HERSCHEL'S SCIENTIFIC APPRENTICESHIP AND THE DISCOVERY OF URANUS

J.A. BENNETT
Whipple Science Museum
Cambridge CB2 3RH

In 1784 Jean-Dominique Cassini, who as Director of the Paris Observatory was one of the foremost professional astronomers of his day, wrote

> 'A discovery so unexpected could only have singular circumstances, for it was not due to an astronomer and the marvellous telescope....was not the work of an optician; it was Mr Herschel, an English musician, to whom we owe the knowledge of this seventh principal planet (Schaffer, 1981, 21).

Cassini later altered his account to describe Herschel as a German musician. Astronomers were generally taken aback and not a little confused by the emergence of this musician from relative obscurity. He was, it seemed, possessed of uncommon astronomical interests, unconventional methods and well-nigh unbelievable instruments. At the same time he was unfamiliar with the norms and conventions that governed communication within the established community. Yet by the time Cassini was writing it was clear that Herschel had to be taken seriously, for he had a single outstanding achievement to his credit - he had added a primary planet to the Solar System, while the other planets had all been known before the beginning of written astronomy.

What were the astronomers to make of this musician? What was his background, his training, his knowledge of astronomy? Although the circumstances of Herschel's early life are fairly well documented, these questions can scarcely be better answered today, and in this paper we will look specifically at his scientific apprenticeship. What was its content? How did it prepare him for the discovery? How did it shape his reaction to the opportunity the discovery presented?

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We know that Herschel did not have a formal education in science, that he learnt his astronomy from the textbooks of his day in parallel with his own practical experiments and observations. The only clue we have to why he began is his own remark that a professional interest in musical theory led him to a general study of mathematics and in turn to a particular interest in optics and astronomy (Dreyer, 1912, xix). Robert Smith's textbook Harmonics, or the philosophy of musical sounds, according to this account, was naturally followed by his Compleat system of opticks in four books .... a popular, a mathematical and a philosophical treatise.

Given Herschel's character, the account is plausible enough. His sister Caroline once referred to the 'uncommon precipitancy which accompanied all his actions' (Lubbock, 1933, 67). She was referring to a characteristic physical enthusiasm, and physical energy and stamina were to be vital to his chosen astronomical career, but the same comment might be made of his intellectual character. He was ever alive to new interests and fresh possibilities, and with great resourcefulness and single-mindedness he undertook programmes of study and research that were ambitious in the extreme. In the light of his other undertakings it is relatively easy to imagine Herschel coming to astronomy through reading widely in the mathematical sciences.

There are two notes of astronomical interests in his diary or 'memoranda' for 1766 (Dreyer, 1912, xix), but nothing of significance until 1773. In April 1773 Herschel bought a Hadley quadrant and a copy of William Emerson's textbook The elements of trigonometry (ibid., xxii, xxiv). An octant or Hadley quadrant was, of course, commonly used for finding latitude at sea, and seems an unlikely instrument for him to choose. By 1778 he was using it to check his clock by the method of equal altitudes (RAS MSS Herschel W2/1.1, 78). In May 1773 he bought what was, so far as we know, his first book on astronomy (Dreyer 1912, xxii, xxiv). This was James Ferguson's Astronomy explained upon Sir Isaac Newton's principles, and made easy to those who have not studied mathematics.

In the same month Herschel began to construct telescopes, but these were not the reflectors with which he is always associated.

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He began in fact by buying object glasses of 4, 12, 15 and 30 feet focal lengths and mounting them in tubes (Dreyer, 1912, xxiv). The problems of managing long telescopes persuaded Herschel to turn to reflectors, and by September he had a copy of Smith's Opticks and was starting to grind and polish mirrors. It is interesting to see that telescopes were playing an important part at the very beginning of Herschel's astronomical interest. Their importance continued throughout his career, and I will argue that it was his early success in telescope building that largely determined Herschel's eventual specialist interests in astronomy.

