Goddu's Copernicus: An Essay Review of André Goddu's *Copernicus and the Aristotelian Tradition*[⋆]

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For some 20 years, André Goddu has made important contributions to Copernicus studies as well as to a wide range of scholarship in medieval history. His work is distinguished by a formidable and unusual combination of skills in languages and paleography. These have given him direct access to marginalia and notes in primary sources and to secondary sources in European languages, especially Polish, that have been generally inaccessible to English speakers. This valuable work is extended and to some extent consolidated in his new

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Figure 1 [p. 322]: Magini 1589, 58r.
Figure 2 [p. 328]: Copernicus 1543, 67r (detail).
Figure 3(a) [p. 329]: Magini 1589, 3v (detail), repr. from Magini 1608, 11.
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book, *Copernicus and the Aristotelian Tradition: Education, Reading and Philosophy in Copernicus's Path to Heliocentrism.*

Goddu begins his long book with a helpful summary and guide for readers with special interests [esp. xxii–xxiii]. We will follow a similar plan. In the first part of our review, we will attempt to summarize Goddu's most important results, highlighting things we hope will be of interest to other scholars. In the second part, we will give a critical appraisal of the book; and in the third, we will present a detailed examination of one specific theme, Goddu's general scepticism about Islamic influence in Copernicus.

1. Major themes

Goddu's book divides into three sections. The first two examine sources on Copernicus' education in Poland and in Italy before his permanent return to Poland. The third section considers Copernicus as a philosopher and divides into separate chapters on logic and methodology, natural philosophy, and mathematical cosmology. Two important themes that distinguish this book from other treatments of Copernicus are the framing of his work as an effort at reform rather than revolution, and a careful distinction between the sources and influences that led to the *Commentariolus*, which Goddu dates to the period 1509–1510, and those that led to the more celebrated *De revolutionibus*, which Copernicus composed between *ca* 1526 and 1543.

Goddu's opening chapters make extensive use of Polish material, making much of it accessible to an English-speaking audience for the first time. The main burden of part 1, as the author summarizes it [xxii], is to establish the pervasive indirect influence on Copernicus of John of Glogow (*ca* 1445–1507) in logic and Albert of Brudzewo (*ca* 1445–1495) in astronomy.

Goddu denies any simplistic direct line between what happened to Copernicus in Cracow and heliocentrism. Rather, he argues, in that period, Copernicus received practical training in astronomy and formed intellectual habits in reading, argumentation, and scholarship that would become important more in how he presented his ideas than in how he came to them [16].

A major thesis of the entire book that emerges in this section defines Copernicus' relation to the Aristotelian tradition. According to Goddu, Copernicus should be seen as part of a complex and multifarious Aristotelian tradition—as an internal critic, not as a revolutionary [92]. Goddu draws on new histories of Cracow, which offer a different picture from the earlier literature on Copernicus [13n35]. This together with his own extensive research allows him to present the most detailed account now available in English of the development and structure of the curriculum at Cracow in astronomy and natural philosophy at the time of Copernicus' education. He also gives what is likely to become the definitive reconstruction of Copernicus' studies, and especially of his astronomical studies, at Cracow.

The most influential teacher in the liberal arts curriculum at Cracow was John of Glogow, also known as John of Glogovia or Joannes Glogoviensis [27], and most instructors in Copernicus' day were his students [30]. In addition to the core subjects of logic and natural philosophy, Glogow himself wrote extensively on astronomy including prognostications, almanacs, ephemerides, and astrological calendars, as well as a commentary on the *Sphere of Sacrobosco* [35]. In astronomy, the dominant influence at the time of Copernicus' education was Albert of Brudzewo, who completed his *Commentariolum super theoricas novas planetarum Georgii Purbachi* (*Little Commentary on Georg Peurbach's* Theoricae novae planetarum) in 1482. Most of the teachers in the 1490s, especially those in astronomy, were trained by Glogow or Brudzewo or by both. Brudzewo was the most famous astronomer among this group and his *Commentariolum* would have been used in teaching and circulated among students in manuscript, even when he was not teaching it himself. It is, therefore, likely that Copernicus knew this book from the beginning of his education. Although Brudzewo himself was not giving lectures on astronomy at this time, it is worth noting that Copernicus may have attended his lectures on Aristotle's natural philosophy [32, 37].

It is useful to recall here that in all Latin universities the curriculum in astronomy followed the same plan: a first course based on *Sacrobosco's Sphere* in some form introduced the fundamental celestial circles and phenomena that could be accounted for by means of the daily motion of the heavens around a central Earth. The second course presented models for the motions of the Sun, Moon and planets; considered the origin of eclipses; and previewed the main application of these techniques, the determination of astrological configurations. The main text for the second course was a version of the *Theorica planetarum* and, at progressive universities from the 1480s on, a version of Peurbach's *Theoricae novae planetarum.* That Cracow was indeed progressive is shown by the adoption of Brudzewo's *Commentariolum* as a teaching text. As far as we know, this was the first major commentary to be written on Peurbach's book and the first in a wave of similar works that appeared all over Europe during the next few decades [Barker 2011, 2013]. After the basic courses covering the *Sphere* and the *Theorica*, advanced students would have gone on to study Ptolemy. According to Goddu's reconstruction [32ff.], in summer of 1494, Copernicus would have attended lectures on the *Sphere* by Stanisław Ilkusch and perhaps on astrology by Albert Szamotuli; in winter 1494–1495, these would have been followed by lectures on the *Theorica planetarum* by Ilkusch and on Ptolemy by Szamotuli. Several of these courses would have obliged Copernicus to study Brudzewo's *Commentariolum*, although Goddu minimizes the likelihood of direct reference in the *De revolutionibus* [37n9].

In the teaching of astronomy at Cracow, the influence of Brudzewo is probably more important than John of Glogow. But Glogow is notable as a source for logical doctrines that Goddu finds in Copernicus' mature work. In chapter 3, Goddu reviews Aristotle's works on logic and their development by Boethius and Peter of Spain, before he moves on to consider Cracow. He pays special attention to the logic of conditionals and especially to the paradoxes of material implication, which, in modern terms, are often summarized by the two principles that anything follows from a contradiction and that a logical truth follows from anything. Phrasing the first of these in the form of a conditional might give, for example, 'If Copernicus is and is not a man, then, the Earth has an annual motion around the Sun'. Most people would reject an argument that included this conditional on the grounds that it violated their intuitions about logical consequence, although formally the conditional is acceptable. Building on earlier discussions, Glogow concluded that the principle that anything follows from a contradiction is acceptable in formal, but not in material, contexts. For a conditional to be acceptable in the latter contexts, some relation is required to exist between the antecedent and the consequent of the conditional. This relation is established by topics or topical maxims, for example,

> essential superior to inferior, whole to essential part, integral whole to part, cause and effect, cause of following, correlative, inclusion and containing and contained. [81]

Later in his book, Goddu argues at length that Copernicus follows Glogow in requiring (at least) the relevance of the antecedent to the consequent as an additional stipulation for any conditional statement about natural philosophy or astronomy to be acceptable, and in making particularly prominent use of the topic 'integral whole to a part' in the arguments of *De revolutionibus* 1.

