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INPOP: evolution, applications, and perspectives

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Abstract. The INPOP ephemerides have undergone several improvements since the last INPOP10a release (Fienga *et al.* 2011). Improvements in the asteroid mass determinations have been made and the effect of the solar corona has also been investigated (Verma *et al.* 2012). Since 2010 and INPOP10a, in anticipation to IAU resolution B2, the au is fixed in the INPOP construction while the mass of the Sun is fitted. Descriptions of tests of general relativity made with INPOP10a are recalled here. Perspectives about Messenger data analysis and new gravity tests are finally introduced.

Keywords. solar system: general, ephemerides, reference systems, methods: n-body simulations, relativity, minor planets, asteroids

1. Improvements since INPOP10a

INPOP10e (Fienga *et al.* 2012) is the latest INPOP version. It is the release developed for the Gaia mission and is available for all users. Compared to INPOP10a, new sophisticated procedures related to the asteroid mass determinations have been implemented: bounded-values least-squares have been associated with *a priori* sigma estimators (Kuchynka 2010). Corrections to the solar corona perturbations on the radiometric measurements have been applied (Verma *et al.* 2012) allowing estimations of new electronic densities for slow and fast solar winds and 8% of supplementary data in the INPOP fit. Have also been added very recent Uranus observations (Viera Martins and Camargo 2012) and Pluto positions deduced from HST (Tholen *et al.* 2008).

In anticipation to the resolution B2 of IAU 2012 and since INPOP10a, the adjustment of the mass of the sun was made while the au was maintained at a fixed value. The solar oblateness (J_2) and the Earth-Moon mass ratio (EMRAT) were also fitted. Masses of the planets have also been updated to the values of the IAU best estimates (Luzum *et al.* 2012). Thanks to the added solar corrections and to the improvements in the fit procedure, 152 asteroid masses have been estimated showing good agreement with values found in the literature, especially for big perturbers (inducing perturbations bigger than 5 m over the Earth-Mars distances and the observational period) (see Figure 1(a)). Improvements in the INPOP extrapolation capabilities have also been achieved with this new version: over 32 months of extrapolation, a 30 m degradation arises with INPOP10e, while the degradation reaches up to 100 m with INPOP10a. Comparisons to other planetary ephemerides and postfit residuals can be found in Fienga *et al.* (2012).

2. Tests of general relativity

Estimates of intervals of PPN β and γ acceptable values (values inducing modifications of the postfit residuals smaller than 5%, see (Fienga *et al.* 2011) for more details) were

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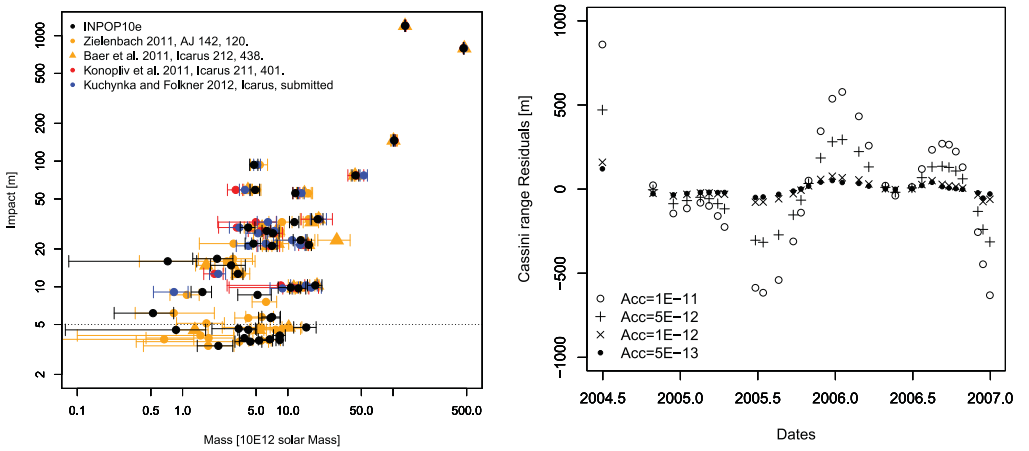

Figure 1. (a) INPOP10e asteroid masses compared to other published values, ranked according to their impact on the Earth-Mars distances over a 1970-2012 period. (b) Differences between Cassini range data and Earth-Saturn distances obtained with supplementary Pioneer-like acceleration on Saturn orbit.

done with INPOP08 (Fienga *et al.* 2009) and INPOP10a. We also estimated the intervals of the acceptable supplementary advances in perihelia and nodes of the planetary orbits, thus allowing some constraints on gravitational models (Blanchet and Novak, 2011). Tests of acceptable supplementary Pioneer-like accelerations were also done and compared to the most accurate observations of outer planets. As one can see in Fig. 1(b), only an acceleration with an amplitude below 5×10^{-13} m s^{-2} is compatible with the observed geocentric Saturn distances deduced from the Cassini tracking data.

3. Perspectives

Complete analysis of the Messenger tracking data during its orbital phases are expected by the end of 2012. These data will be used for improving the Mercury orbit that, since INPOP10a, has been tied to only three positions deduced from the Messenger flybys of Mercury. As described in (Fienga *et al.* 2011), the Mercury positions are crucial for the tests of general relativity. New estimates of the β and γ intervals will be made as well as the first INPOP estimates of $\mathrm{d}(GM_\odot)/\mathrm{dt}$.

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