Orbit Determination of LRO at the Moon

David Smith [1], Maria Zuber [2], Frank Lemoine [1],
Mark Torrence [3], Erwan Mazarico [4]

1. NASA Goddard Space Flight Center Greenbelt, MD
2. Massachusetts Institute of Technology, Cambridge, MA
3 SGT Inc, Greenbelt, MD
4 ORAU NASA postdoctoral program, NASA/GSFC, Greenbelt, DM

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Abstract

The orbit determination of the Lunar Reconnaissance Orbiter (LRO) is particularly important because the mission is designed to select landing sites for future robotic and human landings. For these purposes the program needs an accurate geodetic model of the Moon that provides the best knowledge of the positions of features on the surface, including the far side, and the gravity field to enable spacecraft to return to, or visit, a particular location. LRO is expected to provide this information. The baseline tracking system for LRO is S-band with Doppler accuracy of ~1 mm/s for approx. 20 hours per day but this will not be accurate enough for the LRO requirements which are estimated to be <50m or better in along track position . One-way laser ranging at 10 cm precision has been added to the spacecraft to assist in orbit determination, and in conjunction with the laser altimeter (LOLA) at 10 cm accuracy is expected to provide the position of LRO and, by inference, the position of surface features to the desired accuracy. Important aspects of LRO orbit determination are gravity model improvement, improvement of spacecraft timing and pointing knowledge, and laser altimetry and laser tracking of LRO are expected to be critical components.

Orbit Determination Requirements of LRO

- LRO's primary purpose is to help select and characterize potential landing sites for future robotic and human landings.
- Because of LRO's 10 cm precision altimeter and the camera's 50 cm pixel resolution the orbit determination of LRO needs to be as accurate as possible.
- All available methods and data will be used in this process and must include the improvement of the lunar gravity field model until GRAIL is launched and a definitive model is available in 2012.

LRO Baseline Tracking System: S-band Doppler & Range

White Sands - 1

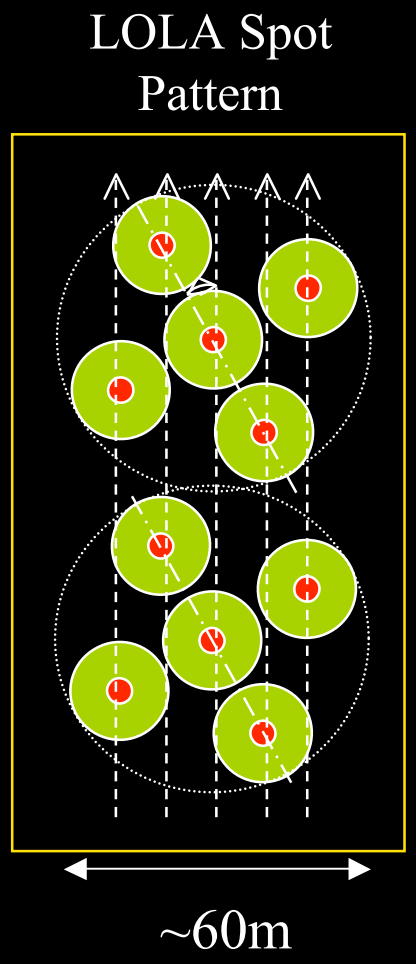
Doppler S-band ~ 0.3 mm/s every 10 seconds. This station is the prime telemetry downlink at Ka-band.

