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A True Demonstration

Bellarmine and the Stars as Evidence Against Earth's Motion in the Early Seventeenth Century

In 1615 Robert Cardinal Bellarmine demanded a "true demonstration" of Earth's motion before he would cease to doubt the Copernican world system. No such demonstration was available because the geocentric Tychonic world system was a viable alternative to the heliocentric Copernican system. On the contrary, recent work concerning early observations of stars suggests that, thanks to astronomers' misunderstanding of the images of stars seen through the telescope, the only "true demonstration" the telescope provided in Bellarmine's day showed the earth not *to circle the Sun. This had been discussed by the German astronomer Simon Marius, in his* Mundus Iovialis, *just prior to Bellarmine's request for a "true demonstration."*

In the early seventeenth century, careful telescopic observations made by skilled astronomers did not support the heliocentric world system of Copernicus, but rather the geocentric world system of the great Danish astronomer Tycho Brahe. This was because early telescopic astronomers did not understand the limitations of their telescopes, which produced spurious views of stars. Since they failed to realize this, they concluded that the stars were not sufficiently distant to be compatible with the Copernican system.[1]

In April 1615, in a letter offering his opinion on the Copernican world system, Robert Cardinal Bellarmine wrote:

> I say that if there were a true demonstration that the sun is at the center of the world and the earth in the third heaven, and that the sun does not circle the earth but the earth circles the sun, then one would have to proceed with great care in explaining the Scriptures that appear contrary, and say rather that we do not understand them then that what is demonstrated is false. But I will not believe that there is such a demonstration, until it is shown me. Nor is it the same to demonstrate that by supposing the sun to be at the center and the earth in heaven one can save the appearances, and to demonstrate that in truth the sun is at the center and the earth in heaven; for I believe the first demonstration may be available, but I have very great doubts about the second, and in the case of doubt one must not abandon the Holy Scripture as interpreted by the Holy Fathers.[2]

Bellarmine had been drawn into a growing controversy concerning Galileo Galilei and the Copernican world system. The discoveries Galileo had made with the telescope in the years prior to 1615 had certainly undermined traditional Aristotelian and Ptolemaic ideas about the heavens. The Sun's spots and the Moon's Earth-like features, such as mountains and plains, were inconsistent with their being made of an unchanging and unearthly "quintessence." Jupiter's satellites revealed that the Earth was not the center of all heavenly motion. Venus's phases showed that body to circle the Sun. That the Milky Way was composed of stars and that far more stars existed than could be seen with the unaided eye illustrated the limitations of existing knowledge.

In reaction to Galileo's success, certain opponents of Galileo and Copernicus had begun to turn to biblical rather than scientific arguments to make their case. In December 1613 the Grand Duchess Dowager Christina and some associates had challenged one of Galileo's friends and followers, the Benedictine Fr. Benedetto Castelli, on the issue of the Earth's movement.[3] Castelli mentioned this to Galileo in a letter dated December 14. Castelli noted to Galileo that those who challenged him "admitted as true all the celestial novelties you have discovered," but they challenged the conclusion that the Earth moves, "especially since Holy Scripture [is] clearly contrary to this claim."[4]

Galileo replied to Castelli with a substantial letter dated December 21 in which he refuted the biblical objection to the Copernican system. This letter was not published, but copies were circulated.[5] Moreover, someone produced altered copies of the letter so as to cast an unfavorable light on Galileo. For example, Galileo wrote to Castelli that "in the Scripture one finds many propositions which look different from the truth if one goes by the literal meaning of the words" and that "the Scripture has not abstained from somewhat concealing its most basic dogmas." These statements were altered to read: "in the Scripture one finds many propositions which *are false* if one goes by the literal meaning of the words" and "the Scripture has not abstained from *perverting* its most basic dogmas."[6] Thus in February 1615, and again in March, complaints against Galileo were filed with the Roman Inquisition (complete with a copy of the altered letter to Castelli).[7] This precipitated a formal investigation of Galileo and the Copernican system—a story that has been often told. Bellarmine was soon involved in the matter.

