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7 The Copernican Revolution

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The intellectual ferment that swept over Europe in the wake of the invention of printing by movable type and the discovery of a New World to the West included, besides profound religious changes, a fresh approach to nature and to the heavens above. In retrospect, it was perhaps inevitable that these radically evolving viewpoints would become mutually entangled. This essay considers a pivotal episode in the transition from a geocentric to a heliocentric universe, with special attention to the religious implications and interactions.

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IN 1543, the year of his death, Nicholas Copernicus (1473–1543) saw his life work, *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Bodies*), finally printed. A four-hundred-page technical treatise, it laid out a heliocentric framework for the planetary system, thereby providing the essential basis for the Newtonian synthesis that was to follow a century and a half later. During this same interval, the gradual overthrow of the long-accepted geocentric worldview created an upheaval in the sacred geography of the cosmos. These changes, both in technical astronomy and mechanics and in humankind's vision of its physical place in the universe, constitute the Copernican revolution.

Copernicus was born in Torun, Poland, in 1473. His father died when he was ten years old, and his maternal uncle, Lucas Watzenrode, took over responsibility for the young man's education. Watzenrode was in a successful career of ecclesiastical politics, becoming in 1489 bishop of the northernmost Roman Catholic diocese in Poland, and here he provided a position for Copernicus as canon in the Frombork (Frauenburg) Cathedral. Copernicus was never ordained as a priest, but he took minor orders and, after appropriate graduate study in Italy, served as personal physician to his uncle and as the principal legal officer of the cathedral chapter.

Precisely when and where Copernicus caught the vision of a heliocentric system we do not know. He was interested in astronomy even while an undergraduate at Cracow, and he continued to develop his understanding as he studied canon law in Bologna from 1496 to 1500. By 1514, he had written out a short precis of the heliocentric astronomy, the so-called *Commentariolus*, which was, however, not printed until its rediscovery in the 1880s. The Latin edition of Ptolemy's *Almagest* in 1515 showed Copernicus the required scope of any treatise that would challenge Ptolemy's authority, and he began work in earnest on his *De revolutionibus*. He quickly realized that he would need a baseline of nearly twenty years of observations to establish the modern parameters for the planets, so he bided his time with a variety of duties for the cathedral as he slowly collected the fresh data. Only toward the end of his life did he finally pull together the various parts of his extensive and highly mathematical account.

The opening chapters of *De revolutionibus* lay the philosophical foundations for a moving earth and a fixed central sun, leading to the glorious chapter I,10, a powerful rhetorical defense of the heliocentric cosmology, pointing to the sun "as if on a royal throne governing the planets that wheel around it. For in no other way can we find such a wonderful commensurability and sure harmonious connection between the motions of the spheres and their sizes." The chapters that follow include a section on basic trigonometry, a catalog of fixed stars, the theory of the sun (i.e., of the earth's annual orbital motion, as well as a heliocentric explanation of the precession of the equinoxes), the theory of the moon, the theory of planetary longitudes, and, finally, the theory of planetary latitudes.

Copernicus never fully explained his reasons for considering a heliocentric arrangement, and a number of hypotheses have been subsequently proposed, many unconvincing if not outright erroneous. For example, a standard account found in numerous secondary works describes the increasing disparity between actual observations and the planetary predictions based on Ptolemy's theory and the continued addition of more and more epicycles to account for these discrepancies. Eventually, this mythological account runs, the system was ready to collapse under its own weight.

In fact, there is no historical evidence for the addition of epicycles upon epicycles to increase the accuracy of the Ptolemaic system. Furthermore, the ingenious and intricately dovetailed tables provided by Ptolemy and used by all of the medieval astronomers could not be readily modified to accommodate additional epicycles. Finally, because Copernicus used the ancient Ptolemaic observations as his fundamental base, his own predictive system was not substantially more accurate than Ptolemy's, and, if accuracy of prediction were the criterion, then Copernicus's work must be deemed a massive failure. Besides, the accuracy of prediction could have been considerably improved without moving to the heliocentric arrangement. Because of the basic geometric equivalence between the two systems, not only would the predictions not be improved merely by moving to a heliocentric arrangement, but, equally important, no simple observational test could differentiate the two arrangements prior to Galileo's (1564–1642) telescopic observation of the phases of Venus in 1610.

