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Geodesy on GEMS (GEophysical Monitoring Station)

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Abstract

We propose to use the X-band radio link of the GEMS lander on the surface of Mars with the objective to better determine the rotation and interior structure of Mars. This X-band radio link consists in two-way Doppler measurements from a direct radio-link between the Martian Lander and deep space tracking stations on the Earth. On the basis of these measurements, it will be possible to monitor the lander position relative to the Earth and in turn to improve the determination of the Mars' orientation and rotation parameters (MOP), i.e. the rotation rate variations (or Length of Days LOD), the precession rate and the nutations of the rotation axis, and the orientation of Mars around its rotation axis (polar motion). In this study we perform analytical and numerical simulations of these Doppler measurements in order to quantify the precision that can be obtained on the MOP. These simulations permit to build a strategy to be applied to future data processing in order to improve the precision on the MOP determination. As these parameters are related to the interior of the planet as well as to its seasonal angular momentum changes induced by the CO_2 sublimation/condensation process, we further discuss the expected improvement in our knowledge of Mars' interior, i.e. state, size, and composition of the Martian core, and of the CO_2 mass budget in the Martian atmosphere and ice caps.

1. Introduction

The paper presents the concept, the objectives, the approach used, and the expected performances and accuracies of a radioscience experiment based on a radio link between the Earth and the GEMS lander at the surface of Mars, and on the link between the lander and the spacecraft orbiting around mars, and the Earth. This experiment involves radioscience equipment installed on the lander at the surface of Mars. The experiment consists of an X-band transponder that has been designed to communicate directly to Earth from the lander and the other way around. These Doppler measurements will be used to obtain Mars' orientation in space and rotation (precession and nutations, and length-of-day variations). More specifically, the relative position of the lander on the surface of Mars with respect to the Earth ground stations allows reconstructing Mars' time varying orientation and rotation in space.

2. Method

With GEMS radio science observations are integrating the variation of Mars' rotation speed (related to the length-of-day), the orientation of Mars' rotation axis in space (precession and nutation), and the orientation of Mars around its rotation axis (polar motion), by monitoring the Doppler shift due to the motion of Mars relative to the Earth on the radio signal between the GEMS lander and the tracking stations of ESA ESTRACK (ESA TRACKing) network and NASA Deep Space Network (DSN).

For the numerical simulations we used the GINS software implemented by the French space agency (CNES) and further developed at Royal Observatory of Belgium (ROB) for planetary geodesy applications. This software allows simulating the relative motion of the Lander relative to Earth's tracking stations and computes partial derivatives of the simulated 2-way Doppler data with respect to the MOP. We have especially studied the effect of the Doppler noise, of the duration of the tracking period, and of the occurrence of the tracking passes during that period on the MOP determination. As numerical simulations are heavy and computer time consuming, we also perform analytical simulations covering a large amount of cases.

Lander-Earth radio links allow in principal 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 percent (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.

3. Expected results

Of course with one lander only all geophysical parameters cannot be determined precisely. The landing site will determine how well they can be determined. Our simulations will allow determining the strategy for getting a maximum of information.

This paper shows how well radioscience can answer major questions related to the internal structure of Mars, its climate, and the global circulation of its atmosphere. Questions related to the interior of Mars will be addressed using precession and nutation observations while atmospheric questions will be addressed using observations of length-of-day variation.

The radioscience will thus partly be able to characterize the present interior of Mars and, in conjunction with other GEMS Payload instruments, will be able to determine the physical state of the core, the size of the core, the possible existence of an inner core, the core composition and the mantle mineralogy. These parameters are very important for understanding the evolution of Mars. Temperature and mineralogy are the basis for obtaining the profiles of density, thermodynamic parameters (bulk and shear moduli), and the thermal conductivity inside Mars. The mass, moment of inertia, impedances (characterizing the inductive response of the conductive planet), heat flow, and seismic velocities are all based on these interior properties.

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