



Is the Recently Proposed Mars-Sized Perturber at 65–80 AU Ruled Out by the Cassini Ranging Data?

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Recently, the existence of a pointlike perturber PX with $1 m_{\oplus} \lesssim m_X \lesssim 2.4 m_{\oplus}$ (the symbol “ σ ” denotes Mars) supposedly moving at 65–80 AU along a moderately inclined orbit has been hypothesized in order to explain certain features of the midplane of the Kuiper Belt Objects (KBOs). We preliminarily selected two possible scenarios for such a PX, and numerically simulated its effect on the Earth-Saturn range $\rho(t)$ by varying some of its orbital parameters over a certain time span; then, we compared our results with some existing actual range residuals. By assuming $m_X = 1 m_{\oplus}$ and a circular orbit, such a putative new member of our Solar System would nominally perturb $\rho(t)$ by a few km over $\Delta t = 12$ year (2004 – 2016). However, the Cassini spacecraft accurately measured $\rho(t)$ to the level of $\sigma_{\rho} \simeq 100$ m. Nonetheless, such a scenario should not be considered as necessarily ruled out since the Cassini data were reduced so far without explicitly modeling any PX. Indeed, a NASA JPL team recently demonstrated that an extra-signature as large as 4 km affecting the Kronian range would be almost completely absorbed in fitting incomplete dynamical models, i.e., without PX itself, to such simulated data, thus not showing up in the standard post-fit range residuals. Larger anomalous signatures would instead occur for $m_X > 1 m_{\oplus}$. Their nominal amplitude could be as large as 50 – 150 km for $m_X = 2.4 m_{\oplus}$, thus making less plausible their existence.

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1. INTRODUCTION

The possibility that the remote outskirts of the Solar System may hide some still undiscovered object of planetary size has often occurred in the last decades. It has arisen so far in a variety of more or less sound theoretical scenarios generally implying its putative effects on other known bodies (see e.g., Hogg et al., 1991; Standish, 1993; Matese et al., 1999; Collander-Brown et al., 2000; Melita and Williams, 2003; Melita et al., 2004; Zakamska and Tremaine, 2005; Lykawka and Mukai, 2008; Fernández, 2011; Matese and Whitmire, 2011; de la Fuente Marcos and de la Fuente Marcos, 2014; Beust, 2016; Brown and Batygin, 2016; Sheppard and Trujillo, 2016; Shankman et al., 2017). Recently, Volk and Malhotra (2017) suggested the existence of a putative new, relatively distant major body of the Solar System whose gravitational tug would allow to explain the deviation of the measured midplane of the Kuiper Belt Objects (KBOs) from the theoretical expectations based only on the currently known planets. Here, we will follow the convention of generically denoting the proposed unseen object as X or PX, in which “X” is not meant as the Roman numeral for ten, but simply as “unknown.” If one wanted to, one could even coin provisionally a dedicated name to better distinguish such a scenario (Volk and Malhotra, 2017), characterized by $m_X \simeq 1 m_{\oplus}$

with an upper limit $m_X \lesssim 2.4 m_\oplus$ and $a_X \simeq 65 - 80$ AU, from the different one recently proposed by Batygin and Brown (2016) and Brown and Batygin (2016) for the so-called Planet Nine, or Telisto (Iorio, 2017), which is a hypothetical more massive and remote new planet with $m_X \simeq 10 m_\oplus$, $a_X \simeq 700$ AU, $e_X \simeq 0.6$, $I_X \simeq 30^\circ$, $\omega_X \simeq 150^\circ$. A possible choice, which captures some of the main features of the putative new member of the Solar System outlined by Volk and Malhotra (2017), could be Taraktor¹. In this note, we propose to preliminarily put to the test its existence as predicted by Volk and Malhotra (2017) in an independent way by looking at the dynamical effects exerted by it on the Earth-Saturn range $\rho(t)$, which is currently known with an accuracy of the order of $\sigma_\rho \simeq 100$ m thanks to the accurate radio-tracking data collected over the last 12 year by the Cassini spacecraft during its exploration of the Kronian² system (Folkner et al., 2016). We will not re-process the Cassini tracking data by including the action of PX. Instead, we will compare the most recent existing post-fit Kronian range residuals³, obtained without explicitly taking PX into account, with our simulated time series of the range perturbation due to the putative perturber. This allows to infer some plausible, independent insights concerning the model proposed by Volk and Malhotra (2017) for it.

