Truth in Science: Proof, Persuasion, and the Galileo Affair

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In 1616 in a letter destined for Galileo, Cardinal Roberto Bellarmine (the leading Catholic theologian of his day) expressed his doubts about finding evidence for a moving earth. Would the annual stellar parallax or the Foucault pendulum have convinced him? The historical setting explored in this essay suggests that the cardinal would not have been swayed by these modern "proofs" of the heliocentric cosmology, even though they are convincing to us today because in the meantime, we have the advantage of a Newtonian framework. What passes today for truth in science is a comprehensive system of coherencies supported more by persuasion than "proofs."

What kind of evidence convinced Galileo and Kepler that the Copernican system was the correct, physically real description of our universe, and yet failed to convince Bellarmine?

On April 12, 1615, Cardinal Roberto Bellarmine, the leading Catholic theologian, wrote an often-quoted letter to Paolo Antonio Foscarini, a Carmelite monk from Naples who had published a tract defending the Copernican system. Bellarmine's letter, which was obviously intended as much for Galileo as for Foscarini, opened on a conciliatory note:

> For to say that assuming the earth moves and the sun stands still saves all the appearances better than eccentrics and epicycles is to speak well. … But to affirm that the sun is *really* fixed in the center of the heavens and that the earth revolves very swiftly around the sun is a dangerous thing, not only irritating the theologians and philosophers, but by injuring our holy faith and making the sacred scripture false.[1]

Bellarmine made very clear that he was unwilling to concede the motion of the earth in the absence of an apodictic proof when he added:

> If there were a true demonstration, then it would be necessary to be very careful in explaining Scriptures that seemed contrary, but I do not think there is any such demonstration, since none has been shown to me. To demonstrate that the appearances are saved by assuming that the sun is at the center is not the same thing as to demonstrate that *in fact* the sun is in the center and the earth in the heavens.[2]

Bellarmine's letter sets the stage for a challenging inquiry: What kind of evidence convinced Galileo and Kepler that the Copernican system was the correct, physically real description of our universe, and yet failed to convince Bellarmine? What would it have taken to convince Bellarmine? For example, most astronomy textbooks today list the Foucault pendulum as the proof of the earth's rotation, and the annual stellar parallax as the proof of the earth's yearly revolution around the sun. Would these evidences have converted Bellarmine to the Copernican doctrine, and if not (as I shall argue), why not? Framing the question in these terms will enable us to distinguish between proof and persuasion, and to gain some insight into the matter of truth in science.

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Copernicus himself does not state directly what induced him to work out the heliocentric arrangement, apart from some rather vague dissatisfaction with his perceived inelegance of the traditional geocentric pattern. But Copernicus was nothing, if not a unifier. In the Ptolemaic astronomy, each planet was more or less its own independent entity. True, they could be stacked one after another, producing a system of sorts, but their motions were each independent. The result, Copernicus wrote in the preface to his book, was like a monster composed of spare parts: a head from here, the feet from there, the arms from yet another creature. Each planet had a main circle and a subsidiary circle, the so-called epicycle. Copernicus discovered that he could eliminate one circle from each set by combining them all into a unified system, and when he did this, something almost magical happened. Mercury, the swiftest planet, circled closer to the sun than any other planet. Lethargic Saturn automatically circled farthest from the sun, and the other planets fell into place in between, arranged in distance by their periods of revolution.

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His monumental treatise, *De revolutionibus*, was published in the year he died, 1543. In chapter 10 of Book I, Copernicus summed up his aesthetic vision: "In no other way do we find a wonderful commensurability and a sure harmonious connection between the size of the orbit and the planet's period."[3] It is the most soaring cosmological passage in his entire book. The key word is commensurability, the translation of Copernicus' *symmetria* (literally *syn* = common and *metria* = measure). The common measure was the earth-sun distance, which provided the measuring rod for the entire system.

