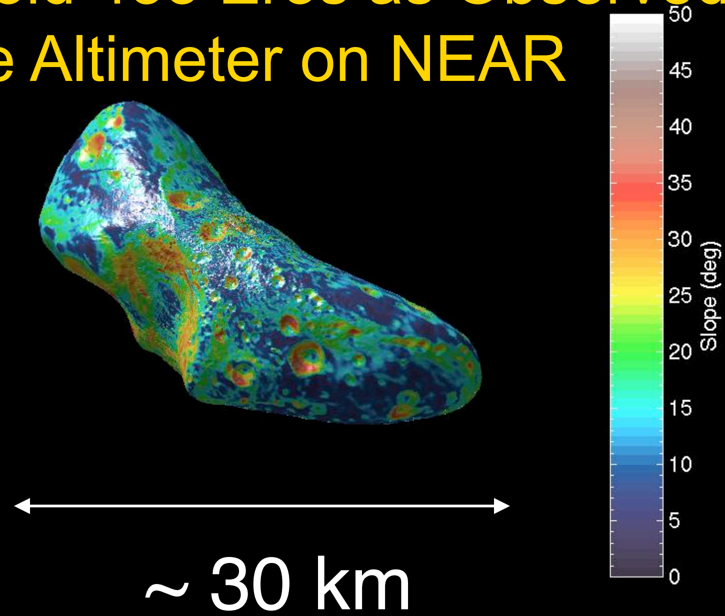
Lunar Topography by Clementine



MOLA Profile Across Mars' Satellite, Phobos



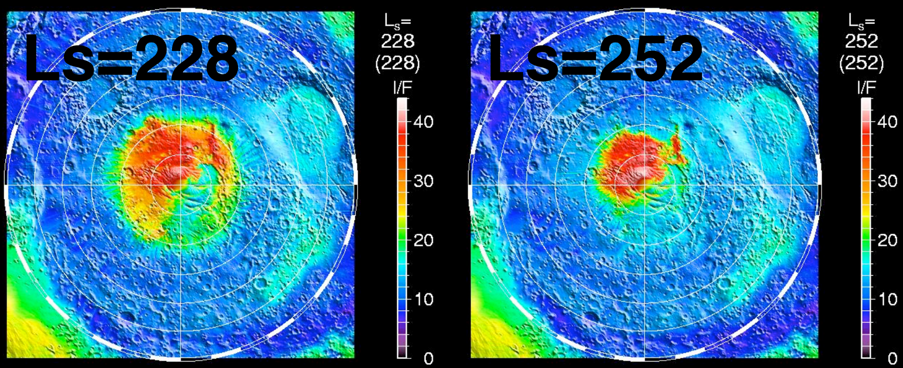
Asteroid 433 Eros as Observed by the Altimeter on NEAR



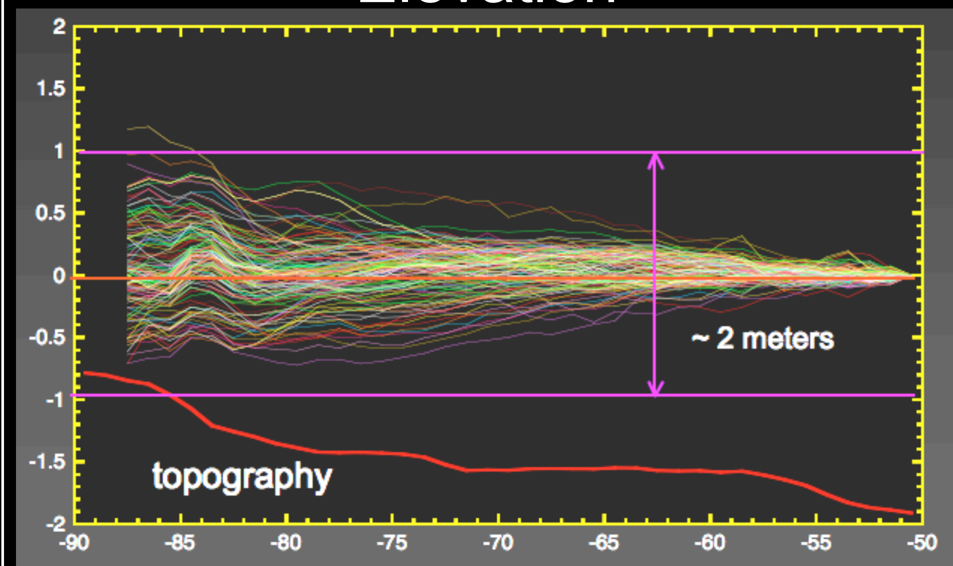
Monitoring the Seasonal Changes in Mars Ice Caps

