

Science Fact

The Great Ptolemaic Smackdown and Down-and-Dirty Mud-Wrassle

Michael F. Flynn

History must be curved, for there is a horizon in the affairs of mankind. Beyond this horizon, events pass out of historical consciousness and into myth. Accounts are shortened, complexities sloughed off, analogous figures fused, traditions "abraded into anecdotes." Real people become culture heroes: archetypical beings performing iconic deeds. (Vansina 1985)

In oral societies this horizon lies typically at eighty years, but historical consciousness endures longer in literate societies, and the horizon may fall as far back as three centuries. Arthur, a late fifth-century war leader, had become by the time of Charlemagne the subject of an elaborate story cycle. Three centuries later, troubadours had done the same to Charlemagne himself. History had slipped over the horizon and become the stuff of legend.¹

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This suggests that *seventeenth-century history has already become myth*. Jamestown is reduced to "Pocahontas," and Massachusetts boils down to "the First Thanksgiving." And the story of how heliocentrism replaced geocentrism has become a Genesis Myth, in which a culture-hero performs iconic deeds that affirm the rightness of Our Modern World-view.

Eppur non si muove!

In "What Science Means to Me," Jerry Oltion states that the geocentric model was based on "argument from first principles," needed continual "patching" to account for new data, and owed more to dogma than to science (Oltion 2012).

So goes Legend. History begs to differ. Geocentrism was an empirical model based on observation, and lasted for two millennia because it accounted for the sensible motions of the stars. Go outside. You can watch the heavens travel in perfectly circular motions from east to west, as if each heavenly body were embedded in a framework of some "dark matter" turning around the Earth.

But (I hear you say) they aren't! They don't! Oh, yeah? Prove it!

Heliocentric Woo-woo

This isn't as easy as you may think, especially if all you have are "eyeballs and armillaries." We believe the Earth moves because we've been taught that. Most folks have no clue how to demonstrate it.²

But . . . didn't Aristarchus and the Pythagoreans propose heliocentrism in ancient times? If only they had prevailed, we might have had Real Science millennia sooner. What was their evidence?

Well, you see, Fire is nobler than earth and

the center is a nobler position. So fire has to be in the center. QED.

There are many names for this sort of thinking, but "scientific" is not one of them. Aristotle says of the Pythagoreans:

In all this they are not seeking for theories and causes to account for observed facts, but rather forcing their observations and trying to accommodate them to certain theories and opinions of their own.

—Aristotle, *On the heavens* II.13.293a

So heliocentrism, not geocentrism, was "dogma deduced from first principles." Sure, they guessed right; but if science was just lucky guesses, we'd credit Jonathon Swift with discovering the moons of Mars.

How could astronomers have been so stupid?

Heliocentrism was falsified because it entailed observations that were not in fact observed.

1. If the Earth turns, "we and the trees and houses are moved toward the east very swiftly, and so it should seem that the air and wind blow continuously and strongly from the east. . . . But the contrary appears by experience."³

2. If we shoot an arrow straight up, the earth will move to the east below it, so it should fall a good distance to the west. But the contrary is clear.

3. If the Sun were at the center of the World, heavy objects would fall toward the Sun, not to the Earth as we commonly see.

4. If the Earth were revolving around the Sun, there should be visible parallax among the fixed stars. There is none.⁴

A further objection was introduced by Giovanni Riccioli in his *Almagestum Novum*.

¹ In AD 778, a Basque war party ambushed the Carolingian rear guard (*Annales regni francorum*). Forty years later, Einhard, a minister of Charlemagne, mentioned "Roland, prefect of the Breton Marches" among those killed ("Hruodlandus Britannici limitis praefectus," *Vita karoli magni*). But by 1098, Roland the "paladin" had become the central character, the Basques had become Saracens, and a magic horn and tale of treachery had been added (*La chanson de Roland*). Compare the parallel fate of a Hopi narrative regarding a Navajo ambush (Vansina, pp. 19-20).

² Analog readers may be a partial exception. Take a moment and jot down how you would do it.

³ An ancient version of the Michelson-Morley experiment!

⁴ Based on brightness and apparent diameter, stellar distance was an incredible 73 million miles (Campanus of Novara, ca. 1250). Even so, parallax should have been visible to the naked eye. (Edward Grant, "Cosmology," in Lindberg 1978, p.292.)

5. If the Earth is rotating, objects dropped from a great height should fall east of the plumb line because they have a greater horizontal velocity. No such deflection is observed.

Today, we have answers to these (and other) objections; but those answers depend on measurements or concepts not then available, like inertia or inverse squares. For example, we could counter the first hypothesis by claiming common motion and many did. But you cannot save one unproven hypothesis by "patching" on another unproven hypothesis. (Christie, But it doesn't move! 2011)

Another fine math you've gotten us into

There were only two practical reasons for studying the heavens: to prepare calendars and to cast horoscopes. Later, oceanic navigation became important. For these, you need more than a "designated center," you need a complete mathematical model. Claudius Ptolemaeus perfected such a model with *Syntaxis Mathematica* (a.k.a. *The Almagest*)—including the method we still use today to record stellar positions. So calendars could be made, and the fates of kings predicted.

One wee problem: it conflicted with Aristotelian physics.