Universal Space Network

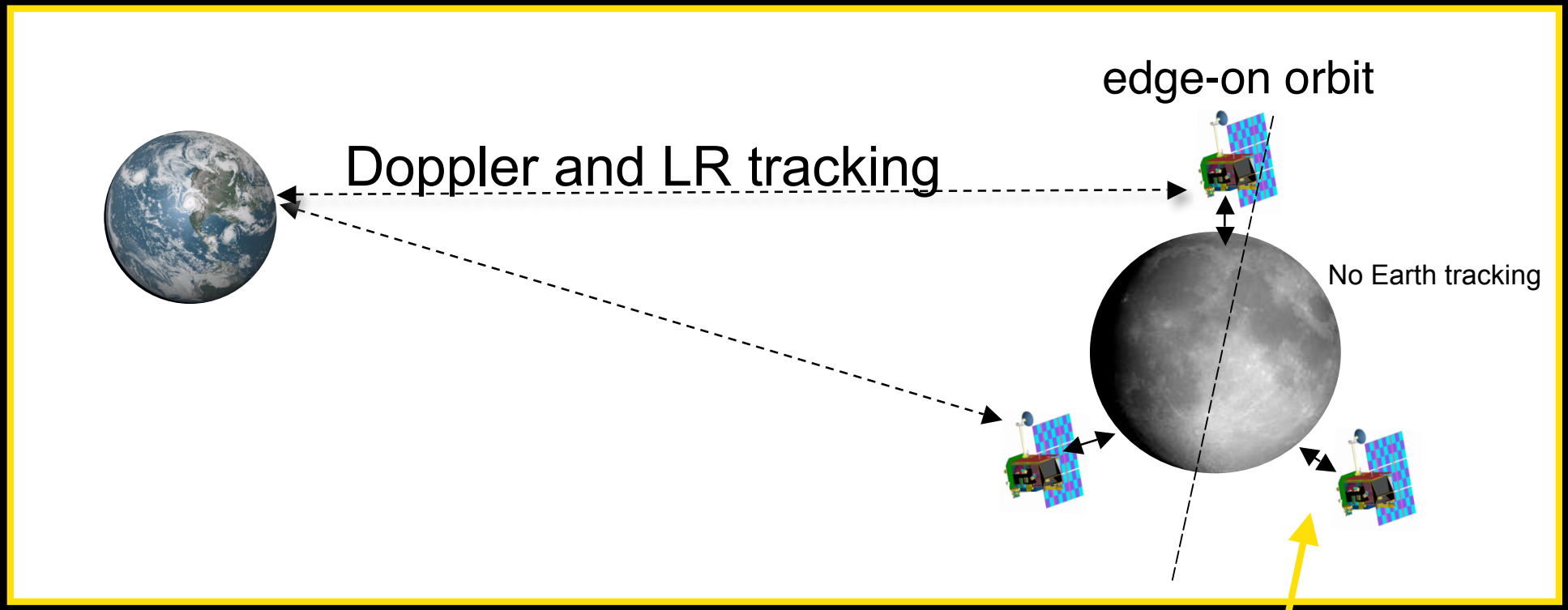
- Commercial Network (*not DSN such as on Clementine or Lunar Prospector, though some DSN tracking may be available*).
- S Band (& Ka downlink - for telemetry only).
- Four Stations:
  Dongara (Yarragadee), Australia; Kiruna, Sweden; Weilham, Germany; South Point, Hawaii, ~2.5 mm/s.

Additional Tracking Data

- LOLA: 10 cm altimeter measurement at 28 Hz. 5 measurements per pulse. 5 parallel profiles with total swath of ~ 60 meters, 50 meters along-track spacing each profile.
- Altimeter cross-over analysis based upon altimeter, surface roughness, and slope data.
- LR: SLR stations; capability of 10cm precision ranging at 28 Hz limited by LOLA.
  - NGSLR the primary ground station for LRO-LR.
  - MLRS is participating as part of NASA network.
  - Herstmonceux, Zimmerwald, Mt. Stromlo submitted responses to the call for participation.
  - Wettzell, Matera, and Grasse have expressed an interest in participating.
- A small array on LRO will allow the possibility for two way laser ranging



