# Lunar gravity field recovery: sensitivity studies from simulated tracking data

A. Maier, O. Baur
Space Research Institute, Austrian Academy of Sciences, Graz, Austria

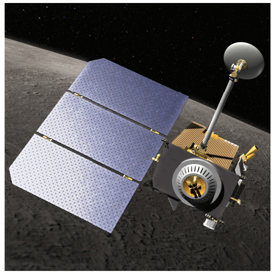
## The Lunar Reconnaissance Orbiter (LRO)

Mission objectives:

- characterization of the lunar radiation environment, biological impacts, and potential mitigation
- development of a high-resolution global, 3-d geodetic grid of the Moon and providing the topography necessary for selecting future landing sites
- assessment of the resources and environments of the Moon's polar regions
- high spatial resolution assessment of the Moon's surface addressing elemental composition, mineralogy, and regolith characteristics
- lunar gravity field determination

Mission phases:

| | |
|---|---|
| Launch | 2009-06-18 |
| Cruise | 2009-06-18 to 2009-06-23 |
| Lunar orbit acquisition | 2009-06-23 |
| Commissioning | 2009-06-23 to 2009-09-14 |
| Nominal mission | 2009-09-15 to 2010-09-15 |
| Science mission | 2010-09-16 to 2012-09-15 |

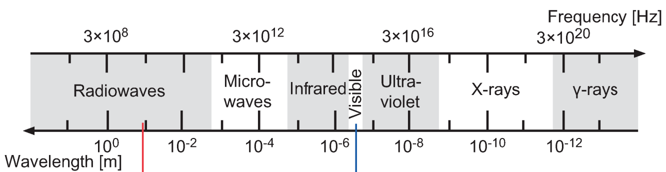


Credit: NASA

Orbit characteristics:

| | |
|---|---|
| Orbital period | 113 min |
| Inclination | ~ 90° w.r.t. lunar equator |
| Eccentricity | ~ 0, bounded by station keeping |
| Altitude | 50 km (±20 km) |

## Tracking data




Doppler range-rates

1. station generates an uplink signal
2. signal is received by LRO
3. LRO generates a downlink signal
4. station receives the downlink signal

Laser ranges

1. station fires a laser beam at LRO
2. LRO records the time of arrival
3. data is sent back to the Earth by its radio telemetry link

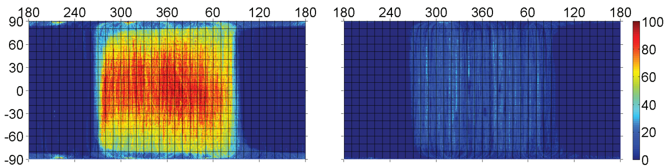


Fig. 1: Total number of Earth-based Doppler range-rates (left) and Earth-based laser ranges (right) to LRO during the nominal mission, averaged over a 1° × 1° grid. The western limb of the Moon as seen from the Earth is located at 270°.

## Tracking data simulation

How well can a 'true' lunar gravity field (up to d/o 5, 12, and 20) be recovered with noise-free/noisy laser ranges in case that

- they are evenly distributed on the Moon's surface?
- they are unevenly distributed (visible vs. actually tracked)?

### STEP 1: LRO orbit generation with GEODYN[1]

| | |
|---|---|
| Arc length | 6 to 14 days (depending on maneuvers) |
| State vector | extracted from SPICE[2] |
| 'True' and a priori gravity field model | JGL165P1 (up to d/o 5, 12, and 20) |

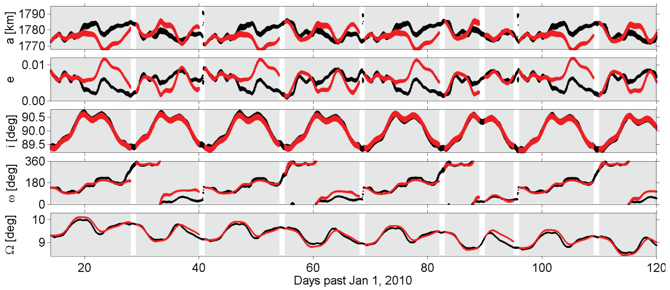



Fig. 2: Kepler elements of simulated LRO orbits considering gravity field coefficients up to d/o 12 (red) compared to Kepler elements derived from SPICE (black). Semimajor axis ($a$), eccentricity ($e$), inclination ($i$), and argument of perigee ($\omega$) are expressed in the body-fixed reference frame. Right ascension ($\Omega$) is expressed in the J2000 reference frame. Gray sections indicate different arcs.

