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Mars rotation and orientation angles from direct to Earth Doppler measurements of the stationary SPIRIT rover.

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Abstract

Doppler measurements between the fixed Spirit rover and Earth ground stations are used to improve estimates of Mars rotation and orientation angles. Since these angles are related to the interior structure of Mars as well as to the dynamic of its atmosphere, Spirit data permit us to better understand the planet Mars. This paper shows the first results obtained on the Mars rotation and Orientation Parameters (MOP) using recent direct to Earth (DTE) Spirit Doppler measurements. Constraints on the physical properties of the planet are also discussed.

1. Introduction

Radio-science data from the Viking landers [4] and Mars Pathfinder [1] have previously been used to study the rotation of Mars. Nevertheless, due to the weaker signal to noise ratio of the Viking landers data (S-band) and due to the short mission life time of Mars Pathfinder (90 days), the precision of the parameters describing the time-dependent rotation of Mars remains too low to precisely constrain the physical parameters involved in Mars' rotation description. These physical parameters are of two kinds, those (describing precession and nutation) related to the deep interior and those (describing the length of day variations and polar motion) related to the atmosphere, in particular the CO_2 seasonal cycle. In the beginning of 2010, NASA has designated the Spirit rover as a stationary science platform after unsuccessful efforts during the past several months to free it from a sand trap. The rover then became an "equatorial fixed station" able to communicate in X-band directly with the ground stations on Earth. Le Maistre et al [3] have shown that such radio tracking data provide an opportunity to improve our knowledge of Mars' interior structure and atmosphere dynamics if the rover stays fixed for more than 300 days on the surface of Mars. In this paper we combine stuck Spirit Doppler data over about 300 days with earlier data to improve the precision on the MOP and better constrain Mars' physical parameters.

2. From DTE Doppler data to MOP estimation

The Spirit "Direct-To-Earth" data consist of 2-way Doppler shift measurements between the rover and an Earth ground station (GS). This frequency shift is a function of the MOP through the "trajectory" of the fixed rover in space (position $\vec{R}_{rover}$ and velocity $\vec{V}_{rover}$), which is driven by the rotation of Mars. Indeed the Doppler measurements Q are induced by the projection of the relative velocity between both antennas (onboard the rover and on the Earth) onto the Earth Line Of Sight (LOS) and can be written as follows:

$$Q = \frac{(\vec{V}_{GS} - \vec{V}_{rover}) \cdot (\vec{R}_{GS} - \vec{R}_{rover})}{\|\vec{R}_{GS} - \vec{R}_{rover}\|}, \quad (1)$$

where $\vec{R}_{GS}$ is the position of the ground station in space and $\vec{V}_{GS}$, its velocity. Therefore, the Spirit data contain information on the MOP which have a contribution to the Doppler above the data noise level (about 0.1mm/s at 10s of integration time). Fig. 1 shows the merged signatures of all these contributions.

2.1. Liquid core contribution on nutation

Recent k_2 Love number solutions obtained from spacecraft data analysis [2] tend to confirme that Mars has a liquid core. This induces a normal mode of Mars called Free-Core-Nutation (FCN) corresponding to a relative rotation of the liquid core and the solid mantle when the instantaneous rotation axes of core and mantle do not coincide. The liquid core modulates the amplitude of the forced nutation Λ_m, depending on the difference between the FCN frequency σ_0 and the forcing frequency σ_m (Fig. 2), according to the following equations:

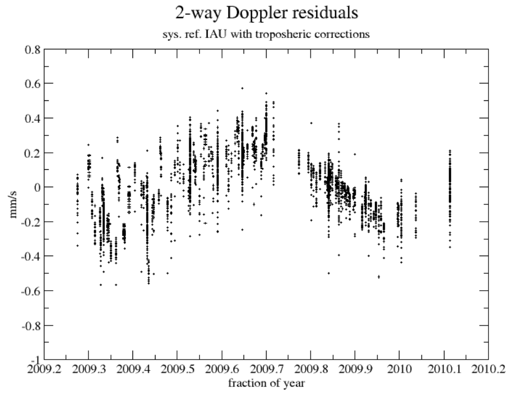

Figure 1: Signature of the MOP on the Spirit data.

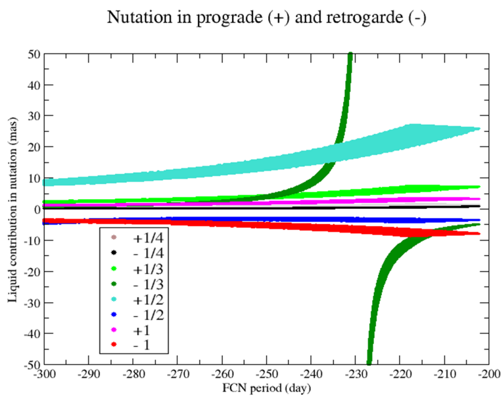

Figure 2: Nutation amplification versus FCN period.

$$\Lambda_m^{'} = \Lambda_m \left(1 + F \frac{\sigma_m}{\sigma_m \pm \sigma_0}\right), \qquad (2)$$

where the primed quantity is the amplitude of nutation for a non-rigid planet and F is the core factor. In order to detect the small signature (Fig. 2) of the liquid core in the Spirit data we need to take into account for its position changes during the data time period.

3. From MOP estimation to physical parameters

In this paper, the determination of the polar moment of interia of the whole planet C is discussed since it can be inferred from the precession rate $\dot{\psi}$ [1]. We also discuss the interior model parameters that can be constrained from nutations as determined from the Spirit Doppler data. Indeed, since the nutation parameters F and σ_0 depend on the core moment of inertia A_f and on its dynamical flattening e_f [3], and since these parameters depend in turn on core size and figure, and on the density distribution inside the planet, Spirit can provide constraints on the density and size of the core as well as on the density of the shell. Moreover, Mars rotation variations determination from Spirit data allows us to better understand the seasonal mass redistribution of Mars, mainly induced by the CO_2 sublimation/condensation process between the atmosphere and the solid body.

4. Summary and Conclusions

After Spirit became embedded into soft sand it provides an opportunity to improve our knowledge on the deep interior of Mars since this can be done *only* with a stationary vehicle. However, a minimum of 300 days of radio-tracking is needed to estimate long-term motion (as those characterizing the variations in rotation and orientation of Mars) with an accuracy of a few milli-arcsecond. This requires to take into account every position changes operated to free Spirit from the sand. Even if more data are needed to reach the precision required to be conclusive, this study shows that such an experiment, involving an X-band radio link between a lander and a ground station on Earth, offers a real chance to better understand the planet Mars.

References

[1] W. M. Folkner, C. F. Yoder, D. N. Yuan, E. M. Standish, and R. A. Preston. Interior Structure and Seasonal Mass Redistribution of Mars from Radio Tracking of Mars Pathfinder. *Science*, 278:1749–+, December 1997.

[2] A. S. Konopliv, S. W. Asmar, W. M. Folkner, Ö. Karatekin, C. Nunes, D., S. E. Smrekar, C. F. Yoder, and Zuber M. T. Mars high resolution gravity fields from mro, mars seasonal gravity, and other dynamical parameters. *Icarus*, 2010.

[3] S. Le Maistre, P. Rosenblatt, A. Rivoldini, V. Dehant, and J-C. Marty. Lander radio science experiment with a direct link between mars and the earth. *Icarus*, submitted, 2010.

[4] C. F. Yoder and E. M. Standish. Martian precession and rotation from Viking lander range data. *Journal of Geophysical Research Planets*, 102:4065–4080, 1997.