FROM COPERNICUS TO KEPLER: HELIOCENTRISM AS MODEL AND AS REALITY

OWEN GINGERICH

Professor of Astronomy and of the History of Science, Harvard University
Astrophysicist, Smithsonian Astrophysical Observatory

(Read April 20, 1973, in the Symposium on Copernicus)

NEAR THE CLOSE of Book One of the autograph manuscript of his great work, Copernicus writes:

> And if we should admit that the course of the sun and moon could be demonstrated even if the earth is fixed, then with respect to the other wandering bodies there is less agreement. It is credible that, for these and similar causes (and not because of the reason of motion, which Aristotle mentions and rejects), Philolaus was aware of the mobility of the earth, and some even say that Aristarchus of Samos was of the same opinion. But since things were such that they could not be comprehended except by a sharp intellect and continuing diligence, Plato says that generally very few philosophers in that time understood the reason for the sidereal motion.[1]

Before a copy of Copernicus's manuscript was sent to the printer, the work was somewhat reorganized and in the process this passage was struck out. The original first and second books were merged into a single section, and the deleted material was rewritten into the preface to Pope Paul III. Apparently by that time Copernicus had access to the 1531 Greek edition of Plutarch,[2] and so he chose to use a direct quotation in Greek, which reads in translation:

> Some think that the earth is at rest, but Philolaus the Pythagorean says that it moves around the fire with an obliquely circular motion, like the sun and moon. Herakleides of Pontus and Ekphantus the Pythagorean do not give the earth any movement of locomotion, but rather a limited movement of rising and setting around its center, like a wheel.[3]

In this way the name of Aristarchus, often called the "Copernicus of Antiquity," was eliminated from the printed edition of *De revolutionibus*. An anniversary such as this, when Copernicus is everywhere apotheosized, inevitably breeds detractors. Among their complaints is the large measure of glory attributed to Copernicus and the silence that attends the speculative suggestions of Aristarchus.

I do not intend to give a judgment here, but rather, I shall first answer with the platitude that nothing succeeds like success. Surely a critical factor is that Copernicus's system has been universally adopted, and that of Aristarchus was not. This, then, leads us to the fascinating study of the reception, the near rejection, and the ultimate acceptance of the heliocentric system. By this I do not mean the dramatic story of Galileo and the Inquisition, but a pattern of events that unfolded and reached their denouement before Galileo wrote his *Dialogo* in 1632.

Two of the key figures in the dessemination of the Copernican doctrine were professors of mathematics at the Lutheran University of Wittenberg. About the senior member of the pair, Erasmus Reinhold, few personal facts are known. In 1531 his name is inscribed in the Dean's Book of the University of Wittenberg along with other students, and in 1536, at age twenty-five, he became professor of higher mathematics, that is, of astronomy. On two occasions he served as dean, and he later became rector of the University of Wittenberg. In 1553, at the peak of his astronomical career, he died of the plague, being only forty-one years old.[4]

---

[1] Translated from the transcription given in *Nikolaus Kopernicus Gesamtausgabe* **2** (F. Zeller and C. Zeller, eds., Munich, 1949): p. 30. I wish to thank Miss Joanne Phillips for preparing an initial translation.

[2] Πλουταρχου Χαιρωνεως περι των αρεσκοντων τοις φιλοσοφοις [*de placitis philosophorum*] (Basel, Joan. Hervagius, 1531), book 3, chap. 13. The location of the copy Copernicus used is unknown, although his copy of 1516 Strasbourg Latin edition is preserved in Uppsala. I have compared the Copernicus text against the British Museum copy of the Basel edition, 524. g. 18, where it is cataloged under "Suppositious Works." In spite of a few minor differences, it seems likely that Copernicus used the Basel edition for his quotation.

[3] N. Copernicus, *Revolutions of the Heavenly Spheres*, in: *Great Books of the Western World* **16** (Chicago, 1952): p. 508.

[4] See my "Reinhold" in a forthcoming volume of the *Dictionary of Scientific Biography;* also see Karl Heinz

In the same year that Reinhold became professor of higher mathematics, Georg Joachim Rheticus received the chair of lower mathematics at age twenty-two. Apart from the fact that they both served together for a few years on the Wittenberg faculty, and both played fundamental although different roles in making Copernicus famous, their subsequent lives have little in common. Unlike Reinhold, who became an establishment figure at Wittenberg, Rheticus became a scholastic itinerant, his interest in Copernicus quickly fading. Nevertheless, his part in getting Copernicus's work published was memorable, and rather similar to Halley's role with respect to Newton's *Principia*.

In 1539 the young Rheticus journeyed to Frauenburg (now the town of Frombork) in remote Polish Prussia to gain first-hand knowledge concerning the astronomical innovations suggested by Copernicus. Although Rheticus came from the hotbed of Lutheranism, the Catholic Copernicus received him with courage and cordiality. Swept along by the enthusiasm of his young disciple, Copernicus allowed Rheticus to publish a first-printed report about the heliocentric system. In a particularly beautiful passage, Rheticus wrote:

> With regard to the apparent motions of the sun and moon, it is perhaps possible to deny what is said about the motion of the earth. . . . But if anyone desires to look either to the principal end of astronomy and the order and harmony of the system of the spheres or to ease and elegance and a complete explanation of the causes of the phenomena, by no other hypotheses will he demonstrate more neatly and correctly the apparent motions of the remaining planets. For all these phenomena appear to be linked most nobly together, as by a golden chain; and each of the planets, by its position and order and very inequality of its motion, bears witness that the earth moves and that we who dwell upon the globe of the earth, instead of accepting its changes of position, believe that the planets wander in all sorts of motions of their own.[5]

His use of the word "hypotheses" is particularly interesting. This reappears on a subsequent page where Rheticus wrote:

> But my teacher had long been aware that in their own right the observations in a certain way required hypotheses which would overturn the ideas concerning the order of the motions and spheres that had hitherto been discussed and promulgated and that were commonly accepted and believed to be true; moreover, the required hypotheses would contradict our senses.