Bellarmine had taken an early interest in Galileo's telescopic discoveries. By April 1611, only a year and a half after Galileo had first constructed a telescope and only one year after Galileo had published his discoveries in his *Sidereus Nuncius*, Bellarmine had seen the Moon and Venus through a telescope for himself. At that time he had written to the Jesuit professors of the Roman College to confirm that what Galileo had discovered was real, and not merely an appearance.[8] Bellarmine had been present when Galileo visited the Roman College that year, and had received Galileo favorably.[9]

Through a letter dated March 7, 1615, written by a subordinate in regard to the investigation, Bellarmine expressed a willingness to listen to Galileo's ideas. But he also expressed caution in regard to interpreting as simply accommodating human perception those scriptural passages that speak of the Sun's motion: "This is not something to jump into, just as one ought not to jump hurriedly into condemning any one of these opinions."[10] This same caution can be seen in the aforementioned letter of April 1615, which Bellarmine wrote to one of Galileo's supporters, the Neapolitan friar Paolo Antonio Foscarini.

The reason Bellarmine could write to Foscarini expressing caution against abandoning traditional interpretations of Scripture absent a "true demonstration" of Earth's motion about the Sun, and the reason the Grand Duchess could accept Galileo's discoveries without accepting the Earth's motion, is because indeed there was no "true demonstration" of Earth's motion at the time he was writing. Galileo's discoveries did not demonstrate that Earth moved; Aristotle and Ptolemy's being wrong did not make Copernicus right. Models of other possible world systems existed.

In the late sixteenth century the great Danish astronomer Tycho Brahe had proposed a new geocentric world system. He was impressed with the Copernican system but was concerned about its conflicts with the physics of the day. The Copernican system, he wrote, "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 it 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."[11] Brahe created a hybrid system in which the Sun, Moon, and stars circled the Earth, while the planets circled the Sun. Regarding the Sun, Moon, and planets, this "Tychonic" world system was identical to the Copernican world system both from the standpoint of mathematics and from the standpoint of astronomical observations. Viewed from a scientific perspective, the Copernican system was the more elegant, but it did suffer from some definite disadvantages when set against the more ungainly Tychonic system.

One disadvantage was that, as Tycho said, the physics of the day could provide no explanation for how the "hulking, lazy" Earth, a large body composed of quite heavy rock, might be made to move in circles around the Sun at prodigious speeds. By contrast an explanation for how the Sun might circle the Earth was easy—it and all heavenly bodies are made of a material not found on Earth. This material, if not quite the perfect and unchanging quintessence Aristotle envisioned,[12] could at least be more moveable than thousands of miles and uncountable tons of earthly rock.[13] Another disadvantage was that a moving Earth should produce observable astronomical effects. An Earth that circles the Sun would move relative to the stars over the course of a year. That movement should create yearly changes in the appearance of the stars, a phenomenon known as "annual parallax." No such parallax could be seen. Copernicus had said that the lack of parallax could be explained if the stars were very far away[14]—in which case the Earth's motions would be negligible by comparison—but this was a disadvantage nonetheless.

All the previously mentioned telescopic discoveries could be reconciled with the Tychonic world system. Indeed, since the Tychonic and Copernican world systems were indistinguishable concerning the Sun, Moon, and planets, the only astronomical observations that could resolve between the two systems were observations of the stars, such as successful detection of annual parallax. For in the Tychonic system the Earth is at rest with respect to the stars, while in the Copernican system it is not. Indeed, many astronomers believed that the telescopic discoveries lent support to the Tychonic world system, not the Copernican one. Among these was Simon Marius, the German astronomer who claimed to have discovered the Jovian satellites simultaneously with Galileo.[15]

In his 1616 "Discourse on the Tides,"[16] and again in his 1632 *Dialogue Concerning the Two Chief World Systems*,[17] Galileo argued that the tides could be taken as evidence of Earth's motion—the "true demonstration" that Bellarmine demanded. According to Galileo, tides were a sloshing back and forth of the oceans that resulted from the combination of Earth's orbital motion about the Sun and its daily rotation about its own axis. But Galileo's tides theory predicted that the period of time between tides would be twice what it actually is. Other Copernican scientists of the time did not ascribe to the tides theory.[18] Kepler argued the tides were caused by the Moon.[19] The problem with Galileo's theory and the period of tides was noted by the papal commission investigating his work:

> [Galileo] says that from the mixture of the annual and diurnal motions [of Earth] there results an acceleration of motion in some parts of the earth and during the same period a retardation in the others, and on page 420 he shows this in a diagram. For at some parts of the earth there is an adding up of the annual and diurnal motions, where they carry the earth in the same direction, while at the opposite parts, the earth being carried in one direction by the annual motion and in the opposite direction by the diurnal motion, subtracting one motion from the other, there results a great retardation of the absolute motion; this acceleration and retardation necessarily causes the rising and falling of the water since, not being firmly attached to the earth, the water does not necessarily follow its motion, as one can observe in a boat full of water which is moving on a lake and whose motion happens to vary in speed and slowness.
>
> However, he does not untangle the difficulty that, given this doctrine, since the change between greatest acceleration and maximum retardation of the earth's motion occurs at twelve-hour intervals, then high and low tides should also occur at twelve hour intervals. But experience teaches that they occur every six hours.[20]

And so the tides were not a true demonstration of Earth's motion. Astronomers looked to observations of the stars for evidence that Earth moved.

Thus the Tychonic world system (and "semi-Tychonic" variations on that system), remained viable for over a century.[21] We find Robert Hooke writing in 1674:

> [May] not the Sun move as Ticho supposes, and the Planets make their Revolutions about it whilst the Earth stands still . . . especially since it is not demonstrated without much art and difficulty, and taking many things for granted which are hard to be proved, that there is any body in the Universe more considerable then the Earth we tread on. Is there not much reason for the Hypothesis of Ticho at least, when he with all the accurateness that he arrived to with his vast Instruments, or Riccioli, who pretends much to out-strip him, were not able to find any sensible Parallax of the Earths Orb among the fixt Stars, especially if the observations upon which they ground their assertions, were made to the accurateness of some few Seconds?[22]

In time, of course, Isaac Newton developed physics that could provide an explanation for how the Earth could circle the Sun, and the English astronomer James Bradley detected aberrations in the light from stars caused by the moving Earth—a true demonstration of Earth's motion. So by the early eighteenth century, the outcome of the struggle over the world system had been determined, and not in favor of Tycho.[23] Yet in the early days of telescopic astronomy the German astronomer Simon Marius claimed that the stars provided a true demonstration in favor of Tycho, and in a sense he was absolutely correct.

Literature about Marius and his work is scarce. What exists typically notes that he observed the Jovian system and claimed that he independently discovered the moons of Jupiter, thereby incurring Galileo's ire,[24] and that he observed the Andromeda galaxy with his telescope, describing its appearance as being like a candle seen through horn.[25] But the literature provides hints that Marius was a skilled observer. His description of the Andromeda galaxy was detailed—he recorded its diameter, noted that it increased in brightness toward its center, and described the center as a dull, pale light.[26] His work on the Jovian moons was superior to Galileo's.[27] And he observed the spurious disks of stars with his telescope.[28]

Small telescopes show spurious disks when used to view stars. These disks are small, a fraction of the diameter of the disk of Jupiter, for example, and easily overlooked by an inexperienced observer or an observer with a poor telescope. They are not real bodies, but are artifacts of the wave nature of light, and only evident when a telescope is used to view objects such as stars, which are so distant as to appear as imperceptibly tiny points of light. Even powerful modern telescopes cannot reveal star's physical globes. The disks are larger for brighter stars, smaller for fainter stars. The spurious disk phenomenon, and the dependence of size on brightness, was noted by astronomers from Hevelius (late seventeenth century)[29] to Halley (early eighteenth century)[30] to Herschel (late eighteenth century)[31] to astronomers at the dawn of photographic astronomy (late nineteenth century).[32] By the time of Halley, astronomers were recognizing that the disks were spurious.[33] During the nineteenth century George Biddell Airy developed a theory that directly explained both their existence and why they appear larger for brighter stars and smaller for fainter stars.[34]