What other books did Herschel read during his apprenticeship? In October 1773 he bought Emerson's The elements of optics (ibid., xxii), which like Smith was based firmly on Newtonian theory. It was technical and fairly dull. Emerson dealt with instruments, though in a less practical way than Smith, but unlike Smith did not treat any astronomy. By 1776 Herschel had added to his library Emerson's The principles of mechanics (ibid., xxv), which dealt with both theoretical and practical mechanics, including the design of machines, and so was useful in his practical work.

Also by 1776 we know that Herschel had Colin Maclaurin's textbook on analytical geometry, A treatise on fluxions, and probably a similar textbook by James Hodgson (ibid., xx). Herschel later recorded that after a long day's work as a professional musician and music teacher, he would use 'a few propositions in Maclaurin's Fluxions' to, as he put it, 'unbend the mind' (Lubbock, 1933, 59).

By 1780 Herschel was familiar with Joseph Priestley's works on light and on electricity, with John Keill's Introduction to the true astronomy, based on his astronomy lectures at Oxford, and with Lalande's Astronomie. (Dreyer, 1912, lxxii, lxxviii, xcvii, cv, 7, etc). In general we can say that Herschel was well served by his informal education in astronomy. He had available textbooks which were both sound and serious, and although popular, in the sense that they assumed no knowledge of the subject, demanded discipline and application if they were to be mastered.

There seems no doubt that Ferguson and Smith had the greatest influence on Herschel. Smith gave him his basic grasp of casting, grinding and polishing mirrors, constructing stands and applying micrometers. Smith dealt also with observational astronomy by running through all the phenomena that might be seen with a telescope. Yet it is difficult not to feel that emotionally Herschel had more sympathy, not with the Cambridge professor Robert Smith, but with his fellow amateur and mechanic James Ferguson.

In his first chapter Ferguson presents his readers with a dramatic and striking view of the universe, which in general terms resembled the one Herschel adopted and attempted to work out in detail. It was presented also with an enthusiasm which Herschel would have appreciated. Traditional, academic, respectable, professional astronomy in the eighteenth century was concerned with the solar system, with the ramifications of Newtonian celestial dynamics and with the navigational, horological and geographical applications of technical precision astronomy. To all this the fixed stars were little more than a convenient backdrop. Ferguson's enthusiasm, however, encompassed the <u>whole</u> universe, which he presents as an immense three-dimensional heavens, having many planetary systems all populated by rational beings, so that the solar system was only one example of its kind.

> 'What an agust! what an amazing conception, if human imagination can conceive it, does this give of the works of the Creator! Thousands of thousands of Suns, multiplied without end, and ranged all around us, at immense distances from each other, attended by ten thousand times ten thousand worlds, all in rapid motion, yet calm, regular, and harmonious, invariably keeping the paths prescribed them; and these worlds peopled with myriads of intelligent beings, formed for endless progression in perfection and felicity! (Ferguson, 1778, 6)

Herschel, of course, made the starry heavens and their three-dimensional arrangement his particular domain. Ferguson's enthusiasm was no doubt one reason for this, though we shall see that Herschel's telescopes were a more immediate stimulus. He also enthusiastically adopted the idea that the whole universe was populated by rational beings, and this included the Moon and the other planets in our system. Ferguson too imagined rational creatures on the Moon, even though he had argued that there was no atmosphere.

We find other links with Herschel in Ferguson's text. Ferguson suggests that a star's brightness is a fair indication of relative distance, and that the Sun is a typical star (ibid., 38) - two assumptions that would be important for Herschel. He also thinks that comets have a role to play in refuelling the Sun (ibid., 39) and the stars (ibid., 355) - another idea that attracted Herschel and one that derived from Newton (Schaffer, 1980, 97). Incidentally, Ferguson also thought that comets were inhabited by beings in an especially privileged position to appreciate the wonders of the heavens (Ferguson, 1778, 39).