Both of these passages use the word "hypotheses" in a somewhat different sense from our modern meaning of the word. Rheticus, in common with most other sixteenth-century astronomical writers, uses "hypothesis" to mean an arbitrary geometrical device by which the observed celestial motions can be explained. Included within this set of geometrical devices was the grand hypothesis of them all, the heliocentric concept itself. The ultimate nature of the hypotheses, that is to say, whether they were hypothetical models or something real, became a fundamental issue in deciding on the relevance of the heliocentric idea.

As a preface to the next stage in our examination of "hypotheses" in Copernican astronomy, we must note that Rheticus not only gained permission to publish the *Narratio prima*, but he also persuaded Copernicus to allow publication of the *magnum opus* itself. Consequently, Rheticus obtained a copy of the manuscript, and upon returning to Germany he arranged for the publication of the book in Nuremberg by Johann Petreius, one of the leading scientific publishers of northern Europe. Rheticus temporarily resumed his teaching duties at Wittenberg but then moved to a professorship at Leipzig. Because he was still too far away to oversee the printing, the job fell to a Lutheran theologian, Andreas Osiander, who had previously worked as an editor for Petreius.

When Rheticus received his copies of the printed volume in the spring of 1543, he was annoyed to discover that an anonymous introduction on the nature of hypotheses had been added to the work. On two copies—one in the private collection of Mr. Harrison Horblit in Connecticut and the other preserved in the Uppsala University Library—Rheticus crossed out Osiander's unsigned introduction, in each case with a red pencil or crayon.

Osiander's introduction contains statements that seem quite innocent today, and which must have struck most sixteenth-century readers as eminently reasonable. I cannot believe that his anonymity in the matter stemmed from any malicious mischievousness, but rather simply from a Lutheran reluctance to be associated with a book dedicated to the Pope. He wrote:

Burmeister, *Georg Joachim Rheticus* (3 v., Wiesbaden, 1967–1968).

[5] Translations of the *Narratio prima* slightly modified from E. Rosen, *Three Copernican Treatises* (New York, 1971), pp. 165 and 192.

Since the novelty of the hypotheses of this work has already been widely reported, I have no doubt that some learned men have taken serious offense because the book declares that the earth moves; these men undoubtedly believe that the long established liberal arts should not be thrown into confusion. But if they examine the matter closely, they will find that the author of this work has done nothing blameworthy. For it is the duty of an astronomer to record celestial motions through careful observation. Then, turning to the causes of these motions he must conceive and devise hypotheses about them, since he cannot in any way attain to the true cause. . . . The present author has performed both these duties excellently. For these hypotheses need not be true nor even probable; if they provide a calculus consistent with the observations, that alone is sufficient. . . . Now when there are offered for the same motion different hypotheses, the astronomer will accept the one which is the easiest to grasp. The philosopher will perhaps rather seek the semblance of the truth. But neither of them will understand or state anything certain, unless it has been divinely revealed to him. . . . So far as hypotheses are concerned, let no one expect anything certain from astronomy, which cannot furnish it, lest he accept as the truth ideas conceived for another purpose, and depart from this study a greater fool than when he entered it. Farewell.[6]

In addition to striking out the introduction, in both copies Rheticus deleted the last two words of the printed title, *De revolutionibus orbium coelestium.* There is an old tradition, further attested to by copies at Yale University and at the Jagiellonian University in Cracow, that Osiander assisted the printer in changing the title from "Concerning the Revolutions" to "Concerning the Revolutions of the Heavenly Spheres." It is difficult to see precisely what Rheticus thought was offensive about the additional words except that, like the introduction, the expression "heavenly spheres" perhaps suggests the idea of model building.

Rheticus's role as midwife in the publication of *De revolutionibus* guarantees his enduring fame. But after his return to Wittenberg, the torch was in effect passed to Erasmus Reinhold. Reinhold himself remains a rather ambiguous figure. In 1551, he published his *Prutenicae tabulae* in the first of several editions. These were a handy and much expanded form of the Copernican tables in *De revolutionibus.* This widely used reference work became a principal avenue for making Copernicus's name known. In the work Reinhold wrote:

All posterity will gratefully remember the name of Copernicus, by whose labor and study the doctrine of celestial motions was again restored from its near collapse. Under the light kindled in him by a beneficent God, he found and explained much which from antiquity till now was either unknown or veiled in darkness.[7]

Though Reinhold's name was closely linked with Copernicus and Copernicanism through these handy tables, his printed writings show a notable lack of commitment with respect to the heliocentric astronomy. For example, his *Prutenic Tables* are carefully framed so that they are essentially independent of the mobility of the earth.

