Seeds of a Tychonic Revolution

Telescopic Observations of the Stars by Galileo Galilei and Simon Marius

Christopher M. Graney[a]

Because early telescopic astronomers did not understand the spurious nature of star images formed by their telescopes, their observations of the stars yielded data that apparently confirmed the geocentric Tychonic world system. Both Galileo Galilei (1564-1642) and Simon Marius (1570-1624) obtained such data. Galileo backed Nicholas Copernicus (1473-1543) despite his data. Marius supported Tycho Brahe (1546-1601) on the basis of his data.

Key words: Aristotle; Ptolemy; Nicholas Copernicus; Tycho Brahe; Galileo Galilei; Simon Marius; Aristotelian-Ptolemaic world system; Copernican world system; Tychonic world system; Airy disk; stellar observations; telescope; history of astronomy.

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Introduction

At the dawn of telescopic astronomy, the data yielded by a good telescope on observations of the stars supported the geocentric Tychonic world system, not the heliocentric Copernican world system. These data were the only observations that could determine which of these two world systems was valid. The data supported the Tychonic world system, because early telescopic astronomers did not understand the spurious nature of stellar images seen through a telescope. Galileo Galilei (1564-1642) acquired all of the data needed to confirm the Tychonic world system, but he backed the Copernican world system.[1] His contemporary, Simon Marius (1570-1624), realized that the data from telescopic observations of the stars undermined the Copernican world system, and he backed the Tychonic world system.[2]

A Thought Experiment: An Astronomer Named Mareo

To convince the skeptical reader that telescopic observations of the stars undermined the Copernican world system, I ask him or her to join me in a thought experiment. Imagine that there is a highly motivated and skilled astronomer, working around the year 1610, whom we shall name "Mareo." Mareo builds or acquires a telescope with an aperture of about 30 millimeters. This instrument is among the first generation of telescopes; nonetheless, it is "optically perfect," that is, diffraction-limited.

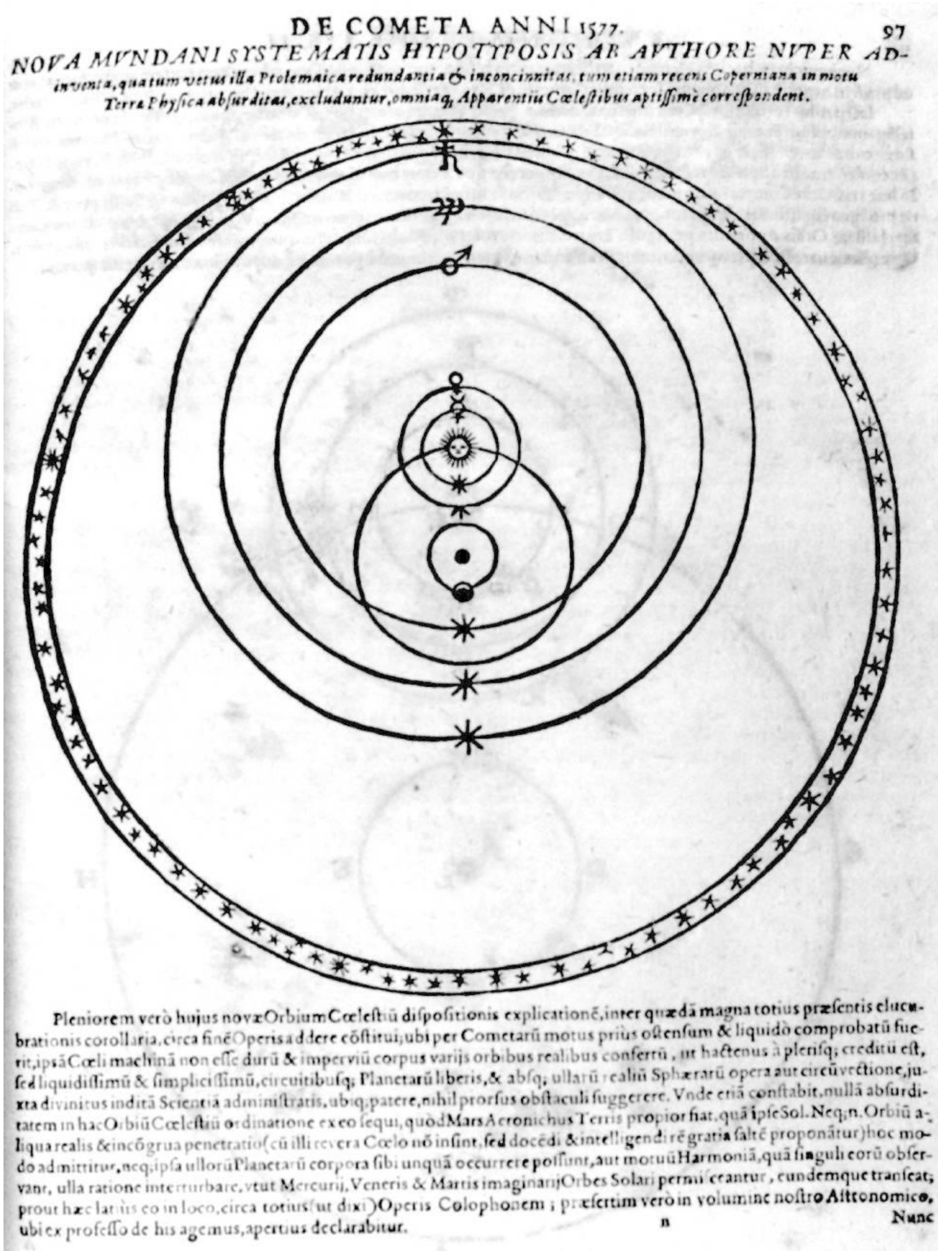
Mareo uses this telescope to systematically study the heavens. He begins his observing campaign with the sun, moon, and planets and finds that his observations undermine the Aristotelian-Ptolemaic world system: The telescope reveals that the sun has spots, the moon has mountains, Venus has phases, and Jupiter has moons – the heavens are neither perfect, nor unchanging, nor absolutely unearthly; Venus circles the sun; a miniature system centered on Jupiter exists. The telescope does not reveal whether the Copernican world system (figure 1) or the Tychonic world system (figure 2) is the better candidate

NICOLAI COPERNICI

net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono menſe reducitur. Sextum deniq; locum Mercurius tenet, octuaginta dierum ſpacio circũ currens. In medio uero omnium reſidet Sol. Quis enim in hoc

pulcherrimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum ſimul poſsit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegiſtus uiſibilem Deum, Sophoclis Electra intuentẽ omnia. Ita profecto tanquam in ſolio re gali Sol reſidens circum agentem gubernat Aſtrorum familiam. Tellus quoq; minime fraudatur lunari miniſterio, ſed ut Ariſtoteles de animalibus ait, maximã Luna cũ terra cognationẽ habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur ſub hac

Fig. 1. The heliocentric Copernican world system. ***Source:*** **Copernicus, *De Revolutionibus* (ref. 1), p. 9.**



DE COMETA ANNI 1577. 97

NOVA MVNDANI SYSTEMATIS HYPOTYPOSIS AB AVTHORE NVPER ADinventa, qua tum vetus illa Ptolemaica redundantia & inconcinnitas, tum etiam recens Copernianа in motu Terræ Physica absurditas, excluduntur, omniaq; Apparentiis Cœlestibus aptissimè correspondent.