2. THE NUMERICALLY SIMULATED RANGE TIME SERIES DUE TO PX

We numerically integrated the equations of motion of all the major bodies of the Solar System in rectangular Cartesian coordinates over the adopted time span $\Delta t = 12$ year with and without PX. Both the integrations shared the same initial conditions for the known planets retrieved from the WEB interface HORIZONS by JPL, NASA. Then, we numerically calculated the corresponding time series $\rho(t)$ for the Earth-Saturn range and took their difference $\Delta\rho(t)$, thus obtaining the nominal range signature due to PX. **Figure 1** shows the outcome of our numerical simulations for it as due to a Mars-sized ($m_X = 1 m_\oplus$) distant ($a_X = 65 - 80$ AU) perturber PX (Volk and Malhotra, 2017) moving along a circular ($e_X = 0$) orbit moderately inclined to the ecliptic ($I_X = 10^\circ$) for various orientations of its orbital plane in space set by the longitude of the ascending node Ω_X ; its location along the orbit is assumed to be close to the ascending node ($u_X = 10^\circ$). In this respect, it must be remarked that no hints are provided by Volk and Malhotra (2017) about the eccentricity, the orientation of the orbital plane

and the position along the orbit of their PX. It can be noted from **Figure 1** that the maximum amplitude of the expected signal amounts to a few km, being limited to the range $\sim 1 - 8$ km. It turns out that, other things being equal, by displacing PX along its assumed circular orbit, i.e., by varying its argument of latitude u_X , the patterns of the resulting time series change, contrary to their amplitudes which remain at the few km level. As far as the inclination I_X of the perturber's orbit is concerned, despite Volk and Malhotra (2017) assumed it to be small, we explored its full range of variation by finding that it does not notably affect the maximum amplitude of the range perturbations which remains at the \sim km level.

In each picture of **Figure 1**, a gray horizontal band 200 m wide is depicted. It summarily represents the width of the actual Kronian post-fit range residuals produced so far by processing the Cassini radiotechnical data without explicitly modeling the dynamics of any distant pointlike perturber PX; cfr. with Figure 1 of Folkner et al. (2016). Our nominal range perturbation time series $\Delta\rho(t)$ due to PX of **Figure 1** are not confined within such a relatively narrow band, so that it may be argued at first sight that the scenario for PX adopted here is neatly ruled out by the accurate observations of Cassini. Actually, it would be a precipitate and, to a certain extent, incorrect conclusion⁴. Indeed, all the currently available “standard” Kronian post-fit range residuals have been produced so far by using dynamical models which include only the gravitational pull of the known major bodies of the Solar System. Thus, it is quite possible that a non-negligible part of an actually existing PX-driven exotic signature may have been removed in the data reduction procedure, being absorbed in, say, the estimated values of some parameters like the initial state vectors and some of their masses. In other words, the absence of an anomalous signature like those in our **Figure 1** in the Cassini range residuals might just be related to the use of incomplete force models in the fit to the observations. Indeed, Figure 3 of Folkner et al. (2016) shows that fitting usual dynamical models, i.e., without PX, to simulated data including the effect of a perturber⁵ able to induce a range perturbation on Saturn as large as just ± 4 km (cfr. with Figure 2 of Folkner et al., 2016) leads to an almost complete removal from the resulting post-fit residuals. Thus, caution is in order before making hasty conclusions about the inconsistency of the scenario depicted in our **Figure 1** with the observations; in light of the example discussed in Folkner et al. (2016), we tend to consider it as still viable, at least as far as the orbital dynamics of the known major bodies of the Solar System is concerned. It can be shown that, in the same conditions as of **Figure 1**, the semimajor axis of PX should be as large as $a_X \simeq 200 - 250$ AU in order to have the PX-driven range time series fully within the gray band of the standard post-fit residuals. On the other hand, the situation is less favorable if larger values of m_X come into play. Indeed, if for $m_X = 1 m_\oplus$

