THE IMPACT ON ASTRONOMY OF THE DISCOVERY OF URANUS

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The discovery of Uranus was a very much more important event than the addition of one primary planet to the Solar System. Indeed, it was to greatly influence future developments in a number of diverse regions. In this paper we shall consider its impact in three such areas: (1) the research on, and the acceptance of, the Titius-Bode Law; (2) the search for, and subsequent discovery of, a planet exterior to Uranus and (3) the direction of William Herschel's own career.

If one reads any general astronomy textbook of today, there is almost sure to be a reference to Bode's Law. Some of the more historically minded authors even refer to it as the Titius-Bode Law. In fact, although it was widely discussed only after the discovery or Uranus, the Law was first suggested in 1766 by Johann Daniel Titius, Professor of Mathematics at the University of Wittenberg. In the course of his studies Titius had noticed in a book by Christian Wolff a series of rounded off distances for the planets. It struck Titius that if he added 1 and 5 units to the distances for Mars and Saturn he could obtain a surprising result since the distances could then be written in the following form:

Mercury=4 =4
Venus=4+3 =7
Earth=4+6 =10
Mars=4+12 =16
? =4+24 =28
Jupiter=4+48=52
Saturn=4+96=100

But why should there be a gap between Mars and Jupiter? Titius

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himself was moved to declare: "Why should the Lord Architect have left the space empty? Not at all. Let us therefore assume that this space without doubt belongs to the still undiscovered satellites of Mars; let us also add that perhaps Jupiter still has around itself some smaller ones which have not been sighted yet by any telescope".[1] Six years later this progression was taken up by the brilliant young German astronomer J. E. Bode. He argued that the gap between Mars and Jupiter was filled not by an insignificant moon (or moons), but by a planet. "Can you believe", Bode exclaimed "that the Founder of the Universe had left this space empty? Certainly not".[2]

After Herschel's sighting of Uranus there had been some delay before it had been generally admitted to be a planet. The common assumption had been that Herschel had stumbled upon a comet. Comets were central to the way astronomers in the 1780s perceived the heavens.[3] They were seen as carriers of divine activity, some natural philosophers speculated that they refuelled the Sun and stars, and it was widely believed that they were capable of bearing life.[4] Also the dramatic recovery of Halley's Comet in 1758 and 1759 had been hailed as a victory for Newtonian theory and had given a further fillip to comet studies. Hence as comets were at the very focus of astronomical thought and as no planet had been found in recorded history, it had seemed almost unthinkable that a new planet could be found.[5] This is certainly not to say that speculations on the existence of further planets were absent before 1781 (witness Bode himself). Nevertheless it took Herschel to break the shackles restraining many, perhaps the overwhelming majority of, astronomers to the tacit assumption that new planets were not to be observed. In particular, the detection of Uranus persuaded some to look more favourably on the Titius-Bode Law and its prediction of a planet between Mars and Jupiter.

Despite Bode's championing, the Law had stirred very little interest before 1784. But in that year Bode had completed a monograph on the recently discovered Uranus (the name Bode had himself proposed for Herschel's planet).[6] Now Bode pointed out that

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the distance of Uranus agreed very well with the progression and he stressed that this could not be a chance result.

There was however a continuing problem with the Law: its complete lack of any physical basis. This meant that some astronomers remained unconvinced of its worth and that others, such as Laplace, judged the Law to be no more than a peculiar game with numbers.[7] Bode dismissed such objections. Indeed, he took every opportunity to discuss the Law in the pages of the prestigious Berliner Astronomisches Jahrbuch that he edited, and the Law was convincing enough for Bode and a few colleagues to resolve upon a systematic search for the elusive planet. Bode and von Zach, the Law's two main advocates, as well as Schröter and Olbers, were among the six astronomers who met at Schröter's home in September 1800 and debated the best way of tracking it down. The favoured scheme relied on the co-operation of 24 astronomers, each of whom was to diligently scan 1/24th part of the sky along the zodiac.

