THE PRE-DISCOVERY OBSERVATIONS OF URANUS

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In his *Astronomisches Jahrbuch* for 1784, Johann Elert Bode[1] summarises the scanty information that had reached Berlin concerning the recent discovery on 13 March 1781 of a new heavenly body by a still-unidentified observer in England.[2] Its easterly progress through the Milky Way during the interim six months had been parallel to the ecliptic, and thus entirely consistent with the view - hitherto based only upon its brightness and clearly-defined disc - that it was a planet and not a comet. Bode therefore asks why this sixth-magnitude object had not been previously detected, and raises the question of whether it had in fact been observed by earlier astronomers but misidentified as a star.[3] He himself had already scanned the star-catalogues of Tycho Brahe,[4] Johann Hevelius,[5] John Flamsteed,[6] and Tobias Mayer;[7] and had come to suspect that a missing sixth magnitude star in the constellation Capricorn, observed by Tycho on 20 November 1589, might have been the planet. A second possibility which still required investigation was Mayer's star No. 964, observed in Aquarius on 25 September 1756.[8]

In order to obtain more precise data on this later and much more reliable observation, Bode wrote to Abraham Gotthelf Kaestner[9] who, as Director of the Göttingen Observatory, had access to the manuscript papers deposited there by Mayer's widow in 1763 in return for a modest payment from the Hanoverian government.[10] Kaestner placed this matter in the capable hands of his colleague Georg Christoph Lichtenberg, the editor of a volume of *Opera inedita* incorporating Mayer's zodiacal star catalogue.[11] Lichtenberg duly supplied the equatorial co-ordinates for the star in question and the precise date and time of observation.[12] With

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the aid of Anders Lexell's elements for the new planet, Bode[13] calculated its longitude and latitude for that date and time and compared these co-ordinates with those of 'star' No. 964. The celestial latitudes agreed completely, while the difference of almost 8° in longitude was attributed by Bode to uncertainties in the values adopted for the orbital eccentricity and mean motion. His conclusion that the identification was "highly probable" was supported soon afterwards by Herschel himself[14] and by Pierre Méchain.[15] Using Mayer's co-ordinates to calculate the heliocentric longitude of Uranus and comparing it with that derived for Tycho's star 27 Capricorni, which he also identified provisionally with that planet, Bode calculated a periodic time of 80 years 8 months - in close agreement with the figure derived from Uranus's observed motion over the 2½-years since its discovery.[16] Since, however, there was reason to believe that Tycho's catalogued values contained copying or printing errors, this result was not regarded as conclusive; and subsequent calculations were soon to cause Bode to abandon this supposition.[17]

Consequently, in March 1784, Bode began to consider the further possibilities of the missing stars 8 and 34 Tauri recorded in the second volume of Flamsteed's catalogue being Uranus.[18] The possibility of 8 Tauri being Uranus was soon to be ruled out, however, by Pierre Charles Le Monnier's identification of it with a star that Flamsteed had observed on 29 September and 1 October 1704.[19] According to Méchain's elements, Uranus had certainly been close to 34 Tauri in June and November 1690; and William Herschel himself thought that this identification might be valid.[20] Méchain and Baron Franz Xavier von Zach had meanwhile independently calculated Uranus's position with improved elements derived by Pierre Simon de La Place. They found, however, that the latitudes of that planet and star agreed but their longitudes differed by more than 2° - a discrepancy now regarded as being unacceptably large in comparison with the high degree of consistency found between calculations based on these same elements and the contemporary observations of Uranus's position. Consequently, Bode rejected 34 Tauri as a possible pre-discovery observation of Uranus

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in favour of "rather large perturbations, a change of the Sun's distance and of the node."[21]