Pleniorem verò hujus novæ Orbium Cœlestiũ dispositionis explicationẽ, inter quædã magna totius præsentis elucubrationis corollaria, circa finẽ Operis addere cõstitui; ubi per Cometarũ motus prius ostensum & liquidò comprobatũ fuerit, ipsã Cœli machinã non esse durũ & imperviũ corpus varijs orbibus realibus confertũ, ut hactenus à plerisq; creditũ est, sed liquidissimũ & simplicissimũ, circuitibusq; Planetarũ liberis, & absq; ullarũ realiũ Sphærarũ opera aut circũvectione, juxta divinitus inditã Scientiã administratis, ubiq; patere, nihil prorsus obstaculi suggerere. Vnde etiã constabit, nullã absurditatem in hac Orbiũ Cœlestiũ ordinatione ex eo sequi, quòd Mars Acronichus Terris propior fiat, quã ipse Sol. Neq; n. Orbiũ aliqua realis & incõgrua penetratio (cũ illi revera Cœlo nõ insint, sed docẽdi & intelligendi rẽ gratia saltẽ proponãtur) hoc modo admittitur, neq; ipsa ullorũ Planetarũ corpora sibi unquã occurrere possunt, aut motuũ Harmoniã, quã singuli corũ observant, ulla ratione interturbare, vtut Mercurij, Veneris & Martis imaginarij Orbes Solari permisceantur, eundemque transeat; prout hæc latiùs eo in loco, circa totius (ut dixi) Operis Colophonem; præsertim verò in volumine nostro Astronomico, ubi ex professo de his agemus, apertius declarabitur.

n Nunc

Fig. 2. The geocentric Tychonic world system. The sun and moon circle the Earth; the planets circle the sun. For an observer on Earth, this system is observationally equivalent to the heliocentric Copernican world system insofar as the sun, moon, and planets are concerned. However, the Earth is at rest with respect to the stars, whereas in the heliocentric Copernican world system it is not. Observations of the stars therefore hold the key to determining which of the two world systems is correct. Note that in both the stars are portrayed as located on a stellar sphere. *Source*: Brahe, *De mvndi ætherei* (ref. 2), p. 158.

to replace the Aristotelian-Ptolemaic world system. These two systems are observationally equivalent as regards the sun, moon, and planets. Mareo can obtain the data needed to decide between these two systems only by observing the stars. For example, if Mareo detects annual stellar parallax, that would support the Copernican world system.

Consider what Mareo will see when he turns his attention to the stars. His telescope, being diffraction-limited, reveals stars to be disks – like planets but smaller, and like planetary disks they respond to magnification. But the stellar disks are spurious. They have nothing to do with the actual sizes of the stars. They are manifestations of the Airy disk formed by the telescope through diffraction. All stars have the same Airy disk diameter (roughly 10 arcseconds for a telescope like Mareo's), which is a function only of wavelength and telescope aperture.[b] However, since the human eye can detect only a limited level of intensity, below which it sees nothing, the spurious disks of brighter stars are larger than those of fainter stars. Mareo is ignorant of all of this. He assumes that the disks he sees are the physical bodies of the stars, revealed by his telescope just as it had revealed the physical bodies of the planets. His data tells him that the disks of brighter stars are of larger diameter than those of fainter stars.

Mareo must consider two possible explanations for his data. One is that the observed variation in disk diameters reflects actual variation in size – stars lie on a sphere centered on either the sun (Copernican system) or Earth (Tychonic system), much as is shown in figures 1 and 2. The other explanation is that the observed variation in disk diameters reflects variation in distance – stars that appear larger are closer than stars that appear smaller. Or both size and distance could vary.

Mareo is a highly skilled observer. He can measure the diameters of the spurious stellar disks with sufficient accuracy to distinguish differences of a mere

[b] The angular diameter θ of the Airy disk goes as λ/d, where λ is the wavelength and d is the diameter of the telescope aperture.

second of arc. He finds that the largest disks measure about five arcseconds in diameter. He establishes that a relationship exists between the diameter of a star's disk in arcseconds and its magnitude (brightness) as seen with the naked eye – diameter decreases with magnitude.[c] To Mareo, the decrease appears to be linear (figure 3).

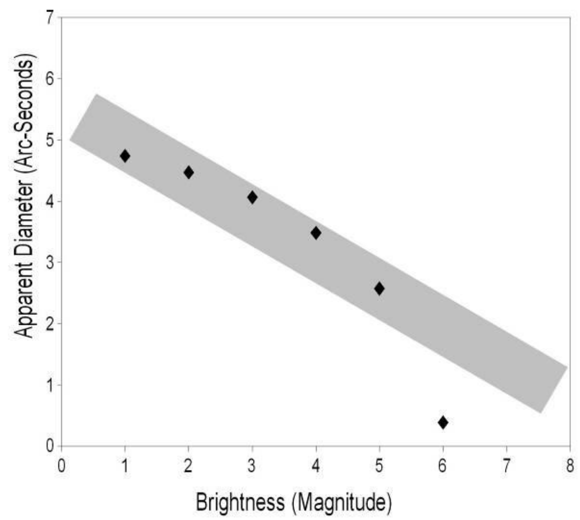


Fig. 3. Author's plot of the sizes of spurious disks formed by a small telescope as a function of magnitude. Points mark the sizes of spurious disks in arcseconds as determined by diffraction-pattern calculations. The gray zone shows that the relationship between disk size and magnitude appears to be linear given even a small amount of uncertainty in measurement, especially considering that the faintest stars will be the ones that are most difficult to measure. Source: Graney, "On the Accuracy" (ref. 10), p. 447.

Inspired by the Copernican world system, Mareo makes a hypothesis: Since the stars share the sun's immobility, and since like the sun they appear brilliant through the telescope as though they emit their own light, they *are* suns, scattered throughout space. The English astronomer Thomas Digges (1546[?]-1595) had argued for something like this in 1576 (figure 4).[3] An important feature of Mareo's hypothesis is that the stars are essentially identical to the sun in size.

Based upon this hypothesis, Mareo calculates the distances to stars. The sun's apparent diameter is roughly 2000 arcseconds; the diameters of the brightest

[c] Recall that dimmer stars have larger magnitudes: Stars of magnitude 1 are bright, those of magnitude 6 are barely visible to the naked eye.

