EPSC Abstracts
Vol. 7 EPSC2012-722-2 2012
European Planetary Science Congress 2012

Librations and Tides of the Moon from Same Beam Interferometry of a Lander Network

M. Gregnanin and L. Iess
Dipartimento di Ingegneria Meccanica e Aerospaziale, Sapienza – Università di Roma, Italy

Abstract

Same Beam Interferometry (SBI) is a powerful technique providing very accurate measurements of the differential range of two spacecraft or landers. In the configuration proposed here, it entails the simultaneous tracking of two or more landers from a single ground station in a coherent, two-way mode. The transmitted signals are relayed from the landers back to the ground station, where they are recorded and combined in an interferometric mode to form a differential phase measurement from each lander pair. The observable quantity is proportional to the difference in line-of-sight distance between the landers of a pair and the ground station. In principle, this tracking technique can be applied to network of landers on any solid body of the solar system. Here we consider the case of the Moon. The investigation of the interior of our natural satellite and its rotational dynamics are primary science goals in lunar exploration, which have been addressed by gravity measurements and Lunar Laser Ranging (LLR). However, the tracking accuracy obtained from LLR is limited to few mm [4], while using accurate SBI measurements, enabled by a lander network, accuracies in the order of 0.1 mm are attainable.

1. Introduction

SBI allows the determination of the Moon's physical librations and tides with unprecedented accuracy, with important geophysical implications. For example, the rotational dynamics and tides may reveal the presence of a fluid core and provide its physical characteristics. A fluid core is suggested by the fact that the spin axis of the Moon is not exactly coplanar with the normal to the orbital plane and the Laplace pole, indicating that dissipative processes are at play. The Love numbers h_2 and l_2, controlling the response of the moon to gravity gradients, provide indications about the elastic properties of the lunar crust, mantle, and core against depth.

2. Common mode rejection

The strength of SBI is the combination of very accurate phase measurements (up to a hundredth of the microwave carrier wavelength) with the common mode rejection of all main noise sources. Indeed, media path delays (due to the Earth's troposphere and ionosphere), mechanical deformations of the ground antenna and instabilities of the station's master frequency standard are largely common to all signals and therefore cancel out when the differential phase is formed. Also the relative motion of the Earth and the Moon are rejected. As common dynamics and noise do not appear in the interferometric observable, the interference fringes retain only information about rotation and tides. Preliminary analysis of thr error budget indicates that a measurement goal of 0.1 mm (corresponding to 1/100 of the wavelength at Ka-band) in each differential range is attainable with integration times of only 10-60 s, with a suitable configuration of the radio link. The daily observation time can be limited to 1 hour in order to attain an adequate data set for geophysical interpretation. To give the order of magnitude of the attainable accuracies, assuming a 1000 km separation of the network nodes, a 0.1 mm accuracy in the differential range corresponds to an accuracy of about 10^{-10} rad in the orientation of the Moon. The large differential phase delay from the Earth's troposphere and ionosphere is almost completely cancelled out, due to the small view angle within which the transponders are seen from the ground antenna (~0.0026 rad for a baseline of about 1000 km). The resiliual tropospheric differential delay can be calibrated using pressure measurements at the ground station location, while for the ionosphere a dual frequency link would improve the measurement performances (although a Ka band carrier already reduces the delay by a large factor). Meeting the 0.1 mm requirement using only X-band frequencies is more difficult and a careful assessment is needed.

3. Technological requirements

In order to take maximum advantage from the cancellation effect of the differential measurement, all transponders need to be identical: thus, they should operate at the same frequency and employ the same turn-around ratio. This is best implemented by using CDMA-like signals, which allow the discrimination of the signals by means of a code signature. The crucial requirement of the interferometer is an excellent coherence between the transponders (any relative phase drift would be indistinguishable from a signal) and maximum suppression of noise sources that are not completely rejected. Best performances are attained by adopting digital architectures and Ka-band radio links. Differential phase stability has to be guaranteed for very long periods (the rotational dynamics of the Moon contains signatures from several effects, both astronomical and geophysical, with important time scales running from months, to years and decades). Thanks to a fully digital architecture of the transponders under development for the missions BepiColombo and Juno, the accuracy of 0,1 mm in differential ranging is attainable over time scales of months.

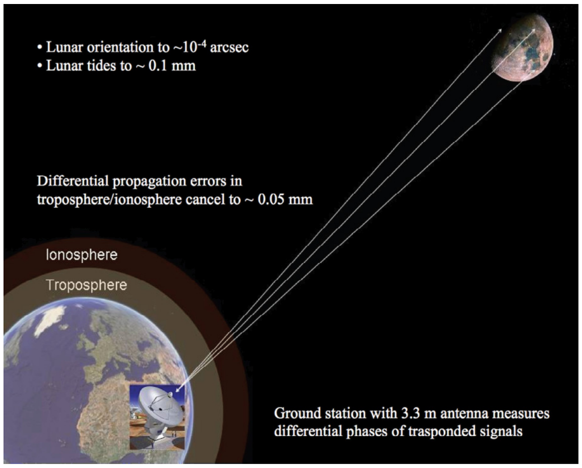

Figure 1: Schematic view of the SBI experiment.

4. Numerical formulation

In the general SBI approach, the mathematical formulation of the differential observable involves the difference between the two-way range to a lander pair. The double precision numerical limit (10^{15}) may affect the calculation of the range difference, introducing relevant numerical noise if the distance from the Earth is large. For this reason, the computed differential observable needs to be adequately formulated. For the Moon, the numerical noise deriving from the straightforward difference between two ranges would be in the order of 0.1 μm, small when compared with the accuracy goal of 0.1 mm. On the other hand, for celestial bodies with distances from the Earth in the order of 10^8 km or more, the magnitude of numerical noise in the differential observable is quite of the same order of the attainable theoretical accuracy, thus limiting the possibility to analyze the data with double precision numeric representation, unless a suitable reformulation of the differential observable is adopted.

5. Observability

A Lunar interferometer operates on a body that is tidally locked with the Earth. For this reason, the separation between tides and rotational dynamics using data from a single landers pair is not straightforward. Indeed, strong correlations arise between estimated parameters. A configuration entailing three landers is needed in order to improve the observability of the parameters of interest. A particularly favorable positioning on the surface entails one lander near the centre of the visible face (for tides), surrounded by three additional landers at the vertices of an equilateral triangle separated by about 1000 km. Other configurations, with only three landers, are also possible and an efficient placement can be studied.

References

[1] Bender, P. L.: Proposed microwave transponders for early lunar robotic landers, Adv. Space Res., Vol. 14, pp. 233-242, 1994.

[2] Fermi, M. et al.: Investigation of the lunar interior with a microwave interferometer, 37th COSPAR Conference, 13–20 July 2008, Montreal, Canada.

[3] Iess, L., Giuliani, S., Dehant, V.: Mars' rotational state and tidal deformations from radio interferometry of a network of landers, Geophysical Research Abstracts, Vol. 14, EGU2012-12664, 2012 EGU General Assembly, 2012.

[4] Murphy T. W. et al.: APOLLO: the Apache Point Observatory Lunar Laser-ranging Operation: Instrument Description and First Detections, Pub. Astron. Soc. Pac., Vol. 120, pp. 20-37, 2008.