EVOLUTION OF INPOP PLANETARY EPHEMERIDES

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ABSTRACT The last version of the planetary ephemerides developed at the Paris Observatory and at the Besançon Observatory is presented here. INPOP08 is a 4-dimension ephemerides since it provides to users positions, velocities of planets and relation between TT and TDB. Investigations leaded to improve the modelling of asteroids are described as well as the new sets of observations used for the fit of INPOP08. New observations provided by the European Space Agency (ESA) deduced from the tracking of the Mars Express (MEX) and Venus Express (VEX) missions are presented as well as the normal point deduced from the Cassini mission. We show the huge impact brought by these observations in the fit of INPOP08, especially in term of Venus and Saturn orbits, Sun oblateness adjustment and PPN parameter β estimations.

1. INTRODUCTION

Since INPOP06 (Fienga et al. 2008), several improvements were brought to the planetary ephemerides developed at the Paris Observatory and at the Besançon Observatory. First, we now integrate at each step the TT-TDB relation defined by IAU 2006. Such integration makes the planetary ephemerides and TT-TDB totally consistent. INPOP08 can then be seen as the first 4-D planetary ephemerides (Klioner 2008). Besides this time-scale aspect, new independent constraints for asteroid modelling were established. New data are used in the fit of INPOP08. These new data are Cassini normal points of Saturn and MEX and VEX tracking observations provided by ESOC.

2. TT-TDB AND ASTEROID MODELLINGS

2.1 TT-TDB

As defined by IAU 2006, TT is such as

$$TT = TCB - L_G.(JD_{TCG} - T_0), \tag{1}$$

and TDB is such as

$$TDB = TCB - L_B.(JD_{TCB} - T_0) + TDB_0. \tag{2}$$

So estimating TT-TDB is equivalent to integrate at each step of the integration of the equation of planet motion:

$$\begin{cases} TT - TDB = F(TDB) \\ \dfrac{dF}{dTDB} = f(\vec{x}, \dot{\vec{x}}, \ddot{\vec{x}}, \mu, \beta, \gamma, c^2, c^4) \end{cases} \tag{3}$$

with TDB_0 estimated at T_0.

Such integration is implemented in INPOP08 and we then can provide to users positions and velocities of planets as well as the differences between TT and TDB as defined in the IAU 2006 recommendations. Such differences are provided under the form of Chebychev polynomials as positions and velocities of planets. Adjustment of INPOP08 is done by using the new TT-TDB relation as estimated during the integration of INPOP planet equations of motion. As no differences are noticeable in the residuals estimated using the Fairhead and Bretagnon (1990) relation or the INPOP08 relation, no iteration is necessary in the estimation of the TT-TDB.

Table 1: Residuals obtained from INPOP06 and INPOP08

Planet	Type of Data [unit]	Nbr	INPOP06 1σ	INPOP08 1σ
Saturn Cassini	ra [mas]	31	11	4
Saturn Cassini	de [mas]	31	10	7
Saturn Cassini	range [m]	31	1851	21
Venus	VLBI [arcsec]	18	0.003	0.003
Venus	range [m]	488	1400	1400
Venus Vex	range [m]	10768	174.829	3.194
Mars MGS	range [m]	10410	3.70	1.371
Mars MEX	range [m]	4704	15.40	1.998
Mars Path	range [m]	90	7.633	7.647
Mars Vkg	range [m]	1245	17.396	19.916
Mars	VLBI [arcsec]	44	0.000	0.001

2.2 ASTEROID MODELLINGS

We have studied individual accelerations on Earth-Mars distances induced by about 25000 known asteroids (ASTORB/Tesdesco et al. 2005 /SIMPS). ¿From there, we have shown that after 300 asteroids, the effects can be averaged and represented by a ring. We have estimated by Monte Carlo simulations on albedo errors, than the mass of this ring is $GM_{ring} = (0.34 \pm 0.1).10^{-10}\ M_{\circ}$ at 3.14 AU . This study gives new independent constraints for asteroids in INPOP because the mass of this ring is obtained independently from the planetary ephemerides. We also stress that such independent constraints help for the Sun oblateness J2 determination because the effects of the asteroid ring and the Sun J2 have very similar impact on the inner planet distances to Earth. For more details, see Kuchynka et al. (2008) in the same volume.