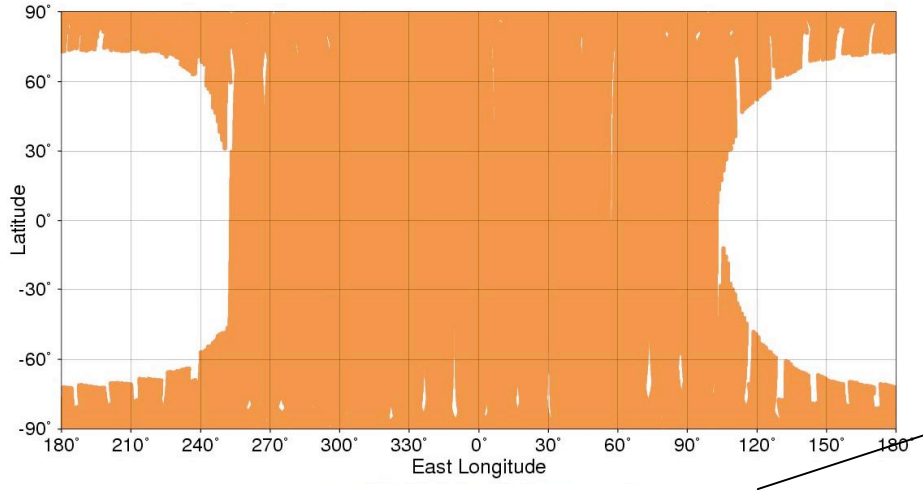
Tracking for Orbit Determination and Gravity



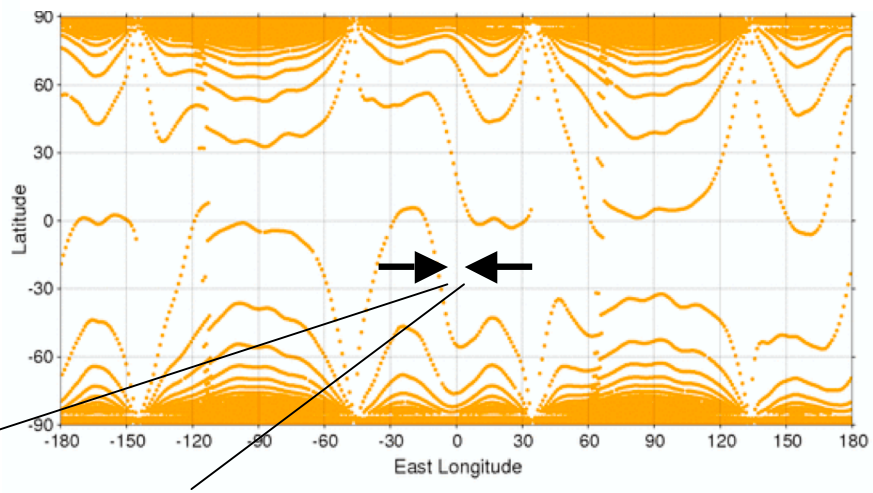
LRO will use the LOLA laser altimeter, orbital cross-overs, and laser ranging from Earth

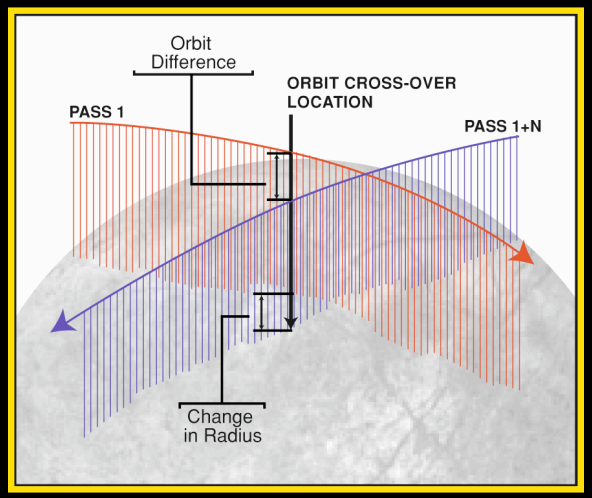
Observation Geometry and Altimeter Cross-Overs