But Simon Marius did not realize that the disks he saw when viewing stars with his telescope were not real. He believed they were the physical globes of stars. And he believed that the disks revealed information about the distance to the stars. In his *Mundus Iovialis* of 1614 Marius writes that gaining possession of a good telescope made it possible for him to see that stars, like the planets, show disks—something he could not see before. He says these disks are most prominent in the brighter stars. He goes on to say that he is truly surprised that Galileo has not seen this, and notes that Galileo writes in his *Sidereus Nuncius* that the stars do not possess a defined circular shape.[35] Indeed, in the *Nuncius* Galileo had written

> Deserving of notice also is the difference between the appearances of the planets and of the fixed stars. The planets show their globes perfectly round and definitely bounded, looking like little moons, spherical and flooded all over with light; the fixed stars are never seen to be bounded by a circular periphery, but have rather the aspect of blazes whose rays vibrate about them and scintillate a great deal. Viewed with a telescope they appear of a shape similar to that which they present to the naked eye.[36]

Marius then remarks that this supposedly is part of the strongest argument in favor of the Copernican world system—that stars lacking a round shape indicates that they lie at an immense distance from Earth. But, says Marius, because the disks of the stars can be seen from Earth, the fixed stars clearly are not at the immense distances required by Copernicus. Thus, the stars actually argue against Copernicus; their appearance agrees with the Tychonic world system.[37]

This skilled astronomer is using telescopic observations of the stars to support a geocentric world system. Unfortunately Marius does not provide details as to why he believes that the disks he sees through the telescope argue in favor of Tycho. The focus of *Mundus Iovialis* is on Jupiter—on showing that Marius's detailed observations of Jupiter's moons could only be explained by their orbiting Jupiter as Jupiter orbited the Sun (he took this as supporting the Tychonic system also)[38]—and he does not provide comparable detail concerning his observations of stars. He says he will provide more details later, but what those are we do not know.[39]

We can gain some insight into Marius's work by looking at the work of—surprisingly—Galileo. Galileo also observed the spurious disks of stars with his telescope, although apparently not before he wrote the *Sidereus Nuncius*. In his *Dialogue* of 1632 he discusses stars not as blazes but as measurable disks, with brighter stars being larger than fainter stars:

> The apparent diameter of the sun at its average distance is about one-half a degree, or 30 minutes; this is 1,800 seconds, or 108,000 third-order divisions. And since the apparent diameter of a fixed star of the first magnitude [a bright star] is no more than 5 seconds, or 300 thirds, and the diameter of one of the sixth magnitude [the faintest the naked eye can see] measures 50 thirds . . . then the diameter of the sun contains the diameter of a fixed star of the sixth magnitude 2,160 times.[40]

Furthermore, Galileo observes, if a beam of wood mounted to serve as a reference for marking a star's position "is not large enough to hide the star, I shall find the place from which the disc of the star is seen to be cut in half by the beam—an effect which can be discerned perfectly by means of a fine telescope."[41] This view of stars as disks can also be found in his 1624 letter to Francesco Ingoli: "I say that if you measure Jupiter's diameter exactly, it barely comes to 40 seconds, so that the sun's diameter becomes 50 times greater; but Jupiter's diameter is no less than ten times larger than that of an average fixed star (as a good telescope will show us), so that the sun's diameter is five hundred times that of an average fixed star."[42] The letter continues, "Many years ago . . . I learned by sensory experience that no fixed star subtends even 5 seconds, many not even 4, and innumerable others not even 2."[43] The same view can be found in his observation notes of 1617. He measures the diameters of the two components of the double star Mizar, finding the brighter to be half again as large as the fainter.[44] He sketches the stars of the Trapezium, a close grouping in the sword of Orion, noting that they vary in diameter.[45]

