As Big as a Universe: Johannes Kepler on the Immensities of Stars and of Divine Power

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Johannes Kepler accepted Tycho Brahe's claim that the Copernican hypothesis required all stars to be giant, something Brahe found absurd. Kepler argued in his De Stella Nova *that some stars were larger than Brahe's size for the entire universe. He also used the issue of star sizes to argue against Giordano Bruno's infinite universe. Kepler's acceptance of Brahe's ideas on star sizes appears in a variety of his writings, including his response to the anti-Copernican essay by Msgr. Francesco Ingoli that cited the star size issue, an essay Galileo had felt was influential in the rejection of the Copernican hypothesis by authorities in Rome in 1616. Kepler's writings illustrate how certain supporters of Copernicus viewed the universe of stars and relied on divine power to undergird that view. Decades after Kepler, the discovery that the star size problem rested on a formerly unrecognized optical effect both freed the Copernican hypothesis from Brahe's charge of absurdity and negated Kepler's argument against Bruno.*

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How did Johannes Kepler handle Tycho Brahe's "star size" argument against the Copernican hypothesis? This is the argument that said that the Copernican hypothesis required the stars to surpass greatly (to the point of absurdity, in Brahe's opinion) the Sun in size. Christiaan Huygens called this Brahe's "principal argument" against Copernicus.[1] It was a key argument in the essay Msgr. Francesco Ingoli wrote to Galileo in 1616 shortly before the authorities in Rome rejected the Copernican

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1. Christiaan Huygens, *The Celestial Worlds Discover'd: or, Conjectures Concerning the Inhabitants, Plants, and Productions of the Worlds in the Planets*, 2nd ed. (London, 1722), 145.

hypothesis. We might expect that Kepler was able to demolish easily this argument. However, an examination of Kepler's writings reveals that he simply accepted the substance of the argument. Indeed, Kepler argued for a heliocentric universe in which the Sun was surrounded by giant stars—so giant, in fact, that every star seen in the sky, even the smallest, was a globe of such size as to fill the orbit of the Earth, while the largest were beyond the size estimated by Brahe for the entire universe. Kepler simply claimed that stars the size of a universe were possible, thanks to divine power, and more reasonable than the geocentric alternative. His views regarding stars and their sizes are consistent with those of other Copernicans such as Thomas Digges, Christoph Rothmann, and Phillips Lansbergen, and they are consistent with the portrayal of Copernican views by anti-Copernican critics like Christoph Scheiner and Johann Georg Locher, and Giovanni Battista Riccioli.

A convenient point from which to begin a study of Kepler's views on this matter is the rejoinder he wrote in 1618 in response to an anti-Copernican essay that Galileo believed to have been particularly influential—the essay by Ingoli.[2] Ingoli had written the essay to Galileo in early 1616, prior to the rejection of heliocentrism by the Congregation of the Index in Rome in early March of that year.[3] Galileo regarded Ingoli's essay to have been an important factor in that rejection.[4] Maurice Finocchiaro has written that the Inquisition in Rome had probably commissioned Ingoli to write an expert opinion on the heliocentrism controversy; Finocchiaro has described Ingoli's essay as being the chief direct basis for the rejection of the Copernican hypothesis by Inquisition consultants in late February of 1616.[5] Ingoli presented Galileo with twenty-two anti-Copernican arguments, four of which Ingoli described as "theological," the rest of which he described as "mathematical" and "physical." Ingoli did not ask Galileo to respond to all the arguments but rather to the better ones from the mathematical and physical arguments. The mathematical and physical argu-

2. Paolo Galluzi, *The Lynx and the Telescope: The Parallel Worlds of Federico Cesi and Galileo* (Leiden, 2017), 240; Kepler's response to Ingoli's essay can be found as "Responsio ad Ingoli disputationem de systemate," in *Nuovi Studi Galileiani*, ed. Antonio Favaro (Venice, 1891), 173–84.

3. Maurice A. Finocchiaro, *Defending Copernicus and Galileo: Critical Reasoning in the Two Affairs* (Dordrect, 2010), 72; Maurice A. Finocchiaro, *The Galileo Affair: A Documentary History* (Berkeley, 1989), 347n2; Annibale Fantoli, *Galileo: For Copernicanism and for the Church* (Rome, 1994), 240–41.

4. Galileo's discussion of this matter can be found in his own 1624 reply to Ingoli, published in translation in Finocchiaro, *Galileo Affair*, 155.