The Ptolemaic model was not strictly geocentric. The planets are carried by their orbs along a circular path called a *deferent*, but to account for the changes in speed that we now associate with Kepler's equal area law, the *deferent* was centered not on the Earth but on a point halfway between the Earth and an imaginary locus called an *equant*. Each planet was solved separately, so each had a *different center*. To account for retrograde motion and changes in size and brightness, planets moved on a second circle called an *epicycle* centered on the *deferent*. Unwittingly, Ptolemy seems to be goading circles to act like ellipses.

These mathematical devices really, really bugged the physicists. In Aristotelian physics all the orbs were homocentric on the Earth. The orbs were like nested ball bearings made of aether, which carried the planets within

them.⁵ There was no room for such foo-foo as epicycles; and no philosophical justification for the @#\$% equants.

The astronomers' only excuse was that their calculations worked. The physicists groused, "Sure, they work in *practice*, but do they work in *theory*?"

There was only one solution.

Astronomy was not physics!

Moderns find this hard to grasp, but the ancients did not consider astronomy a physical science. It was a specialized branch of mathematics. Except to Pythagorean woo-woos, the devices of astronomy did not imply physical existence. *Retrograde motion* was physical; but *epicycles* were merely convenient algorithms to calculate that motion.

Grains of medieval salt

After digesting Aristotle, the medievals began to eliminate parts. Bradwardine, demolished Aristotelian motion using the "new math" (fractions) and coined terms like "instantaneous motion" to explain it. Anticipating Duhem and Quine, Thomas Aquinas noted the underdetermination of science regarding astronomical models:

"The theory of eccentrics and epicycles is considered as established because thereby the sensible appearances of the heavenly movements can be explained; not, however, as if this proof were sufficient, forasmuch as some other theory might explain them."

—*Summa theologiae*, I, q.32, a.1, ad. 2⁶

That is, the same finite set of facts might be explained by different theories. The medievals knew about the Pythagorean model, and also the geo-heliocentric model of Heraclides of Pontus, which accounted for the constrained motions of Mercury and Venus by having them circle the Sun while the Sun and the other planets circled the Earth.

By the fourteenth century, astronomers had begun thinking not only in terms of mathematical devices, but of physical reality.⁷ Nicholas Oresme and later Nicholas of Cusa began to consider the possibility of a rotating earth. Using Witelo's principle of relativity,

⁵ Hence, there should be no "aether wind."

⁶ See also his *Commentary on De caelo*, II, lect. 17 (Crombie 1959) pp166 et seq.

Oresme subverted the best positive evidence for the geostationary Earth—the apparent motion of the heavens.

... one cannot demonstrate by any experience whatever that the heavens are moved with daily movement, because, regardless of whether it has been posited that the heavens, and not the earth, are so moved or that the earth and not the heavens is moved, if an observer is in the heavens and sees the earth clearly, the earth would seem to be moved; and if the observer were on the earth, the heavens would seem to be moved. (Oresme 1999)

He also showed how Scriptural references to a stationary Earth could be read. Unlike a certain Tuscan layman who later got in deep kimchee for amateur exegesis, Oresme was a pro: a theologian and bishop. If only he'd had a telescope!⁸

The medieval Church taught that naïve-literal readings should be abandoned when they conflicted with something known for certain, as St. Augustine had pointed out in Late Antiquity:

"In the Gospel we do not read that the Lord said: 'I send you the Holy Spirit so that He might teach you all about the course of the sun and the moon.' The Lord wanted to make Christians, not astronomers. You learn at school all the useful things you need to know about nature."

—*Contra Faustum manichaeum*, I:10

With the right equipment, they might have had a renaissance. Instead, they got the Renaissance.

The return of mystical woo-woo

The Italian Renaissance was a humanist reaction against Aristotelian obsessions with logic, reason, and natural philosophy. Greco-Roman art and literature were "rediscovered." Platonic mysticism was revived, along with astrology, magic, and Pythagoreanism. Natural science faltered; but since astronomy was only mathematics, it prospered.

⁸ Coincidentally, in "Quaestiones super caelo et mundo," *Analytic* (July/August 2007), he did

⁹ Hey, he was a Renaissance Man™

¹⁰ From the Dedication (Copernicus, Nicholas; Charles Wallis (trans) 1952). The Renaissance replaced the syllogism with the witty insult.

Nicholas Copernicus, a canon lawyer at Frauenberg cathedral, was a medical practitioner, financial advisor, and was once short-listed for the bishop's seat. He was also a gifted "mathematicus."⁹ But he was not a scientist in our modern sense. He made few empirical observations, instead doing new math on existing data: Peuerbach's *Epitome in Almagestum* and Gerard of Cremona's twelfth century Latin translation of the *Almagest*. He defended heliocentrism by quoting Hermes Trismegistus, "a nonexistent propagator of more woo than you pack into an articulated truck," according to Thony Christie. And he wanted to save the Platonic axiom of purely circular orbits by ridding the World of those @#\$% equants.

Cardinal Nicolaus von Schönberg and Bishop Giese urged him to publish, but he had already been satirized on the stage and dreaded the mockery of those who "on account of their natural stupidity hold the position among philosophers as drones among bees."¹⁰ *De revolutionibus* caused great excitement among mathematicians when it appeared. However, the enthusiasm quickly dried up; and for a reason that startles us Moderns.

The new system was no improvement.

The failure of Copernicanism

Folks who know only the Legend suppose the transition to heliocentrism was simply a matter of putting the center *here* instead of *there*. But it's not enough for a new model to equal the standard model; it must do better. And the Copernican model did not.