There was, however, another possibility that required to be eliminated before this interpretation could be accepted; namely, that the discrepancy arose from errors in the reduction of Flamsteed's observation. This was investigated by Father Placidus Fixlmillner, who took account of aberration and nutation when reducing the heliocentric position of 34 Tauri to the time of Flamsteed's observation of 13 December [Old Style] 1690.[22] With this and the heliocentric position of Mayer 964, he was able to calculate orbital elements for Uranus that were compatible with Bradley's and Mayer's respective observations. Von Zach effected a further improvement by comparing the transit times of three bright stars and making a correction for the acceleration of Flamsteed's uncompensated pendulum clock.[23] Finally, following a suggestion from the Abbé Triesnecker in Vienna, Fixlmillner made a careful study of the errors in Flamsteed's mural quadrant and then corrected the transit times for these hitherto-ignored instrumental effects.[24] Calculations based on this last reduction and on Mayer's co-ordinates then appeared to indicate a slower mean motion for Uranus than that based upon contemporary observations.

Despite La Place's own acceptance of Mayer 964 as Uranus, a few practical astronomers still had reservations about the reliability of Mayer's observation, so it too had to be more carefully studied before this apparent inconsistency in Uranus's mean motion could be accepted as real. Joseph Delambre, when preparing new tables of Uranus (1789), made a new reduction using data copied from Mayer's *Tagebuch* previously sent to Lalande by Lichtenberg. When he later came to discuss this in the second volume of his *Astronomie théorique et pratique* (Paris, 1814), he claimed that Mayer had incurred an error of 4 seconds in the timing of the transit and another of 3 seconds in aligning the plane of his mural quadrant with respect to the meridian. He also suggested, without reason or proof, that the observation in question had perhaps been made hastily and perhaps on a cloudy night. Now on the night of 25 September 1756, Mayer observed about a hundred stars in less

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than 3½ hours at an average interval of only 40 seconds, and several of these were faint eighth and ninth magnitude stars. These facts in themselves testify to the excellence of the seeing conditions and surely prove that the time-interval of over 3 minutes that preceded the observation of Mayer 964 must have given him ample time to realign his telescope and to note the precise instant of transit. A strong counter-attack on the credibility of Delambre's conclusions was made by von Zach,[25] who claimed that he was in possession of Mayer's original manuscript catalogue.[26] He accused his French contemporary not merely of unjust criticism but also of incurring errors of transcription in transit times which had distorted his interpretation of Mayer's data. The most significant fact which Delambre did not even attempt to explain was that Mayer 964 remained missing from the place in the sky where it had been observed.

Towards the end of this same article, von Zach repeats a statement which he had already committed to print six years previously in a historical review of astronomical advances during the first decade of the 19th century,[27] to the effect that Flamsteed and Pierre Charles Le Monnier had made pre-discovery observations of Uranus although the original observations had never come to light.[28] Flamsteed's observation of 34 Tauri on 23 December 1690 which Méchain, Fixlmillner and von Zach himself had previously investigated, had been taken not from Flamsteed's original observation-book but from the posthumously-published star catalogue,[29] while Le Monnier's two observations of 20 and 23 January 1769 had already been reduced before being cited in Bode's *Jahrbuch*.[30] Yet Lalande, in introducing Delambre's tables of Uranus,[31] had remarked upon the high degree of precision with which these represented Flamsteed's, Mayer's, and Le Monnier's pre-discovery observations. Perhaps it was this stimulus from von Zach which encouraged Johann Karl Burckhardt[32] and Alexis Bouvard[33] to announce the results of their respective studies on Flamsteed's and Le Monnier's data soon afterwards.