Before the plan could be put into action it was overtaken by events. Even before the invitation from Bode and his friends to search a stretch of the zodiac had reached him, Giuseppe Piazzi, the Director of the Palermo Observatory, had chanced upon on 1 January 1801 (in the course of constructing a new star catalogue) the first of what would later be called minor planets.[8] To begin with Piazzi did not think that he was following in Herschel's footsteps, but he soon became convinced that the object that he had found, named Ceres, was a new planet and the very planet that had been predicted by the Law.[9] The mean distance of Ceres was in excellent agreement with that forecast and so here was exceedingly persuasive evidence the Law was far more than a mathematical curiosity.

However, in March 1802 came the stunning news that Olbers had found what seemed to be another planet, Pallas.[10] Moreover, Pallas was soon calculated to be at almost the same mean distance as Ceres. Now the Law's supporters faced the embarrassing task of explaining away the fact that where there was supposed to be only one planet, there were two. Was it possible to save the Law? Olbers was at first

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inclined to think that Pallas was closer in nature to a comet than a planet. But then in June 1802 Olbers explained to Herschel his own daring hypothesis."What", he proposed, "if Ceres and Pallas were just a pair of fragments, or portions of a once greater planet which at one time occupied its proper place between Mars and Jupiter and was in size analogous to the outer planets, and perhaps millions of years ago, had, either through the impact of a comet, or from an internal explosion, burst into pieces".[11]

Herschel is usually thought of as spending most of his time observing nebulae and stars, but he was constantly interrupting his observing programs to observe the members of the Solar System. He was excited by Ceres and Pallas and himself provided observational evidence for Olber's hypothesis of a disintegrated or shattered planet. His micrometer measurements of Ceres had disclosed them to have unexpectedly small sizes: Ceres had a diameter of 162 miles and Pallas a diameter of 147 miles.[12] These findings had staggered Bode who was sure that Ceres was the eighth primary planet, and that Pallas was a special or exceptional planet, or perhaps comet, in its neighbourhood. By taking this position Bode was of course able to defend the Titius-Bode Law. Herschel was also impressed by the Law and he too sought to avoid its overturn. Herschel reasoned that if Ceres and Pallas were admitted to be primary planets then the Law would be wrecked, whereas if they were members of a different species, the Law's integrity could still be maintained. He judged that the comae that he glimpsed around them, the highly inclined orbits, and the sizes of Ceres and Pallas made it absurd to call them planets and so he coined the title 'asteroids' for them.[13]

The discoveries of Ceres and Pallas were significant not just because of their support for the Titius-Bode Law. They had in addition enlarged ideas on the construction of the Solar System, and in this they were continuing a process begun by the discovery of Uranus. Moreover, the glorious prospect of finding more asteroids motivated astronomers to observe the skies meticulously. Ceres and Pallas also brought home the message that future finds would

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probably be made as the result of careful comparisons of observations. Herschel had already demonstrated the power of methodical examinations of large areas of the heavens, but in 1802 he stressed that although he had made five reviews of the zodiac, both Ceres and Pallas had escaped him. He now pressed examiners of the zodiac to concentrate on the motions of the stars.[14] These sentiments were later echoed by the British Astronomer Royal, Nevil Maskelyne. In his opinion, "If astronomers would observe on two successive nights, they would run a chance of discovering new planets. Or if they observed stars twice in the same night, with an interval of 1, 2 or 3 hours, with a good equatorial instrument, they would find them out by their motion in the interval".[15]

Two more asteroids were soon detected, Juno in 1804 and Vesta in 1807. Vesta indeed being found as the result of a deliberate search for asteroids by Olbers. Both of the new asteroids were at similar distances to Ceres and Pallas.

The accurate predictions by the Titius-Bode Law of the mean distances of Uranus and the asteroids had established a very high reputation for it. The discovery of Ceres in 1801 had at the time even prompted some astronomers to speculate on the existence of a planet orbiting beyond Uranus at a distance in agreement with the Law. A tentative name, Ophion, was actually assigned to the as yet unseen eighth planet.[16] But three decades were to pass before there was good evidence for this surmise and we may look upon Uranus as a beacon brilliantly pointing the way to the new planet since evidence for its existence was to be provided by the motion of Uranus.