Once this heliocentric unification was accomplished, the system showed other advantages. There was, e.g., the curious fact that whenever Mars or Jupiter or Saturn went into its so-called retrograde motion, the planet was always directly opposite the sun in the sky. As Gemma Frisius was to describe it soon after the publication of *De revolutionibus*, from antiquity this had been merely a "fact in itself," but in the Copernican system, it became a reasoned fact.[4]

In the cosmological chapter 10 of Book I, Copernicus noted that the heliocentric arrangement finally provided a natural explanation of this otherwise unexplained coincidence. He mentioned as well that it explained why the retrograde motion of Jupiter was smaller than that of Mars, and why that of Saturn was still smaller. As Copernicus's only student and disciple, Georg Joachim Rheticus put it:

> All these phenomena appear to be linked most nobly together, as by a golden chain; and each of the planets, by its position and order and every inequality of its motion, bears witness that the earth moves and that we who dwell upon the globe of the earth, instead of accepting its changes of position, believe that the planets wander in all sorts of motions of their own.[5]

Yet these explanations were not enough to win the day. Astronomers of the sixteenth century belonged to a long tradition that had distinguished astronomy from physics. At the universities, astronomy was taught as part of the quadrivium, the four advanced topics of the seven liberal arts. The astronomer instructed his students in the celestial circles, the geometry of planetary mechanisms, and the calculation of positions required for making up horoscopes. However, the physical nature of the heavens was described not in Aristotle's *De coelo,* but in his *Metaphysica*, and that text belonged to the philosophy professor. The distinction was clearly stated in the anonymous "Introduction to the Reader," added to *De revolutionibus* by the Lutheran clergyman Andreas Osiander, who had served as proofreader for the publication. He wrote (and I paraphrase):

> You may be worried that all of liberal arts will be thrown into confusion by the hypotheses in this book, but not to worry. It is the astronomer's task to make careful observations, and then form hypotheses so that the positions of the planets can be calculated for any time. But these hypotheses need not be true, not even probable. A philosopher will seek after truth, but an astronomer will just take what is simplest. And neither will find truth unless it has been divinely revealed to him.[6]

Osiander has been much castigated for having had the presumption to preface Copernicus' treatise in this manner, but he was preaching to the choir in what he added. The Protestants in Wittenberg endorsed the interpretation, and surely would have invented it if Osiander had not already clearly stated it. The Catholics likewise fell in line, as Bellarmine's opinion reveals. In the opening lines of his letter to Foscarini, he stated: "First, I say that it appears to me that your Reverence and Signor Galilei did prudently to content yourselves with speaking hypothetically, as I

> *Tycho Brahe, the second most distinguished astronomer of the sixteenth century, … had no problem with the Copernican system as a mathematical construction, but he believed that Copernicus fell short with respect to physics.*

have always supposed Copernicus did."[7] When Galileo was negotiating with Cosimo de Medici for his new position in the Florentine court, he was comparatively indifferent about his salary, but he was insistent on the title: Mathematician *and Philosopher* to the Grand Duke. In other words, he wanted to be credentialed not just to make mathematical astronomical models or hypotheses, but he intended to speak authoritatively about how the universe was really constructed.

Along these same lines Tycho Brahe, the second most distinguished astronomer of the sixteenth century, remarked:

> This innovation expertly and completely circumvents all that is superfluous or discordant in the system of Ptolemy. On no point does it offend the principles of mathematics. Yet is ascribes to the earth, that hulking, lazy body, unfit for motion, a motion as fast as the aethereal torches, and a triple motion at that.[8]

Thus Tycho had no problem with the Copernican system as a mathematical construction, but he believed that Copernicus fell short with respect to physics. Copernicus had attempted to describe the earth's motion as "natural" in a sort of Aristotelian manner, but he was not persuasive. It is interesting to notice that Tycho always put physics first when he criticized the Copernican doctrine, saying that it went against both physics and holy Scripture. Surely if the earth were spinning at a dizzying speed, stones thrown straight up would land far away. And if the earth was wheeling around the sun, how could it keep the moon in tow? These consequences would require new physics, which was not anywhere in sight. But it was not just a problem with the physics. Philosophers and churchmen surely felt threatened by a potential challenge to traditional sacred geography. Where would heaven and hell be found in the new picture? And did not Psalm 104 say that the Lord God laid the foundation of the earth, that it would not be moved forever? Surely the task of reading the evidence was confused, scientifically as well as culturally.

