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Future geodesy missions using triangular radio links between landers, orbiters, and the Earth.

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Abstract

A vision on future geodesy missions to Mars is discussed with particular focus on furthering our understanding of the interior, rotation, and orientation of this terrestrial planet. We explain how radioscience instruments can be used to observe the rotation and orientation and therewith to study the deep interior of Mars and its global atmosphere dynamics. Transponders in X-band and Ka-band are proposed with radio links between a lander or a rover and an orbiter around Mars and/or directly to the Earth and between the orbiter and the Earth. The radio budget links are studied in the frame of possible mission constraints and simulations are performed, which show that important information on the interior of Mars can be obtained from the radioscience data. From the observation of Mars' orientation in space and of tidal effects on a spacecraft orbiting around Mars we show that it is possible for instance to constrain the dimension and composition of the core, the percentage of light element within the core. The use of the triangle link Earth-lander-orbiter-Earth is examined in that respect.

1. Introduction

The objectives of radioscience missions go from detailed studies of Mars' atmosphere (neutral atmosphere and ionosphere), the determination and analysis of its global mass repartition, the study of the surface properties such as roughness, the study of the subsurface mass repartition, the study of the interior of Mars, to Mars' ephemerides. In this presentation, we will concentrate on the use of Doppler or ranging data for studying Mars' interior and atmospheric global dynamics as determined from Mars' orientation and rotation parameters and from time variations of the gravity field as determined from tracking of orbiting spacecraft.

2. Mars' rotation and orientation variations using a lander

Lander-Earth or lander-orbiter radio links allow observing Mars' rotation rate variations (or length-of-day (LOD) variations, arising from the effect of the CO_2 sublimation and condensation processes), Mars' polar motion (also excited by the atmosphere), and Mars' orientation in space, i.e. precession/ nutation (arising from the gravitational interactions between Mars and the Sun or the other planets of the solar system). Precession and nutations provide fundamental constraints on the properties of Mars' deep interior such as core state, composition, and dimension, while rotation variations or LOD variations provide atmospheric angular momentum changes that are measures of the global dynamics of Mars' atmosphere. In particular the LOD seasonal variations are related to the CO_2 sublimation and condensation cycle in the ice caps and atmosphere. The nutations, i.e. the periodic changes in the orientation of the planet in space, are very interesting as they are amplified when the core is liquid. Different dimensions for the core induce different amplifications. The nutations, if observed with enough precision (at a level of better than a few milliarcseconds (*mas*)), will provide an independent observation of the state of the core and allow to estimate its size; the formation and evolution of Mars will better be constrained. In particular, the resonance period and amplification of the Free Core Nutation (FCN), a rotational normal mode of the planet due to the existence of a liquid ellipsoidal core, depend on the dimension of the core and on the core moment of inertia. This FCN period is close to the ter-annual nutation (229 days); it may be very close if the core is large (FCN period close to 235 days for instance), amplifying this nutation at a very high level, and it may be quite far if the core is small (FCN period close to 263 days for instance). This amplification may thus reach values between almost no amplification (sub-*mas* level; 0.9 mas for instance for a 263 day FCN period) and amplification at the 100% level (10 *mas* level for instance for a 235 day FCN period) or several hundreds of percents (when the FCN is very close to the 229 days of the ter-annual nutation period; e.g. 27 mas for 231 day FCN period); this amplification is quite high as 1 *mas* corresponds to 1.6 cm at the surface of Mars when considering the displacement of the pole in space. From these radioscience observations, it is thus possible to constrain the dimension and composition of the core, the percentage of light element within the core, and therewith to determine the presence of a pressure-induced mineral-phase transition at the bottom of the mantle.

2. Knowledge of the interior of Mars from tidal measurements performed by orbiters

Orbiter-Earth radiolinks can also provide information about the tides and therewith about the deep interior of Mars. The periodic deformations of Mars induced by the gravitational forcing of the Sun and the other planets of the solar system induce changes in the spacecraft orbit dynamics: the change in the gravity field induced by the planet tides is mapped into the orbiter trajectory. This effect is measured through the Love number k_2, i.e. the ratio between the mass redistribution potential induced by the tides to the tidal potential. The value of k_2 depends very much on the interior of Mars and, in particular, if the core is liquid, the planet deforms more in response to the tidal forcing, increasing the value of the Love number k_2. The value of k_2 for a solid core (k_2~0.07) is at the level of about one half of that for a liquid core (k_2~0.15). The precision on the k_2 Love number depends on the precision of the orbit determination. It is however difficult to precisely provide numbers in this case, as it is important to consider the geometry of the orbit of the orbiter; particular orbits are better than others for determining the tidal effects.

From recent radioscience observations of the k_2 tidal Love number, we have good indications that the core is at least partially liquid, which is compatible with the present day thinking of the evolution models of Mars. Presently, the best information about the core is deduced from the effect of Mars tides on the trajectory of an orbiter by tracking the effects of Mars' tides on the trajectory of an orbiter (from the determination of the tidal Love number k_2) and from the precession of the spin axis derived from radio tracking of orbiting and landed spacecraft.

3. Results and simulations

Parts of these results have been recently summarized in a paper that is presently in press in PSS (Dehant et al., 2010). Very detailed studies of the lander-Earth links have been presented in a paper that have been submitted recently (Le Maistre et al., 2010). Models of the interior of Mars from recent observations have been presented by Rivoldini et al. (2010). In particular we have performed simulations for the lander-Earth radio link (see Figure 1) and for the lander-orbiter radiolink.

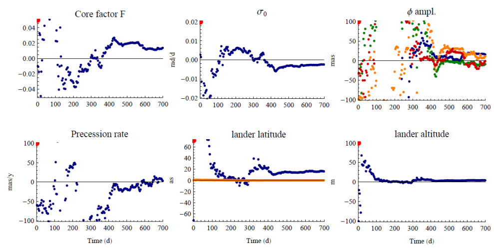

Figure 1: Parameter estimation (FCN amplification factor (F), FCN frequency (σ_0), four amplitudes of cosines and sines in UT seasonal changes (ϕ ampl.), precession rate, and lander coordinates (latitude, longitude, and altitude) as a function of the mission lifetime) for a simulation using a noise level of 0.05mm/s on the Doppler for a direct lander-Earth X-band radio-link.

In the present paper we shall start from these results and we propose to revisit them in the frame of joint usage of the three possible radiolinks involving the Earth, the orbiter, and a lander, or even two landers. To that aim we shall simulate the possible links and examine the performances of these links on the rotation parameters when using them jointly, performing analytical and numerical simulations.

References

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