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Gudrun Wolfschmidt (Hg.)

Astronomie in Franken

Von den Anfängen bis zur modernen Astrophysik.
125 Jahre Dr. Remeis-Sternwarte Bamberg (1889)

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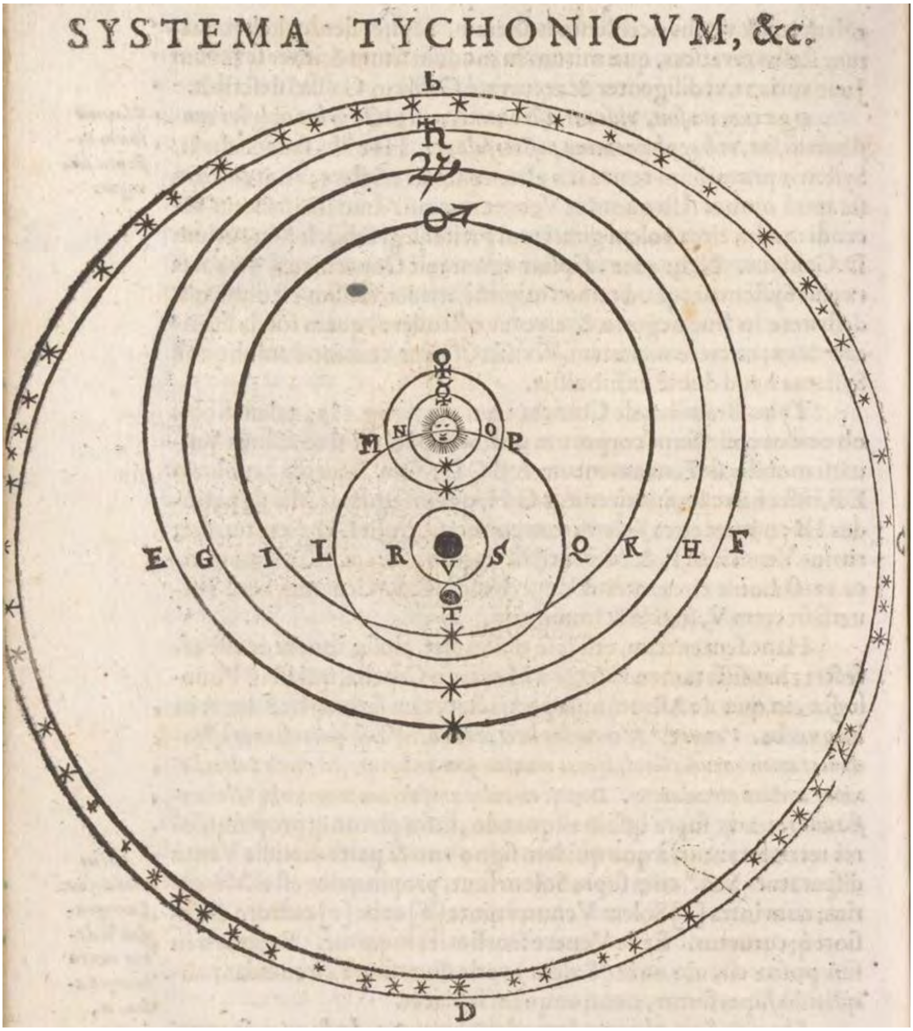

Abbildung 2.1:
The world system proposed by Tycho Brahe (from Locher 1614, 52).

The Sun, Moon, and stars circle a fixed, central Earth (at V) while the planets circle the Sun. This system is mathematically and observationally identical to that of Copernicus insofar as the Sun, Moon, and planets are concerned, and thus would be fully compatible with telescopic discoveries such as the phases of Venus.
Image credit: ETH-Bibliothek Zürich, Alte und Seltene Drucke.

The Telescope Speaks for Tycho – Simon Marius, Giovanni Battista Riccioli, and the Problem of Telescopic Observations of Stars in the Early 17th Century

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Abstract

In his 1614 *Mundus Iovialis*, Simon Marius reported that telescopic observations revealed all the more prominent stars to appear as definite disks. This, said Marius, indicated the hypothesis of Tycho Brahe (in which the planets circled the sun while the sun circled the Earth) to be the correct one. Marius seems to be the first to cite telescopic observations of stars against the Copernican system. I will discuss what Marius saw, and why his telescopic observations of stars were indeed a problem for Copernicans. I will use as illustration the work of Giovanni Battista Riccioli, who took pains to not only use telescopic star observations argue against the Copernican hypothesis, but who also provided a detailed description of how to make such observations, so that any observer could see for himself the problems with that hypothesis.

