EFFECTS OF ASTEROIDS ON THE ORBITAL MOTIONS OF TERRESTRIAL PLANETS

S. ALJBAAE, J. SOUCHAY
Observatoire de Paris - SYRTE
e-mail: safwan.aljbaae@obspm.fr

ABSTRACT. The perturbations from the largest ∼300 asteroids which were taken into account in the ephemerides DE403 (Standish et al. 1995), EPM98 (Pitjeva 2001), and INPOP08 (Fienga et al. 2009) are a major problem in the construction of theses ephemeris. Therefore, it looks important to evaluate of the individual effects of largest asteroids of the solar system on the orbits of the terrestrial planets (Mercury, Venus, Earth and Mars) because these effects could reach a few kilometers in several decades in the case of Mars. This is the purpose of this work. For that our methodology consists in several stages:

- ⋆ A numerical integration of the orbits of the planets at short and long time scales with and without the disturbing asteroid from which we want to know the effects.
- ⋆ A determination of the signal representing the effects, by simple substraction.
- ⋆ The analysis of the signal by the method of FFT (Fast Fourier Transform);
- ⋆ The adjustment of the signal by a set of sinusoids determined in the previous step.

We analyze in detail the influences of 43 among the largest asteroids on the six orbital elements a, e, i, Ω, $\tilde{\omega}$ and λ of Mercury, Venus, the EMB (Earth-Moon barycenter) and Mars. In addition we study their influence on two fundamental parameters: the distance and the orientation vector from the EMB to each of the terrestrial planets. This type of study is interesting in many fields, such as planetary ephemerides, as well as space navigation, to understand better the effects of each asteroid taken individually on the terrestrial planets. Note that this type of study is a continuation of previous ones (Williams, 1984; Mouret et al. 2009).

1. INTRODUCTION

The motion of a given planet around the Sun can be considered at first approximation as a Keplerian motion perturbed by the other planets and the small bodies of the solar system. Each of these perturbations must be treated either analytically or numerically, and can be measured as a change of the planet's osculating orbital elements ($a, e, i, \Omega, \varpi = \Omega + w$ and $L = \varpi + M$) determined from the perturbing function $\Re$, according to the Lagrange formula. The corresponding analytical developments of the perturbing function $\Re$ as a function of the orbital elements of the two bodies considered are particularly complex. On the contrary it is easy to use the numerical integration (Runge-Kutta of the 12th order), in computing the 9-body problem (without asteroids), then of the 10-body problem (with the given asteroid). Then we determine the effect of the asteroid considered on each orbital parameter of the planet studied by simple subtraction of the two signals. We focus our efforts in performing the frequency analysis of the data, using fast Fourier transform (FFT) to determine the leading frequencies. At last we carry out a nonlinear regression in which the differential data are modeled by the least-square method following an equation of the type: $F(t) = a_o + a_1 t + a_2 t^2 + \sum_{i=1}^{N} A_i \sin(f_i t) + B_i \cos(f_i t) + C_i t \sin(f_i t) + D_i t \cos(f_i t)$

We have also calculated the individual effects of the leading asteroids on the Earth-Moon distance, showing that they are quite larger than the level of precision of the LLR (Lunar Laser Ranging), and the individual influences of each asteroid on the distance from the EMB to each terestial planet and their orientation vector as seen from the EMB, which are very important parameters in space navigation and astrometry. Below, we present below an example of our results which consists in tables with the Fourier and Poisson components for the perturbations of the orbital elements of each terrestrial planet due to each asteroid, and the corresponding curves (the initial signal, the adjustment determined by our FFT analysis and the residuals). In each case (planet, astroid, orbital element) we find that our fit is satisfactory, since the post-fit residuals are significantly lower than the original signal.