5. Finocchiaro, *Defending Copernicus*, 72.

ments ranged widely in quality, but the more cogent ones were taken directly from Brahe with Ingoli citing the latter by page number.[6]

Brahe based the star size argument on the requirement of the heliocentric theory that the stars be very distant in order to explain why Earth's annual motion around the Sun produced no corresponding visible annual changes in their appearance—no "annual parallax." For instance, stars were not seen to grow brighter and dimmer owing to Earth moving toward and away from them as it journeyed around the Sun. To explain this Brahe noted the orbit of the Earth was like a point in comparison to the vast distance to the stars—negligible in size. The stars have a measurable apparent size as seen from Earth. He had measured these sizes. He determined that the more prominent or "first magnitude" stars measured a little less than a tenth the apparent diameter of the Moon—a little less than three minutes of arc since the Moon has an apparent diameter of approximately thirty minutes, or one half of one degree. At the vast distance required for the stars in the heliocentric hypothesis, these apparent sizes translated into enormous physical sizes. Were Copernicus correct, every one of the stars would have to dwarf the Sun. The Sun would be a unique, small body in a universe of giants.[7]

A decade after Brahe died, Johann Georg Locher, working under his mentor, the German Jesuit astronomer Christoph Scheiner, neatly summarized Brahe's objection in their 1614 book *Disquisitiones Mathematicae*. Locher wrote that, in the Copernican hypothesis, the Earth's orbit is like a point within the universe of stars; but the stars, having measurable sizes, are larger than points; therefore, in the Copernican hypothesis every star must be larger than Earth's orbit, and thus immensely larger than the Sun itself.[8]

The giant stars of the Copernican hypothesis stood in contrast to the more commensurate star sizes found in Brahe's own hypothesis, a hybrid geocentric (or geo-heliocentric) hypothesis in which the Sun, Moon, and stars circled an immobile Earth, while the planets circled the Sun (Figure 2). Brahe's hypothesis was observationally and mathematically identical to the Copernican hypothesis insofar as the Sun, Moon, and planets were

6. Ingoli's essay, with an English translation and with analysis of the arguments he presents, can be found in Christopher M. Graney, *Setting Aside All Authority: Giovanni Battista Riccioli and the Science Against Copernicus in the Age of Galileo* (Notre Dame, IN, 2015), 66–76, 164–195.

7. Graney, *Setting Aside*, 32–38.

8. Christopher M. Graney, *Mathematical Disquisitions: The Booklet of Theses Immortalized by Galileo* (Notre Dame, IN, 2017), 30.

FIGURE 1. Johannes Kepler (1571–1630), German Astronomer and Mathematician (Wikimedia Commons).

concerned. However, since the Earth did not move relative to the stars in Brahe's geocentric hypothesis, there was no expectation of annual parallax, and thus no need for the stars to be distant in order to explain the absence of observable parallax. Brahe had the stars located just beyond Saturn. Since the stars were roughly similar to Saturn in both distance and in their appearance in the night sky, they had to be similar to Saturn in physical size, too. In Brahe's hypothesis, the sizes of the Earth, Sun, Moon, and planets were commensurate, with the Moon being smallest and the Sun being largest, as opposed to the case in the Copernican hypothesis, where every last star dwarfed Sun, Moon, and planets (see Figures 3 and 4).[9] After the advent of the telescope, various astronomers, starting with Simon Marius in his *Mundus Jovialis* of 1614, would agree that, while the telescope showed that the size measurements by Brahe were too large, the telescope still showed the stars to have measureable disks, and yet the telescope also detected no annual parallax.[10] And so the argument remained. As Locher had said, so long as the apparent sizes of stars were measurable, but the motion of Earth was not, then every star must be larger than Earth's orbit.

9. Graney, *Setting Aside*, 32–38.
10. Graney, *Setting Aside*, 45–59.

FIGURE 2. Tycho Brahe's hypothesis. Earth is immobile at center. Mercury, Venus, Mars, Jupiter, and Saturn circle the Sun as in the Copernican hypothesis, while the Sun circles the Earth (as do the Moon and stars).[11]

Ingoli raised the star size issue early in his essay. His second and third arguments were both mathematical arguments pertaining to matters related to parallax. These two arguments—one which Ingoli cites as coming from Sacrobosco, the thirteenth-century author of a long-standard astronomy textbook, the other from Ptolemy, the ancient astronomer who was the author of the *Almagest*—cite two different effects that would be visible in the fixed stars, were the Earth not in the center of the universe, as it would not be, were it orbiting the Sun. The Copernican answer to such arguments was, of course, that the orbit of Earth is of negligible size compared to the distance to the stars, so the effects are not seen. At this point Ingoli brings in the star size question, saying:

> Nor does the solution [to the two arguments] entirely satisfy by which is said: the diameter of the circle of the orbit of Earth in comparison to the vast distance of the eighth orb [of stars] from us to be made so small [as to yield an effect too small to measure].[12]

11. Johann Georg Locher, *Disquisitiones Mathematicae, de Controversiis et Novitatibus Astronomici* (Ingolstadt, 1614), 52.