Chapter 4 considers the teaching of natural philosophy and begins to argue Goddu's major thesis [92] that Copernicus should be seen as an internal critic of the Aristotelian tradition, not as a revolutionary who rejected it [133]:

> [What Copernicus] learned above all from his teachers was how to adapt Aristotelian principles to ideas different from those held explicitly by Aristotle. [99]

For Copernicus, the Aristotelian tradition is a long way from Aristotle [93]. According to Goddu, we should not expect to find any defining content, commentary tradition, or school at Cracow [95]. In the early 15th century, the curriculum in natural philosophy followed Buridan [93]. This early dominance was replaced by eclectic teaching that embraced the work of Albertus Magnus, Thomas Aquinas, Giles of Rome, and Duns Scotus. The Cracow *milieu* is portrayed as generally hostile to Plato, at least before Copernicus' generation. Any sympathy that Copernicus shows must, therefore, be attributed to later Humanist influences (some described in the next chapter) and to his time in Italy. Major figures considered in this chapter are Versoris, Albert of Saxony and, again, John of Glogow. In a preview of subsequent discussion of the origins of Copernicus' heliocentrism, Goddu highlights Bernard R. Goldstein's paper [2002] on the distance-period relation as a motive for Copernicus' innovation [124n94].

Chapter 5 examines Humanism at Cracow and its influence on the teaching of astronomy, introducing several other themes that reappear in later chapters. Humanist influences strengthened at Cracow after 1480 [139] and while Copernicus was there as a student. Indicating where his own sympathies lay, Copernicus maintained a correspondence with the Cracow humanist Lawrence Corvinus up to 1509 [141]. Hence, he clearly had some contact with scholars who evaluated Plato positively, which mitigates the hostility to Plato indicated in Goddu's previous chapter. In general, however, Goddu minimizes Copernicus' debt to Plato, in contrast, for example, to the recent work of Anna De Pace [2002, 2009].

In the balance of chapter 5, Goddu presents a number of themes that will be important in Copernicus' later work. Throughout the late medieval and early modern periods, Averroist natural philosophers strongly criticized Ptolemaic astronomy for violating (as they saw it) Aristotelian limitations on the nature of celestial motions. Goddu presents a detailed list of the standard Averroist objections. Key claims concern the impossibility of there being more than a single center of rotation, the ruling out of epicycles and eccentrics, and the denial of any penetration or splitting of the celestial substance, which Averroists believed would be required to accommodate such orbs [143–145]. Goddu goes on to consider the contents of the primary texts in the Ptolemaic tradition, the *Sphere* and the *Theorica*, noting that the 'principal problem' of the latter could be seen as one of reconciling Ptolemy's mathematical models with the concentric cosmology of Aristotle [148]. Goddu also mentions the use of tables and canons as goals of astronomical training and concludes by examining the extent to which Copernicus' education might have included the construction and use of instruments. He concludes that Copernicus was likely to have heard descriptions at least of spherical and plane astrolabes, the parallactic ruler, and a quadrant that used a gnomon.

Next Goddu examines criticisms of Ptolemaic astronomy in this *milieu*, especially in the work of Brudzewo, and presents themes that will reappear later in Copernicus' astronomical work. An interesting connection to be made here perhaps is with one of the most striking features of Copernicus' model for the Moon, the use of a double epicycle. This device was singled out for special praise by contemporaries (e.g., Reinhold and Melanchthon). However, Brudzewo had already introduced a double epicycle in the *theorica* of the Moon in his *Commentariolum*. Such double epicycles also appear in the celebrated Tusi-couple, a mathematical device originating in 13th-century Persia that uses two circular motions to produces a simple harmonic motion along a straight line. Islamic astronomers made extensive use of this device to construct systems of eccentric orbs and epicycles, or sometimes concentric orbs and epicycles, that satisfy the primary condition that they rotate uniformly about their own centers even though these were not all identical to the center of the cosmos.

In the second half of the 20th century, a great deal of attention was paid to Copernicus' use of this device and these models, with many scholars concluding that Copernicus must somehow have gained access to Islamic sources, although the precise route of transmission remains unknown. In the context of his discussion of the origins of the double epicycle found in Brudzewo's work, Goddu voices scepticism about the Islamic derivation of Copernicus' work and suggests a series of European sources from whom Copernicus might have learned about double epicycle models without Islamic intermediaries [155]. He also points out that, strictly, the construction introduced by Brudzewo and his predecessor Sandivogius of Czechel (fl. 1430) to account for the Moon's always showing the same face is not a Tusi-couple: the second epicycle controls the orientation of the spherical body of the Moon, not its motion along a hypothetical straight line or its distance from the observer. Moreover, Goddu suggests other reasons for thinking that Copernicus achieved the same results as Islamic astronomers but from different sources. Thus, another possible source for his Tusi-couple may be the model for Mercury in Brudzewo's *Commentariolum* [Birkenmajer 1900, 110ff.], which produces a straight line motion out of several circular motions. Later Goddu will suggest another completely novel source for the origin of the Tusi-couple in Copernicus—a European tradition starting with Oresme.

From his reconstruction of Copernicus' likely course of study in astronomy at Cracow, Goddu concludes that he would have been introduced to the issue of the realism or fictionalism of astronomical models employing orbs like those found in Peurbach's *Theoricae novae*. He would also have encountered some of the problems with Ptolemy's lunar models, the problem of the equant as a violation of the requirement that celestial motions be uniform about their geometrical centers, disputes about the order of the planets Venus and Mercury, as well as problems of the accuracy of tables, and the problem of calendar reform [161]. The chapter concludes with a summary of Brudzewo's *Commentriolum*.

The thesis that Copernicus derived important aspects of his work from Islamic sources usually locates his contact with this tradition in Italy. Goddu, however, has already expressed scepticism about Islamic influence. In the chapter on Copernicus in Italy, he assigns only a very modest role to Copernicus' studies there. Rather surprisingly, Goddu affirms that there is 'little reason' to think that Copernicus learned any more natural philosophy in Italy [172: cf. 185]. Instead, he presents a picture of a student whose time was exclusively occupied by the study of law and medicine, neither of which, according to Goddu, played any major role in his astronomical innovations.

Copernicus left Italy with a degree in canon law but with no formal qualification in medicine. Although his legal training was clearly relevant for the administrative positions that he held in later life, he actually returned to Warmia as his uncle's personal physician and continued to practise medicine for the rest of his life. However, in contrast to the obvious ongoing interest in astronomy shown by the remains of his library, in later life 'as far as we know...[Copernicus] did not own a single legal text' [180]. Goddu concludes that Copernicus' legal training would have been important as a continuation of his training in dialectic, especially in the use of *loci*, that was begun at Cracow. Copernicus would have encountered very similar doctrines on the status of conditionals during his legal studies, reinforcing the doctrines that he would have encountered in John of Glogow. Similarly, legal training would have given him extensive opportunities to develop skill in dialectical argumentation using topics, that is, in techniques 'aim[ing] to support conclusions that are more probable than alternatives' [182]. More generally, Goddu also proposes that his legal training exposed Copernicus to the idea of intellectual reform, based on new situations and experiences, as a necessary part of the tradition of legal methods and scholarship. In this way, his experience as a law student might have reinforced or rendered more plausible to him the general idea of astronomical reform motivated by the problems of the Ptolemaic tradition that he had encountered in Cracow.

Goddu makes even less of Copernicus' medical education. In both legal and medical studies, we lack the kind of detailed evidence that Goddu has deployed so impressively in the first part of his book; and it is, therefore, not possible to reconstruct Copernicus' course of study in the same detail. Nonetheless, while at Padua, Copernicus only studied medicine for two years—not the three required for a degree by the university statutes. Goddu concludes that he had no intention of getting a formal qualification. Returning to the question of whether Copernicus used his time in Italy to learn more natural philosophy, Goddu establishes firmly that Copernicus was back in Poland by January 1504 at latest. As he arrived in Padua only in 1501 and was both studying medicine and preparing to receive a degree in law, Goddu suggests that he would have had no time for protracted study with the celebrated Averroist natural philosophers at Padua or to learn about the Tusi-couple from them, as proposed by Di Bono [1995]. Goddu also denies that Copernicus owed his knowledge of Greek to his Italian education. Although he began learning Greek in Italy, he really taught himself the language after he returned home through the project of translating Theophylactus' *Letters* [194–195].

