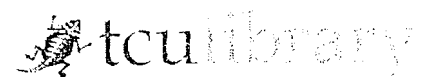


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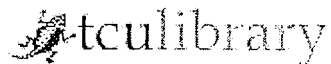
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Astronomy in the Age of Columbus

Aided by his wildly erroneous conception of the earth's circumference, Columbus redrew the globe, perhaps encouraging others to realign the heavens

by Owen Gingerich

Two events of astronomical interest took place in 1492. One was the explosion of a brilliant fireball over central Europe, which dropped its stony meteorite near the Alsatian town of Ensisheim. The other was Columbus's discovery of the New World.

The impressionable young Albrecht Dürer witnessed the fireball while en route to Italy and painted the magnificent phenomenon on a small wood panel. He used the other side for an oil of St. Jerome, however, and his painting of the meteoritic explosion stayed hidden from sight for several centuries. It came to light again about two decades ago, when the St. Jerome painting was lent to the Fitzwilliam Museum in Cambridge, England. Meanwhile the Ensisheim meteorite, which was kept in the parish church and later in the Hôtel de Ville at Ensisheim, remained practically unknown. Not until the past few decades has the Ensisheim stone—the oldest precisely dated meteorite in Europe—captured the attention of meteoriticists.

Curiously enough, what seems like the nonastronomical event of 1492—Columbus's voyage across the Atlantic

and back—may well have had a genuinely significant impact on astronomical thought. Even though Columbus was wrong in his belief that he could sail westward to China and Japan, his pioneering venture and the voyages that followed vividly demonstrated that ancient knowledge—particularly geographic information—was woefully incomplete. The geographic revolution of the New World paved the way for unorthodox astronomical ideas, including the possibility of a radical, sun-centered cosmology.

What was the state of astronomical knowledge when Columbus made his voyage? A good starting point for the answer is Hans Holbein's *The Ambassadors*, painted in 1533, one of the great treasures of the National Gallery in London. Between the ambassador from the French court and his scholarly friend, the bishop of Lavaur, stands a table filled with books and instruments. At first glance these artifacts distribute nicely between the heavens, the earth and the sea, represented, respectively, by the celestial dials and globe on top, the earthly books and lute on the shelf, and a very fishy form near the floor.

More fundamentally, the objects constitute an allegory of the four topics of the advanced university curriculum: astronomy, arithmetic, music and geometry. The instruments represent astronomy, and Peter Apian's *Eyn neue unnd wolgegründte underweysung aller Kauffmanns Rechnung* of 1527, lying open on the shelf, portrays arithmetic. The lute and a songbook open to the Lutheran *Kom Heiliger Geyst* signify music. Geometry is exemplified not only by the challenging perspectives of the mosaic floor (an Italian mosaic in the shrine of Edward the Confessor in Westminster Abbey, unique in England) and the lute—a favorite drawing exer-

cise for Renaissance artists—but also by the curious fishlike object hovering above the floor. Closer inspection, from a vantage point that foreshortens the image, reveals it to be an elongated anamorphic depiction of a human skull, perhaps a pun on the name of the artist (Holbein, "hollow bone").

The skull, a symbol of mortality, brings in yet another level of Renaissance metaphor, reminding us that any quest for earthly knowledge is transitory and ephemeral. The theme is reinforced by the broken lute string, also a traditional symbol of death and decay. In contrast to the highly visible studies of the quadrivium stand the eternal mysteries, symbolized by the crucifix half-concealed behind the curtain at the upper left corner of the painting. The scholarly pursuits may be focused and central, but the larger truths lie hidden beyond mortal powers.

The era of *The Ambassadors* was still a time when some long-gone golden age was thought to hold the keys to the universe, and newness was not yet a virtue. Nevertheless, astronomy took an honored place in the curriculum, for it described the physical arena in which the human drama took place.

The earth—a composite sphere of earth, water, air and fire—was solidly fixed in the middle of the cosmos. Around it were the spheres of the seven planets (counting both the moon and sun) and an eighth sphere containing the fixed stars—fixed with respect to one another but actually spinning at a dizzying rate, once every 24 hours. And beyond that were God the Father with his angels and the elect in a state of eternal bliss. A woodcut in the *Nuremberg Chronicle*, that great coffee-table book of 1493, sets forth the classical cosmology in all its glory.

The *Nuremberg Chronicle* was designed before Europe had heard about

OWEN GINGERICH is a senior astronomer at the Harvard-Smithsonian Center for Astrophysics in Cambridge and chairman of the history of science department at Harvard University. This is his fifth article for *Scientific American*. For many years Gingerich crisscrossed Europe and America searching for copies of Copernicus's *De revolutionibus*; he has inspected more than 500 16th-century copies looking for early annotations. Two anthologies of his articles are just being published: *The Great Copernicus Chase and Other Adventures in Astronomical History* (Sky Publishing and Cambridge University Press) and *The Eye of Heaven: Ptolemy, Copernicus, Kepler* (American Institute of Physics).



HOLBEIN PAINTING, *The Ambassadors*, contains representations of the university curriculum as of 1533: arithmetic, as-

tronomy, geometry and music. Among the astronomical instruments is a globe depicting parts of the New World.

Columbus, and a single look at it debunks one of the most widely disseminated myths about the Italian navigator's voyage. Since the ancient Greeks, people had known the earth as a sphere. Aristotle had taught that the earth had to be a globe because if bits of heavy terrestrial material were dropped into the center of the universe, they would naturally pile up in the form of a sphere. Almost as an afterthought he added that the shape of the shadow of the earth on the moon at the time of a lunar eclipse demonstrated the correctness of his archetypal idea.

Yet every Columbus Day the story is vividly retold of how Columbus had to persuade Isabella and Ferdinand that the world was round. Had Christendom forgotten the round earth? In truth, it is early 19th-century Americans who were forgetful, and the doctrine they were trying to forget was the standard British view that one of theirs, Sebastian Cabot, was the first to make landfall in North America—Columbus had merely found some small islands in the Indies.

In the aftermath of the Revolution, Americans desperately needed some non-British heroes. Columbus filled the

bill even though no one knew much about him until novelist Washington Irving visited Spain, found a rich lode of source materials and produced a widely read biography. Unfortunately, Irving mixed fiction with fact, and one of his most graphic scenes, set in Salamanca, was wildly imaginative.

There Columbus faced a panel of clerics, "an imposing array of professors, friars and dignitaries of the church" who "came prepossessed against him, as men in place and dignity are apt to be against poor applicants." They ridiculed the idea of the roundness of the

earth and quoted Scripture to infer its flatness. Columbus, a profoundly religious man, found himself in danger of being convicted not only of error but also of heresy.

In reality, knowledge of the earth's round shape was always part of the Western heritage. As the Dark Ages had waned, and with the rediscovery of the works of Aristotle, the notion of a spherical earth entered the curriculum of the newly founded universities. Sacrobosco's *Sphaera*, written in the 13th century and today holding the record as the astronomy textbook with the most editions, gave a simple argument for the spherical shape of the earth in a north-south direction: travelers found that the Big Dipper and Pole Star rose

higher in the heavens as they traveled north. As for the east-west direction, Sacrobosco gave a different, more subtle argument: an eclipse of the moon would take place at a particular, unique moment, regardless of where an observer was located, but from different longitudes the height of the moon in the sky would vary in a fashion compatible with a spherical geography.

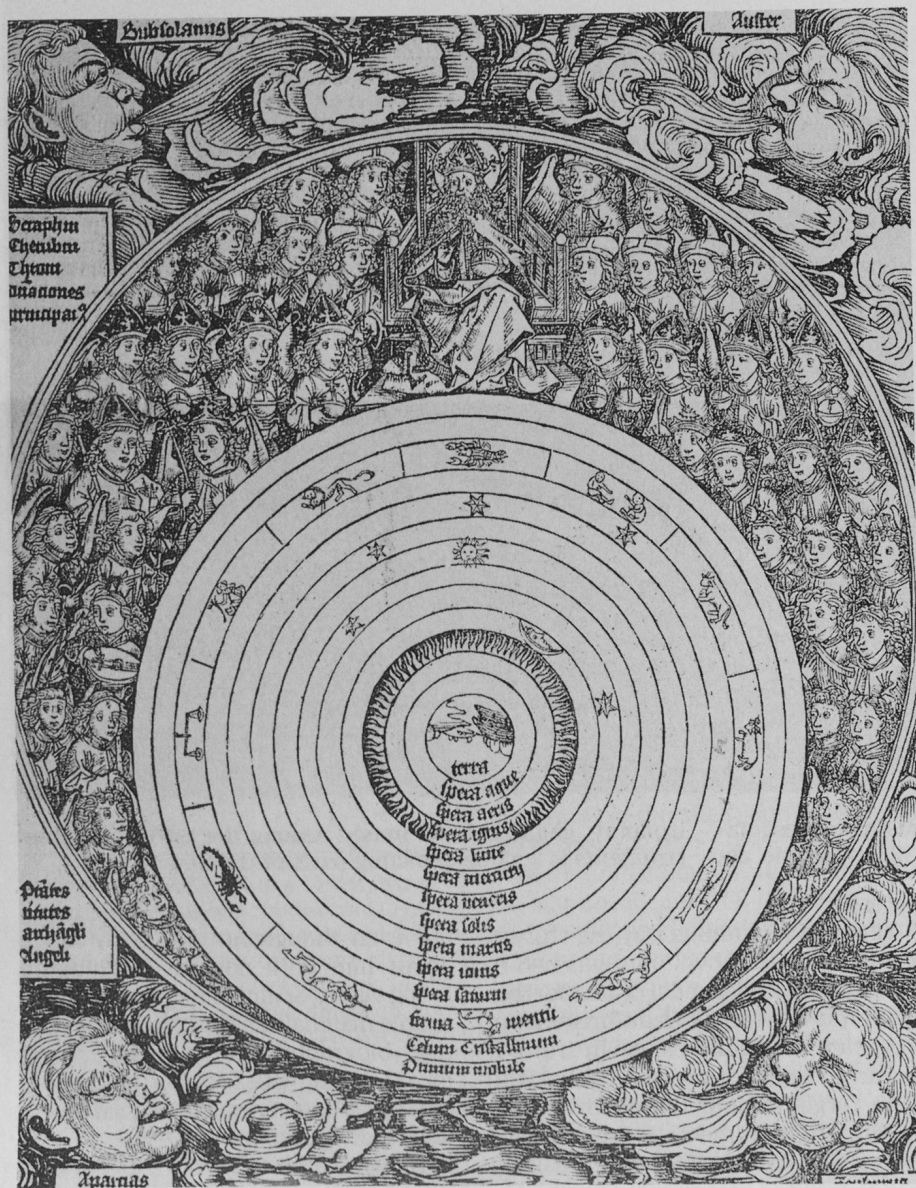
The problem Columbus faced in Salamanca, then, was not convincing Isabella and Ferdinand that the earth was round but rather that its size and the extent of the Eurasian landmass made the bold notion of a westward voyage to Cathay and the Indies not too unreasonable. The diameter of

the earth had been deduced with fair accuracy by Eratosthenes in ancient Alexandria; his round number of 252,000 stadia converts to a circumference of just under 40,000 kilometers, provided that a stade equals 157.5 meters, as the distinguished historian of astronomy J.L.E. Dreyer has argued. Islamic geodesists had reworked Eratosthenes' measurements; al-Farghani, working in the Baghdad group under Calif al-Ma'mun in the early ninth century, had got the equivalent of 20,400 Arabic miles (40,253 kilometers, as compared with the modern figure of 40,075). Columbus assumed, incorrectly, that the Arabic miles were equivalent to Roman ones, which gave him a circumference of 30,044 kilometers, only three quarters of the actual distance.

In addition, Columbus significantly exaggerated the terrestrial longitude of China and hence its distance from Europe. He reckoned the eastward distance to Japan to be as great as 283 degrees, putting the westward distance from the Canaries under 5,000 kilometers. These two erroneous estimates suited Columbus just fine because they made his daring goal of sailing westward to the Indies seem reasonable.

When the court convened in Salamanca around Christmastide in 1486, the scholars there objected to Columbus's diminished estimate of the size of the earth. The circumference they defended was close to the one we accept today. Without his fictitious estimate, Columbus could not have justified his audacious expedition. The myth of the learned flat-earthers is "pure moonshine"; as the eminent biographer Samuel Eliot Morison remarked: "Washington Irving, scenting his opportunity for a picturesque and moving scene, took a fictitious account of this nonexistent university council published 130 years after the event, elaborated it, and let his imagination go completely." Irving's account is gripping drama, "for we all love to hear of professors and experts being confounded by simple common sense. Yet the whole story is misleading and mischievous nonsense."

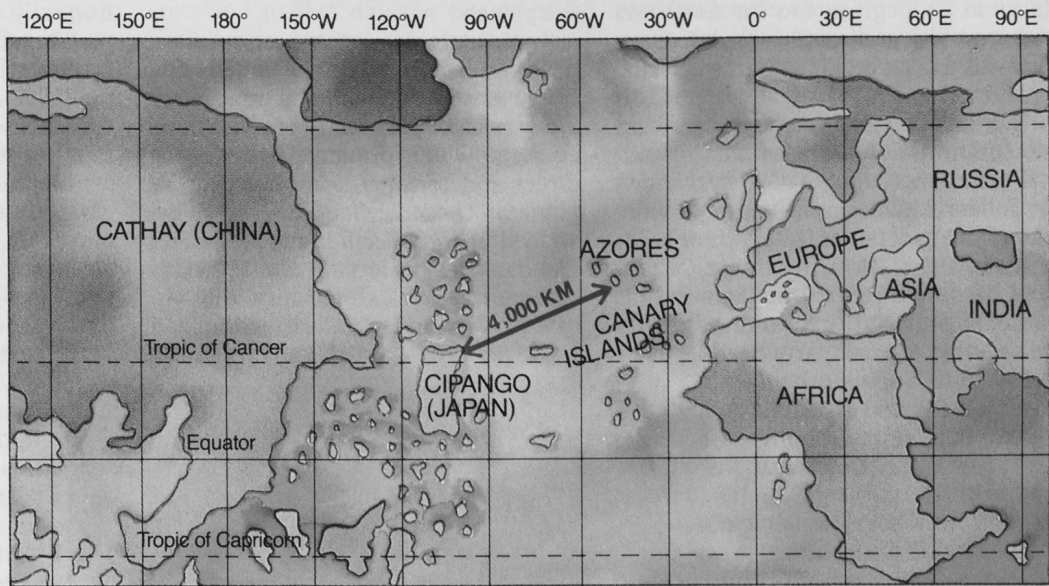
Indeed, except for his wildly mistaken geodesy, Christopher Columbus actually had relatively little to do with astronomy. He is sometimes depicted with stars and primitive navigational devices such as the nocturnal—an instrument for finding the time of night from the position of the Big Dipper—but what little evidence exists concerning Columbus's use of the stars for navigation suggests that he might have got equally good answers just by guessing. Confused by the tropical skies



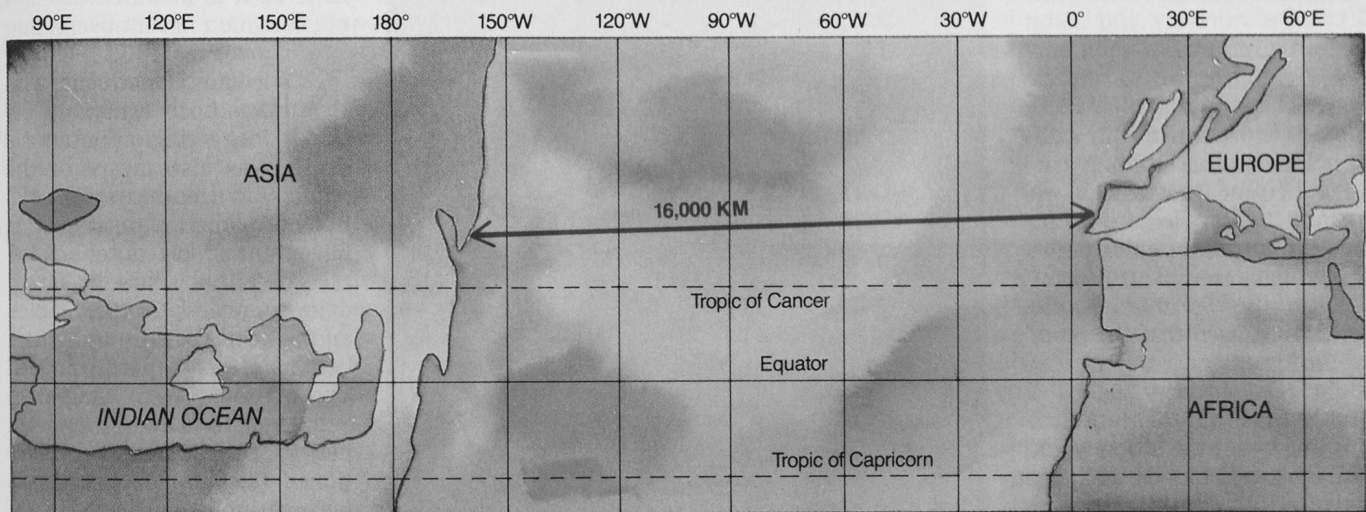
GEOCENTRIC UNIVERSE is shown in this print from the *Nuremberg Chronicle*, a world history published in 1493. The round earth is fixed at the center, surrounded by the planets, including the moon and sun, and by the sphere of fixed stars. In the outermost circle are depicted God and the ranks of angels and the elect. The four winds decorate the corners of the page.

The Earth's Circumference and Continents

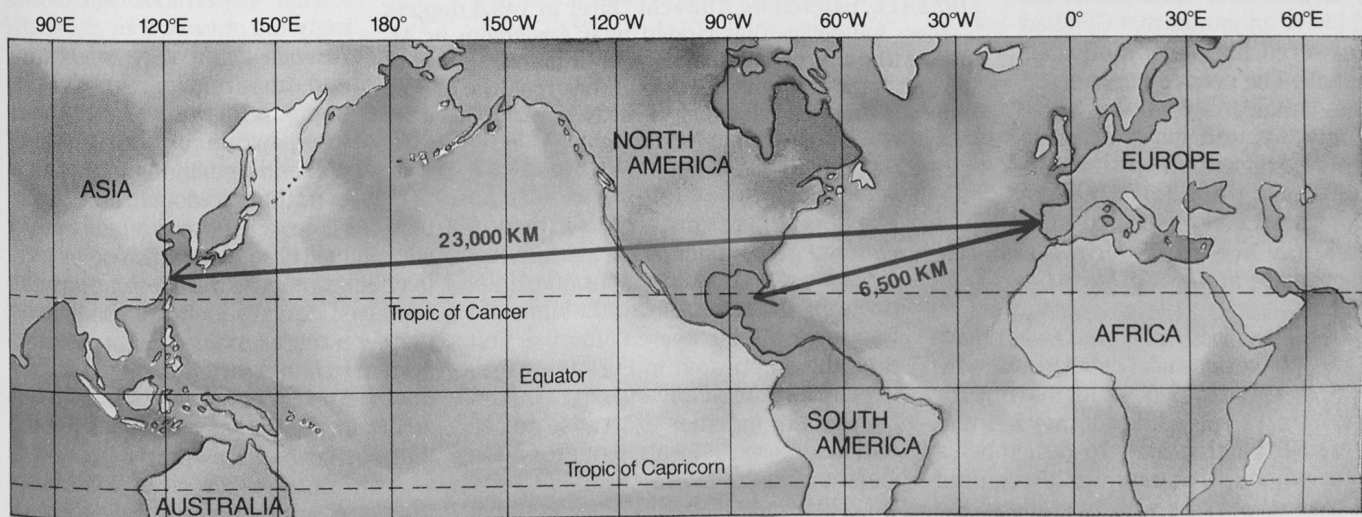
Conflict between Columbus's beliefs about the circumference of the earth and the arrangement of its continents (*top*) and Ptolemaic geography (*middle*) is clear on maps. Only by understating the earth's circumference and overstating the breadth of Asia could Columbus justify a voyage west to the Indies. Both maps of course omitted North and South America (*bottom*). The continents on the top map are taken from a globe made by Martin Behaim in Nuremberg in 1492.



Columbus's View



Ptolemaic View



Modern Map

and the absence of familiar circum-polar constellations, he twice mistook the star Beta Cephei for Polaris, getting a latitude 21 degrees too far north. As Admiral Morison emphasized, Columbus was a dead reckoner, not a celestial navigator.

The one conspicuous and legendary exception to Columbus's unastronomical tastes was his use of *Ephemerides*, by Johann Müller (known as Regiomontanus), to foretell an impending lunar eclipse. On his fourth voyage Columbus became stranded on Jamaica, his ships so wormed they were no longer seaworthy. A small party headed east in an open canoe to seek relief from Hispaniola and its capital, Santo Domingo (in the present-day Dominican Republic). The governor of Hispaniola, however, was by no means pleased with the idea of rescuing Columbus. He feared he might be replaced in his lucrative assignment, and so he dragged his feet in sending aid.

Months wore on, and about half of Columbus's men mutinied and tried to sail by canoe to Hispaniola. The Jamaican Indians, now sated with glass beads and other trading trinkets, became increasingly reluctant to provide food for the diminished but nonetheless hungry crew.

From the *Ephemerides* Columbus learned that the moon would be eclipsed on the leap night of February 29, 1504, and he made sure that the Indians knew that the moon would rise dark and bloody as a sign that God was displeased with them. The navigator kept out of sight until the eclipse was over and then came out of his cabin to announce that God had answered his prayers on their behalf. The event so impressed the Jamaicans that they gave Columbus and his crew more than enough food to stave off starvation. (An echo of the episode has been enshrined in American literature in Mark Twain's *A Connecticut Yankee in King Arthur's Court*.)

Why, then, in light of Columbus's astronomical deficiencies, were his voyages so significant for astronomy? Splendid as it may seem to a modern astronomer to remember a time when astronomy was a required topic for every university student, the actual level of Sacrobosco's text was exceedingly elementary. The *Sphaera*

described the daily and seasonal motions of the celestial sphere, but it said almost nothing about the motions of the planets.

Knowledgeable medieval astronomers, however, believed that embedded within the Aristotelian spheres was a complex series of subsidiary epicycles and equants, which produced the varying direct and retrograde motions of the planets. These devices had been described by the Alexandrian astronomer Claudius Ptolemy around A.D. 150 in his *Almagest*, a work so technical that virtually no one in Latin Christendom had

grasped the details of Ptolemaic astronomy, but they were not pleased with what they saw. In 1464 Regiomontanus wrote a brief but penetrating critique of the theory to a fellow mathematical astronomer. The tables did not give accurate predictions, he reported. He had seen Venus three quarters of a degree out and Mars off by a full two degrees, and a lunar eclipse in 1461 had ended an hour before the calculations indicated. Furthermore, the moon's apparent diameter, according to Ptolemy's theory, should sometimes be twice as large as it is at other times, a phenomenon never observed.

Peuerbach and Regiomontanus wrote a brief but penetrating critique of the theory to a fellow mathematical astronomer. The tables did not give accurate predictions, he reported. He had seen Venus three quarters of a degree out and Mars off by a full two degrees, and a lunar eclipse in 1461 had ended an hour before the calculations indicated. Furthermore, the moon's apparent diameter, according to Ptolemy's theory, should sometimes be twice as large as it is at other times, a phenomenon never observed.

Nicolaus Copernicus, who was born two years before Regiomontanus's death, was also aware of the defects in geocentric predictions of planetary positions. At one point in his notebook he recorded that Mars was two degrees ahead of the tables and Saturn a degree and a half behind [see "Copernicus and Tycho," by Owen Gingerich; *SCIENTIFIC AMERICAN*, December 1973]. Yet he never mentioned this fault in print, and his own heliocentric-based tables did not correct the errors very effectively.

That Copernicus was seemingly unconcerned by these deficiencies is a very interesting and important point. Despite popular literature to the contrary, errors in the tables of planetary positions had virtually nothing to do with the choice

between a geocentric and a heliocentric viewpoint. These two cosmologies were in effect geometric transformations that produced virtually identical predictions: merely transforming to a sun-centered system was insufficient by itself to produce better tables. By the same token, errors in prediction could at least initially be corrected within a geocentric framework as easily as in a sun-centered one.

In fact, Copernicus had no observational proof at all for his new blueprint.



FIREBALL, painted by Albrecht Dürer in 1492, depicts a stony meteorite that landed near Ensisheim in Alsace. Although the meteorite was arguably the most spectacular astronomical event of that year, the author contends that the discovery of the New World had a far greater effect on astronomical thought.

mastered it. Ptolemy was also the pre-eminent geographer of his age, and his maps were accepted without question.

During the 15th century, the *Almagest* was at last rediscovered: for the first time there appeared in Europe two astronomers competent enough to understand that fundamental treatise and to criticize its earlier commentators. Regiomontanus and Georg Peuerbach embarked together on an abridged translation of Ptolemy's masterpiece. After Peuerbach's death in 1461, Regiomon-

As Galileo was to say a century later, "I cannot admire enough those who accepted the heliocentric doctrine despite the evidence of their senses." Instead the Polish astronomer was guided by an aesthetic vision—a "theory pleasing to the mind."

The heliocentric viewpoint explained why Mars, Jupiter and Saturn appeared to reverse their direction of travel through the sky only when they were in opposition to the sun. In the Ptolemaic system this retrograde motion was an accident of nature, a "fact-in-itself." Copernicus made it a "reasoned fact," and the lack of an explanation in Ptolemy's system became an anomaly. Once the linkages were made, it became obvious why the retrogression for Jupiter was smaller than for Mars and why the retrogression for Saturn was smaller than for Jupiter.

Finally, Copernicus made sense of the mysterious slow displacement of the eighth sphere, the so-called precession of the equinoxes. The discovery of this motion had troubled classical cosmologists. If the earth was suspended in space, however, revolving about the sun, and spinning on its axis, it was not difficult to envision a third motion, a slow, conical displacement of that axis.

These radical innovations laid the foundations on which Galileo, Kepler and Newton built a new model of the heavens. Yet Peurbach could have made the same geometric transformation a century earlier; the Islamic cosmologists could have made it in the ninth century. Why did the new astronomy wait until the 16th century and the opening decades of the Age of Exploration?

Copernicus lived in an era of rapid change. Perhaps the most visible of those changes was Gutenberg's invention of printing from movable type. With only one known exception, all of Copernicus's documentary sources were printed books. And once his heliocentric cosmology was written down, it was printed in an edition of perhaps 400 copies, guaranteeing wide distribution and ongoing discussion of his ideas.