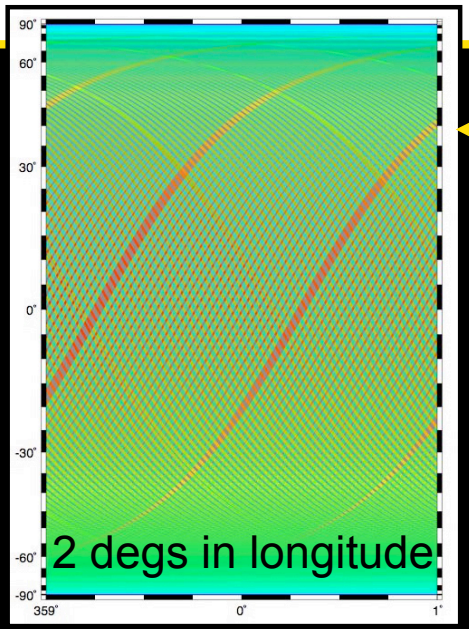
Earth Tracking



Cross-overs - 1 month







← Cross-overs - 1 year

Crossovers occur about every 1 km in longitude and 3 deg in latitude at equator

Laser Ranging to LRO

LOLA:10 cm range accuracy

28 Hz, 1064 nm

LR: 10 cm range precision

28 Hz, 532 nm

LRO Precision Tracking

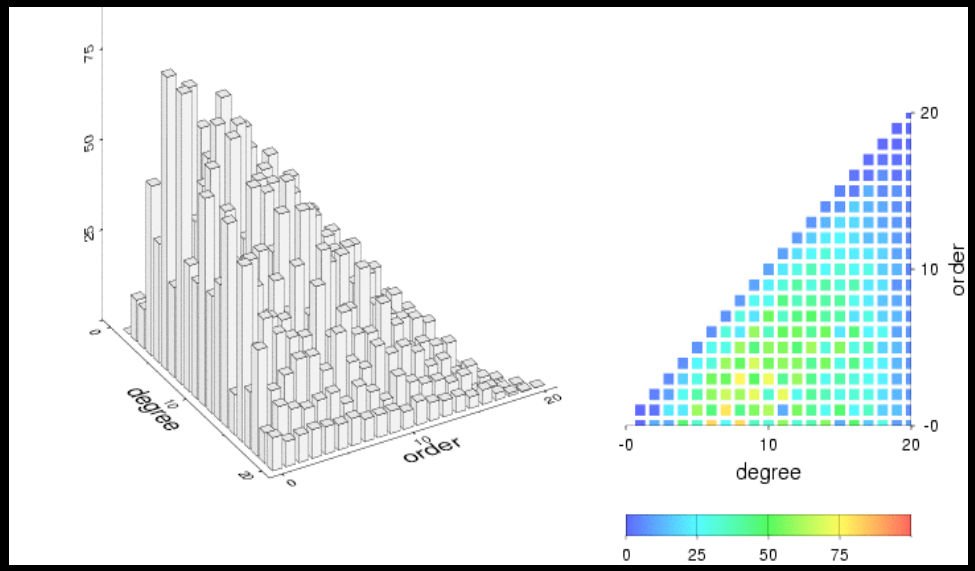
From a combination of LR, altimeter, and S-band tracking we estimate positional accuracies of ~25 m along track and ~0.5 m radially (CoM) after improvement of the lunar gravity field.