Goddu's minimization of the importance of Copernicus' time in Italy is perhaps best understood as a consequence of the limitations in historiographical method that he imposes on himself, although they are not always observed consistently or indeed prudently. We will return to these general considerations in section 2. Even so, Goddu acknowledges that Copernicus' Italian years did include several decisive encounters. First, he lived and worked with the astronomer Domenico de Novara, who may have been important in many ways, but especially for introducing Copernicus to Regiomontanus' *Epitome of the Almagest*, a book that he used constantly in his later research program in astronomy. Second, during his stay in Italy, he became acquainted with the writings of Pico della Mirandola and perhaps with Ficino's translation of Plato's *Parmenides*, which Goddu thinks was especially important in the development of Copernicus' views on method.

In chapter 7, Goddu proceeds chronologically to Copernicus' first statement of his heliocentric ideas. The main concern of the first part of the chapter is to identify and describe the sources that Copernicus assimilated after leaving Italy and on the way to creating his first brief exposition of heliocentrism, the *Commentariolus*. Goddu argues for a date of composition around 1510 and also suggests in passing a novel hypothesis for the appearance in Copernicus' work of the mathematical device now known as a Tusi-couple.

The identification of books owned or used by Copernicus has proceeded primarily by the analysis of notes and marginalia in books that survive at Uppsala. Here Goddu has made a major contribution to scholarship by independently re-evaluating the claims of earlier writers in the light of his careful analysis of Copernicus' handwriting.

In addition to revising a number of earlier attributions, Goddu concludes that, before 1515, Copernicus had access to Regiomontanus' *Epitome of the Almagest* and Bessarion's *In calumniatorem Platonis*, an important source for Neoplatonic ideas. Goddu offers an original argument that Copernicus had also read Ficino's translation of Plato's *Parmenides*, on the basis of the attribution of notes from part 1 of a copy of Ficino's translation of Plato's *Opera omnia* that is preserved at Uppsala. He also makes a case that Copernicus had read Plutarch, pseudo-Plutarch in the translation of Valla [229], and Pliny's *Natural History* [237ff], all of which contain interesting snippets about the cosmologies of Aristotle, the Pythagoreans, and the Stoics. He concludes by considering the possibility that Copernicus had read Achillini, an Averroist critic of Ptolemaic astronomy whose most relevant work appeared while Copernicus was a student at Bologna. This section concludes with an important thesis, that

> *[Q]ualitative* (not technical) mathematical issues *led [Copernicus]* to adopt heliocentrism with its geokinetic consequences. [243: emphasis in original]

The balance of the chapter considers the content of the *Commentariolus*. Goddu's main achievements are the identification of the method that led Copernicus to his postulates and an extended consideration of the date of composition. Goddu concludes that the *Commentariolus* was begun after May 1509 and completed in 1510, thus strengthening the arguments for a date that was already accepted among Copernicus scholars.

Based on the attribution of notes in the Parmenides dialogue that he has just argued for, Goddu proposes that the method which Copernicus uses is dialectical in that it borrows from Plato an approach that examines both the assertion and denial of every relevant hypothesis. As an example, the axiom in astronomy of uniform, circular motion is adopted because its denial is absurd [251]. Non-uniform motion of celestial objects would make them, and the regularity with which they repeat their patterns, incomprehensible. A second important result is that Copernicus rejects Ptolemy's equant device on the grounds that it violates that axiom. However, he accepts that, while the partial orbs of planets have different centers, all the total orbs have a single center. In short, the overall organization of his cosmos follows Ptolemy and Peurbach, although the center of the orbs is relocated. The primary motivation for considering heliocentrism is that if the planetary orbs are ordered around a single center according to a single principle (the distance-period relation), then the Earth cannot be that center [254]. Goddu dismisses Swerdlow's alternative proposal [1973] that Copernicus considered and rejected a Tychonic system, although some of Goddu's reasoning is based on a faulty understanding of the nature of *Theorica* orbs (a matter which we will consider further below). Goddu opts instead for Martianus Capella's system as the inspiration for Copernicus' choice of center.

The chapter ends with an extended presentation of Mario Di Bono's work on Tusi-couples, which had suggested a second possible class of non-Islamic sources for Copernicus' use of the device, the Paduan Averroists. Goddu has, in effect, already dismissed this in his chapter on Copernicus' time in Italy and he has a further original suggestion of his own to make. He does not present it here but in an appendix to the book, where he concludes that rather than encountering techniques for generating straight line motions from circular motions in some Islamic source,

> Copernicus did not invent or discover these solutions independently, but that he adopted and modeled solutions deriving immediately from Brudzewo and Regiomontanus, and indirectly from Oresme and Hesse. [484]

We find that a number of points in this discussion are off-track, and return to the whole topic in detail in section 3 below.

Chapter 8 is titled 'Copernicus as logician'. Goddu published major articles on these issues in 1995 and 1996. Since then, his main new conclusion is that, after his Cracow period, Copernicus would have encountered very similar ideas about the paradoxes of implication and conditionals during his legal education in Italy [275]. Goddu asserts that on matters of philosophy, especially dialectics and what would today be called methodology, 'Copernicus resolved the principal issues well before 1520' [276]. The techniques considered here are, thus, presented as a stable foundation for Copernicus' mature work and especially for the composition of the *De revolutionibus*.

The title of this chapter is perhaps unfortunate, as the main inferences Goddu describes are not deductive and, hence, only logical in an extended sense. Although these arguments can be reconstructed as enthymemes—Goddu does so in an appendix—he portrays Copernicus as primarily using a dialectical method that employs topics as his main persuasive technique in the *De revolutionibus*. A reader using modern logical theory or expecting modern logical arguments may not find Copernicus' arguments satisfying as presented by Goddu, but the important historical question is whether they were satisfying to Copernicus' contemporaries. Goddu shows that such techniques were both common and uncontroversial before and during Copernicus' education; however, he does not go on to address the efficacy of these methods as persuasive techniques beyond a blanket negative appraisal of Copernicus' success.

Goddu adopts a format for presenting topical arguments developed by the 20th-century philosopher Stephen Toulmin [293 and n40]. The arguments are presented in three elements: the claim or conclusion that the argument supports, the grounds offered for the claim, and the warrant or rules that license a conclusion of this type from evidence of the kind offered. As Goddu notes, the schema attracted strong criticism when Toulmin introduced it and, to make matters worse, Goddu employs it in an abbreviated form [293n40] that omits the 'qualifications' or conditions that often have to be specified to establish an evidential link. For all these reasons then, modern readers unfamiliar with this pattern of argument may find it, and the reconstructions of Copernicus' arguments by means of it, difficult to follow and less than persuasive. Although this section of Goddu's book provides a detailed layout of the subjects addressed in *De revolutionibus* 1, the reader leaves the section puzzled by why Copernicus would have chosen these techniques if they raised even more potential objections against his already controversial conclusions. A second consequence of Goddu's almost exclusive attention to topical arguments is that little attention is paid to the theory of demonstration, which was widely acknowledged by Copernicus' contemporaries—and indeed by Copernicus himself—as a higher standard that astronomy ideally ought to meet.