The section of Ferguson's book that was perhaps most significant for Herschel was his treatment of the nebulae, which he calls either 'lucid spots' or 'cloudy stars'. The Orion nebula he describes as 'the most remarkable of all the cloudy Stars', and says that

> 'It looks like a gap in the sky, through which one might see (as it were) part of a much brighter region. Although most of these spaces [the 'nebulae'] are but a few minutes of a degree in breadth, yet, since they are among the fixed Stars, they must be spaces larger than what is occupied by our Solar System; and in which there seems to be a perpetual uninterrupted day among numberless Worlds, which no human art ever can discover (ibid., 353)

Smith had painted a similarly intriguing picture of the Orion nebula (Smith, 1738 ii, 447-8), and both accounts derived from a short paper in the Philosophical transactions published in 1716 (Phil.trans., 29, 1714-16, 392) and generally attributed to Halley.

My selections from Ferguson probably do not give an accurate impression of his book. Much of the text is fairly mundane and technical, though not advanced, but it is interspersed with his enthusiastic view of the subject as a whole.

Herschel's first year of serious astronomy is evidence in itself of his 'uncommon precipitancy'. Between May 1773 and March 1774 he assimilated the astronomy of the popular textbooks, mounted several long refractors before rejecting their use for good, arranged to have blanks cast in speculum metal, learnt the basic techniques of grinding and polishing the mirrors by hand, mounted one finished primary mirror in a Newtonian telescope, and began his 'Journal' of observations. All of this was done during what time he could spare from his extremely demanding musical life. It is difficult to know how representative are the entries in his very meagre diary, but on 8 November he recorded 'Attended 40 scholars this week. Public business as usual', and on 15 November, 'Attended 46 private scholars; nearly 8 per day' (Dreyer, 1912, xxii). Spare time during November was spent polishing. For January, when he was setting up the telescope, he writes, 'Gave 6,7 and 8 private lessons every day'. For March he writes, 'Nearly the same number of scholars. Astronomical journal begun'.

The telescope was, as I have said, a Newtonian of 5½ feet focal length, and an aperture of perhaps 4½ inches (RAS MSS W.5/12.1, 2; Dreyer, 1912, i, 109). This was a very respectable size for a maker with only a few month's experience. To give some idea of contemporary limitations on reflectors, James Short, the famous maker who had died in 1768, offered a six foot reflector of one foot aperture, but the price was 300 guineas (King, 1955, 86) - more than the annual salary of the Astronomer Royal.

On 1 March 1774 Herschel began his astronomical journal in a folio volume that now forms the first of a series of twelve preserved in the Archives of the Royal Astronomical Society. (RAS MSS Herschel W.2/1.1-12). It is not surprising, in view of what he had read in Smith and Ferguson, that his attention on his first evening's observing was directed to Saturn and the Orion nebula. He observed Saturn again on 2 March and the Orion nebula on 4th. Volume one of the Journal is a fascinating record of Herschel's first original work in astronomy, and of more immediate interest than the subsequent volumes, for in the early years he recorded, not only his observations, but also his ideas, his speculations and his plans for the future. The entry for 4 March, for example, on the very first page, shows that already questions of central importance in his future research were beginning to take shape:

> 'Saw the lucid Spot in Orions Sword, thro' a 5½ foot Reflector; its Shape was not as Dr. Smith has delineated in his Optics; tho' something resembling it....from this we may infer that there are undoubtedly changes among the fixt Stars, and perhaps from a careful observation of this Spot something might be concluded concerning the Nature of it. (RAS MSS Herschel W.2/1.1, 1)

During March and April of 1774 Herschel was mainly interested in observing Saturn and its satellites, but he looked again at the Orion nebula, and he also found his first double star:

> 'Observed the last but one in ursa Major's tail which is a double Star, and found when I magnify'd 211 times that it appeared very plainly to be double; being then separated nearly (as one might say) a couple of inches the lower being considerably larger than the other. (RAS MSS Herschel W.2/1.1, 5)

These few observations mark the end of Herschel's first burst of astronomical activity, at least so far as we can discover from surviving manuscripts. It had lasted for about a year and for some two years from April 1774 only a few observations are recorded. Some of these are of eclipses of Jupiter's satellites, and they occasioned Herschel's earliest contact with the professional astronomical community, for he exchanged letters on the subject of these eclipses with the Radcliffe observer, Thomas Hornsby (RAS MSS Herschel W.1/13. H.23, 24).