In his lecture to the Institut de France on 16 December 1816, Burckhardt[34] attributes Flamsteed's second observation of Uranus on

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22 March 1711/12 [Old Style] to the fact that he began observing a few minutes later than he required to do in order to observe the star ρ Leonis in which he was then interested. He also claims that Flamsteed unknowingly observed the planet on three days - 21, 22, 27 February 1714/15 [Old Style] - when it happened to be in opposition to the Sun and in conjunction with Saturn, and yet again on 18 April 1715 [Old Style] when it transited several minutes later than σ Leonis. He himself had not deliberately set out to find these observations, since he had supposed that Bode would have detected them in the course of his earlier researches.[35] Rather, he had found them accidentally while comparing the star positions in some southerly zones in La Caille's catalogue[36] and that of Caroline Herschel[37] to those in Lalande's *Histoire céleste* (Paris, 1801). His own elements of Uranus represented Flamsteed's first observation of 1690 to about ± 1'.[38]

Bouvard explains that Le Monnier's frequent observations of Uranus were due to his requiring a reliable catalogue of zodiacal stars as a basis for the lunar observations that he wanted to make. He had not identified any of these as the planet because he had not needed to make day-to-day comparisons of their positions. Although Le Monnier had made his observations from 1736 to 1780 with a mural quadrant and poor-quality pendulum clock at the Observatory of the Capuchines in Paris, his fifteen rough observation books were subsequently deposited at the Paris Observatory where Bouvard had obtained access to them. Their quality was not good, since many figures were scarcely decipherable, errors of several seconds often occurred in the carelessly-recorded times of transit, and the quadrant had not been placed exactly in the plane of the meridian. Nevertheless, he managed to identify twelve instances (including three previously noticed by Le Monnier himself) where Uranus had been mistaken for a star, and listed the date, calculated mean time, apparent right ascension, and apparent declination of each in a table.[39] His careful reductions were founded upon Friedrich Wilhelm Bessel's recently-published catalogue of James Bradley's stars, in which Bessel himself detected a misidentified observation of Uranus's declination made on 3 December 1753.[40] Two similar unpublished observations by Bradley were to be discovered later,[41] but these were unreliable since they had been made before proper instrumentation was installed at the Greenwich Observatory.

In the introduction to his "Tables of Uranus" (1821), Bouvard[42] makes an explicit distinction between the seventeen other pre-discovery observations known at that time and the uninterrupted series made after Uranus's discovery forty years previously and concludes that, after due allowance had been made for the effects of planetary perturbations, it was still impossible to reconcile them. Because of this, he decided to adopt the elements for Uranus's orbit calculated from the later (more numerous and reliable) observations, leaving discordances of a few minutes of arc in several of the former for future astronomers to explain. Continued observations of this planet made during the following decade merely increased the complexity of the problem and, by 1834, led him to speculate on the existence of a disturbing body beyond the orbit of Uranus. This idea was not new. It had occurred as early as 1787 to Lexell, who reasoned that since certain comets return periodically after many decades, gravity must extend to much greater distances than the orbit of Uranus.[43] Bessel himself again makes explicit reference to it in a letter to Gauss dated 14 June 1824[44] and, after continued observations during the following decade served merely to emphasise that the discrepancies in the theory of Uranus's orbital motion could not be accounted for by errors in observation, he engaged a young student Friedrich Wilhelm Flemming to make a thorough study of the observed perturbations using this as the working hypothesis.[45] Owing to Flemming's nervous illness and Bessel's own preoccupation with other matters, this approach had not yielded any positive result before the young Cambridge undergraduate John Couch Adams independently resolved to undertake this laborious task in the summer of 1841.

The initial stimulus to Adams's investigation appears from his own testimony to have been the offer of a mathematical prize by the Göttingen Academy of Sciences, for the best analysis of the problem of Uranus's orbital motion;[46] and it is evident from another letter from Bessel to Gauss that it was he who instigated and Gauss who arranged that such a prize should be awarded.[47] Later, however, in a lecture to the Royal Astronomical Society on 13 November 1846 at which the Astronomer Royal George Airy was present, Adams gives him credit for having been the guiding spirit of his researches.[48] An autobiographical history of Airy's involvement in this matter was presented by the Astronomer Royal himself at the same meeting.[49] He was first directly confronted with the problem in 1834 by the Reverend T.J. Hussey, who had been talking to Bouvard during a visit to Paris. On his return to England, Hussey wrote to Airy, telling him that they were independently of the opinion - shared by others - that there must be another planet superior to Uranus producing the latter's unexplained perturbations, and asking him where one ought to conduct a search for this disturbing body.