The next chapter is on natural philosophy and expands Goddu's claim that Copernicus modifies rather than rejects Aristotle's principles, in line with the earlier claim that he should be seen as a reformer of Ptolemaic astronomy rather than as a revolutionary intent on its overthrow. Goddu notes that although the 'reformer' reading of Copernicus has recently made headway among scholars, the 'revolutionary' reading is still common when people come to address Copernicus' relation to Aristotle's physics. Goddu argues that 'Copernicus was inclined to revise principles rather than to reject them altogether' [330]. For example, Copernicus modifies Aristotle's principle that an object can have only a single simple natural motion, arguing that a more complex principle is required to accommodate falling bodies on a rotating Earth. The radial component of such a body's motion is clearly natural, in accord with long standing Aristotelian ideas. However, the circular component of a falling body's motion, which is required for it to 'keep pace' with the spot toward which it is falling as the Earth rotates, is also a natural motion [344]. The ultimate application of this new principle is to the Earth itself, which has not one but three natural motions. The chapter proceeds with sections devoted to Copernicus' views on the movement of celestial objects, the movement of terrestrial elements, and the possible infinity of the cosmos.

There is a sustained analysis of the very limited extent to which impetus theory can be attributed to Copernicus: for Goddu, it appears to be confined to situations where a non-natural or violent component was required to explain motion. Throughout, Goddu admits that he may be being more systematic and scrupulous than Copernicus himself, concluding that 'Copernicus' doctrine of motion was undeveloped' [344] and that 'From the brief account that Copernicus provides we are hardly able to construct a coherent physics...' [353]. A further important conclusion is that, at least in the limited area where mathematical astronomy and physical cosmology overlap, priority belongs to the former and not to the latter, as Aristotle and his followers had accepted [337]. As a whole, the reasoning attributed to Copernicus in this chapter further illustrates Goddu's general thesis about the role of dialectical techniques in Copernicus, while also showing their limitations. After all, arguments that show convincingly that one of a series of complex positions is wrong do not establish an alternative demonstratively; at best, they make it more likely. As Goddu notes, Copernicus' efforts to persuade Aristotelians of his position 'have to be counted in the short term among the most miserable failures in the history of philosophy' [359]. So, perhaps the unpersuasive character of the preceding chapter on logic is historically accurate and unavoidable.

Having considered several typical issues in natural philosophy from Copernicus' viewpoint, Goddu proceeds in the penultimate chapter to matters that he calls 'mathematical cosmology'. Here he considers Copernicus' views on the nature of hypotheses and the still controversial question of the extent to which Copernicus endorsed the existence of celestial spheres or orbs as part of his overall cosmic scheme. The chapter has one generally positive feature and one generally negative one. First, Goddu's response to the question of the reality of spheres and orbs in Copernicus converges on the position introduced by Barker and Goldstein [1998] and developed in detail by Barker in more recent papers. Although this is a positive sign, and perhaps an indication of a wider convergence among scholars in the field, Goddu then goes on to discuss a number of points about the nature of *Theorica* orbs in a much less satisfactory way. We will consider these issues in more detail below.

In the conclusion and epilogue, Goddu reiterates his main points about the nature of the Aristotelian tradition in Copernicus' time and his relation to it. The tradition was multifarious. Copernicus saw himself as working within it, not rejecting it. The main positive thesis that Goddu proposes is that Copernicus used topical arguments, particularly the dialectical topic 'from an integral whole', to supply a relevance condition linking the antecedent and consequent of conditional sentences expressing hypotheses. Goddu repeats that, judged historically, Copernicus' innovations were wholly unpersuasive to other Aristotelians.

In the epilogue, he then goes on to review the reception of Copernicus' work by a series of contemporaries and successors beginning with Rheticus and prominently including Tolosani, Offusius, Maestlin, and Kepler. The main sources that he employs are the marginalia and notes recorded in Gingerich's *Census* [2002], and he locates one passage in which Maestlin plausibly can be seen as recognizing and endorsing Copernicus' rhetorical strategy. Goddu proposes an interesting fivefold division of positions about the status of Copernicus' hypotheses:

(1) Tolosani regards them as physical and remains a geocentrist.
(2) The Melanchthon circle and many others take the primary content to be mathematical and retain a geocentric framework.

(3) Maestlin, Goddu suggests, also emphasizes the mathematical content of the hypotheses but shifts to a heliocentric framework.
(4) Rheticus and Kepler represent positions closer to Copernicus himself, both accepting heliocentrism while endorsing the hypotheses as physically significant in different ways. Rheticus is closer to the tradition of natural philosophy and
(5) Kepler innovates in physics.

We look forward to hearing more about Goddu's ideas for understanding the reception of Copernicus, an account that will be based, we hope, on consideration of a larger group of Copernicus' readers and of sources that reach beyond the notes written in the *De revolutionibus*.

Although the main text ends with the epilogue, the book concludes with just over 50 pages of appendices. These include supporting material for some earlier sections—for example, a summary list of dialectical topics from Peter of Spain, extended Latin excerpts from important sources used at Cracow, and the reconstructions of Copernicus' deductively invalid topical arguments as valid enthymemes. Appendix 6 presents an 'Excursus on Transmission' that amplifies Goddu's scepticism about Islamic sources and perhaps belongs in the main text. The same could be said about three paragraphs on Copernicus' understanding of Ptolemy that appear as appendix 9. There is an extensive bibliography, an index of names divided pre- and post-1800, an index of places, and an index of subjects.

In summary, then, Goddu's Copernicus learned a great deal about topical or dialectical reasoning and natural philosophy at Cracow. He also studied astronomy and was introduced to the standard problems of the Ptolemaic tradition, but what he learned had little direct bearing on his later astronomical innovations. He learned little new natural philosophy in Italy, although he strengthened his command of certain techniques in dialectical reasoning. He apparently got onto the track of some important new ideas in astronomy but not from Islamic sources. Exactly when he decided that astronomy needed to be reformed and that the reform entailed abandoning geocentrism for heliocentrism, is not clear, although his legal education may have fostered the idea of intellectual reform. When he returned to Poland, he began a process of self-education that led fairly quickly to a concise statement of his novel heliocentric ideas. The equant problem motivated the reform of Ptolemaic astronomy but the idea that the planets should be ordered around the center of the cosmos according to a single principle, the distance-period relation, led to the postulation of heliocentrism. Copernicus adopted dialectical techniques as the means to establish his new ideas and, having accepted a stable methodology by 1520, he continued to use it for the rest of his life. He worked on the material that would become the *De revolutionibus*, solving technical problems but without adding any major new ideas, and without any real interest in publishing until Rheticus persuaded him to finish the book and get it into print.

This is an oddly unsatisfactory outcome from a long book with many valuable sections. Several big questions go unanswered:

- 'Where and why did Copernicus begin his research into heliocentrism?'
- 'Why are there so many similarities between his work and the work of Islamic astronomers?'
- 'Did he really select a methodology that would itself have been predictably unpersuasive to contemporaries?'
- Although Goddu presents Plato as a key source of Copernicus' dialectical method, why should Copernicus be seen as working within an Aristotelian tradition and addressing Aristotelians, rather than working within a nascent Platonic tradition and addressing Platonists?

Goddu's detailed work on the Cracow context and on the textual evidence of various doctrines in Copernicus has lasting value. However, it is difficult to take the picture that he presents as definitive: too many historical factors are excluded or unaccounted for.

2. Critical evaluation

We begin our more critical section of this review by wishing that Goddu's long book was longer—or at least more comprehensive in its coverage of Goddu's own work. Goddu repeatedly draws on his earlier papers but also repeatedly fails to include the full range of evidence and argument that he had presented in them. It would have been very valuable for this book to be self-contained: this would aid readers new and old by bringing together in a single place all the work that is now scattered through various and, in some cases, rather inaccessible articles. This is perhaps less the author's fault than a sign of inadequate editorial advice. On occasion, the placement of material also indicates lapses in editing. It makes little sense, for example, to review the contents of the *Sphere* and the *Theorica* in chapter 5, when the reader needs this information to understand the discussion of the curriculum at Cracow and Copernicus' education in astronomy that takes place in chapters 1 and 2.