Just as we might imagine Herschel's enthusiasm to be waning, a note in the Journal, which can be dated approximately to the summer of 1774, gives an important clue to how his plans were developing:

> 'If the nearest fix'd Star be 32 Billions of miles from our Sun, and of the same Bigness what angle will it subtend at the naked Eye and what must be the Magnifying power of a

Telescope to make it of any visible Diameter. (RAS MSS Herschel W.2/1.1, 7)

He then devotes a few pages to this problem. Herschel had already had the pleasure of separating double stars, and was clearly beginning to wonder how far he would be able to go in improving his telescopes and applying them to the stars. In particular, might he be able to enhance his light-grasp and definition such that the application of very high magnifications would reveal the true apparent diameters of the stars? It is significant that the next developments of any importance in Herschel's astronomy involved a striking improvement in his telescopes.

The year 1776 marks the second surge in Herschel's activity. We have little record of his work on their construction, but in the space of three months he introduced three new telescopes and dramatically increased his observing capability. We have seen already that he had in mind an attempt on the true apparent diameters of the stars, and for this he would need to increase not only magnification but also light-grasp and quality of definition.

On 1 May 1776 he noted 'Observed Saturn with a New Reflector Focus 7ft'. On 28 May he introduced a 10ft reflector,and on 13 July he wrote 'I had a very good view of Saturn with a new reflector of 20ft Focus' (ibid., 13, 25). Telescopes of 7, 10 and 20 feet focal lengths, whose apertures were respectively 6.2, 9 and 12 inches, served Herschel for the remainder of his time at Bath, and he would have nothing larger for over seven years. Yet in the meantime there were plenty of improvements to be made.

First the stands were continually being reviewed and underwent frequent changes, aimed at more convenient management (for details and references on the telescopes, Bennett, 1976). We know that in 1778 Herschel arrived at the familiar design used for the 7ft and 10ft telescopes. It was a model of economy and convenience, for the observer had every motion - coarse and fine vertical and fine lateral - ready to hand while viewing at the Newtonian focus, and in addition could observe in almost any altitude from a comfortable standing position. The drawing by William Watson of Herschel's own 7ft was made in 1783, and the design was used subsequently for all the 'small' telescopes he made.

The mounting of the 20ft (the 'small 20ft'), however, was far from convenient. For some time Herschel had to be content with modifying the standard mount for a long refractor, which he must, of course, have used himself in 1773. This consisted simply of a single pole and a system of pulleys for raising one end of the tube: essentially the same arrangement as had been used since long refractors were introduced in the mid-seventeenth century. A long reflector, however, was a novelty and Herschel, of course, needed to position himself close to the Newtonian focus - hence the simple expedient of a free-standing ladder. The result was somewhat crude and _ad hoc_, though Herschel, again using strings and pullies, managed to arrange fine vertical and lateral motions controlled by the observer. The result was not only _ad hoc_ but uncomfortable for the observer, and very susceptable to wind disturbance. On one night in April 1777 he gave up after, as he noted, 'the uneasy posture and cold prevented farther Observ:' (RAS MSS Herschel W.2/ 1.1, 42) but in general his perseverance with this instrument was admirable. On later occasions he was even prepared to continue while keeping his ink bottle in his hands, to prevent the contents freezing (_ibid_., 5, 16).