12. Graney, *Setting Aside*, 71, 167.

He then cites a page of Brahe's *Astronomical Letters* and calculations showing that the stars would have to be distant by 16,506,000 semidiameters of the Earth in the Copernican system for annual parallax to be too small to detect, versus 14,000 in Brahe's hypothesis—this being the first time that Ingoli mentions him in the essay. Ingoli continues:

> [S]uch a truly great distance not only reveals the universe to be asymmetric, but also clearly proves, either the fixed stars to be unable to operate in these lower regions, on account of the excessive distance of them; or the fixed stars to be of such size, as to surpass or equal the size of the orbit circle of Earth itself.[13]

This star size objection is arguably the strongest argument in Ingoli's essay (unsurprisingly, it being Brahe's "principal argument"). Albert van Helden has written that "Tycho's logic was impeccable; his measurements above reproach. A Copernican simply had to accept the results of this argument" and agree that the stars were giant. Yet Paolo Gulluzi has recently written that Kepler "had no difficulty in demolishing Ingoli's weak arguments."[14] Granted that Ingoli's arguments were largely Brahe's, and at least one was not weak, that seems unlikely.

Indeed, in his response to Ingoli's essay Kepler did not demolish the star size argument; rather he did exactly as Van Helden said: he simply accepted that the stars were giant. Referring to his *De Stella Nova*, Kepler writes:

> [Ingoli] declares such a great distance of the fixed stars from the Earth to be 'asymmetrical'; he speaks ungeometrically concerning a geometrical thing: no size is made 'asymmetrical' on account of an exceedingly great quantity, because indeed 'asymmetry' considers quantities rendered according to a subject. . . . But if he speaks concerning the form of the universe, I ask, based on what laws might he examine the works of the hands of God, so as to declare them out of proportion? I have shown [in *De Stella Nova*] the proportion to be greater between a mite in the skin of the hand of a man and that [120-foot] African serpent. . . . Why, in the eyes of Ingoli, is a distance of 16,506,000 semidiameters of Earth excessive, but not 14,000? Men make what comparison? Based on what human examples might the confident mind of Ingoli reject the works of God as excessive? Has he said, the fixed stars are unable to *operate* on Earth? We may say nothing concerning *operating*, a thing not acknowledged by all: we may say something concerning *illumination*, which is the operation which lies open to the eyes. Why might those fixed stars,

13. Graney, *Setting Aside*, 71–72, 167–168.
14. Galluzi, 240.

> which illuminate through 14,000 semidiameters, not illuminate through 16,506,000? If they are a thousand times more remote, they will also be that many times larger: thus the effect of the illumination of the Earth will remain the same.[15]

Thus Kepler readily grants that a thousand-fold increase in the distance of the stars requires a thousand-fold increase in their physical size as well. Referring to *De Stella Nova*, he writes, "I have dissolved the pretended absurdity of the magnitudes of the fixed stars"[16] in the Copernican hypothesis. It is the absurdity that Kepler claims to dissolve, not the magnitudes.

Kepler refers to Chapter 16 of *De Stella Nova*.[17] There we find him discussing Brahe's view on giant stars:

> Brahe finds a lack of elegance in the most perfect of works, if the vastness of the sphere of one of the fixed stars be so insane; the meagerness of all the wandering stars [planets] so contemptible. How huge the fault in the human body, he says, if the finger, if the nose, might surpass by many times the bulk of the whole remainder of the body.[18]

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15. Kepler, "Responsio," 175: "Primo dicit tantam distantiam fixarum respectu telluris esse ασυμετρον, non Geometrice loquitur de Geometrica re: nulla magnitudo fit ασυμμετρος propter quantitatem nimis magnam, quia ασυμμετρια habet quidem quantitates relatas pro subiecto.... Si autem loquitur de conformatione mundi, quaero ad quas leges examinet opera manuum Dei, ut ea improportionata dicat. Ostendi maiorem esse proportionem inter scirum animalculum subcutaneum in manu hominis, et serpentem illum africanum.... cur nimium est in oculis Ingoli quod continent 16506000 semidiametros Terrae, nec est nimium quod 14000 continetur? quid simile faciunt homines? quibus exemplis humanis confirmatus Ingoli animus repudiet opera Dei ut nimia? Convincit, inquit, fixas nihil in terram operari? nihil de operatione dicamus, re non ab omnibus confessa: dicamus de illuminatione, quae est operatio quae patet oculis, cur quae per 14000 semidiametros illuminant, non illuminent per 16506000? Si millies ducenties sunt remotiores, erunt et toties maiores: ita effectus illuminationis terrae manebit idem." In the translation, italics are my addition, and words in 'single quotation marks' are words Kepler wrote in Greek.

16. Kepler, "Responsio," 175: "de stella nova... ubi pluribus dissolvi praetensam absurditatem magnitudinis fixarum"

17. For secondary sources that discuss Chapter 16 see Patrick J. Boner, "Kepler's Copernican Campaign and the New Star of 1604," in *Change and Continuity in Early Modern Cosmology*, ed. Patrick J. Boner (New York, 2011), 101–106; Albert Van Helden, *Measuring the Universe: Cosmic Dimensions from Aristarchus to Halley* (Chicago, 1985), 62–63; Robert S. Westman, *The Copernican Question: Prognostication, Skepticism, and Celestial Order* (Berkeley, 2011), 398–99. For a complete English translation of Chapter 16, see Christopher M. Graney, "Of Mites and Men: Johannes Kepler on Stars and Size (with an English translation of Chapter 16 of his 1606 *De Stella Nova*)" (2018) https://arxiv.org/abs/1802.03313. This translation has not been peer reviewed.

18. Johannes Kepler, *De Stella Nova*, (Prague, 1606), 83: "Braheus... dum concinnitatem in perfectissimo opere desiderat; si Sphaerae unius fixarum tam insana sit vastitas;

Here also we find a discussion of that proportion of length mentioned by Kepler in his response to Ingoli, between a 120-foot serpent noted by Pliny and a mite. He remarks that the length of the snake exceeds that of the mite by a factor of 100,000. Then he compares the size of human beings to the Earth and to the universe. A variety of sizes clearly exists in the universe.[19] Thus Kepler finds no problem stating that the distance from the Sun to the fixed stars holds the same proportion to the orbit of Saturn as the distance from the Sun to Saturn holds to the diameter of the Sun itself. The Sun seen from Earth has an apparent diameter of thirty minutes. Saturn is ten times farther from the Sun than Earth. Thus the Sun seen from Saturn would have an apparent diameter of three minutes. And therefore, says Kepler, the orbit of Saturn seen from the fixed stars would have an apparent diameter of three minutes.[20]

Kepler argues that what is commensurate in a Copernican universe are speeds. "The perfection of the universe is motion, which is, as it were, a certain life of it," he states.[21] In a Copernican universe, speeds range from Saturn, moving at 300 German miles per hour, to Mercury, moving at 1000—"a beautiful proportion," he writes, "where what is nearer to the quiescent Sun (the dispenser of all movement) is always swifter."[22] Even the speeds of the day and night sides of Earth, and the velocity of the moon, fall into this same general range. Everything in the Copernican solar system moves at speeds ranging from about 250 to about 1250 miles per hour.

Kepler contrasts this with the geocentric universe:

> Go now to Ptolemy and the ancient opinion; you will find everything more incredible. In that, the semidiameter of the sphere of the fixed stars occupies twenty thousand semidiameters of Earth. The circumference therefore will be 63,000[23]—truly a reasonable number, compared to the Copernican, but which all is said to go round in one day. Therefore 2625

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mobilium vero omnium tam contempta exilitas. Quemadmodum, ait, in corpore humano ingens vitium, si digitus, si nasus, multis partibus superet molem totius reliqui corporis."

19. Kepler, *De Stella Nova*, 87–88.

20. Kepler, *De Stella Nova*, 86–87.

21. Kepler, *De Stella Nova*, 86: "Mundi perfectio est motus, quae ejus quasi quaedam vita est."

22. Kepler, *De Stella Nova*, 83: "Pulchra proportio, ubi semper velocior, qui est Soli quiescenti, motusque omnis dispensatori propinquior." Kepler's German mile is equal to 4.4 English miles—Van Helden, *Measuring the Universe*, 177.

23. $20{,}000 \times \pi = 63{,}000$. As circumference is π times diameter rather than semidiameter, this number is too small by half. There are a variety of such typos in Kepler's text of Chapter 16.

> semidiameters (each of which contains 860 miles) are covered in one hour.[24] Behold here what to me is an immense distinction. In the view of Ptolemy, Saturn is the nearest to the fixed stars, such that it will almost touch them. Following Copernicus, in one hour it traverses 300 miles; following Ptolemy, 2,257,500 miles.[25] Saturn must be believed to be 7,525[26] times swifter under Ptolemy, than under Copernicus. Whoever attempts mentally to comprehend this incredible velocity is overcome just as much as, and indeed more severely than, someone who attempts to comprehend the Copernican immensity.[27]

Kepler notes that Tycho Brahe's hypothesis yields a somewhat more compact universe, and thus somewhat lower speeds, but the geocentric speed problem remains.[28] He adds that it is more credible to have a vast thing with no motion, than a small thing with great motion.[29] He also notes that size means nothing to God:

> Where magnitude waxes, there perfection wanes, and nobility follows diminution in bulk. The sphere of the fixed stars according to Copernicus is certainly most large; but it is inert, no motion. The universe of the movables [the planets] is next. Now this—so much smaller, so much more divine—has accepted that so admirable, so well-ordered motion. Nevertheless, that place neither contains animating faculty, nor does it reason, nor does it run about. It goes, provided that it is moved. It has not developed, but it retains that impressed to it from the beginning. What it is not, it will never be. What it is, is not made by it—the same endures, as was built. Then comes this our little ball, the little cottage of us all, which we call the Earth: the womb of the growing, herself fashioned by a certain internal faculty. The architect of marvelous work, she kindles daily so many little living things from herself—plants, fishes,

