Precision Orbit Determination of Low Altitude Lunar Spacecraft with Laser Systems

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Science Requirements for precision Orbits around the Moon

- Future scientific exploration of the Moon will certainly need improved knowledge of spacecraft orbital position at the Moon.
- Studies of the lunar surface, its cratering history, and the lunar interior require higher resolution topography, gravity,and imaging than is presently available.
- The return of humans to the surface of the Moon will probably require the establishment of a precision geodetic control grid for the Moon (gravity, topography, horizontal position).

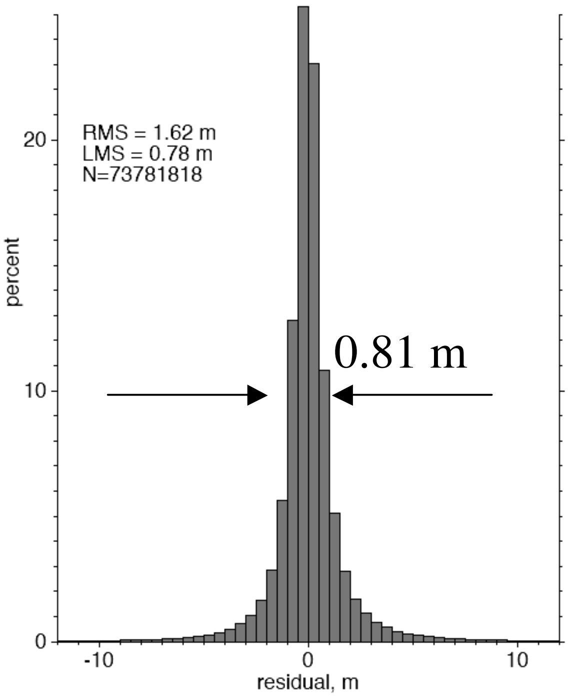
Abstract

The need for high accuracy positioning of spacecraft in orbit about the Moon is becoming more important as many nations consider going to the Moon for both exploration and science. Particularly challenging is the control and knowledge of spacecraft position on the farside of the moon where spacecraft are unobservable from the surface of the Earth. Although, spacecraft are routinely out of view of Earth when behind any planet or body it is unique that we are never able to see and study the farside of Earth's moon from the Earth's surface. This is particularly difficult for the positioning of low altitude spacecraft that are very sensitive to even small gravity anomalies of unknown location and magnitude on the lunar farside. Of course, a variety of 2-spacraft gravity missions could reduce the problem of unknown gravity and if suitably placed could also act as a communications relay. In the long term the establishment of a farside communications spacecraft system will probably be the solution to this problem for most spacecraft. For scientific spacecraft in low altitude orbits requiring very precise spacecraft location this may not be adequate. This issue reveals itself in fig 1, a map of the gravity anomaly field of the Moon derived from Clementine and prospector tracking data.

The State of the Art in Planetary Spacecraft Orbit Determination

- The most precise planetary orbit determination is for Mars Global Surveyor (MGS) operating in orbit at Mars since Sept. 1997.

- The orbital "accuracy" evaluated by laser altimeter cross-overs is ~ 1 meter rms radially and 100 meters horizontally.



- The tracking of MGS is X-band doppler with precision ~ 50 microns/s every 10 seconds.

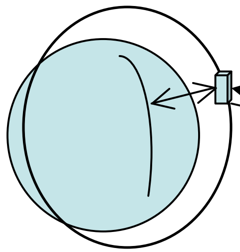
- <u>How much better could we do if we tracked planetary orbiters using laser transponders?</u>

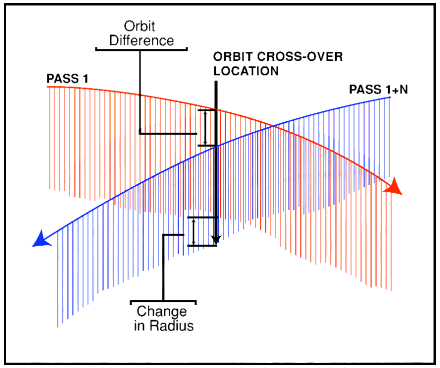
Lageos Quality Orbit Determination of a Lunar Orbiter

- We routinely track Lageos at the 1 cm level and derive similar quality orbits.