At that time, Airy had been highly sceptical of the idea, and thought that it would be virtually impossible to discover such a planet in any case. His considered opinion was that the unexplained steady increase of Uranus's celestial longitude might simply result from the adoption of too small a value for its mean distance from the Sun. Thus he encouraged Alexis Bouvard's nephew (Eugène) to explore this possibility. It was only after Eugène Bouvard's careful and determined effort to reconcile theory and observation failed, that French and English astronomers finally became convinced that the hypothesis of a superior planet beyond Uranus had to be taken very seriously. Airy himself, however, was more concerned with the question of whether a gravitational influence of this nature was capable of explaining the error in Uranus's distance, than with the existence of the disturbing body itself; and he blamed Adams's failure to respond to his query on that issue for his own tardiness in studying the manuscript containing Adams's solution to the problem itself.[50]

Meanwhile, Urbain-Jean Joseph Le Verrier had begun to publish a series of memoirs in the *Comptes rendus* dealing in depth with various aspects of Uranus's motion, including the reduction of the nineteen pre-discovery observations which Alexis Bouvard had dismissed as uncertain. He too became firmly convinced in the existence of another planet exterior to Uranus and, in his important

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memoir of 1846,[51] makes a full analysis culminating in the prediction of its longitude as about 325° on 1 January 1847. He communicated this result to astronomers at the Berlin Observatory on 23 September 1846, who had no difficulty in discovering the new planet (Neptune) that same evening.[52]

Now that the problem of Uranus's anomalous motion was satisfactorily resolved, astronomers were able to re-compute its positions for the times when the pre-discovery observations had been made. In view of the care with which the reductions of Flamsteed's, Mayer's and Bradley's observations had already been made, Le Verrier, in his revision of Bouvard's tables, considered that it sufficed merely to correct the mean times of Le Monnier's observations and to revise the positions of the two made in 1750.[53] The results of his corrections to Bouvard's reductions of these observations, his own reductions of Flamsteed's observations, and Bessel's reduction of Mayer's observation, are listed in Table I.[54] Bradley's three observations have been omitted since only their right ascensions can be determined with sufficient accuracy to be of value. In view of the uncertainties inherent in these observed data, and the difficulties involved in their reduction, little would be gained from any further attempt to improve them.

Simon Newcomb was the first person to employ the general theory of perturbations by Neptune (as well as by Jupiter and Saturn) when determining the elements of Uranus's orbit.[55] He calculated the values of the mean star positions from the "Star Tables of the American Ephemeris" and the Greenwich Seven-Year Catalogues for 1860 and 1867, and made the reductions to apparent place with modern constants. His revised value for the mass of Neptune was taken from an earlier publication by Safford.[56] The results of a comparison between the pre-discovery observations of Uranus and the positions obtained by numerical integration from this more sophisticated theory, illustrated in Table II,[57] clearly reveal that the level of agreement is exceptionally high. The fact that a marginally poorer fit is obtained if Newcomb's own reductions are substituted for those of Le Verrier[58] confirms both the validity of the identifications and the rigour of the reductions. Taking account of the three observations of Bradley, and a recent new identification with a Flamsteed observation on 3 December [Old Style] 1714,[59] we may safely conclude that Uranus was observed as a star on no fewer than 22 occasions during the 81-year period between December 1690 and December 1771, before William Herschel discovered it and recognised it for what it was.

