Virtual Research Presentation Conference

Multipath Fading and Soil Property Characterization at Lunar South Pole from Ground-based Observations

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Program: Spontaneous RTD

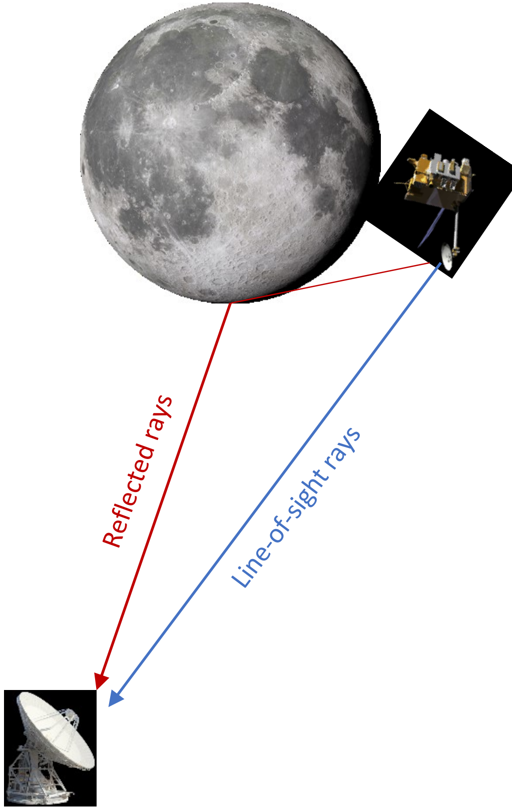
Assigned Presentation #: RPC-076

Tutorial Introduction

Abstract

We conducted an experimental campaign to measure multipath reflections from the lunar South Pole using downlinks from the Lunar Reconnaissance Orbiter (LRO), and the Deep Space Network's (DSN) open loop receivers. The primary observable of this campaign was the Doppler spread of the received reflections as the spacecraft sets or rises from the far side of the Moon. We then used these measurements, together with digital elevation maps of the Moon and LRO trajectory information, to bound the scattering area and correlate its properties with the terrain roughness.

To demonstrate the feasibility of this experiment in a short 6 month period, all measurements were collected opportunistically and without imposing any constraints on LRO. Despite this, we were able to demonstrate that multipath reflections can be measured above the noise level, and the resulting scattering signature is highly correlated with the South Pole region being sampled. We were also able to correctly predict the location of specular reflection (through its associated Doppler shift), and use the Doppler spread together with Fresnel zones to estimate the extent of the scattering area. Finally, we used the Doppler spread, as well as the received power on two orthogonal polarizations, to correlate our measurements with surface roughness maps from LRO's Lunar Orbiter Laser Altimeter (LOLA).



Problem Description

a) Context

- Lunar South Pole is an area of recent programmatic and scientific interest (e.g., water-ice in permanently shadowed areas).
- Human Landing System (HLS) and VIPER rover going to the lunar South Pole in the next decade.
- Their communication links with Earth will likely experience multipath reflections that are not well understood at present.

b) State-of-the-art

- There are currently no landed assets on the lunar South Pole that can be used to obtain channel measurements.
- Bistatic radar measurements with the Moon have been collected in the uplink direction using LRO's Mini-RF instrument, but the system geometry was optimized for science activities.