Nevertheless Tycho, being a perceptive and highly motivated scientist, set out to distinguish observationally between the Ptolemaic and Copernican arrangements. He knew that in the Ptolemaic system, the epicycle of Mars always lay beyond the sun, whereas in the Copernican arrangement, Mars at its closest was only half that distance away. Because Tycho, like Copernicus and Ptolemy before him, accepted an erroneously small earth-sun distance (in fact, too small by a factor of 20), he believed that he had a chance to triangulate the distance to Mars using as his baseline the difference in viewpoint between an evening and a morning observation, the so-called diurnal parallax. We know today that this parallax is actually too tiny for naked-eye visibility, though if the solar distance had been as small as he believed, he could just have managed to detect it.

Tycho's quest for the parallax of Mars was a driving factor during the golden years at his Uraniborg observatory in the 1580s. At first, when he found no parallax, he believed that the Copernican arrangement had to be rejected since Mars seemed, even at it closest approach, to be farther than the sun. But he continued his assault on the problem and two years later discovered that he had to correct for differential refraction of the earth's atmosphere. As it subsequently worked out, his refraction table had an error exactly equal to the effect he was seeking, which led to a spurious result for the distance to Mars. Believing that he had proved that Mars came closer than the sun, he then declared against the Ptolemaic arrangement. Interestingly, however, he did not endorse the Copernican system, but rather, he adopted his own geoheliocentric scheme. In the Tychonic system, the earth remained fixed in the center of the cosmos, with the two great luminaries cycling around it. In turn, the sun carried a retinue of planets around it. These were spaced with intervals exactly as in the Copernican system, except that the fixed earth broke the pattern, as may be seen in the detail from the frontispiece of Riccioli's *Almagestum novum* (see Figure 1).

Consequently, by the 1590s, there was no unambiguous evidence in favor of a moving earth. Why, then, did Kepler and Galileo both opt for the Copernican arrangement at that time, when the choices were so confused? The sole observational distinction between the Ptolemaic and Copernican blueprints resided in Tycho's claim about the parallax of Mars, which remained unpublished until he printed an unsubstantiated remark in his 1596 volume of letters. As Galileo would say, he could not sufficiently admire those who had embraced the heliocentric arrangement *despite* the violence to their own senses.[9] As for the advantages pointed out by Copernicus, most of these inhered equally in the Tychonic arrangement.

Nevertheless, what was perhaps the most attractive aesthetic feature of the Copernican arrangement was shattered by Tycho's alternative. This was the sheer beauty of all the planets arrayed around the bright central sun, with the planets naturally ranked according to their periods of revolution. Copernicus wrote:

> In the center of all rests the sun. For in this most beautiful temple, could we place this luminary in any better position from which it can light up the whole at the same time? For the sun is rightly called by some the lantern of the universe, by others the Mind, and by still others its Ruler. … So the sun, sitting as upon a royal throne, governs the family of planets that wheel around it.[10]

In placing his paean to the sun at this central juncture in his soaring cosmological chapter, Copernicus must have understood that this would necessarily be the crux of his argument and the key to the new physics. Traditionally the driving power for the planets had come from outside, from the prime mover that spun the entire system in its swift daily motion, with each successively further inward sphere lagging more and more behind, so that the moon circled the earth in about 24½ hours. Hence, compared to the starry background, the moon appeared to move the fastest, though in reality it was the tardiest. It was all tied into a very neat package with Aristotle's remark that it was the love of God that kept the prime mover spinning, so from the beginning the arrangement of the heavens had theological overtones.