South Polar Seasonal Icecap

Radiometry

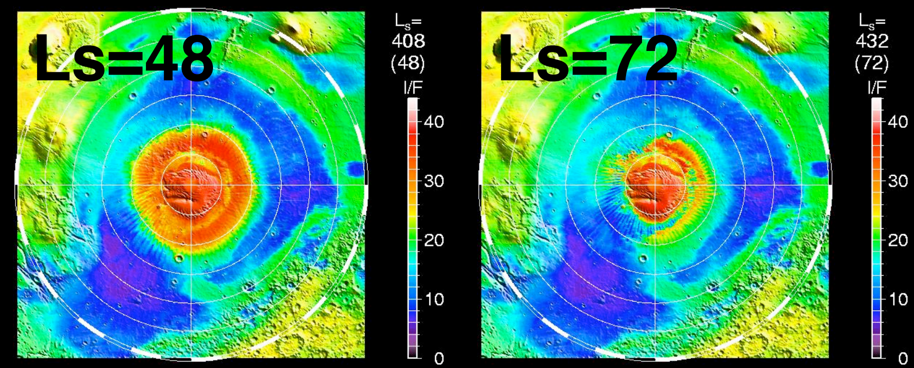


Elevation

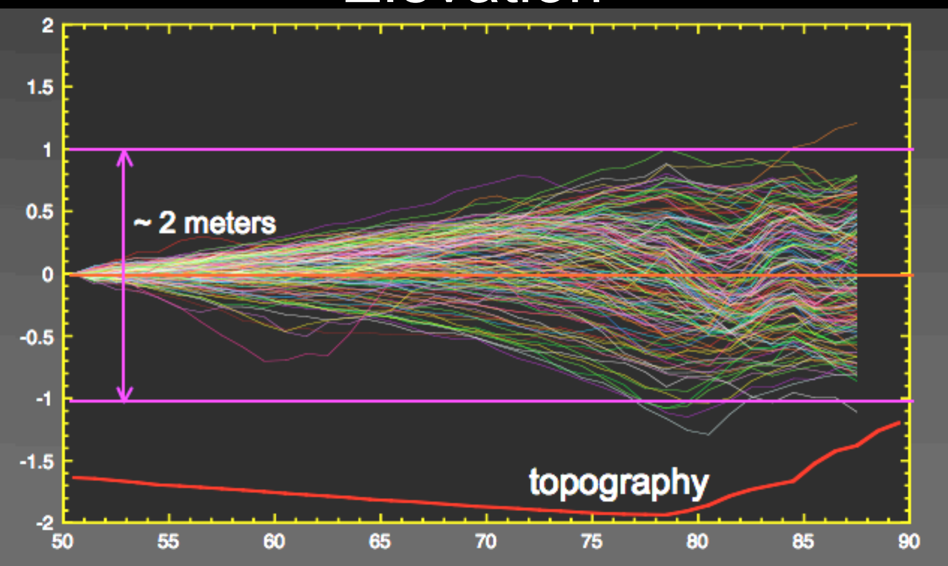


North Polar Seasonal Icecap

Radiometry



Elevation



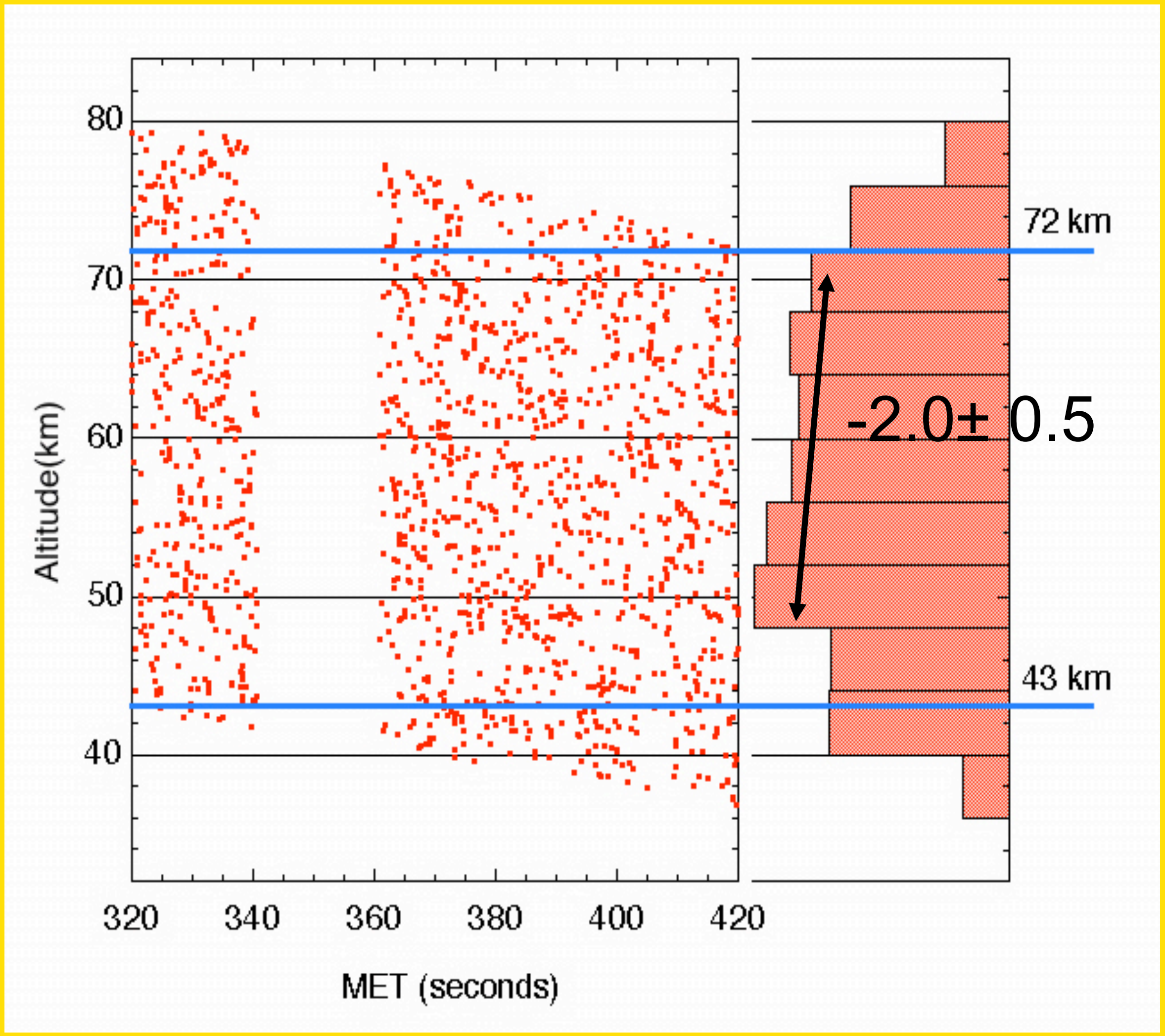
Laser Altimeters on US Missions Since Apollo