As Professor Forbes discusses elsewhere in this volume, searches through early records soon after the discovery of Uranus had turned up a number of observations of the planet, including one by Flamsteed as far back as 1690. Unfortunately the pre-1781 observations of Uranus did not mesh at all well with those made after the discovery, and no single elliptical orbit adequately represented the old and modern observations. One try to explain this anomaly was that a comet had struck Uranus close to the time

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of its discovery, and that this collision had sensibly shifted its orbit. But the mounting errors of the tables of Uranus calculated solely from the post-discovery observations put paid to this hypothesis.[17] Further, by 1832 G. B. Airy, the Director of Cambridge Observatory and soon to be Astronomer Royal, was reporting that the true position of Uranus on the sky differed by nearly half a minute of arc from the then current tables of predicted positions. The very size of this discrepancy meant that there was a growing pressure to devise some sort of explanation of such seemingly bizarre behaviour.

By about 1840 the choice seemed to be between two possibilities: firstly, that the law of gravitation might act in some unexpected manner at the enormous distance of Uranus, secondly, that a planet lay beyond Uranus and was causing the disturbances. As to the first possibility, there was a tradition of suspecting the correctness of, and even tinkering with, the inverse square law. However, by the early 1840s Laplace had long since shown to just about everybody's satisfaction that Newtonian Theory could explain away any alleged irregularity in the orbits of the planets and their satellites. Thus Newtonian Theory appeared to nearly all astronomers to be the true system of the world and beyond reproach, beyond reproach that is until all other means of explaining the motion of Uranus had been thoroughly explored and had failed.[18] In consequence, the generally favoured hypothesis was that a planet was beyond Uranus and was perturbing Uranus. But if an unseen planet was the cause, how could its location be calculated?

Astronomers were familiar with the classical problem of perturbations, but the problem they now had to tackle was the entirely novel one of inverse perturbations in which one needed to describe the disturbances of Uranus and then infer the mass and orbital elements of the disturbing planet. Of course the story of how John Couch Adams and U.J.J. Leverrier solved this forbidding problem is now well known.[19] By the middle of 1846 Sir John Herschel, who knew of the mathematical researches of both Adams and Leverrier, looked upon the detection of a planet beyond Uranus as merely a matter of time. He declared: "We see it as Columbus saw

America from the shores of Spain. Its movements have been felt trembling along the far-reaching line of our analysis, with a certainty hardly inferior to that of ocular demonstration".[20] In England, James Challis at the Cambridge Observatory was trying to provide just such an ocular demonstration. The observing method that he was employing was that used in the searches for asteroids: that is, scrutinising an area of sky on several occasions and checking for sensible motions of any of the stars. But the method was to prove to be too slow and Challis was beaten to the prize of Neptune by the Berlin astronomers Galle and d'Arrest. Galle and d'Arrest had the enormous advantage over Challis of having an accurate star map of the zodiac complete to the ninth magnitude. In 1830, when no asteroid had been found for some 23 years, Bessel had suggested to the Berlin Academy of Sciences that such maps of the zodiacal region be constructed. Galle and d'Arrest were thus able simply to compare the area of sky around Leverrier's predicted position for the planet with the stars on the appropriate star map. Almost immediately they found Neptune. Unfortunately for Challis, who had already been searching for two months, this particular map had not even reached England on 23 September 1846, the date of Neptune's discovery.[21]

It is worth noting here that both Adams and Leverrier had exploited the Titius-Bode Law in their calculations, and as Uranus had done much to make this Law respectable,[22] it had pointed the way to Neptune in more than one way. But it is ironical that Neptune also led to the downfall of the Law, at least in its simple form. Observations of the new planet soon disclosed a distance much smaller than that predicted by the Law, roughly 30 astronomical units from the Sun instead of the predicted 38. This was much too large for the Law in its simple form to remain credible.

But so far I have not discussed what was the most far-reaching implication of Herschel's sighting of Uranus. This was that the discovery of the seventh planet marked a turning point in Herschel's life. He became famous almost overnight and soon with

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this fame came royal patronage.[23] Herschel was thereby freed from the need to make his living as a musician, and he was able to devote his entire energies to his passion for astronomy. Through his programme of research on the natural history of the heavens he broke with the traditional astronomy of the eighteenth century.[24] In so doing, he was to alter fundamentally the concerns, goals and techniques of astronomers. As a result, astronomy is still shaking with the consequences of Herschel's discovery of Uranus.