Nor were its calculations simpler. To preserve Platonic circles, Copernicus used twice as many circles as Peuerbach's then-current edition of Ptolemy! The Earth revolved around the Sun on two circles; the Moon ran on an unprecedented *double epicycle*, and Mercury librated idiosyncratically across the center of an epicycle. Try explaining *that* with a theory of universal gravitation! Technically, Copernicanism wasn't even heliocentric: The Sun is off-center, and planetary motions are referenced to the center of the Earth's orbit in

stead. And because each planet was solved as a separate problem, *each planet orbits a different center!*

At least he got rid of those @#\$% equants.

There were two reasons for the failure:

- Copernicus insisted on Platonic circles; and
- Accumulated copyist errors in the *Alfonsoine Tables* carried into his *Prussian Tables*.

What a let-down. If only the data were better!

Anything you can do I can do better

Irritated by both models, Tycho Brahe set out to gather new, precise data. He designed and calibrated new instruments and compiled meticulous observations with errors as small as the width of a quarter seen from a football field away.

And produced a geo-heliocentric system regarded today as a kludge.

How did he manage that? Like any good scientist, he followed the data. (Graeley, 2012)

Procyon appeared the same diameter and brightness as Saturn. If it were much farther than 100 times Saturn's distance, simple geometry proved its actual size would dwarf the sun. All the stars would dwarf the Sun, which would then be the only pea in a universe of melons.¹¹ But if Procyon were any closer, there would be visible parallax if the Earth revolved around the sun. Lack of parallax coupled with the apparent size of the stars therefore required a stationary Earth.

Because Tycho otherwise admired Copernicus' treatment, his solution was an updated Heraclidean model: all planets circling the Sun, and the Sun and Moon circling the Earth! His great kludge was thus the best model that accounted for the data. Further, *it was mathematically equivalent to the Copernican model*. Anything the one model could do the other model could do as well.

Hey (I hear you say) Procyon doesn't have a disk!

Right. It's atmospheric aberration. Tycho

¹¹ In response, the Copernicans cried Goddidit! "Who cares how big the stars are?" wrote Christoph Rothmann, since an infinite Creator God is far bigger still.

¹² *Mysterium Cosmographicum* was called by Christie "a strange Renaissance piece of Platonic Pythagorean mathematical mysticism that however revealed its author to be a very good mathematical astronomer."

¹³ Crombie 1959, pp. 176-182.

knew about it, but underestimated its effects away from the horizon.

The Imperial Mathematician, Nicolai Reymers Bär, styled "Ursus," proposed a similar model—but with a rotating Earth. Tycho accused him of plagiarizing his data and a feud developed that caught a young math teacher named Johann Kepler smack in the middle.

Like many new authors, Kepler had sent copies of his book to famous people, hoping for blurbs.¹² Ursus used Kepler's thank-you note to make it seem that Kepler favored the Ursine over the Tychonic model. Since Kepler was asking Tycho for a job at the time, this caused problems.

Kepler also received an unsolicited fan letter from an unknown math professor at Padua whose name amused him. "His forename and family name are the same!" Kepler wrote to a friend. "Galileus Galileus." In Italian, Galileo Galilei.

The Last Hurrah of Eyeball Astronomy

Copernicus had really messed up his analysis of Mars. Tycho had already eliminated one Copernican error—the "trepidations of the equinoxes" was simply observational error—now he hired Kepler to fix the orbit of Mars; though, remembering Ursus, the secretive Tycho would not allow Kepler to make copies of the data. But when Kepler succeeded Tycho (who had succeeded Ursus) as Imperial Mathematician in 1601, he negotiated better access with Longomontanus, Tycho's long-time assistant.

Kepler worked Mars in the Ptolemaic, Copernican, and Tychonic models, and none of them gave a good account. He assumed (as Copernicus had not) that all orbital planes passed through the Sun, which reduced the error to eight or nine arc minutes. Not good enough. He tried re-introducing the @%& equants, though his heart wasn't in it.¹³

A Neoplatonic mystic, Kepler was convinced that physics must reduce to simple

Comparison of Ptolemaic and Copernican/Modern Values

	Ratio of Radii * (Ptolemaic)	Mean Distance (from Sun, in AU) (Copernican)	Modern Value	Ptolemaic Angular Velocity ** (deg./day)	Modern Value Sidereal Mean Motion (deg./day)
Mercury	0.3708	0.3763	0.3871	4.09233	4.09234
Venus	0.7194	0.7193	0.7233	1.60214	1.60213
Sun				0.98563	0.98561
Mars	1.5206	1.5198	1.5237	0.52406	0.52403
Jupiter	5.2167	5.2192	5.2028	0.08312	0.08309
Saturn	9.2336	9.1743	9.5389	0.03349	0.03346

* Epicycle/Deferent for the inferior planets; deferent/epicycle for the superior. The Sun had no epicycle.

** Along epicycles for the inferior planets and along deferents for the superior.

Table after Crombie, p. 173

mathematical forms, but he was more liberal than either Copernicus or Galileo. He began to try ovals.

This bugged Longomontanus, who accused Kepler of shoveling shit.¹⁴ Kepler replied:

If you are angry that I cannot eliminate the oval path, how much more ought you to be angry with the spirals [epicycles], which I abolished. . . . This is like being punished for leaving behind one barrow full of shit although I have cleaned the rest of the Augean stables.¹⁵

The mathematical difficulty of ovals had led Kepler to complain earlier to David Fabricius: "I lack something: knowledge of the geometrical generation of the oval path . . . If the figure were a perfect ellipse . . ." Yeah, if only.