While observational evidence could not have entered directly into Copernicus's enthusiasm for the heliocentric layout, undoubtedly aesthetic considerations played a powerful role. Copernicus describes the pleasure of a theory "pleasing to the mind." When the planets were linked together in the sun-centered arrangement, Mercury, the fastest planet, automatically fell into the innermost position, and Saturn, the slowest, fell farthest from the sun, with a gradation in between. As cited above, Copernicus commended this arrangement "that can be found in no other way." He also noticed that, in his system, the so-called retrograde motion of the superior planets was required to occur when the planet was opposite the sun in the sky, thereby giving a natural explanation to what was just an arbitrary observation in the Ptolemaic scheme.

It is quite possible that Copernicus would never have published his hypotheses except for the persuasive intervention of a young Lutheran astronomer from Wittenberg, Georg Joachim Rheticus (1514–74). Rheticus's initial account of Copernicus's ideas, *Narratio prima* (*First Narrative* [1540]), did not create the opposition Copernicus feared, so the Polish astronomer gave him permission to take a manuscript of *De revolutionibus* to Nuremberg for publication. The printer arranged for a local Lutheran clergyman, Andreas Osiander (1498–1552), not only to take charge of the proofreading but also finally to add at the very beginning an anonymous warning to readers concerning the hypotheses in the work. In highly abridged form, here is the gist of Osiander's *Ad lectorem* (*To the reader*): "It is the duty of an astronomer to make careful observations, and then to make hypotheses so that the positions of the planets can be predicted. This the author has done very well. But these hypotheses need not be true nor even probable. Perhaps a philosopher will seek after truth, but an astronomer will take whatever is simplest, but neither will learn anything certain unless it has been divinely revealed to him."

When Copernicus, on his deathbed, finally received the front matter of his book (the last part to be printed), he was greatly agitated, but whether this was in disagreement with what Osiander had written or perhaps merely the excitement of having his work completed is unknown. Did Copernicus believe in the physical truth of his heliocentric arrangement? Certainly, some parts of the work well reflect Osiander's instrumentalist stance (e.g., when Copernicus gave three different arrangements of the small circles for the solar theory, remarking with consummate illogic that "it must be one of these since they all yield the same result"). On the other hand, at the end of the cosmological chapter I,10, Copernicus declared, "So vast, without any doubt, is the handiwork of the Almighty Creator." This pious passage was later censored by the Inquisition, apparently because it implied that this was the way God had actually created the cosmos, but its enthusiasm suggests that Copernicus really believed that the Creator had placed the planets heliocentrically.

The Initial Reception of the Copernican Hypothesis

Whether or not Copernicus considered his work simply a mathematical hypothesis, not to be taken as a literal description of the physical world, the astronomers and theologians at the University of Wittenberg (where the book received its first detailed study) were convinced that astronomers used fictional circles in their modeling of the cosmos and that these were not to be confused with the actual physical reality sought by the professors of philosophy. Erasmus Reinhold (1511–52), Wittenberg's beloved and authoritative professor of astronomy, devoured the technical details of *De revolutionibus*, reveling in Copernicus's strict adherence to uniform circular motion (which corrected Ptolemy's heuristic digressions with respect to these aesthetic standards), but he essentially skipped the heliocentric cosmology. His attitude aptly illustrates what historian Robert Westman has called "the Wittenberg interpretation" of Copernicus.