3. MEX,VEX AND CASSINI NEW DATASETS

Cassini normal points are the first tracking data about Saturn. They are synthetic observations deduced from the navigation tracking of the Cassini spacecraft orbiting the Saturn satellite system. These observations are synthetic is the sense that they are estimated after the adjustment of the Saturn satellite orbits to Cassini tracking data. We then have to deal with differences in Earth-Saturn distances, geocentric angles between DE405 and synthetic positions of Saturn deduced from Cassini tracking. These observations have a few meter and few milliarcsecond (mas) accuracy. This accuracy has to be compared to the 100 mas accuracy of optical observations used to fit the planetary ephemerides. Thanks to these data, a huge improvement in the Saturn orbit was done as one can see on table 1.

The VEX data are the first Venus observations since Magellan (VLBI) in 1994. They are deduced from the tracking data of the VEX spacecraft orbiting Venus. They are provided by ESOC navigation team and they are one-way range residuals of the VEX probe after accurate determination of its orbit. The remaining signature in such residuals is induced by systematic errors in the Venus orbit itself (see for instance red curve on figure 1). The VEX data have a few meter accuracy compared to about 1 km accuracy of direct range used to fit INPOP06. The improvement of the Venus orbit is very important as one can see on table 1 and on figure 1. Before VEX, the orbit of Venus was accurate of about 200 m thanks to 18 VLBI Magellan data (1994). With VEX, Venus orbit has a few meter accuracy over the VEX time interval.

The MEX data are the first data with VEX tracking one-way range provided by ESOC from navigation processes. The MEX dataset represents now 30 % of the Mars INPOP08 dataset. They are the same level of accuracy that the MGS and Mars Odyssey data provided by JPL. With the MEX data, we have been able to test the correlation between the JPL navigation procedures and the adjustment of the planetary ephemerides used by the same navigation softwares. The fact that the MEX observations provide the same type of residuals as the JPL MGS and MO do tells us that no systematic effects are introduced in the JPL reduction procedures. Furthermore, in a more political point-of-view, the MEX data and the VEX data are a unique chance for European teams to develop fully independent planetary ephemerides.