One of the difficulties in falsifying an estab-

¹⁴ Literally. In a letter of 6 May 1604, he told Kepler he was *submerged in shit in the Augean stable of old . . .*

¹⁵ Cited in James R. Voelkel, *The Composition of Kepler's Astronomia Nova*, Princeton Univ. Press, Princeton and Oxford, 2001, quoted at *The Renaissance Mathematicus*, <http://thonyc.wordpress.com/2010/11/21/shovelling-shit/>

¹⁶ Falsification: IF theory p THEN consequence q and NOT-q, then NOT-p. But Duhem pointed out that no physical theory consists of a single p. Instead we have IF p_1 and p_2 and . . . p_n then q and NOT-q, then (NOT- p_1 or NOT- p_2 or . . . NOT- p_n). Thus, when no stellar parallax was observed, it was not heliocentrism that was falsified, as Archimedes and the rest believed, but the assumed stellar distances. But they had no way yet of confirming that empirically. (And just to keep things interesting, Carnap pointed out that there is never just one q, either. (Wallace 1996, pp. 244-249.)

work on Mars rather than Venus! Venus' orbit is nearly a perfect circle, while Mars has the most elliptical orbit of the then-known planets.¹⁷

Kepler wrote this up in *Astronomia nova* (1609). Since he believed mathematics caused physics, he decided that there must be a universal cause of planetary motions: the Sun projected a field, which by rotating would chivvy the planets around their ellipses which an impetus inversely proportional to their distance. Okay, you can't get everything; but this prepared the way for Newton. He thought the field was the Holy Spirit, which proceeded from the Father (the Sun) toward the Son (the fixed stars). This did not prepare the way for Newton.

Game, set, and match, dudes! Except for one thing. He had only Platonic number mysticism. He had no empirical evidence that his model was physically true. It predicted the heavens; but so did the Tychonic system.

Kepler sent a copy of *Astronomia nova* to Galileo—but Galileo never read it.¹⁸

The Magnificent Seven

In case you're keeping tabs, there were by this time seven models in play (Christie, Galileo's great bluff 2010).

Heraclidean. Geo-heliocentric. Mercury and Venus circle the Sun; everything else circles the Earth.

Ptolemaic. Geocentric, stationary Earth.

Copernican. Heliocentric, pure circles with lots of epicycles.

Gilbertian. Geocentric, rotating Earth (William Gilbert, in *De magnete*).

Tychonic. Geo-heliocentric. Sun and Moon circle the Earth; everything else circles the Sun.

Ursine. Tychonic, with rotating Earth.

¹⁷ Except Mercury, which was hard to observe by eyeball.

¹⁸ This was typical of Galileo. Even after his friend Cesi wrote him (21 July 1612) extolling the need for ellipses, Galileo stuck with Copernicus' perfect Platonic circles – and epicycles.

¹⁹ Aristotle, quite aware of this, cautioned against accepting his cosmology as certain.

²⁰ Galileo discovered the first three moons of Jupiter on 7 January 1610. Simon Marius, court mathematician in Ansbach Franconia, discovered them independently *one day later*. But Marius was using the Julian Calendar while Galileo was using the Gregorian, so Marius erroneously claimed priority. Galileo went into flame mode and accused him of plagiarism, but their notebooks make clear that their observations were independent. Marius' were more precise.

²¹ Because to be a celebrity there had to be a formal celebration.

Keplarian. Heliocentric, with elliptical orbits.

The Tychonic model blew away the Heraclidean model, but to decide among the remainder required not simply new data, but new *kinds* of data.

The far-seeing look-glass

Astronomers from Hipparchus to Tycho had been able to gauge only the position, movement, brightness, and size of the stars and planets.¹⁹ That all changed with the look-glass and the era of Gosh! Wow! Look! astronomy. Harriot and Galileo saw mountains on the Moon. Galileo and Marius saw moons around Jupiter. Later, Harriot, the Fabricii, Scheiner, and Galileo saw sunspots, all within months of one another.²⁰

Lunar mountains? Jovian moons? Hooray for Copernicus! Down with Ptolemy!

In March 1611, Galileo went to Rome to promote *The Sidereal Message* and was celebrated in a round of parties and banquets. On Friday the 13 of May, the Jesuits (who had confirmed Galileo's observations with their own telescopes) threw a big shindig for him at the Roman College. Afterward Galileo could be called a "celebrated" astronomer.²¹

But that Jupiter has moons does not prove that the Earth circles the Sun. It only proves that not everything *directly* circles the Earth—and Tycho had already dealt with that. The physics problem was not where the Sun and Earth are situated, but *whether the Earth is in motion*.

Neither discovery laid a glove on Ptolemaic astronomy.

The Last Hurrah of Claude Ptolemy

Try telling that to Galileo. In a letter to his former student Castelli (Dec. 1610), he wrote that those not convinced of the truth of

Copernicus were bookish philosophers who cared only for the empty applause of the vulgar crowds.²² He was a charmer, all right. Lacking evidence, he wanted Copernicanism accepted on faith.

The true telescopic revolution was to convert the planets from lights in the sky to objects about which physical discoveries could be made. Astronomy began to transition from the math department to the physics department.²³

In September 1610, Galileo discovered that Venus went behind the Sun. This was predicted by the Copernican model, but was incompatible with the Ptolemaic (and Gilbertian) model. Two thousand years of scientific consensus went on the ash heap of history.