Martin Luther (1483–1546), who heard of Copernicus's cosmology through his Wittenberg astronomers before its publication, made an offhand remark that was recorded in his "table talk," to the effect that "whoever wants to be clever has to do his own thing. This is what that fool does who wants to turn astronomy upside down." His remark has gained publicity out of proportion to its significance; more important is the fact that Wittenberg became the intellectual center for teaching and publishing about Copernicus. Luther's right-hand man, Philip Melanchthon (1497–1560), referred indirectly to Copernicus in the first edition of his *Initia doctrinae physicae* (*Elements of the Knowledge of Natural Science* [1549]), saying: "The joke is not new. . . . The young should know it is not decent to defend such absurd positions publicly," but he promptly watered down his opinion in subsequent editions.

In the initial stages of the reception, any response on the Roman Catholic side was muted. Only later, in the wake of the Galileo affair in the early seventeenth century, was it discovered that a Florentine Dominican, Giovanni Maria Tolosani, had quickly written against Copernicus, but his patron died before the manuscript was printed, and his blast languished on an archival shelf. Because of the vehemence of the later Catholic response, some nineteenth-century commentators, such as Andrew Dickson White (1832–1918), hoped to give the Protestants equal time, and various anti-Copernican sentiments were attributed to John Calvin (1509–64), but careful research has been unable to substantiate any of them.

A principal point of tension in the religious community centered on various scriptural proof texts that seemed to demand a fixed earth or a moving sun. Psalm 104, "The Lord God laid the foundations of the earth that it should not be moved forever," was an often-cited verse, as was Joshua's command for the sun, and not the earth, to stand still to prolong the battle at Gibeon (Josh. 10:12–14). Rheticus supposedly wrote a "Second Narrative" defending the Copernican doctrine, but it remained lost until it was serendipitously recovered by the Dutch historian Reijer Hooykaas in 1973. Rheticus's account had been printed anonymously in the seventeenth century, in a little book now known in only two copies. Rheticus addressed the Scriptures concerning the stability of the earth by saying: "For, although on earth there occur corruptions, generations, and all kinds of alterations, yet the earth itself remains in its wholeness as it was created." He went on to argue that Scripture should be understood to mean that each object (e.g., the earth or the moon) had been founded on its own stability. As for the apparent motion of the sun, he stated: "Common speech, however, mostly follows the judgment of the senses. . . . We must distinguish in our minds between appearance and reality."

The Later Protestant Reception of Copernicanism

De revolutionibus was immediately recognized as an important and magisterial book and was widely quoted in various technical contexts even in its first two decades, though rarely with respect to its cosmology. An interesting exception is Robert Recorde's (c. 1510–58) *Castle of Knowledge* (1556), in which in the dialogue the Scholar protests, "Nay syr in good faith, I desire not to heare such vaine phantasies," to which the Master rejoins, "You are to yonge to be a good judge in so great a matter." An interesting comment was given by the Louvain astronomer Reiner Gemma Frisius, who pointed out in 1555 that Copernicus had provided a reasoned explanation for the retrograde motion at opposition and that it was no longer merely a "fact in itself," as it had been for Ptolemy.

One of the first committed sixteenth-century Copernicans was the English astronomer Thomas Digges (d. 1595), who published an English translation of the cosmological chapter of *De revolutionibus* in 1576, "to the ende such noble English minds might not be altogether defrauded of so noble a part of Philosophy." He proposed that the stars extended infinitely upward and that, therefore, the sun was immovable in this frame. He also provided the first step in revising the sacred cosmology of heaven by locating "the habitacle for the elect, devoid of greefe" among the stars, "garnished with perpetual glorious shining lights innumerable."

Tycho Brahe (1546–1601), the Danish observer, remarked that "Copernicus nowhere offends the principles of mathematics, but he throws the earth, a lazy, sluggish body unfit for motion, into a speed as fast as the ethereal torches." Tycho's name is not closely associated with religion, but he had a pew in the Lutheran church on his fiefdom of Hven, and, in evaluating the Copernican system, he repeatedly said that it offended physics and Holy Scripture, always in that order. Eventually, he proposed his own geoheliocentric version of the Copernican layout, in which the sun revolved around a fixed earth, but the moving sun carried the planets in orbit around itself. The arrangement saved some of the compelling Copernican linkages but destroyed part of the beauty of the system to preserve a fixed, central earth consistent with physics and the Bible.

His contemporary, Michael Maestlin (1550–1631), a Lutheran clergyman before taking up his astronomy professorship and a virulent critic of the new "popish" Gregorian calendar reform, is probably best known for teaching Johannes Kepler (1571–1630) about Copernicus at the University of Tübingen. Maestlin concluded from his own study of the comet of 1577 that the comet's motion was best understood as being seen from a moving earth. Maestlin clearly hoped to find other circumstantial evidence for the Copernican arrangement by looking for parallel changes in the eccentricities of the planetary orbits that could be attributed simply to the change in eccentricity of the earth's orbit, but the ancient observations proved too insensitive for the test. His stance toward the reality of the Copernican system was ambiguous, and he remains an enigmatic but important transitional figure, especially because of his encouragement to Kepler.

Kepler was in the final year of the Lutheran theological program at Tübingen when he was sent as a high-school teacher to Graz in Austria. He had already become a devoted Copernican, believing that the sun-centered cosmos was an image of the Holy Trinity, with God represented by the sun, Christ by the shell of fixed stars, and the Holy Spirit by the intervening space. While in Graz he stumbled upon an imaginative explanation for the Copernican spacing of the planets, a scheme involving the five regular polyhedra. Maestlin helped him publish his book, *Mysterium cosmographicum* (*Cosmographic Mystery* [1596]), but his theological introduction was suppressed when the university senate objected. Kepler simply saved his theological defense of the Copernican system for his greatest book, *Astronomia nova* (*New Astronomy* [1609]). There he explained (as Rheticus had done earlier in his as yet unpublished *Narratio secunda* [*Second Narrative*]) that Scripture is written in common language for universal understanding and is not to be taken as a textbook of science. He wrote especially concerning Psalm 104:

> I implore my reader not to forget the divine goodness conferred on mankind, and which the Psalmist urges him especially to consider. . . . Let him not only extol the bounty of God in the preservation of living creatures of all kinds by the strength and stability of the earth, but let him acknowledge the wisdom of the Creator in its motion, so abstruse, so admirable.
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> Whoever is so weak that he cannot believe Copernicus without offending his piety, and who damns whatever philosophical opinions he pleases, I advise him to mind his own business and to stay at home and fertilize his own garden, and when he turns his eyes toward the visible heavens (the only way he sees them), let him pour forth praise and gratitude to God the Creator. Let him assure himself that he is serving God no less than the astronomer to whom God has granted the privilege of seeing more clearly with the eyes of the mind (Kepler 1983, 321–22).

The Later Catholic Reception of Copernicanism

Among the Roman Catholics who wrote on Copernican matters was the Spanish theologian Diego de Zuñiga (1536–97), who argued that certain passages in Job could actually be read with a Copernican interpretation. The eclectic philosopher Giordano Bruno (1548–1600), who had only a very faulty technical understanding of the Copernican theory, espoused it as part of his arguments for the plurality of inhabited worlds. While the reasons for his condemnation as a heretic were many and complex, his dalliance with the Copernican doctrine gave pause to many Catholics when he was burned at the stake in 1600.

Although Galileo had written to Kepler in 1597 that he was secretly a Copernican, he kept silent on the subject until his remarkable telescopic discoveries of 1609–10. Then he became increasingly open in his suggestions about the efficacy of heliocentrism. When the question arose at the Florentine court about scriptural objections to Copernicus, his protégé Benedetto Castelli (1578–1643) announced that Galileo could no doubt answer them. Galileo was probably taken by surprise, but he promptly began a review of the relevant materials by the church fathers and produced an essay on scriptural interpretation. The similarity of some of his arguments to those Kepler had used suggests that Galileo knew of the introduction to *Astronomia nova*, but it would have been folly for a Catholic astronomer to quote a Lutheran in such a delicate matter. Galileo's most memorable line, borrowed from the cardinal director of the Vatican Library, was that "the Bible teaches how to go to heaven, not how the heavens go."

Matters came to a head in 1616 when Galileo went to Rome in an effort to keep the Catholic authorities from banning the Copernican system. Galileo was silenced, and *De revolutionibus* was declared erroneous (but not heretical) and placed on the Index of Prohibited Books "until corrected" (along with Zuñiga's book and a few others). For the first and only time for any prohibited book, the Inquisition actually specified the corrections; in 1620 Inquisitors announced ten changes to make Copernicus's book appear more hypothetical. A recent study has shown that about 60 percent of the copies of Copernicus's book in Italy were censored, but essentially none in the other Catholic countries.

Earlier, in 1581, Christopher Clavius (1537–1612), the leading Jesuit astronomer, had written that what the Copernican system showed was that

Ptolemy's arrangement was not the only possibility. Nevertheless, he held firmly to the Ptolemaic cosmology, and he was unenthusiastic when Tycho proposed his alternative geoheliocentric arrangement. After Clavius's death in 1612, and especially after Copernicus's book was placed on the Index, the Jesuits espoused the Tychonic system in their teaching. This had a curious effect on the Jesuit mission to China, which had started out teaching the Copernican system as a demonstration of the advanced state of Western science but, after 1620, rapidly backpedaled to the Tychonic arrangement, leaving Chinese students in great confusion.

At the University of Louvain, the maverick astronomer Libert Froidmond argued in 1631 that the Copernican system should be considered heretical. In France, however, Marin Mersenne (1588–1648), in a careful analysis in 1623, had concluded that the heliocentric cosmology was merely erroneous but not heretical. Earlier, in 1616, internal Vatican examiners had decided that the proposition that the earth moved was erroneous, whereas the belief that the sun was fixed was actually heretical. However, their hastily prepared memorandum was not publicized. After the publication in 1632 of Galileo's *Dialogo*, a brilliant polemical defense of Copernicanism, and after his trial that followed for "a vehement suspicion of heresy," the Copernican doctrine became de facto heretical, and Copernicus's book remained on the Index well after the matter was all but settled in scientific circles.

In 1757, action by Pope Benedict XIV (b. 1675, p. 1740–58) essentially made the heliocentric doctrine acceptable in Catholic schools; nevertheless, the original decree stood, and *De revolutionibus* still appeared in an Index published in Rome in 1819. A pivotal moment arrived when a Catholic astronomer, canon Guiseppe Settele, was refused an imprimatur for his astronomy textbook in 1820 because his book treated the Copernican system as a thesis instead of as a hypothesis. It eventually required a papal command to overrule an obstinate censor, and in 1835 a new edition of the Roman Index finally appeared without a listing for Copernicus, although it had actually been removed from the Index in 1820.

In the mid–twentieth century, Catholic physicists, still embarrassed by the Galileo affair, urged the papacy to "do something" about it. John Paul II (b. 1920, p. 1978–), a pope from Copernicus's homeland, announced to the Pontifical Academy at the time of the Einstein centennial (in 1979) that the case would be reexamined. Thirteen years later, in 1992, with little consultation with the Roman Catholic historians of science who had been commissioned to look into the matter, he made a final statement. Since Galileo had not been found guilty of heresy (as he denied believing in the truth of the Copernican doctrine) but rather of disobedience (for teaching it), Pope John Paul II's options were limited. He said that Galileo had suffered much but that times were different then. He repeated the aphorism "the Bible tells how to go to heaven, not how the heavens go" and declared that Galileo had been a better theologian than those opposing him.

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