A number of authors have argued that Reinhold's own philosophical position was very close to that of Osiander.[8] He has left scattered clues throughout his writings, and a few hints in a single long manuscript preserved in Berlin. Although we seem to have less material extant from Reinhold than from Copernicus himself, I was able, by a happy piece of serendipity, to find and identify his personal copy of *De revolutionibus*, now preserved in the Crawford Library of the Royal Observatory in Edinburgh. At the bottom of its title page he wrote in Latin "The axiom of astronomy: celestial motion is circular and uniform or made up of circular and uniform parts." Clearly, what Reinhold saw as important in Copernicus's work was not the heliocentric cosmology, but some of the small technical details—minor hypotheses that were not part of the major cosmological revolution. In particular, he appreciated that Copernicus, in seeking to reform astronomy, had adopted a mechanism to eliminate the so-called equant of Ptolemaic astronomy, thereby returning the description of celestial motion to a pure combination of circles. Reinhold's *Prutenic Tables* are strictly based on this technical scheme, as I have demonstrated by a modern recomputation.

I should now like to describe some new material that shows the influence of this at-

[6] The greatly abridged text printed here is based on the translation of E. Rosen, *op. cit.*, pp. 24–25.

[7] E. Reinhold, *Prutenicae tabulae* (Tübingen, 1551), part 1, f. 35 in section 21, "Praeceptum. De Calculo adparentis magnitudinis tropici anni ad datum tempus." This quotation was inserted as an advertisement in the second edition of Copernicus, *De revolutionibus* (Basel, 1566).

[8] O. Gingerich, "The Role of Erasmus Reinhold and the Prutenic Tables in the Dissemination of the Copernican Theory," *Studia Copernicana* 6 (Wroclaw, 1973): pp. 43–62; this article cites previous authors including P. Duhem, L. A. Birkenmajer, E. Zinner, and A. Birkenmajer.

titude on the teaching of astronomy at Reinhold's university twenty-five years after the publication of *De revolutionibus*. Two years ago, when the Smithsonian Institution enabled me to spend part of a sabbatical year in England, I made a systematic search of the manuscript astronomical tables in the Cambridge colleges. In the course of this investigation, I came upon a manuscript that proved to be a set of notes for the astronomy lectures at the University of Wittenberg in the late 1560's, roughly two decades after the death of Reinhold. Because no comparable material has ever been described in the literature, I should like to present some details, especially to show in what connection Copernicus's name came up in the lectures.

At that time, the introductory astronomy course was based on the late medieval text of John of Hollywood, better known as Sacrobosco. Sacrobosco's *Sphere* was a very low-level treatment of spherical astronomy that scarcely mentioned planetary motion or the sophistication of the Ptolemaic theory. A new feature of the teaching at Wittenberg, however, was the recent availability of cheap printed textbooks. It almost seemed as if each astronomy teacher had printed, or was organizing his notes for the printing of, a new commentary on Sacrobosco.

The manuscript is No. 387 in the Gonville and Caius College Library; it contains about 200 leaves, written in two different hands.[9] The first three quires of eight leaves each appear to have been written by Laurentius Rankghe of Colburg in 1564,[10] and constitute a Latin commentary on Sacrobosco's *Sphere*. The commentary goes up to the definitions of circles including the zodiac, and then stops in midstream. Rankghe's writing ends on the first page of the fourth quire, thus suggesting that the entire volume with its vellum binding was bound together originally as a blank notebook.

The rest of the manuscript has apparently been written by Johannes Balduinus between May 27, 1566, and sometime in 1570. All the dates given are consecutive, and sometimes record weekly progress through the astronomy lectures. Balduinus became dean in the autumn of 1569 and, therefore, he may have been taking an official record of the lectures.[11] This could perhaps account for the fact that elementary material is covered repeatedly. He begins by recording the "Erotemata in Questiones Sphaerae" (which might be roughly translated "questions on the questions of the sphere") of Sebastian Theodoricus Winshemius. Theodoricus was professor of mathematics at Wittenberg at that time, and his textbook on this subject was printed at least seven times in Wittenberg beginning in 1564.[12] The manuscript notes approximately parallel the printed textbook. Of particular interest are the references to Copernicus, who is first mentioned in both the manuscript and the printed text in connection with the size of the earth.[13] A little later, in a discussion of precession found in the notes but not in the printed textbook, Copernicus is cited for his numerical values, along with Reinhold's *Prutenic Tables*.[14] A few pages later Copernicus's name appears again in a discussion of the moon.[15]

Both the manuscript and textbook then move on to the question "does the earth move?" The discussion proceeds through the standard arguments of the preceding centuries, and there is no hint that Copernicus had proposed the mobility of the earth.

The next group of notes in the manuscript probably comes from lectures given in the 1567 winter term by Bartholomew Schönborn, a medical doctor who published some small astronom-

[9] See M. R. James, *A Descriptive Catalogue of the Manuscripts in the Library of Gonville and Caius College* (Cambridge, 1907–1908). Under 387, p. 447, in line 3 read "Vuinshemii" in place of "Avinstemii" and in lines 9 and 10, read "Peuceri" in place of "Pruerii."

[10] I have not been able to locate Rankghe in the student lists in *Album Academiae Vitebergensis ab A. Ch. MDII Usque ad A. MDCII* 2 (Halle, 1894), but since there is no name index I could have overlooked him.

[11] Balduinus's handwriting in this manuscript agrees with the more formal specimen in the Wittenberg Dean's Book, which is now preserved at the Archives of the Martin Luther University in Halle. In 1574 Balduinus published *Vorhersage für 1574* (Wittenberg), Zinner 2664, but I have found no other trace of him.

[12] Sebastian Theodoricus Winshemius, *Novae questiones spherae, hoc est, de circulis coelestis, primo mobile, in gratiam studiosae iuuentutis scriptae* (Wittenberg, 1564, 1567, 1570, 1578, 1583, 1591, 1605). Theodoricus served as dean at Wittenberg in the spring of 1568.

