PLANET X: NO DYNAMICAL EVIDENCE IN THE OPTICAL OBSERVATIONS

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ABSTRACT

It is shown that the alleged "unexplained anomalies in the motion of Uranus" disappear when one properly accounts for the correct value of the mass of Neptune and properly adjusts the orbit of Uranus to the observational data. Also, it is shown that each of the "irregularities in the measured positions of Neptune" has a complete explanation within the framework of the presently known solar system. As a check of certainty, an actual planetary ephemeris is integrated which well fits the observations of Uranus. Minor systematic errors do remain in the data, but they are very small; they are easily explained by a number of uncertainties in the observations themselves. There is now known to be a mass concentration of significant size in the outer solar system—1992 QB1. In comparison to any of the major planets, though, this object is miniscule. For the meridian circle observations, there is still no evidence which requires or even indicates the existence of any planet-sized object; there remains no need to hypothesize the existence of a tenth planet in the solar system.

1. INTRODUCTION

The discovery of Neptune in 1846 accounted for the large residuals which had been seen in the orbit of Uranus prior to that time. The residuals had amounted to dozens of arcseconds—undeniable and unexplainable without the presence of an additional gravitational source. After accounting for the effects of Neptune, however, the residuals of Uranus shrank to only a fraction of an arcsecond—an amount which is comparable in size to the many known possible sources of systematic errors in the observations themselves. Nevertheless, a number of authors (Harrington 1988; Gomes 1989; Gomes & Ferraz-Mello 1988; Powell 1989; Brunini 1992a) have attempted to predict the position of a tenth planet in the solar system, solely on the basis of these residuals. The subsequent searches for Planet X have been unsuccessful, but have prompted a remarkable amount of conjecturing about the source of such "unexplained residuals" (see, e.g., Seidelmann & Williams 1988; Seidelmann & Harrington, 1988). These last two references, however, do not include the latest: a collision of Uranus with a 1000 km-sized body (Brunini 1992b)!

A proper investigation of the signatures in the meridian circle (transit) residuals of Uranus *must* contain an adjustment of the parameters of the solar system model (i.e., ephemeris) against which the residuals have been computed. Prior to the Voyager Spacecraft Mission, these parameters should have included not only the orbital elements of Uranus but also the masses of the perturbing planets. Now, however, accurate corrections to the Jovian planets' masses have been accurately determined from Voyager. These are given in Table 1 along with two lists of previously accepted values—those of the IAU (1976) standards and those of the JPL Ephemeris DE200 (Standish 1990). Nowadays, it would be wrong to do anything but to adopt the Voyager masses and then to solve for only the orbital elements. In this respect, the mass of Neptune is especially important since the correction to the previously adopted value was nearly 0.5%.

This paper presents such a proper analysis of the residuals of Uranus. Section 2 presents plots of the residuals of Uranus in three stages: (1) the residuals as originally received; (2) the residuals after an adjustment of only the elements of the orbit of Uranus; and (3) the residuals after applying the modern values for the masses of the outer planets and then readjusting the elements of the orbit of Uranus. It is seen that the residuals in the third stage have no appreciable structure; the "anomalies in the motion of Uranus" have disappeared.

There also have been statements in the literature regarding "irregularities in the measured positions of Neptune, possibly due to an unknown force in the solar system." There are three cases: (1) the measurement of Neptune by

TABLE 1. The masses of the Jovian planets: the previous standards (IAU and DE200) and the presently most accurate as determined by the Voyager Mission, given in units of M(sun)/M(planet).

	IAU1976	DE200	Voyager	Std. dev.	Reference
Jupiter	1047.355	1047.350	1047.3486	0.0008	Campbell & Synnott 1985
Saturn	3498.5	3498.0	3497.898	0.018	Campbell & Anderson 1989
Uranus	22869.0	22960.0	22902.94	0.04	Anderson *et al.* 1990
Neptune	19314.0	19314.0	19412.240	0.057	Tyler *et al.* 1989

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the astronomer Galileo in 1613, (2) the measurements of Neptune by Lalande in 1795, and (3) the general inability of modern-day ephemerides of Neptune to remain accurate when extrapolated into the future. These three cases are discussed in Sec. 3. Section 4 indicates some of the possible sources of errors remaining in the residuals; it also discusses possible reasons why the Uranus observations have remained so long without having been properly reduced. There is a conclusion in Sec. 5.