- This level of 1 cm would open up a number of lunar scientific areas if this quality of tracking and orbit determination could be obtained on a low altitude lunar spacecraft, including:
  - lunar gravity
  - decimeter altimetry
  - geodetic control and reference frame
  - relativistic parameters
  - lunar interior
  - tidal studies
  - rotation and libration studies

Laser Tracking Scenario for a Lunar Orbiter - 1



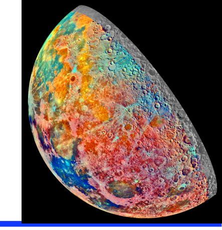


- Consider a lunar geodetic satellite carrying a 10 cm laser altimeter and a laser transponder operating in conjunction with an SLR station with SLR2000 performance.

E

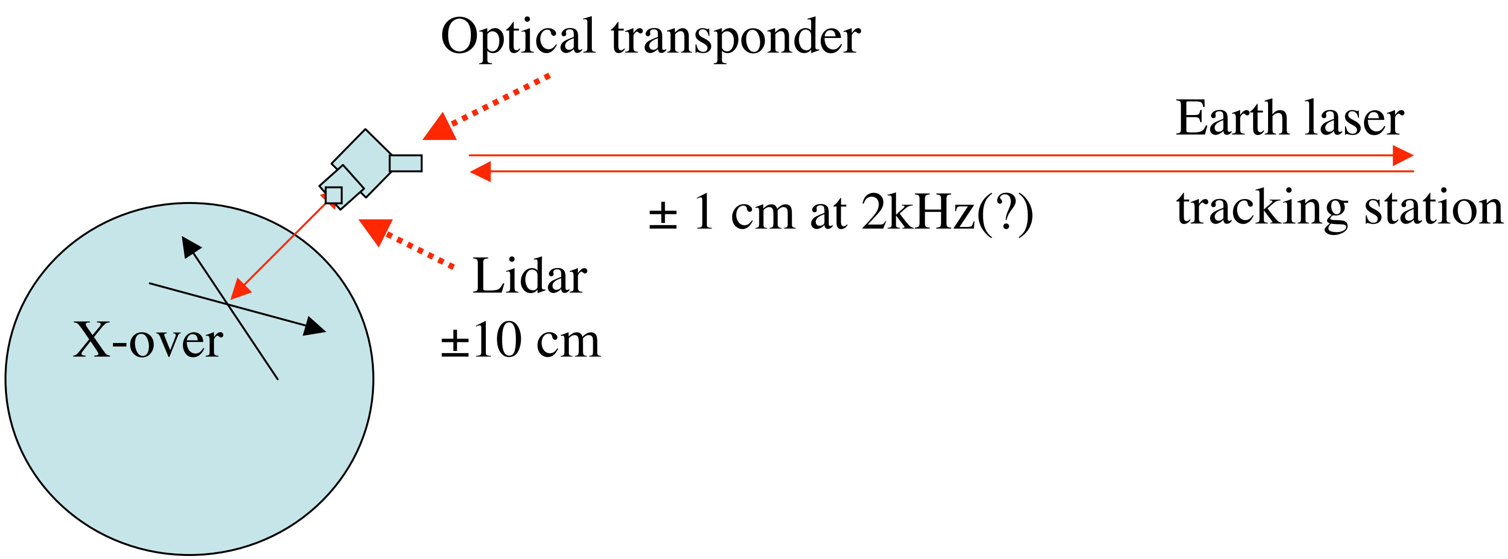
- The laser altimeter operates continuously over both the near-side and far-side of the Moon:
  - it provides the distance of the spacecraft from the surface of the Moon continuously, and
  - it provides cross-over observations that can be used as tracking data.

