Huygens, Titan, and Saturn's ring

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1 Introduction

The received story is that Christiaan Huygens made superior telescopes, which allowed him to discover a satellite of Saturn (now called Titan) and to see that the planet is surrounded by a ring. This version of the events partially goes back to Huygens himself, who argued that since he had been the first to see the satellites, his telescopes were the best; as a consequence, he was able to divine the true shapes of Saturn's 'anses' ('handles', from *ansae*) where others had been fooled by inferior instruments, and thus he was entitled to discard any previous observations that did not fit his ring-theory. In this paper I want to examine this account in the light of evidence that has come to light in the past half-century, and present a hopefully somewhat more accurate version of the events. Huygens stood at the centre of a major change in the instrumentation of astronomy that took place between 1650 and 1675 and that was marked by a second wave of celestial discoveries. It is therefore natural to ascribe his discoveries to his superior instruments. But, although his telescopes were very good and he understood their workings better than anyone else, it was ultimately the quality of his mind more than the quality of his instruments that resulted in his celestial discoveries.

2 Telescopes, reputations, and celestial novelties

The telescope most confidently ascribed to Galileo himself [i] had apertures of 15 mm. If we assume a diameter of the dark-adapted pupil of 6 mm, then this instrument gathered about 6 times as much light as the naked eye, but in this type of telescope not all the light enters the eye of the observer.[ii] The instrument thus allowed an observer to see celestial objects of rather less than two magnitudes smaller than the faintest naked-eye object, a 'star' of the sixth magnitude.[iii] Now the magnitudes of the satellites of Jupiter range from 5 to 6, which would ordinarily make them just visible to the naked eye, but the brightness of Jupiter itself hid them from view. Galileo's telescope

[i] Telescopes with a concave ocular. For details of their construction, see [1]

[ii] The pupil of the observer is smaller than the beam of light exiting the ocular – see [2]

[iii] The modern definition of stellar magnitude – designed to fit best with historical magnitude designations – is that an increase of five magnitudes represents a hundredfold increase in light. One magnitude is thus a factor of 2.5. Note that in the seventeenth century, the word 'star' was still often used to refer to a planet or moon.

gathered just enough power to make them clearly visible. These 'Medicean Stars' made Galileo famous, and the discovery of a moon or planet did the same for other astronomers.

Figure 1: Saturn as observed by Galileo in July 1610 (Opere, 10: 410)

Obviously, Galileo examined the other planets as they came into favourable positions for observing. He was rewarded (or so he thought), when, in July 1610, he saw Saturn flanked by two close 'companions' (Figure 1). But, as he quickly discovered, these lateral bodies did not move with respect to the central body. Whatever they were, they were not moons like those of Jupiter. And so, whereas he observed Jupiter's moons whenever possible, in order to determine their periods so that he could predict their positions,[iv] he only looked at Saturn and its companions from time to time, convinced as he was that their positions did not change at all.

Until 1612, that is, when he suddenly found them gone! In his third sunspot letter, written in the autumn of 1612, he expressed his astonishment at this development, and then cautiously offered a possible scenario for their return. This scenario, as has been shown recently, was based on a satellite model: the companions' visibility depended on the relative positions of Saturn and the Earth. Indeed, the companions did return pretty much as Galileo had predicted, and assumed their former positions flanking the central body.

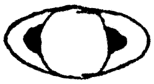

Figure 2: Galileo's observation of the "handled" appearance, 1616.(Opere, 12: 276)

After again not observing them for some time, Galileo found in 1616 that, although the lateral bodies had not moved, they had grown and taken on the shapes of 'half eclipses', in the shapes of handles, or 'anses' (Figure 2).

That his instruments could present a shape of the anses that we can hardly not interpret as a ring is shown by a sketch Galileo made in 1616.[v] And we can thus say that in the case of Saturn there was more to seeing than meets the eye. The scientific problem for Galileo and his successors was making sense out of *all* the shapes presented by the planet's attachments – from small spheres to large handles – and how the changes came about.

Between 1612, when Galileo first observed that Saturn's 'companions' had (temporarily) disappeared, and 1642, when this happened again,[vi] there was little progress in the study of Saturn and his companions. It was generally believed that an explanation had to be found in terms of a satellite model (Figure 3), but observations showed Saturn in a large variety of appearances.

[iv] Galileo and others quickly figured out that the configuration of the Jupiter and its moon was, as it were, a celestial clock. It therefore offered a solution to the problem of longitude at sea. In 1612, Galileo observed an eclipse of one of the moons by Jupiter. These disappearances and reappearances of the satellites are virtually instantaneous, and thus offered an extremely precise version of this method, provided that these events could be accurately predicted.

[v] Although the sketch has no accompanying text, all entries surrounding it are dated between June and October 1616. [3]

[vi] Except for a passing reference by Galileo, the solitary appearance of 1625-27 passed unnoticed [4].

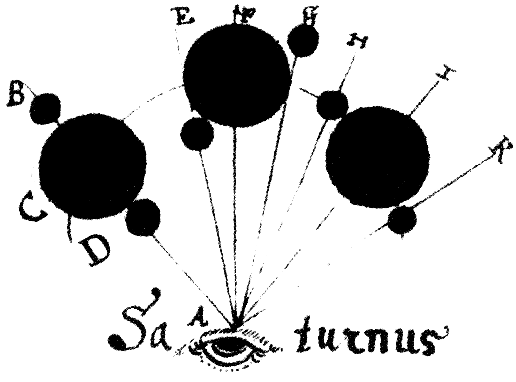

Figure 3: "Satellite model" to explain Saturn's appearances. From Christoph Scheiner, "Tractatus de Tubo Optico." (*Munich, Bayrische Staatsbiobliothek, MSS Clm. 12425, p. 65)*

A selection of observations made by Pierre Gassendi (1592-1655) illustrates this (Figure 4).

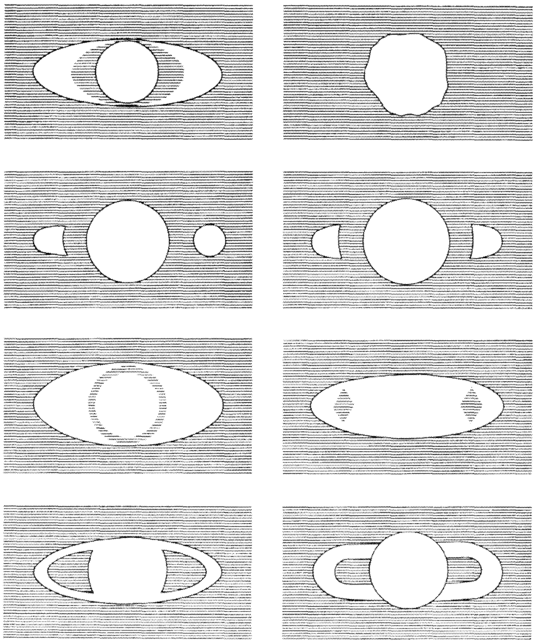

Figure 4: Observations of Saturn by Pierre Gassendi, 1630-1655. From Journal for the History of Astronomy 5 (1974): 26. (Courtesy of Science History Publications)

Gassendi was, however, one of only a handful of observers who regularly studied the heavens through telescopes[5] – instruments of questionable quality. (The lenses sent to him by Galileo in 1636 did not improve the quality of his observations[6].) In the early 1640s, when the problem of Saturn's appearances was three decades old, and the lateral bodies were becoming smaller and smaller, heralding a 'solitary' appearance, interest among astronomers grew. The number of observations of the planet now increased rapidly, and by the time of the next solitary appearance, in 1655/6, a significant body of observations could be found in books and letters. During this period, the handled appearance replaced the triple-bodied one as the primary one, a step in the right direction. But the centre of the problem was still to reconcile these two appearances in an explanatory theory, and the published observations often were contradictory: after all, Saturn was difficult to observe, and the lenses of the telescopes were primitive.

But telescopes were getting better. During this period, the Galilean telescope with its concave ocular was being superseded by the simple astronomical telescope with its convex ocular. This instrument gave a larger field of view, which in turn made higher magnifications possible. Telescopes with more than two (convex) lenses[vii] were introduced by Johannes Wiesel of Augsburg and popularised by the Capuchin monk Antonius Maria Schyrlaeus de Rheita. In 1643 he claimed to have discovered a large number of moons of the superior planets. His claim was dismissed by Gassendi and others[7], and the general opinion was that there were no further moons to be discovered. Huygens was to prove this idea wrong.

3 Huygens and Titan

By 1654, as the anses had shrunk again down to little spheres and the next solitary appearance was approaching, interest in the problem of Saturn reached a new height, and this time astronomers were ready to publish their theories to explain Saturn's appearances. With one exception, they were prompted by a challenge issued by Christiaan Huygens. With his brother Constantijn, Christiaan had begun grinding and polishing lenses, and in February 1655 they finished a 12-foot (ca. 350 cm) telescope. Its objective had an aperture of about 30 mm, and, as in all astronomical telescopes, all the light gathered – roughly 25 times as much as the naked eye – by the objective entered the eye. This telescope could thus show stars three magnitudes fainter than the naked eye. On 25 March, as Huygens was examining Saturn to see its gradually disappearing anses, he noticed a small 'star' on the extension of the anses. On that day, the magnitude of Titan was 8.2, and it was therefore comfortably visible with this telescope. Huygens thought it might be a moon of Saturn, and his guess was confirmed during the following days, as the little moon travelled back and forth on a line through the planet's anses with a period of roughly 16 days.

It is astounding that with his very first research telescope and little experience as an observer Huygens was able to detect the satellite. The more so since the objective of this telescope (preserved in the museum of the university of Utrecht) was by contemporary standards not particularly good.[viii] There were several observers in Europe with comparable – perhaps even better – instruments. Why, then, did they not discover the satellite? It is not clear that others were actually looking for satellites. The moons of Saturn move in the plane of the ring, and therefore only when the ring is edge-on do they appear to travel back and forth in a straight line, as Jupiter's satellites do. At all other times, the satellites move around Saturn in apparent ellipses, and they do not stand out among the neighbouring fixed stars. Perhaps the other observers whose instruments could have revealed the satellite were

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[vii] The simple astronomical telescope produces an inverted image. Erector lenses therefore became common. In addition, the field lens made its first appearance in the 1640s.

[viii] This lens was tested in 2000 by Ir. Rolf Willach, by means of a Ronchi interference test. It is substantially overcorrected near the edges, and the practical aperture is ca. 3 cm.

convinced that there were no satellites around Saturn. Perhaps they were unlucky – or Huygens was lucky. Huygens scratched his name on the lens and the information *X [pedem] 3 FEBR MDCLV* (10 [feet], 3 Febr.1655).[ix]

Before publishing his results, Huygens wanted to determine the period of the satellite, and this took some time. In the meantime, he sent an anagram to a number of scientists:

admovere oculis distantia sidera nostris vvvvvvv ccc rr h n b q x

He later also scratched this line from Ovid's *Fasti* on the edge of the lens (Figure 5).

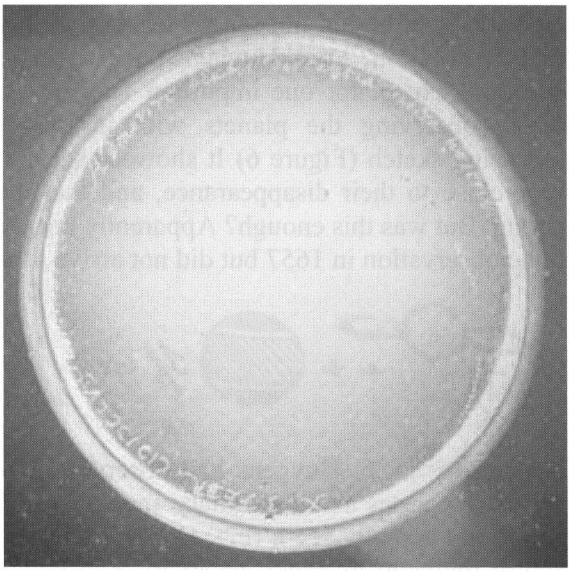

Figure 5: Objective lens of Huygens's 12-foot telescope with which he discovered the satellite of Saturn. (Courtesy of University of Utrecht Museum)

In an age when priority, or intellectual property, had become important but no suitable institutions had been developed to protect it, scientists resorted to various ways of trying to protect their priority. Galileo had used this device to protect his priority of discovery of Saturn's appearance and the phases of Venus. Huygens, always an admirer of Galileo, followed the example of the Florentine.

4 Solving the problem of Saturn

Huygens continued his observations of Saturn and its moon, and some time in the fall or winter of 1655-56 he came up with his explanation of the appearances of Saturn. Now, several facts are important here. First, Saturn disappeared in the rays of the Sun on June 1655 and did not become visible again until October of that year. Second, on 28 June 1655 Huygens left for an extended visit to France (among other things to pick up a Doctor's diploma at the University of Angers) and returned to The Hague on 19 December of that year. He mentions no observations made during that period, and observed Saturn again for the first time on 16 January 1656,

[ix] Huygens specifies the focal distance of the objective as 10 feet – in reality 333 cm, or 10.6 Rhineland feet, while he refers to the instrument as a 12-foot telescope [8].

when the planet appeared solitary. On 19 February 1656, he observed it for the first time with a newly-made telescope of 23 feet. So it is clearly in error to say, as some have, that the new telescope enabled Huygens to 'see' a ring: there was no ring to be seen. In fact, on 8 February he had already written to a correspondent:

> I hope soon to show you a beautiful result of my telescopes, when I send you the System of Saturn which I plan to publish, and which will teach the cause of all the different appearances of that planet[9]

This is the first indication that Huygens had solved the puzzle, and the question is: if he did not see a ring through his telescopes, then how did he find the solution? From Huygens himself we get little help in answering this question, except for one important fact. In March 1655, when he had just begun observing the planets with his 12-foot telescope, he made the following sketch (Figure 6) It showed that the anses kept their length even very close to their disappearance, and that the satellite model was clearly wrong. But was this enough? Apparently not, for Christopher Wren made the same observation in 1657 but did not arrive at a ring theory.

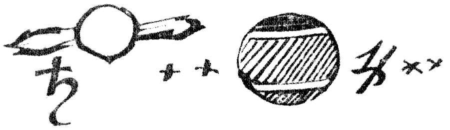

Figure 6: Sketch of Jupiter and Saturn made by Huygens in March 1655. (O.C. *1: 322)*

By January 1656, Huygens had observed only two appearances of Saturn, the narrow anses and the solitary appearance. The sketch makes it clear that he did not actually see a ring. But he had seen a number of appearances of Saturn rendered by other observers, and being able to eliminate the triple-bodied appearance (that had led Galileo and his contemporaries to the 'satellite model'), narrowed the problem down to explaining how the anses could get thinner and thinner until they disappeared, while all the time keeping their length. At this point, several solutions were possible, one of which is that Saturn is surrounded by a ring. But the observation of 16 January perhaps gave Huygens another clue: he saw a dark band across the planet's face in the line of the (disappeared) anses. What Huygens saw was the shadow of the ring on the body. He interpreted it, however, as the dark edge of the anses. The anses were flat, of constant length, and could show themselves both edge-on and opened into the handled appearance. Sometime between 16 January and 8 February Huygens found the solution: a ring. But he did not find it by seeing a ring through his telescope: there was no ring to be seen. No, he found it by seeing a ring in his mind's eye.

Galileo figured out that Jupiter was surrounded by four moons, a momentous discovery, in the second week of January 1610, and *Sidereus Nuncius* came off the press less than two months later. Galileo knew that speed was of the essence because others might discover the same. Likewise, when Huygens arrived at his ring-solution, he knew that he had to stake his claim quickly. He hurriedly wrote a four-page tract, which he entitled *De Saturni Luna Observatio Nova* ("On a new observation of a Moon of Saturn"), which he dated 5 March 1656 and began to send out to correspondents a few days later. In it, Huygens announced his discovery of Saturn's moon, (which he had already revealed to a few colleagues the previous August when he visited scientists in Paris). He promised a full exposition of his observations and his determination of the period of the moon, to be published together with his explanation of his new theory about Saturn's appearance in his System of Saturn, and he continued:

> "In the meantime it seemed useful to consign the essential [of that theory] in the following anagram, so that, if perhaps someone thinks he has found the same thing, he will have time to make it known, and so that it will not be said that he borrowed it from us, nor we from him:
>
> *"a a a a a a a c c c c c d e e e e e g h i i i i i i i l l l l m m n n n n n n n n n n p p q r r s t t t t t u u u u u"*[10]

5 Rival theories

Systema Saturnium did not appear until more than three years later. This was a very fertile period in Huygens's life. Besides gathering Saturn observations that had been published by others so that he could review them, he worked hard to improve the practice and theory of the telescope, invented and published on the pendulum clock, and made important contributions to mathematics. Moreover, he wanted the book to be more than a mere account of Saturn's moon and its ring. And his call for others to come forward with their theories produced a number of them.

The Polish astronomer Johannes Hevelius had been working on a book on the subject for several years, waiting for the solitary appearance of 1655-56 to complete his series of observations, and he published *De Nativa Saturni Facie* ("On the genuine shape of Saturn") in 1656. Hevelius's explanation of the appearance can be seen from the figure: Saturn had an ovate central body with two crescent-shaped attachments, and the entire formation rotated as shown (Figure 7).

Clearly, in the transition from the handled to the tri-corporeal appearance, the handles did not retain their length.

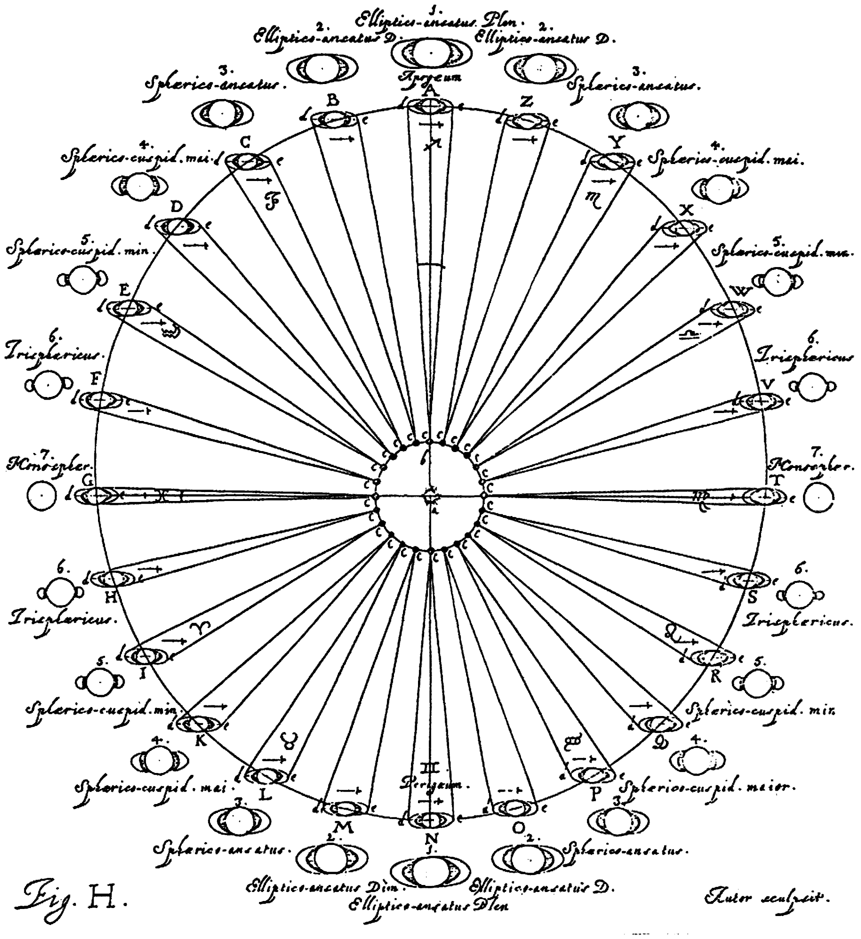

Figure 7: Johannes Hevelius's theory to explain Saturn's appearances. From De nativa Saturni facie *(Gdansk, 1656), plate H*

Huygens's Parisian friend and colleague Giles Personne de Roberval wrote to Huygens that he postulated thin vapours that arose from Saturn's equatorial 'torrid zone'. Their varying height and tenuousness explained all Saturn's appearances. And from Sicily, Huygens received a little book written by Giovanni Battista Odierna, the priest and mathematician of the Duke of Palma: *Protei Caelestis Vertigines seu Saturni Systema* ("The Turnings [or Changes] of the Celestial Proteus, or System of Saturn"), in which he explained the appearances by postulating that Saturn and its anses were one "elliptical or oviform body" with two large dark spots, and that this body rotated on a minor axis (Figure 8).

Figure 8: Saturn as observed by Giovanni Battista Odierna. From Protei Caelestis Vertigines seu Saturni Systema *(Palma, 1657), frontispiece.*

The most interesting hypothesis, but one which Huygens did not read until much later, was formulated by the English mathematician and astronomer Christopher Wren. Late in 1657, Wren and Sir Paul Neale observed the narrow anses that had become visible again and noticed that the anses "kept their length". Wren went on to write a tract. *De corpore Saturni*, in which he supposed that a thin elliptical corona was attached to Saturn at two points, and that the formation rotated or librated around the corona's major axis. This theory could explain all the appearances of Saturn. When this corona was seen edge-on it was invisible because it was "so thin as to be a mere surface". Wren built a model of this hypothesis, and the drawing shows how the various appearances were generated (Figure 9).

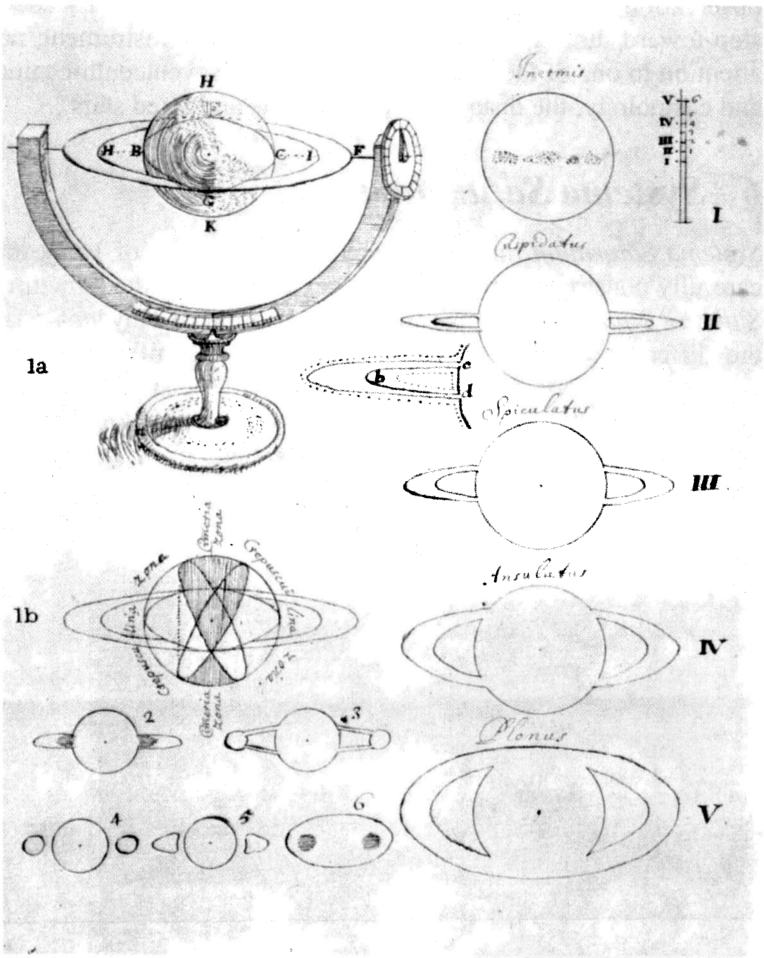

*Figure 9: Christopher Wren's theory of Saturn's appearances. From "*De corpore Saturni*", 1657 (O.C. Vol 3 p429-25)*

But the tract remained unpublished for the time being, and when Wren saw Huygens's ring hypothesis a year later, he put his own in a drawer. When, in 1661, several years after the events, Wren was asked by some of his English colleagues to acquaint others with his theories, he sent the tract and gave the reason why he had never published it:

> ...when a shorte while after, the Hypothesis of Hugenius was sent over in writing, I confesse I was so fond of the neatnesse of it, & the Naturall Simplicity of the contrivance agreeing soe well with the physical causes of the heavenly bodies, that I loved the invention beyond my owne & though this

> [hypothesis] be so much an equipollent with that of Hugenius, that I suppose future observations will never be able to determine which is the trewest, yet I would not proceed with my designe… [11]

Even today this would be a generous admission; in the seventeenth century, when there were no agreements on intellectual property, to admit that a hypothesis is preferable to your own, *even when you consider the two equivalent* is rare for any age.

In the meantime, Huygens was working on his 'System of Saturn'. He continued his observations of Saturn's moon, gathered published observations of the planet, improved his telescopes and made an important step toward turning the device into a measuring instrument, and turned his attention to one of the important questions of seventeenth-century astronomy and cosmology: the distances of the planets and fixed stars.

6 Systema Saturnium

Systema Saturnium finally appeared in the summer of 1659. Its argument is carefully constructed and to a large extent follows the structure of Galileo's *Sidereus Nuncius*. It begins with a description of Huygens's telescopes and the different manners of determining their magnifications, followed by a survey of the heavens (showing for the first time surface markings on Mars) ending at Saturn, and then discusses the discovery of that planet's moon. Huygens lists his observations of the moon, from 25 March 1655 to 26 March 1659 (69 observations), and from these he calculates the elements of the moon's orbit around Saturn. Then he gets to the main part of the book, Saturn's appearances.

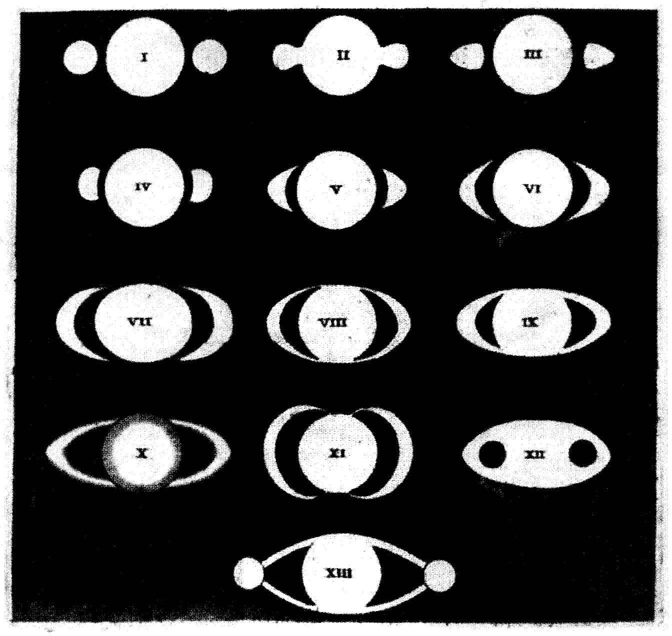

Figure 10: Huygens's classification of previous observations of Saturn. From Systema Saturnium *1659 (O.C. Vol 15 p621)*

Huygens classifies the various appearances observed by others into thirteen types (Figure 10), and then launches into a discussion of each type, naming names and making judgments. But on what authority did he base his position as a judge? Huygens's argument for this right was to lead to some spirited replies:

> In this investigation, we require that we are conceded that because we have with our telescopes discovered for the first time the satellite of Saturn, and because we see it distinctly whenever we want, for that reason our telescopes should be preferred over those with which others, although daily engaged observing Saturn, were unable to see that satellite; and that consequently the results of our observations concerning the shape of the planet must be judged as conforming to the truth, each time that the different appearances were simultaneously observed by us and by them.[12]

After critiquing, and often dismissing, these observations, Huygens reveals his own theory, beginning with the solution to the anagram he had published three years earlier in *De Saturni Luna*:

> *Annulo cingitur, tenui, plano, nusquam coherente, ad eclipticam inclinato.*
>
> It is surrounded by a ring, thin, flat, touching it nowhere, inclined to the ecliptic.

A diagram shows how the ring could give rise to the various appearances (Figure 11).

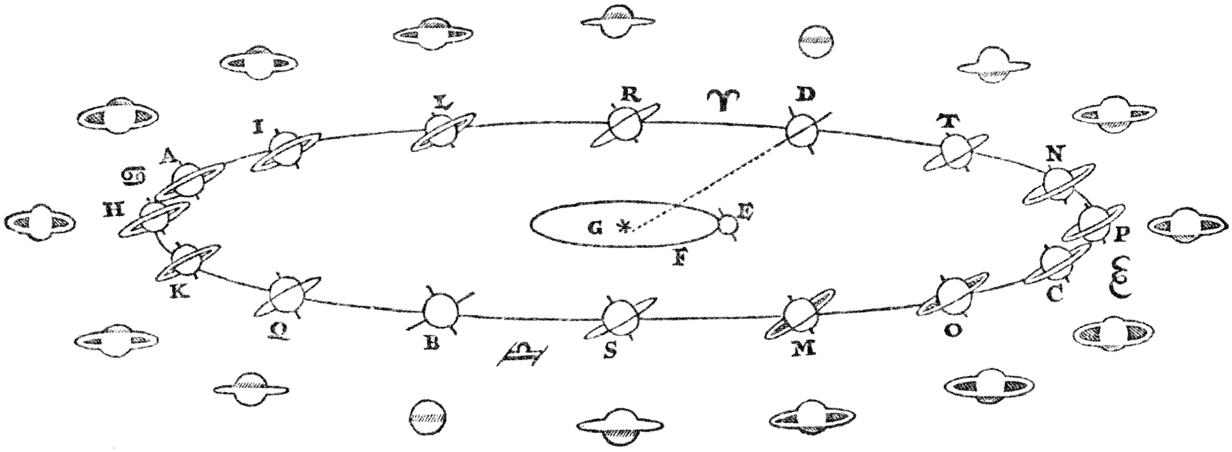

Figure 11: Diagram to explain how the ring gives rise to the various appearances of Saturn. From Systema Saturnium *1659 (O.C. Vol 15 p319)*

But the ring's properties had to be specified. Huygens showed that the ring was in the same planes as the orbit of the satellite. He located the 'equinoxes' of Saturn, and then showed how his ring-theory explained the 'solitary' appearance. He specifically rejected the possibility that when the Earth passes through the ring-plane the ring is invisible because of its extreme thinness. The ring is thin, he argued, but not *that* thin. He believed that the ring had an appreciable thickness but that its edge did not reflect the light of the Sun.

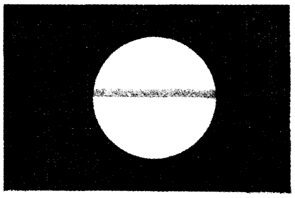

Figure 12: Huygens's observation of the 'solitary' appearance, 1657. Systema Saturnium, *(O.C. Vol 15 p247)*

He supported this argument by pointing to his own observation of Saturn shorn of its appendages early in 1656 (Figure 12), showing a black line across its disk.

One other aspect of the ring theory caused Huygens problems. He had determined that the plane of the ring was parallel to the celestial equator, so that Saturn's axis of rotation was inclined 23½° to the ecliptic, like the Earth's axis. He had also determined that the ratio of the diameters of the ring and the planet was 9:4. This combination predicted that at its most open aspect the ring would not entirely enclose the disk of the planet. Within a year or so of the publication of *Systema Saturnium* the appearances proved these figures to be somewhat in error.

Huygens ends *Systema Saturnium* by explaining his technique for measuring small distances within the field of his telescope. He inserted an aperture stop in the focal plane, so that the field of view was sharply delimited. He knew the linear diameter of this aperture, and he measured its angular diameter by timing the progress of star across the field of view. He then inserted small rods or sticks of differing thicknesses into the focal plane of his instrument, and when he had found one that just covered the body of a planet, he took it out and measured its diameter. The ratio of the linear diameters of rod and field was equal to the ratio of angular diameters of planet and field. Others were to follow up on this suggestion and produced a full-fledged screw micrometer within a decade. (But as it turned out, the English *virtuoso* William Gascoigne had anticipated everyone in this by producing a screw micrometer in the early 1640s, an instrument that lay forgotten until it was brought to the attention of the learned world by Richard Townley and John Flamsteed in the 1660s).

Huygens measured the angular diameters of all the planets except Mercury. He did not know their absolute distances and thus could not determine their actual sizes. But he argued that the size of the Earth must be intermediate between those of Venus and Mars, and on the basis of that assumption found a solar distance twice as great as the most daring estimates up to that time. Indeed, it was about 10% larger than the modern value.[x] He now had the one absolute distance he needed and could thus specify all distances and sizes of the primary planets in the Solar System.

Systema Saturnium was the most important book on telescopic astronomy since Galileo's *Sidereus Nuncius* (1610). It not only described a new satellite and gave the solution to the problem of Saturn's mysterious appearances, but it also contained the first clear outline of the dimensions of the modern Solar System. By 1660, he was the most renowned scientist in Europe, and within

[x] Huygens had determined the ratio of Mars and Venus to the solar diameter to be 1:166 and 1:84. These ratios are not very good: the modern values are 1/202 and 1/112. But by choosing the arithmetic mean of those fractions, 1/111, Huygens ended up with a value very close to the modern value, 1/109 – an 'accurate guess?' Since the angle subtended by the radius of the Earth seen from the Sun, the horizontal solar parallax, is, thus, 1/111th of the solar radius (ca. 15 arcminutes) the solar parallax came out to be 8.2 arcseconds and the Earth-Sun distance (the astronomical unit) was ± 25,000 Earth-radii, or ±160 million km.

a few years he was rewarded by being called to Paris to become the intellectual leader of the newly founded *Académie Royale des Sciences*.

7 Reception of the ring theory

The reception of Huygens's ring theory was generally positive. Scientists by and large accepted the theory but quarrelled about two details. First, the combination of Huygens's figure for the inclination of the ring-plane to the ecliptic and the ratio of diameters of the ring and the body of Saturn. Here, the phenomena showed that these numbers were not correct, and Huygens made the necessary adjustments in the 1660s and 1670s. Clearly, this was a matter of fine-tuning the theory. Second, Huygens's insistence that the ring, although thin, was of appreciable thickness, and then postulating that the edge of the ring did not reflect light was generally deemed unsatisfactory. Although Huygens never changed his mind on this score, others generally preferred a ring so thin "as to be considered a mere surface," arriving at their conclusion independently from Wren. The question of whether the ring was one solid structure, as Huygens thought, or was a very large aggregation of small bodies, or even "vaporous exhalations," remained in the realm of speculation, but the observation that the outer part of the ring was less bright than the inner part, and the discovery of the gaps between those parts, now called Cassini's Division (see below, Figure 17), tended to incline astronomers against the notion of a solid structure.

But there were a few more hostile receptions, mostly centred on Huygens's claim for the superiority of his telescopes. Johannes Hevelius had emerged in the 1640s as the leading telescopic observer in Europe. His sumptuous *Selenographia* of 1647 was a complete survey of the Moon in all its phases. Hevelius himself observed, drew, engraved, and printed the images. In the intervening years he had become known for the power of his telescopes. He therefore felt deeply offended by Huygens's claim that his instruments were the best. But he had had good relations with Huygens, and he was not about to change this. In his letter to Huygens he calmly and politely argued that only time would tell whose hypothesis was better, but in a long letter to their mutual friend Ismael Boulliau, Hevelius vented his spleen, arguing that establishing the complete cycle of appearances was the most important thing, and he had done that. He defended the ovoid shape of the planet's central body in his hypothesis, and against Huygens's claim of authority based on his telescopes, with which he had been the first to observe Saturn's moon, Hevelius defended his own telescopes and showed that they could show the satellite as well. And on the subject of the supposedly elliptical shape of the body of the planet itself he asked:

> Does Huygens perhaps suppose that I and others are not able to discern what is elliptical or spherical, or that it was invented by my mind as he writes… or rather that I dreamed it? No, by Hercules![13]

In the learned world, many reputations were based on the possession of powerful telescopes, and Hevelius's outburst should not surprise us. And he was by no means the only one to object to Huygens's authority claim. From Rome, there came a reply in the form of a book by Eustachio Divini, *Brevis*

Annotatio in Systema Saturnium Christiani Hugenii (1660). In fact, this Latin book was, for the most part, written by the French Jesuit Honoré Fabri. Divini, considered by most the best telescope maker in Europe, argued against Huygens's claim that his telescopes were better than those of others, and he challenged Huygens to submit his telescopes to a direct comparison with his own. Divini had several times been victorious in such *paragoni* (comparisons by means of contests).

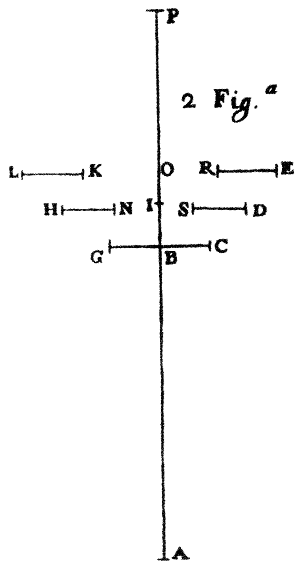

Figure 13: Honoré Fabri's hypothesis of Saturn's appearances. GC represents Saturn, HN and SD light-absorbing satellites, and LK and RE light-reflecting satellites. All satellites revolve around (empty) points behind Saturn. From Eustachio Divini, Brevis annotatio in Systema Saturnium *(Rome 1660) (O.C. Vol 15 p425)*

Fabri objected to Huygens's open Copernicanism (which was irrelevant to the ring-hypothesis), and proposed an ad hoc theory of his own to explain Saturn's appearances (Figure 13).

If Fabri's theory strikes us as ridiculous, it struck many in the seventeenth century the same way. But there was a catch. Following the example of Galileo, Huygens had dedicated his *Systema Saturnium* to a Medici prince, in this case Leopold, the son of Galileo's patron. Leopold and his brother, the ruler Ferdinand II, had founded the *Accademia del Cimento* (Academy of Experiment) in Florence in 1657 and had attracted a number of well-known scientists. The Prince was in a difficult position: on the one hand a brilliant hypothesis put forward by a follower of Copernicus (whose doctrine had been forbidden by Rome in 1616) and a (Protestant) heretic, and on the other a rather silly hypothesis put forward by a proponent of old-fashioned geocentrism who was also a member of a powerful order in the Catholic Church. When he was a boy, Prince Leopold had witnessed Galileo's condemnation for his advocacy of the Copernican System, and the days when the Medici were powerful enough to thumb their nose at Rome were long past. The *Accademia del Cimento* had been set up to promote experimental science, to let nature speak for itself, independent of any speculation. It was this founding idea that brought the solution: models of the hypotheses of Huygens and Fabri were to be made, and the merits of the two hypotheses were to be determined empirically.

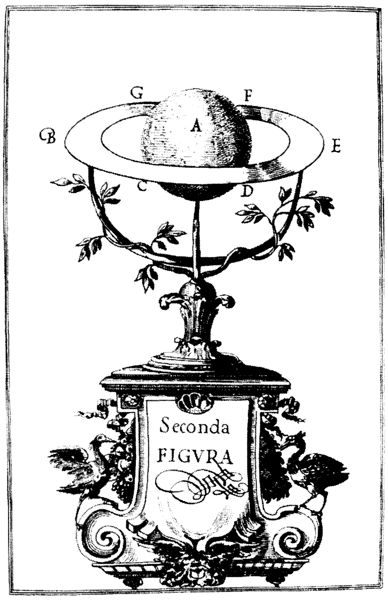

Figure 14: Model of Huygens's ring-theory, made by the Accademia del Cimento. (See O.C. Vol 3 p154-55)

The models were set up in long galleries, illuminated obliquely by torches, and observed from a distance with the naked eye and with telescopes of various powers. And not only the scientists (and their Prince) observed, but realising that they might be prejudiced in favour of one hypothesis or the other, they also involved people who knew nothing about the subject, even some *idioti*, people without any learning. Everyone was ordered to draw what he saw. The result was an almost complete victory for Huygens. Fabri's hypothesis was utterly incapable of reproducing the appearances of Saturn. Huygens did not entirely escape criticism: no matter how thin the scientists made the ring, they could never make it completely disappear in the edge-on position. To Huygens, this was, of course no problem, but to those who assumed the ring to be so thin as to be a mere surface, it was. The Prince had the carefully written reports sent to Huygens, but asked him not to make them public so that Fabri and his colleagues in Rome would not be angered and the Church embarrassed.

Huygens duly replied to *Brevis Annotatio* with a defence of his telescopes and ring-theory: *Brevis Assertio Systematis Saturnii* (1660), which was in turn countered by Fabri's *Pro Sua Annotatione in Systema Saturnium Christiani Hugenii* (1661). No doubt in response to the report of the *Accademia del Cimento* on his hypothesis, Fabri added two more light-reflecting satellites (Figure 15), which shows how Fabri proposed to represent the handled appearance of Saturn.

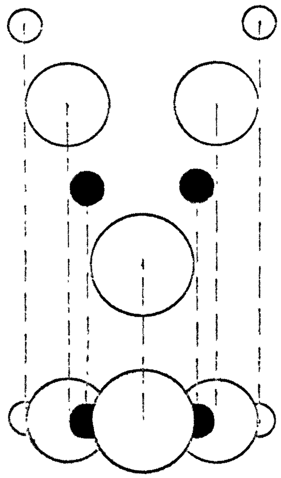

Figure 15: Fabri's improved hypothesis of Saturn's appearances. From Eustachio Divini, Pro sua annotatione in Systema Saturnium Christiani Hugenii. *(Rome 1661), pp. 56-58, redrawn by the author.*

If his first hypothesis had given rise to some merriment among Huygens's correspondents (Hevelius called the hypothesis "unworthy of learned men"[14]), things were now getting silly. Fabri himself probably recognised this, and in this book he admitted, while maintaining his own modified hypothesis, that he could not help seeing a ring around the planet. Huygens had won a complete victory. Divini, so enamoured with *paragoni*, was himself soundly thrashed in such comparisons, a few years later, when a new telescope maker in Rome challenged him to a series of *paragoni*, in which the agents of Prince Leopold acted as overseers and referees.

By 1662, the ring-theory was more or less generally accepted, subject to some technical tweaking. And besides being recognised as the finest scientist in Europe, Huygens himself enjoyed the reputation as having the best telescopes. But this latter reputation he would quickly lose.

By 1664, Giuseppe Campani was making telescopes that far surpassed all others. In a little book about his telescopes and observations, Campani showed an engraving of Saturn with its ring, with the outer part of the ring darker than the inner part.

He had made that observation with telescopes of 13 and 17 feet. And that same year he published a single sheet showing the same view of Saturn and an image of Jupiter in which the shadow of one of the satellites could be seen on the body of the planet (Figure 16)[15].

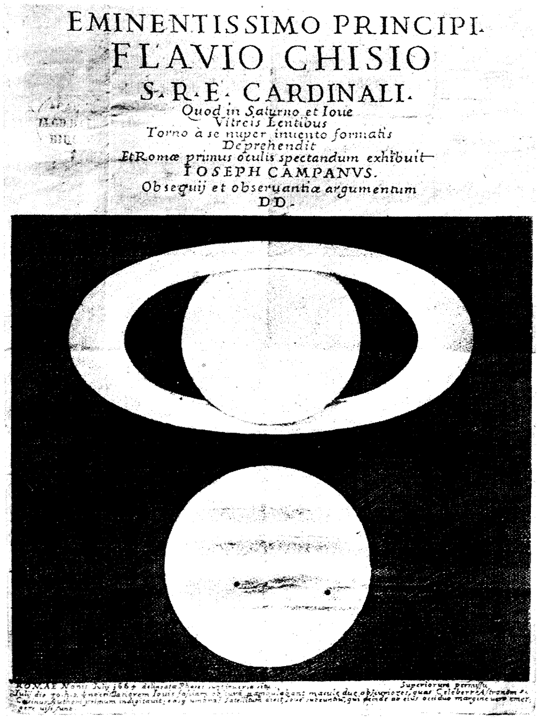

Figure 16: Jupiter and Saturn observed by Giuseppe Campani. Note the shadow of two of Jupiter's satellites on the body of Jupiter. (O.C. Vol 5 p118)

In both images of Saturn, the shadow of the ring on the body as well as that of the body on the ring was shown. Indeed, observations of Saturn published by several astronomers around this time showed not only these shadows, but, in retrospect, also the transparent so-called crepe ring (the C ring) 'discovered' in 1848. Clearly, observers were now seeing Saturn surrounded by a ring.

8 Campani and Cassini

Although Campani was a good observer, his great talent was in grinding and polishing lenses. Modern examinations of some of these lenses show that Campani could grind perfectly spherical lenses of predetermined focal lengths[16]. Indeed, up to the twentieth century, no one could do better (although the quality and size of glass blanks left something to be desired in the seventeenth century). In the hands of Giovanni Domenico Cassini, then professor of Astronomy at the University of Bologna, and the Pope's superintendent of fortifications and flood control, Campani's telescopes were responsible for a series of further discoveries that redounded to the fame of both. With a telescope of 17 feet given to him by Campani, Cassini observed surface markings on Mars and determined its rotation period, made observations of the satellites of Jupiter that led to the first reasonable accurate tables of their motions, and determined the rotation period of Jupiter. These and other astronomical achievements led to Cassini being called to Paris to become director of the new Royal Observatory being built. There, around the invisibility of the ring in 1671-2, he discovered two more satellites of Saturn (now called Rhea and Iapetus), and at the next disappearance, in 1684, he discovered two more (nowadays called Tethys and Dione). In the meantime, in 1676 he had also discovered the gap now named after him between the two parts of the ring (Figure 17).

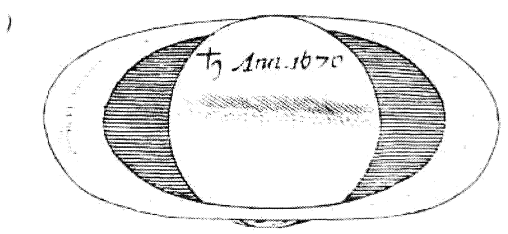

Figure 17: Saturn and its rings, showing Cassini's Division.
(Journal des Sçavans, *1 March 1677, p. 58)*

After his arrival in Paris, in 1669, Cassini, a consummate courtier, had gradually replaced the melancholy Huygens as the leader of the *Académie*. After Cassini's discovery of the first two satellites, Huygens wrote to his brother Lodewijk,

> It is Mr. Cassini who first perceived the two new companions of Saturn, after he received the telescopes [of Campani] from Rome. He has lived in the Observatory for almost a year, and does not miss a clear night for observing the sky, to which I would by no means wish to subject myself, contenting myself with my old discoveries, which are worth more than all those that have been made since.[17]

In spite of Huygens's petulance here, this statement illustrates the difference between Huygens and Cassini. Huygens was a versatile scientist, working mostly alone in pure mathematics, clock design, telescope making, geometrical optics, and astronomical observation. It was not his temperament to sit or stand at the eyepiece of a telescope all night, every clear night, and devote his life to one subject. Cassini's considerable achievements were all in observational astronomy, and he was a great organiser and director. While still a professor at Bologna, he renovated the meridian of the cathedral of San Petronio (built earlier by Egnatio Danti) and produced results that led to a complete revision of the corrections that had to be made in positional measurements for atmospheric refraction and solar parallax. In Paris, he was responsible for the expedition to Cayenne, in 1673, which produced a correction of no less than two arc-minutes to the obliquity of the ecliptic. If Huygens had the better mind, Cassini was better at getting things done.

Huygens had already returned for good to The Hague when, in 1684, Cassini discovered the fourth and fifth satellites of Saturn. During this period, he and his brother Constantijn made objective lenses with focal lengths of 34 to 200 feet. Yet Huygens, for reasons that are not clear, was never able to see these new satellites for himself. In 1692, Constantijn made a present of a 123-foot objective with a 7½-inch aperture to the Royal Society, and this instrument was used in 1718 by James Pound to measure the positions of the satellites of Jupiter and Saturn with a micrometer. He saw all five of Saturn's moons, but he cautioned the reader that the air had to be very dry and "limpid"[18].

In his posthumous *Cosmotheoros*, Huygens presented a popular exposition of his cosmology, and Saturn featured prominently in it. He speculated about the inhabitants of Saturn and how the huge ring would appear to them. He did not address the issue of its thickness, but the accompanying figure (Figure 18) leaves little doubt that until the end of his life he believed in a solid ring of appreciable thickness.

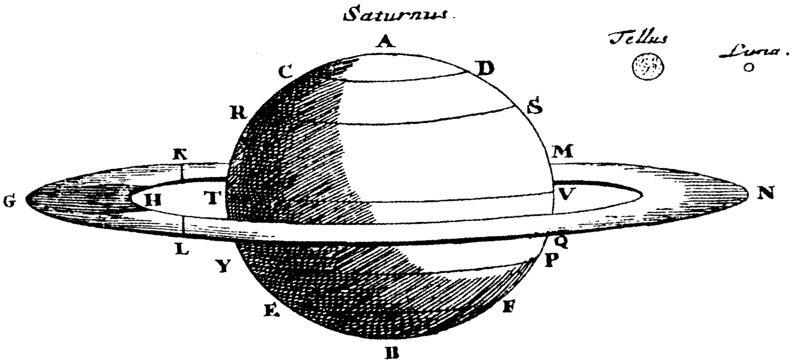

Figure 18: Saturn as represented by Huygens in Cosmotheoros *(1698) Note that the ring has an appreciable thickness, approaching the diameter of Earth's Moon (*Luna*). (O.C. Vol 21 p788)*

On this point, the world had passed him by. But in the cosmology presented in *Cosmotheoros*, read by numerous people in several languages, Saturn with its magnificent ring stood central in the new cosmology and provided Huygens's 18th-century successors, from Thomas Wright of Durham to Immanuel Kant and Pierre-Simon de Laplace, with a model for their theories about the origin and constitution of the Solar System and universe (Figure 19).

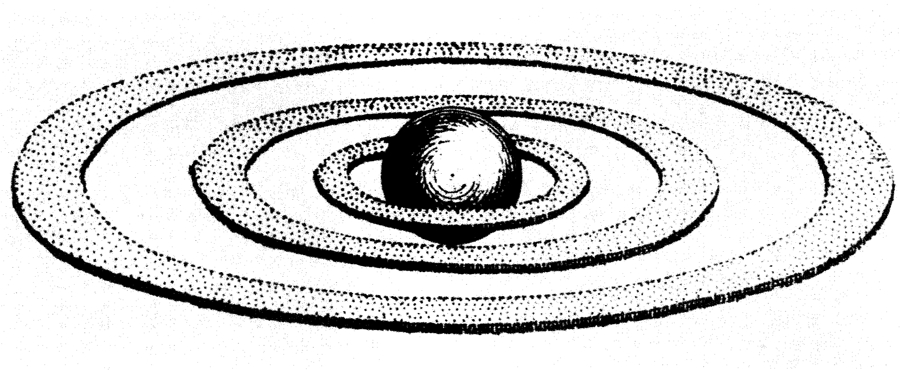

Figure 19: Thomas Wright of Durham's 'alternate hypothesis' of the shape of the Milky Way. From An Original Theory or New Hypothesis of the Universe *(1750). Reprint with introduction by M. A. Hoskin (London: Dawson's, 1971).*

This paper draws on the following articles published earlier:

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"'Annulo Cingitur': The Solution to the Problem of Saturn," *Journal for the History of Astronomy*, 5 (1974): 155-74.

"A Note on Christiaan Huygens's *De Saturni Luna Observatio Nova*," *Janus*, 62 (1975): 13-15.

"Christopher Wren's *De Corpore Saturni*," *Notes and Records of the Royal Society of London*, 23 (1968): 213-29.

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"The Accademia del Cimento and Saturn's Ring," *Physis*, 15 (1973): 237-59.

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[6] Peiresc and Gassendi to Galileo, 24 February 1637, G.G., XVII: 34.

[7] Antonius Maria Schyrlaeus de Rheita, *Novem Stellae circa Jovem, circa Saturnum sex, circa Martem nonnullae* (Louvain, 1643).

[8] Oeuvres Complètes de Christiaan Huygens [hereafter: 'O.C.'] Vol. 15, p. 10-12

[9] Huygens to Colvius Andreas Colvius, 8 February 1656, O.C. 1: 380.

[10] O.C. 15: 177.

[11] Christopher Wren to Sir Paul Neile, 1 October 1661 (Julian). See C. A. Ronan and Sir Harold Hartley, "Sir Paul Neile, F.R.S.," *Notes and Records of the Royal Society of London* 15 (1960): 159-65, at p. 163.

[12] O.C. XV: 270.

[13] Hevelius to Ismael Boulliau, 9 December 1659, Paris, Bibliothèque Nationale, MSS Collection Boulliau XXV (FF 13042), fols. 89v-92v, at 90v.

[14] Hevelius to Huygens, 1 August 1661, O.C., III: 308-09.

[15] Giuseppe Campani, *Ragguaglio di due Nuove Osservazioni* (Rome, 1664), p. 18. This sheet can be found in *O.C.* V: 18.

[16] M. Miniati, V. Greco, and G. Molesini, A. van Helden, "Seventeenth-Century Telescope Optics of Torricelli, Divini, and Campani," *Applied Optics* 41 (2002): 644-47.

[17] O.C. 7: 348.

[18] James Pound, "A Rectification of the Motions of the five Satellites of Saturn; with some accurate Observations of them," *Phil. Trans.* 30 (1718): 769-774.