A Simulation of the LRO Orbit Determination

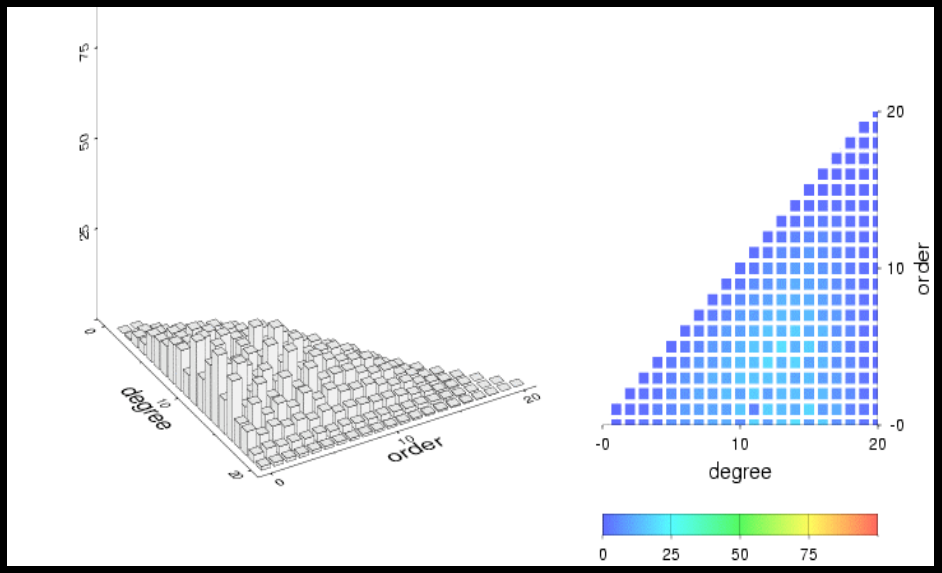
- LRO Operations Simulated for the 3 months
  - S-band data from White Sands (NM)1 mm/s every 5 s
  - S-band data from Dongara (Australia) 8 mm/s every 5 s
  - *LR data from Hawaii at 1 m every 5 secs (75% clear)*
  - LR data from Greenbelt at 1 m every 5 secs (35% clear)
  - LOLA data at 10 cm accuracy
- Data simulated with a model of the lunar gravity field (JGL100J, *Knopoliv et al,* Icarus 2000*)* and the planned LRO orbit.