While developments in stands represent one line of improvement, figuring and polishing the mirrors was of more critical importance. All of Herschel's early grinding and polishing was done by hand - by moving the speculum metal mirror on top of the brass tool or the pitch polisher - and the manipulative skills he acquired by long and laborious experience were fundamental to his success as a telescope maker. A serious programme of long and tedious experiments in polishing began in earnest in March 1778, with Herschel trying all sorts of materials and techniques and carefully recording the results he achieved. Eventually the mirrors improved markedly in quality, and in particular, on 14 November, recording a repolishing of one of the primary mirrors for the 7ft, he says 'I used the divided reducing stroke of the 170th experiment, and in a very short time made it a most capital speculum' (RAS MSS Herschel W.5/12.1, 42). It was when using this mirror that he later discovered Uranus.

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But before this a third component in the link between the heavens and the astronomer would have to be refined. In addition to his stands and his mirrors Herschel would need to develop his own sensitivity as an observer, and this he proceeded to do in a systematic way. 'Seeing is in some respect an art, which must be learnt', he wrote to William Watson (RAS MSS Herschel W.1/1, 17-18), and his learning technique was disciplined in a way not unlike his musical training. We have seen that he was interested in applying the maximum possible magnifying powers, and when he was able comfortably to observe with a particular power, he would then purposefully apply a higher one than he found easy to use (ibid., 27). When Herschel's work eventually became known, the extravagant powers he claimed sometimes to use (of up to 6,000) were generally doubted or frankly disbelieved, and Herschel explained the ability he had acquired by a musical comparison: 'To make a person see with such a power is nearly the same as if I were asked to make him play one of Handel's fugues upon the organ' (ibid., 17-18).

It is important to notice how early Herschel was equipped with the best reflecting telescopes in existence. His telescopes and his research programme always influenced each other, and it is difficult to say at any time which was determining the character of the other. Questions such as the nature of the Orion nebula and the true apparent diameters of the stars were early stimuli to building telescopes with large apertures, but Herschel's early success in telescope making was, in its turn, an important determinant in the kind of astronomy he would undertake.

We can take up the record of the Journal once again to discover what Herschel was observing with his greatly enhanced range of instruments. The 7ft we saw was first trained on Saturn and on 28 May he writes:

> 'This evening I tryed a new ten foot reflector first on the Moon. with the Eye glass it had, it magnifyed 240 times very distinctly. The Moment I saw the Moon I was struck with the appearance of something I had never taken notice of before which I immediately took to be woods or large quantities of growing Substances in the Moon.' (RAS MSS Herschel W.2/1.1, 13)

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The next page or two are devoted to this exciting discovery and to drawings of the lunar forests, with the conclusion that the appearance of the so-called seas 'can be solved no other way than by admitting....[them] to be Forests or some kind or other of Trees or Plants.' Naturally the Moon was observed again a number of times during 1776, as was Saturn. There is also one detailed account of the Orion nebula.

The general impression of the Journal so far is that Herschel had no very definite aims - no research programme that might regulate the telescopes' use in a systematic way. The observation pattern seems largely unstructured. The same is true of the year 1777, though he did begin to observe Mars, Venus and Jupiter, as well as Saturn, and became interested in the variable star Mira Ceti. This marks the beginning of work that would eventually form part of the first three papers he presented to the Royal Society, two in May 1780 and one in January 1781. They concerned Mira Ceti, the rotation of planets and the heights of mountains on the Moon. This last paper was published only after Herschel had agreed to remove passages about the lunar inhabitants (Dreyer 1912, xc - xci).