Now to anyone who thought in deeply physical terms, as both Kepler and Galileo did, an alternative source of motion would be required for the Copernican system, because in it the stars, in the outermost sphere, were fixed. Somehow the sun had to offer this motive power, and

Figure 1. Tycho's geo-heliocentric system, with a fixed, central earth, hangs more weightily in Urania's balance than Copernicus' heliocentric system in this detail from the frontispiece of Giovanni Battista Riccioli's *Almagestum novum* (Bologna, 1651).

In the Ptolemaic arrangement, the epicycle of Venus always lay between the earth and the sun. So if the planet shone by reflected sunlight, it could never show a full phase. … Galileo … confirmed that [Venus] displayed the entire gamut of phases …, and therefore it had to go around the sun …

Copernicus had hinted at it with his statement that "the sun, sitting as upon a royal throne, governs the family of planets circling round it." In this regard, the Tychonic arrangement was a very mixed bag. For Tycho, the stars still wheeled around a centrally fixed earth each day, but how would the sun in turn control the planets? As a unified physical system, it did not quite make it. In other words, it was simply not persuasive.

Neither Kepler nor Galileo tells us precisely why he became a Copernican. Kepler always justified his choice in terms of the Holy Trinity, but this hardly could have been the starting point. Surely it was the aesthetic appeal that arrested their attention, the sheer geometrical beauty of an arrangement that included the distant promise of a new physics. And it was Kepler who first glimpsed this new physics when he discovered not only that Mars moved in an orbit with the sun at one focus of the ellipse—that focal point is far more important than the elliptical shape itself—and also that the earth in its orbit had the property of speeding up when it was closer to the sun. I hasten to point out that this momentous physical discovery was not present in *De revolutionibus* and had to be teased out through Kepler's insight into the nature of the problem. These discoveries were made by 1605, though publication of Kepler's *Astronomia nova* was delayed until 1609.

It was then that Galileo turned his optical tube, not yet named the telescope, to the heavens. In the following January, he found the four bright satellites of Jupiter, and by March 1610, his *Sidereus nuncius* was in print. And there he allowed himself a Copernican remark. He wrote:

> We have here a splendid argument for taking away the scruples of those who are so disturbed in the Copernican system by the attendance of the moon around the earth while both complete the annual orbit around the sun that they conclude this system must be overthrown as impossible. For our vision offers us four stars wandering around Jupiter while all together traverse a great circle around the sun.[11]

I would suggest that this realization that the earth could likewise keep the moon in tow was absolutely central to Galileo's conversion to a strong, enthusiastic heliocentrism. Later, when he had determined the periods of the circumjovials, he realized that the innermost satellite was the quickest to round Jupiter, the outer satellite was the slowest, and so on. Behold! A miniature Copernican system! This could not but help authenticate the Copernican arrangement, and Galileo presented it as such in his *Dialogo* of 1632, the book that got him into trouble with the Inquisition.

But meanwhile, toward the end of 1610, Galileo made another discovery that bore directly on the viability of the Ptolemaic system. In the Ptolemaic arrangement, the epicycle of Venus always lay between the earth and the sun. So if the planet shone by reflected sunlight, it could never show a full phase. By late December, Galileo had confirmed that "the mother of loves" (as he encoded her) displayed the entire gamut of phases from full to crescent, and therefore it had to go around the sun as in the Copernican arrangement (See Figure 2).

Was this the brilliant confirmation of a Copernican prediction? A. D. White, in his infamous *A History of the Warfare of Science with Theology in Christendom* (published in 1896) had it so. The so-called Galileo affair played a central role in his account, introduced by the following wholly fictitious episode:

> Herein was fulfilled one of the most touching of prophecies. Years before, the opponents of Copernicus had said to him, "If your doctrines were true, Venus would show phases like the moon." Copernicus answered: "You are right; I know not what to say; but God is good, and will in time find an answer to this objection." The God-given answer came when, in 1611, the rude telescope of Galileo showed the phases of Venus.[12]

Copernicus had, in fact, mentioned the possible phases of Venus in the opening of chapter 10. The context was that those who held that Venus was a dark body, shining by reflected light, argued that its interposition between us and the sun would diminish the sun's light, and since this was never observed, Venus must lie farther than the sun. That was it, nothing more. Copernicus' passing remark may have provided the basis for a few comments made by the English astronomer John Keill in a Latin textbook he published in 1718.[13] Thus the seeds for the myth were planted. With each retelling the story was more richly embroidered, reaching its apotheosis with White's well-embellished vignette.