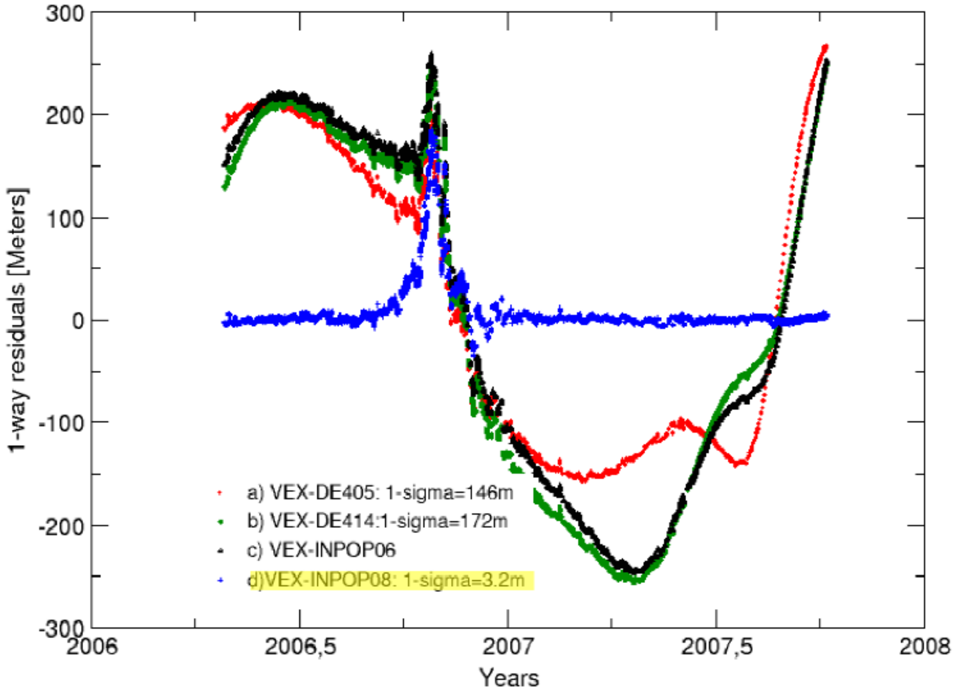

Figure 1: VEX 1-way residuals with the new INPOP08 fitted to VEX and MEX data, and other ephemerides not fitted on VEX observations (INPOP06, DE405, DE414). The solar conjunction is clearly identified with the pick of residuals in October 2006.

4. RESULTS

As it is described previously, the new data used in INPOP08 fitting procedure bring a lot of improvement in the estimation of the planet orbits. Besides these improvements, 33 asteroid masses as well as Earth-Moon ratio, Astronomical Unit, Sun J2 and PPN parameter β are estimated. The most important fitted parameters are presented on table 2. As Venus is 7 times more sensitive to general relativity than Mars, the use of the new VEX data allow to decorrelate the J2 and the PPN β with a good accuracy. Tests of sensitivity of the most accurate datasets (Mercury range, Mars tracking, VEX tracking, Saturn Cassini normal points) to the determination of the Sun J2 and PPN β have been done. They show that the most sensitive data are the Mars and VEX tracking data because even if the two planets are less sensitive to J2 and β than Mercury, their tracking observations are far more accurate than the Mercury direct range. Furthermore they indicate a limit of $|1-\beta| < 5.10^{-4}$: if β is such as $|1-\beta| > 5.10^{-4}$, then residuals of MGS, MEX and VEX are changed significantly. However if β is such as $|1-\beta| < 5.10^{-4}$, then no modification in the residuals are noticeable. We can then conclude than INPOP is not sensitive to β upto $|1-\beta| < 5.10^{-4}$.

5. REFERENCES

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Table 2: Physical parameters fitted in INPOP08. Other values deduced from planetary ephemerides are presented for comparisons.The given uncertainties are given at 5-sigma for the GMs and 1 formal sigma for others. NC stands for non-considered and NE as non-estimated. For AU, the presented values are the differences in meters between the fitted values and the AU value of the IERS conventions 2003, AU_{IERS03} = 149597870.691 km.

	Unit	DE414	DE421	INPOP06	INPOP08
Mass of Ceres	$10^{-10} M_\odot$	4.699 ± 0.028	4.685	4.756 ± 0.020	4.658 ± 0.045
Mass of Vesta	$10^{-10} M_\odot$	1.358 ± 0.016	1.328	1.348 ± 0.015	1.392 ± 0.015
Mass of Pallas	$10^{-10} M_\odot$	1.026 ± 0.028	1.010	1.025 ± 0.005	1.076 ± 0.010
Mass of Juno	$10^{-10} M_\odot$	0.149 ± 0.015	0.116	NE	0.075 ± 0.015
Mass of Iris	$10^{-10} M_\odot$	0.060 ± 0.010	0.060	0.058 ± 0.005	0.050 ± 0.010
Mass of Bamberga	$10^{-10} M_\odot$	0.047 ± 0.007	0.048	0.046 ± 0.003	0.056 ± 0.004
Mass of Ring	$10^{-10} M_\odot$	3.12 ± 0.27	NE	0.34 ± 0.1	1.0 ± 0.3
Distance of Ring	UA	2.8	NE	2.8	3.14
Density of the C class		1.62 ± 0.07	1.09	1.56 ± 0.02	1.54 ± 0.07
Density of the S class		2.08 ± 0.19	3.45	2.18 ± 0.04	1.94 ± 0.14
Density of the M class		4.32 ± 0.37	4.22	4.26 ± 0.12	4.98 ± 0.50
Sun J2	10^{-7}	2.34 ± 0.49	2.0	2.46 ± 0.40	1.82 ± 0.47
EMRAT		81.300568	81.300569	NE	81.300540 ± 0.00005
$AU-AU_{IERS03}$	m	8.62	8.62	NE	8.22 ± 0.11