NOTES

1. *Astronomisches Jahrbuch für das Jahr 1784 nebst einer Sammlung der neuesten in die astronomischen Wissenschaften einschlagenden Abhandlungen, Beobachtungen und Nachrichten. Mit Genehmhaltung der Königl. Akademie der Wissenschaften berechnet und herausgegeben von J.E. Bode, Astronom der Akademie* (Berlin, 1781). The abbreviated title of this periodical, adopted below, is *Astr.Jahrb.*

2. "Ueber einen im gegenwärtigen 1781sten Jahre entdeckten beweglichen Stern, den man für einen jenseits der Saturnsbahn laufenden, und bisher noch unbekannt gebliebenen Planeten halten kann", *ibid.*, pp.210-20. In a footnote on p.211 of this article, Bode gives the following five variants of Herschel's surname that had appeared in the early French and English reports of the discovery: Mersthel, Hertschel, Herthel, Herrschell, and Hermstel.

3. *Ibid.*, p.218.

4. Brahe, T. *Historia coelestis jussu S.C.M. Ferd. III. edita complectens Observationes Astronomicas Varias ad historiam coelestem spectantes* (Augustae Vindelicorum, 1666).

5. Hevelius, J. *Machinae Coelestis pars prior* (Gedani, 1673); *pars posterior* (Gedani, 1679).

6. Flamsteed, J. *Historia Coelestis Britannicae*, 3 vols. (Londini, 1725).

7. Mayer, T. "Fixarum zodiacalium catalogus novus ex observationibus Gottingensibus ad initium anni 1756 constructus", in Lichtenberg, G.C. (ed.), *Opera inedita Tobiae Mayeri I* (Gottingae, 1775), pp.49-74.

8. *Ibid.*, p.72

9. *Astr.Jahrb. für 1785* (Berlin, 1782), p.189.

10. The circumstances which resulted in this arrangement being made are described in the introduction to Forbes, E.G. (ed.) *Tobias Mayer's Opera Inedita* (London, 1971), p.12.

11. *Op.cit.*, note 7.

12. "Aus einen Schreiben des Herrn Prof. Lichtenberg an Herrn Hofrath Kästner, vom 1. Sept. 1781", *op.cit.*, note 9, p.192.

13. *Ibid.*, p.190.

14. "Aus einem Schreiben des Herrn Herschel an mich" (London, 13 August 1783), in Bode's *Astr.Jahrb. für 1786* (Berlin, 1783), p.258.

15. Méchain to Bode; Paris, 1 April 1784, in Bode's *Astr.Jahrb. für 1787* (Berlin, 1784), p.141.

16. Bode, J.E., "Fortgesetzte Bemerkungen über den neuen Planeten (Uranus)" in *op.cit.*, note 14, pp.219-23.

17. *Op.cit.*, note 18, p.246.

18. Bode, J.E., "Versuch eines Beweises, dass bereits Flamsteed im Jahr 1690 (so wie Tobias Mayer im Jahr 1756) den neuen Planeten beobachtet", *Astr.Jahrb. für 1787* (Berlin, 1784), pp.243-6.

19. Le Monnier, P.C., "Mémoire sur la Disparition de l'Etoile de la constellation du Taureau, que Flamstéed a placée dans son Catalogue, pour 1690, à 51^{d}46'50" de longitude, avec une latitude de 0^{d}5'¼ méridionale", *Histoire de l'Académie Royale des Sciences, Année MDCCLXXXIV* (Paris, 1787), pp.353-4.

20. "Astronomische Beobachtungen und Nachrichten, von Herrn Prof. von Zach. Aus zweyen Briefen desselben an mich", Bode's *Astr. Jahrb. für 1788* (Berlin, 1785), pp.214-20. In a letter of 21 May 1785, von Zach told Bode that the Graf von Brühl, de Luc, Aubert, and himself had all spent a night with Herschel at Datchet, discussing this and other matters; during which time, Herschel had expressed the opinion that 34 Tauri was "very probably the new planet" (*ibid.*, p.214).

21. *Op.cit.*, note 18, p.246.

22. Fixlmillner, P., "Untersuchung der Elemente der wahren Laufbahn des neuen Planeten", *ibid.*

23. *Op.cit.*, note 20, pp.214-15.