Galileo indirectly informed Kepler of the phases of Venus, and Kepler promptly published the news. Galileo himself publicized his discovery at the end of his book on sunspots, printed in 1613. The Ptolemaic system thus was destined for the scrapheap; this was the situation in 1615 when Bellarmine wrote his letter to Foscarini. Recall what Bellarmine said:

> To demonstrate that the appearances are saved by assuming that the sun is at the center is not the same thing as to demonstrate that *in fact* the sun is in the center and the earth in the heavens.[14]

In other words, the Copernican system very nicely explained the appearances, the phases of Venus, but this explanation did not guarantee that the sun was fixed in the center. Why not? Because Tycho's geo-heliocentric arrangement also had Venus going around the sun, albeit a mobile sun, and therefore the Tychonic system explained the Cytherian phases equally well.

Earlier I asked the question, what would it have taken to persuade Bellarmine that the earth moved? Suppose that the Foucault pendulum had been set in motion with its shifting orientation of the swing. What would Bellarmine have made of that? Why not suppose that the influences of the whirling stars caused the plane of oscillation of the pendulum to rotate? This is not a frivolous way out, for it is the general relativistic explanation. And what if the annual stellar parallax had been found? Why not let each star have its own tiny epicycle, cycling around each year? I think such an explanation would have naturally occurred to Bellarmine. You may immediately think of Ockham's razor, that the simpler explanation would surely prevail. But remember that Ockham's razor is not a law of physics. It is an element of rhetoric, in the toolkit of persuasion. In the absence of new physics, a myriad epicycles might not have been an obstacle to keeping the earth safely fixed.

Also, the absence of an observed stellar parallax worked seriously against the acceptance of the Copernican system throughout the seventeenth century. Copernicus himself recognized the problem, and he addressed it in the final sentences of his cosmological chapter 10. The parallax was not seen because the stars were so far away. "So vast, without any question, is the Divine Handiwork of the Almighty Creator."[15] When in 1616 Copernicus' book was placed on the *Index of Prohibited Books* "until corrected," one of the corrections ultimately made was to excise that sentence. It was not that the censors thought the argument was faulty. Rather, they feared that Copernicus made it read as if that was the way God actually had created the cosmos.

In 1674, Robert Hooke summarized the state of play of the arguments. The problem of the earth's mobility, he wrote, "hath much exercised the Wits of our best modern Astronomers and Philosophers, amongst which notwithstanding there hath not been any one who hath found out a certain manifestation either of the one or