In January 1778 the Journal grants us another glimpse into the development of Herschel's thinking. In several fascinating pages, full of implications for what was to come, he begins to speculate about the three-dimensional arrangement of the stars, supposing that fainter stars are more distant and that in general stellar magnitude is a gauge of distance. He also develops the ideas behind the method that had first been suggested by Galileo for detecting stellar parallax. Without a measured parallax the quantitative information basic to a study of the heavens in three dimensions was not available, and the traditional fixed instruments with graduated arcs had so far failed to find it. If, however, micrometric measures were taken of close pairs of double stars, a parallax might well be detected, especially if the members differed greatly in brightness. Some such pairs would be optical doubles, with one member much more distant than the other, and the distant star could be regarded as a fixed point against which to measure the motion of the other. One particular advantage of the method was that no attention need be paid to the known disturbing influences such as refraction, aberration, etc. Herschel writes:

> '... it is evident that nothing can be gained by this Method, except that we hereby reduce the annual parallax of a Star to a quantity that may be estimated by actual Inspection and is not liable to the accidents that render the Observation of so small an angle with any degree of precision next to impossible. Let us therefore examine to what degree of perfection a Telescope must be had in order to discover a Parrallax [sic] on the supposition that it is but .1".'
> (RAS MSS Herschel W.2/1.1, 50-51)

So again the question is seen in relation to perfecting the telescopes, and of course it is significant that he had such fine instruments, well suited to the task, before the plan was conceived.

There followed a few attempts to find suitable double stars, but nothing systematic, and Herschel quickly resumed his planetary observations. However on 5 March he returned to the double star he had first seen four years previously:

> 'I directed my Telescope out of Curiosity to the double Star in the Bear and if I am not very much mistaken in the Eye piece I formerly used for this purpose the Stars were closer together this Evening than when I observed them last. This shall be farther examined and ascertained by proper experiment.' (ibid., 72-3)

But for 12 March we find:

> 'To my great disappointment I found the Stars in the tail of Ursa Major just as I saw them three months ago, at least not visibly different.' (ibid., 75)

On the same evening he found no change in the Orion nebula.

So the observations continue on the usual subjects through 1778 and 1779 - Saturn, Jupiter, sometimes Mars, very occasionally the Orion nebula. In July 1779, however, we come upon another speculative interjection, and find Herschel back with his old quest for the true apparent stellar diameters. For a moment he feels that the perfection of his telescopes has now achieved this illusive goal. On 17 July he writes:

'The Evening being very fine my Telescope bore a power of 280 and convinced me that the Stars are of a Sensible magnitude as I could see Arturus's Body very well defined. Also the 2d Star in the Bear's tail which is double showed both the bodies very distinct. from this some consequences may be drawn different from what has been comonly believed heitherto [sic].' (ibid., 107)

When Herschel's work became generally known, the fact that his telescopes showed the stars 'round and well defined' did indeed cause a considerable stir among astronomers (Lubbock, 1933, 90-102). He himself drew out the consequences he had mentioned on the following evening, 18 July:

'I continued my Observation in the Stars found the Stars in the Bear, the pole Star, Altair & Star in the Crown all of a visible but unequal magnitude.

Question. Suppose a Star of the first magnitude equal to our Sun, to subtend an angle of 1" at the Naked eye what is its distance and what will be the annual parallax of the Orbit of the Earth. Let the Sun be 32' or 1920" and let the Distance of the Sun be 100 Millions of Miles. then the Distance of that Star must be, 192,000,000,000 Miles.

Next, what will be the parallax of the Earth's Orbit, answer near 2 minutes, or rather 4' taking the whole diameter of it.

Next question is - Suppose the anual parallax of the Diar of the Orb to be 2" what will be the Size of a Star to subtend an angle of 1" at the naked Eye.

The distance in that case must be 20, 626, 400 Millions, and to subtend ~1" at that Distance the real Diar must be 107 times as large as that of our Sun. From this, it should seem that the Optic illusions represent the Diar of the Stars much larger than they are. Or on the other hand, that there are hopes that an annual parallax may be found.

The Method of two Stars must be resumed. their Situation ought to be near the pole of the ecliptic, and the difference of their Magnitudes as great as possible, also their distances should not exceed 2" or 3".

This Method has the superior excellence that none of the known causes such as aberation, Nutation, refraction, or any kind of Libration in the Earth's axis can effect it.' (ibid., 107-108).