[13] MS. section 4, f. 2r. The printed text reads on p. 90: "Terra maior est centies sexagies sexies. Est enim proportio Diametrorum secundum Ptolemaeum, quintupla sesquialtera, que est 11 ad 2. Secundum Copernicum vero quintupla superpartiens novem vicesimas, quae est 5 inteq. & 27 scrup ad unum."

[14] MS. section 4, f. 64; also f. 7r. On f. 7v, "vide Reinholdum in tabulis Prutenicis."

[15] *Ibid.*, f. 8v.

ical works during that decade.[16] The material follows in part the Wittenberg astronomer Casper Peucer's *Elementa doctrinae de circulis coelestibus*.[17] Needless to say this book does not espouse heliocentrism, but it does give Copernicus, as well as Reinhold, a certain prominence in the chronological section that opens the book. In the manuscript Copernicus is mentioned along with Regiomontanus and Apianus for his trigonometric tables.[18] The manuscript notes then turn to a second book by Peucer, a *De dimensione terrae*, where another reference to Copernicus's trigonometric tables occurs.[19] The section ends with calculations and a poem for the eclipse of April 8, 1567, by Sebastian Theodoricus.

In May, Schönborn lectured on still another work of Peucer, *Novae questiones sphaerae*, another of the seemingly endless commentaries on Sacrobosco, but one not actually printed until 1573. Here we find a more interesting and more technical citation of Copernicus, in connection with the motion of the solar apogee. The words "Etsi aut Copernici hypothesis ut absurdas" jump out from the page, the reference turns out to be a technical point on the motion of the apogee, and not on the mobility of the earth itself.[20] However, a few pages later, the numerical information for Mars is quoted with a book and chapter reference to *De revolutionibus*. Several pages later, after a section of rough calculations, Copernicus's name appears again, in a discussion on the measurement of star positions. The same topic reappears in more detail again with Copernicus's name, in the next section, in which yet another commentary on the sphere becomes the subject of the lectures.[21] This time the book is apparently *Epitome doctrinae de primo motu* of Vitorin Strigel,[22] a former student of Caspar Peucer who was at that time professor of theology at Leipzig and just about to be silenced because of suspected Calvinism. Once more Copernicus's sine table is mentioned, and a few pages later his value of the obliquity of ecliptic is contrasted with that of Ptolemy. But when the notes discuss the possible mobility of the earth, once more the standard rebuttals appear, and Copernicus is nowhere in sight.

The concluding, and largest single section of the manuscript, deals with a slightly different work, Caspar Peucer's *Hypotheses astronomicae.* It is not clear to me whether these lectures were given by Sebastian Theodoricus, or by Peucer himself. Peucer, the son-in-law of the Lutheran theologian Melanchthon, held considerable authority in the University at that time, although in 1576 he lost out in a faculty power struggle and was jailed, ostensibly for theological errors. In any event, the first part of the lectures mostly parallels a work called *Hypotyposes orbium coelestium*, published anonymously in Strasbourg in 1568, but republished in 1571 (that is, a year or two after the date of the lectures) under the title *Hypotyposes astronomicae* with Caspar Peucer as author. At the beginning Peucer declared that the Strasbourg edition had been pirated from him. His preface to this rare printed text is an extraordinary commentary on the state of the Copernican hypothesis as taught in Wittenberg. Peucer complains of the "offensive absurdity so alien to the truth, of the Copernican theories." [23] The proper solution, he contends, is the Ptolemaic model made consistent with recent observations. This is implied in the full title of his book, which in English reads "Astronomical Hypotheses or the Theory of the Planets, from Ptolemy and other old doctrines, accommodated to the observations of Nicholas Copernicus and the canon of motion based on them."

Interestingly enough, the manuscript notes themselves are not so specific in their rejection of Copernican cosmology, but nonetheless this topic is given the treatment of silence. The manuscript contains numerous numerical comparisons between the tables of Johann Schöner, and Reinhold's *Prutentic Tables*, but entirely divorced from any questions of the earth's motion. Finally the manuscript ends with a horo-

[16] Schönborn authored *Computus astronomicus* (Wittenberg, 1567, 1579) and *Oratio de studiis astronomices astronomices* (Wittenberg, 1564). He was dean at Wittenberg in 1564.

[17] Caspar Peucer, *Elementa doctrinae de circulis coelestibus* (Wittenberg, 1551, 1553, 1558, 1563, 1569, 1576, 1587); *De dimensione Terrae* (Wittenberg, 1550, 1554, 1579); *Novae questione sphaerae* (Wittenberg, 1573).

[18] MS. section 6, f. 3v.

[19] MS. section 7, f. 10v.

[20] MS. section 9, f. 9v; also f. 9r.

[21] MS. section 11, f. 16r; also section 10, f. 5r.

[22] Victorin Strigelius, *Epitome doctrinae de primo motu, aliguot demonstrationibus illustrata* (Leipzig, 1564; Wittenberg, 1565). MS. section 11, f. 22r; f. 24v.

[23] Caspar Peucer, *Hypotyposes astronomicae, seu theoriae planetarium. Ex Ptolemaei et aliorum veterum doctrina ad observationes Nicolai Copernici & canones motuum ab eo conditos accomodatae* (Wittenberg, 1571).