But the phases of Venus were also predicted by the Tychonic/Ursine models. So Ptolemy was down for the count, but not the stationary Earth.

Bellarmino throws a flag

Because they agreed with long-settled science, certain Scripture passages regarding the fixity of the Earth had been read by the second and third century Church Fathers as narrative-literal. And while the Church had abandoned such readings when there was certainty that they could not be literal, they did not do so when there was merely plausibility. The Protestant Reformation was in high gear, and everyone was gun-shy about Scripture.

Consequently, when Carmelite priest Paolo Foscari wrote a book in 1615 defending Copernicanism, and explained how the Scriptures could be read contrary to the Church Fathers, he sounded an awful lot like Martin Luther and had to be reminded that he was not actually a theologian. Bellarmino wrote to him:

[I]f there were a true demonstration that the sun was in the center of the universe and the earth in the third sphere, and that the sun did not travel around the earth but the earth circled the sun, then it would be necessary to proceed with great caution in explaining the passages of Scripture which

²² Shea, William R. & Mariano Artigas 2003, p. 26

²³ The telescope quickly reached China and the Ottoman and Mughal Empires; but it triggered no scientific revolution there. (Huff 2011)

seemed contrary, and we would rather have to say that we did not understand them than to say that something was false which has been demonstrated. But I do not believe that there is any such demonstration; none has been shown to me. It is not the same thing to show that the appearances are saved by assuming that the sun really is in the center and the earth in the heavens. I believe that the one demonstration might exist, but I have grave doubts about the other, and in a case of doubt, one may not depart from the Scriptures as explained by the holy Fathers. (Bellarmine 1999)

In short: Show me the proof. Until then, stick with the settled science.

Galileo's former pupil Castelli meanwhile had been questioned at dinner by the Grand Duchess Christina, the mother of Galileo's boss, on the matter of Scripture. Galileo, typically, decided Castelli had not answered as well as Galileo would have in his place, so he wrote to Castelli and explained how Scripture could be reinterpreted in the light of Copernicanism. Big mistake.

After reading a copy of this letter, Dominican Niccolo Lorini denounced Galileo and his followers to the Holy Office (7 February 1615) for "taking upon themselves to expound the Holy Scriptures according to their private lights." Copernicanism was cited as only Galileo's *motive* for private interpretation.

Getting wind of this, Galileo asked his friend Archbishop Piero Dini to scope things out. Dini replied 7 March:

As to Copernicus, [Cardinal Bellarmino] said that he could not believe his work would be forbidden, and that the worst possibility, in his opinion, would be the insertion of a note stating that the theory was introduced to save the celestial appearances, or some similar expression, in the same way as epicycles had been introduced. With this reservation, he continued, you would be at liberty

to speak freely on these matters whenever you liked . . . [Regarding Scriptural passages] I [Dini] answered that the Holy Scriptures might be considered in this place as simply employing our usual form of speech, but the Cardinal said that in dealing with such a question we must not be too hasty, just as it would not be right to rush into condemnation of anyone for holding the [Copernican] views which I had put before him . . . He told me that he intended to invite Father Grienberger to his house that he might discuss the question with him, and this very morning I have been to visit the Father, to see if there were any further news. I found that there was nothing fresh except that Father Grienberger would have been better pleased if you had first given your proofs before beginning to speak about the Holy Scriptures . . .

Let's not be hasty, Bellarmine had told Dini, either to accept or condemn the theory. But while he had no problem with Scripture if Copernicanism were demonstrated with certainty, he did have a problem so long as it remained merely plausible. Theology certainly evolved with new knowledge, but it had to be *knowledge* and not just hypothesis. And if he had to warn Foscarini not to play theologian, he certainly had to warn a layman like Galileo.²⁴

Consequently, in 1616 Galileo was summoned to Rome where he signed an agreement not to hold or teach Copernicanism *as proven*. Cardinal Maffeo Barberini interceded on his behalf, so the injunction was not as severe as it might have been. Galileo returned to Florence figuring he had come off pretty well. He'd just whump up a book that would demonstrate with certainty the physical reality of the Earth's dual motion. Then he hit a snag.

He didn't have such a demonstration. Then opportunity knocked.

²⁴ On 21 December 1614, Tommaso Caccini had preached a sermon denouncing Copernican views. Caccini's outraged brethren had then denounced *him* to the Dominican Master General, who promptly apologized to Galileo. As this and other sources demonstrate, there was no overriding theological concern.

²⁵ (De Santillana 1955) pp. 156-157.

²⁶ Pope beat Popper by 300 years. Letters of Dini and Zollern from Shea & Artigas 2003, pp. 111-112.

²⁷ To be fair, Kepler later said that he had tried to read his own book and found it impossible to follow. Kepler was the better mathematical astronomer; but Galileo was by far the better writer.

Urban renewal

Suddenly, in August, 1623, the news burst like a star shell over the bleak landscape: Maffeo Barberini had been elected Pope. There was rejoicing in Florence . . . Urban VIII, as he was now, was a friend of the arts and a Lycean academic himself. . . . [O]nly three years before, following the Discourse on the Comets, he had written his "Adulatio perniciosa" in honor of Galileo.²⁵

When Prince Cesi went to congratulate Urban on his election, the Pope interrupted him eagerly: "Is Galileo coming? When is he coming?"