The book's greatest strength is also its greatest weakness. Its greatest strength is Goddu's meticulous attention to sources, both historical and contemporary. In some cases, he brings a unique spectrum of talents to the re-examination of key historical evidence. The book's greatest weakness is its discomfort with historical evidence or historical conclusions beyond this sort of textual analysis. A case in point is the nature of Copernicus' knowledge of Brudzewo's *Commentariolum*. In the early chapters, Goddu builds what we consider an overwhelming contextual case for Copernicus' having knowledge of this book. But in chapter 10, he concludes:

> In my opinion there is no evidence that Copernicus knew this text directly, but he very likely received instruction on astronomy and astrology from Albert's students. [370n15]

This is bizarre. On Goddu's own account, Brudzewo controlled the curriculum that Copernicus studied, trained Copernicus' teachers and, consequently, Brudzewo's text was used pervasively at Cracow. It is surely unlikely, therefore, that Copernicus was not familiar with the book by the time he left Cracow. How, then, can Goddu say 'there is no evidence that Copernicus knew this text directly'? There is, admittedly, no direct, textual evidence and that is, unfortunately, what Goddu seems to want.

Another blind spot is the Platonic tradition. Goddu documents Copernicus' familiarity with the *Timaeus* and *Laws* [226], in addition to the works of Plutarch and pseudo-Plutarch [229ff.]. But with the exception of his original argument for the influence of Plato's ideal of dialectic from the *Parmenides*, little use is made of the Platonic tradition. Although its influence is acknowledged, Goddu continues to insist that Copernicus should be read as an Aristotelian but without rebutting those who derive more of the structure of Copernicus' work from Plato [e.g., De Pace 2009]. Again the problem seems to be lack of the kind of evidence that Goddu prizes, specifically annotations or direct references.

The question of whether to accept historical evidence and inferences deriving from the context in which Copernicus was working goes to the heart of several contentious issues treated in the book. For example, Goddu rejects Swerdlow's analysis of Copernicus' route to heliocentrism [1973, 1976]. Two important premises of Swerdlow's account are that 16th-century astronomers accepted the real existence of the orbs described in the *Theoricae novae*, and that Copernicus, educated in this context and addressing an audience that shared these values, also accepted the reality of celestial orbs. Both these premises were rejected—inappropriately—by Rosen [1973, 3.123n326, 1975, 1976]. Since the Rosen-Swerdlow controversy, a pall has hung over the whole question of the reality of celestial orbs and the status of the basic texts in astronomy at the time of Copernicus. Rosen's side of the controversy denied the reality of the orbs. He also implicitly denigrated the astronomical texts in use before Copernicus and, with them, the astronomical context in which Copernicus was educated and worked.

Goddu's comments on both the *Sphere* and the *Theoricae novae* seem influenced by the continuing effects of this controversy. For example, he considers the *Sphere*, 'of almost no practical use' [147]. It is not clear what standard of judgment is being invoked here—no use to whom? Practical for what? The *Sphere* was an introductory textbook that served its purpose if it taught students the overall structure of the geocentric cosmos and, particularly, the names and definitions of such basic celestial circles as the tropics, equator, and ecliptic. It is practically useful for learning how to describe the location of a celestial phenomenon (e.g., the rising or setting of an object). It does not really teach astronomical calculations—those come later for Copernicus, along with planetary theory and the motions of the Sun and Moon, in the *Theoricae novae*.

Goddu is equally unsympathetic to the *Theoricae novae*, saying, for example, 'The traditional accounts of orbs never make it clear how the orbs are consistent with the mathematical models' [378 text to n41]. Actually, as Goddu comes close to acknowledging elsewhere, the main purpose of the *Theoricae novae* was precisely that, beginning on its very first page. Any student who had mastered it would have

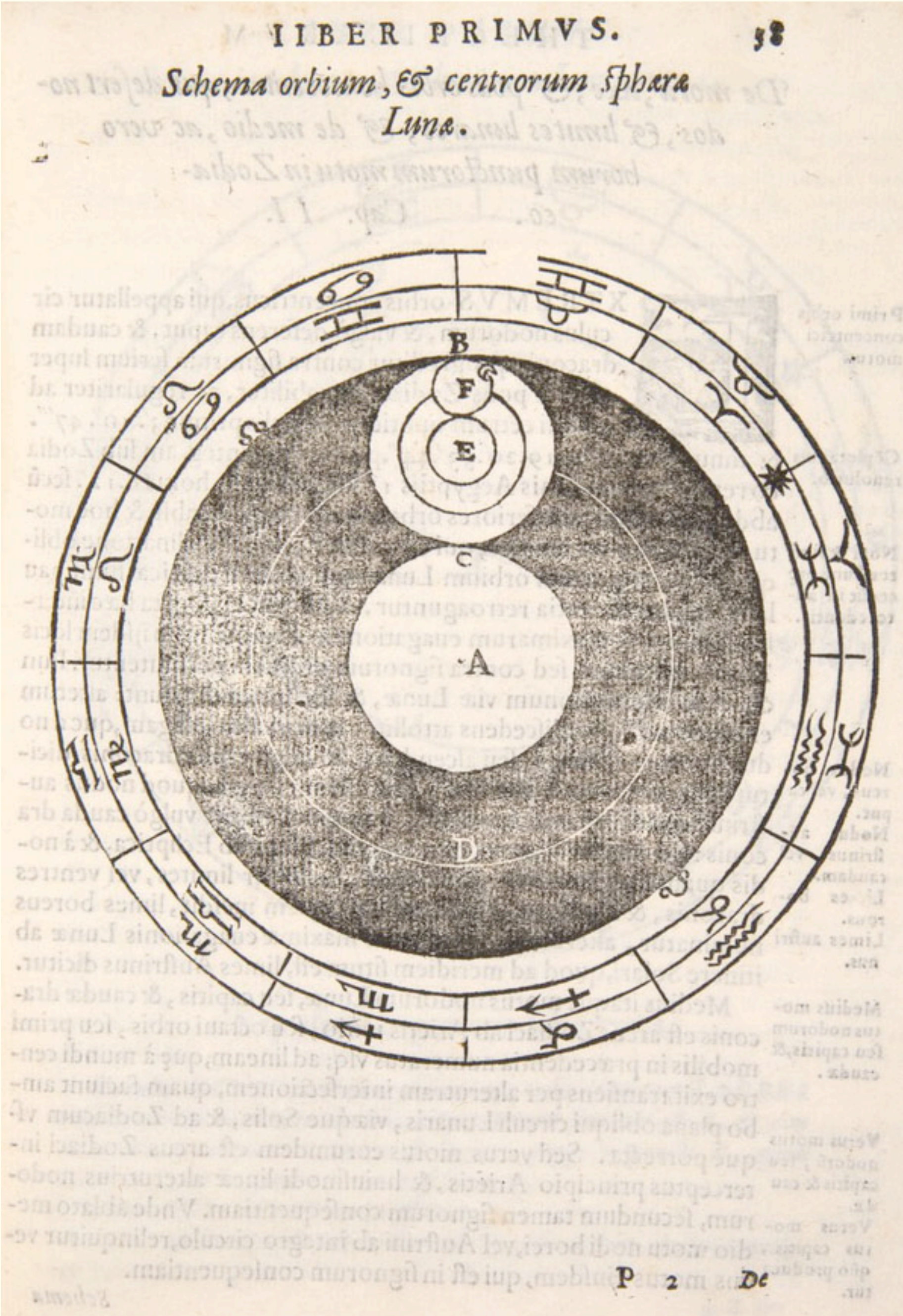

Figure 1. Double epicyclic orb-system for the Moon
[Magini 1589]

been able to pass back and forth between physical orb-models and the two dimensional mathematical representations found in books like Ptolemy's *Almagest* or the old *Theorica*. Perhaps understandably, Goddu is confused about the construction of the *Theoricae novae* orbs and the constraints that they place on astronomical and cosmological theories.