Simon Marius, in this 1614 *Mundus Jovialis*, stated that the telescope clearly shows fixed stars to not be at the immense distances required by Copernicus, and that the appearance of the fixed stars agrees with the geocentric world system of Tycho Brahe (Fig. 2.1, p. 58). Thus he writes:

> *"I obtained an instrument, through which not only the planets, but also all the more conspicuous fixed stars I observed, are seen round*

(especially the great dog, the small dog, and the brighter stars in Orion, Leo, Ursa Major, etc.). Before that time I had never happened to see this. I am truly surprised Galileo did not see this with his most excellent instrument. Indeed he writes in his Sidereus Nuncius, the fixed stars to appear in no way restricted by a circular periphery-something which certain persons since have considered grounds of the greatest of arguments. In truth, by this statement itself they confirm the Copernican world system: it is on account of the immense Copernican distance of the fixed stars from Earth that their globe shape cannot be perceived from Earth by any method at all. Since truly now it may be most certainly established, that by this telescope on the Earth even the fixed stars to be seen to be circular, this line of argument surely falls, and the contrary is plainly built up: specifically, that the sphere of the fixed stars is by no means removed from the Earth by such an incredible distance as the speculation of Copernicus produces. Rather, such is the segregation of the fixed stars from the Earth, by the harmonious Tychonic ordering of the spheres of the heavens, as the structure of those bodies may nevertheless be distinctly seen the shape of a circle by this instrument."[1]

Why did Marius make this statement, which indicates that telescopic observations of the stars support the Tychonic world systemü Marius was a skilled observer. His observations of the moons of Jupiter were more precise than those of Galileo.[2] His description of the telescopic appearance of the Andromeda Galaxy is remarkable. He describes it as –

"a fixed star or kind of star of remarkable form which I came upon and saw by means of a telescope the night of 15 December of the Year 1612. In the whole heaven I am not able to discover another such star. But it is near the third and northernmost star in the belt of Andromeda. Without the instrument it is discerned as a kind of little quasi-cloud in that spot; with the instrument no distinct stars are seen (like in the nebula of Cancer, and other nebulous stars), but whitish rays, which where they are nearer the center there grow brighter. The light is dull and pale in the center. It occupies almost the quarter part of a degree in diameter. The luster appears almost like if a candle shining through translucent horn were to be discerned

1 Marius 1614, sixth-seventh page of *"Praefatio ad candidem lectorem."* English translation from Graney 2015, 51.
2 Pannekoek 1961, 231.

from far off. It appears not unlike to that Comet in the Year 1586 ...."[3]

Only the experienced modern observer, who has seen the Andromeda Nebula through telescopes far larger and more sophisticated than any available in 1614, can truly appreciate this outstanding description, made so early in the history of telescopic astronomy. It seems reasonable, then, to suppose Marius's report on the appearance of stars to be accurate. So the question is, what did Marius see when observing stars, and why did this support the Tychonic system?

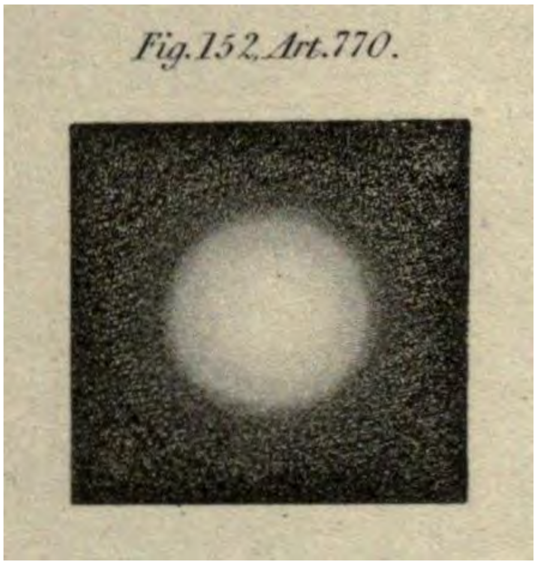

Figure 2.2:
Illustration from Herschel 1828 (491 and Plate 9) of the appearance of a star as seen through a telescope of very small (<2 cm) aperture.