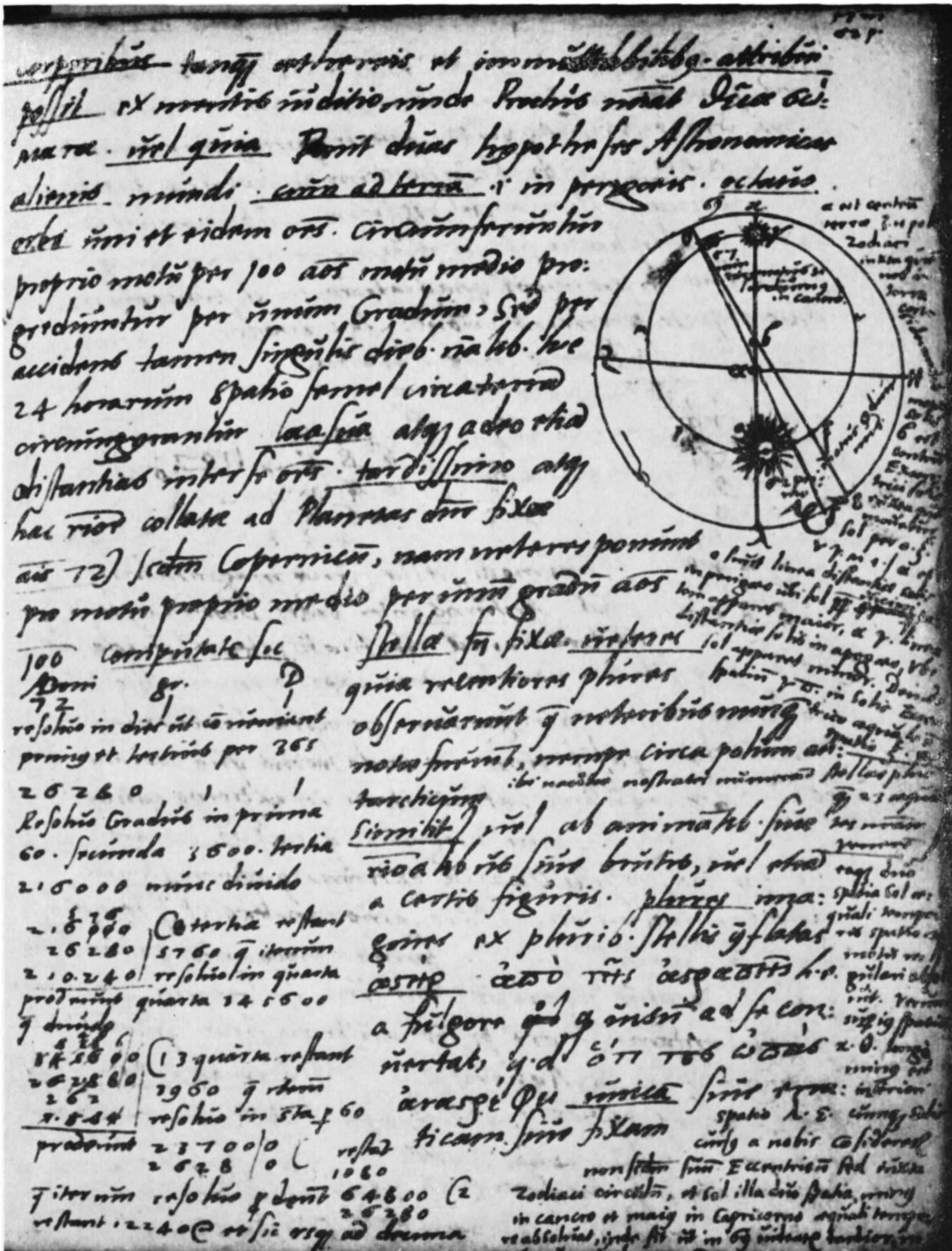


FIG. 1. Copernicus's ideas on the motion of the solar apogee are mentioned near the center of the page in these astronomy lecture notes from the University of Wittenberg in 1566. Gonville and Caius MS. 387, section 4, folio 9r.