Then there was the Reformation. Copernicus was a canon in a Catholic cathedral, whereas the young pupil who persuaded him to allow his *De revolutionibus orbium coelestium* to be printed was a Protestant from Wittenberg, the hub of Lutheran activity. It was a time of religious upheaval, when many traditional ideas were under challenge.

But even more to the point, Copernicus lived in an age when courageous seamen were rewriting the time-honored geography of Ptolemy. Copernicus

was a student at Cracow when Columbus made his first voyage. News of these discoveries came quickly to Cracow, and to this day the Jagiellonian University preserves the oldest known globe showing the New World. Even if Copernicus had left before the news arrived, he surely heard it soon thereafter while he was pursuing graduate studies in Italy.

The Alexandrian astronomer was probably even better known for his geography than for the geocentric cosmology that bears his name. His *Geography*, written in the second century A.D., left a crucial legacy to cartographers in its instructions for map projections. Reworking information sorted out from travelers' reports and from his predecessor, Marinus of Tyre, Ptolemy had assembled his best estimates of the latitudes and longitudes of locations in the then-known world. These, in turn, became the basis of spectacular atlases eventually published in the 1480s. But by the early 1500s his reputation was fast eroding. Although Columbus had believed himself to be following the old geography, his landing in the "Indies" challenged accepted maps. And when it became clear that he had indeed discovered a new continent, the classical globe was clearly obsolete. If Ptolemy's geography had fallen by the wayside, could not his cosmology also be questioned?

The defects Regiomontanus saw in classical astronomy for the most part went uncorrected by Copernicus. Yet the heliocentric blueprint was the single most essential step for the ultimate reform of astronomy. It offered a wrenching realignment of human thought, and it paved the way for the brilliant technical achievements of Kepler and Galileo.

Copernicus's *De revolutionibus* was published in Nuremberg in 1543, in a world already prepared for change. In 1566 the Basel publisher Henricpetri issued a second edition of the work. Among those who obtained the reprint was Thomas Digges, who became the first English astronomer to convert to the new cosmology. Above the title on his copy he wrote, "*Vulgi opinio error*," "the common opinion is wrong," meaning that he no longer accepted the time-honored notion that the earth was fixed at the center of the universe.

In offering an English translation of its key cosmological passages, Digges wrote, "I thought it convenient to publish this, to the ende such noble English minds (as delight to reache above the baser sort of men) might not be altogether defrauded of so noble a part of

Philosophy." He appended a magnificent heliocentric diagram to his presentation, which contained a novel feature: no longer were the stars fixed to a distant shell, but they were spread out toward infinity. "And therefore," he concluded, "immovable." Presented in 1576, this model was a mind-boggling conception, an astonishing step from the closed world of the ancients toward today's vast universe.

Digges and several of his contemporaries, including Kepler's teacher, Michael Maestlin, searched hard for empirical ways to confirm the sun-centered planetary arrangement, but in vain. It remained a leap of faith but a compelling aesthetic vision to those who understood its unity. The faithful also had to discard the long-accepted Aristotelian physics, which predicted that birds and clouds would be left far behind as the earth spun on its axis. As another contemporary astronomer, Tycho Brahe, declared, "Copernicus nowhere offends the principles of mathematics, but he throws the earth, this lazy, sluggish body, unfit for movement, into a motion as swift as the aethereal torches [the stars]."

In the absence of observational proof, the adoption of Copernicus's blueprint required a climate of opinion willing to accept new ideas and no longer locked into hoary traditions in which ancient learning stood on a pedestal. Columbus helped to provide that new intellectual climate. His empirical evidence decisively demonstrated the incompleteness of Ptolemy's geography and so prepared the way for a revised understanding of the place of the earth in the cosmos. The old views were crumbling. By 1611 John Donne would write, "And new Philosophy calls all in doubt;/ The Element of fire is quite put out;/ The Sunne is lost, and th'earth, and no man's wit/Can well direct him where to look for it."

FURTHER READING

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