This appearance of a disk or sphere of measureable size is entirely spurious, an artefact of the diffraction of light through the circular aperture of the telescope, and is known as an Airy disk. However, early telescopic astronomers took such telescopic images to be the physical bodies of stars.

Image(s) credit: ETH-Bibliothek Zürich, Alte und Seltene Drucke.

3 Marius 1614, fifth page of *"Praefatio ad candidem lectorem."* English translation from Graney 2015, 50.

Note that Marius reports that roundness is apparent in the more conspicuous fixed stars, and especially the brighter ones among those. In fact, this is exactly what a good observer who uses a small-aperture telescope should see when observing stars. A telescope of very small aperture (2 cm or less), if it is of good optical quality, will produce star images that appear to be distinct disks. This can be observed quite easily by observing stars with a modern telescope whose aperture has been masked down to such a size. This disk-like appearance was described and illustrated by John Herschel in the nineteenth century in his treatise on light. Herschel noted that when the aperture of a telescope of seven foot focal length was masked down to an inch or half-inch diameter, a bright star would present an appearance somewhat like a planet, with perhaps some haziness, an appearance which he illustrated (Fig. 2.2, p. 61). He also noted that the size of the disk was different for different stars, *"being uniformly larger the brighter the star."*[4]

However, as Herschel noted, the telescopic disks of stars are entirely spurious. The reason a spurious disk is seen when observing a star, and the reason the disk is larger when the star being observed is brighter, is the phenomenon of diffraction. When light from a point source (a star, in this case) passes through a circular aperture, it diffracts, by reason of the wave nature of light. The diffraction pattern consists of a central maximum and concentric rings of decreasing intensity. This pattern, combined with the limited sensitivity of the human eye, produces a spurious appearance of a disk-a disk which is smaller in the case of a fainter source (Fig. 2.3, p. 63). Thus what Marius describes regarding stars seen through his telescope agrees perfectly with optics.

We now understand what Marius saw when observing stars. This supported the Tychonic system because, in order for the stars to have a disk-like appearance (which of course Marius did not know to be spurious), they must be relatively close in terms of distance. Were they at the distances required to explain the absence of any detectable annual parallax in the fixed stars under the Copernican system, their shapes should not be resolved. Or, on the other hand, were the stars indeed at the distances required under the Copernican system, they would then have to be huge in order for their circular shapes to be seen.

The problem of star sizes and the Copernican system had been recognized by Tycho Brahe. Brahe had measured, using non-telescopic instruments, the apparent sizes of the celestial bodies. Then, combining their apparent sizes with their distances in a geocentric system, he calculated their true physical sizes. Keep in mind that Saturn and a star such as Altair appear very similar as