So, if Herschel is within reach of the true apparent stellar diameters, either, on the one hand, the stars are very much larger than the Sun, or, on the other, the annual parallax by the method of double stars can be found. On 17 August, 1779 he began what he called his 'second review of the heavens' (RAS MSS Herschel W.2/2.1) with a very clear purpose. It was a systematic search for double stars, employing the 7ft telescope and using a power of 227, and resulted in a catalogue of 269 specimens presented to the Royal Society.

From that point on the discovery of Uranus was assured. Herschel was now equipped with very fine telescopes and a visual sensitivity atuned to their use, and the sky was to be completely reviewed. He later wrote:

'It has generally been supposed that it was a lucky accident that brought this new star to my view; this is an evident mistake. In the regular manner I examined every star of the heavens, not only of that magnitude but many far inferior, it was that night its turn to be discovered.... Had business prevented me that evening I must have found it the next, and the goodness of my telescope was such that I perceived its visible planetary disc as soon as I looked at it..' (Lubbock, 1933, 78-9)

The close of 1779 is noteworthy for Herschel's meeting with William Watson and his introduction to the Bath Philosophical Society. During 1780 he presented papers to the Society on a range of scientific topics, and two minor astronomical papers were communicated by Watson to the Royal Society of London.

The year 1781 began with plans for a really large telescope. Herschel wrote in his polishing journal:

'Having long ago intended to make a very large reflector, as soon as I should find myself sufficiently acquainted with the method of constructing specula, I now began to project the following instrument.' (RAS MSS Herschel w.5/12.1, 48) This was to have been a telescope of 30ft focal length with a primary mirror originally intended to be of 4ft diameter, and work was begun on the mounting. In principle the mount was not unlike that for the small 20ft, though an observing platform was to be included within the support for the tube.

On Tuesday 13 March 1781 Herschel was proceeding with the review in the search for double stars and so observing with his 7ft telescope. He found what he noted as 'a curious either Nebulous Star or perhaps a Comet' (RAS MSS Herschel W.2/1.2, 23). Uranus had, of course, been observed before and mistaken for a star. With Herschel's telescopes it was noticeably non-stellar and had at last been recognized as worthy of individual attention. He found that, like a planet, its apparent size increased in proportion to the powers he applied to it. On Saturday 17 March Herschel noted:

> 'I looked for the Comet or Nebulous Star and found that it is a Comet, for it has changed its place.' (ibid., 24)

The assumption that he had found a comet was the natural one to make, and Herschel quickly informed Maskelyne at Greenwich, Hornsby at Oxford and the Royal Society (Schaffer, 1981, 13). Although he continued to observe his comet, a determination of its orbit would require the kind of instruments that Herschel did not possess. As he wrote to Watson:

> '... my apparatus being but ill-adapted to such observations as are necessary to settle the orbit of a Comet, which may be much better done in a regular Observatory, I resign it to abler hands (ibid.)

Meanwhile Herschel pursued his search for double stars and made plans for casting the primary mirror of his new telescope - an instrument designed for what was now his chosen specialism, sidereal astronomy.

The story of the immediate consequences has often been told and I will not repeat it in detail. The recognition of the planetary status of the new discovery came gradually. As early as 4 April Maskelyne wrote to Watson of Herschel's 'comet or new planet' (RAS MSS Herschel W.1/13.M. 14) and on 23 April he wrote to Herschel:

> 'I am to acknowledge my obligations to you for the communication of your discovery of the present Comet, or planet, I don't know which to call it. It is as likely to be a regular planet moving in an orbit nearly circular round the sun as a Comet moving in a very excentric ellipsis. I have not yet seen any Coma or tail to it.' (ibid., M. 15)

On the other hand, as late as February 1782, Hornsby could write to Herschel of his 'comet':

> 'It is the fashion I think now to call it a new star or planet, but I cannot help thinking that it will prove to be a comet.' (ibid., H. 29)