c) Relevance to NASA and JPL

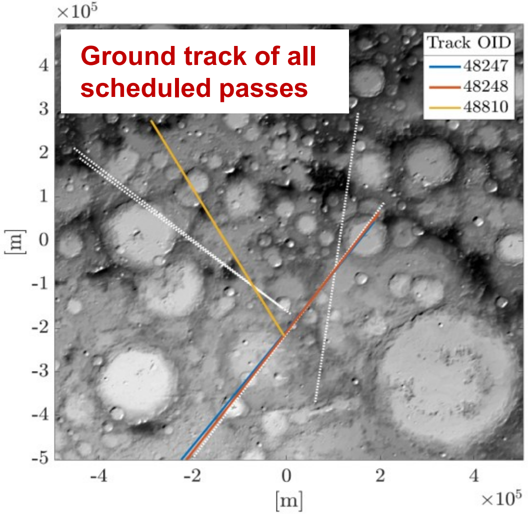
- Obtain measurements of multipath reflections in the downlink direction that are "similar" to those experienced by landed assets.
- Results from this effort have already been used to support VIPER's Preliminary Design Review and are aiding in the communication subsystem design of HLS.
- Tools, expertise and lessons-learned from this effort are being leveraged for the design of the Mars Fetch Rover, which is expected to have tactical passes at low elevation angles.
- The tools developed in this RTD can be used for radio science at the Moon and other solar system bodies.

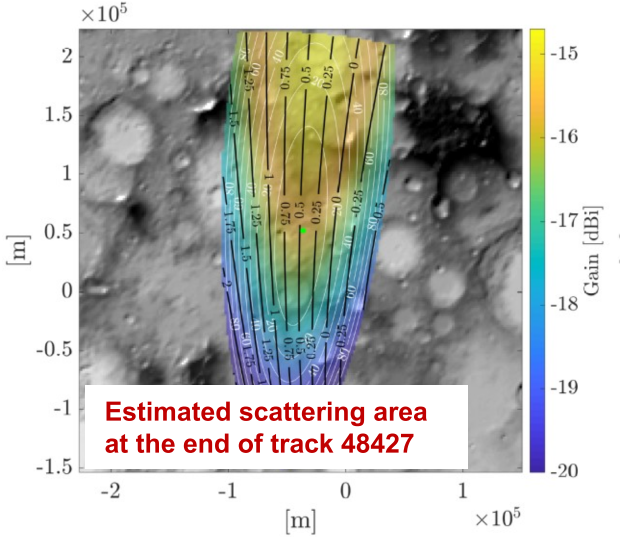
Methodology

a) We schedule multiple DSN passes such that:
   - They record LRO's downlink carrier for ~10 minutes as the spacecraft sets behind or rises from the back-side of the Moon.
   - Preferably sample the same lunar region multiple times.
   - Preferably record the received signal in the co- and cross-polarization.
   - Use an open-loop receiver to record I/Q samples of the received carrier at a rate of 1 kHz, 16 kHz and 16 MHz.

b) After each pass, we reconstruct the system geometry and estimate the scattering properties using the measurements together with:
   - High resolution (5m) digital elevation maps (DEM) of the lunar South Pole from the Lunar Orbiter Laser Altimeter (LOLA) on-board LRO.
   - LRO reconstructed trajectories from NASA's Flight Dynamics Facility.

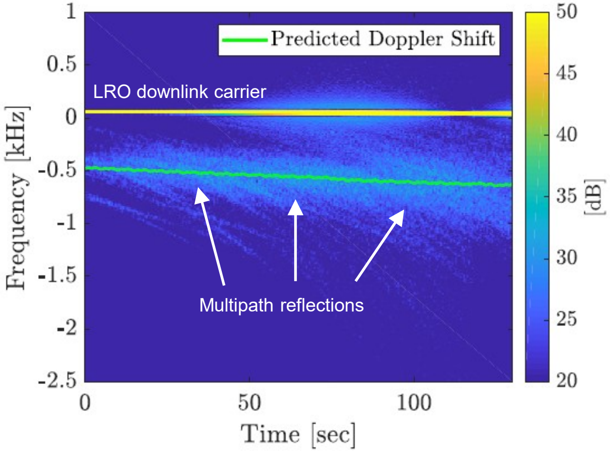
c) Innovation:
   - First opportunistic bistatic radar experiment on the Moon in downlink direction and with very large bistatic angles (approx. 180 deg, surface grazing).