Laser Tracking Scenario for a Lunar Orbiter - 2



- The laser transponder operates only on the near-side when visible from Earth.

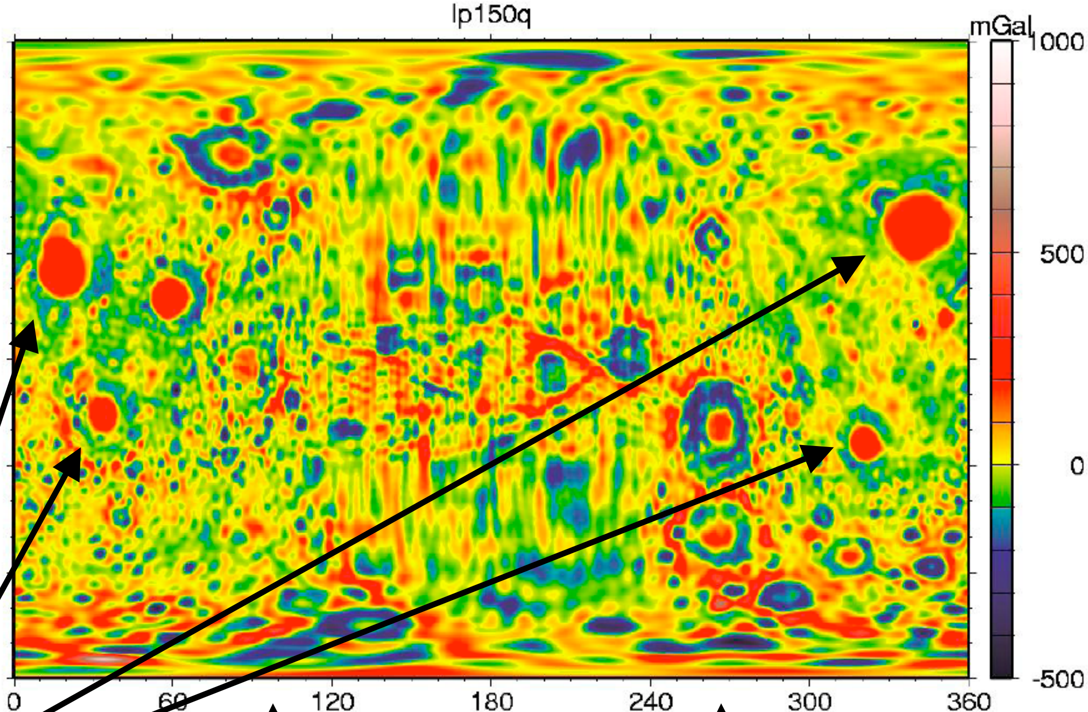
- Together, the SLR and the altimeter cross-overs provide a very strong constraint on the spacecraft position even though we never observe the spacecraft directly on the lunar far-side.



Extracting the Far-side Gravity Field of the Moon

- Present knowledge based upon Clementine and Lunar Prospector S-band tracking:
  - ± 20 mGal near-side
  - ± 100 mGal far-side

- Science needs ± 1 mGal



"Mascons"

Lunar Far-side

Striping indicates unresolved gravity signal

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1 mGal = 10^{-5} meters/sec^2

Altimeter Cross-Over Pattern after 1 year

2° long

Correct proportion

180° lat

There is a cross-over in every 1x1 km block over the complete surface of the Moon

