New constraints on the Kuiper belt mass and P9 location from INPOP19a planetary ephemerides

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The accuracy achieved by modern deep space radio tracking systems has dramatically increased the precision of planetary ephemerides in the last decade. This improvement is particularly beneficial to the study of the trans-Neptunian solar system, still a relatively unknown region (Prialnik et al. 2020).

The Kuiper belt has a pivotal role in our understanding of the outer solar system, and a better constrain of its mass inferred by its gravity perturbations on the planets can help to explain the observed clustering of Kuiper belt objects (KBO), and the potential presence of a ninth planet beyond the orbit of Neptune, P9 (Batygin et al. 2019).

We thus provide a new estimate of the cumulative mass of KBOs located in the 2:1 and 3:2 mean motion resonances with Neptune deduced from INPOP19a. INPOP19a is the last version of INPOP planetary ephemeris, which, among the numerous updates (Fienga et al. 2019), benefits from the addition of the new normal points obtained with the gravity experiment of the Juno mission and the new normal points deduced from Cassini radio tracking data. The latter, in particular, play a decisive role for constraining the mass of the Kuiper belt, thanks to the enhanced accuracy registered in the analysis of navigation and gravity data (Di Ruscio et al. 2020; Durante et al. 2019) and the extended time-frame covered with the inclusion of the Grand Finale measurements (Iess et al. 2019).

We modeled the Kuiper belt by including in INPOP dynamical model three circular, not inclined rings located at 39.4, 44.0, and 47.5 AU, to which we attributed one-sixth, two-thirds, and one-sixth of the total mass, respectively, using the same approach adopted by Pitjeva & Pitjev (2018). In addition, we included the orbits of nine KBOs, beside Pluto, whose masses are independently constrained by observations of their satellites dynamics.

Solving for the mass of the Kuiper belt together with the orbits of the eight planets of the solar system, Pluto, and the Moon, plus the mass of 343 asteroids of the main belt, we fitted the entire INPOP dataset (Fienga et al. 2019) and estimated a total mass for the rings of KBOs of $(0.061 \pm 0.001)M_{\oplus}$. 
We also provide new constraints on the location of P9 by analyzing the potential gravity perturbation on planetary ephemerides, specifically on the orbit of Saturn. We used two statistical criteria to identify the possible regions compatible with INPOP19a: i) based on the propagated covariance matrix, and ii) on the $\chi^2$ likelihood of P9-perturbed postfit residuals (Fienga et al. 2020). We show that, according to INPOP19a, there is no clear evidence for the existence of P9, but we identified two zones for which its existence is compatible with the accuracy of INPOP planetary ephemerides (see Fig. 1).

Fig. 1. The plots show the two compatible zones we identified for the potential location of P9 with a mass of $5\, M_\oplus$ at a distance of 600 AU. The x and y axes report the angular position in Right Ascension (RA) and Declination (Dec) of the planet in the International Celestial Reference Frame. The colorbar indicates the $\chi^2$ Likelihood computed for each P9-perturbed solution.

References: