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COPERNICUS ON THE PHASES AND THE LIGHT OF THE PLANETS

What was new and what was old in Copernicus' opinions about the phases and the light of the planets? Did he regard the planets as opaque bodies, which in certain positions should show phases like the moon's? Or did he view the planets as self-luminous, like the sun? Or did he think of the planets as transparent throughout, so that the sunlight passing through them illuminated the whole visible disk, leaving no areas dark and thereby eliminating the possibility of phases?

A convenient starting-point in our effort to answer the foregoing questions will be the single most spectacular achievement in the long history of computational astronomy, namely, the discovery of the planet Neptune through the perturbations which it produced in the motion of Uranus [1]. At a meeting of England's Royal Astronomical Society on November 13, 1846, the Astronomer Royal, Sir George Biddell Airy (1801—1892), took the floor to defend himself against severe censure of his conduct in the exciting events which had culminated in the discovery of Neptune [2].

In the course of his *Account of Some Circumstances Historically Connected with the Discovery of the Planet Exterior to Uranus*, Airy praised the French theoretical astronomer Urbain-Jean-Joseph Le Verrier (1811—1877) for "the firmness with which he proclaimed to observing astronomers, «Look in the place which I have indicated, and you will see the planet well». Since Copernicus declared that, when means should be discovered for improving the vision, it would be found that

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[1] Morton Grosser, *The Discovery of Neptune*. Cambridge, Mass. 1962, pp. 49—57, 69, 75—76, 78—90, 92—123.

[2] Airy was recently defended in a paper of a later Astronomer Royal, Sir Harold Spencer Jones; see: Sir Harold Spencer Jones, *G. B. Airy and the Discovery of Neptune*. "Nature", CLVIII, 1946, pp. 829—830; reprinted in: "Popular Astronomy", LV, 1947, pp. 312—315.

Venus had phases like the Moon, nothing (in my opinion) so bold, and so justifiably bold, has been uttered in astronomical prediction".

Airy's oral reference to a prediction by Copernicus (1473—1543) that the phases of Venus would be detected by improved vision was promptly printed in the "Memoirs of the Royal Astronomical Society". But in the printed version Airy added the following footnote to his statement about Copernicus' prediction: "I borrow this history from Smith's *Optics*, sect. 1050. Since reading this «Memoir», I have, however, been informed by Professor De Morgan that the printed works of Copernicus do not at all support this history, and that Copernicus appears to have believed that the planets are self-luminous" [3].

Airy's footnote soon came to the attention of Alexander von Humboldt (1769—1859), the illustrious scientist whose name is now borne by the university which was founded principally by his brother [4]. At the time when Airy adverted to Copernicus' supposed prediction, Humboldt was engaged in writing his last and most famous work, into which he introduced the following passage:

"Whether Copernicus p r e d i c t e d the necessity of a future discovery of the phases of Venus, as is asserted in Smith's *Optics*, sect. 1050, and repeatedly in many other works, has recently become altogether doubtful, from Professor De Morgan's strict examination of the work *De Revolutionibus*, as it has come down to us" [5].

By inserting this passage in his *Kosmos*, which was repeatedly published in the original German as well as in numerous translations, Humboldt rendered the history of science a valuable service. That service would have been even more valuable had Humboldt indicated that the volume containing Airy's footnote also included De Morgan's "strict examination".

Augustus De Morgan (1806—1871), the immensely learned professor of mathematics at University College, London, had once been Airy's pupil at Cambridge, and later became his intimate friend. When the Royal Astronomical Society met on June 11, 1847, some seven months after Airy had told it about Copernicus' supposed prediction, it heard from De Morgan, who had recently been elected a secretary of the Society, a report *On the Opinion of Copernicus with Respect to the Light of the Planets*:

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[3] "Memoirs of the Royal Astronomical Society", XVI, 1847, p. 411; also: "Monthly Notices of the Royal Astronomical Society", VII, 1847, p. 142.

[4] *Die Humboldt-Universität, Gestern — Heute — Morgen*. Berlin 1960, p. 18.

[5] Alexander von H u m b o l d t, *Kosmos*. Berlin 1850, vol. 3, p. 538. Citing "the letter from Adams to the Rev. R. Main on September 7, 1846". But John Couch Adams' letter to Robert Main, Airy's chief assistant at the Greenwich Observatory, did not refer to Copernicus. That reference was made by Airy, not by Adams.

"The common story is, that Copernicus, on being opposed by the argument that Mercury and Venus did not shew phases, answered that the phases would be discovered some day. The first place in which I find this story is in Keill's *Lectures*. It is also given by Dr. Smith, in his well-known treatise on *Optics*, by Bailly, and by others. But I cannot find it mentioned either by Melchior Adam or Gassendi, in their biographies of Copernicus; nor by Rheticus, in his celebrated *Narratio* [6], descriptive of the system of Copernicus; nor by Kepler, nor by Riccioli, in their collections of arguments for and against the heliocentric theory; nor by Galileo, when announcing and commenting on the discovery of the phases; and, what is most to the purpose, Müller, in his excellent edition of the great work of Copernicus, when referring to the discovery of the phases of Venus, as made since, and unknown to, Copernicus, does not say a word on any prediction or opinion of the latter. This story may then be rejected, as the gossip of a time posterior to Copernicus" [7].

This "gossip" was presumably started by John Keill (1671—1721), the excessively zealous proponent of Newton's priority over Leibniz in the invention of the calculus. In 1718, when Keill published the lectures which he gave as Savilian professor of astronomy at Oxford University, he emphasized the gossip by displaying *The Prophecy of Copernicus* as a marginal note alongside the following remarks:

"It was objected to him [Copernicus] that if the motions of the planets were such as he supposed them to be, then Venus ought to undergo the same changes and phases as the moon does. Copernicus answered that perhaps the astronomers in after-ages would find that Venus does really undergo all these changes. This prophecy of Copernicus was first fulfilled by that great Italian philosopher Galileo who, directing his telescope to Venus, observed her appearances to emulate the moon, as Copernicus had foretold" [8].

Keill's unsubstantiated gossip was repeated twenty years later by Robert [9] Smith (1689—1768), Plumian professor of astronomy at Cambridge University: "When Copernicus revived the ancient Pythagoric system, asserting that the earth and planets moved round the sun in the center of their orbits, the Ptolemaics objected, if this were true, that the phases of Venus should resemble those of the moon. Coperni-

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[6] Translated into English by Edward Rosen, see: *Three Copernican Treatises*, 2nd ed. New York 1959, London 1959, pp. 107—196.

[7] "Monthly Notices of the Royal Astronomical Society", VII, 1847, pp. 290—291.

[8] John Keill, *Introductio ad veram astronomiam.* Oxford 1718, p. 194; English translation: *An Introduction to the True Astronomy.* London 1721, p. 163.

[9] Not "Thomas", as in: A. v. Humboldt, *op. cit.*, vol. 2, p. 362; this slip was corrected in: idem, *op. cit.*, vol. 5, p. 1289.

cus replied, that some time or other that resemblance would be found out" [10].

In the next generation Keill's gossip crossed the Atlantic Ocean with the eminent botanist José Celestino Mutis (1732—1808), a Spaniard by birth who founded at Bogotá in 1803 the first astronomical observatory in the Western Hemisphere. His voice was the earliest publicly to espouse Copernicanism in the New World, to the dismay of the Roman Catholic clergy. In the course of his eloquent reply to their attack on him, Mutis declared in 1774:

"The astronomers contemporary with Copernicus argued against him by saying that if his system were true, Venus should be observed crescent-shaped and less than full. Copernicus admitted that this should happen, and that the absence of this observation was due to the astronomers not having found the means of perfecting vision, a prophecy which came to be fulfilled in Galileo's time through the most fortunate invention of the telescope" [11]. Although Mutis was a friend of Humboldt, he died decades before the latter became aware of the dubious character of Keill's gossip.

While it was still unchallenged, Keill's gossip was brought, probably through the French translation of his book [12], to the notice of Jean-Sylvain Bailly (1736—1793), the great astronomer and revolutionary leader. Bailly explained that in both the Ptolemaic and Copernican systems virtually the same appearances would be presented by the biggest planets:

"But if the two smallest planets, Venus and Mercury, revolve around the earth while following the sun step by step, they must at all times appear full when they are beyond the sun [13]; almost always black and dark when they are on this side of the sun; and barely marked by a very thin crescent of light when they move to the right or the left of the sun. On the other hand, in Copernicus' system, in which they revolve around the sun, they should sometimes show a full disk, at other times a dark disk, and all the intermediate phases which we observe in the moon as it changes from its feeble crescent to its full and

[10] Robert Smith, *A Compleat System of Opticks.* Cambridge 1738, p. 415, section 1050.

[11] Guillermo Hernández de Alba, *Crónica del Colegio Mayor de Nuestra Señora del Rosario.* Bogotá 1938—1940, vol. 2, p. 145; idem, *Copernico y los origines de nuestra independencia,* in: *Nicolás Copérnico.* Bogotá 1943, p. 19. The archival documents pertaining to the conflict between Mutis and the Dominicans were published in: John Tate Lanning, *El Sistema de Copérnico en Bogotá.* "Revista de Historia de America", XVIII, 1944, 279—306.

[12] John Keill, *Institutions astronomiques.* Paris, 1746, pp. 267—268.

[13] But in the Ptolemaic system Venus and Mercury are never beyond the sun. Therefore they would never appear full, since they follow the sun step by step, and never come into opposition to it.

complete light [14]. Copernicus dared to proclaim that if our eye had the strength to see these two small planets as we see our satellite, we would perceive that they undergo the same variations" [15].

This story was told in 1779 by Bailly, as by Keill and Smith before him, without any indication of its source. But Jan Czyński (1801—1867) [16], a Polish refugee living in France, explicitly ascribed it to tradition, the favorite haunt of the mythopoetic mind: "Tradition has preserved for us some expressions used by Copernicus in defending his principles. In less enlightened times these expressions would have been taken for prophecies by a superior being. Some people maintained that his theory was false because phases of Venus and Mercury were not seen. «If Venus and Mercury», they said to him, «revolved around the sun and we revolved in a larger orbit, we ought to see them sometimes full and sometimes crescent-shaped, but that is what we never observe». «Nevertheless that is what happens», Copernicus replied, «and that is what you will see if you find a means of perfecting your sight»" [17].

This imaginary conversation between Copernicus and his opponents was published by Czyński in 1847, the very same year in which De Morgan demonstrated that the whole episode was the merest gossip. But De Morgan's demonstration appeared in a specialized periodical of limited circulation, whereas Czyński's book attracted many readers and exerted a powerful influence. Observe, for example, how the imaginary conversation was amplified in 1872 by the distinguished astronomer and highly successful popularizer of that science, Camille Flammarion (1842—1925):

"«If it were true», people said to Copernicus, «that the sun is at the center of the planetary system, and that Mercury and Venus revolve around the sun in orbits inside the earth's, these two planets should have phases. When Venus is on this side of the sun, it ought to be a crescent, like the moon when it sets in the evening; when Venus forms a right angle with the sun and us, it ought to present the aspect of the first quarter, and so on. Now that is what nobody has ever seen». «Nevertheless that is the fact», Copernicus answered, «and that is what

[14] Diagrams comparing the phases of Venus in the Ptolemaic and Copernican systems as well as in a low-power telescope were provided by Thomas S. Kuhn, *The Copernican Revolution.* Cambridge, Mass. 1957; reprinted: New York 1959, p. 223; reviewed by Edward Rosen, see: "Scripta Mathematica", XXIV, 1959, pp. 330—331.

[15] Jean-Sylvain Bailly, *Histoire de l'astronomie moderne.* Paris 1779, vol. 2, p. 94.

[16] For a brief sketch of his life and character, see: Stanisław Wędkiewicz, *Études coperniciennes.* Paris 1955—1957, pp. 58—61; reviewed by Edward Rosen, see: "Isis", L, 1959, pp. 177—178.

[17] Jan Czyński, *Kopernik et ses travaux.* Paris 1847, pp. 100—101; *cf.* pp. 16—17.

people will see some day if they find a means of perfecting their vision»" [18].

It is not surprising that Czyński's imagination prevailed over De Morgan's erudition in France. But even in England De Morgan was not effective enough to stop all the damage still being done by Keill of Oxford and Smith of Cambridge. For instance, thirty-five years after De Morgan had demolished the story, a "scholar of St. John's College, Cambridge" lauded Copernicus for making "the remarkable prediction that «if the sense of sight could ever be rendered sufficiently powerful, we should see phases in Mercury and Venus»" [19]. Toward the close of the nineteenth century another Englishman asserted: "Copernicus's conviction was so thorough that he predicted that we should see the phases of Mercury and Venus" [20].

At the turn of the century Edward Singleton Holden (1846—1914), former director of the Lick Observatory, told trustful American children that "Mercury and Venus show phases just as the moon does, and just as Copernicus had foretold that they would do... The prediction of Copernicus was correct; Venus had phases like the moon" [21]. A generation later adults in the United States were offered the same tale, embroidered with a little piety:

"As he [Copernicus] began to submit the outlines of his theory to some of his more intimate friends, another objection was brought to his attention. If Venus revolved about the sun, some argued, it should show phases like the moon, as its bulk, passing between earth and sun, obscured part of its light. The validity of this objection Copernicus quickly recognized, and asserted that here also one must wait upon the invention of more accurate instruments of observation. In God's good time, he added devoutly, the phases of Venus would be seen by human eyes. His prophecy was fulfilled in 1616 when Galileo's telescope showed them clearly" [22].

As the date for Galileo's discovery of the phases of Venus, 1616 is

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[18] Camille Flammarion, *Vie de Copernic.* Paris 1872, p. 207. Through the Spanish translation by Mariano Urrabieta: idem, *Vida de Copérnico.* Paris and Mexico City 1879, Flammarion's vivid version of the imaginary conversation was transmitted to: Oscar Miró Quesada, *Copérnico: su vida y su obra.* Lima 1950, pp. 110—111.

[19] Edward John Chalmers Morton, *Heroes of Science: Astronomers.* London and New York 1882, p. 44. Since chapter 2 (pp. 32—62) is *On Copernik and His System,* Morton should have been included in: Henryk Baranowski, *Bibliografia kopernikowska.* Warszawa 1958; reviewed by Edward Rosen, see: "Isis", XLIX, 1958, pp. 458—459.

[20] J. Villin Marmery, *Progress of Science.* London 1895, p. 55.

[21] Edward S. Holden, *Stories of the Great Astronomers.* New York 1900; reissued: New York and London 1912, pp. 110—111.

[22] Ernest R. Trattner, *Architects of Ideas.* New York 1938, pp. 25—26.

six years too late, and another recent popular work came closer to the mark: "At the beginning of 1611 Galileo published his discovery of the phases of Venus. According to the Copernican system these had to exist. But to the naked eye Venus had always appeared round. Lacking better proof, Copernicus had counted upon God's eventual help" [23].

Our last reverberator of the unfounded gossip started by Keill almost two and a half centuries ago is a historian and philosopher of science, Thomas S. Kuhn (b. 1922), who said: "Copernicus himself had noted in Chapter 10 of the First Book of the *De Revolutionibus* that the appearance of Venus could, if observable in detail, provide direct information about the shape of Venus's orbit" [24].

A curious feature of this most recent reverberation is that Kuhn's book [25] includes a translation of *De Revolutionibus,* I, 10, where Copernicus said nothing about the possibility of Venus' being "observable in detail". Neither there nor elsewhere did Copernicus make the statement "that the appearance of Venus could, if observable in detail, provide direct information about the shape of Venus's orbit". The shape of any planet's orbit, according to Copernicus, must be a circle or a combination of circles; as Kuhn himself translates [26] *De Revolutionibus,* I, 4, "the motion of the heavenly bodies is... circular... or composed of circular motions" [27].

By now we have seen ample evidence of the hardy persistence, despite De Morgan's valiant opposition, of Keill's gossip about "the prophecy of Copernicus" that future astronomers would discover the phases of Venus. The astronomer who did discover them was Galileo Galilei (1564—1642). He had converted to Copernicanism his former pupil and devoted friend Benedetto Castelli (1578—1643). On December 5, 1610, Castelli sent his beloved teacher a letter reading in part as follows:

"The Copernican system of the world is true, absolutely true, as I believe. Therefore Venus at equal distances from the sun must appear sometimes with horns and sometimes without horns, according as it will be on this side or on the other side of the sun. But such observations were impossible in previous centuries on account of the smallness of Venus' body and the disappearance of its form [when near the sun]. Now that with your immortal discoveries you have observed in the

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[23] Herman Kesten, *Copernicus and His World.* New York 1945, London 1946, p. 369; in German: *Copernicus und seine Welt.* Amsterdam 1948, p. 443.

[24] T. S. Kuhn, *op. cit.,* pp. 222—223.

[25] *Ibidem,* ed. 1957, pp. 176—179; ed. 1959, pp. 177—180.

[26] *Ibidem,* ed. 1957, p. 146; ed. 1959, p. 147.