Improvement in Lunar Gravity Model

Spherical Harmonic Coefficient Standard Deviations



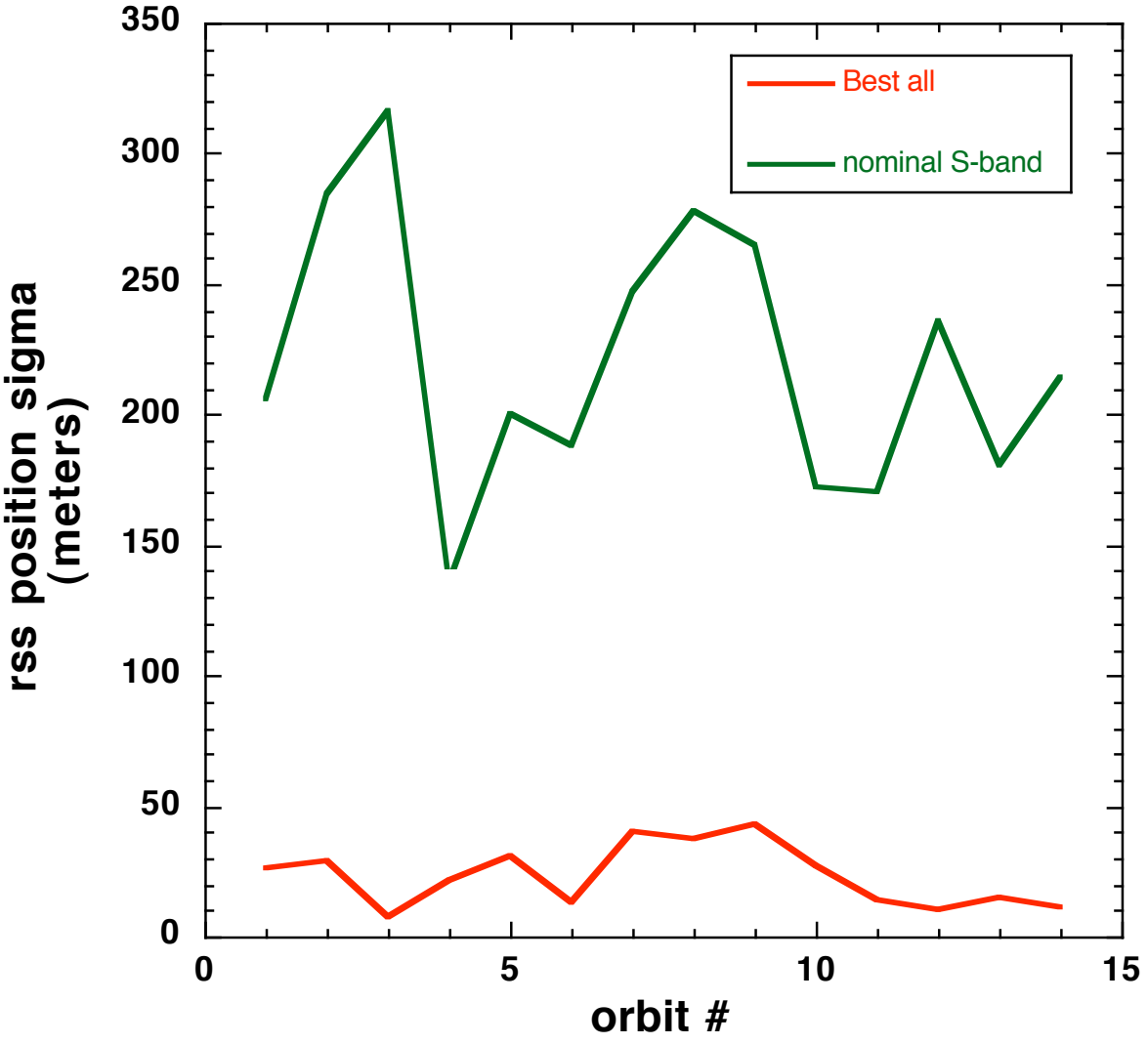
S-band and
Altimeter cross-overs



S-band and
Altimeter cross-overs
plus LR

Position Error after Gravity Model Improvement

LRO simulation suggests significant improvement



Average RSS Position Error

221 m Approx. orbital accuracy with present gravity field.

23 m Altimetry+Laser Ranging+S-band

Expanded Parameterization for LRO Orbit Determination

- Use altimeter crossovers to enhance the OD and refine instrument and spacecraft pointing.
- Use LRO macro model with panel self-shadowing to refine solar radiation and Lunar albedo perturbations.
- Empirical parameters (once per orbit or constant accelerations) can mitigate gravity model and other force model error.
- Updates to the planetary radiation pressure model are expected using LRO data from the Diviner Lunar Radiometer instrument (David Paige, PI).

refs: Precision Orbit Determination for the Lunar Reconnaissance Orbiter, Lemoine et al., 37th COSPAR Scientific Assembly Montreal, Canada, 13-20, July 2008.
"Simulation Study of Multi-Beam Altimetry for LRO and Other Planetary Missions", D.D. Rowlands, F.G.Lemoine, D.S. Chinn, S.B. Luthcke, J. Geodesy, in review, July 2008.