Mission	Clementine	Mars Observer	NEAR	MGS	MESSENGER	LRO
Destination	Moon	Mars	433 Eros	Mars	Mercury	Moon
Launch	Feb. ‘92	Sept. ‘92	Feb. ‘96	Nov. ‘96	Aug ‘04	Apr ‘09
Cruise	3 days	11 mnths	4 yrs	11 mnths	7 years	3 days
Altimeter	CL	MOLA-1	NLR	MOLA-2	MLA	LOLA
Instr. Mass	?	25 kg	10 kg	25 kg	7 kg	12 kg
# Lasers	1	1	1	1	1	2
# Beams	1	1	1	1	1	5
Energy, mJ		50		50	20	2.7
Wavelength nm	1064	1064	1064	1064	1064	1064

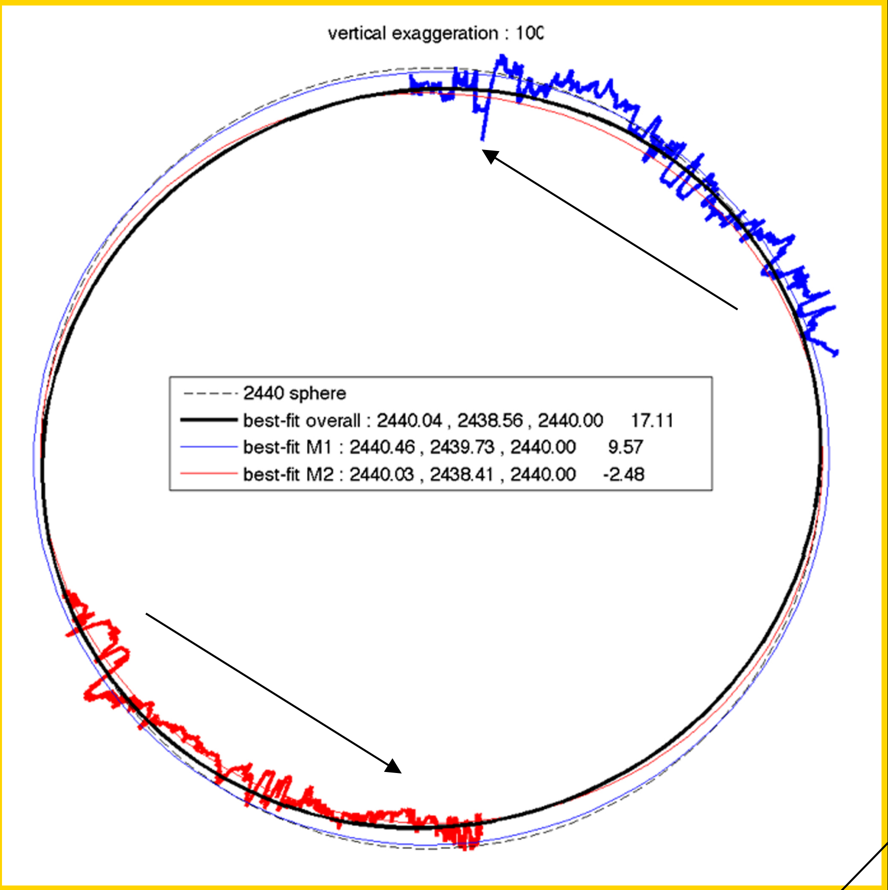
MESSENGER Passes by Venus, Altimeter Ranges to the Atmosphere