24. Fixlmillner, P., "Ueber die Tafeln vom Uranus und neue Flemente der Bahn dieses Planeten", Bode's *Astr.Jahrb. für 1792* (Berlin, 1789), pp.158-60.

25. Zach, F.X. von, "Ueber den von Tobias Mayer im Jahr 1756 beobachteten Planeten Uranus", in B. von Lindenau and J.G.F. Bohnenberger (eds), *Zeitschrift für Astronomie und verwandte Wissenschaften, 3* (Tübingen, 1817), pp.3-22.

26. This would seem to be contradicted by Francis Baily in his introductory remarks on "Mayer's Catalogue of Stars", *Memoirs of the Royal Astronomical Society 4* (1831), 395-6.

27. Zach, F.X. von "Versuch einer geschichtlichen Darstellung der Fortschritte der Sternkunde im verlorenen Decennio", *Monatliche Correspondenz zur Beförderung der Erd- und Himmels-Kunde 23* (1811), 205-56. See p.221.

28. *Op.cit.*, note 25, p.20.

29. *Op.cit.*, note 6; vol.2, p.86.

30. *Astr.Jahrb. für 1793* (Berlin, 1790), p.20.

31. Lalande, J.J. de, *Histoire Céleste Française, contenant les observations faites par plusieurs astronomes français 1* (Paris, 1801), p.188.

32. Burckhardt, J.C., "Sur plusieurs observations de la planète Uranus qu'on trouve parmi les étoiles de Flamsteed", *Connaissance des Tems, ou des mouvemens célestes, à l'usage des astronomes et des navigateurs, pour l'an 1820* (1818), 408-9.

33. Bouvard, A., "Extrait des registres des observations astronomiques faites par Lemonnier, à l'Observatoire des Capucins, rue Saint-Honoré, à Paris", *ibid. pour l'an 1821* (1819); *Additions*, 339-47.

34. Burckhardt, J.C., "Sur l'opposition d'Uranus en 1715, et sur les résultats qu'on peut en tirer", *loc.cit.*, note 32, 410-12.

35. *Ibid.*; footnote, p.410.

36. La Caille, N.L. de, *Coelum Australe Stelliferum* (Paris, 1763). This catalogue contained a selection from a total of approximately 10,000 stars observed over a period of nineteen months at the Cape of Good Hope. The star-positions in it were later adjudged by Francis Baily (*Monthly Notices of the Royal Astronomical Society 5* (1833), 93) to be reliable only to within $\pm$ 30".

37. Herschel, C. *Catalogue of Stars, taken from Mr. Flamsteed's observations ... and not inserted in the British Catalogue ... With ... remarks by William Herschel* (London, 1798).

38. *Op.cit.*, note 34, p.412.

39. *Op.cit.*, note 33, p.341.

40. Bessel, F.W. *Fundamenta Astronomiae pro Anno MDCCIV deducta ex Observationibus viri incomparabilis James Bradley in Specula Astronomica Grenovicensi per Annos 1750-1762 institutis* (Regiomonti, 1818), p.283. Mayer's observation of 25 September 1756 is reduced by Bessel on pp.284-5.

41. Breen, H., "On early Observations of Uranus by Bradley", *Monthly Notices of the Royal Astronomical Society 24* (1864), 124-5.

42. These are discussed by their author in the second part of the introduction to his *Tables Astronomiques publiées par le Bureau des Longitudes de France, contenant les Tables de Jupiter, de Saturne et d'Uranus, construites d'après la Théorie de la Méchanique Céleste* (Paris, 1821).

43. Lexell, A.I. "Recherches sur la nouvelle Planète découverte par M. Herschel & nommée par lui Georgium Sidus", *Nova Acta Academiae Scientiarum Imperialis Petropolitanae, I* (1787), 78 and 79.

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44. *Briefwechsel zwischen Gauss und Bessel herausgegeben auf Veranlassung der Königlich Preussischen Akademie der Wissenschaften* (Leipzig, 1880), p.435.