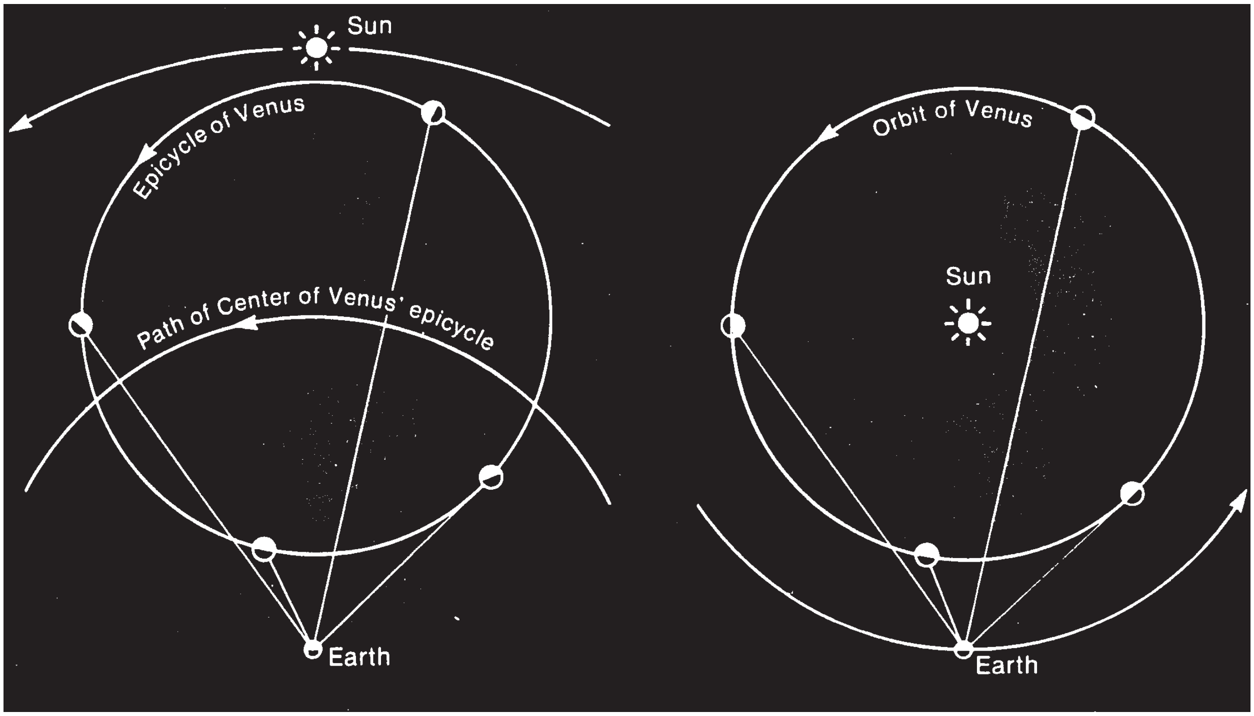

Figure. 2. In the Ptolemaic system (left), Venus rides on its epicycle always between the earth and sun, so that it would never be possible to see the fully illuminated face of Venus. In the Copernican system (right), Venus displays an entire set of phases like the moon.

Without the new [Newtonian] physics, Galileo could scarcely have found a convincing apodictic proof of the earth's motion. Yet he paved the way for the acceptance of the Copernican idea by changing the very nature of science. He argued for a coherent point of view … and … made it intellectually respectable to believe in a moving planet Earth.

the other Doctrine."[16] Thus, he suggested, people let their prejudices reign. Some "have been instructed in the Ptolemaik or Tichonick System, and by the Authority of their Tutors, over-awed into a belief, if not a veneration thereof: Whence for the most part such persons will not indure to hear Arguments against it, and if they do, 'tis only to find Answers to confute them."[17]

Hooke confirms what I have been arguing, namely that the best and most persuasive reason for adopting the Copernican system up through his time was the proportion and harmony of the world. He wrote:

> On the other side, some out of a contradicting nature to their Tutors; others, by as great a prejudice of institution; and some few others upon better reasoned grounds, from the proportion and harmony of the World, cannot but embrace the Copernican Arguments.[18]

But Hooke allows:

> What way of demonstration have we that the frame and constitution of the World is so harmonious according to our notion of its harmony, as we suppose? Is there not a possibility that things may be otherwise? nay, is there not something of a probability? may not the Sun move as Ticho supposes, and that the Planets make their Revolutions about it whilst the Earth stands still, and by its magnetism attracts the Sun and so keeps him moving about it?[19]

There is needed, Hooke declares, an *experimentum crucis* to decide between the Copernican and Tychonic systems, and this he proposed to do with a careful measurement of the annual stellar parallax. I will not describe Hooke's attempt, which used what might well be described as the first major instrumentation set up for a single purpose, but let me merely state that Hooke thought he had confirmed the effect and therefore the Copernican arrangement.