4 Herschel 1828, 491–492.

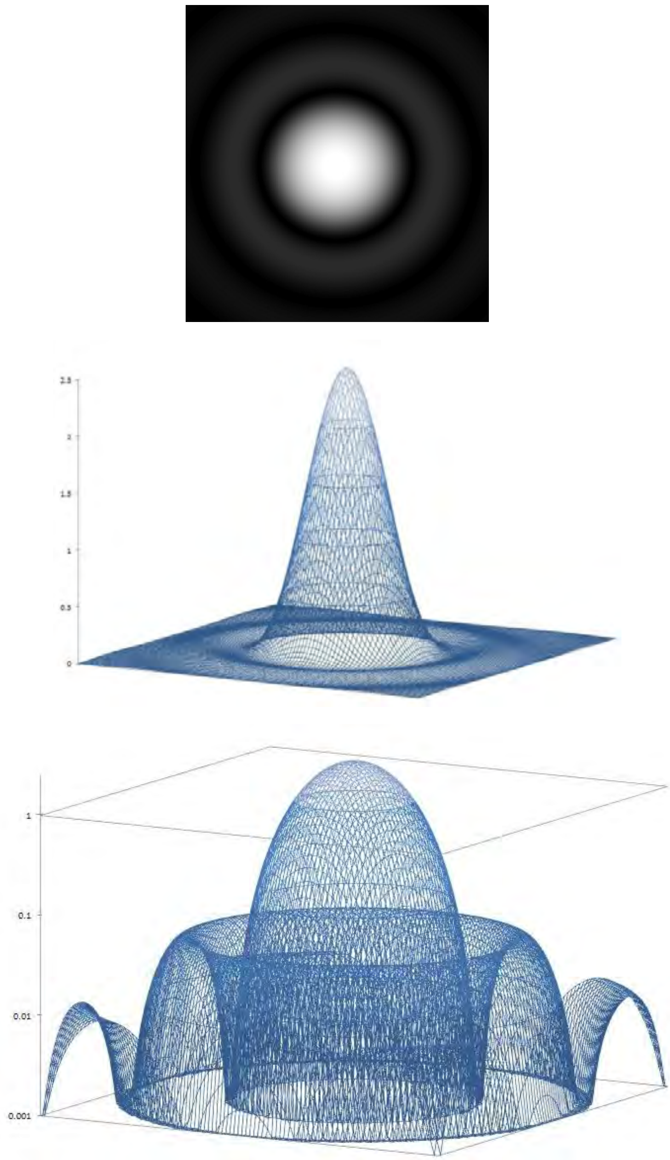

Figure 2.3:
Simulation of the diffraction pattern formed by light from a point source passing through a circular aperture (top-compare to Figure 2.2); surface plot of the intensity in such a pattern, using a linear axis (middle), and a logarithmic axis (bottom).

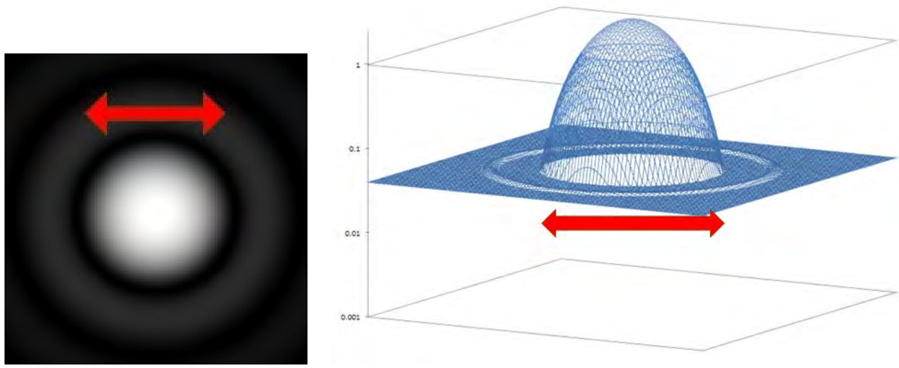

Figure 2.4:
The appearance of a star depends on the intensity in the diffraction pattern and the sensitivity of the eye that observes the star (the eye has a threshold below which it detects no light). Here a brighter star (greater intensity) is shown, with a larger diameter spurious disk (red arrow).

seen from Earth: according to Brahe they have about the same apparent size. In a geocentric system, the stars lie just beyond Saturn: Altair is a little more distant than Saturn. Since Altair is comparable to Saturn in apparent size, and comparable to Saturn in distance, then it must be comparable to Saturn in true physical size as well. Thus stars in a geocentric system are comparable to other celestial objects in physical size, according to Brahe (Fig. 2.6, p. 66). However, under the Copernican system, Altair much be vastly more distant than Saturn. The only way for Altair to appear comparable in size to Saturn in this case is if the true physical size of Altair is vastly larger than Saturn-and indeed, vastly larger than the Sun (Fig. 2.7, p. 67). Thus Brahe determined that, under the Copernican system, all stars-even those barely visible to the eye-must dwarf the Sun. This was what Christiaan Huygens referred to as Brahe's principal argument against the Copernican system.[5]

The stellar disks (spurious) revealed by the telescope were of course much smaller than Brahe's measurements-as were the planetary disks (not spurious) revealed by the telescope.[6] However, this did not resolve the star size problem, because the telescope also provided a more precise measurement of annual par-