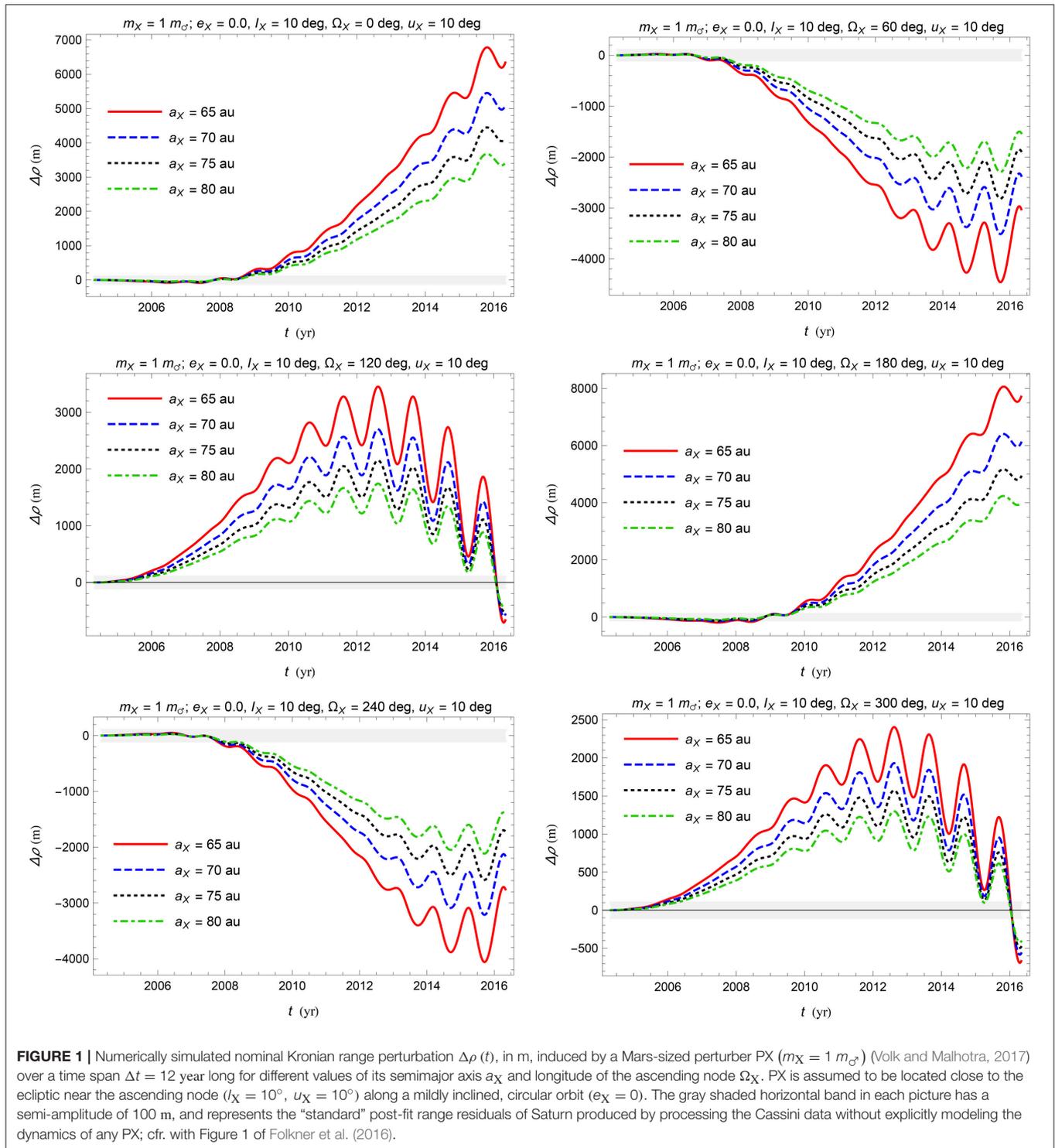
¹From ταρακτωρ: disturber. It is likely better than the anodyne and uninformative Planet Ten, which is gaining popularity on the Internet at the time of writing. What if Planet Nine/Telisto (proposed by Batygin and Brown, 2016) was not finally found? Would the body put forth by Volk and Malhotra (2017) become the new Planet Nine? Not to mention even a possible... Planet Eleven in prospect (de la Fuente Marcos and de la Fuente Marcos, 2017)!

²From Κρόνος (“Cronus/Cronos/Kronos”), corresponding to the Roman deity Saturn.

³They are statistically compatible with zero, and look like a somehow unstructured band with semiamplitude of the order of about 100 m. See, e.g., Figure 5 of Hees et al. (2014), Figure 35 of Folkner et al. (2014), Figure 1 of Folkner et al. (2016), or the blue dots of Figure 1 of Fienga et al. (2016).