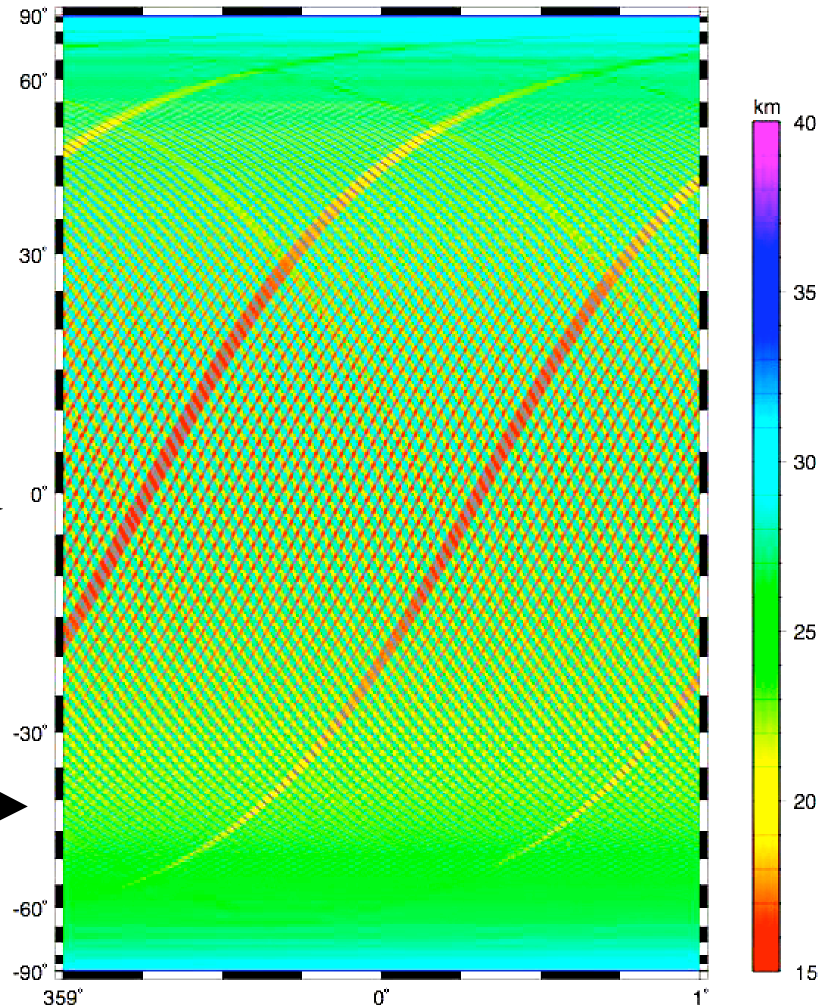
2° long

N.Pole

Equ

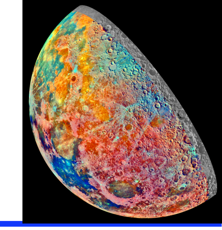
S.Pole

Stetched in longitude



Altimetric cross-overs have been successfully used at Mars to sub-meter

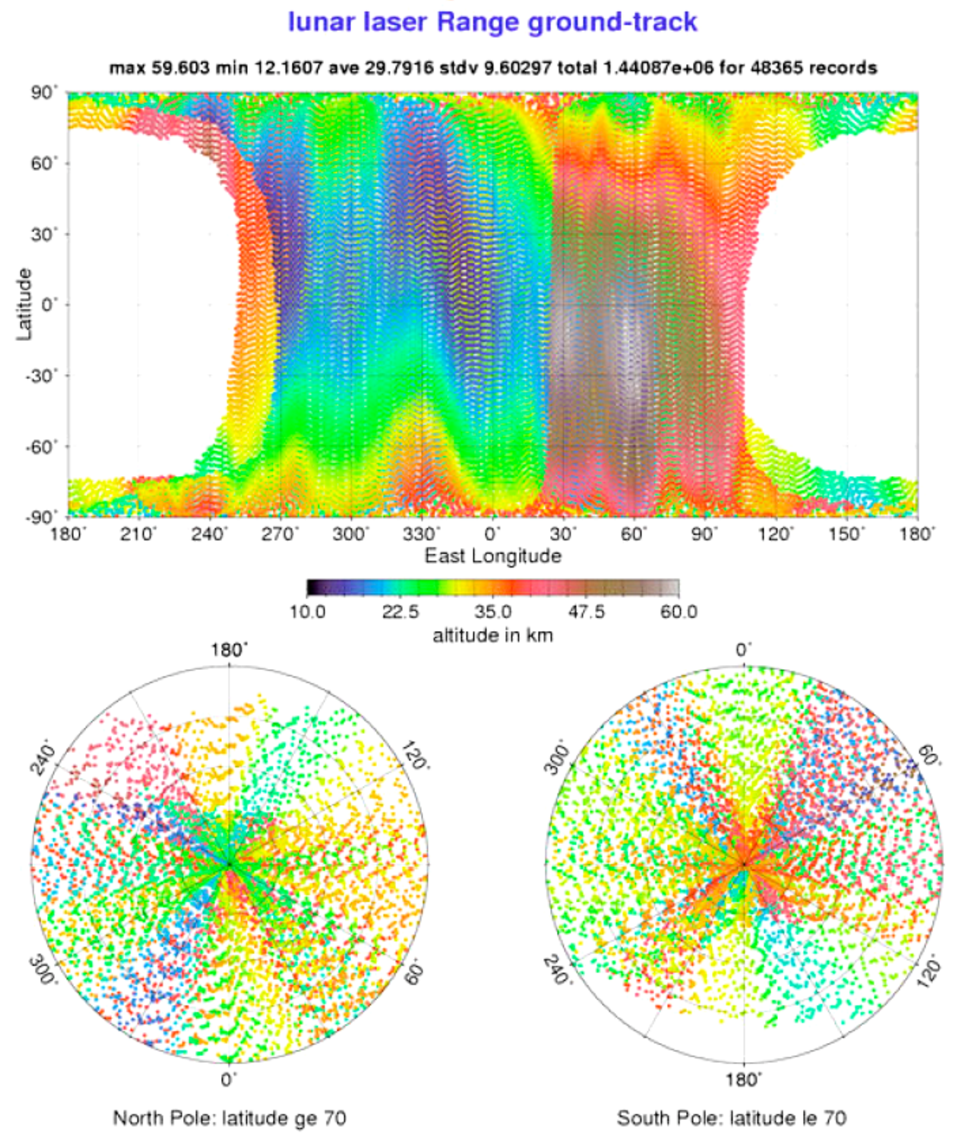
Earth-based Tracking Coverage - 1 Month



- For a low altitude (25 km) lunar satellite there is always are large area on the far-side of the moon over which the spacecraft cannot be tracked from Earth.

- This "hole" is approximately 38% of the lunar surface.

Lunar Laser Range Data Ground-track



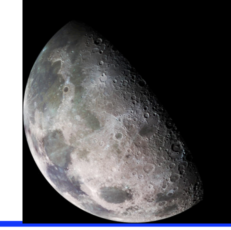
Topography and Gravity from Altimetry Cross-Overs

- Altimeter measurements of ±10 cm quality over solid surfaces can provide the shape (topography) of the Moon to ~ ±10 cm when the cross-overs are minimized over the surface of the Moon.