45. Bessel, F.W., "Ueber die Verbindung der astronomischen Beobachtungen mit der Astronomie", in H.C. Schumacher (ed.), *Populäre Vorlesungen über wissenschaftliche Gegenstände* (Hamburg, 1848), p.452.

46. Adams, J.C., "An Explanation of the Observed Irregularities in the Motion of Uranus", *Memoirs of the Royal Astronomical Society 16* (1847), 429.

47. Bessel to Gauss; Konigsberg, 8 November 1843, *op.cit.*, note 44 p.567.

48. Adams, J.C. "On the Perturbations of Uranus", *The Nautical Almanac and Astronomical Ephemeris for the Year 1851, with an Appendix* (London, 1847), pp.265-93.

49. *Monthly Notices of the Royal Astronomical Society 7* (1847), 121-52.

50. *Ibid.*, p.131.

51. Le Verrier, U.-J.J., "Recherches sur les Mouvements de la Planète Herschel, dite Uranus", *Connaissance des Temps ... pour l'An 1849* (Paris, 1846); *Additions*, pp.1-254.

52. Detailed accounts of the circumstances surrounding this discovery are contained in A.F.O'D. Alexander, *The Planet Uranus* (London, 1965) and Edward M. Grosser, *The Discovery of Neptune* (Cambridge, Mass., 1962).

53. *Op.cit.*, note 51, p.126. A table in *ibid.*, p.129 contains the corrected mean times (based on the Paris meridian), the observed and calculated equatorial co-ordinates, and the residual differences in both these and the ecliptic co-ordinates.

54. This is taken from Edgar W. Woolard, "Comparison of the Observations of Uranus previous to 1781 with theoretical positions obtained by numerical integration", *The Astronomical Journal 57* (1952), 35-38. Compare his Table 1, p.36 with that in Le Verrier, *op.cit.*, note 51, p.129.

55. Newcomb, S., "An Investigation of the Orbit of Uranus, with general Tables of its Motion", *Smithsonian Contributions to Knowledge* No. 262, vol.19 (Washington [D.C.], 1874).

56. Safford, T.H., "On the Perturbations of Uranus and the Mass of Neptune", *Monthly Notices of the Royal Astronomical Society 22* (1862), 142-4.

57. *Op.cit.*, note 54, p.37.

58. This can be appreciated by an inspection of the results of Newcomb's reductions of Flamsteed's observations; namely, for cases 1, 3, 4, 5 in Table II: $-0\overset{s}{.}8$, +5"; $-0\overset{s}{.}1$, -6"; $+0\overset{s}{.}9$, +2"; and $-1\overset{s}{.}5$, +10" respectively.

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59. Rawlins, D., "A Long Lost Observation of Uranus: Flamsteed, 1714", *Publications of the Astronomical Society of the Pacific* *80* (1968), 217-19.

TABLE I. OBSERVED POSITIONS OF URANUS

No.	Date (Gregorian)	Paris Mean Time	Observed App. α	Observed App. δ	Observer
1	1690 Dec. 23	$9^h41^m25^s$	55°49'19".7	+19°35'14".4	Flamsteed
2	1712 Apr. 2	9 46 47	155 38 29.4	+11 00 55.2	Flamsteed
3	1715 Mar. 4	12 43 35	170 40 02.7	+ 4 54 27.9	Flamsteed
4	Mar. 10	12 19 02	170 25 39.3	+ 5 00 38.2	Flamsteed
5	Apr. 29	8 55 49	168 45 55.5	+ 5 41 53.1	Flamsteed
6	1750 Oct. 14	8 04 08	324 15 25.4	-15 01 41.3	Lemonnier
7	Dec. 3	4 48 51	324 34 52.4	-14 53 19.8	Lemonnier
8	1756 Sept.25	10 21 12	348 00 54.5	- 6 01 49.4	Mayer
9	1764 Jan. 15	5 12 00	12 37 39.0	+ 4 43 47.2	Lemonnier
10	1768 Dec. 27	7 38 42	31 26 52.0	+12 15 35.0	Lemonnier
11	Dec. 30	7 26 54	31 24 45.8	+12 14 55.4	Lemonnier
12	1769 Jan. 15	6 23 41	31 22 07.7	+12 14 26.0	Lemonnier
13	Jan. 16	6 19 46	31 22 23.4	+12 14 36.3	Lemonnier
14	Jan. 20	6 04 09	31 24 06.6	+12 15 19.0	Lemonnier
15	Jan. 21	6 00 16	31 24 33.8	+12 15 31.8	Lemonnier
16	Jan. 22	5 56 21	31 25 04.7	+12 15 45.7	Lemonnier
17	Jan. 23	5 52 26	31 25 28.5	+12 16 07.5	Lemonnier
18	1771 Dec. 18	9 06 53	43 58 06.0	+16 25 20.2	Lemonnier

