

HISTORY OF SCIENCE

THE CASE AGAINST

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Copernicus famously said that Earth revolves around the sun. But opposition to this revolutionary idea didn't come just from the religious authorities. Evidence favored a different cosmology

By Dennis Danielson and Christopher M. Graney

IN BRIEF

Copernicus's revolutionary theory that Earth travels around the sun upended more than a millennium's worth of scientific and religious wisdom.

Most scientists refused to accept this theory for many decades—even after Galileo made his epochal observations with his telescope.

Their objections were not only theological. Observational evidence supported a competing cosmology—the “geoheliocentrism” of Tycho Brahe.

Illustrations by Kirk Caldwell



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IN 2011 a team of researchers at CERN near Geneva sent a beam of neutrinos on a 730-kilometer journey to Gran Sasso National Laboratory in L'Aquila, Italy. When the researchers clocked that trip, it appeared as though the neutrinos had somehow surpassed the speed of light in a vacuum. How did the scientific community respond to this surprising result?

Almost everyone, rather than abandoning the well-established teachings of Albert Einstein—who said that nothing travels faster than light—argued that the researchers' measurements had to be wrong (as, indeed, they turned out to be).

Now imagine ourselves four centuries from now, in a future in which Einstein's ideas have been supplanted; scientists have long ago experimentally confirmed that neutrinos really can travel faster than light. How would we then, looking back on physicists today, construe their reluctance to accept the evidence? Would we conclude that 21st-century physicists were just set in their ways? Unreceptive to new ideas? Maybe motivated by nonscientific considerations—a bunch of closed-minded Einsteinians toeing a line dictated by tradition and authority?

We hope today's reluctant scientists would get a fairer shake than that. For their unwillingness to abandon apparently sound conclusions—even if these may eventually be proved wrong—is scientifically reasonable, not merely a sign of stiff-necked prejudice.

Stories such as theirs are not uncommon in the history of science. Astronomers in the

19th century, assuming that the Milky Way galaxy constituted the entire universe, examined the first images of the Andromeda galaxy and justifiably believed that they were looking at a single star surrounded by a nascent solar system—not, as we now know, a distant collection of perhaps a trillion stars. Similarly, Einstein was sure that the universe was static, and so he introduced into his equations a cosmological constant that would keep it that way. Both assumptions were reasonable. Both were wrong. As David Kaiser of the Massachusetts Institute of Technology and Angela N. H. Creager of Princeton University argued in these pages in June 2012, it is possible to be both wrong and very productive. And everything is always clearer in hindsight.

In the case of the speeding neutrinos, of course, we have little hindsight. One famous story whose end we do know, however, is that of Nicolaus Copernicus and his theory of “heliocentrism,” the claim that Earth rotates daily and revolves annually around the sun, which we all accept today. The Copernican system was a direct challenge to the long-held belief, codified by second-century astronomer Ptolemy in his book the

Almagest, that the sun, moon and stars rotate around a fixed Earth at the center of the universe.

Copernicus proposed his revolutionary ideas in 1543 in his book *De Revolutionibus Orbium Coelestium*, which many scientists then read, admired, annotated and used for improving their astronomical predictions. Yet even by 1600, 57 years later, no more than a dozen serious astronomers had given up belief in an unmoving Earth. Most scientists continued to prefer the more commonsense geocentrism we ourselves still appear to endorse when we talk, for example, about the sun rising and setting.

This cosmological logjam is sometimes presented as having been held together by prejudice and broken by Galileo when he assembled a telescope in 1609 and started using it to observe the stars, moon and planets. Neither is true. **For a long time after 1609, astronomers still had compelling scientific reasons to doubt Copernicus. Their tale offers a particularly striking illustration of the good reasons that researchers can have for resisting revolutionary ideas—even ones that turn out, in the end, to be spectacularly correct.**

BRAHE'S NEW COSMOLOGY

A PARTICULARLY POWERFUL wellspring of doubt came courtesy of Danish astronomer Tycho Brahe, who in 1588 proposed a different kind of geocentric system [see box at right]. This new “geoheliocentric” cosmology had two major advantages going for it: it squared with deep intuitions about how the world appeared to behave, and it fit the available data better than Copernicus’s system did.