[27] *Cf.: Nikolaus Kopernikus Gesamtausgabe,* ed. by Fritz Kubach, Franz Zeller and Karl Zeller. Munich and Berlin 1944—1949, vol. 2, p. 12, l. 25—26; also: p. 150, l. 22—23. Cited hereafter as *Gesamtausgabe.*

celestial domain so many other wonders invisible with ordinary powers, I should like to know whether you have made any observation in this regard, and whether what I have supposed is true" [28].

Castelli's supposition was confirmed by Galileo in the following reply to his favorite disciple on December 30, 1610: "About three months ago I began to observe Venus with the instrument, and I saw it round in shape and quite small [29]. From day to day it grew bigger while preserving the same round shape until finally, reaching quite a great distance from the sun, it started to lose its roundness on its eastern side, and in a few days it was reduced to a semicircle. It kept this shape for many days, while becoming larger in size. It is now commencing to become horned [30], and as long as it is visible in the evening, the horns will grow thinner until it disappears. But then when it returns in the morning, it will be seen with very thin horns turned away from the sun, and it will expand toward a semicircle up to its greatest distance [from the sun]. Then it will remain semicircular for some days, while decreasing in size. Afterwards it will pass from a semicircle to a full circle in a few days, and later it will be seen for many months as morning-star and evening-star, completely round but very small. The obvious consequences which follow herefrom are well known to you" [31].

These consequences were spelled out in detail in a communication which Galileo wrote on the same day, December 30, 1610, to the foremost contemporary Jesuit astronomer [32], who was not a Copernican: "Venus (and Mercury unquestionably does the same thing) goes around the sun,

[28] *Le Opere di Galileo Galilei, Edizione Nazionale.* Vol. 1—20. Firenze 1890—1909; reprinted: 1929—1939. Cited hereafter as *EN*. Here: *EN*, vol. 10. p. 482, l. 13—21. The circumstances surrounding this letter were distorted by a priest intent on besmirching Galileo's reputation. For a crushing rebuttal of the priest, who had not been appointed to the editorial commission of the national edition of Galileo's works, see: Antonio Favaro, *Galileo Galilei, Benedetto Castelli e la scoperta delle fasi di Venere.* "Archivio di Storia della Scienza", I, 1919—1920, pp. 284—293; *cf.* also: pp. 276—277.

[29] Since Galileo says that he began to observe Venus with the telescope about the end of September 1610, Humboldt's statement that Galileo saw Venus crescent-shaped in February 1610, misdated the discovery of the phases of Venus by more than half a year. *Cf.*: A. v. Humboldt, *op. cit.*, vol. 2, p. 362.

[30] This emphasis on the gradualness of the changes in Venus' appearance (*di giorno in giorno, finalmente, in pochi giorni, molti giorni, hora*) demonstrates the erroneousness of the undocumented reference to "Galileo's statement that Venus altered its appearance by leaps and bounds (*sprunghaft*)" in: Ernst Zinner, *Entstehung und Ausbreitung der coppernicanischen Lehre.* Erlangen 1943, p. 343; reviewed by Edward Rosen, see: "Isis", XXXVI, 1945—1946, pp. 261—266.

[31] *EN*, vol. 10, p. 503, l. 16—31.

[32] Christopher Clavius (1538—1612), who was the subject of a useful little article by Otto Meyer; see: O. Meyer, *Christoph Clavius Bambergensis.* "Kleine Veröffentlichungen der Remeis-Sternwarte Bamberg", XXXIV, 1962, pp. 137—143.

which is without any doubt the center of the principal revolutions of all the planets. Moreover, we are certain that the planets are in themselves dark, and shine only when illuminated by the sun. That this does not happen with the fixed stars, I believe as a result of some of my observations, and that the [actual] planetary system is surely different from the one which is generally accepted" [33].

In his magnificent *Dialogue (Dialogo sopra i due massimi sistemi del mondo, tolemaico e copernicano,* Florence, 1632), which was condemned as heretical by the Roman Catholic church, Galileo explained to his readers, who were not assumed to be professional astronomers, how the phases of Venus prove that this planet rotates around the sun:

"It never moves further away from the sun than a certain definite interval of some 40°, so that it never becomes opposite the sun, nor at right angles to it, nor even at an angle of 60° to it. Moreover, it appears almost 40 times larger at one time than at another, being very big when it proceeds in the retrograde direction toward its evening conjunction with the sun, and very small when it moves in the forward direction towards its morning conjunction. In addition, when it appears biggest, it shows a horned shape; when it appears smallest, it is seen perfectly round. Since, I say, these phenomena are true, I do not see how it is possible to avoid the statement that this planet revolves in a circle around the sun. This circle can nowise be said to embrace and contain the earth within itself, nor to be below the sun (that is, between the sun and the earth), nor to be above the sun. This circle cannot embrace the earth, because [in that case] Venus would sometimes become opposite the sun. Nor can the circle be below the sun, because Venus would appear horned near both its conjunctions with the sun. Nor can the circle be above the sun, because the planet would always look round and never horned" [34].

Although Galileo's discovery of the phases of Venus proved Copernicus' thesis that the planet revolves around the sun, Copernicus himself never actually saw Venus' phases. They are not visible to the naked eye, and the telescope was not invented until nearly half a century after Copernicus died in 1543. In Galileo's *Dialogue,* when one of the interlocutors asks why the phases of Venus were concealed from Copernicus and were revealed later, the principal spokesman for Galileo answers as follows:

"These things can be grasped only with the sense of sight, which nature did not give to mankind so perfect that it could succeed in discerning such differences. Indeed the organ of sight makes trouble for itself. But in our age it pleased God to grant to human ingenuity an invention

[33] *EN*, vol. 10, p. 500, l. 36—42.