### STEP 2: Simulation of tracking data

| | Laser Ranging | Doppler range-rates |
|---|---|---|
| Tracking stations | Greenbelt, Maryland<br>Yaragadee, Australia<br>McDonald, Texas | White Sands, New Mexico<br>Dongara, Australia<br>Kiruna, Sweden |
| Elevation cut-off angle [°] | 20.0 | 0.0 |
| Interval between observations [s] | 5.0 (even coverage) | 5.0 (even coverage) |
| Observation geometry | even/uneven coverage | even/uneven coverage |
| Noise level | 10.0 cm | not applied |

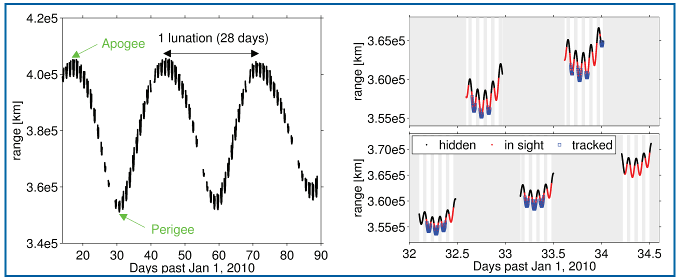



Fig. 3: (left) Simulated laser ranges from Yarragadee to LRO whenever the satellite is visible. Detailed view of laser ranges from Yarragadee (upper right) and laser ranges from Greenbelt (lower right). Gray sections indicate time spans when LRO is not in view. The large occultation intervals (~12 hours) stem from the Earth's rotation, the smaller ones (~1 hour) are due to LRO orbiting the Moon.

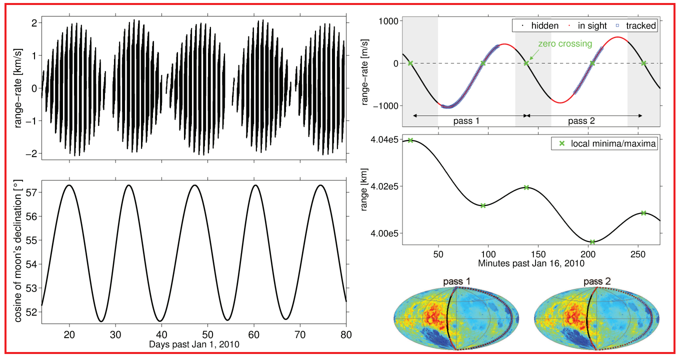



Fig. 4: (upper left) Simulated range-rates from Dongara to LRO whenever the satellite is visible (top). (lower left) The range-rates' amplitudes are correlated with the cosine of the Moon's declination. (top right) Detailed view of two Doppler S-curves. Range-rates are zero whenever the distance between station and satellite is at local minimum or maximum (middle right). (bottom right) Footprints of pass 1 and pass 2 on top of lunar topography. The plots are centered at the western limb of the Moon as seen from the Earth (270°).

## Reconstructed gravity field coefficients

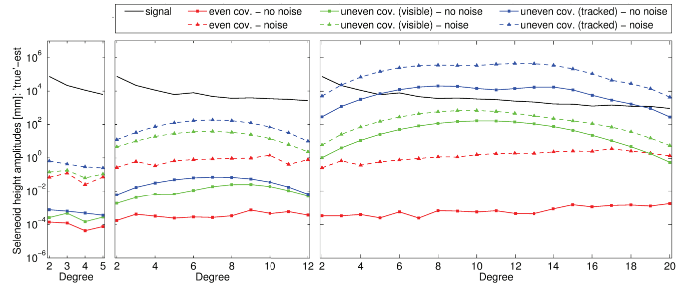



Fig. 5: Difference between 'true' and estimated coefficients based on simulated laser ranges expressed in selenoid height amplitudes. Having data on the nearside and on the farside available clearly allows the estimation of gravity field coefficients up to d/o 20. For the case that tracking data has been simulated for the nearside only, the level of precision degrades considerably with increasing number of estimated coefficients (green and blue lines). The viewer the number of simulated observations, the more drastical is the degradation. If the observations are superposed with noise, the amplitudes are generally well above the noise-free solutions.

## Conclusion & Outlook

For the case that laser ranges are available on the nearside and considering a time span of 100 days, the maximum d/o should not exceed 12 due to numerical instability. We expect, however, that the stability will increase once laser ranges are combined with Doppler range-rates.

## References

[1] McCarthy, J.J., Rowton, S., Moore, D., Pavlis, D.E., Luthcke, S.B., Tsaoussi, L.S. GEODYN II systems description, vol. 1. Hughes STX Systems Corporation, 4400 Forbes Blvd., Lanham, MD 20706, 1993.

[2] Acton, C.H. Ancillary Data Services of NASA's Navigation and Ancillary Information Facility. Planetary and Space Science, vol. 44, no. 1, pp. 65–70, 1996.

Austrian Academy of Sciences (ÖAW) / Space Research Institute (IWF), 8042 Graz, Austria, www.iwf.oeaw.ac.at, Contact: andrea.maier@oeaw.ac.at