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24. 63,000 / 24 = 2625

25. 860 × 2625 = 2,257,500

26. 2,257,500 / 300 = 7,525

27. Kepler, *De Stella Nova*, 84: "Ito nunc ad Ptolemaeum, & antiquam sententiam; omnia invenies incredibiliora. In illa semidiameter Sphaere fixarum vicies millenas Telluris semidiametros possidet; ambitus igitur erit sexagies ter millium. Modesta sane multitudo, comparata ad Copernicanam; sed quae omnis in uno die circumire dicitur. Debentur igitur uni horae semidiametri 2625: quarum quaelibet 860 milliaria continet. Hic vide mihi immensum discrimen; Saturnus, qui est apud Ptolemeum fixis proximus, ut eas tantum non tangat, Copernico in una hora trajicit per 300 milliaria, Ptolemaeo vicies bis centena millia quinquagies septies mille quingenta milliaria. Credendus est igitur velocior apud Ptolomaeum, quam est apud Copernicum, septies mille, quingenties vicies quinquies. Quicunque tentaverit mente comprehendere hanc incredibilem velocitatem; aeque fatigatur, & vehementius etiam, quam qui Copernicanam immensitatem."

28. Kepler, *De Stella Nova*, 86.

29. Kepler, *De Stella Nova*, 85.

> insects—as she easily may scorn the rest of the bulk in view of this her nobility. Lastly behold if you will the little bodies which we call the animals. What smaller than these is able to be imagined in comparison to the universe? But there now behold feeling, and voluntary motions—an infinite architecture of bodies. Behold if you will, among those, these fine bits of dust, which are called Men; to whom the Creator has granted such, that in a certain way they may beget themselves, clothe themselves, arm themselves, teach themselves an infinity of arts, and daily accomplish the good; in whom is the image of God; who are, in a certain way, lords of the whole bulk. And what is it to us, that the body of the universe has for itself a great breadth, while the soul lacks for one? We may learn well therefore the pleasure of the Creator, who is author both of the roughness of the large masses, and of the perfection of the smalls. Yet he glories not in bulk, but ennobles those that he has wished to be small.
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> In the end, through these intervals from Earth to the Sun, from Sun to Saturn, from Saturn to the fixed stars, we may learn gradually to ascend toward recognizing the immensity of divine power.[30]

This brings Kepler to the question of star sizes. Since he has stated that the orbit of Saturn would have an apparent diameter of three minutes as seen from the sphere of the stars, any star with an apparent diameter of three minutes as seen from Earth must be equal in physical size to the orbit of Saturn—that is, to the entire solar system. Hence Sirius, the most prominent of all the stars, which according to Kepler appears larger than three minutes, must be larger than the entire solar System, and the awe-

30. Kepler, *De Stella Nova*, 88: "Ubi superat magnitudo, ibi deficit perfectio, & in molis deminutionem succedit nobilitas. Amplissima sane est Copernico Sphaera fixarum; sed iners, motu nullo. Sequitur Mundus mobilis. Hic jam quanto minor tanto divinior quod motum accepit tam admirabilem, tam ordinatum. Neque tamen vegetante facultate constat locus iste; neque ratiocinatur, neque discurrit: quod agit (dum movetur,) non didicit, sed impressum sibi a principio retinet; quod non est, neque erit unquam; quod est, id a seipso non est factus; idem manet, qui conditus est. Succedit ergo pilula haec nostra, tuguriolum nostrum; quod Tellurem dicimus, matrix vegetabilium, ipsa intus informata facultate quadam, mirabilium operum architectatrice; quae accendit de se ipsa tot stirpium, tot piscium, tot insectorum animulas quotidie; ut facile molem reliquamprae hac sua nobilitate contemnat. Denique vide mihi corpuscula, quae animalia dicimus, quibus quid exilius in comparatione mundi fingi potest? At ibi jam sensus, & voluntarij motus, architectura corporum infinita. Vide mihi inter illa, pulvisculos hos, quos Homines dicunt; quibus Creator hoc dedit, ut quodammodo a seipsis nascantur, seipsos vestiant, arment, doceant infinitas artes, & quotidie proficiant in melius; in quibus Dei imago; qui domini quodammodo sunt totius molis. Et quis est nostrum, qui optet sibi corpus, Mundi amplitudine, ut pro ea careat anima? Discamus igitur creatoris bene placitum; qui & rudis molis, & minutorum perfectionis author est: nec tamen mole gloriatur, sed nobilitat illa, quae minuta esse voluit. Denique per haec intervalla a Tellure ad Solem, a Sole ad Saturnum, a Saturno ad fixas, discamus paulatim conscendere ad agnoscendum divinae potentiae immensitatem."

some "new star" or *nova* of 1604 that is the subject of his book must be even larger than Sirius:

> I have gladly inserted so much here concerning the objections to the Copernican vastness of the fixed stars, because it all pertains to the incredible magnitude that must be estimated for the new star. For if it occupies only four minutes (the size Sirius appears), then through this hypothesis of Copernicus it is much greater than the whole machinery of the movables [the planetary system]. For earlier we were granting to that machinery only three minutes, were it to be seen from the fixed stars.[31]

It follows from Kepler's numbers that Sirius and the nova must each rival or exceed the size of an entire geocentric universe, since, as he has noted, in geocentric hypotheses the fixed stars lay just beyond Saturn. Furthermore, any star whose physical size was the same as Earth's orbit, namely one tenth the size of Saturn's orbit, would have an apparent diameter of three tenths of a minute, or eighteen seconds. This is the apparent diameter that Brahe had determined for the sixth-magnitude stars (those barely visible to the eye). Since according to Kepler the physical diameter of the Sun is less than one hundredth that of Earth's orbit, clearly every last star in the sky utterly dwarfs the Sun. To Kepler, the Sun and its planets are surrounded by giants, and only by giants.

Later on, in Chapter 21 of *De Stella Nova*, Kepler discusses further the link between stellar sizes and distances. Regarding stars in Orion's belt that all have an apparent diameter of about two minutes he writes:

> Certainly should any one [of these stars] be higher by two, three, a hundred times, it will therefore be larger by two, three, a hundred times. Indeed, you may say it is elevated however much you like—you will never arrange things so that it may be seen by us to not have a diameter of two minutes. Consequently the diameter will always be two thousandths, one thousandth, or some such portion of the distance from us. . . . And so by whatever amount anyone moves the stars up further into an infinite altitude, by that amount he creates more monstrous bulks therein.[32]

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31. Kepler, *De Stella Nova*, 89: "Et haec, de objecta Copernico vastitate fixarum, tanto libentius inserui, quod pertinuerint ad incredibilem novi sideris magnitudinem aestimandam. Nam si quatuor solum minuta occupavit (quantus Sirius apparet) jam per hanc hypothesin Copernici tota machina mobilium multo fuit major; ut cui tria solum minuta tribuebamus supra, si quis illam a fixis respiceret."

32. Kepler, *De Stella Nova*, 108: "Certe ut quaelibet duplo, triplo, centuplo altior, ita duplo, triplo centuplo erit major. Quippe quantumcunque dicas elevatam; nunquam efficies, ut non videatur habere a nobis duum minutorum diametrum. Semper igitur diameter distanciae a nobis erit pars bis millesima, aut millesima, aut tale quippiam....

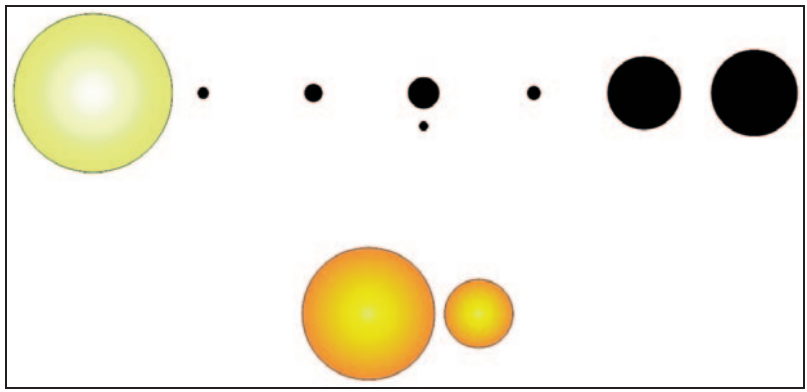

FIGURE 3. The relative sizes of celestial bodies calculated by Tycho Brahe, based on his observations and measurements, for (from left to right, upper row) the Sun, Mercury, Venus, Earth and Moon, Mars, Jupiter, Saturn, as well as for (lower row) a large star and a mid-sized star in a hybrid geocentric universe (where the stars lie just beyond Saturn, as in Figure 2). Sun, stars, and planets all fall into a fairly consistent range of sizes. (Courtesy of the Author)

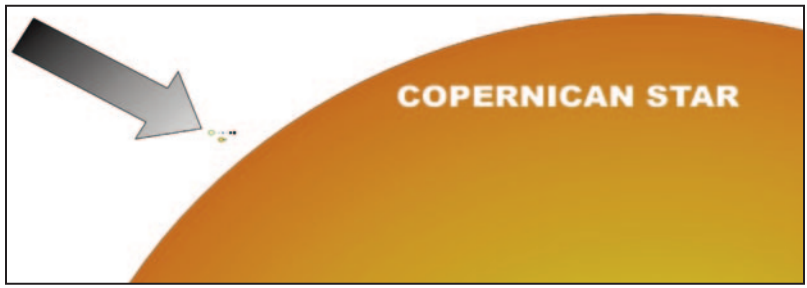

FIGURE 4. The arrowed dots are those in Figure 3 above, reproduced to scale compared to Brahe's calculated relative size for a mid-size star in the Copernican universe (where the stars lie at vast distances, and thus must be enormous to explain their apparent sizes as seen from Earth). Brahe said the huge Copernican stars were absurd. (Courtesy of the Author)

Itaque quo magis quis stellas in infinitam subvehit altitudinem; hoc monstrosiores illic fingit moles; quales ex hoc nostro mundi loco non cernuntur." See Alexander Koyré, *From the Closed World to the Infinite Universe* (Baltimore, 1957), 68, for a looser translation, but note that Koyré does not translate the double negative of "you will never arrange things so that it may be seen by us to not have a diameter of two minutes [nunquam efficies, ut non videatur habere a nobis duum minutorum diametrum]," writing instead "you will never obtain that it would be seen by us as having a diameter of two minutes."