Galileo rushed to Rome to meet with his old friend and benefactor—six audiences in six weeks!—tête-à-tête over the System of the World. Urban pointed out that it was not enough to show that a replacement model was plausible, or even that it worked better than the standard model. You had to show that if the replacement model were false it would lead to a contradiction. Then he made a suggestion: Hey, dude, why not write a book setting out the arguments for and against each system? Galileo thought that was a keen idea.

The Pope later told Cardinal Zollern (and Zollern told Galileo) that "the Church had not condemned nor was about to condemn Copernicanism as heretical but that the theory was rash and that, furthermore, astronomical theories were of such a kind that they could never be shown to be necessarily true."²⁶

Dialogue of the Deaf

Galileo intended all along not to weigh the pros and cons, but to demonstrate Copernicanism beyond all doubt. This was a daunting task, since the Copernican model was in fact wrong. Galileo's refusal to consider ellipses (or to credit Kepler in any way) was a major obstacle.²⁷

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Meanwhile, Galileo set about alienating his biggest fans: the Jesuit astronomers. He had already flamed Scheiner over the sunspots²⁸; now it was Grassi's turn. Grassi had meticulously observed the three Comets of 1618 and concluded (as Tycho had in 1577) that comets were on non-circular orbits originating beyond the Moon. Offended that Grassi didn't mention him in the book, Galileo marked up his copy: "piece of asininity," "buffoon," "evil poltroon," "ungrateful," and in *The Assayer* (1627), he addressed Grassi,

"You cannot help it . . . that it was granted to me alone to discover all the new phenomena in the sky and nothing to anybody else."

So much for Harriot, Marius, Fabricius, Scheiner, and the rest. He also referred to Tycho's "alleged observations" and to comets as "Tycho's monkey-planets." Then, although he had not observed them himself, he confidently proclaimed that comets were emanations in the Earth's atmosphere! Starting a flame war is bad enough. Starting one when you're dead wrong is worse.

Galileo kept looking for the knock-out punch. At first he thought the path of sunspots proved the Earth's motion. They traced a straight line across the Sun's face only during Earth's solstices. If the Earth circled a Sun inclined to the ecliptic, this semi-annual cycle made sense! But in 1629, Fr. Scheiner accounted for sunspot paths more accurately and deduced the Sun's inclination while retaining a stationary Earth. It made sense the Tychonic way, too.

Galileo thought he had answered the parallax problem, too. The stars were much farther away and the parallax too small to see. But stars seen through telescopes of small aperture, such as those used in the seventeenth century, "appear as well-defined, albeit entirely spurious, disks," which argued against the Copernican model for the same reasons Tycho had given. Telescopic resolution wasn't yet up

to the task. (Graney, 126 Arguments Concerning the Motion of the Earth 2011)

Galileo proposed a test. Find an optical double: a small dim star right next to a large bright star. Like everyone else, he thought small and dim meant farther away and the optical double was therefore a near-by star with a small angular distance from a far-off star. You ought to see parallax. But his notebooks tell us that he had already tried such an observation and had found no parallax. By his own test, he had falsified heliocentrism. So he did what any Renaissance scholar worth his salt would do and kept his mouth shut.

Finally, Galileo devised the Argument of the Tides: the dual motions of the Earth caused the oceans to slosh about. Belatedly, Galileo learned that real-world tides followed a twelve-hour cycle rather than the twenty-four hour cycle his theory predicted, but "his faith in his theory was greater than his trust in what sailors reported."²⁹ He wrote the *Dialogue* anyway.

And used Medici muscle to wrangle the necessary permissions. The political maneuvers need not concern us. Fr. Riccardi, Master of the Palace, had enthusiastically approved *The Assayer* but was now being asked "to buy a pig in a poke." He hadn't read *The Dialogue*.

"Manipulating Father Riccardi, always so anxious to please, did not seem to them to be objectionable. Hoodwinking Cardinal Francesco Barberini or, worse still, the pope, however unwittingly, was another matter."³⁰

When the *Dialogue* came out in 1632, Urban's cautions about the uncertainty of astronomical theories had been placed in the mouth of Simplicio, in a very prominent position in the text. A social climber like Galileo was not foolish enough to do this on purpose, but he may have been vain enough to suppose that no one would notice. He never could resist a zinger.

Which was not a good idea in Machiavellian Italy.

²⁸ In an exchange of letters passing through Marcus Welser, Scheiner and Galileo had, in today's parlance, cross-posted. If rash judgment were an Olympic sport, Galileo would have been the gold medalist. Sunspots are a side-show in this story, but Scheiner went on to develop the notation still used for sunspot observations and to discover the differential rotation of the Sun's hemispheres.

²⁹ Shea, William R. & Mariano Artigas 2003, p. 132.
³⁰ Shea, William R. & Mariano Artigas 2003, p. 133

Got Troubles on My Mind

Urban had other concerns. The Thirty Years War was fourteen years old and the Papacy favored the French Bourbons while trying not to annoy the Spanish and German Hapsburgs too badly. The German Hapsburgs ruled Milan and the Spanish the Two Sicilies, with the Papal State smack between. The Spanish cardinals, especially Gasparo Borgia, were in open dissent from the Francophile policy.³¹ Galileo's friend and supporter, Msgr. Ciampoli, was discovered to be in league with this faction, while Galileo's patron, the Grand Duke of Florence, was an ally of the Austro-German Hapsburgs. And Florence had claims on Roman territory, the Duchy of Urbino.