Brahe was a towering figure. He ran a huge research program with a castlelike observatory, a NASA-like budget, and the finest instruments and best assistants money could buy. It was Brahe’s data on Mars that Johannes Kepler, an assistant of Brahe’s, would eventually use to work out the elliptical nature of planetary motion. Harvard University historian Owen Gingerich often illustrates Brahe’s importance with a mid-17th-century compilation by Albert Curtius of all astronomical data gathered since antiquity: the great bulk of two millennia’s worth of data came from Brahe.

This supremely accomplished astronomer had been impressed by the elegance of the Copernican system. Yet he was bothered by certain aspects of it. One thing that unsettled him was the lack of a physical explanation for what could make Earth move. (Brahe lived more than a century before the invention of Newtonian physics provided just such an explanation.) The size of Earth was known reasonably well, and the weight of a sphere of rock and dirt thousands of kilometers in diameter was clearly huge. What could power such a body around the sun, when it was difficult just to pull a loaded wagon down the street?

In contrast, the motion of celestial bodies such as stars and planets was easy to explain—astronomers since the time of Aristotle had postulated that celestial bodies were made of a special aethereal substance that was not found on Earth. This substance had a natural tendency toward rapid circular motion, just as a wagon had a natural tendency to come to a halt if not pulled vigorously. Brahe said that the Copernican system “expertly and completely circumvents all that is superfluous or discordant in the system of Ptolemy.... Yet it ascribes to the earth, that hulking, lazy body, unfit for motion, a motion as quick as that of the aethereal torches.” In this regard, ancient astronomers had something in common with modern astronomers, who, to explain what they see, postulate that much of the universe is composed of “dark

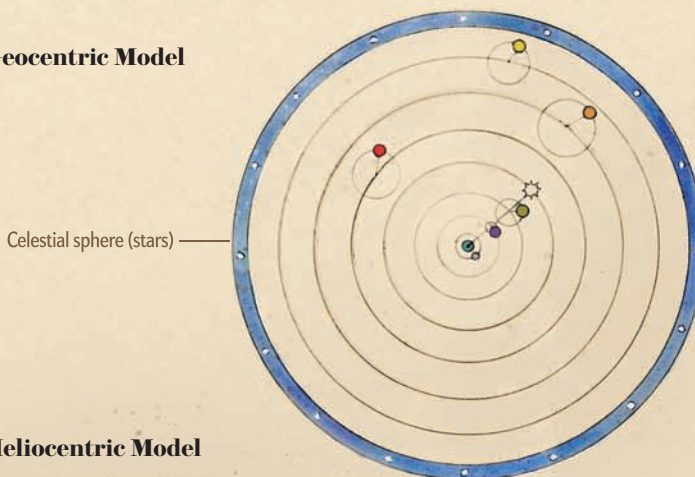
ANCIENT COSMOLOGIES

The Cosmos Three Ways

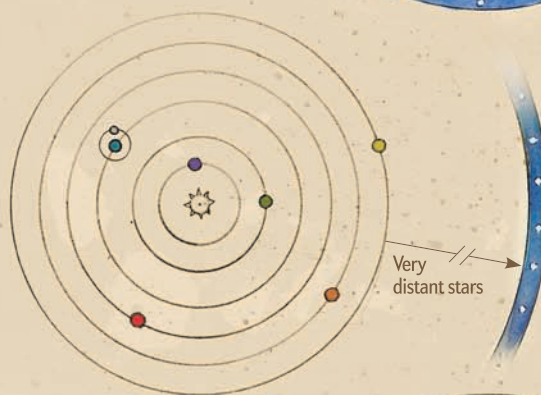
Seventeenth-century astronomers had three models for the universe. The geocentric model featured an unmoving Earth circled by the sun, moon, planets and stars. Astronomers accounted for the retrograde motion of the planets with “epicycles,” smaller loops added to the main orbits. Nicolaus Copernicus’s heliocentric universe appeared simpler, but it presented new conceptual problems—stars had to be unthinkably distant, for example. Tycho Brahe’s geoheliocentric model split the difference—the sun, moon and stars orbited Earth, the planets orbited the sun, and the stars came back close.