[34] *EN*, vol. 7, pp. 351, l. 21—352, l. 1.

so remarkable that it could improve our vision by increasing it 4, 6, 10, 20, 30, and 40 times. Thereafter countless objects which had been invisible to us either on account of their distance or on account of their extremely small size were made perfectly plain by means of the telescope" [35].

The spokesman then goes on to say that when Venus approaches its evening conjunction, "the telescope clearly shows us its horns just as definite and well-marked as those of the moon. The horns of Venus look like part of a very big circle, and they are almost 40 times larger than the disk of Venus when it is above the sun and making its last morning appearance". Thereupon the questioner exclaims: "O Nicholas Copernicus, what joy would have been yours to see this part of your system confirmed by such clear observations!" [36].

Do we not have in the foregoing passages of Galileo's *Dialogue* some of the raw materials out of which Keill built his unhistorical gossip about "the prophecy of Copernicus"? To locate the rest of Keill's raw materials, let us now look at what Copernicus said about the phases of Venus. In his *Revolutions (De Revolutionibus orbium coelestium,* Nuremberg, 1543), I, 10, he discussed the arrangement of the planets in space:

"With regard to Venus and Mercury differences of opinion are found, because these planets do not pass through every angular distance from the sun, as the other planets do. Therefore some people, like Timaeus in Plato, locate Venus and Mercury above the sun. Other people, like Ptolemy and a good many of the recent writers, place Venus and Mercury below the sun. Al-Bitruji puts Venus above the sun [37] and Mercury below it. Plato's followers believe that all the heavenly bodies, being otherwise dark, shine because they receive the light of the sun. Hence, if Venus and Mercury were below the sun, since their angular distance from it is not very great, they would look semicircular or at any rate less than completely round. For, the light which they receive would be reflected mostly upward, that is, toward the sun, as we see in the new or the dying moon" [38].

The foregoing passage clearly shows us that the phases of Venus did not have the same significance for Copernicus as they subsequently acquired. For they were interpreted by Galileo, the first human being who ever saw them, as confirmation of Copernicus' contention that Venus revolves around the sun and not around the earth. But in

[35] *EN, ibidem,* p. 363, l. 15—23.

[36] *EN, ibidem,* p. 367, l. 5—12.

[37] This statement has been turned topsy-turvy by some recent writers, whose errors were corrected in: Edward Rosen, *Copernicus and Al-Bitruji.* "Centaurus", VII, 1961, pp. 152—156.

[38] *Gesamtausgabe,* vol. 2, p. 22, l. 10—19.

Copernicus' thinking the phases of Venus belong in a completely different context. They have nothing to do with the debate whether Venus revolves around the sun or around the earth. They are discussed entirely within the framework of the geocentric theory.

Assume that the earth is motionless at the center of the universe. The moon is the earth's nearest neighbor, and it revolves around the earth. Which of the other heavenly bodies revolving around the earth is its second nearest neighbor? "The sun", answered Plato [39]. In defense of Plato's arrangement (central earth, moon, sun, then Venus and Mercury), and in opposition to a rival geocentric arrangement (earth, moon, Mercury, Venus, sun), the following argument was developed by Platonists [40]. If you put Venus between the earth and the sun, then Venus should show phases like those of the moon, which is also a dark body between the earth and the sun. But Venus shows no such phases to the unaided eye, which sees this planet perfectly round whenever it is visible. This absence of the phases of Venus, argued the Platonists, supports Plato's version of the geocentric theory as against Ptolemy's version of the geocentric theory.

In the Ptolemaic system, Venus should show phases. Their nonappearance was regarded by Copernicus as a defect in the Ptolemaic system, which enjoyed virtually universal support when he was writing his *Revolutions* in the sixteenth century. But two hundred years later, in Keill's time, the Ptolemaic system had long been dead, having suffered fatal blows at the hands of Copernicus, Galileo, Kepler, and Newton. Under these altered conditions the absence of Venus' phases was anachronistically transformed by Keill from an anti-Ptolemaic argument (as it had been for Copernicus) into an anti-Copernican argument as a basis for his mythical "prophecy of Copernicus".

If we have correctly identified the passages in Galileo's *Dialogue* and Copernicus' *Revolutions* which served Keill as the ingredients from which he concocted his "prophecy of Copernicus", we now face a more difficult question: how did Copernicus explain the absence of Venus' phases? Recalling the Platonists' use of this argument against Ptolemy was no doubt an effective maneuver on Copernicus' part. But what about Venus' phases in Copernicus' own system? Of course he never saw them. Nor, despite Keill, Smith, Mutis, Bailly, Czyński, Flammarion

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[39] Plato, *Timaeus*, 38 C—D.

[40] Not by Plato himself, as in the English translation of the Preface and Book I of the *De Revolutionibus* by John F. Dobson and Selig Brodetsky, "Occasional Notes of the Royal Astronomical Society", II, 1947, p. 16; reissued: 1955; and: T. S. Kuhn, *op. cit.*, ed. 1957, p. 176; ed. 1959, p. 177; and: Milton K. Munitz, *Theories of the Universe*. Glencoe 1957, London 1958, p. 165. Copernicus says: "...those who follow Plato" ("...*qui Platonem sequuntur*"), *cf.*: *Gesamtausgabe*, vol. 2, p. 22, l. 15.

and their followers, did Copernicus, who was not a clairvoyant, foresee that Venus would some day be found to have phases.

How, then, did Copernicus explain their non-appearance in his own pre-telescopic times? To this question Humboldt gave the right answer by pointing out that Copernicus discusses "the doubts which the more modern adherents of the Platonic opinions advance against the Ptolemaic system on account of the phases of Venus. But in the development of his own system Copernicus does not speak explicitly about these phases" [41]. As Galileo's spokesman in the *Dialogue* remarks about another serious problem in the Copernican system, "Maybe Copernicus himself could not find a solution of it which satisfied him completely, and perhaps for that reason he kept quiet about it" [42].