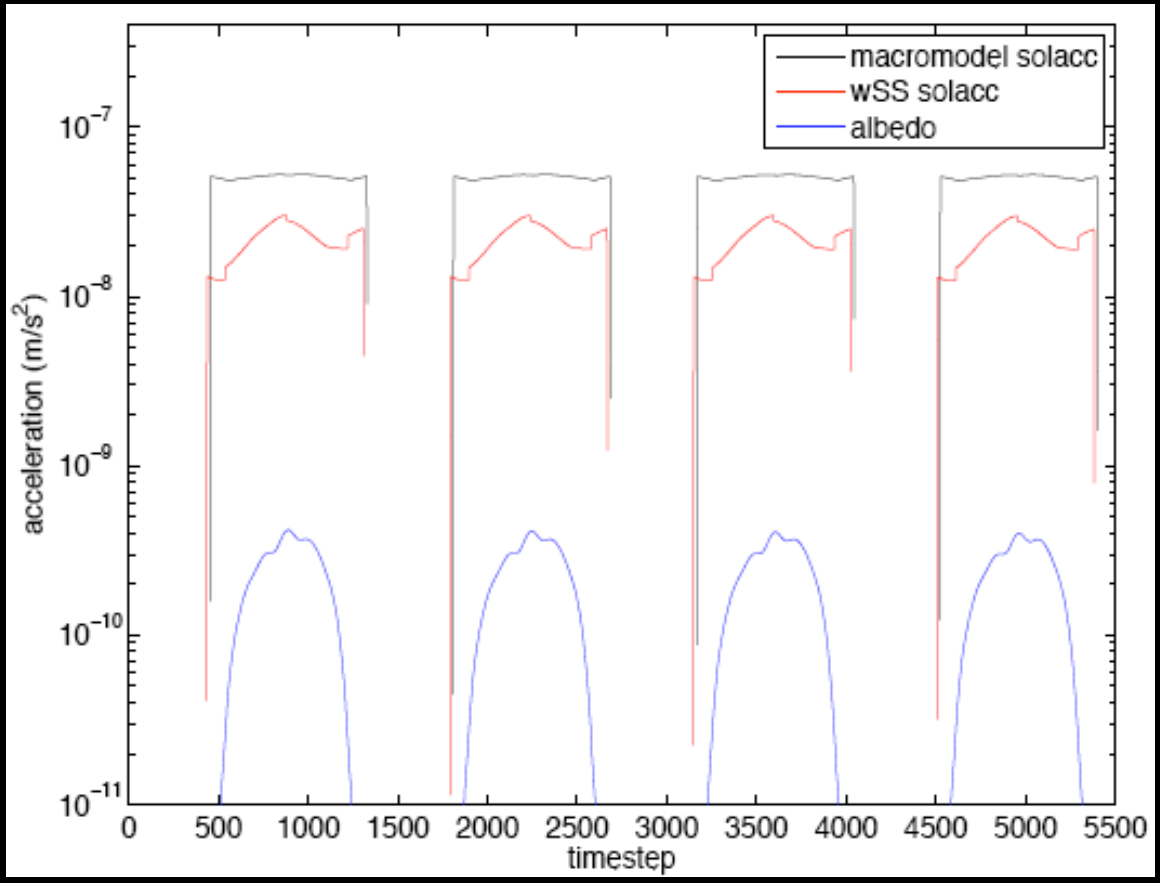
LRO Macromodel

LRO Plate	Cs	Cd	Area m^2
+X	0.29	0.22	2.82
-X	0.39	0.19	2.82
+Y	0.32	0.23	3.69
-Y	0.32	0.18	3.69
+Z	0.32	0.18	5.14
-Z	0.54	0.15	5.14
SA+	0.05	0.05	11.00
*SA-	-	-	11.00
*HGA+	0.18	0.28	1.00
*HGA-	0.019	0.0495	1.00

* *Cs/Cd values taken from MRO analog values. All other Cs/Cd values from LRO Project.*

Nonconservative Force Modeling and LRO

- Solar radiation pressure (macromodel);
- Macromodel with self-shadowing (using analytical quaternions and 3D model)
- Planetary radiation pressure (albedo) - Delft Albedo Model-1 (15x15) (*Floberghagen et al., 1998*)



Summary

- Laser Ranging to LRO is very important for the LOLA Science Team's generation of an improved lunar gravity model, orbits and reference frame definition. This one-way ranging system (LR) has the potential to have a major impact on the quality of spacecraft tracking at the Moon.
- Gravity model error is the largest source of orbit error for LRO.
- Enhanced force modeling will contribute to better determination of the Lunar gravity field, and more accurate orbits.
- We welcome ideas, suggestions, LR tracking data, in this new experiment for lunar spacecraft orbit determination.