Domestically, the Roman public was disgruntled with the Barberini family, and horoscopes were being cast against them predicting an early fall from power. On 18 May 1629, the Roman gossip sheet *Avvisi* had reported that Galileo had cast horoscopes on the Barberini family foretelling the Pope's imminent death. Not good.³²

The last thing Urban needed was some pidgin hoo-hah over *astronomical mathematics*.

Then someone pointed out the apparently gratuitous insult offered in the conclusion of the *Dialogue*.

And the rest is history.³³

Aftermath

But this is the story of how heliocentric models overthrew geocentric ones, and Galileo's *Dialogue* didn't do that. In it, he referred to his opponents as "dumb idiots" and "mental pygmies, hardly deserving the name of human beings," but while that might pass for Renaissance wit, it will not do for scientific

³¹ At the consistory of 8 March 1632, Borgia denounced Urban for supporting the "Protestant" side and the pro-Hapsburg and pro-Bourbon cardinals got into a fistfight. The Swiss Guard was called to restore order; and from then on, Urban saw Hapsburg plots everywhere.

³² Galileo asked his friend Michelangelo, nephew of the late sculptor, to speak to the Pope's nephew, Cardinal Francesco Barberini. But before Michelangelo could so much as mention the gossip, the cardinal cut him short. He did not believe a word of it and said that Galileo "had no better friend than the Pope and himself." Shea, William R. & Mariano Artigas 2003, p. 140.

³³ And rather complicated history at that. For details, see De Santillana 1955, Shea, William R. & Mariano Artigas 2003, and Rowland 2003.

³⁴ Letter: Galileo to Diodati (25 July 1634) reported in (De Santillana 1955)

³⁵ Letter: Galileo to Peiresc (22 Feb and 16 March 1635) reported in (De Santillana 1955)

ic refutation. All the models had champions and opponents both within the Church and among the astronomers. In a letter to Gassendi (6 Sept. 1633), the great polymath Nicolas de Peiresc reported a remark made by Fr. Athanasius Kircher SJ, who had succeeded Kepler that year as Imperial Mathematician:

[Fr. Kircher] could not hold himself from admitting . . . that Fr. Malapertius and Fr. Clavius himself did not really disapprove of the opinions of Copernicus; in fact, that they were not far from it themselves, although they had been pressed and ordered to write in favor of the common doctrine of Aristotle, and that Fr. Scheiner himself followed only by order and through obedience.

Father Grienberger remarked that "If Galileo had only known how to retain the favor of the Jesuits . . . he could have written what he pleased about everything, even about the motion of the Earth."³⁴

Galileo himself wrote:

But my most holy intention, how clearly it would appear if some power would bring to light the slanders, frauds, stratagems, and trickeries that were used eighteen years ago in Rome in order to deceive the authorities! . . . You have read my writings, and from them you have certainly understood which was the true and real motive that caused, under the lying mask of religion, this war against me . . .³⁵

From Plausible to Proven

The great dishonesty of Galileo's *Dialogue* was to present a contest between the Copernican and Ptolemaic models. By that time, both had been smacked down and the real contest was between the Tychonic/Ursine

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models and Kepler's model, with the Ursine model being "ahead on points." Galileo did not mention them.

Galileo's book "proved popular amongst literati who were not astronomers [and] who enjoyed his very obvious polemic writing skills; but contrary to popular opinion it didn't play a significant role in the contemporary scientific discussion." (Christie, Galileo's great bluff 2010)

In 1651, Fr. Giovanni Battista Riccioli SJ published *Almagestum novum*, in which he gave 49 arguments in favor of the Copernican model and 77 arguments against, with rebuttals of each.³⁶ This was the book Galileo was supposed to write. Contrary to popular belief, Riccioli did not simply count the number of arguments, since they were of unequal weight; nor did he decide on the Tychonic model for religious reasons. Rather, he emphasizes again and again the need for sensible evidence as the deciding factor.

Both sides present good arguments as point and counter-point. Religious arguments play a minor role in the debate; careful, reproducible experiments a major role. To Riccioli, the anti-Copernican arguments carry the greater weight, on the basis of a few key arguments against which the Copernicans have no good response. . . . Given the available scientific knowledge in 1651, a geo-heliocentric hypothesis clearly had real strength, but Riccioli presents it as merely the "least absurd" available model . . . (Graney, 126 Arguments Concerning the Motion of the Earth 2011.)

The "key arguments against which the Copernicans had no good response" were the lack of parallax and Coriolis effects. Graney states, "Today, a new theory which predicts observable effects that are not observed, while requiring the ad hoc creation of an unprecedented new type of object [gigantic stars], would have limited appeal, even were it mathematically elegant." The Tychonic

³⁶ Summarized in capsule form in (Graney, 126 Arguments Concerning the Motion of the Earth 2011)

³⁷ This is about par for the course for new scientific paradigms. Both relativity and quantum mechanics needed about a century to go from "wild hypothesis overthrowing the wisdom of the ages" to "standard model."

model fit the data better. It predicted all the same phenomena as the Copernican, plus it explained why there was no visible parallax or Coriolis.

But by 1660, nearly 120 years after heliocentrism had been formally proposed, Kepler's elliptical model had won the contest.³⁷ Kepler's *Rudolphine Tables* were just easier. In the Platonic Renaissance, that carried weight.