While it soon became apparent that Hooke's handful of observations had not established a convincing annual parallax, further attempts led James Bradley to the discovery of stellar aberration, published in 1728.[20] This phenomenon, easily explained in terms of a moving earth, did not have the historical cachet that the quest for parallax had. Hence, ironically, what persuaded the Catholic Church to take Copernicus' book off the *Index* was ultimately a false claim for the discovery of an annual stellar parallax. The new edition of the *Index* appearing in 1835 finally omitted *De revolutionibus*, three years before a convincing stellar parallax observation was at last published.[21]

Why is it that we today find the so-called proofs of the earth's motion—the stellar parallax and the Foucault pendulum—so convincing when they could not have been guaranteed to convince Bellarmine? The answer is that the required new physics has arrived. We are post-Newtonian, and it is in the Newtonian framework that these fundamental experiments provide persuasive evidence. In fact, the Newtonian achievement was so comprehensive and coherent that the specific proofs were not needed. Thus there was no dancing in the streets after Foucault swung his famous pendulum at 2 a.m. on Wednesday morning, January 8, 1851, nor had there been grand celebrations in 1838 after Bessel had announced the successful measurement of an annual stellar parallax. The Copernican system no longer needed these demonstrations to win universal acceptance. Nor was Bradley's interpretation of aberration a watershed in belief about a moving earth, which is why his work, which came a century before Bessel's findings, seems so curiously neglected in the heroic retelling of the Copernican conquest.

Without the new physics, Galileo could scarcely have found a convincing apodictic proof of the earth's motion. Yet he paved the way for the acceptance of the Copernican idea by changing the very nature of science. He argued for a coherent point of view, with many persuasive pointers, and his *Dialogo* (the *Dialogue on the Two Great World Systems*), while not containing much new science, nevertheless made it intellectually respectable to believe in a moving planet Earth. While it would be foolhardy to claim that he changed the nature of science singlehandedly, he was surely a principal figure in the process. Today science marches on, not so much by proofs as by the persuasive coherency of its picture.

No doubt this is old stuff to epistemologists, whose business it is to probe how we understand things. But today it seems to be forgotten by two widely divergent camps. In one camp, there is—especially in America—a hard minority core of anti-evolutionists, who feel that biologists should furnish apodictic "proofs" of macro-evolution, and until that demonstration is in hand, evolution is a "mere hypothesis" that should not have a place in true science. They fail to understand that evolution offers biologists and paleontologists a coherent framework of understanding that links many wide-ranging elements, that it is persuasive, and that any critique of evolution will fall on stony ground unless it provides a more satisfactory explanation than evolution already does.

Of course, the view of the nature of science that I am proposing is a two-edged sword. There are some informed people who passionately believe that a coherent framework of understanding includes the notion of intelligent design, i.e., that a hit-and-miss pattern of mutations by itself is insufficient to explain the extraordinarily pervasive complexity of the biological world. Let me give a simple example of this dichotomy. I am grasping an apple, which I am about to drop. How can I understand what is about to happen? I can hold that God, the Sustainer of the universe, is recreating the world every moment, and that in each re-creation the apple will be slightly closer to the floor. Or, I can use Newtonian physics and calculate how long it will take for the apple to reach the floor and its velocity when it smashes onto the carpet. This calculation can be very useful, but it will not explain *why* the apple went down. As Newton himself said in the General Scholium added at the end of the second edition of his *Principia:* "This most elegant system of the sun, planets, and comets could not have arisen without the design and dominion of an intelligent and powerful being," and then a few paragraphs later, "I have not yet been able to deduce from phenomena the reason for these properties of gravity, and I do not 'feign' hypotheses."[22] In other words, Newton could accept both views of gravity, as God's action and as a measurable, predictive phenomenon. The latter view can guide a spacecraft to Saturn, but the first view cannot. Likewise the stochastic view of evolution may help us understand the seemingly capricious ordering of genes on the human chromosomes, whereas the intelligent design hypothesis, which just might be true, has yet to make any brilliant predictions.