2. RESULTS

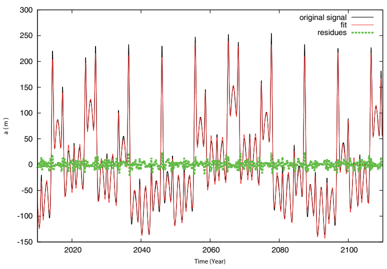

Figure 1: Influence of Ceres on Mars semi major axis (in red)

BIAS : 0.137559 $\times 10^{+2}$
LINEAR : -0.377681 $\times 10^{-2}$
T^2 : 0.333290 $\times 10^{-5}$

PERIOD (Day)	PERIOD (Year)	SIN $\times 10^0$	COS $\times 10^0$	$\times 10^0$	T SIN $\times 10^{-4}$	T COS $\times 10^{-4}$	$\times 10^{-3}$	amplitud $\times 10^1$	Asteroid
27960.94	76.55	2.644	2.158	3.413	0.291	- 3.054	0.432	0.563	1_ Ceres
16191.36	44.33	- 54.282	- 53.165	75.981	67.182	62.329	8.815	5.757	1_ Ceres
4886.42	13.38	- 1.227	9.966	10.042	2.164	- 13.844	1.958	0.691	1_ Ceres
3754.72	10.28	15.277	57.810	59.794	- 9.105	- 0.557	0.079	5.954	1_ Ceres
3047.01	8.34	- 16.680	- 0.495	16.687	7.171	0.221	0.031	1.542	1_ Ceres
1877.01	5.14	24.877	16.008	29.582	- 20.336	- 10.365	1.466	2.495	1_ Ceres
1251.31	3.43	8.691	- 0.233	8.694	- 10.205	0.628	0.089	0.671	1_ Ceres
1161.51	3.18	6.924	- 12.634	14.407	6.635	2.299	0.325	1.484	1_ Ceres
887.06	2.43	3.562	- 39.634	39.793	14.293	19.194	2.714	3.622	1_ Ceres
717.51	1.96	- 5.645	- 11.862	13.136	9.587	5.867	0.830	1.149	1_ Ceres
687.06	1.88	- 3.017	- 0.612	3.078	1.168	- 1.459	0.206	0.304	1_ Ceres
602.38	1.65	- 4.163	- 2.346	4.779	6.308	0.588	0.083	0.316	1_ Ceres
580.76	1.59	- 43.229	24.966	49.921	- 13.036	- 34.487	4.877	4.935	1_ Ceres
502.95	1.38	- 11.922	15.858	19.840	- 7.375	- 15.356	2.172	1.844	1_ Ceres
443.53	1.21	- 0.836	8.157	8.199	- 5.500	- 8.805	1.245	0.669	1_ Ceres
408.23	1.12	11.695	- 37.093	38.893	- 56.454	184.861	26.143	1.956	1_ Ceres
396.66	1.09	1.263	2.717	2.996	- 3.399	- 2.282	0.323	0.215	1_ Ceres
387.17	1.06	19.798	0.132	19.798	- 3.570	24.294	3.436	2.008	1_ Ceres
350.98	0.96	9.686	- 4.009	10.483	- 0.729	12.473	1.764	0.962	1_ Ceres
320.97	0.88	3.050	- 3.512	4.652	0.594	5.911	0.836	0.402	1_ Ceres
314.71	0.86	4.284	2.959	5.207	- 5.783	3.139	0.444	0.473	1_ Ceres
AMPLITUDE	Before= 409.294276			After= 57.641405					

Table 1: Influence of Ceres on Mars' semi major axis. Decomposition in Fourier and Poisson series