2. THE OBSERVATIONAL RESIDUALS OF URANUS

The author obtained a set of Uranus observations and residuals from members of the US Naval Observatory. The observations, taken at a number of different observatories, have been transformed, by the USNO, first onto the FK4 reference frame by the means of catalogue corrections, and then onto the FK5 reference frame by the application of the IAU-adopted equinox correction (Fricke 1982). Evidently, the residuals on the tape were computed with respect to JPL's planetary ephemerides, DE200, since similar computations by the author give nearly exact agreement with the USNO residuals. It is basically this set of observations and residuals that has been widely distributed to other authors. This set, however, is far from complete. It contains no Greenwich data and only a scattering of Paris data; possibly, catalogue corrections for these were not available at the time of the tape's creation and, as such, it is better to exclude them. For the observations that are on the tape, the coverage is quite good, starting around 1830. Before that time, there does exist a series of observations from the Radcliffe Observatory in the late 1700's. These are reported to be highly inaccurate (Seidelmann & Harrington 1988), so I have made no attempt to use them. Nor have I made any attempt or to locate any data other than that on the original tape.

Figures 1(a) and 1(b) show the residuals in right ascension and declination as received, computed against DE200. The systematic trends are quite evident in right ascension: a negative slope during the present century and a strong negative bias plus negative slope during the 1800's.

How much of the signature is due to a poor-fitting ephemeris for Uranus in DE200? Figures 2(a) and 2(b) show the corresponding residuals after merely adjusting the orbit of Uranus to the data, weighted according to the apparent scatter in the observations: $1''.2$ for the data before 1911; $0''.4$ since. This adjustment alone provides a noticeable improvement in the plots.

When the correct masses of the outer planets (in particular, that of Neptune) are introduced and the orbit of Uranus is then readjusted, the signatures are almost completely gone, as shown in Figs. 3(a) and 3(b).

Systematic trends are more easily seen graphically if one uses normal points instead of the individual data points. Normal points, means and standard deviations of the data computed for each opposition, are shown in Figs. 4–6, corresponding directly to Figs. 1–3. The pronounced and unmistakable trends in Fig. 4 are all but eliminated in Fig. 6. (Note that the vertical scale of Figs. 4–6 has been expanded by a factor of two in comparison with Figs. 1–3.) It is seen that the root-mean-square value of the normal points is reduced nearly 20% from Fig. 4 to Fig. 6. This is a significant improvement, especially when compared with the criterion of 10% used by Harrington (1988).

Closer scrutiny of the residuals in Figs. 6(a) and 6(b) reveals a large positive bias in right ascension during the interval, 1895–1905. This is almost certainly an observational problem. Indeed, the majority of the observations forming this bias are from a single catalogue of the 9 in. transit of the USNO: during the period 1895–1905, the 165 residuals from the USNO 9 in. transit show a mean in right ascension of $+0''.90\pm0''.08$, while during the same period, 15 observations from Besancon have a mean of $-0''.39 \pm0''.19$ and 44 observations from the 6 in. transit at the USNO have a mean of $-0''.04\pm0''.10$. Certainly, a single poorly determined catalogue equinox correction could account for the whole bias of the 9 in. data; so could the inadvertant omission of such a correction, similar to that reported by Oesterwinter & Cohen (1972).

"First runs showed a distinct bias in the right ascension residuals of Sun, Mercury, and Venus. The problem was quickly traced to a difference in procedure employed in the reduction of source code 6 data [USNO 6 in., 1911–1918] in contrast to later volumes. The so-called equinox correction of $-1''.218$ was not applied to the observed right ascension in those days."

Quite possibly, some of the prior catalogues (from the same observatory, in fact) still have the same problem.

The effects of the outer planets' masses computed for this study were done by integrating differenced equations of motion similar to those described by Harrington (1988). The orbit adjustments for Uranus used the Set-III correction formulation of Brouwer & Clemence (1960). In fact, both formulations have been used successfully at JPL for well over a decade in computing the effects of asteroids upon the orbits of Mars and the Earth and for the adjustment of the ephemerides. However, as an additional check, the plots shown in Figs. 3(a) and 3(b) and in Figs. 6(a) and 6(b) were compared with, and found to be identical to, actual residuals computed against DE298, a complete, self-consistent, numerically-integrated ephemeris. DE298 is an experimental ephemeris; the sole purpose behind its creation was the demonstration that it is indeed possible to create an actual good-fitting ephemeris for all of these Uranus observations.

