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Measurement of Phobos librations and tidal surface displacements

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Abstract

In this paper, we assess the precision that can be achieved on the determination of Phobos' libration angles using both Direct-To-Earth (DTE) Doppler (as done in [1] for Mars) and star tracker (ST) measurements. The tidal deformation of Phobos is also evaluated and compared against the estimated precision that can be obtained on the surface displacement by using DTE Doppler data. To do so, we perform numerical simulations based on a least squares fit to simulated DTE and ST data [2].

1. Phobos librational motion

Phobos is in synchronous spin-orbit resonance around Mars. Due to the interaction of its non-spherical dynamical figure [3] with the gravitational field of Mars and due to the variations in its orbital velocity, the constant rotational motion of Phobos is superimposed by physical librations. A recent numerical model [4] of these oscillations in the rotation of the martian moon is used in this study to simulate DTE tracking data and ST data.

2. Libration amplitudes estimates

We show that the librational motion of Phobos can be measured from DTE and ST data with very high precision of 10^{-3} to 10^{-5} degree depending on the period of the estimated signal with respect to the mission duration (see Fig. 1). The short-period libration amplitudes are the most precisely estimated in a very short period of tracking.

The longitudinal libration amplitudes at the orbital period is estimated at the 0.1% level of precision after few days of operation. We point out that this libration at orbital period, while being clearly distinct from the resonance period, will certainly provide the best precision on the relative moment of inertia $\gamma = (B-A)/C$.

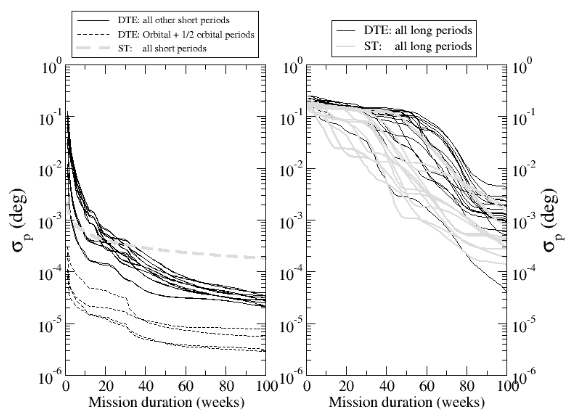

Figure 1: Post-fit uncertainties of librational amplitudes of [4] using DTE and ST measurements.

We find that a precision of 10^{-5} after only 10 weeks of mission duration can be reached.

3. Moment of Inertia (MOI)

Even with such high precision on the relative moment of inertia, it remains challenging to infer the MOI with a precision better than the actual 10% level unless we can also improve our knowledge of Phobos degree-two gravity coefficients. We show that the latter must be determined at the percent level for the MOI to be derived with the precision needed to identify lateral variations in heterogeneities in Phobos' interior.

4. Tidal deformation

Firstly we quantify the diurnal tidal displacement of Phobos' surface using a range of plausible values for Phobos' tidal Love number h_2. For a broad parametric space encompassing a uniform monolithic and elastic solid body to a rubble-pile interior, h_2 ranges between 10^{-7} and 10^{-3}. This means that the position of the

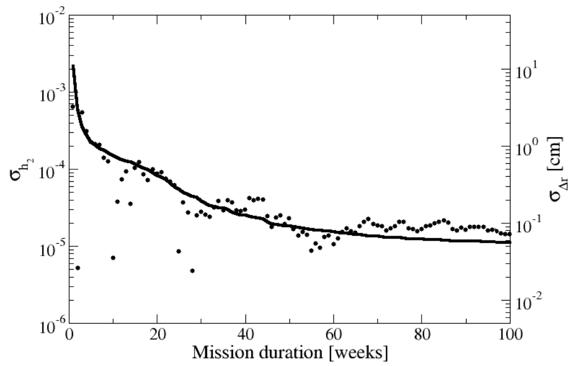

Figure 2: h_2 true errors and uncertainties as a function of mission duration.

lander with respect to the center of mass of Phobos could vary by up to few centimeters over an orbital period if Phobos is a rubble-pile.
Then we determine the precision to which h_2 can be obtained by using DTE Doppler data (see Fig. 2). We find that this precision is better than 10^{-3} after a few days of tracking and reaches a threshold at 10^{-5} after about one Earth's year.

Finally, we find that less than 20 weeks of DTE Doppler data will enable the detection of the tidal surface displacements of Phobos, provided that this moon is a rubble-pile, independently from its composition. Moreover, less than six months of DTE operations will permit us to definitely conclude as to Phobos' rubble-pile nature, providing therefore tight constraint on its origin and evolution [5].

5. Conclusions

This study shows that a lander mission will bring strong constraints on the geophysical properties of Phobos through the estimation of its librations and tidal response. The former will help identify lateral departures of homogeneity, while the latter will reveal the nature of Phobos' interior, as a rubble-pile or a mostly solid body, leading to valuable information about the physical processes prevailing at its origin. This will in turn help address the crucial question of the presence and nature of volatiles inside this Human exploration target.

Acknowledgements

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