The Copernican system, an immense revolution in human thought, brought in its train a host of perplexing difficulties. Some of them were solved correctly by Copernicus, but some of the solutions proposed by him have turned out to be wrong. About other questions he remained silent, as Galileo's spokesman put it, "because he could not explain to his own satisfaction a phenomenon so contrary to his system. And yet, convinced by so many other indications, he stuck to his theory and held it to be true... These are the difficulties which make me wonder about Aristarchus and Copernicus. They must have noticed them, and then could not solve them. Yet, as a result of other remarkable confirmations, they trusted so much in what reason told them that they confidently asserted that the structure of the universe could have no other form than the one described by them" [43].

But with regard to the phases of Venus Galileo did not believe that Copernicus resorted to the strategy of silence. In his *Sunspots (Istoria e dimostrazioni intorno alle macchie solari,* Rome, 1613), Galileo remarks that the anti-Copernicans will explain the absence of phases in Venus by saying that "either Venus is self-luminous or its substance is penetrable by the sun's rays, so that it is illuminated not only on its surface but also throughout its entire depth". The anti-Copernicans "can have the courage to shield themselves with this reply because there has been no lack of philosophers and mathematicians who held this belief... Copernicus himself has to accept one of the aforementioned theories as possible, or rather as necessary, since he could not explain why Venus does not look horned when it is below the sun. In fact nothing else could be said before the coming of the telescope let us see that Venus is actually as dark as the moon and that, like the moon, it changes its shape" [44]. This

[41] A. v. Humboldt, *op. cit.*, vol. 2, p. 362.
[42] *EN*, vol. 7, p. 194, l. 3—5.
[43] *EN, ibidem*, pp. 362, l. 13—363, l. 1.
[44] *EN*, vol. 5, pp. 99, l. 16—100, l. 1.

was what Galileo wrote on May 4, 1612, about Copernicus' attitude toward the phases of Venus.

Nearly two decades later in the *Dialogue* Galileo reiterated the same view: "If the body of Venus is itself dark and, like the moon, shines only because it is illuminated by the sun, as seems reasonable, when Venus is below the sun it ought to look horned, like the moon when it is similarly near the sun. The phenomenon is not visible in Venus. Copernicus therefore declared that it [45] was either self-luminous or made of such material that it could imbibe sunlight and transmit it throughout its entire depth, so that it could always look bright to us. In this way Copernicus accounted for the absence of phases in Venus" [46].

Actually Copernicus did not account for the absence of phases in Venus in this way or in any other way. He himself expressed no opinion about the matter, as Humboldt correctly said. In the *Revolutions*, I, 10, we recall, Copernicus has the followers of Plato agree with the followers of Ptolemy in placing the earth at the center of the universe. But these two schools disagree about the position of Venus, the Platonists putting it above the sun, and the Ptolemaists below the sun. Copernicus then proceeds to say, as we saw above:

"Plato's followers believe that all the heavenly bodies, being otherwise dark, shine because they receive the light of the sun. Hence, if Venus and Mercury were below the sun, since their angular distance from it is not very great, they would look semicircular or at any rate less than completely round. For, the light which they receive would be reflected mostly upward, that is, toward the sun, as we see in the new or the dying moon".

This objection by the Platonists to the Ptolemaic theory, Copernicus reports, was answered by the Ptolemaists, who "say [*fatentur*] that in the planets there is no opacity like the moon's. On the contrary, these bodies shine either with their own light or with the sunlight absorbed throughout their bodies" [47].

Although these ideas about the nature of the planets were ascribed to the Ptolemaists by Copernicus, Galileo attributed them to Copernicus himself. He did so because the first edition of the *Revolutions* (Nuremberg, 1543) put the verb "say" in the first person (*fatemur*) [48]. This

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[45] Venus, not the moon, as in: Giorgio de Santillana, *Galileo Galilei, Dialogue on the Great World Systems*. Chicago 1953, p. 343. This error was introduced by Santillana in his revision of the translation of Galileo's *Dialogue* by Thomas Salusbury in *Mathematical Collections and Translations*, London 1661—1665, tome 1, part 1, p. 302; see: Stillman Drake, *A Kind Word for Salusbury*. "Isis", XLIX, 1958, p. 27.

[46] *EN*, vol. 7, p. 362, l. 3—12.

[47] *Gesamtausgabe*, vol. 2, pp. 22, l. 35—23, l. 1.

[48] Fol. 8r, line 13.

typographical error was corrected in the second edition of the *Revolutions* (Basel, 1566), which shifted the verb "say" to the third person (*fatentur*) [49]. Copernicus' holograph manuscript [50] plainly shows that the reading in the first edition was wrong: it is not "we" (the author), but "they" (the Ptolemaists), who say that the planets are either self-luminous or transparent.

Galileo had a copy of both the first and the second edition of the *Revolutions* [51], but unfortunately in this matter he relied on the first edition. I say "unfortunately", because Galileo's magisterial prestige induced others to accept his statement that it was Copernicus who explained the absence of the phases of Venus by describing the planet as either self-luminous or transparent. Thus, according to a note in the 1744 edition of Galileo's works, "Copernicus wrote that either Venus was self-luminous or it absorbed sunlight throughout its entire depth so that it could appear bright even when it turns and shows us the part of its globe that the sun does not strike" [52].

Of the two alternatives supposedly adopted by Copernicus, the self-luminosity of Venus was dropped by a biographer of Galileo, John Elliot Drinkwater Bethune (1801—1851), who retained only the transparency: "Copernicus, whose want of instruments had prevented him from observing the horned appearance of Venus when between the earth and sun, had perceived how formidable an obstacle the non-appearance of this phenomenon presented to his system; he endeavoured, though unsatisfactorily, to account for it by supposing that the rays of the sun passed freely through the body of the planet" [53].