A particularly important instance concerns the double-epicyclic model introduced by Copernicus for the Moon and for one type of Tusi-couple. Goddu mistakenly thinks that orb-models for double epicycles are impossible on the grounds that they require the penetration of orbs:

> If Copernicus thought that the epicycles are also spheres, then it is apparent that the spheres do penetrate one another, for the secondary epicycle penetrates the space occupied by the primary epicycle and the primary epicycle penetrates the space occupied by the deferent sphere. [249]

In fact, orb-systems for double-epicyclic models were not only possible, they were actually published by Copernicus' successors, for example, by Giovanni Antonio Magini in 1589 and 1608 [see Figure 1, p. 322; Swerdlow 1976, 137–141]. To put the matter briefly: in the standard *Theoricae novae* introduced by Peurbach, the eccentric orb carries the epicycle in the form of a small sphere within it 'like a gem-stone in a finger ring' to use a convenient and historically accurate metaphor. The epicycle sphere may rotate freely within its socket and does not penetrate the eccentric orb at all. Similarly the planet is carried within the epicycle sphere as it rotates and again without penetration. Copernicus' models merely add a second epicycle sphere in the place of the planet and embed the planet in this further, smaller sphere. All these objects can now rotate freely within their sockets as they are carried by the orbs in which they are embedded. If the ratio of the radii and speeds of the two epicycle spheres is 2:1, a Tusi-couple and, hence, motion in a straight line on the part of the planet will result. This arrangement of two orbs with one rotating freely within the other was proposed by Tusi himself when he introduced what we now call the Tusi-couple in the *Tadkhira* [see 263 Fig. 1; Ragep 1993, 1.196–199].

A similar misconception occurs when Goddu discusses an aspect of Swerdlow's analysis:

> Some experts[1] speculate that Copernicus anticipated a Tychonic arrangement that he would have rejected because of the interpenetration of the spheres of Mars and the Sun. In fact the spheres of Mercury and Venus, even on the Capellan arrangement, penetrate the sphere of the Sun, yet Copernicus says nothing about it. [254 and nn137, 138]

Copernicus says nothing about it because there is no penetration of spheres: the Sun is carried at the center of the orb of Mercury; the orb of Mercury is carried at the center of the orb of Venus. Both orbs rotate in their sockets without penetrating the orbs inside or outside them. For Tycho, the whole arrangement would be carried by the eccentric orb of the Sun in the same manner as an epicycle orb in the *Theoricae novae*. It is the eccentric orb carrying this entire collection (Sun, Mercury and Venus) that penetrates the (eccentric) orb of Mars and leads Tycho to abandon solid spheres.

Despite these errors and confusions, Goddu concludes, correctly, that it is too simple to classify Copernicus as a realist or a fictionalist in the sense used by modern commentators. In a series of papers beginning with Barker and Goldstein [1988], the general question of the reality of celestial spheres in the 16th century has been addressed in a new way. In addition to new historical evidence, these authors suggested that the issue should be reappraised against the background of the theory of demonstration employed by 16th-century scientists, rather than by means of 20th-century categories like realism and instrumentalism paired with retrojections of 20th-century philosophical conceptions of scientific method. But 16th-century theories of scientific method—in other words, the theory of demonstration—required a three-step process to arrive at a definitive causal explanation, which was taken to correspond to the correct physical constitution of the system considered. The three steps may be labelled 'demonstratio quia', 'negotiatio', and 'demonstratio propter quid'.[2]

[1] Swerdlow is cited in the subsequent note; but see especially 1976, 134–136.

[2] These three terms correspond to demonstrations of an effect from possible causes, the reasoning process that eliminates all but the actual cause, and demonstration from the actual or real cause. For example, consider as an effect the shape of the shadow cast on the Moon by the Earth during an eclipse, which according to Aristotle always has a semicircular edge. It is possible to explain a shadow with a semicircular edge by postulating

These issues are treated only briefly by Goddu, who advocates treating Copernicus' method as almost exclusively dialectical. But, given the existence of a clearly articulated standard for scientific knowledge in the form of complimentary arguments *quia* and *propter quid* specified in the theory of demonstration, it is not enough to give a positive account of Copernicus' alternative method of dialectic. It is also necessary to address why Copernicus failed to meet the requirement of demonstration (if that is in fact the case) and how he expected to make headway with an audience that took these standards as the basis for scientific knowledge, without at least himself addressing the divergence between his own methods and the method of demonstration and giving some substantial motivation for doing so.

Barker and Goldstein concluded that the requirement that astronomical theories represent real physical systems was generally accepted by 16th-century astronomers, with the *proviso* that there were special difficulties in meeting this standard in astronomy. Although most people agreed that demonstrations *quia* were possible, the remaining steps in establishing a unique cause were not available. It was not that there was no truth of the matter to discover but rather that terrestrial observers lacked the evidence needed to discover it. Hence, Barker and Goldstein described 16th-century astronomers as 'permanently frustrated realists'. A small number of Copernicans were controversial exceptions.

In subsequent work, Barker has developed these themes and applied them to the specific case of Copernicus. First, he has argued that the introduction of Peurbach's *Theoricae novae* led to the general adoption of partial and total celestial orbs by most mathematical astronomers in the 16th century—the century of Copernicus' career and written work. This did not include natural philosophers and

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an Earth that is cylindrical, disk shape or spherical, among other options. Each of these explanations would be a *demonstratio quia*. By appealing to the principles of mathematics (a process that is not always possible or successful), we may eliminate all but the last option on the grounds that the sphere is the only solid body that will cast a semicircular shadow regardless of the direction from which it is illuminated. This reasoning constitutes the *negotiatio*. If we now explain the shape of the shadow's edge by appealing to a spherical earth, which we have established is the actual cause, that will constitute a *demonstratio propter quid*.

a few astronomers who supported Averroes' strict reading of Aristotle's physics as it applied to the substance of the heavens, and who accused the astronomers in the Ptolemaic tradition as modified by Peurbach with perpetrating 'fictions'. Copernicus was, therefore, educated in astronomy at a moment when Peurbach's eccentric and epicyclic celestial orbs were becoming a standard feature of courses in astronomy at universities throughout Europe, and this innovation was being opposed by Averroists who insisted that all celestial spheres were concentric to the Earth. In both the *Commentariolus* and *De revolutionibus*, Copernicus was addressing an audience trained in Peurbach's methods and aware of this dispute. There are clear indications that he expected his mathematical models to be understood as collections of partial and total orbs in the former but not in the latter. Copernicus' silence on orbs in his *De revolutionibus* has caused continuing controversy [see Barker 2009, 2011].

Recently Barker has suggested that Copernicus' failure to present orb-models in his *De revolutionibus* has several obvious explanations—some of which are also noted by Goddu. The first, and perhaps least important, is that although Copernicus appears to have taken the *Theorica* as a model for his abbreviated presentation in the *Commentariolus*, he took Ptolemy's *Almagest* as his model for the *De revolutionibus*. Considering orbs would be natural in a *Theorica* but the *Almagest* presents only mathematical models—notably two-dimensional combinations of circles that model motions in longitude. Adding orb-models might also be deemed unnecessary because, in principle, anyone who had read Peurbach could construct orb-models for the new mathematical models that Copernicus was introducing. But there were at least two major obstacles to completing this task. The first obstacle was Copernicus' inability to choose between mathematically equivalent models (for example, eccentric circles *versus* concentrics carrying epicycles) that would lead to quite different orb-models. Copernicus repeatedly presented such alternatives in his solar and planetary models. Although it would be possible to construct orb-models for each one, there was no obvious way of choosing between them. A second major difficulty, and one much more difficult to resolve, was the overall structure of Copernicus' cosmos. In Ptolemy, and in Ptolemy's system as reframed by Peurbach, each set of partial orbs formed the total orb for a single planet. The total orb for one planet fitted perfectly inside the total orb for the next planet out, with the fixed stars forming a boundary to the whole system. There was no empty space between orb-clusters. However, calculating the dimensions of total orbs in Copernicus by the same methods and then applying the fundamental ordering of distances introduced by Copernicus showed that there were substantial gaps between the orbs for Copernicus, and an enormous gap between the outermost surface of the orbs of Saturn and the inner surface of the orb of fixed stars [Barker 2011].