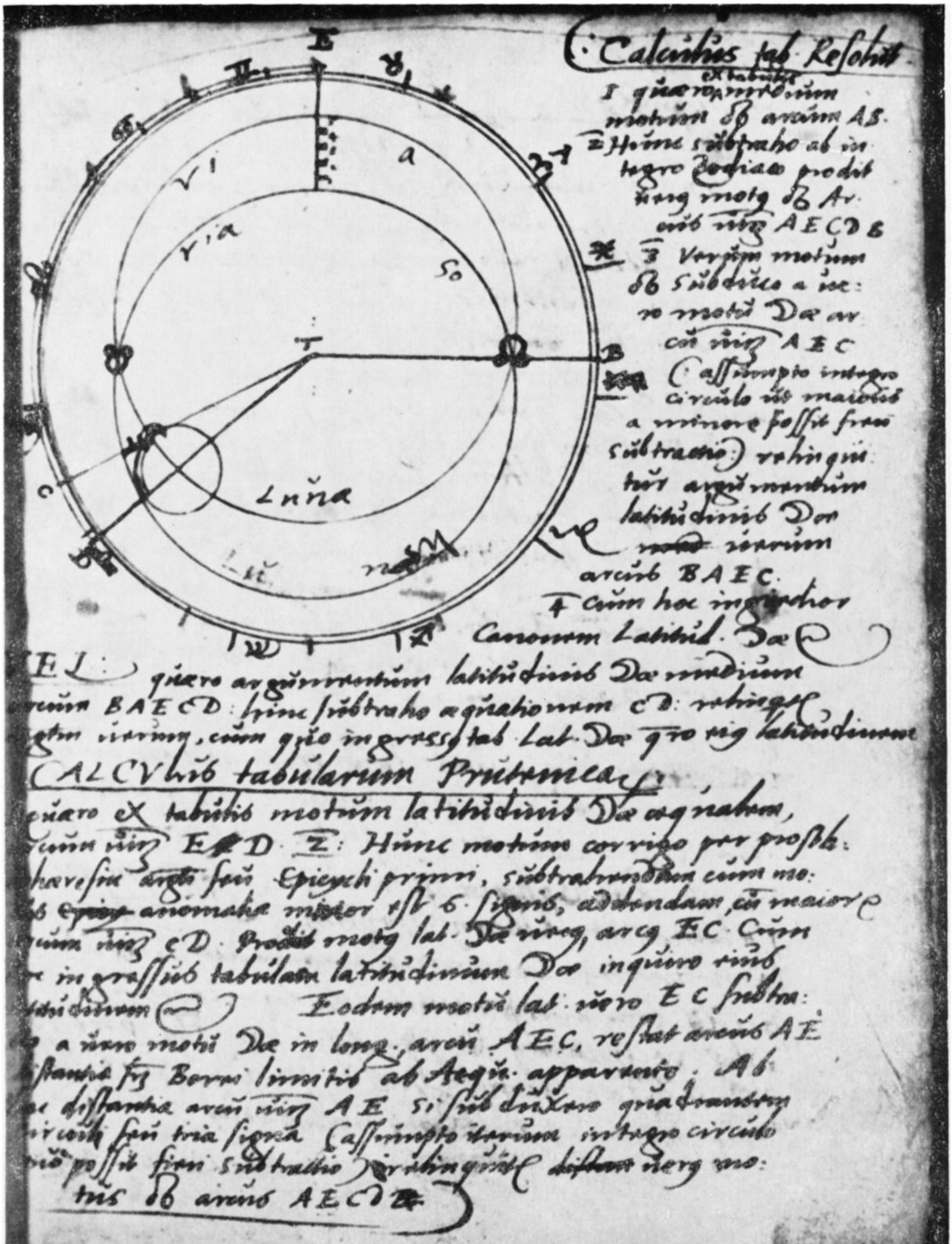


FIG. 2. Calculation of lunar positions according to both Schöner's *Tabulae resolutae* and Reinhold's *Prutenicae tabulae*, in astronomy lecture notes from 1569. Gonville and Caius MS. 387, section 12.

scope and calculations for the eclipse of August 15, 1570, these apparently being the ultimate product of an astronomical education at Wittenberg on the eve of the first centenary of Copernicus's birth.

The document shows clearly that Copernicus was well known and esteemed as a mathematician and astronomer. Nevertheless, at that great academic center—the home of the *Prutenic Tables* and the spot from which Rheticus had gone to Poland to encourage the publication of *De revolutionibus*—the students were fully protected from possible confusion by Copernicus's absurd cosmology. These lecture notes show vividly the remarkable silence that seemed almost everywhere to shroud the Copernican system in the sixteenth century.

In fact, this is not news to any attentive reader of the astronomical literature between 1550 and 1600. Thus, Copernicus's name appears often in print, but his heliocentric system is virtually never discussed. A nice example, worth noting only because it is comparatively early, 1556, is the *Tractatus Brevis et utilis, de Erigendis Figuris Coeli* of Johannes Garcaeus. Primarily an astrological work, it cites Copernicus ten times and uses his numbers to get celestial positions of the planets. Another, more interesting, example is Michael Maestlin's *Epitome astronomiae*, first printed in 1582 and then issued six more times, the last in 1624. In this textbook Maestlin mentioned the name of Copernicus several times, but never once did he breathe a hint of the heliocentric cosmology.

In spite of the silence accorded the Copernican system in printed works and in academic lectures, I am convinced that Copernicus's arguments were rather widely known. Arthur Koestler, in his *Sleepwalkers*, has called *De revolutionibus* "the book that nobody read" and "all-time worst seller." In fact, my examination of over 100 copies of the first edition of the book has convinced me that the contrary is the case. Sixteenth-century astronomers read with pen in hand, and their tracks persuade me that the book had a fair readership. So far I have found locations for approximately 180 copies of the original 1543 edition of the book. It is difficult to estimate the rate of attribution, but the original edition must have totaled at least 400 copies, a substantial number for a Renaissance science book. Nevertheless, by 1566 a second edition of a comparable size had become economically feasible. It would seem, then, that anyone seriously interested in astronomy would not have had much difficulty in encountering Copernicus's ideas.

This then leads us back to the theme of this paper—from model to reality. I can well imagine that the majority of sixteenth-century readers found Copernicus's ideas profoundly unsettling. As long as people could view the heliocentric idea as just another geometrical hypothesis for saving the phenomena, there was no need to get particularly upset. One could always hope for another alternative, such as the geocentric model later developed by Tycho Brahe. The matter is very nicely put around 1555 in a letter from Gemma Frisius that was published in several editions of Stadius's *Ephemerides*. In one of the rather few printed references in that century to the heliocentric hypothesis, Gemma allowed that the Copernican system gave a better understanding of planetary distances as well as certain features of retrograde motion. He added, however, that those who objected to the ephemerides because of the underlying hypothesis understood neither causes nor the use of hypotheses. "For these are not posited by the authors as if this must exist this way and no other." He further remarks: "Nay, even if someone wished to refer to the sky those motions that Copernicus assigns to the earth, he could do so and according to the very canons of calculation." [24]

This position is even more clearly confirmed by the censorship imposed by the Inquisition when *De revolutionibus* was placed on the *Index* "until corrected," and by the dozen corrections issued in 1620. For example, the title of chapter 11 was changed from "On the demonstration of the triple motion of the earth" to "On the hypothesis of the triple motion of the earth and its demonstration." Most of the other corrections have a similar nature.