The second alternative was reinstated by De Morgan, when reporting on this subject to the Royal Astronomical Society in the address from which we have already read an excerpt: "If we try to examine what the opinion of Copernicus on this matter really was, a point of some little curiosity arises. It depends on one word, whether he did or did not assert his belief in one or other of these two opinions — that the

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[49] *Loc. cit.*

[50] *Gesamtausgabe*, vol. 1, fol. 8r, line 3 up.

[51] *Cf.*: Antonio Favaro, *La libreria di Galileo Galilei.* "Bullettino di Bibliografia e di Storia delle Scienze Matematiche e Fisiche" (Boncompagni), XIX, 1886, pp. 246—247; the entire Boncompagni's "Bullettino" has just been re-issued by Johnson Reprint Corporation of New York and London. For Galileo's autograph notes on Copernicus' *Revolutions* see: A. Favaro, *Nuovi studi galileiani.* Venice 1891, pp. 76—78 (*Postille galileiane all' opera capitale di Niccolò Coppernico*).

[52] *Opere di Galileo Galilei.* Padua 1744, vol. 2, p. 36; presumably this unsigned note was written by the editor, Giuseppe Toaldo (1719—1798).

[53] J. E. D. Bethune, *Life of Galileo.* London 1833, p. 35; New York 1835, p. 31. This is not the only error committed by Bethune, "whose scholarship and minute accuracy are beyond question", in the excessively generous judgment of S. Drake. see: "Isis", XLIX, 1958, p. 29.

planets shine by their own light, or that they are saturated by the solar light, which, as it were, soaks through them. I support the affirmative: that is to say, I hold it sufficiently certain that Copernicus did express himself to the effect that one or the other of these suppositions was the truth" [54].

De Morgan's restoration of the second alternative was overlooked by John Joseph Fahie (1846—1934), a close friend of the editor of the national edition of Galileo's works. Despite such guidance Fahie's biography of Galileo echoed Bethune's twofold error: "Copernicus himself had endeavoured to account for this [absence of Venus' phases], by supposing that the sun's rays passed freely through the body of the planets" [55].

The same double mistake was made by John Gerard (1840—1912), provincial of the Jesuits in England and author of the article on Galileo in the *Catholic Encyclopedia*: "It had been argued against the said system [of Copernicus] that, if it were true, the inferior planets, Venus and Mercury, between the earth and the sun, should in the course of their revolution exhibit phases like those of the moon, and, these being invisible to the naked eye, Copernicus had to advance the quite erroneous explanation that these planets were transparent and the sun's rays passed through them" [56].

That Venus was transparent or self-luminous was a theory imputed by Copernicus to the followers of Ptolemy. It was not Copernicus' own conception of the physical nature of the planet, despite Galileo, Toaldo, Bethune, De Morgan, Fahie, and Father Gerard. All but one of these writers merely enunciated the unsupported dictum that Copernicus believed Venus to be transparent or self-luminous. The single exception is De Morgan, whose attempt to justify this statement about Copernicus' belief will be examined in a moment. The others simply copied from Galileo, or from those who had previously copied from Galileo. But, as we saw above, Galileo was misled by a misprint, which he would doubtless have detected had he compared the text of the first edition of the *Revolutions* with the text of the second edition. We know from his letter of August 19, 1610, to Kepler that he despised the comparers of texts for trying to learn the truth about nature from books [57]. Of course, if we want to know nature, we must read the Book of Nature,

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[54] "Monthly Notices of the Royal Astronomical Society", VII, 1847, p. 291.

[55] John Joseph Fahie, *Galileo, His Life and Work*. London 1903; reprinted: Dubuque 1962, p. 124; idem, *The Scientific Works of Galileo*, in: *Studies in the History and Method of Science*, ed. by Charles Singer. Oxford 1917—1921, vol. 2, p. 239.

[56] *Catholic Encyclopedia*. New York 1907—1914, vol. 6, p. 343.

[57] *EN*, vol. 10, p. 423, l. 59—62; Johannes Kepler, *Gesammelte Werke*. Vol. 16. Munich 1954, p. 329, l. 58—61.

that is, the physical world. But if we want to know what Copernicus thought about Venus, the Book of Nature cannot help us. We must read the book of Copernicus; and if its first edition contains a crucial misprint, comparison of texts will help us to detect that fact.

Such a comparison was instituted by De Morgan. But despite his enormous erudition, in this instance he went astray [58]. Concerning the Ptolemaic arrangement of Mercury and Venus between the earth at the center and the sun, De Morgan said that Copernicus "describes the opinion just mentioned favourably, referring, not to his own view, but to that of those others who had held it. This is not an uncommon idiom: persons advocating an unpopular opinion are very apt to describe the maintainers of it in the third person, though themselves be of the number... Copernicus is evidently speaking with approbation of the opinions which he describes; and it would be difficult to say why *comperiunt* or *putant* in one sentence should imply approbation, and *fatentur*, in the next, should be at least disavowal, if not disapprobation" [59].

De Morgan evidently made the foregoing analysis with less than his customary care, as is indicated by his misquotation of *putant* instead of *supputant*, the word actually used by Copernicus [60]. Much more serious are De Morgan's two mistakes about the Copernicus passage under consideration. In the first place, the Ptolemaic arrangement of the planets was not "an unpopular opinion" in Copernicus' time; in fact he says, as we saw above, that it was held by "a good many of the recent writers" (*bona pars recentiorum*). Did De Morgan anachronistically transpose the nineteenth-century unpopularity of the Ptolemaic planetary arrangement back to the sixteenth century?