5 Huygens 1722, 145.
6 See Graney 2015, 45–61 for a detailed discussion of this issue.

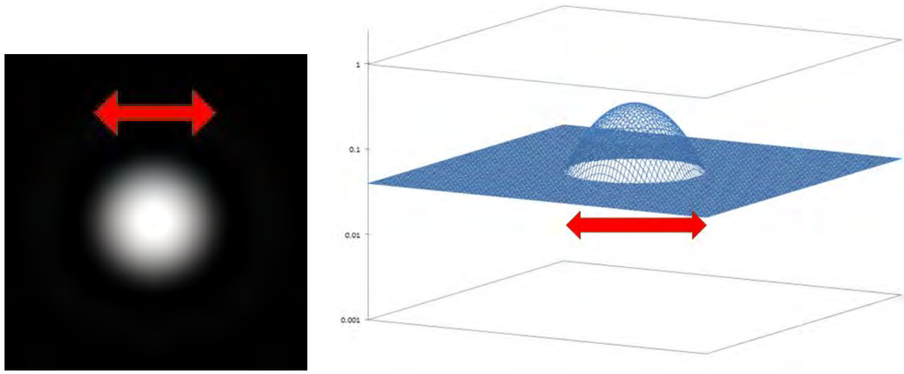

Figure 2.5:
Here a less bright star (lesser intensity) is shown, with a smaller spurious disk.

In regards to this George Biddell Airy wrote *"thus the radius of the spurious disk of a faint star, where light of less than half the intensity of the central light makes no impression on the eye, is* [smaller], *whereas the radius of the spurious disk of a bright star, where light of 1/10 the intensity of the central light is sensible, is* [larger]*."* See Airy 1835, 288.

allax, or the absence thereof. Like Brahe, Giovanni Battista Riccioli measured the apparent sizes of the celestial bodies, but with a telescope. Riccioli also provided a full description of the procedure he used for making these telescopic measurements, so others could reproduce his results. And, like Brahe, Riccioli combined the apparent sizes of stars with their distances under the Tychonic and Copernican systems to calculate their true physical sizes under both systems. In his 1651 *Almagestum Novum* he produced tables showing the results of these calculations (Fig. 2.8, p. 68). His results were again that, under a geocentric system, stars would be of reasonable size, whereas under the Copernican system, stars would have to be huge. Indeed, his results showed that one single star in the Copernican system could possibly (if he chose the most extreme set of values proposed by Copernicans) exceed the size of the entire Tychonic universe.[7]

However, well before Riccioli, in the same year that Marius's *Mundus Jovialis* was published, Johann Georg Locher of Ingolstadt published in his *Dis-*

7 See Graney 2012; Graney 2015, 129–139.

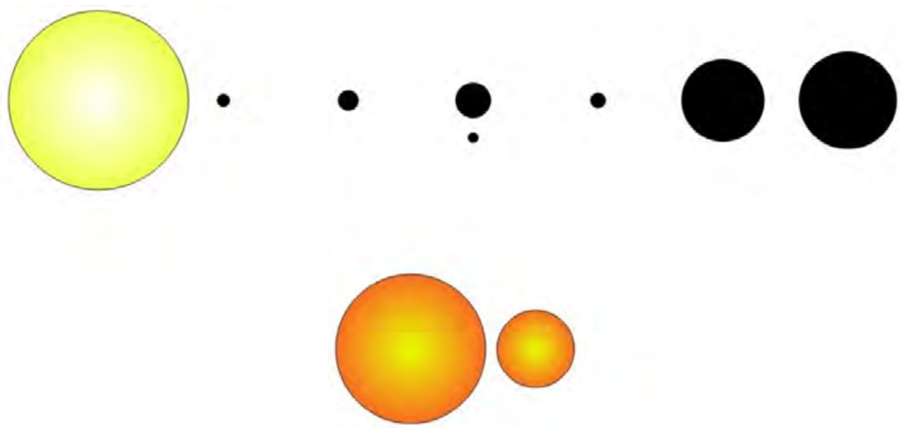

Figure 2.6:
The relative sizes of celestial bodies as calculated by Tycho Brahe, based on his observations and measurements.