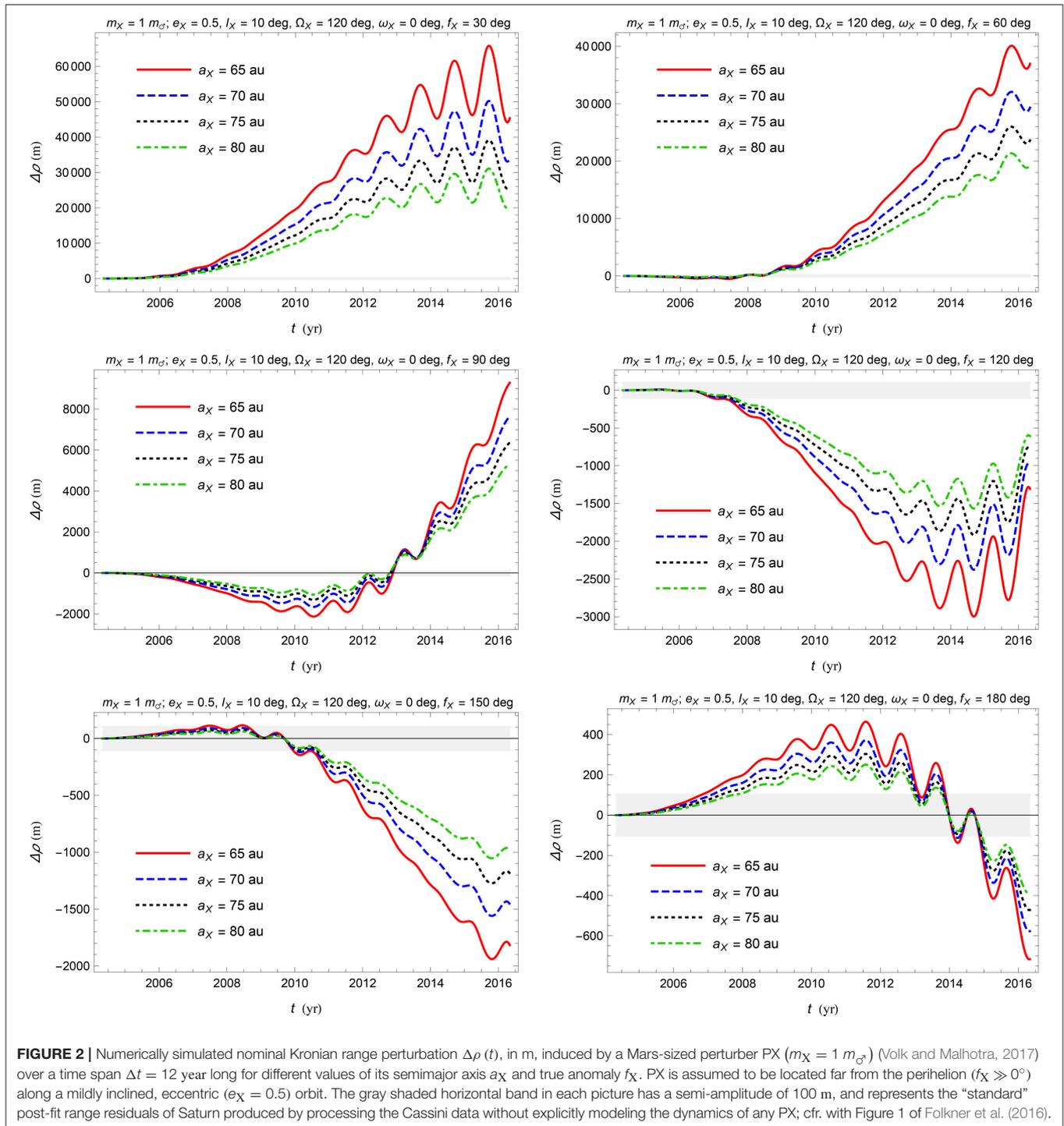
⁴I am indebted to W.M. Folkner, JPL-NASA, for insightful discussions about such a delicate point.

⁵Folkner et al. (2016) dealt with the Planet Nine/Telisto scenario (Batygin and Brown, 2016; Iorio, 2017) encompassing a much more distant and more massive putative planet with respect to the one considered here.



we are just at the edge of the compatibility with the existing Cassini-based Kronian range residuals, for $1 m_{\text{♃}} < m_X \lesssim 10 - 20 m_{\text{♃}} \simeq 1 - 2 m_{\text{♁}}$, still encompassed in the scenario proposed by Volk and Malhotra (2017), the amplitudes of the corresponding nominal range perturbations may be too large to realistically invoke the previously mentioned mechanism of

signal removal in the existing “standard” residuals. Suffice it to say that, for $m_X = 2.4 m_{\text{♁}}$, which is the upper limit for the perturber’s mass proposed by Volk and Malhotra (2017), the nominal range perturbations can be as large as 50 – 150 km. In this case, it is more difficult that so huge signatures may have not left some statistically non-zero traces in the currently available



post-fit residuals even after the unavoidable partial absorption in the data reduction.