3. THE LACK OF PROBLEMS WITH NEPTUNE

There have been a number of suggestive comments in the literature about the residuals of Neptune. For the sake of completeness, it is appropriate to remark about these.

(1) In reference to the observation of Neptune by the astronomer Galileo in 1613: "The task now is to check Galileo's careful measurements by recalculating the orbit of Neptune" (Drake & Kowal 1980) and "We are left,

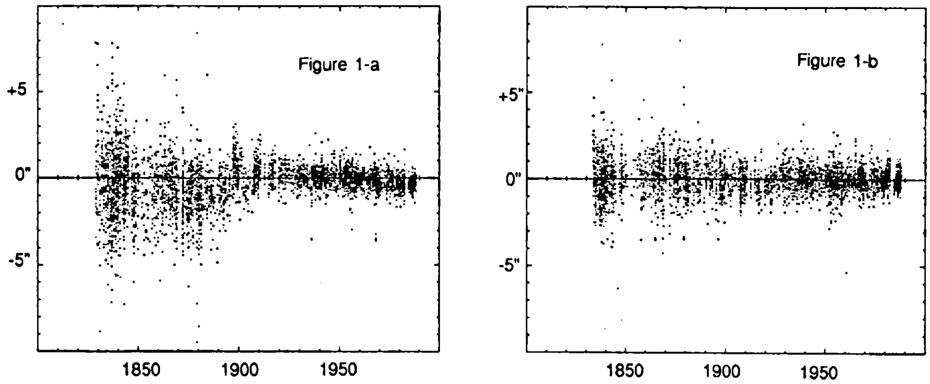


FIG. 1. Residuals of Uranus in right ascension (1-a) and declination (1-b) as received directly from the US Naval Observatory, computed with respect to the JPL Ephemeris DE200. The negative bias and slope in the 1800's and the negative slope in the 1900's are obvious.

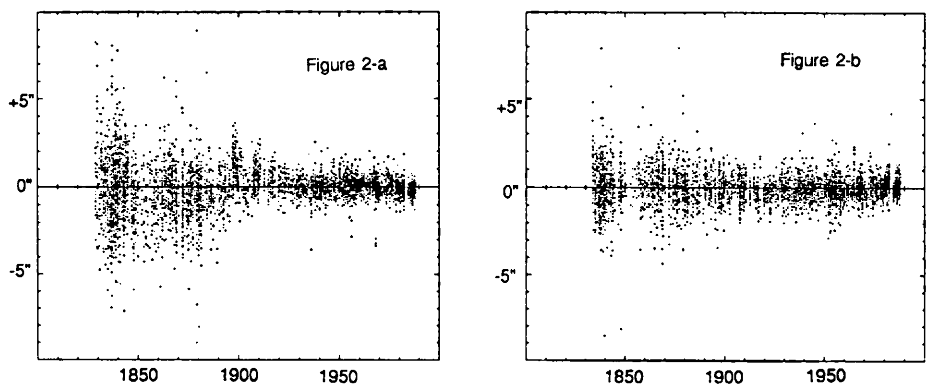


FIG. 2. Residuals from the same data as in (1-a) and (1-b), but reduced against an adjusted orbit of Uranus.

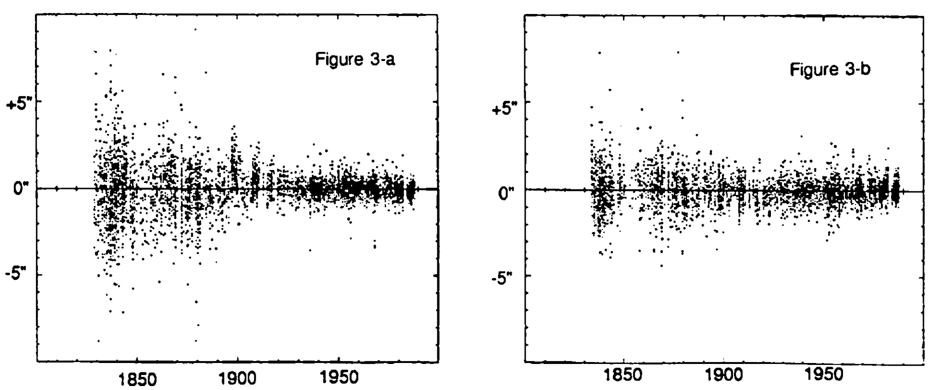


FIG. 3. Residuals from the same data as in (1-a) and (1-b) and (2-a) and (2-b), but reduced against an adjusted orbit of Uranus, after having accounted for the more accurate outer planet masses (in particular, Neptune) found by the Voyager spacecraft. The signature is all but gone. Any remaining trend is easily within the expected uncertainty introduced by the uncertainties associated with the observational data. For example, the section of high positive points from 1895–1905 come mostly from one single catalogue and possibly have not had a catalogue correction applied to them.