Top row is (from left to right) the Sun, Mercury, Venus, Earth and Moon, Mars, Jupiter, Saturn. Bottom row is a large star and a mid-sized star under a geocentric universe (where the stars lie just beyond Saturn, as in Figure 2.1). Sun, stars, and planets are all of comparable size.
From Graney 2013.

quisitiones Mathematicae a very elegant argument for why the telescope would support Brahe's "principal argument". Locher writes –

> [Under the Copernican system] *"it follows that even the smallest star visible to the eye is much larger than the whole circle of Earth's orbit. This is because the ratio of any star to the circumference of the firmament is perceptible. But according to the Copernican opinion, the ratio of the semidiameter of the circle of Earth's orbit to the size of the firmament of stars is imperceptible. For as the globe of the Earth compares to the firmament in our common [geocentric] opinion, so the circle of Earth's orbit compares to that same firmament in the Copernican opinion. And yet Earth is insensible compared to the firmament, by tested experience; and therefore so is the circle of Earth's orbit, following the Copernican opinion."*[8]

8 Locher 1614, 28.

Figure 2.7:
The arrowed dots are Figure 2.6, 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). The star dwarfs the Sun, Moon, and planets.
From Graney 2013.

In other words, since in the Copernican system Earth's orbit is imperceptible compared to the firmament, while any star is not, any star must be larger than the circle of Earth's orbit, and thus far larger than even the Sun.[9]

Many other astronomers observed and measured the telescopic disks of stars, including Halley, Flamsteed, Hevelius, Horrocks, William Herschel, Hortensius, Cassini, and Galileo.[10] Galileo is a particularly interesting case. Despite his early remarks in the *Sidereus Nuncius* that Marius noted, he discussed telescopic stellar disks in many of his works. Most notably, he observed the star

9 Locher does briefly discuss stars as seen through the telescope-see Locher 1614, 54 – noting that the sizes of stars as seen through a telescope are not the same as seen with the naked eye. The mathematics of Locher's argument are such that it is valid so long as a star has any measurable apparent size. That apparent size is an angle measure-a certain number of seconds of arc. Those few seconds of arc are in fact a measurable fraction of the 360 degrees that is the full circumference of the sky as seen from Earth. By contrast, in the Copernican system the semidiameter of Earth's orbit is vanishingly small compared to the distance to the stars (so long as annual parallax is not detected). The distance to the stars and the circumference of a circle at that distance are related by a simple proportion of 2p. Thus Earth's orbit must be smaller than any star whose apparent size can be measured, but whose parallax cannot, no matter how small that apparent size may be. Since through a telescope every star will have some sort of disk (spurious, thanks to diffraction), every star will be larger than Earth's orbit.

10 See Graney 2015; Graney & Grayson 2011.

II. TAB. MAGNITVDO VERA FIXARVM MAXIMÆ ideſt SIRII, & MINIMÆ, cuiuſmodi eſt ferè Alcor: Poſita Diametro obſeruata à nobis in Sirio 18″. in Alcor 4″. 24‴. & Diſtantia Fixarum aſſerta in Hypotheſi TERRÆ QVIESCENTIS.

Auctores	Diſtantia Fixarum à Terra	Magnitudo Vera Sirij ſeu Canis Maioris		Magnitudo Vera Alcor, quæ eſt prope mediam caudæ Vrſæ maioris	
Diſtantiæ	In ſemidiametris Terræ rotundè	Diameter vera habet Terræ Diam.	Corpus cõtinet Terram vicib.	Diameter habet Diamet. Terræ	Corpus continet Terram vicib.
Tycho	14000	0 $\frac{61}{100}$	0 $\frac{1}{5}$	0 $\frac{15}{100}$	0 $\frac{3}{10000}$
Ptolemaici	Max. 40000	3 $\frac{1}{2}$	42 0	0 $\frac{86}{100}$	0 $\frac{7}{10}$
Nos	210000	17 $\frac{1}{2}$	5355 0	4 0	64 0

IV. TAB. MAGNITVDO VERA FIXARVM MAXIMÆ & MINIMÆ Ideſt Sirij & Alcor: Poſita diametro apparenti obſeruatâ à nobis in Sirio 18″. in Alcor 4″. 24‴. & Diſtantia aſſerendâ à Copernicanis, ſi velint Parallaxim Fixarum factam à motu Terræ annuo non excedere 10″. & tueri Diametrum Orbis Annui ab ipſis poſitam.

