EPSC Abstracts
Vol. 6, EPSC-DPS2011-1879, 2011
EPSC-DPS Joint Meeting 2011

Asteroid mass determinations with INPOP planetary ephemerides

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Abstract

Thanks to the Mars orbiter tracking data, the Mars orbit is known with an accuracy of few meters over more than 10 years. The main limitation of the modern planetary ephemerides are then the perturbations of the main-belt asteroids on the inner planet orbits. In the other hand, mass determinations of asteroids are now done during the construction of planetary ephemerides on a regular basis.

Compared to the previous INPOP versions, the INPOP10a [3] planetary and lunar ephemeris has several improvements. For the planets of our solar system, no big change was brought in the dynamics but improvements were implemented in the fitting process, the data sets used in the fit and in the selection of fitted parameters. We report here the main results obtained with INPOP10a related to asteroid mass determinations.

1. General context

The estimations of the asteroid perturbations on planet orbits are a critical point for the extrapolation capabilities of the planetary ephemerides ([8]).

The usual approach to this problem has been suggested by [9] and consists of accounting in the dynamical model for a selection of approximately 300 individual asteroids. The masses of the most perturbing asteroids are fitted to observations. For the other objects, masses are deduced from radiometric diameters and the assumption of constant densities within three taxonomic classes. This classic approach has been used in INPOP08 [2] and achieves in terms of the Earth-Mars distance prediction an accuracy of 20 m over 2 years. It is based on an unrealistic hypothesis of constant densities within taxonomic classes. It also relies on an empirical choice of the selection of asteroids to account for and on the choice of the subset of asteroid masses to adjust individually. We used INPOP10a as a benchmark to test an alternative approach. [6] showed that approximately 240 asteroids in a list of 287 probable asteroids and a ring should represent the perturbations induced by the main belt on planetary orbits down to an order of a meter. In INPOP10, we use the Bounded Variable Least Squares (BVLS) algorithm developed by ([7]) in order to fit the masses of all the 287 asteroids listed in [6] with constraints requiring the adjusted masses to be positive or zero. Setting an asteroid mass to zero is equivalent to removing it from the dynamical model. Thus the BVLS algorithm performs simultaneously parameter selection and estimation. From this method and the original list of 287 asteroids, about 161 asteroid masses were planed to be estimated in the fit, the other masses being put to zero.

Table 1: Values of parameters obtained in the fit of INPOP10a to observations. Only the three biggest asteroid masses fitted in INPOP10a are given in this table. K11 stands for [4].

$[10^{12} \times M_\odot]$	INPOP10a $\pm 1\sigma$	K11 $\pm 1\sigma$
Ceres	475.836 ± 2.849	467.900 ± 3.250
Pallas	111.394 ± 2.808	103.440 ± 2.550
Vesta	133.137 ± 1.683	130.970 ± 2.060

Based on a study of the correlations between the asteroid masses, we found however 30 highly correlated asteroids among the most perturbing objects. In order to decrease the mass uncertainties, we fixed 16 asteroid masses to values determinated by other methods (close encounters, binary).

Besides these fixed values, 145 asteroid masses have been estimated using constraints on the densities ($0 < \rho < 20$ g.cm^{-3}) in order to keep the fitted values in the frame of realistic physics.

2. Results

On figure 1 are presented the asteroid densities deduced from INPOP10a compared to values found in the literature, ranked by their impact on the Earth-

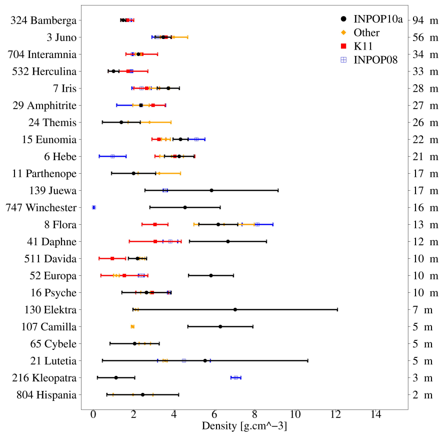

Figure 1: Distribution of densities in g.cm^{-3} ranked with the impact on the Mars- Earth distances over 1970-2010 period. The right-hand side axis gives the differences in Mars geocentric distances in meters induced by an integration of the Mars motion over the 1970-2010 period with and without the corresponding asteroid. *K11* stands for [4] and *Other* for the determinations induced by close-encounters or binary systems. The error bars represent the 1-sigma error on the mass determinations.

Mars distances over the 1970 to 2010 period. The major sources of comparisons are the values obtained with INPOP08, [4] and close encounters or binary system estimations gathered by ([1]). The densities are deduced from the mass estimations and diameters extracted from the [5] database. It appears clearly from figure 1 that the estimations for the most perturbing objects are quite consistent while the estimations of the less perturbing objects show bigger discrepancies. On table 1 are given the masses obtained with the adjustment of INPOP10a for the 3 Bigs, Ceres, Pallas and Vesta. As expected the three bigger asteroid masses are compatible at 2-sigmas with other determinations.

3. Summary and Conclusions

We present here new mass determinations for main belt asteroids obtained with the construction of INPOP planetary ephemerides. 26 of them have been compared to other masses estimated by other methods and show good agreement for the most bigger Mars perturbers.

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