Kepler writes this as part of an argument against an infinite universe. Indeed, he turns Brahe's star size argument to his own purposes: if the universe goes out to infinity as Giordano Bruno has said, then all sorts of problems arise in the sizes of the stars.[33] A more explicit example of this, also from the discussion against Bruno:

> If some stars are infinitely high, they themselves will also be infinite in themselves by bulk of body. For, imagine some star which seems to subtend a definite angle—suppose four minutes. The breadth of such a body is always one thousandth of its distance, as is absolutely certain from geometry. Therefore, if the distance is infinite, the diameter of the star is one thousandth part of infinity. But all the fractional parts of the infinite must themselves be infinite. Consequently such a star will be infinite. But at the same time it is also finite, because it has a shape. . . .[34]

Accordingly, when Kepler says that in *De Stella Nova* he dissolved the pretended absurdity of giant stars in the Copernican hypothesis, he clearly means that he has successfully argued that giant stars are not absurd. He does not intend that he has argued against the existence of giant stars, for *De Stella Nova* certainly endorses Brahe's argument that all stars in the Copernican universe must be giant.

The Ingoli rejoinder and *De Stella Nova* are not the only places where Kepler writes on these matters. In his *Dissertatio cum Nuncio Sidereo* of 1610 we find the following, as part of a discussion on the nature of stars, against Bruno's infinite universe:

> Will my opponent tell me that the stars are very far away from us? This does not help his cause at all. For the greater their distance, the more does every single one of them outstrip the Sun in diameter.[35]

In his 1618 *Epitome astronomiae Copernicanae* we again find the example of the stars in Orion's belt and the argument against stars being

33. Koyré, 58–87.

34. Kepler, *De Stella Nova*, 109: "si fixae aliquae sunt infinite altae, erunt ipsae in seipsis infinita etiam mole corporum. Finge namque stellam aliquam, quae videtur certo sub angulo, puta minutorum quatuor; hujusmodi corporis amplitudo semper est millesima distantiae, quod certissimum est, ex Geometria. Ergo si distancia est infinita; diameter igitur stellae, est infiniti pars millesima. At omnes infiniti partes aliquotae, infinitae & ipsae sunt necessario. Stella igitur hujusmodi erit infinita. At simul & finita, quia figurata"; translation borrowed from Edward Rosen, *Kepler's Conversation with Galileo's Sidereal Messenger* (New York, 1965), 129, with minor modifications.

35. Rosen, 35.

at infinite distances, again all part of an argument against any infinity of the universe.[36]

Clearly Kepler was a Copernican who believed that the universe as a whole is heliocentric—that our solar system is surrounded by a finite universe of distant but giant stars that all vastly exceed the Sun in size, and that the whole thing testifies to the Power of God. He seems to not have been alone. Christoph Rothmann granted to Brahe whatever sizes for stars he wanted. "It reckons that the greater the King, so much more greater and larger the palace befitting his Majesty," Rothmann wrote Tycho, asking him what palace is too large for God. Thomas Digges described the starry universe as the "palace of felicity," full of innumerable stars "far excelling our Sun both in quantity and quality," the very court of celestial angels and the dwelling place of the Elect. Philips Lansbergen proposed that the stars were God's army and the palace guard of Heaven itself—their vast sizes showing them to be suitable warriors for, and their vast numbers (as revealed by the telescope) showing them to be suitably numerous to make an army large enough for God—a view Lansbergen believed to be well-supported by scripture.[37]

Thus the anti-Copernicans Locher and Scheiner noted that Copernicus's "minions" invoked God in response to the star size question. "They go on," Locher wrote in *Disquisitiones Mathematicae*, "about how from this everyone may better perceive the majesty of the Creator. This is laughable, since the stars appear so small, and even the most learned person cannot easily perceive this monstrous size."[38] The anti-Copernican Riccioli also dismissed appeals to divine power in his *Almagestum Novum* of 1651. Riccioli, who had brought the telescope to bear on the star size question and still found that in a Copernican universe Sirius might be larger than Brahe's entire universe, noted how Brahe's star size objection could be answered by appealing to the speed issue, but he dismissed this answer. Either the rotation of the Earth or the rotation of the stars causes the rising and setting of the stars, Riccioli said, and in either case, that which rotates turns though one circumference per day—proportionally the rates of motion are exactly the same either way. As for appealing to the power of God, that answer cannot be refuted, said the Riccioli, but it does not satisfy the prudent. Besides, he said, if divine power can be called in as an explanation for the difficult aspects of a hypothesis, could not the geocentric

36. Koyré, 58–87.
37. On Rothmann, Digges, and Lansbergen, see Graney, *Setting Aside*, 77–85.
38. Graney, *Mathematical Disquisitions*, 29.