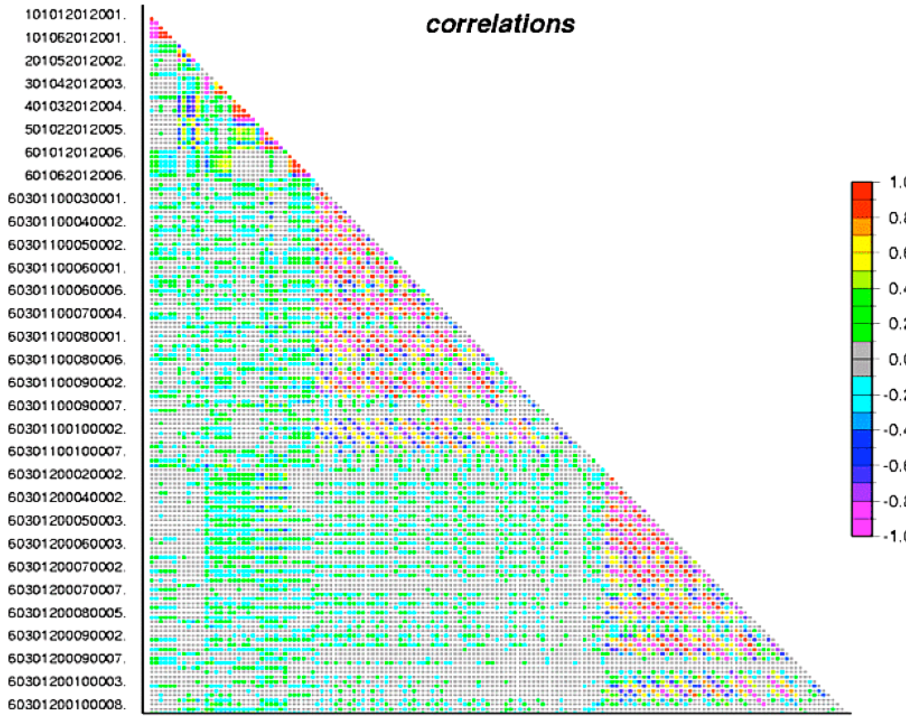
- In conjunction with tracking data cross-overs can provide gravity information from the radial sensitivity and along-track velocity.

- A detailed simulation of the gravity field improvement from laser tracking and laser altimeter cross-overs is in progress.

Correlations between Gravity Coefficients (range, and range-rate)