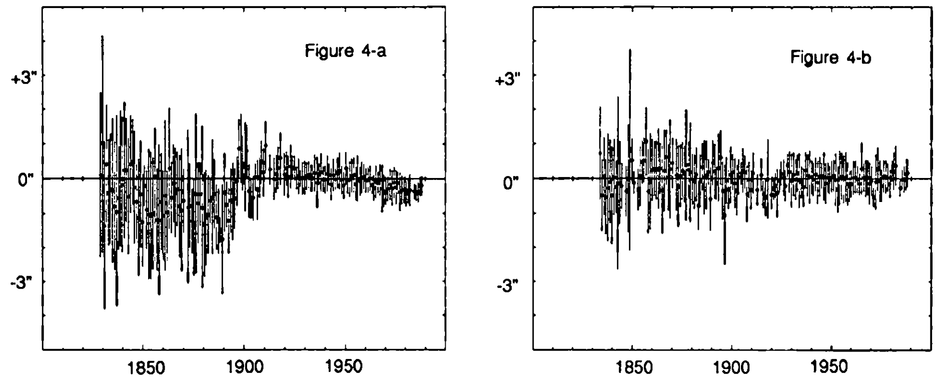


FIG. 4. Normal points (means and standard deviations for each opposition) corresponding to the residuals of the actual data points shown in Figs. (1-a) and (1-b). The signatures are even more apparent in these plots. Note that the vertical scale has been expanded by a factor of two over the scale in Figs. 1–3.

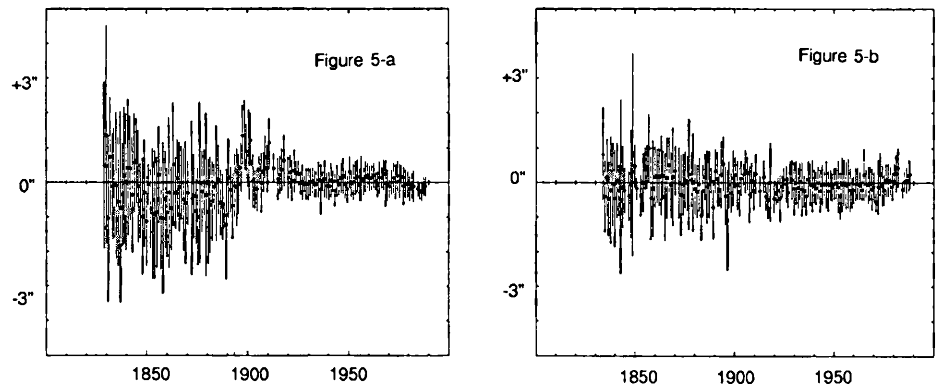


FIG. 5. Normal points from the residuals plotted in Figs. (2-a) and (2-b).

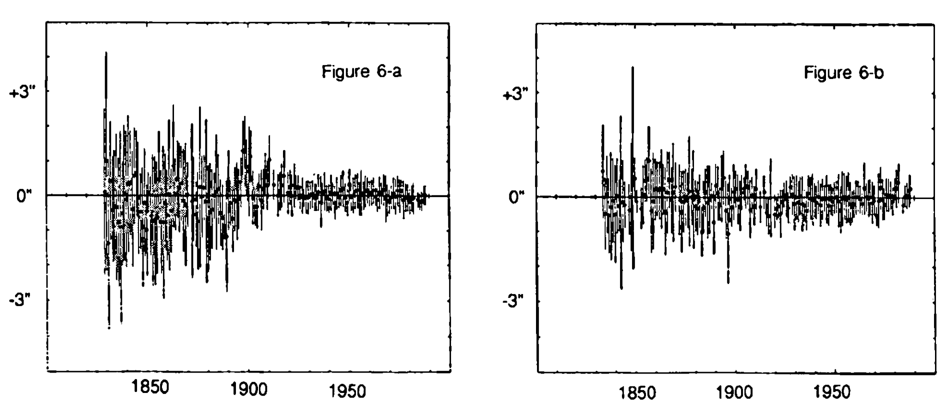
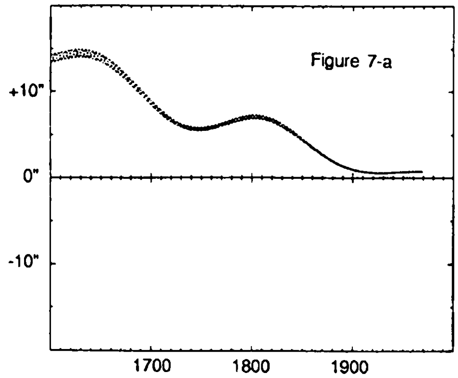