Notes

1. J.D. Titius von Wittenberg, translation into German from French of Betrachtung über die Natur, vom Herrn Karl Bonnett (Leipzig, 1766)7. The translation given is from p. 1014 of S. L. Jaki's "The early history of the Titius-Bode Law", American Journal of Physics, 40 (1972), 1014-1023. Jaki's paper gives a full account of the Law's early history. On this see also M. M. Nieto, The Titius-Bode Law of planetary distances: Its history and theory, (Oxford 1972) chapters 1-6.

2. J.E. Bode, Anleitung zur Kenntniss des gestirnten Himmels (Hamburg, 1772) second edition, 462. See also Jaki, op.cit. ref. 1, 1015.

3. See S. Schaffer"'The Great Laboratories of the Universe': William Herschel on matter theory and planetary life" Journal for the History of Astronomy, 11 (1980), 81-111, pp. 96-100.

4. See, for example, J. Ferguson, Astronomy explained upon Sir Isaac Newton's principles.... (London, 1756) 30.

5. This point is made by S. Schaffer in "Uranus and the establishment of Herschel's astronomy", Journal for the History of Astronomy, 12 (1981), 11-26, p. 15.

6. J. E. Bode, Von dem neu entdeckten Planeten, (Berlin, 1784).

7. Jaki, op. cit. ref. 1, 1019.

8. See F. von Zach, "Über einen zwischen Mars und Jupiter längst vermutheten, nun wahrscheinlich entdecken neuen Hauptlaneten unseres Sonnen-Systems", Monatliche Correspondenz zur Berförderung der Erd-und Himmels-Kunde, 3 (1801), 592-623.

9. J. E. Bode Mémoires de l'Acadamie Royale des Sciences et Belles-Lettres.... (Berlin, 1804) 141.

10. A helpful account of the discoveries of Ceres and Pallas is given in R. Grant, History of physical astronomy from the earliest ages to the middle of the nineteenth century, (London, 1852), 238-240.

11. Olbers to Herschel, 17 June 1802, quoted in C. Lubbock, The Herschel chronicle, (Cambridge, 1933) 272.

12. W. Herschel, "Observations on the two lately discovered celestial bodies", Philosophical Transactions, 92 (1802) 213-233.

13. Op. cit. ref. 12, 228.

14. Op. cit. ref. 12, 228-230.

15. Maskelyne to Gauss, 18 October 1804, quoted in E. Forbes "The correspondence between Carl Friedrich Gauss and the Rev. Nevil Maskelyne (1802-5)", Annals of science, 27 (1971) 213-237, p. 235.

16. L. Gilbert, "Ist der Ophion, (ein Planet der Uranusbahn,) ein noch unbekannter Weltkörper?", Annalen der Physik, 11 (1802), 482-485.

17. M. Grosser, The discovery of Neptune, (Cambridge, Mass., 1962) 47.

18. See J. Merleau-Ponty, "Laplace as Cosmologist" in Cosmology, History and Theology, (New York, 1977), edited by W. Yougrau and A. Breck, 283-291.

19. See Grosser, op. cit. ref. 17.

20. J. Herschel, letter on "LeVerrier's planet," Athenaeum, 3 October 1846, 109.

21. There had been earlier sightings but the planet had been mistaken for a star. It has recently been argued that Galileo saw Neptune: C. Kowal and S. Drake, "Galileo's observations of Neptune", Nature, 287 (1980) 311-313.

22. On the Law's high reputation see the comments of J.P. Nicholl Professor of Astronomy at the University of Glasgow: The phenomena and order of the Solar System, (Edinburgh, 1838) 238.

23. See Lubbock, op. cit. ref. 11, 78-132.

24. See the article by Dr. Hoskin in this volume as well as his William Herschel and the construction of the Heavens, (London, 1963) and Schaffer, op. cit. ref. 5.