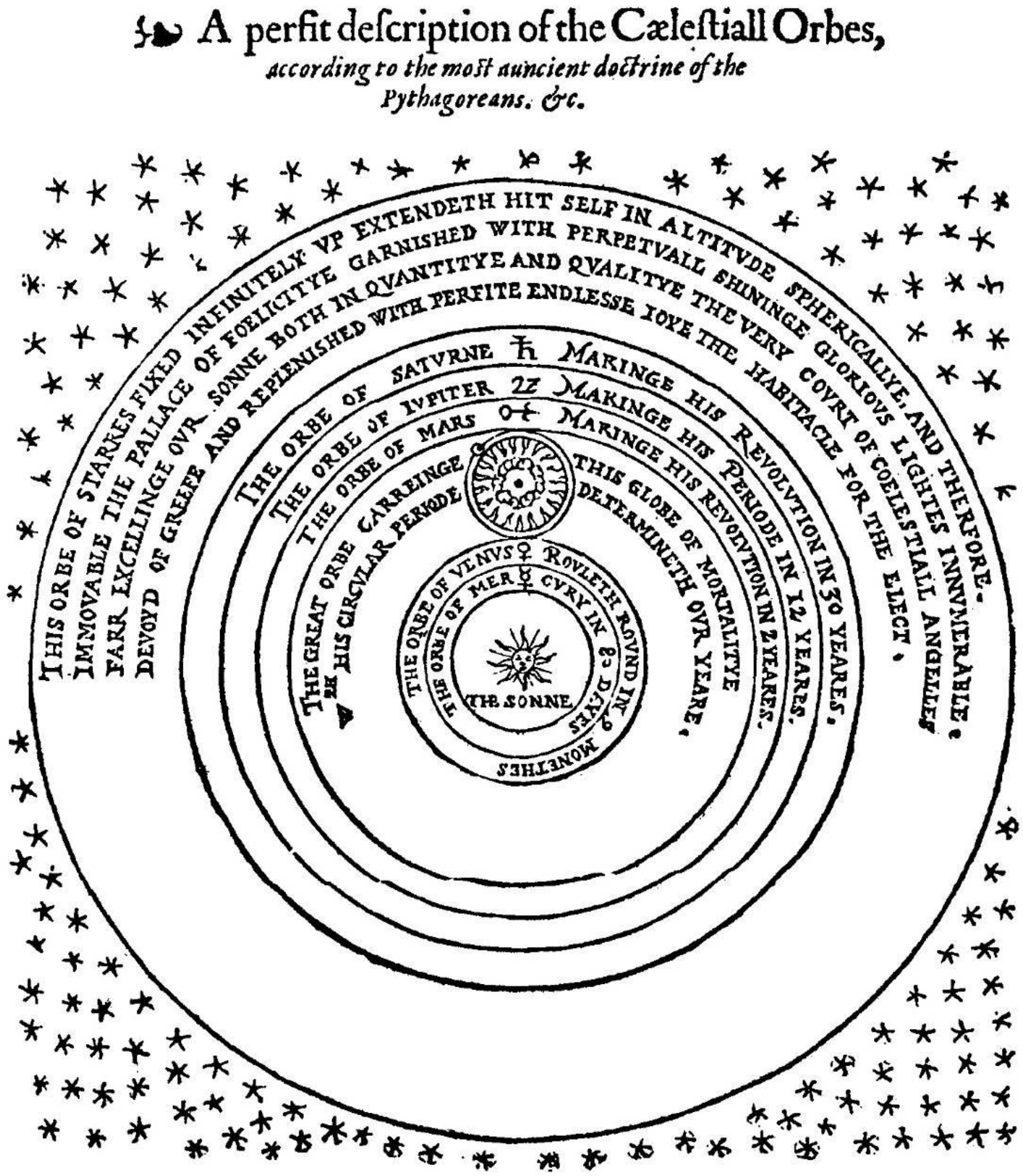


Fig. 4. Thomas Digges's depiction of the heliocentric Copernican world system in 1576, in which the stars are not on a stellar sphere but rather are scattered throughout space. ***Source*****: Digges,** ***PERFIT DESCRIPTION*****, in Johnson and Larkey, "Thomas Digges" (ref. 3), p. 78.**

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stars less than 10. Since these stars are suns and have disks a few hundred times smaller than the sun, they must be a few hundred times more distant than the sun, that is, more distant by a few hundred astronomical units (AU). The fainter stars have disks that are less than half the size of the brightest stars, and so must be more than twice as far away. In fact, the faintest stars visible to the naked eye, whose diameters, as seen through Mareo's telescope, are an arcsecond or less, must be two thousand or more AU distant. Very faint stars, seen only with his telescope, must be still more distant.

Mareo has a keen mind. He quickly realizes that this hypothesis is not just another speculation that can be backed only by assertions. This hypothesis is testable. Mareo's telescopic observations have told him that a star's apparent diameter D and its naked-eye magnitude M are linearly related, or $D \sim C - M$, where C is a constant. Since he believes he is seeing the physical bodies of stars, he believes that a star's apparent diameter D and its distance R are inversely related, or $D \sim 1/R$.[d] And if his hypothesis is correct and stars are indeed suns scattered throughout space, then the number of stars N within a radius R from Earth will go as the volume enclosed within that radius, or $N \sim R^3$. Tying everything together, if Mareo's hypothesis is correct, then the number of stars visible to the naked eye should increase with magnitude according to $N \sim 1/(C - M)^3$.

Intrigued, Mareo consults Ptolemy's star catalog in the *Almagest* for data on the number of stars by magnitude. He is pleased to find that the *Almagest* data is consistent with this equation (figure 5). Mareo has shown that the number of stars visible to the naked eye are observational evidence that supports his hypothesis – the night sky literally looks like suns scattered throughout space.[e]

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[d] Note that the inverse-square law is not used here – only simple geometry.

[e] I note that Johannes Kepler (1571-1630), in his *Epitome of Copernican Astronomy*, argued that the appearance of the night sky shows that the stars are not scattered throughout space; see Max Casper, ed., *Johannes Kepler Gesammelte Werke.* Band VII. *Epitome Astronomiæ Copernicanæ* [1618]. Liber Primvs. Pars Secvnda (München: C.H. Beck'sche Verlagsbuchhandlung, 1953), pp. 42-46; see also the 1635 edition, Book I, Part II, pp. 32-37, available online through Google books. His argument, however, assumed that stars in an infinite universe must be uniformly