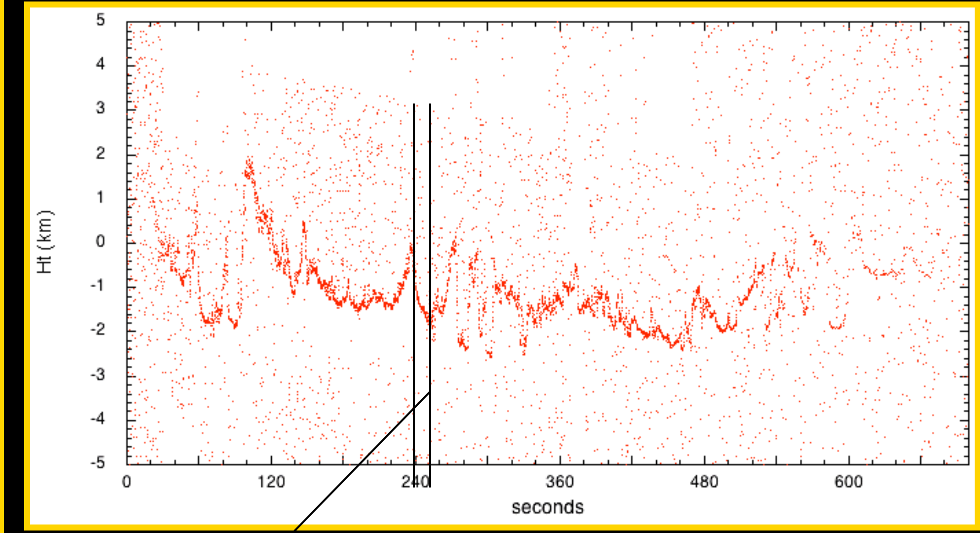
- Detector counts are shown as a function of altitude and MET.
- Number of counts in each 4-km-wide bin is shown on right.
- Number of counts increases slightly but steadily as altitude decreases, reaching a maximum at ~50 km.
- Outside blue lines the number of counts decreases due to the lack of data at all MET's.

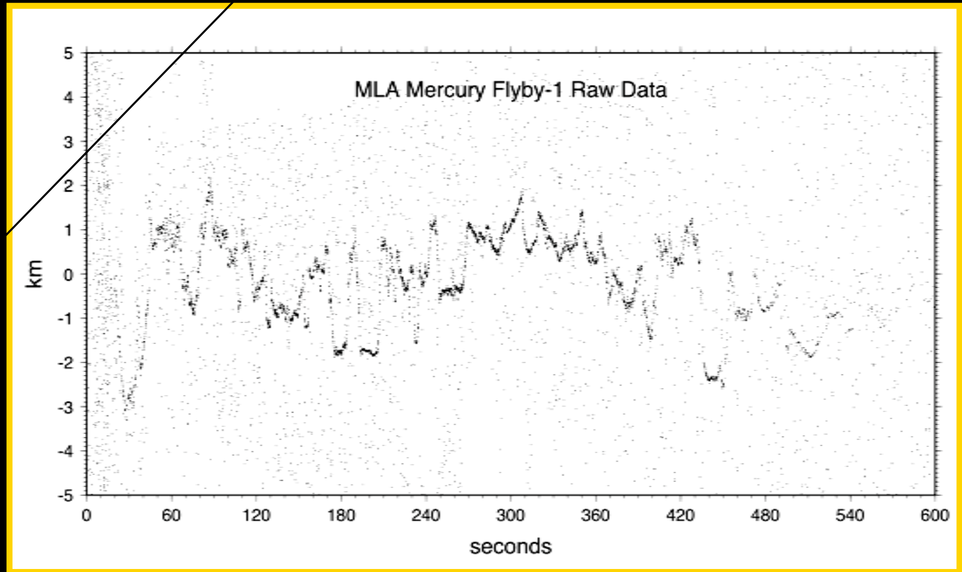
Channel 3 optimized for 270 ns (40 m)

