EPSC Abstracts
Vol. 12, EPSC2018-1238-1, 2018
European Planetary Science Congress 2018

Mars nutation estimates from radio-tracking of landed missions prior to InSight and ExoMars 2020

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1. Introduction

We analyse the complete data set of Doppler tracking data ever acquired from the surface of Mars in order to see whether the liquid core signature in the nutation signal can be observed. This study also allows us to refine and validate our data processing chain and software that will be used to process the forthcoming InSight-RISE and ExoMars 2020-LaRa measurements.

2. Historical data

All rover and lander Doppler tracking data available so far from a fixed point on the surface of Mars are combined in order to determine the Mars rotation and Orientation Parameters (MOP), and especially the nutation parameters. The characteristics of the different mission tracking datasets used in this study are summarised in Table 1.

Table 1: 2-way Doppler data points at 60-s of integration time used in the Mars rotation and orientation solutions presented here. The approximative accuracy in the last column corresponds to the standard deviation of 2-way residuals obtained at first iteration with the rotation model of [1].

rover/lander mission	Begin time, dd-mm-yy	End time, dd-mm-yy	time span dur. [day]	Nb of kept/total 2-way Doppler	Approx. acc. [mm/s]
Viking lander1	21-07-76	30-12-78	892	13144*/15030	2*
Pathfinder	04-07-97	07-10-97	95	6950/7315	0.1
Stuck Spirit	26-03-09	24-02-10	335	231/250	0.2
Fixed Spirit	29-05-09	07-11-09	162	105/118	0.17
Opportunity	02-01-12	04-05-12	123	1303/1373	0.07

The tracking of the Mars Exploration Rovers has been acquired at different epochs in the Martian year with respect to the previous X-band tracking of the surface provided by *Mars Pathfinder*. As shown on Fig. 1, the now available distribution of X-band tracking data is favorable to the observation of seasonal variations in the Martian rotation and orientation such as nutation signatures introduced by a liquid core.

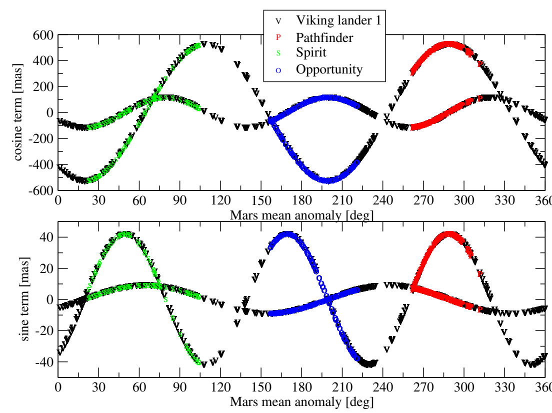

Figure 1: Data repartition along Mars nutations semi (top) and ter-annual (bottom) signals.

To analyse the different sets of radio-science data we use the software package "Geodésie par Intégrations Numériques Simultanées (GINS)" developed at the Centre National d'Etudes Spatiales (CNES) and adapted for use in planetary geodesy applications at the Royal Observatory of Belgium (ROB).

3. Mars rotation and orientation parameters

The MOP considered in this analysis are $\dot{I}$ the secular change in the Mars obliquity and $\dot{\psi}$ is the precession rate of Mars spin axis, the sine amplitudes, I_m^s, ψ_m^s, and cosine amplitudes, I_m^c, ψ_m^c, of the nutation in obliquity and longitude and the amplitudes of the seasonal variations of the spin angle, $\phi_m^{c,s}$. Subscripts m denotes the harmonics of Mars orbital periods (e.g. m=1 is the annual period of 687 Earth days).

Table 2: Summary of Mars rotation parameters solutions from various authors and datasets. The uncertainties of our solutions are about 3 times the formal errors. [a] Starting with $F = 0.07$ and $\sigma_0 = -240$ days.