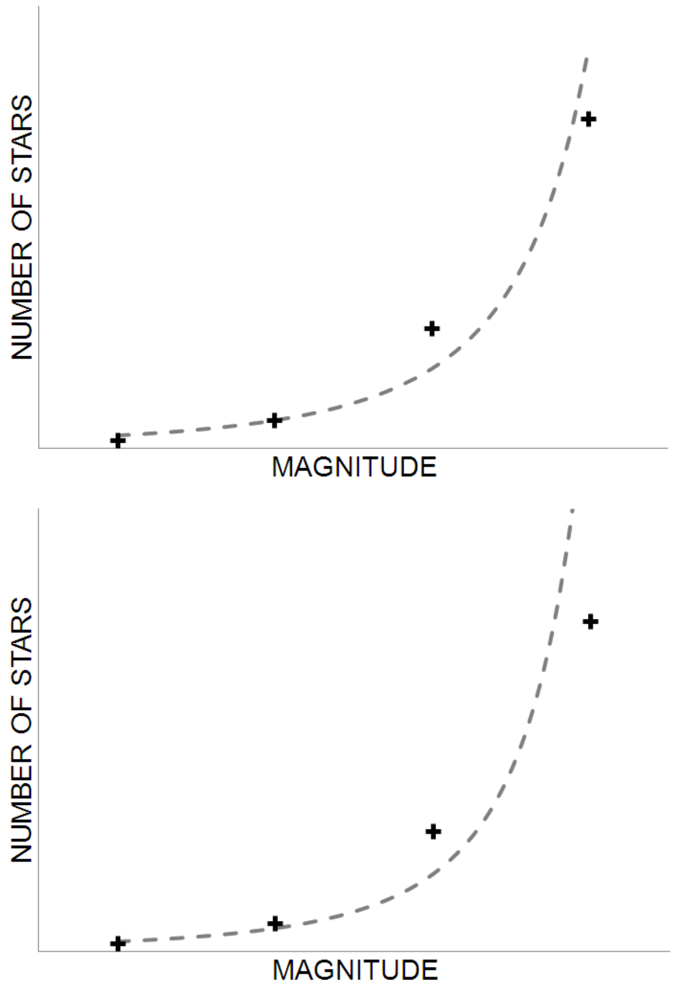

Fig. 5. Author's plot of fits of $N \sim 1/(C\text{-}M)^3$ to data from Ptolemy's *Almagest* on the number of stars *N* by magnitude *M* (*C* is a constant). Note that the "number of stars" is inclusive (the number of all stars brighter than a given magnitude). This shows stars of magnitudes 1, 2, 3, and 4; Ptolemy's *Almagest* contains only a few select stars fainter than magnitude 4. *Source*: C. Jaschek, "The Almagest: Ptolemy's star catalogue," *Bulletin d'information du Centre de la données stellaires* 33 (1987), 125; website <http://vizier.cfa.harvard.edu/viz-bin/VizieR?-source=V/61>.

arranged throughout space with geometric regularity, and that if stars varied in distance by a factor of two or three or more, then the more distant stars would not be visible; see Rhonda Martens, *Kepler's Philosophy and the New Astronomy* (Princeton and Oxford: Princeton University Press , 2000), p. 146. Kepler's arguments did not persuade those who had accepted Digges's ideas; see Johnson and Larkey, "Thomas Digges" (ref. 3), p. 116.

Now, if the stars are scattered throughout space – out to vast distances and perhaps to infinity – then it is absurd to think that the Earth is at rest with the stars rotating about it once each day. Even in the Aristotelian-Ptolemaic world system, where the stars are attached to a sphere that lies just beyond Saturn and circles Earth daily, the velocities of the stars are immense. If stars are scattered throughout space, yet still revolve about Earth, their velocities are simply immense beyond reason – even infinite if the universe is infinite. The Earth, not the stars, must be what rotates daily.

Mareo's systematic observations of the stars seem to be backing a Copernican (or Diggesian) world system – until he makes another discovery: A star that appears to be a single star when viewed with the naked eye is double when viewed with the telescope. The pair consists of a small star in close proximity to a large star. The data already has indicated that the stars are suns scattered throughout space, so such a pair must be in line-of-sight alignment. However, at the distances implied by Mareo's hypothesis, these two stars should exhibit parallax if the Earth is moving, and the difference between the parallaxes of the two stars (differential parallax) must greatly exceed their separation, as shown in figure 6. Mareo sees no differential parallax in this double star. He hunts for other double stars and finds a few – none of which show differential parallax. The data indicate that the Earth rotates, but does not circle the sun.

In light of all of his telescopic observations, Mareo concludes that in the true world system: (1) The Earth is fixed in location but has a daily rotation about its own axis. (2) The moon circles Earth monthly. (3) The sun circles Earth yearly, with its Tychonic retinue of moons (the planets), some of which (for example, Jupiter) have their own moons. (4) The stars are suns, scattered throughout space. (5) The universe is indefinitely large, at least thousands of AU in diameter, and possibly infinite.

This is the world system toward which Mareo's observational data drives him. It is not the Copernican world system. It is essentially the Tychonic world