Nowadays this Osianderian view of hypotheses strikes a sympathetic chord. Hypothetical model building is once more a familiar procedure not only for astronomers and physicists, but for biologists and sociologists. To this extent our world view finds kinship with the astronomers of the late 1500's. Thus the "progress" from model to realism in the sixteenth century and the profound philosophical revolution of the early seventeenth century concerning the know-

[24] In Johannes Stadius, *Ephemerides novae* (Cologne, 1556, 1559, 1560, 1570). Translation by Joanne Phillips.

ability of physical reality now takes on a bittersweet poignancy.

How did the view of heliocentrism change from a mere model to physical reality? Two men played the leading roles in the transformation of the prevailing opinions: Johannes Kepler, who found that the aesthetic arrangement of the Copernican system led to a coherent mathematical description of the motions, and Galileo Galilei, whose telescopic observations helped convince people that the Copernican system was not so absurd after all.

Kepler's own account of becoming a Copernican appears in the introduction to his *Mysterium cosmographicum*, where he mentions hearing about Copernicus in Michael Maestlin's astronomy lectures at Tübingen; Kepler was so delighted that he began to collect all the advantages that Copernicus had over Ptolemy, and he initiated a quest for the mathematical relationships between the number, the dimensions, and the motions of the planets. "At last on a quite trifling occasion I came near the truth," he wrote. "I believe Divine Providence intervened so that by chance I found what I could never obtain by my own efforts. I believe this all the more because I have constantly prayed to God that I might succeed if what Copernicus had said was true." [25]

What Kepler found was that the spacing of the planets could be closely approximated by an appropriately arranged nesting of the five regular polyhedra between spheres for the six planets of the Copernican system. Quixotic or chimeral as Kepler's polyhedra may appear today, we must remember that the *Mysterium cosmographicum* was essentially the first Copernican treatise of any significance since *De revolutionibus* itself. Without a sun-centered universe, the entire rationale of his book would have collapsed.

Furthermore, Kepler recognized that, although in the Copernican system the sun was near the center, it played no physical role. Kepler argued that the sun's centrality was crucial, for the sun itself must provide the driving force to keep the planets in motion, and he set out for the first time to show this connection mathematically.

Kepler knew that the more distant a planet was from the sun, the longer its period—indeed, this was one of the most important regularities of the heliocentric system, already noted by Copernicus, who wrote:

> In this arrangement, therefore, we discover a marvelous symmetry of the universe, and an established harmonious linkage between the motion of the spheres and their size, such as can be found in no other way.[26]

Undoubtedly Kepler himself had been inspired by this passage in *De revolutionibus*. And it is fascinating to notice that at least one of Kepler's contemporaries recognized this connection. Johannes Broscius, professor at Cracow, underscored those lines in his own copy of Copernicus's book, and in the margin wrote in Latin (see fig. 3):

> Was perhaps this underlined part what Kepler afterwards deduced in his *Mysterium cosmographicum?* It seems by the brevity that something more is involved. See also Kepler in his *Commentary on the Motion of Mars*.[27]

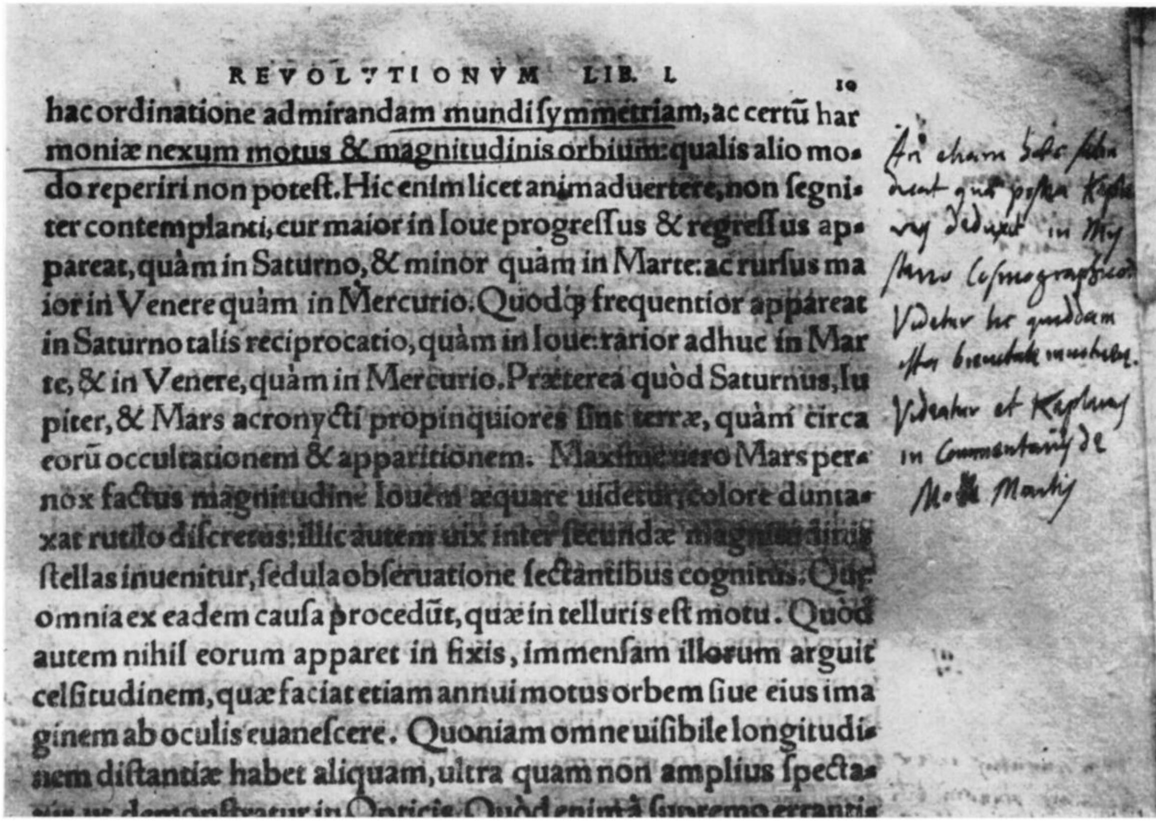
For Kepler, there was an essential physical difference between a geocentric and a heliocentric universe; only in the latter case would the sun provide the central motive power for the planetary system. Hence, Kepler believed firmly in the reality of the Copernican system. Armed with this conviction, he realized that, if the orbit had a physical reality, the same orbit must yield latitudes as well as longitudes. This may be obvious today but, in Kepler's age, this was a novel idea that became a fundamental tool for his attack on the problem of Mars and an important link in the chain that led to the discovery of the elliptical orbit of Mars. Thus, for Kepler's work, belief in the heliocentric system really mattered, and made a vital difference in his approach to the subject.