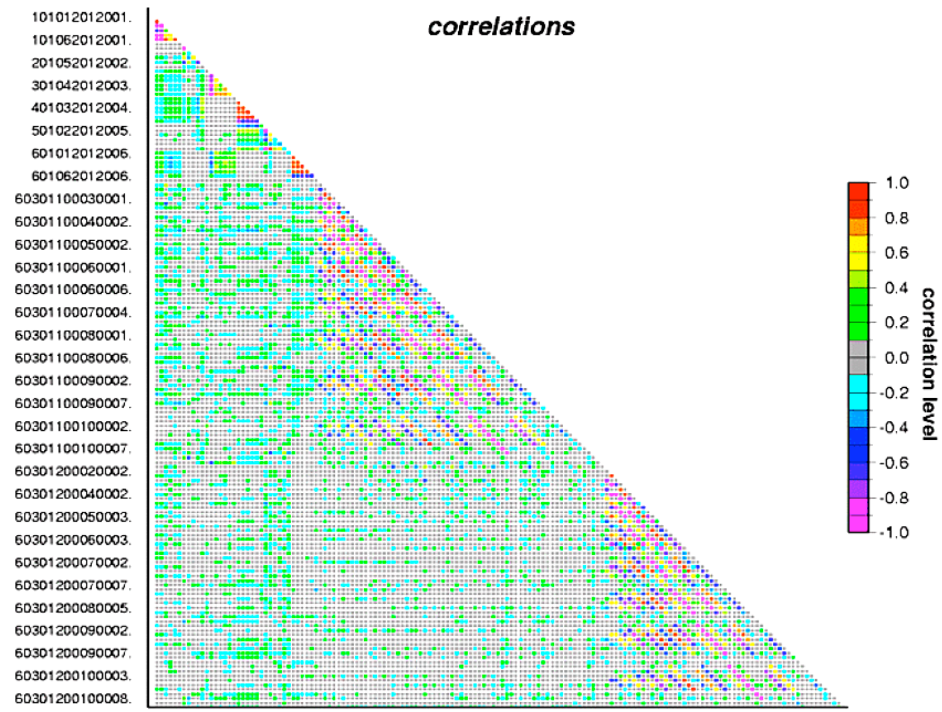


range rate (scale 0) 0x0 gravity



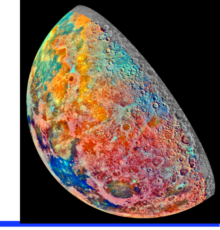
Doppler Tracking

range (scale 36) 10x10 gravity

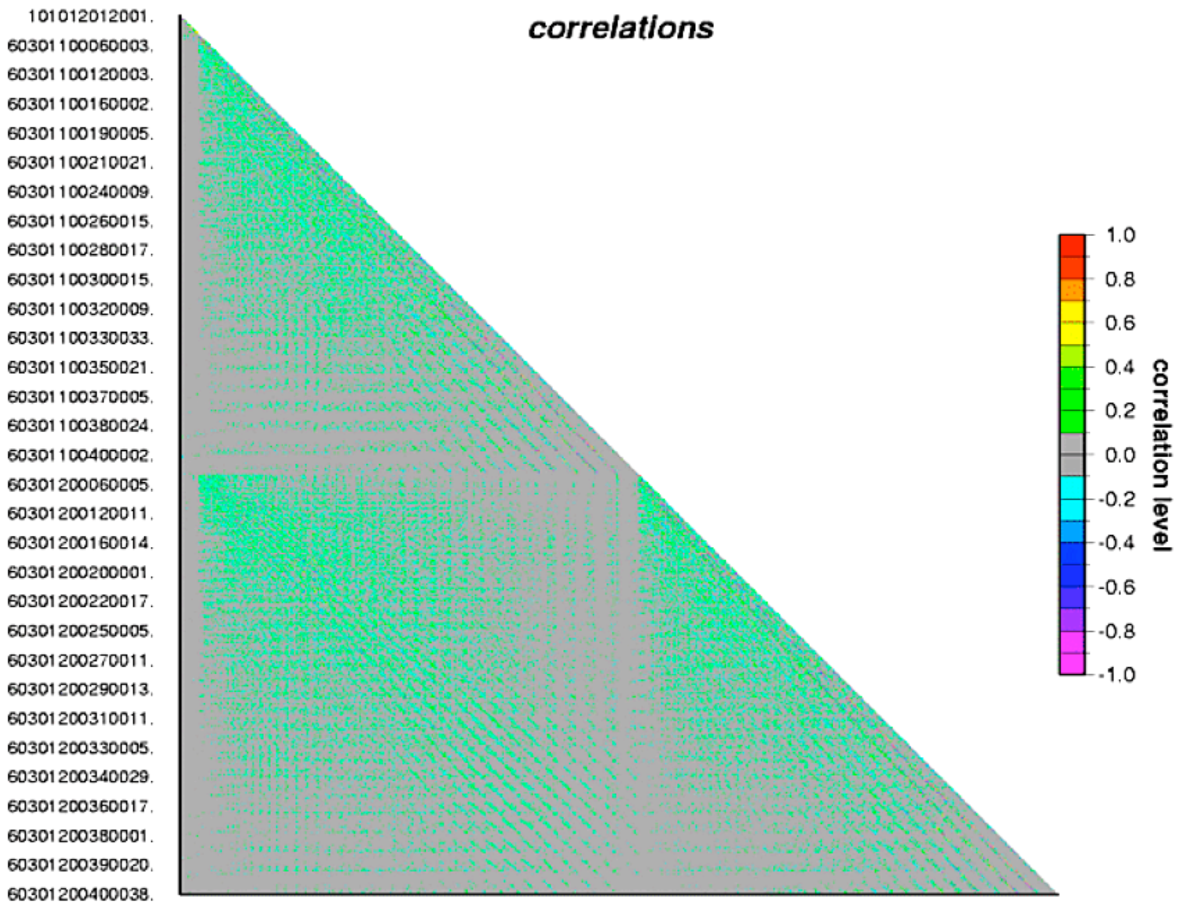


Laser Tracking

Impact of Adding Altimeter Cross-Over Data



range (scale 36) range rate (scale 1) cross over (scale 400) 40x40 gra



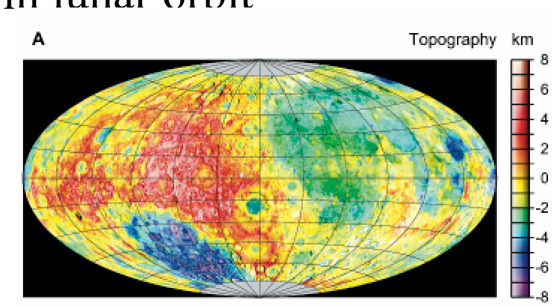
Laser Tracking, Doppler Tracking, + Altimeter Cross-Overs