Like Marius, Galileo also says that the disks of stars reveal something about stellar distances. But Galileo provides details. In his 1617 observation notes, in his 1624 letter to Ingoli, and in his 1632 *Dialogue*, he repeats his theory about the stars—they are identical in actual size to the Sun, and so their apparent size reveals their distance. The reader can see this if we slightly expand our earlier quotes from the letter to Ingoli: "The sun's diameter is five hundred times that of an average fixed star; from this it immediately follows that the distance to the stellar region is five hundred times greater than that between us and the sun."[46] It can also be seen in an extended quotation from the *Dialogue*:

> The diameter of the sun contains the diameter of a fixed star of the sixth magnitude 2,160 times. Therefore if one assumes that a fixed star of the sixth magnitude is really equal to the sun and not larger, this amounts to saying that if the sun moved away until its diameter looked to be 1/2160th of what it now appears to be, its distance would have to be 2,160 times what it is in fact now. This is the same as to say that the distance of a fixed star of the sixth magnitude is 2,160 radii of the earth's orbit.[47]

So to Galileo the average star was a sun several hundred solar distances from Earth, while a faint star was a sun a couple of thousand solar distances from Earth.

The idea that stars are suns was not original to Galileo—Giordano Bruno promoted the idea, for instance.[48] The idea was a good fit with the Copernican world system in which Sun and stars all share immobility. And it is essentially correct; today we know that stars are indeed suns.[49]

But today we also know that stars are not hundreds or thousands of solar distances from Earth—they are hundreds *of* thousands and more, far too distant for their parallaxes to be seen with seventeenth-century telescopes. At the distances Galileo calculated, "sun-stars" must show clear and obvious parallax if the Earth circles the Sun. As no parallax is seen, the Earth necessarily must not circle the Sun.

Interestingly, Galileo used his star distance calculations to argue for Copernicus. In the letter to Ingoli he proceed from the five hundred solar distances to say that "ordinary astronomers" could never detect a change of one part in five hundred.[50] He makes a similar argument in the *Dialogue*.[51] However, Galileo was no ordinary astronomer. He had a highly sensitive method for detecting parallax that hinged on the use of a pairing of stars:

> I do not believe that the stars are spread over a spherical surface at equal distances from one center; I suppose their distances from us vary so much that some are two or three times as remote as others. Thus if some tiny star were found by the telescope quite close to some of the larger ones, and if that one were therefore very very remote, it might happen that some sensible alterations would take place among them [that is, they would exhibit parallax].[52]

This method, frequently referred to as "Galileo's double star method" would easily reveal parallax for stars located hundreds to thousands of solar distances from Earth.[53] But what Galileo did not reveal when he wrote in the *Dialogue* that this could be done "if" some faint star were found close to some larger one is that he had already found such a pairing—several in fact—as early as 1617 (including Mizar and the Trapezium mentioned previously).[54] Moreover, the idea of using differences in parallax to test for Earth's motion had been suggested to him in 1611 by one Lodovico Ramponi.[55]

Of course none of the pairings Galileo studied exhibited the parallax, once again apparently hammering home the point that Earth was not circling the Sun.[56] So Marius was right—the spurious disks of stars, interpreted as being their physical globes, imply that the Tychonic world system is correct: a true demonstration that the Sun is *not* at the center of the world and the Earth in the third heaven, and that the Sun *does* circle the Earth.[57]

Simon Marius and Galileo Galilei both observed the spurious telescopic disks of stars. Both made the mistake, quite reasonable for the first telescopic observers, of taking those spurious disks for the stars' physical globes. Both realized that if the physical globes of stars can be seen with the telescope then information about the distances to stars can be determined. And both essentially determined that the stars are too close to be compatible with the Copernican world system. Marius says this directly. Galileo does not.[58]

Questions about why Galileo does not are beyond the scope of this article. I hope that this article will stimulate research that will eventually answer such questions.[59] It is clear, however, that had Galileo been so inclined, he could have used his observations of the disks of stars to construct a forceful argument against the Copernican system. Not knowing that the stellar disks were spurious, he could have used them to provide a "true demonstration" that the earth did not orbit the Sun. Simon Marius had said this was the case, but Simon Marius did not write books like the *Dialogue*. We can only imagine the effect of the persuasive power of Galileo, mustered in defense of the Tychonic system and backed by observations of the stars themselves.