Part of the problem at the time was semantic. Comets are in orbit round the Sun, and this body was certainly placed in a very much larger orbit than the known planets. The question of the precise status of the comet, Hornsby notwithstanding, had come to a head around November 1781, when Herschel's discovery had been judged sufficient qualification for the Royal Society's Copley Medal. In replying to Sir Joseph Banks's letter informing him of the award, Herschel responded to the question of his comet's status with his usual enthusiasm for speculation:

> '... a Body is now exposed to the attention of Philosophers, which may prove to be either a new Planet or perhaps a star that may partake both of the nature of Comets & Planets, and be, as it were, a Link between the Cometary and Planetary Systems, uniting them together by that admirable connection already discover'd in so many other parts of the creation....'

and since it will at least be visible for many years,

> '... we may probably become perfectly acquainted with its real nature & thereby obtain a still more extended view of the wonderful order that reigns throughout the whole solar and sydereal System'(RAS MSS Herschel W.1/7).

As well as the status of his comet the astronomers were during 1781 concerned with other questions relating to Herschel: his claims of very large magnifying powers, doubts and disputes over his micrometer measurements on the comet, his seeing the stars round and well defined. There was also much curiosity over the musician from

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Bath. Maskelyne's letter of 23 April is full of questions about Herschel's telescopes, their stands, their micrometers, whether he casts his own mirrors, etc. Many questions had to be answered before Herschel's new status in the astronomical community was assured.

He too would learn from this period of probation, for in his isolation he had been genuinely unaware of how uniquely well equipped he had become. When he eventually visited Greenwich and compared his 7ft with the telescopes available to Maskelyne, he realized the exciting possibilities that lay ahead. 'Let me but get at it again!' he wrote to his sister Caroline, 'I will make such telescopes and see such things...' (Lubbock, 1933, 116).

By the summer of 1782 the queries surrounding Herschel's comet and his methods and apparatus had been sufficiently clarified for his friends to lobby successfully for a permanent astronomical position for him. Granted a stipend by George III, he moved from Bath to near Windsor at the beginning of August.

The popular view of the significance of the discovery has always been a romantic one, and justifiably so: an obscure amateur, observing in his back garden with a home-made telescope discovers the first primary planet to be found since the dawn of history. Yet the more important significance for the development of astronomy was that the discovery gave Herschel his opportunity: it gave him a position in the scientific community and the chance to devote himself to astronomy. As an outsider, unrestricted by the established pattern of the professional astronomy of his day, he chose a novel theoretical domain, for his subsequent planetary work was always secondary to his work on what he called 'the construction of the heavens'.

In this sense it was fortunate that the discovery fell to Herschel, for who else possessed the energy and vision - the sheer audacity - to undertake a programme that required him to build huge telescopes for penetrating deep into space and to speculate in a wholly new theoretical domain that embraced the entire universe?

We began with the comments of the Director of the Paris Observatory. On 8 August 1782 Herschel had only just moved to

Windsor when the Astronomer Royal, Nevil Maskelyne, wrote him a letter which seems to represent an official recognition of his position in the astronomical community and an official sanction on the new career he was about to begin:

> 'Astronomy and Mechanics are equally indebted to you for what you have done; the first [sic] for your shewing to artists to what degree of perfection telescopes may be wrought; and the latter [sic] for your discovering to Astronomers a number of hitherto hidden wonders in the heavens, which could not be explored before for want of telescopes equal to yours; and they are both likely to receive equal improvement from it in the construction of better telescopes, and in the application that may be made of them to the heavens for repeating and extending your observations. I hope you will do the astronomical world the faver to give a name to your planet, which is entirely your own, & which we are so much obliged to you for the discovery of.' (RAS MSS Herschel W.1/13 M 20)

Maskelyne could scarcely have guessed where it would all lead. With Herschel's move from Bath the immediate consequences of the discovery were complete. The far-reaching consequences had barely begun.

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NOTES

William Watson's drawings of the 7ft and small 20ft telescopes are reproduced in Bennett 1976.

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