	asteroide	Δa [m]	$\Delta e \times a_{Mars}$	Δi ["] $\times 10^{-6}$	$\Delta\Omega$ ["] $\times 10^{-6}$	$\Delta\varpi$ ["] $\times 10^{-6}$	$\Delta\lambda$ ["] $\times 10^{-6}$
1	Ceres	385.99973	1018.25341	837.97915	37190.92552	16391.84563	19419.20264
2	Pallas	193.24460	413.14399	441.88830	12173.16362	3700.64524	18125.33458
3	Juno	29.79749	47.96241	35.77520	869.55154	430.40624	3198.86497
4	Vesta	404.55975	1636.34551	586.32212	8301.55218	14585.61346	64574.80064
6	Hebe	61.28165	319.84333	74.70642	1275.36428	2971.28411	4854.97680
7	Iris	63.86719	135.36684	10.91732	972.29642	1218.83655	1869.09102
8	Flora	22.17044	65.30294	27.75361	131.25152	362.96686	2024.49401
9	Metis	66.42932	218.60586	11.70010	876.90488	2098.95546	2956.91830
10	Hygiea	40.41443	244.13825	38.31212	1254.45965	2798.38321	2998.78852
11	Parthenope	7.79214	51.54678	7.89198	42.35986	505.50615	464.19872
13	Egeria	11.49283	23.51995	6.00169	1626.31059	361.99825	619.36587
14	Irene	12.16370	21.63927	13.84427	483.07604	271.56248	1050.89770
15	Eunomia	22.84708	71.25421	64.06555	1315.85795	470.31980	2029.37351
16	Psyche	6.99493	21.21170	9.41352	229.74675	161.67922	645.65713
17	Thetis	2.17981	7.78699	2.12143	5.41765	68.21111	219.80180
18	Melpomene	6.50754	13.38326	14.99738	180.46621	105.09344	119.62906
19	Fortuna	25.64017	117.05157	1.45028	241.74259	1004.49811	6000.85764
20	Massalia	43.15692	87.96440	0.52064	92.24314	785.42295	2598.67141
21	Lutetia	4.85095	36.77710	0.95140	13.72545	290.94054	488.24872
22	Kalliope	2.24835	8.23317	3.41134	335.01872	66.82759	193.40492
24	Themis	8.29007	35.55968	0.45115	40.77149	263.71602	2145.45218
28	Bellona	13.00662	27.20348	20.89924	241.43927	481.31076	666.97955
29	Amphitrite	14.75650	49.64686	21.15240	273.76387	582.36206	1189.20823
31	Euphrosyne	5.12241	22.00394	5.49823	240.62689	302.94482	359.52655
45	Eugenia	7.74860	23.94010	19.99905	233.45638	290.71744	267.90582
46	Hestia	17.96786	63.84851	10.11392	600.04503	585.88586	1087.43324
47	Aglaja	0.56693	1.52783	0.98627	13.06890	14.46588	3.34039
48	Doris	2.88513	13.51154	4.41259	192.22558	143.69507	293.43395
49	Pales	1.36624	6.58591	0.74581	33.42004	44.87418	46.59249
52	Europa	6.43481	26.91968	13.23229	69.31637	342.50298	1296.25556
65	Cybele	2.39575	7.49899	3.32215	76.06273	71.36757	325.08383
87	Sylvia	1.35168	3.38215	3.47084	213.27108	43.60731	26.55712
88	Thisbe	4.08374	12.87875	6.41856	289.82627	119.82741	613.18320
90	Antiope	0.42065	2.01203	0.04924	0.74104	18.39564	53.38957
107	Camilla	1.45676	3.18390	5.05085	147.73203	63.08296	17.97039
111	Ate	144.29700	397.32342	171.68672	4215.37702	5169.29002	31583.25731
121	Hermione	0.65030	1.99023	0.94898	52.20717	20.46184	138.98339
130	Elektra	2.82965	10.37911	10.78122	110.47445	115.07394	132.25069
165	Loreley	6.50281	27.76875	28.27952	465.04322	345.34894	231.09589
189	Phthia	0.06564	0.31375	0.02352	2.13209	3.13691	8.40850
243	Ida	0.02475	0.03559	0.00574	0.31220	0.46578	2.44193
253	Mathilde	0.11630	0.19786	0.12028	4.48961	2.69194	8.82521
283	Emma	0.35806	1.11882	1.04708	16.94125	9.49715	9.82103

Table 2: Influence of each asteroid on each Mars orbital parameter: peak-to-peak amplitude for a 100 yr time interval