And while we are imagining, we can conceive of Bellarmine's letter of April 1615 being written in light of Marius's just published work. Then Bellarmine's words take on a very different tone than what is usually ascribed to them. For now Bellarmine is not demanding the most rigorous support for the Copernican world system, and demanding that geocentric tradition stand in absence of such support. Rather, Bellarmine, who had looked through a telescope himself and who did not adhere to a traditional Aristotelian and Ptolemaic world system, but did favor a world system with a central, unmoving Earth,[60] is asking for the sort of rigorous support for the heliocentric Copernican system that Marius has already provided for the geocentric Tychonic system. It would appear that Bellarmine is not closing the door on Galileo. Rather, isn't he holding it open for him—giving him a chance to "put up" and counter Marius, before he is told to "shut up" because he cannot back up the Copernican system with hard data?

Observations and interpretations of spurious stellar disks were made by others besides Marius. At the same time Galileo was publishing his *Dialogue*, the Dutch astronomer Martinus Hortensius published a short table of star disk sizes measured telescopically.

Hortensius acknowledged (even though he was a Copernican), that they might lead people to reject the Copernican system.[61] In 1651 the Italian Jesuit astronomer Giovanni Battista Riccioli published a much more extensive table of telescopically measured star disk sizes in his prominent *Almagestum Novum*. Riccioli argued at length that these telescopic observations of stars weighed in against the Copernican system.[62] These works show that the notion of telescopic observations of stars supporting a geocentric world system was not limited to Marius or to Germany. But whether Bellarmine indeed had direct knowledge of Marius's observations of and interpretation of spurious stellar disks is another question worth further research.

Eventually astronomers would have discovered the spurious nature of telescopic stellar disks. In 1637 Jeremiah Horrocks observed the Moon passing in front of the stars of the Pleiades, and noted that the rapidity with which the stars winked out as the Moon passed in front of them was inconsistent with their apparent sizes seen in telescopes.[63] By the early seventeenth century, while some astronomers were still treating stellar disks as though they were the physical globes of stars, the idea that they were spurious, an "Optick Fallacy" caused by the telescope, was gaining strength.[64] Such observations and discoveries did not hinge on which world system was favored, so it seems likely that eventually astronomy would have found its way to the Copernican world system—although considering that the Tychonic theory had significant staying power even despite Galileo's support of Copernicus, "eventually" may have been quite a while.

Simon Marius and the spurious disks of stars show that the standard story of the development of science, in which the telescope opens the door to a modern understanding of the universe and Galileo supports Copernicus based on what telescopic observations revealed, ought not to progress so smoothly. Marius's skillful telescopic observations of stars convinced him that the telescope provided a true demonstration, such as Bellarmine was looking for, in favor of the geocentric Tychonic world system. Galileo supported Copernicus despite what telescopic observations revealed.