The issue of the reality of celestial orbs and the constraints on their physical construction reappears when Goddu examines the Tusi-couple. He again mistakenly asserts that the corresponding arrangement of orbs would be impossible according to Aristotle's physics on the grounds that there can be no void in the heavens [262 and n150]. But as we have shown above, double-epicyclic models require neither penetration nor voids. Orb-models were fundamental to the application of Tusi-couples in astronomy by Maragha astronomers and their successors, and almost any plausible source for Copernicus' knowledge of Islamic astronomy would have contained diagrams showing such orb-models. So here, Goddu's misapprehensions about the nature of the *Theorica* orbs may have not only misled him on the status of orb-models corresponding to Copernicus' mathematical constructions, but also contributed to his resistance to the possibility of Islamic sources for Copernicus' ideas and especially for the Tusi-couple.

3. Copernicus' debt to Islam

Goddu's treatment of Tusi-couples in Copernicus leans heavily on the work of Di Bono [1990, 1995]. Goddu follows Di Bono in classifying Tusi-couples into three types. The first of these is a 'spherical version with parallel axes and radii in the ratio 1:2' [see 263: Fig. 1]. The second is a 'spherical version with oblique axes and equal radii' [see 265: Fig. 2] and the third is a 'plane version with equal radii' [see 266: Fig. 3]. Only the third or flat version is supposed to appear in the *De revolutionibus* [see Figure 2, p. 328]. However the alleged separation between the first and third forms collapses immediately when we note that a flat version of the Tusi-couple can be generated in the first version by the equatorial circles of the rotating spheres. These are the circles that appear in Copernicus' figure, read by Di

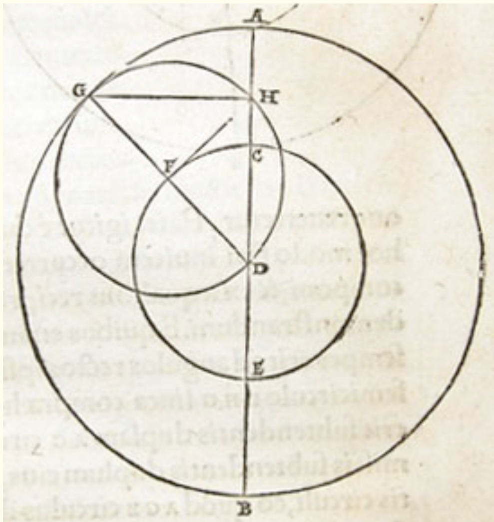
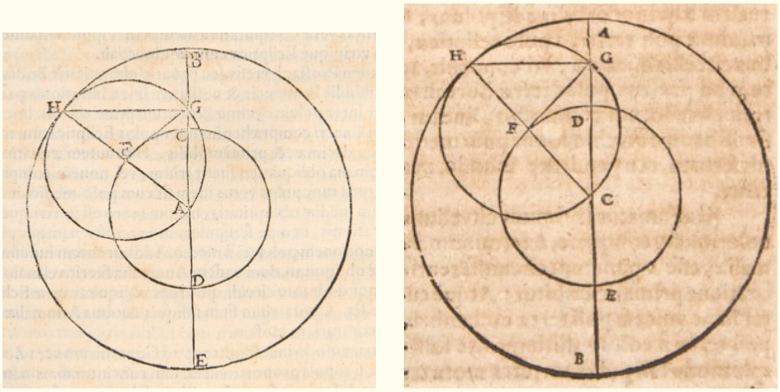


Figure 2. Copernicus' diagram explaining a Tusi-couple [1543]

Bono and Goddu as the unique third version. Goddu goes on to cite Di Bono's denial that the figures representing the third version are the same in Tusi and in Copernicus on the grounds that the first version of the device (ratio 1:2) appears in Tusi's *Tadkhira* but the third version ('equal radii') appears in the *De revolutionibus* [267]. This is simply a mistake. Both figures appear in the *Tadkhira*: the former figure shows the motion of the Tusi-couple spheres as four 'snapshots'; the latter shows the general case and converts to the flat form as indicated above. This latter is the counterpart of the diagram found in Copernicus.[3]

Goddu also quotes Di Bono to refute the key argument that the lettering of the diagrams is identical in Tusi and Copernicus, 'and even where they are, such a coincidence can be explained by mathematical conventions of nomenclature in geometrical figures' [267]. In his original article, Hartner [1973] established that the lettering in Tusi and in Copernicus was suspiciously similar—indeed identical, except for the lettering of the point at the center of the smaller circle.

[3] Hartner 1973, 421 fig. 3, reproducing MS Leleli 2116, fol. 38b–39a. Cf. Ragep 1993, 1.198–199.



(a) Magini 1589 (b) Maestlin 1596

Figure 3. Later versions of Copernicus' diagram

Copernicus' diagram contains one additional auxiliary circle (tracing the locus of the motion of the center of the smaller circle comprising the couple) and one additional line (connecting points G, H). Excluding the points introduced by these amendments, Hartner established that five out of six letters in Tusi's diagram were phonetically transliterated in Copernicus' diagram. George Saliba [2007, 200–201] has since explained the discrepancy at the sixth point. Quite simply, the original Arabic letter at that point would easily be misread by someone not very confident in Arabic as the letter translated in Copernicus. We are left with the historical fact that the diagrams in Tusi and Copernicus are identical, including—inexplicably—the orientation of the radii drawn for the large and small circles and all the lettering.

For further evidence that the correspondence between Tusi's lettering and Copernicus' is not accidental or the result of 'mathematical conventions of nomenclature in geometrical figures', consider the subsequent appearances of the same diagram in Europe in 1589 and 1596 [see Figures 3 (a)–(b), p. 329].[4] The first of these is in Magini's

[4] The earliest copy of Copernicus' diagram that we have found is in the *Hypotyposes orbium coelestium* published at Strasbourg by Rihelius in 1568. The author is sometimes given as Conrad Dasypodius, although this appears to be a work begun by Erasmus Reinhold and completed by Caspar Peucer, whose authorship is acknowledged in a later edition. For the complex publishing history of the work, see Barker 2009. The corresponding diagram

Novae coelestium orbium theoricae, to which we have already referred. The second is Michael Maestlin's new edition of Georg Rheticus' *Narratio prima*, appended to the first edition of Kepler's *Mysterium cosmographicum* and paginated continuously with it. Although both figures reproduce the circles and lines in the same orientation, the lettering differs significantly in both cases.

Taken together the similarities between the diagrams in Tusi and Copernicus are almost inescapable evidence that Copernicus had access to some version of the Arabic astronomical tradition. But Goddu uses other arguments borrowed from Di Bono to cast doubt on this, including the variation in the versions of the Tusi-couples used or implied in the *Commentariolus* and *De revolutionibus*. Di Bono claims that the first and second patterns occur in the former but only the third in the latter, where it accounts for 'variability in precession, variability in the obliquity of the ecliptic, the variations in latitude of all planets, and the variation in longitude for Mercury' [267]. But, according to Swerdlow and Neugebauer, all three versions of the Tusi couple appear in the *De revolutionibus*. Copernicus' famous figure [1543, fol. 67r, v] may be classified as the third type. But Swerdlow and Neugebauer [1984, 1.47: cf. 1.408–409] classify the Tusi-couples used in the precession model, the obliquity of the ecliptic, and the latitude variation mechanism as the second type with oblique axes. As for the longitude model for Mercury, they suggest that this implicitly contains a Tusi-couple of the first type that is carried forward from the *Commentariolus*, where it is explicit, although Copernicus does not explain it in the later book.