FIG. 6. Normal points from the residuals plotted in Figs. (3-a) and (3-b).



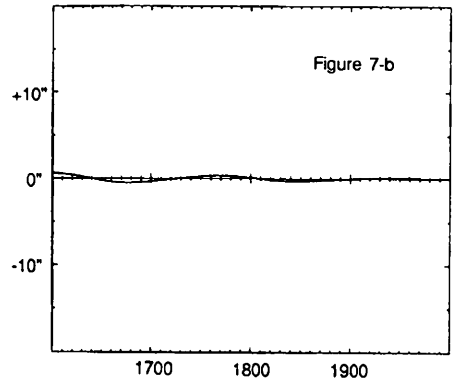


FIG. 7. The differences in longitude (7-a) and latitude (7-b) of Neptune between the JPL ephemerides, DE102 and DE118 (DE118 is the 1950 version of DE200).

then, with the strong possibility that the ephemeris of Neptune is in error by a significant amount ..." (Kowal & Drake 1980).

This observation by Galileo has an ambiguous interpretation (see, e.g., Standish 1981). One interpretation implies a major problem with the ephemeris of Neptune, since Neptune is drawn at the wrong position on the dotted line. (This interpretation assumes that Galileo intentionally drew that part of the diagram to scale.) The other interpretation implies the opposite: the ephemeris agrees with the drawing since they both put Neptune on the dotted line (assuming that Galileo did not bother to draw the separation to scale).

Further, there has recently been noticed another probable observation of Neptune by Galileo (Standish & Nobili 1993); this observation, if it is indeed true, shows with certainty that Galileo saw Neptune in just the spot predicted by modern ephemerides.

(2) "...Newcomb had studied Lalande's observations in general and found that ... for Neptune the residuals with current ephemerides are 12.5 arcseconds." (Seidelmann & Williams 1988).

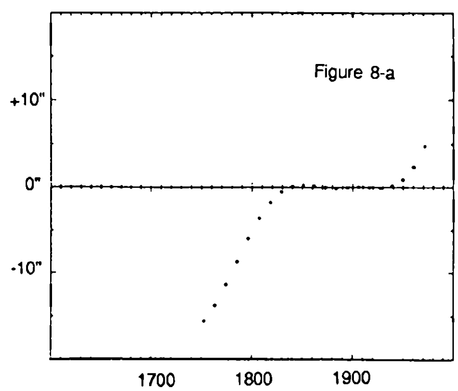
There is a 9 arcsecond scatter in all of Lalande's observations over the two nights during which he observed Neptune; the reduction of these observations is quite uncertain in longitude (see, e.g., Rawlins 1970).

For the ephemerides, the uncertainty in longitude for the time of Lalande (1795) is on the order of Lalande's residuals themselves. An estimation of the lower-bound (!) of the ephemeris uncertainty can be obtained by comparing different ephemerides and noting the amount of their agreement. Figures 7 and 8 show comparisons of three different ephemerides of Neptune; namely, JPL's DE102, JPL's DE200, and the ephemeris from the USNO Publications, Volume XII. Even though these ephemerides were based upon essentially the same observational data, the differences in longitude amount to several arcseconds during the past two centuries. It is not surprising that the Lalande residuals in longitude are seemingly large.

In contrast, the reduction for the latitude is more straightforward; the disagreements in latitude between the ephemerides are less than one arcsecond; Lalande's latitude residuals are small.

(3) "The puzzle is that approximately ten years after a prediction ephemeris has been calculated, the observations systematically differ from the prediction ephemeris." (Seidelmann & Harrington 1988).