Notes

1. Early telescopic observations of the stars have come to attention in recent years thanks to the work of Leos Ondra and Harald Siebert, who have discussed Galileo's observations of double stars, and thanks to the work of Maurice Finocchiaro, who translated Galileo's letter to Ingoli, which contains extensive commentary regarding the stars. Specific works by Ondra, Siebert, and Finocchiaro are cited in later notes.
2. "Cardinal Bellarmine to Foscarini (12 April 1615)" in M. A. Finocchiaro, *The Galileo Affair: A Documentary History* (Los Angeles: University of California Press, 1989), 68.
3. Finocchiaro, *The Galileo Affair*, 27.
4. "Castelli to Galileo (14 December 1613)" in ibid., 48.
5. Finocchiaro, *The Galileo Affair*, 28.
6. Ibid., 331, italics added.
7. Ibid., 28.
8. James M. Lattis, *Between Copernicus and Galileo: Christoph Clavius and the Collapse of Ptolemaic Cosmology* (Chicago: University of Chicago Press, 1994), 190.
9. Finocchiaro, *The Galileo Affair*, 332.
10. "Monsignor Dini to Galileo (7 March 1614)" in Finocchiaro, *The Galileo Affair*, 59.
11. J. L. E. Dreyer, ed., *Tychonis Brahe Dani Opera Omnia 4* (Copenhagen: Libraria Gyldendaliana, 1913–29), 156, ll. 14–18. Translation from Owen Gingerich and James R. Voelkel, "Tycho Brahe's Copernican Campaign," *Journal for the History of Astronomy* 29 (1998): 23–24.
12. Tycho had shown the heavens could change when he used triangulation to determine that a new star or "nova" was more distant than the Moon. To Aristotelian thinking, the heavens beyond the Moon were unchanging, so phenomena in the sky that changed must be located in the earthly region below the Moon.
13. If this type of ad hoc creation of an unknown class of material to explain a phenomenon strikes the reader as being unscientific, consider that astronomers today regularly invoke "dark matter" and "dark energy," each unobserved on Earth, to explain observations.
14. Nicolaus Copernicus, *On the Revolutions of Heavenly Spheres*, trans. C. G. Wallis (Amherst, NY: Prometheus Books, 1995), 26–27.
15. Mario Biagioli, *Galileo, Courtier: The Practice of Science in the Culture of Absolutism* (Chicago: University of Chicago Press, 1993), 92–95.
16. "Galileo's Discourse on the Tides (1616)" in Finocchiaro, *The Galileo Affair,* 119–33.
17. Galileo Galilei, *Dialogue Concerning the Two Chief World Systems—Ptolemaic and Copernican,* trans. Stillman Drake, 2nd ed. (Los Angeles: University of California Press, 1967), 416–65.
18. D. B. Wilson, "Galileo's Religion Versus the Church's Science? Rethinking the History of Science and Religion," *Physics in Perspective* 1 (1999), 78.
19. Galileo, *Dialogue*, 462.

20. "Pasqualigo's Report on the *Dialogue* (17 April 1633)" in Finocchiaro, *The Galileo Affair*, 273–74.

21. Christine Schofield, "The Tychonic and Semi-Tychonic World Systems" in *Planetary Astronomy from the Renaissance to the Rise of Astrophysics, Part A, Tycho Brahe to Newton*, R. Taton and C. Wilson, ed. (Cambridge: Cambridge University Press, 2003), 43.

22. Robert Hooke, *An Attempt to Prove the Motion of the Earth from Observations* (London, 1674), 3–4.

23. Owen Gingerich, "Truth in Science: Proof, Persuasion, and the Galileo Affair," *Science & Christian Belief* 16 (2004), 13–26.

24. John Robert Christianson, *On Tycho's Island: Tycho Brahe and his Assistants, 1570–1601* (Cambridge: Cambridge University Press, 2000), 319–21.

25. Fred Watson, *Stargazer: The Life and Times of the Telescope* (Cambridge, MA: Da Capo Press, 2005), 85–86.

26. George P. Bond, "An Account of the Nebula in Andromeda," *Memoirs of the American Academy of Arts and Sciences*, New Series 3 (1848), 75–76.

27. A. Pannekoek, *A History of Astronomy* (New York: Interscience Publishers, 1961), 231.

28. J. L. E. Dreyer, "The Tercentenary of the Telescope," *Nature* 82 (1909), 191.

29. Robert Grant, *History of Physical Astronomy* (London: Henry G. Bohn, 1852), 545.

30. Edmund Halley, "Some Remarks on a Late Essay of Mr. Cassini, Wherein He Proposes to Find, by Observation, the Parallax and Magnitude of Sirius," *Philosophical Transactions of the Royal Society of London* 31 (1720–21): 3.

31. William Herschel, "Experiments for Ascertaining How Far Telescopes Will Enable Us to Determine Very Small Angles, etc.," *Philosophical Transactions of the Royal Society of London* 95 (1805): 40–44.