TABLE II. OBSERVED AND COMPUTED POSITIONS OF URANUS, AND RESIDUALS

No.	Date Reckoned from Greenwich Mean Noon	GMT	Observed α	Observed δ	Computed α	Computed δ	O–C Δα	O–C Δδ
1	1690 Dec. 23	$9^h32^m04^s$	$3^h43^m15^s.87$	+19°35'02".7	$3^h43^m15^s.62$	+19°35'02".0	+^{s}.25	+0".7
2	1712 Apr. 2	9 37 26	10 22 31.92	+11 01 04.9	10 22 32.52	+11 01 03.2	-.60	+1.7
3	1715 Mar. 4	12 34 14	11 22 38.03	+ 4 54 42.6	11 22 38.07	+ 4 54 51.8	-.04	-9.2
4	Mar. 10	12 09 41	11 21 40.48	+ 5 00 52.8	11 21 40.36	+ 5 01 00.9	+.12	-8.1
5	Apr. 29	8 46 28	11 15 02.17	+ 5 42 03.9	11 15 01.58	+ 5 42 10.4	+.59	-6.5
6	1750 Oct. 14	7 54 47	21 36 59.98	-15 01 49.7	21 37 00.17	-15 01 45.7	-.19	-4.0
7	Dec. 3	4 39 30	21 38 18.91	-14 53 23.4	21 38 18.97	-14 53 26.7	-.06	+3.3
8	1756 Sept.25	10 11 51	23 12 03.04	- 6 01 54.9	23 12 03.11	- 6 01 51.9	-.07	-3.0
9	1764 Jan. 15	5 02 39	0 50 30.99	+ 4 43 47.7	0 50 31.23	+ 4 43 44.8	-.24	+2.9
10	1768 Dec. 27	7 29 21	2 05 45.74	+12 15 26.0	2 05 45.59	+12 15 25.0	+.15	+1.0
11	Dec. 30	7 17 33	2 05 37.38	+12 14 46.7	2 05 37.96	+12 14 50.4	-.58	-3.7
12	1769 Jan. 15	6 14 20	2 05 27.16	+12 14 19.0	2 05 27.34	+12 14 25.9	-.18	-6.9
13	Jan. 16	6 10 25	2 05 28.23	+12 14 29.4	2 05 28.39	+12 14 33.5	-.16	-4.1
14	Jan. 20	5 54 48	2 05 35.20	+12 15 12.5	2 05 34.60	+12 15 14.4	+.60	-1.9
15	Jan. 21	5 50 55	2 05 37.03	+12 15 25.4	2 05 36.65	+12 15 27.3	+.38	-1.9
16	Jan. 22	5 47 00	2 05 39.11	+12 15 39.5	2 05 38.90	+12 15 41.2	+.21	-1.7
17	Jan. 23	5 43 05	2 05 40.72	+12 16 01.3	2 05 41.35	+12 15 56.2	-.63	+5.1
18	1771 Dec. 18	8 57 32	2 55 50.57	+16 25 18.5	2 55 49.75	+16 25 16.5	+.82	+2.0

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