Volk and Malhotra (2017) did not provide insights about the admissible values of the eccentricity e_X of the perturber’s orbit. Here, for the sake of concreteness, we will explore the possibility that it is $0.1 \leq e_X \leq 0.5$ for $m_X = 1 m_J$. If, on the one hand, the amplitude of the nominal Kronian range time series

does not change too much for $e_X = 0.1$, on the other hand, the situation is different for $e_X = 0.5$. By discarding a priori orbital positions too close to the perihelion, i.e., $f_X \simeq 0^\circ$, because of lacking of direct visual evidence⁶, some of the remaining portions

⁶A Mars-sized body at just $r_X \simeq 32 - 40$ AU would hardly have escaped a direct detection so far.

of the orbit may be questioned based on our Kronian dynamics-based analysis. Indeed, **Figure 2** shows that the nominal range perturbation of Saturn would be as large as $\simeq 20 - 60$ km for $f_X \simeq 30 - 60^\circ$ for certain values of ω_X , Ω_X . It must be noted that, however, such constraints are not too surprising since, after all, they would correspond to heliocentric distances as little as $r_X \simeq 34 - 48$ AU which should have allowed a relatively simple direct visual detection of a Mars-sized body. Instead, for orbital positions departing from the perihelion more markedly ($f_X \gtrsim 90^\circ$) and approaching the aphelion ($f_X \simeq 180^\circ$) it is not possible to rule out dynamically the corresponding anomalous signature because it is at the \simeq km level or even less. Similar results essentially hold also for other values of ω_X , Ω_X . Larger values of e_X imply larger portions of the orbit to be dynamically excluded because of a resulting enhancement of the amplitude of the Kronian nominal range perturbations and possible visual detection.

3. SUMMARY AND CONCLUSIONS

The Cassini spacecraft ended its life by finally plunging into the atmosphere of the ringed planet on mid of September 2017. The availability of its full ranging data around Saturn, starting in 2004, will offer a unique opportunity to constrain several scenarios put forth in the latest years involving the presence of a distant, pointlike planetary body PX lurking in the remote peripheries of the Solar System. Latest data reductions, covering the time span 2004–2016, were performed without explicitly modeling the dynamical action of any hypothetical PX; the resulting standard post-fit Kronian range residuals are statistically compatible with zero, and have an amplitude as little as $\simeq 100$ m. We used them to study the PX model recently hypothesized by Volk and Malhotra (2017) involving a Mars-sized body orbiting at heliocentric distances of about 65 – 80 AU along a moderately

inclined path. We emphasize the preliminary nature of our investigation, which has not pretensions of being an exhaustive study of all possibilities: it detailed just two specific scenarios. It turned out that, for $m_X = 1 m_\oplus$ and by assuming a circular orbit for it, such a putative perturber, tentatively dubbed Taraktor (perturber, disturber), would nominally shift the range of Saturn by several km over 12 year. This does not necessarily imply that its existence is ruled out by the existing Cassini-based post-fit range residuals of the giant planet since it has been recently demonstrated by a NASA-JPL team that a hypothetical anomalous signal of about 1 – 4 km was almost completely removed in fitting dynamical models not explicitly encompassing PX to simulated data including its action. Thus, we conclude that, as far as the existing Cassini telemetry is concerned, the PX scenario considered here is likely still compatible with the orbital dynamics of Saturn. On the other hand, according to Volk and Malhotra (2017), it is also theoretically possible that the mass of the putative perturber can be as large as up to $2.4 m_\oplus$, implying nominal range perturbations of the order of 50 – 150 km. Such hypothetical anomalous signatures might turn out to be too large to have been absorbed by other parameters in the data reductions yielding the standard post-fit Kronian range residuals produced so far. Dedicated analyses by reprocessing existing Cassini data would allow for a more rigorous analysis. Furthermore, it is worth noticing that new missions toward the ice giants (Arridge et al., 2012, 2014; Turrini et al., 2014; Hofstadter and et al., 2017) would be beneficial in order to get better constraints on the mass distribution in the distant regions of the Solar System.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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