It has been shown by Hogg *et al.* (1991) that an ephem-



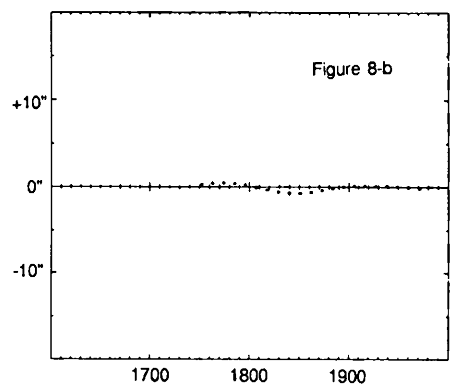


FIG. 8. The difference in longitude (8-a) and latitude (8-b) of Neptune between the ephemeris of the USNO Publications, Volume XII and the JPL ephemeris, DE118.

eris of Neptune, fit to less than one period's worth of observational data (as has been the case), can easily drift by as much as 1″ in longitude when extrapolated only a decade or so outside the data span. Furthermore, this result was found assuming only random observational errors; the actual ephemerides fitted to the observations could easily drift even more, considering the systematic errors that are also known to be present in the observations.

4. DISCUSSION

The findings in this study are contrary to those of other authors who indicate the presence of unmodeled residuals which are not explainable by observational errors. In hindsight, it seems apparent the residuals have not been correctly modeled in previous investigations. Either the orbit of Uranus was not adjusted at all, or it was adjusted incorrectly, or the wrong mass for Neptune was chosen, or the mass of Neptune was determined incorrectly, or the whole question of Neptune's mass was ignored completely. An exception to this was the ephemeris adjustment of Ash *et al.* (1971), using the full set of Uranus observations. One of their adjusted parameters was the mass of Neptune; their value differed only 0.1% from that of the now-known Voyager value.

There are still systematic errors remaining in the residuals of Uranus; there are still systematic errors remaining in the residuals of all of the planets. These are easily explainable in light of the known problems associated with the optical data: there are inconsistencies between the pre- and post-1911 observations (Fricke 1973, 1975; Duncombe & Van Flandern 1976; etc.); there are even known problems with the twentieth century data (Seidelmann *et al.* 1985; Seidelmann 1986; etc.); the J2000 adopted value of precession is now known to be in error by 0.″3/century (see e.g., Williams *et al.* 1991); and the whole J2000 system may have a further error amounting to 1″/century (Stumpff & Lieske 1984; Standish & Williams 1990). Any remaining systematic trends in the residuals of Uranus and Neptune are certainly explainable by these uncertainties in the observational data.

It might be instructive to sometime compare the residuals from a number of different observatories; however, this should be done only after the appropriate catalogue corrections have been applied. Such a comparison would give an independent measure of the observational consistencies involved.

As indicated above, the fit of the orbit of Uranus to the whole set of observations is not very good in JPL's ephemeris, DE200 (Standish 1990); there are a number of reasons for this. First, DE200 was adjusted to only the observations taken after the introduction of the impersonal micrometer in 1911; the pre-1911 observations were known to have significant systematic errors. Secondly, for DE200, it was decided to adopt the then-existing IAU value for Neptune's mass; this author did not have much confidence in any determination of that quantity, especially with only 65 years of observational data. Thirdly, the 1″/century inconsistency in the optical data prompted the introduction of a series of catalogue offsets into the least-squares adjustment leading to DE200; these may have done more harm than good for the outer planet ephemerides.

However, the DE200 ephemeris of Uranus should not have created the misconception that the observations cannot be fit well. Certainly, anyone who predicts a Planet X must first readjust the orbit of Uranus; certainly, testing the various masses of Neptune or adopting a new one requires the readjustment of the orbit of Uranus; and certainly, one must readjust the orbit of Uranus when realizing that DE200 was not necessarily fit to the same set of data with the same weighting scheme as that presently being considered.

The Voyager mass corrections will now be incorporated into future JPL ephemerides. Also, since the older (pre-1911) observations now seem to be more reliable than the author had previously believed, they also will probably be incorporated into the data set to which the ephemerides are adjusted.

5. CONCLUSION

Many professional lives have been dedicated to the long series of meridian circle (transit) observations of the stars and planets throughout the past three centuries. These observations represent some of the most accurate scientific measurements in existence before the advent of electronics. The numerous successes arising from these instruments are certainly most impressive. However, as with all measurements, there is a limit to the accuracy beyond which one cannot expect to extract valid information. There are many cases where that limit has been exceeded; Planet X has surely been such a case.

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