Geocentric Model



Heliocentric Model



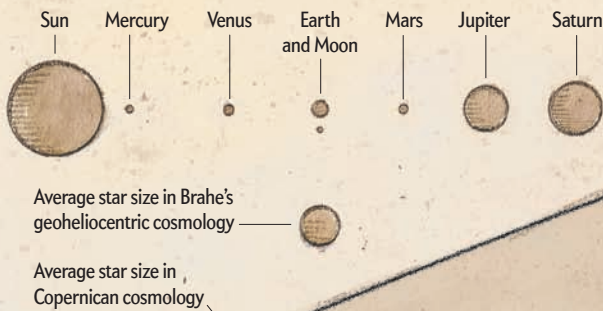
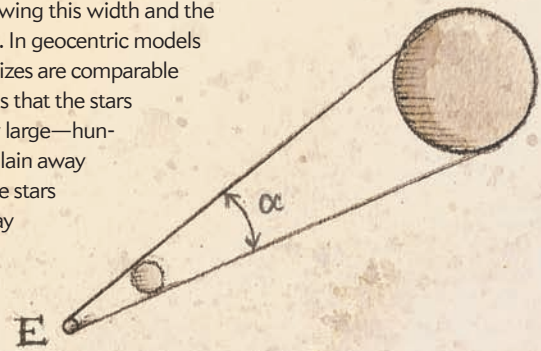
Geoheliocentric Model



Planets and orbits not to scale

The Problem with Star Sizes

The most devastating argument against the Copernican universe was the star size problem. When we look at a star in the sky, it appears to have a small, fixed width. Knowing this width and the distance to the star, simple geometry reveals how big the star is (*right*). In geocentric models of the universe, the stars lie just beyond the planets, implying that star sizes are comparable to that of the sun (*below*). But Copernicus's heliocentric theory demands that the stars be extremely far away. This in turn implies that they should be absurdly large—hundreds of times bigger than the sun (*bottom*). Copernicans could not explain away the anomalous data without appeals to divine intervention. In reality, the stars are far away, but their apparent width is an illusion, an artifact of the way light behaves as it enters a pupil or telescope—behavior that scientists would not understand for another 200 years.



Relative sizes as calculated by Tycho Brahe

matter” or “dark energy” that is unlike anything we know.

Another thing that bothered Brahe were the stars in the Copernican system. Ptolemy said the sphere of the stars is “immeasurably large” because we can detect no diurnal parallax in them—no noticeable alterations in their positions or appearances caused by the changing angles and distances between an Earth-bound observer and those stars as they pass from the horizon, to overhead, to the horizon. The corollary of this observation is that the diameter of Earth is as nothing compared with stellar distances; Earth is “as a point,” Ptolemy wrote.

Copernicus knew, however, that we could not even detect *annual* parallax—changes in the relative positions of stars caused by the movement of Earth in its orbit. If Earth really was revolving around the sun, the absence of annual parallax would imply that the diameter of its orbit (Copernicus called it the *orbis magnus*) was itself as nothing, “as a point,” compared with stellar distances.

The size of the universe then became a whole new—and almost impossible to believe—kind of “immeasurably large.”

Moreover, as Brahe well knew, the Copernican proposal had big implications not only for the size of the universe but also for the size of individual stars. **When we look up at the night sky, individual stars appear to have fixed widths, which both Ptolemy and Brahe measured. We now know that the distant stars are effectively point sources of light, and these apparent widths are an artifact of the passage of light waves through a circular aperture such as a telescope or an iris.**

Yet at the time, astronomers knew nothing of the wave nature of light. **Brahe used simple geometry to calculate that if the stars were to lie at Copernican distances, then they would have to have a width comparable to that of the *orbis magnus*.** Even the smallest star would utterly dwarf the sun, just as a grapefruit dwarfs the period at the end of this sentence. That, too, was

hugely hard to believe—Brahe said such titanic stars were absurd. As historian Albert Van Helden puts it, Brahe’s “logic was impeccable; his measurements above reproach. A Copernican simply had to accept the results of this argument.”

Rather than give up their theory in the face of seemingly incontrovertible physical evidence, Copernicans were forced to appeal to divine omnipotence. “These things that vulgar sorts see as absurd at first glance are not easily charged with absurdity, for in fact divine Sapience and Majesty are far greater than they understand,” wrote Copernican Christoph Rothmann in a letter to Brahe. “Grant the vastness of the Universe and the sizes of the stars to be as great as you like—these will still bear no proportion to the infinite Creator. It reckons that the greater the king, so much greater and larger the palace befitting his majesty. So how great a palace do you reckon is fitting to GOD?”