The astronomical community accepted the ellipses with nary a murmur and the Third Law with positive glee. However, the Second Law (the Equal Area law) was rejected as ugly and Kepler's proof was deficient. Not until 1672, did Nicolas Mercator develop a correct mathematical derivation. (Christie, Galileo's great bluff 2010)

Then, in 1687, Newton presented his theory of Universal Gravitation. It's hard for the Late Modern to grasp what a stunning achievement this was. Suddenly, everything made sense! There was one solution to all the planets, to all the motions! Finally, a simple, elegant reason why Kepler's model ought to be true.

Just one problem; or rather two:

- There was still no parallax.
- There was still no Coriolis effect.

Dang! But we can't let inconvenient facts get in the way of a really cool theory.

Fat lady finally sings

By this time the telescopes were good enough that the stars were clearly pinpoints. That meant they really could be much farther away without being gigantic new entities. Everybody supposed the parallax was simply too small to detect.

The lack of Coriolis was more troubling. Even though a rotating Earth had been more easily accepted than a revolving Earth, the motion was still undetected. Newton had described an experiment—dropping a musket ball from a tower—and Hooke had carried it out. But he reported finding no deflection.

Then in 1728, James Bradley detected stellar aberration in γ -Draconis (Phil. Trans. Royal Soc., 1729). The effect was small, variable, and detectable only with special instruments, but counts as a proof of the motion of the Earth.³⁸ Bradley's paper was translated into Italian after 1734, and Copernicanism was removed from the Index in 1758, about as fast as the "Ents of Rome" ever move.

In 1806, Giuseppe Calandrelli, director of the observatory at the Roman College published *Osservazione e riflessione sulla paralasse annua dall'alfa della Lira*, reporting parallax in α -Lyrae. This provided a simple direct observation of the revolution of the Earth.

In a series of experiments conducted between 1789 and 1792, Giovanni Guglielmini, a professor of mathematics at the University of Bologna, dropped weights from the Torre dei Asinelli in Bologna and found an eastward deflection. Concerned with windage, he repeated the experiment down the center of the spiral staircase at the Istituto delle Scienze and found a 4-mm Coriolis deflection over a 29-m drop; thus providing direct empirical evidence of the rotation of the Earth.³⁹

Keplerian heliocentrism had been accepted because it was computationally easier and because it fell out mathematically from Newton's theory like Athena from the brow of Zeus. But now, finally, 263 years after Copernicus, it was finally established by empirical fact.

Giuseppe Settele, astronomy professor at the Sapienza (now the University of Rome) incorporated these findings into the second volume of his *Elementa di Ottica e di Astronomia*, and told his colleague, Benedetto Olivieri (who was Commissary of the Holy Office) that this provided the demonstration requested by Bellarmine in 1616. Olivieri agreed, and convinced the Office and Pope Pius VII. The imprimatur was granted in 1820 and the ban on teaching heliocentrism as proven fact was lifted.

That's a long time to hold out for empirical confirmation.⁴⁰

Conclusion: Our ancestors were not fools

In three centuries, the long complex story of how the mobile Earth replaced the stationary Earth dipped below the horizon from History into Legend. Like all good legends, the story of heliocentrism and the culture-hero Galileo is simple and general and geared toward supporting the Rightness of the Modern worldview. But history is always detailed and particular.

The reasons for the stationary Earth were rooted in empirical experience and successful modeling. The dual motion of the Earth is not sensibly evident and was difficult to establish on empirical grounds. Heliocentrism triumphed first of all because Neoplatonic number mysticism had become *au courant* during the Renaissance, and Platonists equated mathematical elegance with physical evidence.

Resistance to heliocentrism was rooted in the science of the day and religion entered the picture mainly because the Church Fathers had interpreted Scripture in the light of that science. They weren't about to change until there was solid evidence that the science (and hence the interpretation) was wrong; not in the middle of the Reformation they weren't. Thomas Huxley said after investigating the affair that "the Church had the better case." But Pierre Duhem put it differently. The Copernicans were "right for the wrong reasons." The Ptolemaics were "wrong for the right reasons."

Science doesn't follow a mythic positivist ideal but the plural scientific methods of Feyerabend, a mixture of empiricism, flights of fancy, intuition, aesthetics, doggedness, and jealousy. Scientific theories are underdetermined. Any finite set of facts can support multiple theories. For a long time the available facts were equally explained by geostationary or geomobile models.

³⁸ For the same reason that the apparent origin of raindrops hitting your windshield seems to be ahead of you proves that your car is moving.

³⁹ The experiments were replicated in 1804 by Johann Benzenburg down a mineshaft at Schlebusch. (Wallace 1996) pp. 394-396.

⁴⁰ Credit for establishing the revolution and rotation of the Earth is usually granted respectively to Friedrich Bessel, who measured parallax in 61 Cygni in 1838, and to Léon Foucault, who built his pendulum in 1851.

In the Legend, the conflict was between Science and Religion. But in the History, the conflict was between two groups of scientists, with churchmen lined up on all sides. Copernicanism was supported by humanist literati and opposed by Aristotelian physicists; so it was a mixed bag all around.

Science does not take place in a bubble. International and domestic politics and individual personalities roil the pot as well. The mystery is not why Galileo failed to triumph—he didn't have good evidence, made enemies of his friends, and stepped into a political minefield. The real mystery is why Kepler, who actually had the correct solution, constantly flew under the radar. A deviant Lutheran working in a Catholic monarchy, he pushed Copernicanism as strongly as Galileo; but no one hassled him over it. Too bad he couldn't write his way out of a paper bag. ■

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