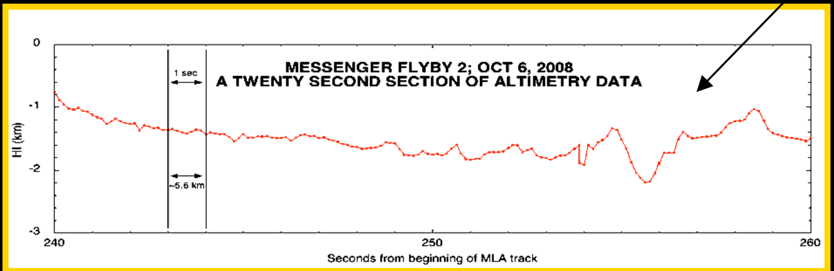


MESSENGER Flies By Mercury, Jan and Oct, 2008









LOLA

Lunar Orbiter Laser Altimeter

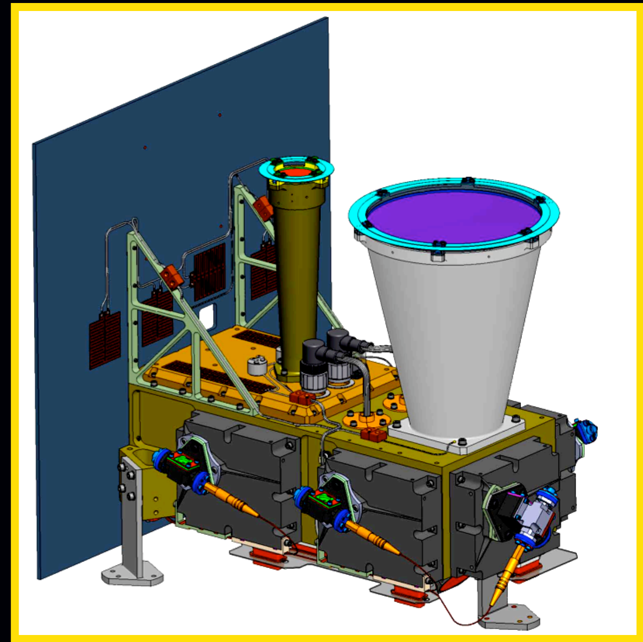
LOLA on LRO

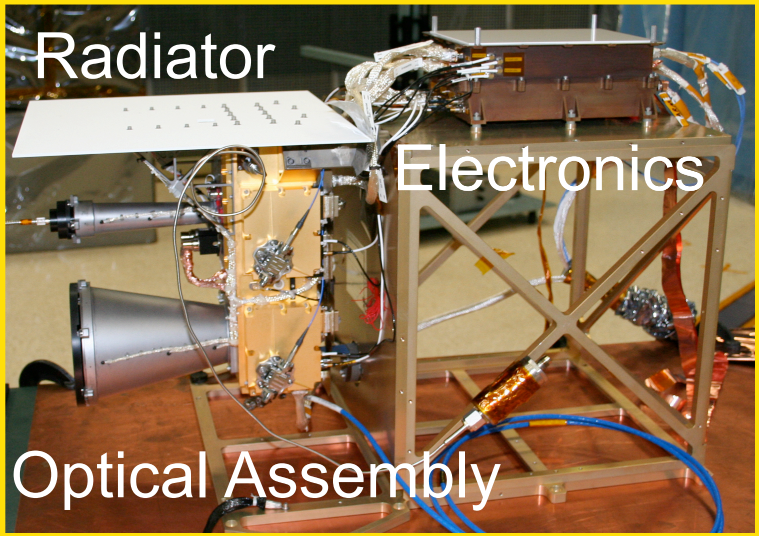
- LOLA will characterize a swath ~ 50 meters wide under LRO ground-track.

- LOLA will make 140 measurements/second of range to surface below spacecraft.

- Every observation will be registered to a global lunar center-of-mass coordinate system.

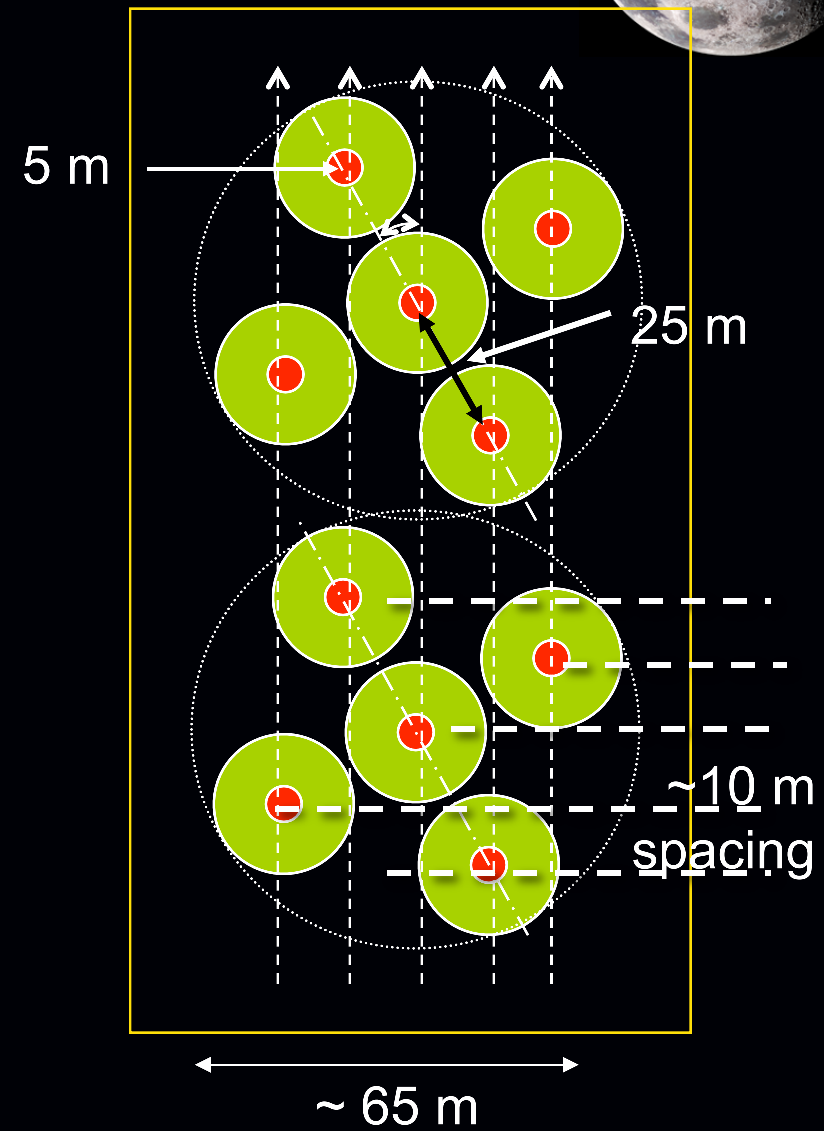
- LOLA designed to provide data necessary to identify locations for safe landing of robotic spacecraft.