Unswayed by arguments such as this, Brahe proposed his own system: the sun,

moon and stars circle an immobile Earth, as in the Ptolemaic system, while the planets circle the sun, as in the Copernican system [see box on page 75]. This “Tychonic” system retained the advantages of geocentrism. With it there was no motion of the hulking, lazy Earth to explain. Neither was there any missing annual parallax demanding vastly distant, and giant, stars—the stars in Brahe’s system lay just beyond the planets and were quite reasonably sized. Yet so far as the planets were concerned, the Tychonic system and the Copernican system were mathematically identical. Thus, Brahe’s system also retained the Copernican mathematical elegance that Brahe thought circumvented all that was superfluous or discordant in Ptolemy’s system.

When Galileo began to view the heavens with his telescope, he made a number of findings that directly contradicted Ptolemy’s ancient cosmology. He saw that Jupiter had moons, proving that the universe could harbor more than one center of motion. He also observed the phases of Venus, showing that it circled the sun. These findings were not, however, understood as proof that Earth revolves around the sun because they were fully compatible with the Tychonic system.

THE 200-YEAR ARGUMENT

IN THE MIDDLE OF THE 1600S, well after the deaths of pioneers such as Copernicus, Brahe and Galileo, Italian astronomer Giovanni Battista Riccioli published an encyclopedic assessment of cosmological options that he called (after Ptolemy’s great work) the *Almagestum Novum*. Riccioli weighed many arguments for and against the Copernican system, arguments dealing with matters of astronomy, physics and religion. But Riccioli judged that two main arguments tipped the balance decisively against Copernicus. Both were based on scientific objections. Both were rooted in Brahe’s ideas. Neither would be answered decisively until some hundreds of years later.

One argument was based on the inability to detect certain effects that Riccioli said a rotating planet *should* produce in projectiles and falling bodies. Brahe had felt that a rotating Earth should deflect a projectile away from a straight path. Yet these deflections would not be observed until the 19th century, when French scientist Gaspard-Gustave de Coriolis worked out a full mathematical description of such effects.

The other argument was the one Brahe had made about star size, which Riccioli

Rather than give up their theory in the face of seemingly incontrovertible evidence, Copernicans were forced to appeal to divine omnipotence.

updated with telescopic observations. (Brahe had worked without a telescope.) Having designed a repeatable procedure for measuring the diameters of stars, he found that stars looked smaller than Brahe thought. Yet the telescope also increased the sensitivity to annual parallax, which still had not been detected, implying that the stars had to be even farther away than Brahe had assumed. The net effect was that stars still had to be every bit as titanic as Brahe had said.

Riccioli complained about the Copernicans appealing to divine omnipotence to get around this scientific problem. A Jesuit priest, Riccioli could hardly deny the power of God. But still he rejected this approach, saying, “Even if this falsehood cannot be refuted, nevertheless it cannot satisfy the more prudent men.”

The acceptance of Copernicanism was thus held back by a lack of hard scientific evidence to confirm its almost incredible claims about cosmic and stellar magnitudes. In 1674 Robert Hooke, curator of experiments for the British Royal Society, admitted, “Whether the Earth move or stand still hath been a problem, that since Copernicus revived it, hath much exercised the wits of our best modern astronomers and philoso-

phers, amongst which notwithstanding there hath not been any one who hath found out a certain manifestation either of the one or the other.”

By Hooke’s time a growing majority of scientists accepted Copernicanism, although, to a degree, they still did so in the face of scientific difficulties. Nobody convincingly recorded the annual stellar parallax until Friedrich Bessel did it in 1838. Around that same time, George Airy produced the first full theoretical explanation for why stars appear to be wider than they are, and Ferdinand Reich first successfully detected the deflection of falling bodies induced by Earth’s rotation. Also, of course, Isaac Newton’s physics—which did not work with Brahe’s system—had long since provided an explanation of how Brahe’s “hulking, lazy” Earth could move.

Back in Galileo’s and Riccioli’s day, however, those opposed to Copernicanism had some quite respectable, coherent, observationally based science on their side. They were eventually proved wrong, but that did not make them bad scientists. In fact, rigorously disproving the strong arguments of others was and is part of the challenge, as well as part of the fun, of doing science. ■

MORE TO EXPLORE

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