32. G. Knott, "On the Telescopic Disks of Stars," *Monthly Notices of the Royal Astronomical Society* 27 (1867): 88.

33. Halley, "Some Remarks," 3.

34. George Biddell Airy, "On the Diffraction of an Object-glass of Circular Aperture," *Transactions of the Cambridge Philosophical Society* 5 (1835), 288.

35. Simon Marius, *Mundus Iovialis/Die Welt des Jupiter*, trans. Joachim Schlör (Gunzenhausen: Schenk-Verlag, 1988), 46–48.

36. Galileo Galilei, "The Starry Messenger" in Stillman Drake, *Discoveries and Opinions of Galileo* (Garden City, NY: Anchor Books/Doubleday & Co., 1957), 47.

37. Marius, *Mundus Iovialis*, 48.

38. "The 'Mundus Jovialis' of Simon Marius, trans. A. O. Prickard," *The Observatory, A Monthly Review of Astronomy* 39 (1916): 404, 408–9.

39. Marius, *Mundus Iovialis*, 48.

40. Galileo, *Dialogue*, 359.

41. Ibid., 388.

42. "Galileo's Reply to Ingoli (1624)" in Finocchiaro, *The Galileo Affair*, 167.

43. Ibid., 174.

44. Leos Ondra, "A New View of Mizar," *Sky & Telescope* 108 (July 2004), 73–75. Castelli worked with Galileo on the study of Mizar, and of double or multiple stars in general.
45. Christopher M. Graney, "On the Accuracy of Galileo's Observations," *Baltic Astronomy* 16 (2007), 445.
46. Galileo, "Reply to Ingoli," 167.
47. Galileo, *Dialogue*, 359–60.
48. Giordano Bruno, *The Ash Wednesday Supper*, ed. and trans. Edward A. Gosselin and Lawrence S. Lerner (Toronto, Canada: Renaissance Society of America, 1995), 71.
49. They are suns in that they are, like the Sun, incandescent spheres of gravitationally bound gas powered by nuclear fusion. However, they vary immensely in size, temperature, luminosity, and other factors.
50. Galileo, "Reply to Ingoli," 167.
51. Galileo, *Dialogue*, 360.
52. Ibid., 382–83.
53. In fact, this method would play a key role in the eventual detection of annual stellar parallax. See Agnes Mary Clerke, Alfred Fowler, and John Ellard Gore, *Astronomy* (New York: D. Appleton & Co, 1898), 417–23, or Alan Hirshfeld, *Parallax: The Race to Measure the Cosmos* (New York: W. H. Freeman, 2002), 131–32, 173.
54. Siebert, "The Early Search for Stellar Parallax: Galileo, Castelli, and Ramponi," *Journal of the History of Astronomy* 36 (2005), 257–62.
55. Ibid., 254.
56. Christopher M. Graney, "But Still, It Moves: Tides, Stellar Parallax, and Galileo's Commitment to the Copernican Theory," *Physics in Perspective* 10 (2008), 258–68.
57. A detailed treatment of the data that can be obtained from observations of stellar disks shows that Marius's interpretation appears to be very strongly supported by any observations of stars that an early seventeenth century astronomer might undertake. See Christopher M. Graney, "Seeds of a Tychonic Revolution: Telescopic Observations of the Stars by Galileo Galilei and Simon Marius," *Physics in Perspective* 12 (2010).
58. Ibid.
59. Siebert offers some commentary on these questions. See Siebert, "Early Search," 256, 261–62.
60. Lattis, *Between Copernicus and Galileo*, 215.
61. Martinus Hortensius, *Dissertatio de Mercurio in Sole Viso* (Leiden, 1633), 60–64.
62. Giovanni Battista Riccioli, *Almagestum Novum* (Bologna, 1651). See bk. 7, sec. 6, chapt. 11 (vol. 1: 715–17); and bk. 9, sec. 4, chap. 30 (vol. 2: 460–63). For an English translation and discussion of this work, see Christopher M. Graney, "The Telescope Against Copernicus: Star Observations by Riccioli Supporting a Geocentric Universe," *Journal for the History of Astronomy* 41 (2010), 453–67.
63. Grant, *History*, 545.
64. Halley, "Some Remarks," 3.