Mercury		Venus		Mars	
asteroide	EMB-Mercury $\times \frac{\Delta M}{M}$	asteroide	EMB-Venus $\times \frac{\Delta M}{M}$	asteroide	EMB-Mars $\times \frac{\Delta M}{M}$
46_ Hestia	694.01010	46_ Hestia	1164.60600	111_ Ate	12258.22000
111_ Ate	390.65110	111_ Ate	389.29540	46_ Hestia	2484.66100
3_ Juno	77.53379	3_ Juno	141.34980	19_ Fortuna	1485.34900
165_ Loreley	61.31650	165_ Loreley	84.56231	24_ Themis	1291.46300
88_ Thisbe	35.62771	18_ Melpomene	70.40396	3_ Juno	1221.21800
6_ Hebe	32.65011	88_ Thisbe	65.21992	6_ Hebe	1109.21300
18_ Melpomene	25.56851	28_ Bellona	49.60696	9_ Metis	1058.72800
52_ Europa	23.19845	6_ Hebe	47.85985	29_ Amphitrite	676.18000
19_ Fortuna	19.74131	52_ Europa	28.09674	52_ Europa	529.57310
28_ Bellona	18.67213	2_ Pallas	26.95967	88_ Thisbe	374.38660
9_ Metis	12.18488	13_ Egeria	26.70767	20_ Massalia	349.37370
65_ Cybele	11.15585	45_ Eugenia	26.37660	8_ Flora	342.20010
2_ Pallas	10.79248	29_ Amphitrite	26.10475	165_ Loreley	311.62700
20_ Massalia	10.47764	20_ Massalia	23.69739	14_ Irene	263.50100
48_ Doris	10.30252	7_ Iris	23.64386	28_ Bellona	261.16760
47_ Aglaja	9.39728	10_ Hygiea	23.34137	7_ Iris	236.89170
24_ Themis	8.70575	24_ Themis	21.92538	4_ Vesta	226.52210
16_ Psyche	8.32899	65_ Cybele	16.96635	2_ Pallas	189.73690
29_ Amphitrite	8.32330	14_ Irene	14.22438	48_ Doris	189.62930
7_ Iris	7.55930	4_ Vesta	13.51992	13_ Egeria	185.14450
14_ Irene	7.49308	19_ Fortuna	12.13824	10_ Hygiea	168.26760
10_ Hygiea	7.24384	9_ Metis	10.88285	15_ Eunomia	165.01150
31_ Euphrosyne	5.37681	1_ Ceres	9.52207	16_ Psyche	152.56800
15_ Eunomia	4.74114	16_ Psyche	9.44188	65_ Cybele	144.84320
4_ Vesta	4.70565	49_ Pales	9.38891	45_ Eugenia	129.93130
13_ Egeria	3.79465	48_ Doris	6.92858	31_ Euphrosyne	86.37314
8_ Flora	3.65469	130_ Elektra	4.64705	18_ Melpomene	66.79982
45_ Eugenia	2.95697	8_ Flora	4.34414	21_ Lutetia	42.14033
49_ Pales	2.60837	31_ Euphrosyne	3.12844	1_ Ceres	39.82367
189_ Phthia	2.25191	22_ Kalliope	2.01498	17_ Thetis	32.21822
130_ Elektra	1.70296	11_ Parthenope	1.97254	11_ Parthenope	19.60792
243_ Ida	1.47892	107_ Camilla	1.92639	130_ Elektra	16.72673
121_ Hermione	1.36178	15_ Eunomia	1.87222	121_ Hermione	14.81428
11_ Parthenope	0.98616	47_ Aglaja	1.65449	49_ Pales	10.80631
253_ Mathilde	0.94971	189_ Phthia	1.37761	22_ Kalliope	9.68023
21_ Lutetia	0.90056	121_ Hermione	0.83037	189_ Phthia	7.42760
22_ Kalliope	0.56491	21_ Lutetia	0.77383	47_ Aglaja	4.95920
17_ Thetis	0.55424	17_ Thetis	0.55975	107_ Camilla	2.31888
283_ Emma	0.52483	283_ Emma	0.52277	90_ Antiope	1.03507
107_ Camilla	0.47895	243_ Ida	0.25822	253_ Mathilde	0.87222
90_ Antiope	0.28519	87_ Sylvia	0.20355	87_ Sylvia	0.50908
1_ Ceres	0.14139	253_ Mathilde	0.18701	283_ Emma	0.14407
87_ Sylvia	0.09770	90_ Antiope	0.10771	243_ Ida	0.07351

Table 3: Uncertainty of the EMB-Mercury, EMB-Venus and EMB-Mars distance due to the asteroid masses inaccuracy

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