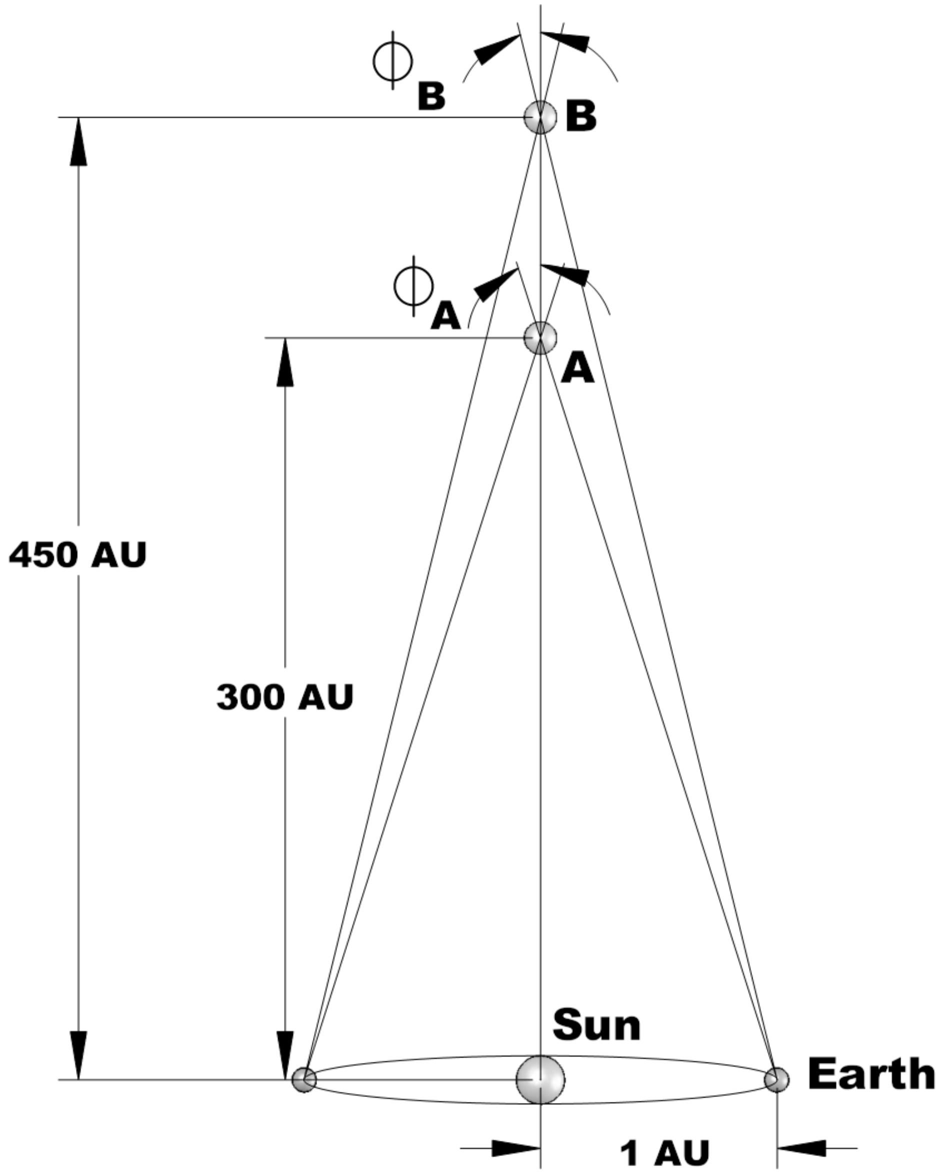

Fig. 6. Author's comparison of the differential parallax and the separation of two stars. Suppose, for example, that Mareo observes a double star and measures its larger component (A) to be 6″ in diameter, and its smaller component (B) to be 4″, and their separation to be 15″. Mareo takes the sun to measure 1800″ in diameter. Since he believes that he is seeing the physical bodies of stars, and that stars are suns, he concludes that the larger star is 1800/6 = 300 AU distant, and that the smaller star is 450 AU distant. Thus, the parallax angle for A is $\Phi_A = \tan^{-1}(1/300) = 688''$; likewise $\Phi_B = \tan^{-1}(1/450) = 458''$. The differential parallax $\Delta = \Phi_A - \Phi_B = 230''$, far greater than their separation of 15″. Thus, changes in separation should be noticeable in a short period of time.

system, but set within an indefinitely large universe of stars. A number of variations on the Tychonic world system had been proposed by the early 17th century; such systems are often referred to as "semi-Tychonic."

More Than a Thought Experiment: Galileo Galilei

Our thought experiment about Mareo is meaningless unless there is reason to believe that early 17th-century astronomers actually used the sort of instrument our Mareo used, made the sorts of observations our Mareo made, and thought the sorts of thoughts our Mareo thought. In fact, one early 17th-century astronomer, Galileo Galilei (1564-1642, figure 7), did use such nearly "optically perfect" instruments,[4] did make such observations, and did think such thoughts. Much of our thought experiment is based upon Galileo's ideas about the stars.

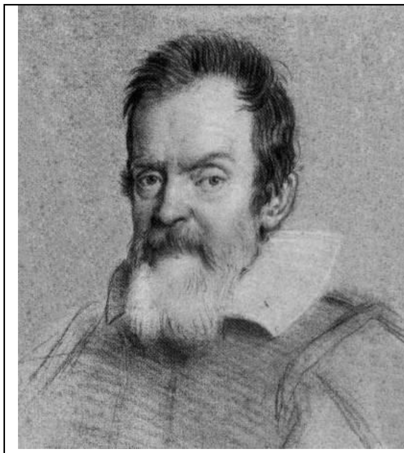

Fig. 7. Galileo Galilei (1564-1642). Ottavio Leoni, Italian (1578-1630) Portrait of Galileo Galilei, 1624. Engraving and etching 14.2 × 11.1 cm (image). Fine Arts Museums of San Francisco, Museum purchase, Achenbach Foundation for Graphic Arts Endowment Fund, 1968.13.27.

That Galileo had such ideas may surprise the reader. Modern discussions of Galileo's astronomical work tend either to overlook his views and discoveries concerning the stars, or to limit themselves to his description of them in his *Starry Messenger* of 1610, his first publication of his telescopic observations.

In his *Starry Messenger* Galileo describes his early impression of stars as seen through the telescope:

> [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, but sufficiently enlarged so that a star of the fifth or sixth magnitude seems to equal the Dog Star, largest of all the fixed stars.[5]

Galileo abandoned that early impression of the stars: In 1617, when he observed the double star Mizar,[f] he was thinking of stars as being measurable disks. His observing notes contain the following measurements in arcseconds: separation 0°, 0', 15″; larger star radius 0°, 0', 3″; smaller star radius 2"; gap between them 10".[6] He also notes that the radius of the sun contains 300 radii of the larger star, so the distance to the star contains 300 distances to the sun, if the star is the size of the sun.[7]

This mode of thought concerning the stars appears again in Galileo's ”Reply to Ingoli” of 1624:

> 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; from this it immediately follows that the distance to the stellar region is five hundred times greater than that between us and the sun.
>
> ……………………………..

[f] Mizar was neither the only double (or multiple) star that Galileo observed, nor the only one for which he left precise notes; see Seibert, “Early Search” (ref. 16). Galileo made a precise observation of the Trapezium; see Graney, “On the Accuracy” (ref. 10). His observing notes on the Trapezium are available in Favaro, *Opere* (ref. 7), Vol. III, p. 880. The reader will recognize these values as the ones used in calculating the differential parallax of the hypothetical double star in our thought experiment.

> [M]any 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.
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> ……………………………..
>
> I do not think the fixed stars are all placed on a spherical surface, so as to be equidistant from a particular point, such as the center of their sphere; indeed only God knows whether for any group larger than three there is a single point from which they are equidistant....[8]

Finally, the following ideas appear in Galileo's *Dialogue* of 1632:

> See, then, how neatly the precipitous motion of each twenty-four hours is taken away from the universe, and how the fixed stars (which are so many suns) agree with our sun in enjoying perpetual rest.
>
> ……………………………..
>
> [T]he 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 is no more than 5 seconds, or 300 thirds, and the diameter of one of the sixth magnitude measures 50 thirds [5/6 seconds]..., then 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.
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> ……………………………..
>
> For 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 corresponding to those of the outer planets [that is, exhibit differential parallax].
>
> ……………………………..
>
> [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.[9]

Thus, to a great extent, our Mareo resembles Galileo. Mareo's observations, measuring stellar disks that are mere arcseconds in diameter,[10] concluding that bright stars have larger disks than faint stars (specifically, that stars of magnitude $M = 1$ have diameter $D = 5''$ while stars of magnitude $M = 6$ have diameter $D = 5/6''$),[g] hypothesizing that stars are suns scattered throughout space – Galileo did all of this. However, Galileo did not follow his observations to their logical conclusions. He chose to back Nicholas Copernicus (1473-1543), relying on his unconvincing tidal theory to serve as evidence of Earth's motion.[11] He argued, in fact, that the stellar distances he calculated supported Copernicus. We see this by quoting further from his letter to Ingoli of 1624:

> [T]he distance to the stellar region is five hundred times greater than that between us and the sun. Now, what would you expect if the earth is displaced from the center of the stellar sphere by one or two parts in five hundred…? Who will be so simpleminded as to believe that ordinary astronomers can detect such a small increase or decrease in the diameter of a star [owing to Earth's annual motion around the sun]…? Thus the

[g] The evidence suggests that Galileo could indeed make the precise measurements he claimed to have made: He certainly seems to have been able to measure positions and diameters of stars at the arcsecond level; see Graney, "On the Accuracy" (ref. 10), pp. 443-446.