Rotation parameter	Konopliv et al. (2016) MRO120D (All)	Kuchynka et al. (2014) FIT A (rover/lander)	This study trans. func.[a]	This study amplitude
$\dot{I}$ [mas/yr]	-2 ± 1.1	-3 ± 4	-3.5 ± 5	-5 ± 4
$\dot{\psi}$ [mas/yr]	-7608.3 ± 2.1	-7619.5 ± 6.4	-7619 ± 7	-7616 ± 8
ϕ_{c_1} [mas]	481 ± 10	489 ± 16	492 ± 11	477 ± 14
ϕ_{c_2} [mas]	-103 ± 9	-126 ± 14	-121 ± 9	-113 ± 18
ϕ_{c_3} [mas]	-35 ± 8	-20 ± 12	8 ± 7	65 ± 39
ϕ_{c_4} [mas]	-10 ± 6	-1 ± 7	-14 ± 3	-18 ± 9
ϕ_{s_1} [mas]	-155 ± 12	-231 ± 20	-160 ± 6	-160 ± 18
ϕ_{s_2} [mas]	-93 ± 8	-87 ± 14	-64 ± 20	-93 ± 15
ϕ_{s_3} [mas]	-3 ± 7	2 ± 9	3 ± 15	-36 ± 30
ϕ_{s_4} [mas]	-8 ± 6	-26 ± 8	14 ± 8	24 ± 9
I_1^c [mas]	46.1 (fixed)	46.1 (fixed)	46.1 (fixed)	43.4 ± 10
I_2^c [mas]	-514.8 (fixed)	-514.8 (fixed)	-514.8 (fixed)	-530 ± 9
I_3^c [mas]	-105.8 (fixed)	-105.8 (fixed)	-105.8 (fixed)	-167 ± 9
I_1^s [mas]	15.8 (fixed)	15.8 (fixed)	15.8 (fixed)	14 ± 12
I_2^s [mas]	6.4 (fixed)	6.4 (fixed)	6.4 (fixed)	7.6 ± 3
I_3^s [mas]	38.6 (fixed)	38.6 (fixed)	38.6 (fixed)	-22 ± 10
ψ_1^c [mas]	-242.7 (fixed)	-242.7 (fixed)	-242.7 (fixed)	-248 ± 18
ψ_2^c [mas]	-41.2 (fixed)	-41.2 (fixed)	-41.2 (fixed)	-40 ± 8
ψ_3^c [mas]	-85.65 (fixed)	-85.65 (fixed)	-85.65 (fixed)	117 ± 25
ψ_1^s [mas]	-497 (fixed)	-497 (fixed)	-497 (fixed)	-476 ± 35
ψ_2^s [mas]	-1129.5 (fixed)	-1129.5 (fixed)	-1129.5 (fixed)	-1166 ± 5
ψ_3^s [mas]	-227.3 (fixed)	-227.3 (fixed)	-227.3 (fixed)	-324 ± 60
F	0.07 (fixed)	0.07 (fixed)	0.04 ± 0.035	N/A
σ_0 [days]	-240 (fixed)	-240 (fixed)	-248 ± 10	N/A

A fluid core modifies the nutation amplitudes according to the following equations:

$$I'_m = I_m \left(1 + F \frac{\sigma_m^2}{\sigma_m^2 - \sigma_0^2}\right) + \psi_m \left(\sin I_0 \, F \frac{\sigma_m \sigma_0}{\sigma_m^2 - \sigma_0^2}\right), \quad (1)$$

$$\psi'_m = \psi_m \left(1 + F \frac{\sigma_m^2}{\sigma_m^2 - \sigma_0^2}\right) + I_m \left(\frac{F}{\sin I_0} \frac{\sigma_m \sigma_0}{\sigma_m^2 - \sigma_0^2}\right),$$

where σ_m are the Mars suborbital frequencies and F, the core momentum factor, and $\sigma_0 = 1/T_{FCN}$, the Free-Core-Nutation (FCN) frequency, are two nutation parameters (also estimated here), which enter in the nutation transfer functions (in brackets in the previous equations).

The MOP solutions obtained in the present study are summarised in Tab. 2 and compared to the solutions found in the literature [2, 3].

4. Nutation estimates

The range of FCN period (T_{FCN}) that we estimate is confined in [-225,-290] days as clearly shown on Fig. 2. Considering only the nominal solutions (magenta) starting from $F = 0.07$ and $T_{FCN} = -240$ days (grey circle) as proposed in the literature [4], we obtain $T_{FCN} = -248 \pm 10$ days and $F = 0.04 \pm 0.035$, which is in very good agreement with the FCN period that can be inferred from the measured tides (e.g. Rivoldini et al, this meeting) .

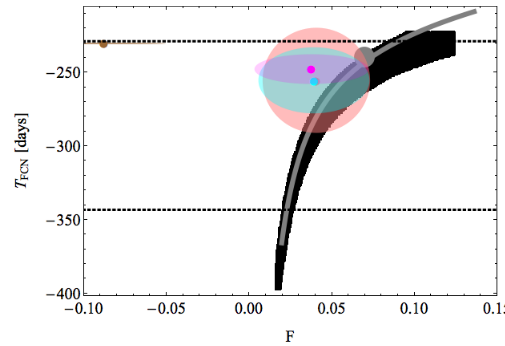

Figure 2: FCN period (T_{FCN}) solutions as a function of the core momentum factor (F) solutions for four different *a priori* values. Solutions have been obtained starting from: $F = 0.1$ and $T_{FCN} = -232$ days (brown), $F = 0.07$ and $T_{FCN} = -240$ days (magenta), $F = 0.06$ and $T_{FCN} = -250$ days (cyan) and $F = 0.055$ and $T_{FCN} = -260$ days (pink). The allowed range of theoretical pairs of F and T_{FCN} is in black (assuming Mars core in hydrostatic equilibrium). Grey line shows the relation between F and T_{FCN} for a rigid planet.

5. Conclusions

- We provide new estimates of the Mars rotation parameters based on the tracking of the all historical landed missions.
- The liquid core contribution in nutation is difficult to extract from the available data with a sufficient precision to constraint interior models of Mars.
- The measurements that will soon be acquired by RISE (NASA InSight) and LaRa (ESA ExoMars 2020) will definitely provide new constraints on the deep interior of Mars from the accurate determination of its liquid core contribution in the nutation.

References

[1] A. S. Konopliv et al. 2011, *Icarus*, 211:401–428

[2] P. Kuchynka et al. 2014, *Icarus*, 229:340–347

[3] A. S. Konopliv et al. 2016, *Icarus*, 274:253–260

[4] W. M. Folkner et al. 1997, *Science*, 278:1749–1751

This work was financially supported by the Belgian PRODEX program managed by the European Space Agency in collaboration with the Belgian Federal Science Policy Office.