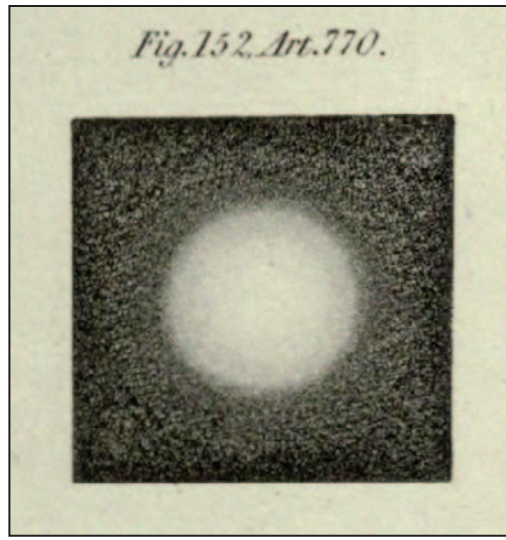

FIGURE 5. A star as seen through a small aperture telescope.[39] This appearance of a sphere of measurable size is entirely spurious—an artifact of optics, namely the diffraction of light waves. However, early telescopic astronomers took such telescopic images to be the physical bodies of stars.[40]

hypothesis's vast speeds also be explained via divine power?[41] Thus whereas Johannes Kepler wrote that he had dissolved Tycho Brahe's star size objection to the heliocentric theory of Nicolaus Copernicus, that objection still carried force almost five decades later.

What would answer Brahe's objection would not be comparisons to geocentric speeds, or discussions of the sizes of snakes and mites, or appeals to divine power. Rather it would be the discovery that the apparent sizes of stars, whether measured visually or with a telescope, were the spurious product of optical systems, a product which gave no indication of the true sizes of stars (see Figure 5). Ingoli's suggestion, that a possible answer to Brahe's star-size argument was that the stars might operate differently, was

39. John F. W. Herschel, *Treatises on Physical Astronomy. Light and Sound Contributed to the Encyclopædia Metropolitana* (London, 1828), 491 and Plate 9.

40. Christopher M. Graney and Timothy P. Grayson, "On the Telescopic Disks of Stars—a Review and Analysis of Stellar Observations from the Early 17th through the Middle 19th Centuries," *Annals of Science* 68 (2011), 351–373.

41. Graney, *Setting Aside*, 133, 137–38.

crudely correct (but there is no reason to believe that Ingoli had a prescient understanding of optical systems). The first evidence suggesting the spurious nature of apparent stellar sizes, Jeremiah Horrocks' observations that stars winked out instantaneously when being occulted by the Moon, was not published until a decade after Riccioli's *Almagestum Novum*, six decades after *De Stella Nova*. Such evidence would eventually show that all stars did not have to be giants in a Copernican universe.[42] Such evidence would also undermine Kepler's own use of star sizes to argue for a universe centered on our solar system. Indeed, recent progress in astronomy has shown that, while some giant stars do exist that dwarf the Sun, these are relatively rare; most stars are smaller than the Sun, with a large majority of stars being small, dim "red dwarfs" that are far outclassed by the Sun. Of course, today we know that the stars are not centered on our solar system in any way.

Johannes Kepler, like several other Copernicans, did not envision a universe like the one we know today. He saw a universe in which the Sun and its planets were unique bodies surrounded by distant, giant stars—in which every star seen in the sky, even the smallest, was at least the size of the orbit of the Earth, while the largest stars exceeded the size of an entire geocentric universe.[43] Such giant stars were an absurdity in the eyes of anti-Copernicans like Brahe, and unsatisfactory to Ingoli, but Kepler argued that stars the size of a universe were possible through divine power, and more reasonable than the geocentric alternative, and that they militated against an infinite universe. The process by which Copernicans abandoned the "giant stars" view of the universe and transitioned to a view more like that of today, thereby freeing heliocentrism from Brahe's charge of absurdity, should be a subject of fruitful further study by scholars in a variety of disciplines.

42. Graney, *Setting Aside*, 147–57.

43. For a longer, more technical discussion regarding Kepler's view of the heliocentric universe of stars, what view could be supported by astronomical observations in Kepler's time, and what observations eventually brought an end to the viability of the Keplerian view, see Christopher M. Graney, "The Starry Universe of Johannes Kepler," *Journal for the History of Astronomy* 50 (2019), in press.