> objections of opponents [to the Copernican world system] are removed, as you see, simply by taking fixed stars … to be equal in size to the sun.[12]

Moreover, Galileo suggested that double stars could serve as convincing evidence of Earth's motion. In his *Dialogue* of 1632, he said that double stars would "appear in court to give witness to [annual] motion in favor of the earth."[13]

Unlike our Mareo, Galileo seems never to have realized that his hypothesis that stars are suns could be tested by naked-eye star counts. Had he attempted to do so, his results would have been much like our Mareo's results.[14] Thus, as noted above, the number of stars N visible to the naked eye increases with magnitude M according to $N \sim 1/(C - M)^3$, where C is a constant (figure 5), which agrees with Galileo's measurements within observational error, as seen in figure 8.

Concerning double stars, the degree of similarity between our Mareo and Galileo is questionable. When Galileo wrote in his *Dialogue* of 1632 about double stars appearing in court on the side of Copernicus, he had data on double stars in his notes that gave witness against Copernicus.[15] Thus, when he had observed Mizar in 1617 he was certainly aware that differential parallax in double stars could be used to test the Copernican world system. Harald Siebert has pointed out that one Lodovico Ramponi (baptized in 1577) wrote to Galileo in 1611 suggesting such use of differential parallax.[16] Both Siebert and Leos Ondra have pointed out that there is reason to believe that Galileo observed double stars intending to look for differential parallax.[17] Galileo's observations of double stars, combined with his later claims that data from double stars would support Copernicus "if" such double stars were found, pose difficult questions.[h]

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[h] One is tempted to impose sense on these questions by deciding that Galileo must have concluded that, in the case of Mizar, its two stars actually were physically close. This requires that Galileo allow for some variation in their physical sizes, but would explain why Mizar does not display the expected differential parallax. Then one decides that in his *Dialogue* he was speaking of what would occur "if" a true line-of-sight double star were found. However, in his observation

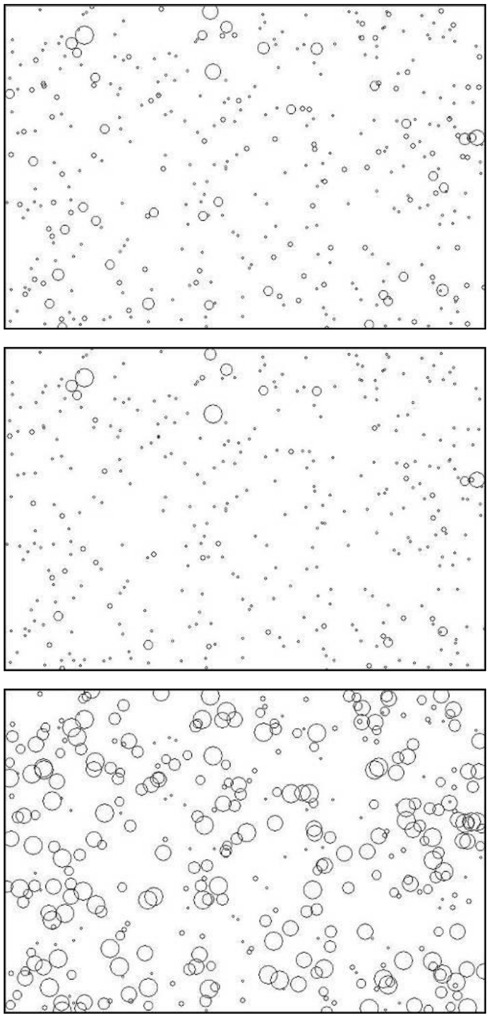

Fig. 8. Simulated field of stars of magnitudes 1 through 6 (larger circles represent brighter stars). *Top*: Number of stars of each magnitude in the proportions found in the actual sky. *Middle*: Number of stars calculated according to $N \sim 1/(C\text{-}M)^3$ assuming Galileo's measurements given in his *Dialogue* of 1632. *Bottom*: For comparison, equal number of stars of each magnitude. If stars are on a sphere any combination of magnitudes is possible. Note that their positions are unchanged; only the distribution of magnitudes varies from one simulation to the other.

of the Trapezium he records a factor of four or five in the variation in the size of stars separated by no more than Mizar's separation; see Favaro, *Opere* (ref. 7), Vol. III, p. 880. To explain the lack of differential parallax in the Trapezium requires those stars to be physically close – and varying in physical size by a factor of four or five. Galileo, as we saw, believed that the difference in apparent size between the brightest and faintest stars visible to the naked eye was only a factor of six. If stars can vary in physical size by a factor of four or five, then all of Galileo's ideas about stellar sizes and distances are completely undermined, and he may as well have advocated that the stars lie on the surface of a sphere.

At any rate, Galileo did not follow the data to its logical, Tychonic conclusion as did our Mareo. He withdrew from the data and backed the Copernican world system.

More Than a Thought Experiment: Simon Marius

Galileo did not follow the data to its logical Tychonic conclusion, but he was not the only early 17th-century astronomer with a telescope. Might a Mareo actually have lived? I hunted for a Mareo through the HASTRO-L history of astronomy discussion group. I proposed the ideas discussed in our Mareo's thought experiment and asked if anyone knew of a less well-known figure than Galileo who promoted such ideas. Discussion-group member Thony Christie pointed out that Simon Marius (1570-1624, figure 9) of Anspach, Germany, claimed that the appearance of stars through a telescope showed the universe to be Tychonic.[18]

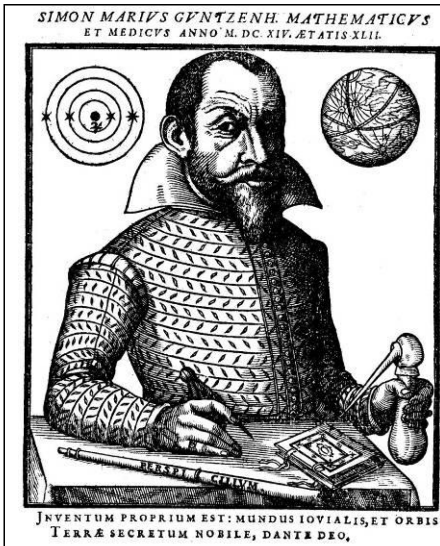

Fig. 9. Simon Marius (1570-1624) with tools, including a telescope. *Source*: *The 'Mundus Jovialis' of Simon Marius* (ref. 24), facing p. 403.