LOLA Ground Pattern

- In each 5 meter spot:
  - Range to surface
  - Roughness of surface
  - Reflectance of surface
- LOLA operates continuously
- Transmitter Energy: 2.7 mJ
- DOE: 5 Beams, 100 μrad div.
- Receiver: 0.14-m diameter
- FOV: 400 μrad
- Detectors: 5 fiber optically-coupled avalanche photodiodes



Surface Slopes

- Within a 100 m x 50 m along-track area there will be 10 5-m spots.
- There will be 22 slopes with baselines ranging from 25 m to 50 m.
- There are another 23 slopes with baselines of >50 to <100 m.
- For slopes $< \pm 3^{\circ}$ in a 5-m spot, height precision will be $< \pm 10$ cm and slope accuracies will be $\pm 0.3^{\circ}$ to 0.15°.

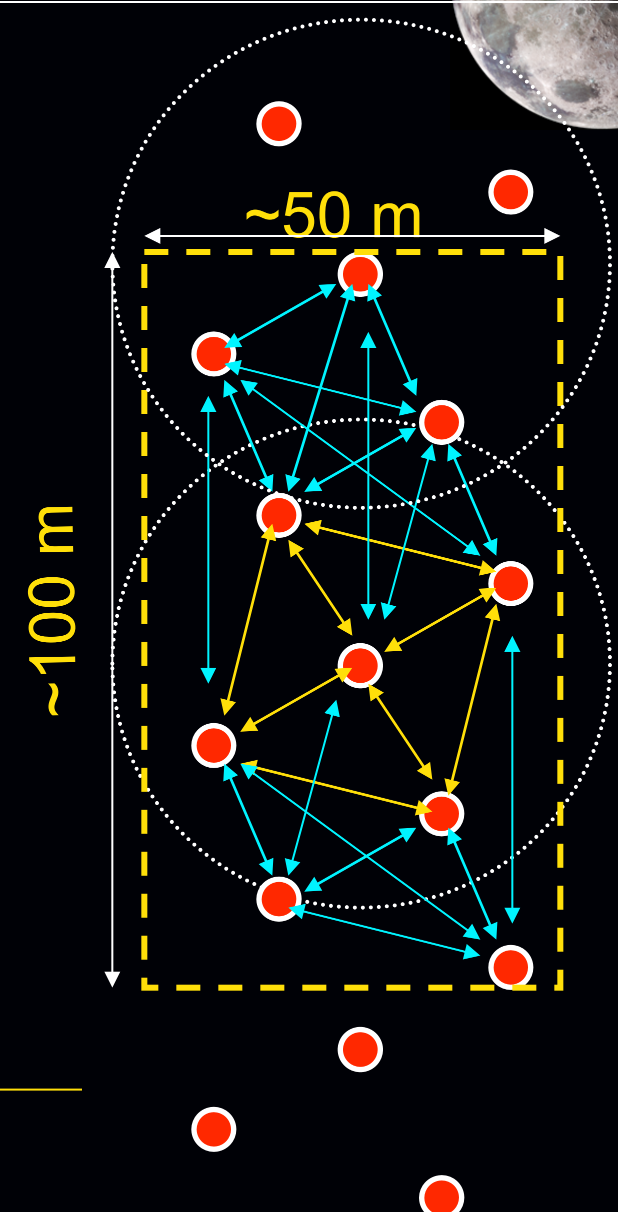
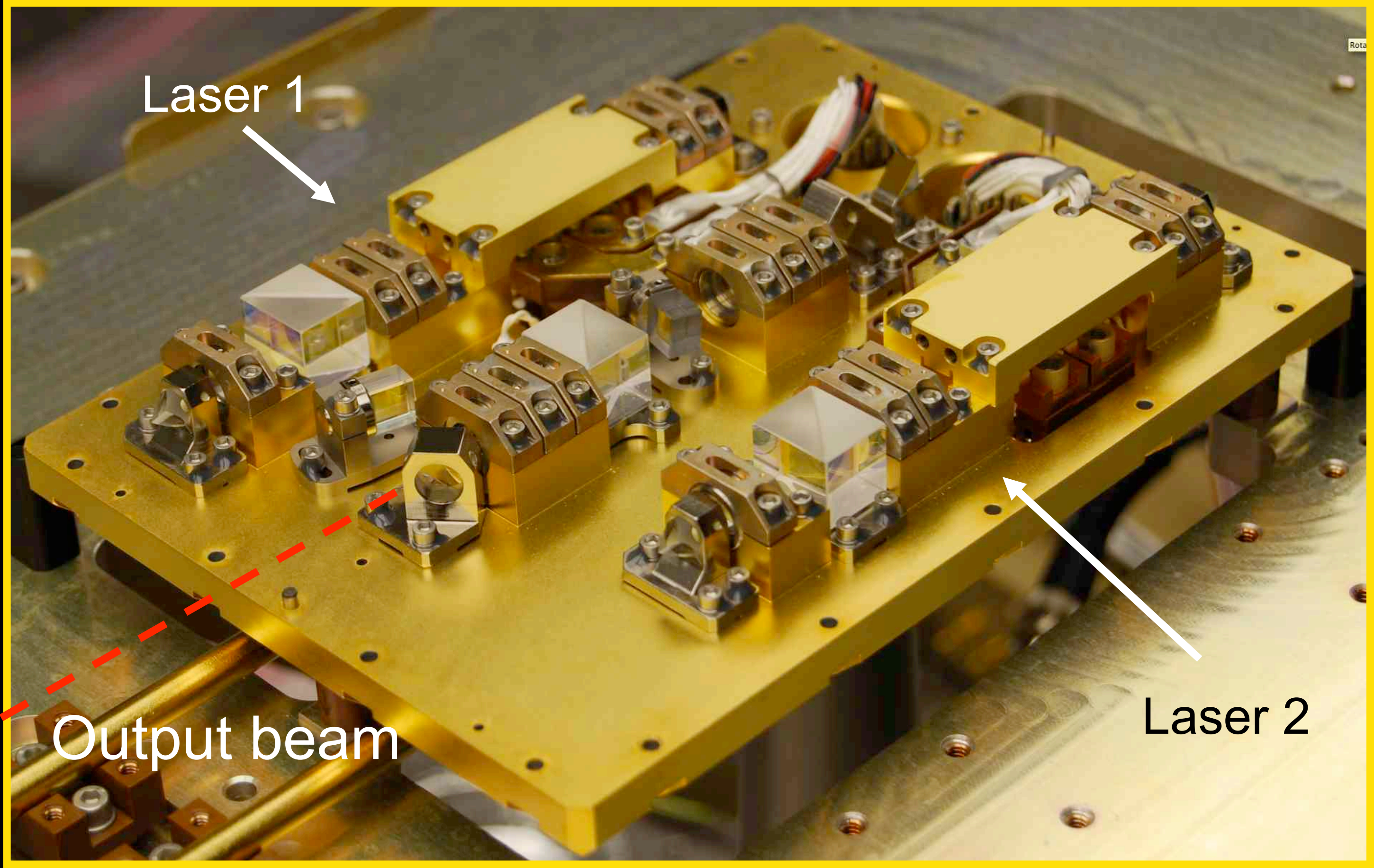


