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Same Beam Interferometry on Mars for obtaining information on the interior

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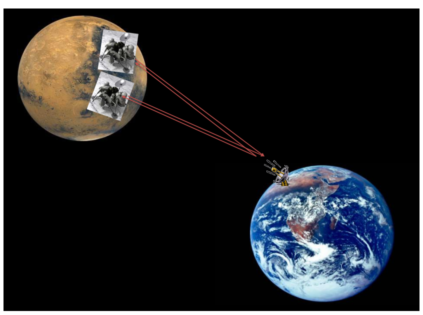
1. Introduction

A mission involving **Mars' landers** will almost certainly envisage a **direct-to-Earth radio system** for tracking telemetry and command. If the mission entails a network of landers, accurate geodesy and geophysics experiments can be enabled by a tracking configuration known as **Same Beam Interferometry** (**SBI**).



SBI was proposed in connection to network of landers for the moon and recently for Mars. The observable quantity is the difference between the phases of a microwave carrier sent simultaneously by an Earth antenna to several Mars landers, equipped with transponders highly stable in frequency. In the differential configuration the path delays due to interplanetary plama, Earth's troposphere and ionosphere cancel out in the differential range, as they appear with nearly identical contributions in both legs. The cancellation does not occur for the Mars atmospheric and ionospheric delays, which however may be kept at a level below 1 mm by suitable calibrations. Preliminary estimates of the error budget indicate an accuracy of about 1 mm at integration times > 60 s in the differential range.

These observations, if available in a future mission, would provide measurements of Mars deformation, rotation and orientation with an unprecedented accuracy. A good determination of tides and rotational state with such an accuracy will allow to focus on interior processes and provide essential constraints for models of the thermal, geochemical, and geologic evolution of Mars.

In this work we show how well SBI measurement can be used to observe Martian precession and nutation and relate these observational accuracies to the internal structure of Mars.

2. The SBI observable

For the purpose of a covariance analysis, the SBI observable can be approximated by the projection of the baseline vector between the 2 landers on the Earth-Mars line of sight. This is almost equivalent to the difference between the 2 ranges between each lander and the Earth.
The error budget of the SBI observable is dominated by differential phase drifts of the transponders and uncertainties in the atmospheric delay corrections in Mars' atmosphere. Because the (much larger) delays in the Earth's troposphere and ionosphere appear as a common noise, they are rejected in the differential measurement. To a large extent, also the delay due to interplanetary plasma is cancelled out. For these reasons the SBI technique is more precise than the traditional Doppler observable. The overall accuracy goal of the SBI measurement at Mars is $\sim$ 1mm.

3. The simulation method

- Rotation model for Mars
- Tidal model for the motion of the landers
- Analytical SBI observable
- Computation of the derivatives of the observable w.r.t the parameters
- Covariance analysis: uncertainty of each parameter and correlations between them using a least square fit

The Martian Orientation Parameters (**MOP**) and the geophysical parameters:

Rotational motion	Simulation parameter	Interior/Atmospheric property
Nutations or 2 transfer function param.	24 nutations amplitudes or F, σ_0 (Free Core Nutation freq.) or λ_0	Size and moment of inertia of the liquid core
Precession rate	$\dot{\psi}$	Moment of inertia of the planet
Irregular rotation rate	4 UT amplitudes (C=Cos, S=Sin, A=Annual, S=Semi-an.)	Atmospheric CO_2 sublimation and condensation process
Polar Motion x_p or y_p component	12 amplitudes (C=Cos, S=Sin, A=Annual, S=Semi-an., C=Chandler frequ.)	Atmosphere

The tidal effect on the lander position:
The Love numbers h_2 and l_2 describe the radial and

horizontal tidal displacements of the surface.
For Mars, for different interior structures:
$0.1 < h_2 < 0.25$ and $0.03 < l_2 < 0.08$ (Van Hoolst et al 2003).

Assumptions of the simulations:
- Gaussian noise on the simulated data with a RMS of 1mm
- 2 or 3 landers → 1 or 3 baselines (separation between the landers between 1700 and 2300 km).
- mission duration of 700 days
- measurements are simulated twice per week, when the Earth is visible

The adjusted parameters are the Martian Orientation Parameters, 2 Love numbers and the initial position of the baseline.
All the other effects on the observable are supposed to be perfectly known.

4. Results

4.1. Sensitivity analysis

We can compute the signatures of the geophysical parameters in the Same Beam Interferometry observable. The liquid core has a signature in the SBI observable of about 10-15cm through the nutations while the rotation angle UT has a large signature of about 3-10 meters.

4.2. Covariance analysis

With a least square analysis, we can find the a posteriori uncertainties and the true errors for each parameter as a function of the numbers of observation and also at the end of the observational time. Configurations with one or 3 baselines have been investiguated.

If there is only a baseline, large correlations between the parameters exist. The correlations between the parameters are smaller when there are 3 baselines with repect to the situation with 1 baseline.

5. Summary

Because the errors on the common line of sight are removed, the Same Beam Interferometry (SBI) technique is more precise than the traditional Doppler observable. The gain is more than one order of magnitude on the range measurements.
The method allows to obtain precession, nutation parameters, polar motion amplitudes, Chandler Wobble period, UT variations and the Love numbers with unprecedent accuracy.
The geometry covered by the use of three baselines (three landers) instead of one (two landers) allows to improve the parameter determination otherwise correlated. It allows to better determine the orientation variations (e.g. factor 2 in the nutation parameters), to converge towards the true values for UT variations, polar motion amplitudes and CW periods.
The baseline positions are obtained as well very accurately. Even the tidal effects on the lander positions ($\sim$ cm) will be above the expected accuracy goal and therefore the Love numbers h_2 and l_2 will be solved for.

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