Literature about Marius and his work is scarce. What there is typically notes that he observed the Jovian system and claimed that he independently discovered the moons of Jupiter, thereby incurring Galileo's ire.[19] Commonly noted also is that Marius observed the Andromeda galaxy with his telescope, poetically describing its appearance as being like a candle seen through horn.[20] But his description of the Andromeda galaxy went well beyond poetry: He recorded its diameter, noted that it increased in brightness toward its center, and described the center as a dull, pale light.[21] Further, the well-known historian of astronomy J.L.E. Dreyer has suggested that Marius's skill at telescopic observation rivaled Galileo's: Marius observed the spurious disks of stars.[22] Anton Pannekoek, another well-known historian of astronomy, has pointed out that Marius, from his observations of Jupiter's moons, derived better values than Galileo had for their periods of revolution and other orbital elements.[23]

In any case, Marius's comments about stellar observations in his book, *The Jovian World* of 1614, are neither detailed nor well known: They are not included in the commonly available English translation of his book.[24] They are, however, included in its German translation.[25] Thus, Marius writes that gaining possession of a good telescope made it possible for him to see that brighter stars show disks, like the planets; this was something he could not see earlier. He goes on to say that he is truly surprised that Galileo has not seen this, and notes that Galileo writes in his *Starry Messenger* that the stars do not possess a defined circular shape. Marius then remarks that this supposedly is part of the strongest argument in favor of the Copernican world system – the lack of a round shape, indicating that the stars lie at an immense distance from Earth, as Copernicus said they must. But, says Marius, because the disks of the stars can be seen from Earth this argument is undercut – the fixed stars clearly are not at the immense distances required by Copernicus. Marius does not stop there. He makes clear that the stars actually argue against Copernicus, that their appearance agrees with the Tychonic world system (and Marius's own world system, which he claims he developed independently). Marius notes additional evidence for the Tychonic system in the moons of Jupiter (whose observed motions he could reconcile with his calculations only if they circled Jupiter while Jupiter circled the sun).[26] He adds that these ideas will require further discussion and explanation (which he does not provide). Finally, Marius concedes to Galileo that the stars shine by their own light – they are distinct in appearance from the planets, being notably more intense in brilliance.[27]

We see that Marius, like Galileo, observed the spurious disks of stars with a telescope and interpreted the disks as being the physical bodies of stars. Further, like Galileo, Marius observed that stellar disk size varies with magnitude,[i] and concluded that this variation reveals something about stellar distances. Unlike Galileo, however, Marius concluded that the telescopic appearance of the stars undermined – did not support – the Copernican world system. Instead, Marius used the stars to support a Tychonic world system, arguing that the telescopic appearance of stars shows that they are not distant enough to satisfy the requirements of a Copernican world system.

Unfortunately, Marius provided no details of his argument, so I must surmise what they were from what he did provide. Marius says that stellar disks argue for a Tychonic world system, but because stars show disks, this is in itself not a convincing argument for anything. The stars could be very large – they could be very large bodies at various great distances;[j] or they could be very large lights of various sizes on a stellar sphere. Still, Marius states that because the stars show disks they cannot be distant enough to satisfy the requirements of the Copernican world system. Since size alone cannot indicate distance, and since Marius was a careful observer who sought consistency between theory and observation (as can be seen in his study of the Jovian moons), I conclude that Marius followed the data and came to at least some of the conclusions to which our Mareo came. Marius's views seem to be more consistent with the data than Galileo's.

Conclusions

In the absence of an understanding of the wave nature of light, and hence an understanding of the Airy disk, early telescopic observers who possessed both high-quality telescopes and sufficient observing skill should conclude that they

[i] I infer this, because Marius notes that these disks are most prominent in the brighter stars.

[j] There was precedent for this idea: Digges had argued that the stars were bodies far larger than the sun; see figure 4 and Johnson and Larkey, "Thomas Digges" (ref. 3), pp. 69-117.

saw the physical bodies of stars. Then, careful observations, both of how the number of stars visible to the naked eye increases with magnitude, and of the lack of differential parallax in close double stars, should impel them to draw certain conclusions about the universe, namely, that the arrangement of the sun, moon, and planets are geocentric in a Tychonic world system, and that the stars are suns scattered throughout space. Galileo made the observations he needed to reach these conclusions, but despite the data his telescope provided he supported the Copernican world system. It seems that Simon Marius also made such observations, but unlike Galileo he followed the data to its Tychonic conclusion. Marius may well have been Galileo's equal in observing skill, and Galileo's superior in maintaining a clear-eyed, data-driven approach to learning about the universe.

A common view in the history of astronomy is that the telescope provided the means to determine that Copernicus was right – that Galileo and the telescope precipitated a revolutionary scientific breakthrough because observations broke down the old Aristotelian-Ptolemaic world system and supported the new Copernican world system. This is often overstated to the point of saying that Galileo "proved" that the Earth moves. We have seen that at the time of Galileo a thoughtful, thorough, logical acquisition and analysis of telescopic data indeed would have broken down the Aristotelian-Ptolemaic world system, but it would have supported a Tychonic, not a Copernican world system.

The above common view of the history of astronomy overlooks the powerful appeal that the Tychonic world system had even in the 17th and 18th centuries, as seen in the *Almagestum Novum* of Giovanni Battista Riccioli (1598-1671) of 1651 (figure 10) and in the *Atlas Coelestis* of Johann Gabriel Doppelmayr (1677-1750) of 1742 (figure 11). Perhaps because we know today that Tycho was wrong, we assume that his world system was merely a distraction – a last gasp of ancient geocentric thought that was doomed by the telescope. We have seen, however, that the telescope did not doom Tycho, at least around and