But I stated that *two* widely divergent camps somehow fail to recognize that we come to our fundamental human understanding not by proofs but by persuasion, by the coherence of the picture we construct of the world and our place in it. The other camp is inhabited by the hard core scientists who have adopted scientism as their world view, those who believe that the world of understanding runs by proofs, and who dare those of us who are theists to prove that an intelligent and powerful being exists, with design and dominion as its brief. I cannot *prove* the existence of a designing Creator any more than I can solve the problem of evil. I am simply personally persuaded that an intentionally created universe, with one of its likely purposes the emergence of conscious and self-contemplative intelligence, makes sense to me, is satisfyingly coherent, and is persuasive.

I am reminded of the poet Robinson Jeffer's lines about truth in science:

> The mathematicians and physics men
> Have their mythology; they work alongside the truth,
> Never touching it; their equations are false.
> But the things *work*.[23]

As for me, examining the great change in the world view that took place during the so-called Scientific Revolution gives me a richer understanding of the nature of truth in science: it is an intricate process of observation, interpretation, and persuasion. Ultimately it may not be true, but, for now, it makes sense. ✦

Notes

[1]Bellarmine to Foscarini, 12 April 1615, *Opere*, 12, 171–2; abridged from *Discoveries and Opinions of Galileo,* trans. Stillman Drake (Garden City: Doubleday, 1957), 162–4. (The Galileo *Opere* cited here is the so-called National Edition, ed. Antonio Favaro [1890–1909; reprint, Florence, 1968]).

[2]Ibid.

[3]My translation from Nicolaus Copernicus, *De revolutionibus orbium coelestium* (Nuremberg, 1543), Book I, chapter 10.

[4]Reiner Gemma Frisius in Johannes Stadius, *Ephemerides novae et auctae* (Cologne, 1560), signatures b3–b3v.

[5]Georg Joachim Rheticus, *Narratio prima* (1540), trans. Edward Rosen, *Three Copernican Treatises* (New York: Octagon Books, 1971), 165.

[6]My paraphrase from Andreas Osiander, "Ad Lectorem," at the beginning of Copernicus' *De revolutionibus.*

[7]Bellarmine, to Foscarini, 12 April 1615, *Opere*, 12, 171–2.

[8]J. L. E. Dreyer, ed., *Tychonis Brahe Dani opera omnia* 4 (Copenhagen, 1913–1929), 156, lines14–18.

[9]Galileo Galilei, *Dialogue concerning the Two Chief World Systems*, trans. Stillman Drake (Berkeley: University of California Press, 1953), 328.

[10]Copernicus, *De revolutionibus orbium coelestium*.

[11]Galileo Galilei, *The Starry Messenger*, in *Discoveries and Opinions of Galileo,* trans. Stillman Drake (Garden City: Doubleday, 1957), 57.

[12]Andrew Dickson White, *A History of the Warfare of Science with Theology in Christendom* (New York: D. Appleton, 1896), 130.

[13]See Edward Rosen, "Copernicus on the Phases and the Light of the Planets," in *Copernicus and His Successors* (London: The Hambledon Press, 1995), 81–98, esp. p. 84.

[14]Bellarmine to Foscarini, 12 April 1615, *Opere*.

[15]Copernicus, *De revolutionibus orbium coelestium* at the very end of the chapter.

[16]Robert Hooke, *An Attempt to Prove the Motion of the Earth from Observations* (London, 1674), 1.

[17]Ibid., 3.

[18]Ibid.

[19]Ibid.

[20]James Bradley, "An Account of a New-Discovered Motion of the Fixed Stars," *Philosophical Transactions* 35 (1727–1728), 637–61.

[21]See Pierre-Noël Mayaud, SJ, *La Condamnation des Livres Coperniciens et sa Révocation: á la lumière de documents inédits des Congregation de l'Index et de l'Inquisition* (Rome: Editrice Pontificia Universita Gregoriana, 1997).

[22]Isaac Newton, "General Scholium," in *The Principia: A New Translation,* trans. I. Bernard Cohen and Anne Whitman (Berkeley: University of California Press, 1999), 940, 943.

[23]Robinson Jeffers, "The Great Wound," in *The Beginning and the End* (New York: Random House, 1963), 11.