Goddu's scepticism about Copernicus' access to Islamic astronomy rests upon a doubtful analysis of the historical evidence and the mathematical interconnections between the versions of the Tusi-couple. To that extent, it is also incomplete. In Copernicus studies, Islamic astronomy is the elephant in the room and the Tusi-couple is only its trunk. Goddu simply never mentions a range of equally important issues beyond Tusi's models. Most significant of these is the mathematical device dependent on 'Urdi's lemma', which is

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appears on p. 529 of the Strasbourg edition but is lettered in Greek. The first eight letters of the Greek alphabet have been used. Similarly, Copernicus used the first eight letters of the Roman alphabet. However, the Strasbourg edition letters the points in a different order.

a much larger part of the elephant [Saliba 2007, 151–155]. Used repeatedly by Copernicus, it is not a mathematical variation of the Tusi-device. Copernicus used Tusi-couples of the first type to replace Ptolemy's equant in the longitude models for the outer planets in the *Commentariolus*. But in the *De revolutionibus*, he used a second method by redefining the eccentricity of the main circle producing motion in longitude and transferring one quarter of the eccentricity to the radius of a very small epicycle. This mathematical technique was developed by Mu'ayyad al-Din al-Urdi (d. 1266), a collaborator of Tusi, and used subsequently by al-Shirazi (d. 1311), Ibn al-Shatir (d. 1375), al-Qushji (d. 1474)—who used it in a new Mercury model—and Copernicus [Saliba 2007, 202–205]. Copernicus used it both in the models for the outer planets as well as in a Mercury model which seems to be copied from Ibn al-Shatir. In contrast to the Tusi-couple, then, which appears in the *De revolutionibus* only in the few very limited applications already indicated, the Urdi-construction appears repeatedly and in the main models.

Now it is, perhaps, logically possible that Copernicus could have developed the Tusi-couple himself or from European sources before he wrote the *Commentariolus* and then went on to develop the separate Urdi-device and to apply it in the models for the outer planets, while also developing, among other things, the same Mercury model as Ibn al-Shatir. But for this to have happened, as Ragep has succinctly put it, we are required to believe that

> the 500 years tradition of non-Ptolemaic astronomy in Islam was recapitulated in Europe in scrupulous detail in a 50 year span in the last part of the fifteenth century. [2005, 363]

And this is to consider only the most conspicuous correspondences in mathematical models. Ragep [2007] has recently suggested that a variety of other seeming novelties in Copernicus, including the subordination of physics to mathematical astronomy noted by Goddu and Copernicus' attitude to Aristotle's physics, can equally be located in plausible Islamic sources. Suppose we grant—as Goddu proposes in an ingenious appendix—that there is a European tradition providing access to a device equivalent to the Tusi-couple, perhaps starting with Oresme and perhaps even available to Copernicus. Given the massive collateral evidence, we submit that it is virtually certain that Copernicus had direct access to Islamic materials, quite apart from his access to parallel European traditions, and that what we see in the *De revolutionibus* is a brilliant if imperfect adaptation of them.

4. Two versions of Copernicus

According to Goddu, Copernicus learned a lot in Cracow but very little in Italy. In Cracow, he was interested in logic, natural philosophy, and technical astronomy. Because he was interested in astronomy, he was also interested in everything connected to it, which turns out to be natural philosophy and logic. According to Goddu, in Italy, he added depth in logic but nothing in natural philosophy and was already treating astronomy as a vocation. The knowledge of law and medicine that he acquired had no real bearing on his astronomy (and he made none of the connections a modern reader might conjecture about methods, for example, linking medicine and astrology). So, although we are to believe that his stay in Italy was decisive for his astronomical development, while there he is not supposed to have added to his knowledge in any of the related fields that interested him at Cracow. He also did not have time to study with the Averroist critics of Ptolemaic astronomy at Padua. On his return to Poland, his self-education progressed along with his program of astronomical reform. According to Goddu, he adopted dialectic as a method and developed several new mathematical techniques, including three forms of the Tusi-device, based on hints in earlier Northern European sources which may not themselves have employed the device and which certainly did not apply it to the problems that concerned Copernicus. His methodology and his views on natural philosophy remained unchanged for most of his adult life and the *De revolutionibus* represents the late distillation of several decades' work.

The limitations of this reconstruction of Copernicus are entirely the limitations of Goddu's method which considers textual evidence but little else and gives little consideration to Platonic influences in addition to Aristotle. It may well be true that there is textual evidence to support this 'minimalist' Copernicus. But direct citations, notes, and marginalia are not the only classes of evidence available to the historian.

By contrast, we propose that Copernicus was educated in the latest astronomical ideas at Cracow, including the *Theoricae novae* orb-models, that he heard about the Averroist attacks on them, and became familiar with internal problems of Ptolemaic astronomy such as the equant. He also belonged to a circle of Cracow Humanists that evaluated Plato positively. However, the decisive years for the development of his ideas seem to have been those he spent in Italy. He deepened his understanding of the sources and problems of Ptolemaic astronomy under Domenico de Novara, a direct link to Regiomontanus, and through him to Peurbach and Bessarion. At the same time, and again with the likely mediation of Novara, Copernicus encountered a further set of criticisms of Ptolemaic astronomy in Pico della Mirandola's *Disputationes adversus astrologiam divinatricem*, regarding the order of the planetary spheres and the length of the tropical year [Westman 2011, 84–87]. Also, at Bologna, he very probably encountered the renewed objections to Peurbach's version of Ptolemaic astronomy raised by the Averroist Alessandro Achillini. While in Padua, or perhaps in nearby Venice, Copernicus encountered Arabic astronomical ideas containing techniques from many different authors [Langermann 2007, 295–296; Morrison 2011, 388], including two different methods of circumventing the equant problem. Possibly, this material constituted the common source for the subsequent appearance of Tusi-couples in the works of Amico and Fracastoro. Finally, it was in Italy that Copernicus was exposed to Platonic and Neoplatonic influences that either deepened his already existing Platonist views on the status and tasks of astronomy, or, more likely, incited him to study Plato in depth, which he did with the aid of Bessarion's *In calumniatorem Platonis* and Marsilio Ficino's translation of Plato's works.

On returning to Poland, Copernicus began to work through all the material that he had accumulated in Italy and in the process convinced himself that geocentrism was indefensible. Between the *Commentariolus* in, perhaps, 1510 and the completion of his *De revolutionibus* in the early 1540s, Copernicus continued to work with the material that he had gathered, to read, to make observations, and to add to his fundamental ideas. These included increasing his knowledge of Plato and keeping abreast of the new Averroist astronomical theories. Consequently, when he wrote the preface to the *De revolutionibus*, he claimed to be remedying defects in both Ptolemaic astronomy and its Averroist alternative.

Goddu has written an indispensable book for specialists, and one that has many valuable ideas for those with a less specific interest in

Copernicus the man, his period, or his contribution to the history of science. Where textual evidence is central or an appraisal of textual evidence is required, Goddu's work is nearly irreproachable. However, the wider field of historical evidence is barely touched, and, where this affects matters as important as the influence of Islamic science on the origins of the modern Western scientific tradition, readers are advised to supplement Goddu's approach with a cultural and contextual one.

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