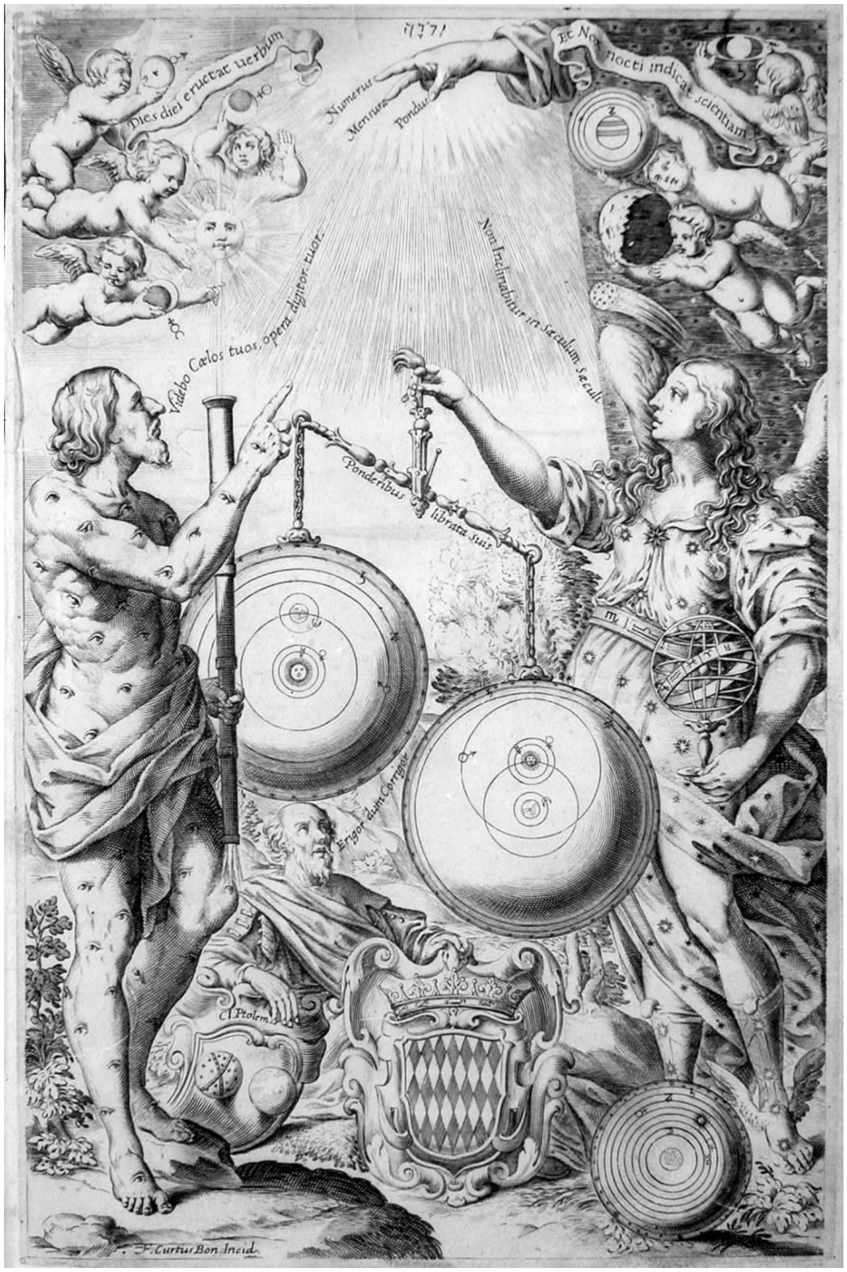

Fig. 10. In his *Almagestum Novum* of 1651, Ioanne Baptista Ricciolo [Giovanni Battista Riccioli] (1598-1671) compares the heliocentric Copernican and geocentric Tychonic world systems and finds that the latter is weightier. Note the Aristotelian system cast to the ground. *Source*: Ricciolo [Riccioli], *Almagestvm novvm astronomiam veterem novamqve complectens observationibvs aliorvm, et propriis Nouisque Theorematibus, Problematibus, ac Tabulis promotam, in tres tomos distribvtam qvorvm argvmentvm Sequens pagina explicabit.* Tomvs Primvs (Bononiæ: Ex Typographia hæredis Victorij Benatij, 1651), frontispiece.

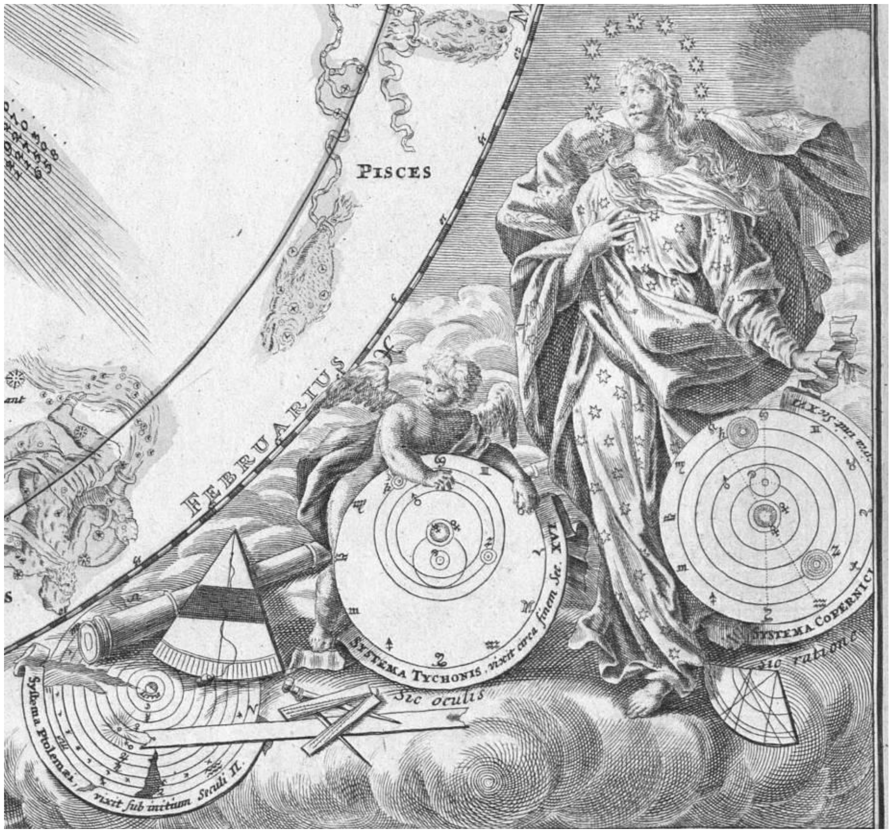

Fig. 11. In his *Atlas Coelestis* of 1742, Johann Gabriel Doppelmayr (1677-1750) shows the geocentric Tychonic world system in a place of respect, although it is shown as secondary to the heliocentric Copernican world system. Note the Aristotelian system smashed by the telescope. References to the geocentric Tychonic world system are not limited to this figure: Doppelmayr devotes a full page to it (and to various semi-Tychonic possibilities). *Source*: Doppelmayr, *Atlas Coelestis in quo Mundus Spectabilis et in eodem Stellarum omnium Phoenomena notabilia*… (Nuremberg: Heirs of Homann, 1742), plate 2.

even well after the time of Galileo and Marius. Thus, Robert Hooke (1635-1703), in his *Attempt to Prove the Motion of the Earth From Observations* of 1674, wrote:

> [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?[28]

Decades later, in 1720, astronomer Edmund Halley (1656-1742) still discussed the issue of whether telescopes revealed the physical bodies of stars.[29] Thus, he criticized a fellow astronomer who measured Sirius to have a disk with a diameter of 5″ and took that to be the physical body of the star. Halley said that the diameter of the disk might be an "Optick Fallacy," and argued (correctly, as it turned out) that the rapid disappearance of stars as the moon occults them showed that they were far smaller than 5″ in size.

At the dawn of telescopic astronomy, the data supported the Tychonic world system.

Acknowledgment

I thank Roger H. Stuewer for his careful and thoughtful editorial work on my paper.

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