However this may be, De Morgan committed a second error in saying that Copernicus "describes the opinion just mentioned favourably", and "is evidently speaking with approbation of the opinions which he describes". Actually Copernicus describes the opinion neither with approbation nor with disapprobation, neither favorably nor unfavorably. He describes it dispassionately and accurately. Then he proceeds to present powerful arguments against it. He is "referring, not to his own view, but to that of those others who had held it", as De Morgan correctly saw. The view in question is the Ptolemaic planetary arrangement. To disprove this view was Copernicus' prime purpose in writing the *Revolutions*. In sum, then, De Morgan's attempt to show that Copernicus

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[58] For other examples, see: Edward Rosen, *De Morgan's Incorrect Description of Maurolico's Books*. "Papers of the Bibliographical Society of America", LI, 1957, pp. 111—118; idem, *Maurolico's Attitude toward Copernicus*. "Proceedings of the American Philosophical Society", CI, 1957, pp. 177—194.

[59] "Monthly Notices of the Royal Astronomical Society", VII, 1847, pp. 291—292.

[60] *Gesamtausgabe*, vol. 1, fol. 8r, line 4 up; *op. cit.*, vol. 2, p. 22, l. 33.

conceived Venus to be self-luminous or transparent must be adjudged a complete failure. Copernicus himself did not regard Venus as self-luminous or transparent. He ascribed that opinion to the followers of Ptolemy.

Since Copernicus did not hold Venus to be self-luminous or transparent, what did he think was the source of the planet's light? Did he, like "Plato's followers, believe that all the heavenly bodies, being otherwise dark, shine because they receive the light of the sun"? Just as he did with the followers of Ptolemy, Copernicus describes this opinion of the Platonists dispassionately. He neither approves it nor disapproves it. Having no decisive evidence for or against the Platonists' view, Copernicus does not say how Venus obtains its light. Refraining altogether from treating this question, he leaves it for others to decide.

Since we do not know from Copernicus' own statements what he believed the source of Venus' light to be, can we perhaps make an inference from the prevailing contemporary or traditional opinion about the subject? In other words, can we put our trust in Galileo's deadliest opponent? Finding no shadow cast by Venus on the sun in a predicted conjunction of those two bodies, the Jesuit Christopher Scheiner (1573—1650), or Apelles, as he then called himself, wished to dispose of the possible explanation that:

"The planet Venus does not produce a shadow or spot for us because it is endowed with its own light, which is not, like the moon's, received from the sun. But this will be contradicted by experience, reason, and the common agreement of all the ancient and modern mathematicians" [61].

Is it true, as Scheiner-Apelles maintained, that "all the ancient and modern mathematicians" agreed in denying the self-luminosity of Venus? Or was Galileo right in insisting that, according to some philosophers and mathematicians, Venus has its own light "and let this be said by leave of Apelles, who writes otherwise" [62]. As one example among many, Galileo could have pointed to Al-Bitruji, who declared:

"What convinces me that Mercury and Venus do not receive their light from the sun nor from outside themselves is the fact that we always see them shining when they are near the sun... If their light were, like the moon's [derived from the sun], the bright part of Mercury would always be crescent-shaped because its angular distance from the sun is not very great, and the same is true for Venus" [63].

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[61] Christopher Scheiner, *Tres epistolae de maculis solaribus.* Augsburg 1612, fol. A4v; reprinted: *EN*, vol. 5, p. 28, l. 26—29; *cf.:* Ch. Scheiner, *Accuratior disquisitio.* Augsburg 1612, p. 14; reprinted: *EN, ibidem,* p. 46, l. 17—18.

[62] *EN, ibidem,* p. 99, l. 21; *cf.:* p. 197, l. 19—24.

[63] Al-Bitruji, *De motibus coelorum,* ch. 16, no. 11; idem, *ibidem,* ed. by Francis J. Carmody. Los Angeles 1952, p. 128.

Whereas Al-Bitruji believed in the self-luminosity of Venus, its absorption of sunlight was defended by Regiomontanus (1436—1476), the greatest astronomer of the fifteenth century: "The bodies of the planets other than the moon absorb sunlight into themselves. They do so to no greater extent than the moon. Yet [64], perhaps on account of the different variation in the planets and stars, the planets other than the moon receive the sun's rays into their very depths. On the other hand, on account of its greater density, the moon is not illuminated down to its center. Hence it looks to us like a crescent. But Venus, even though it is quite close to the sun, never appears in this way as a crescent, because its body is penetrated throughout by sunlight" [65].

We need look no further than Al-Bitruji's belief in the self-luminosity of Venus and Regiomontanus' conception of that planet's thorough absorption of sunlight to decide between Galileo and Scheiner. The great Italian was right, and the Jesuit was wrong in contending that by "the common agreement of all the ancient and modern mathematicians" Venus was a dark body. There was no such common agreement. There was in fact sharp disagreement. On both sides of the question Copernicus had ample and respectable authority. But he had no observational evidence to decide between the opposing opinions. He did not foresee the invention of the telescope. Nor did he ever predict that that marvelous instrument would some day disclose the phases of Venus. With regard to the source of that planet's light, his prudent silence anticipated the wise counsel of the eminent twentieth-century philosopher who said: *"Wovon man nicht sprechen kann, darüber muss man schweigen"* [66].

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[64] Reading *tamen* rather than *tantum*. Much more serious blunders by F. J. Carmody were corrected in: Edward Rosen, *Regiomontanus' Breviarium*. "Medievalia et Humanistica", XV, 1963, pp. 95—96.

[65] Francis J. Carmody, *Regiomontanus' Notes on Al-Bitruji's Astronomy*. "Isis", XLII, 1951, p. 129, no. 32—33.

[66] Ludwig Wittgenstein, *Tractatus logico-philosophicus*. Reprinted: London 1961, New York 1961, pp. 150—151.