Chart shows 22 measured baselines <50 m

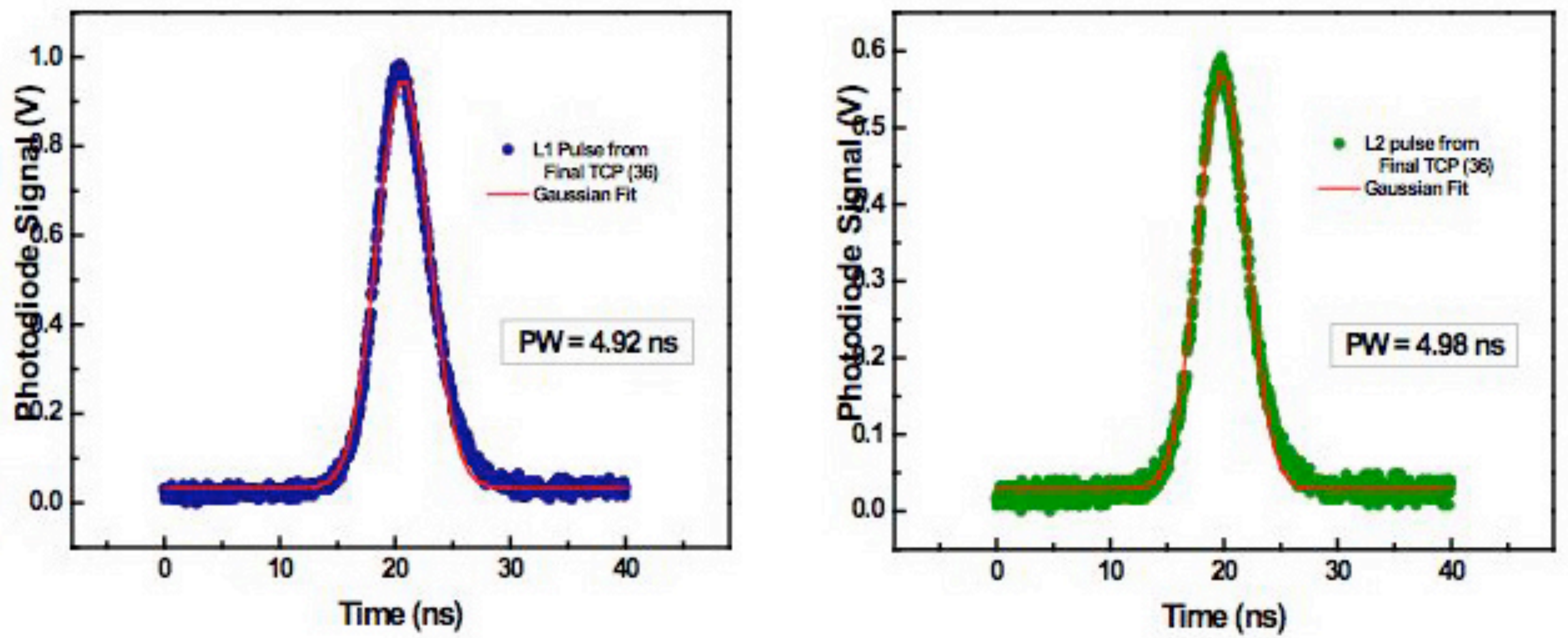
Flight Model Laser



Flight lasers on flight laser bench

Laser Pulse Width

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

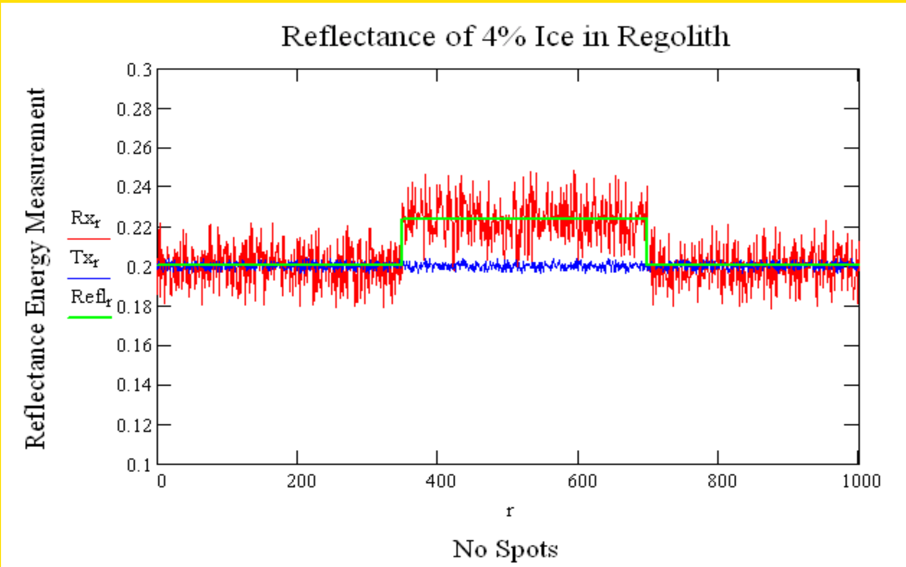


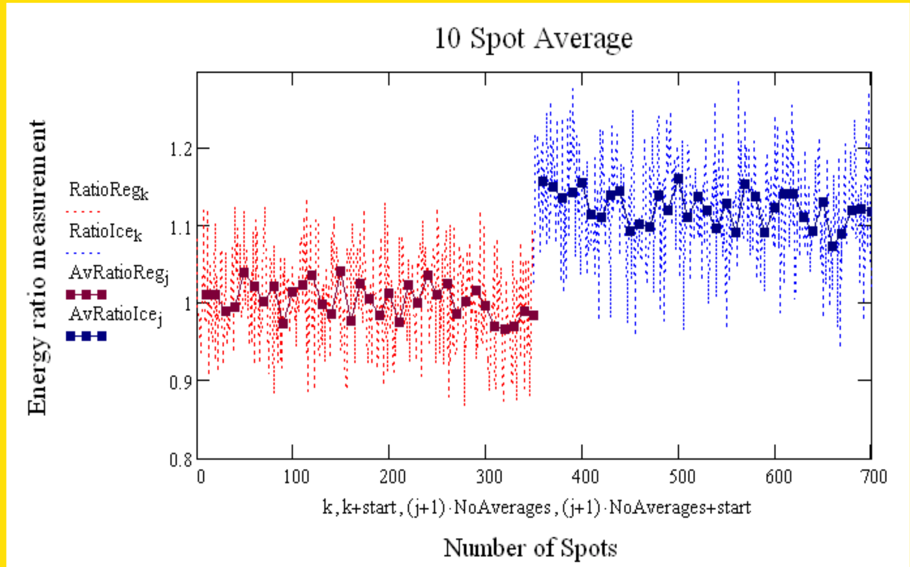
Timing resolution 30 ps; accuracy 100 ps (3 cm)

Lunar Orbiter Laser Altimeter

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 (β = 80% ice, β = 20% regolith) than surrounding areas.





Simulated Regolith-Ice mixture detection assuming 2% noise in Tx and 12% in Rx

Laser Corner Cube Array (LArray)

- 12, 31.7mm diameter solid corner cubes
- Materials:
  - Suprasil (quartz) cubes, Al frame
- Mass: 650.25 g
- Volume:15x18x5 cm
- Oper. temp range: -150 to +30 C
  Thermally isolated from the spacecraft
- Tested to 14g vibration.
- Optical characteristics:
  - 90 deg. dihedral angle(unspoiled), with 0.3 arcsec tolerance
  - Total internal reflection (uncoated back surfaces)
  - AR coating on top surface

Altimetry as Art; Mars by MOLA and Kees Veenebos

LOLA

Lunar Orbiter Laser Altimeter


~ 100km
Shaded relief of Mars' south polar layered terrains from MOLA
A view a camera can never take.