In 1609, when Kepler published the results of his researches on Mars and his *Astronomia nova*, he placed on the back of the title page

[25] Johannes Kepler, *Mysterium cosmographicum* (Tübingen, 1596), p. 6; translated by Owen Gingerich in "Kepler," *Dictionary of Scientific Biography* 7 (New York, 1973): pp. 289–312.

[26] *Nicholas Copernicus Complete Works II On the Revolutions*, Edward Rosen, translator (London–Warsaw–Cracow, 1973), Book 1, chap. 10.

[27] "An etiam haec subindicat quam postea Keplerus deduxit in Mysterio Cosmographico. Videtur hic quiddam ista brevitate involvere. Videatur et Keplerus in Commentariis de Motibus Martis." Broscius's copy of the 1566 edition is preserved at the Observatory in Cracow. I wish to thank Professor E. Rybka for arranging for me to see and photograph this book. My transcription differs slightly fiom the one given by L. Birkenmajer, *Mikolaj Kopernik* (Cracow, 1900), p. 657.



REVOLVTIONVM LIB. I 10
hac ordinatione admirandam mundi ſymmetriam, ac certũ harmoniæ nexum motus & magnitudinis orbium: qualis alio modo reperiri non poteſt. Hic enim licet animaduertere, non ſegniter contemplanti, cur maior in Ioue progreſſus & regreſſus appareat, quàm in Saturno, & minor quàm in Marte: ac rurſus maior in Venere quàm in Mercurio. Quodq; frequentior appareat in Saturno talis reciprocatio, quàm in Ioue: rarior adhuc in Marte, & in Venere, quàm in Mercurio. Præterea quòd Saturnus, Iupiter, & Mars acronycti propinquiores ſint terræ, quàm circa eorũ occultationem & apparitionem. Maxime uero Mars pernox factus magnitudine Iouem æquare uidetur, colore duntaxat rutilo diſcretus: illic autem uix inter ſecundæ magnitudinis ſtellas inuenitur, ſedula obſeruatione ſectantibus cognitus. Quæ omnia ex eadem cauſa procedũt, quæ in telluris eſt motu. Quod autem nihil eorum apparet in fixis, immenſam illorum arguit celſitudinem, quæ faciat etiam annui motus orbem ſiue eius imaginem ab oculis euaneſcere. Quoniam omne uiſibile longitudinem diſtantiæ habet aliquam, ultra quam non amplius ſpecta-

FIG. 3. Broscius's annotation in his copy of Copernicus's *De revolutionibus* (1566) in the Cracow Observatory Library; a transcription appears in note 27.

an indignant notice revealing in print for the first time that Osiander was the author of the anonymous preface to Copernicus's book. He wrote, "It is a most absurd fiction, I admit, that the phenomena of nature can be demonstrated by false causes. But this fiction is not in Copernicus . . . as evidence, I offer this work."

Accompanying Kepler's bold proclamation was a second remarkable paragraph. Petrus Ramus, professor of philosophy and rhetoric in Paris during the middle of the sixteenth century, had offered his chair to anyone who could produce an "astronomy without hypotheses," and Kepler declared that if Ramus were still alive he would have claimed the reward. Clearly Kepler believed that his recourse to physics had freed astronomy from the arbitrary geometrical devices that were still present in the work of Copernicus. Fundamental to Kepler's "astronomy without hypotheses" was the concept that one special physical object, the sun, was physically and mathematically linked to planetary motions. In essence this is the central power of the Copernican idea and the essential stepping stone to Newton's law of gravitation. It is, of course, in this context that Copernicus, rather than Aristarchus, is being celebrated in 1973.

ACKNOWLEDGMENTS

I wish to thank F. L. Whipple, Director of the Smithsonian Astrophysical Observatory, and S. D. Ripley, Secretary of the Smithsonian Institution, for their continued support of this work and especially for the sabbatical year abroad, during which I discovered the Reinhold copy of *De revolutionibus* as well as the Wittenberg astronomy notes. I also wish to thank J. H. Prynne, Librarian, and J. Needham, Master, Gonville and Caius College, for their interest and cooperation, and especially for a microfilm of the Wittenberg manuscript and for permission to reproduce several pages.