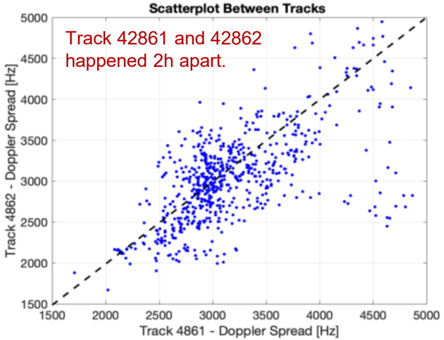


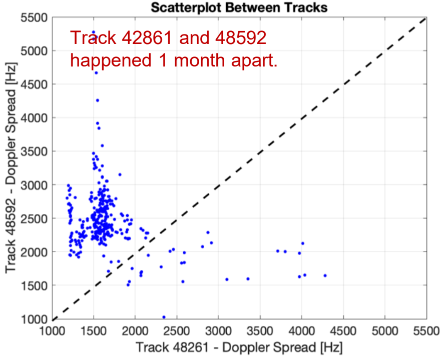
Results

- We have successfully detected multipath reflections in all passes.
- We have successfully validated our approach to predicting Doppler shifts of reflections.
- We are now using the same procedure to estimate the Doppler spread for a link between a rover/lander on the lunar surface and the DSN.

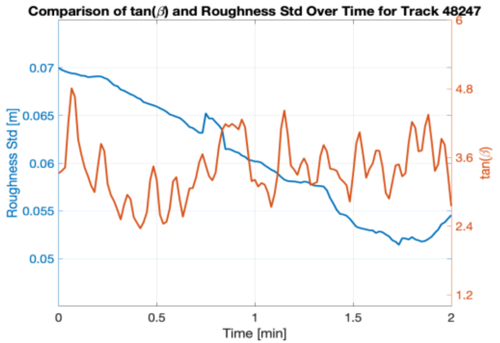


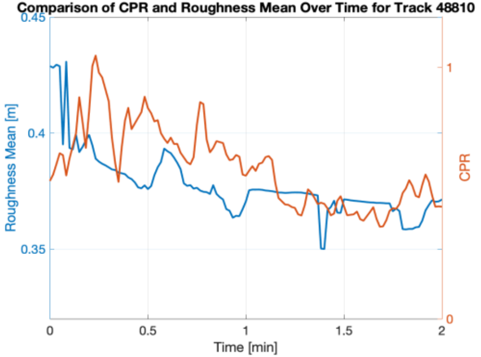
- The scattering signature is consistent across measurements in consecutive orbits.
- Therefore, the scattering signatures contain information about the lunar terrain being sampled.





- Doppler spread and Cross Polarization Ratio (CPR) do not represent surface roughness measured by LOLA altimeter, as wavelength is different.
- Future efforts will focus on characterizing the surface-related signatures observed on the scattered signal.





Publications and References

[1] Marc Sanchez Net, Nereida Rodriguez-Alvarez, Daniel Kahan, David D. Morabito, and Harvey M. Elliott. Multipath Measurements at the Lunar South Pole from Opportunistic Ground-based Observations -- Part I: Experiment Concept. The Interplanetary Network Progress Report, Volume 42-222, pp. 1-22, August 15, 2020. https://ipnpr.jpl.nasa.gov/progress_report/42-222/42-222C.pdf

[2] (Under review) Nereida Rodriguez-Alvarez, Marc Sanchez Net, Daniel Kahan, David D. Morabito, and Harvey M. Elliott. Multipath Measurements at the Lunar South Pole from Opportunistic Ground-based Observations -- Part II: Experiment Results. The Interplanetary Network Progress Report, Volume 42-223, November 15, 2020.

[3] Haynes, Mark S. "Surface and subsurface radar equations for radar sounders." *Annals of Glaciology* (2020): 1-8.

[4] Nozette, Stewart, et al. "The Lunar Reconnaissance Orbiter miniature radio frequency (Mini-RF) technology demonstration." *Space Science Reviews* 150.1-4 (2010): 285-302.