Future Lunar Mission Opportunities in the US

<u>Moon-Mars Initiative</u> (Bush Exploration Initiative):
Plan calls for a Robotic Lunar Orbiter in 2008
- 100 kg instrument payload

Proposal for instruments due Sept 15, 2004

- Characterization of the deep space radiation environment in lunar orbit
- **Geodetic global topography**;
- High spatial resolution hydrogen mapping;
- Temperature mapping in polar shadowed regions;
- **Imaging of the lunar surface in permanently shadowed regions**;
- Assessment of meter and smaller scale features for potential landing sites;
- Characterization of the changing lunar surface illumination conditions in polar regions at time scales as short at hours



"The first three are given highest priority"

Future Lunar Mission Opportunities in the US

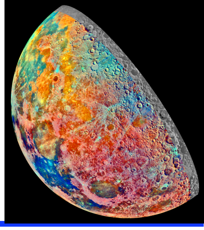
Discovery 2005: Opportunity to propose a full mission (L ~ 2010)

- The Massachusetts Institute of Technology, NASA Goddard, and JPL are preparing a Lunar Discovery proposal (*Moonlight*) that has a laser altimeter as the prime instrument

- we hope to carry a laser transponder and laser tracking to be a (the?) primary tracking system; laser communication is a possibility (50Mb/s required)

- we will need the "support" of the ILRS and individual laser stations who would like to participate in tracking the spacecraft.

Transponder-Laser Ranging Requirements for Science



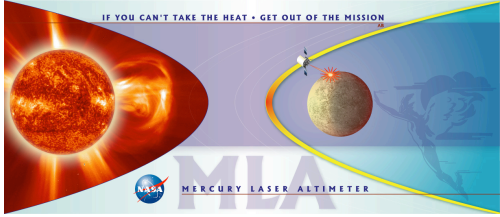
- The tracking requirements of a lunar satellite tracking system are similar to those for geodetic Earth satellites:

  - sub-centimeter ranging;
  - 10 □m/sec velocity (derivable for the range?)
  - 5-second normal points (~ 8km along track)

[*Mircowave tracking at X-band provides 2 meter ranges, ~50 □m/sec velocity at 10-second intervals; Ka-band tracking "can" provide ~40 cm ranges, ~20 □m/sec at 10 second intervals. Weather limitations at Ka-band*]

- Provide the timing system for the spacecraft instrumentation at the 0.1 millisecond level (the transfer of GPS timing to the Moon.

Observations of the MESSENGER Spacecraft



- At the end of July 2004, the MESSENGER spacecraft will be launched to Mercury.

MESSENGER carries a laser altimeter

1064 nm ; 8 Hz; 20 mJ
25 cm diameter effective aperture
Max range ~1800 km

- We are interested in receiving visual and photographic observations of MESSENGER as it recedes from Earth during August and September 2004 when distance < 50 M km. (vis mag ~ +18)

- The laser will be operated and pointed at Earth in Summer 2005 during an Earth fly-by for calibration of signal strength and instrument pointing.   Participation is welcome.

Summary and Conclusions

- Precision orbit determination of lunar satellites appears feasible with laser tracking and laser altimetry.

- Significant improvement in the lunar gravity field improvement can be expected.

- Missions to the Moon that could carry a laser transponder could happen in the next 5 or 6 years.

- This could revolutionize lunar and planetary science.