Auctores	Diſtantia Fixarum Aſſerenda	Magnitudo Vera Sirij ſeu Canis Maioris		Magnitudo Vera Alcor in cauda Vrſæ maioris	
Diſtantiæ	Semidiametri Terræ	Diam. habet Terrę Diam.	Corpus continet Terram vicibus	Diam. habet Terræ Diam.	Corpus continet Terram vicibus
Copernicus	47,439,800	4170	71,677,713,000	1992	4,378,454,048
Herigonius	49,502,400	4350	82,312,875,000	2068	8,844,058,432
Galilæus	49,832,416	4380	8,427,672,000	2092	9,155,562,688
Bullialdus	60,227,920	5300	148,877,000,000	2530	15,941,277,000
Lansbergius	61,616,122	5424	159,371,956,024	2588	17,333,761,472
Keplerus	142,746,428	12550	1,976,656,375,000	6000	216,000,000,000
Vendelinus	604,589,312	53200	15,056,882,800,000	25380	1,767,384,872,000

Fundamenta harum diſtantiarum vide in lib. 6. cap. 7. num. 15.

Figure 2.8:
Riccioli's tables showing the sizes of two stars, bright Sirius and faint Alcor, based on a geocentric world system, in which stars lie just beyond Saturn (top), and based on a heliocentric world system in which stars have a maximum annual parallax of 10 seconds of arc (bottom).
(Riccioli 1651, vol. 1, 716–717)

Mizar in Ursa Major to consist of two component stars, one whose disk was half again as large as the other, separated by a very small gap, the measurements of all of which he recorded. He supposed these disks to be the physical bodies of the stars. Were Mizar a double star of the sort Galileo supposed, it would be a very sensitive probe of annual parallax. That it does not reveal any parallax at all thus would seem, based on Galileo's suppositions, to very much uphold the position of supporters of the Tychonic system such as Marius (Fig. 2.9, p. 70).[11]

Thus we understand both what Simon Marius saw when observing stars, and why that supported the Tychonic system. Marius's support for the Tychonic system seems now to have been very reasonable-very "scientific" and "data driven". That the telescopic stellar disks that Marius observed were spurious would not begin to be suspected until decades later (starting, it seems, with the work of Jeremiah Horrocks[12]), and a full theoretical understanding of them would not be achieved until the nineteenth century and the work of George Biddell Airy, whose name is now attached to the phenomenon known as *"the Airy disk"*.

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11 Galileo did not publish his observations of Mizar and other multiple star systems. Interestingly, in his 1632 *Dialogue Concerning the two Chief World Systems – Ptolemaic & Copernican*, he proposes using double stars as a probe for annual parallax, *"if"* a close pairing of a fainter and brighter star could be found (see Galilei 2001, 444), even though he had observed Mizar and other multiple star systems more than a decade earlier. Galileo's notes on Mizar etc. were discovered in 2004. See Ondra 2004; Graney 2007; Graney 2008; Graney & Sipes 2009; Graney 2015, 45–49 and 236.

12 Graney 2015, 148–156.

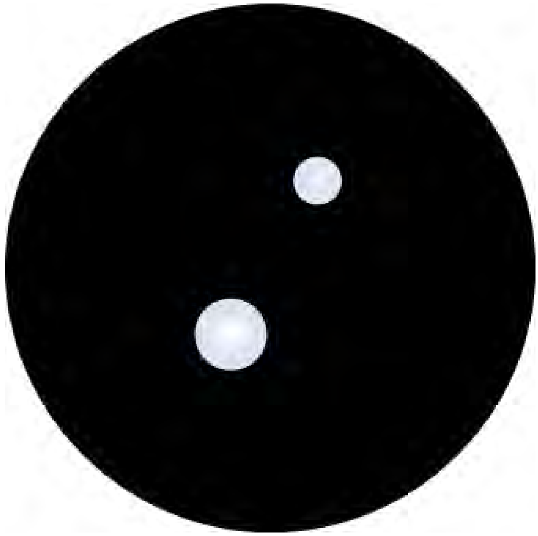

Figure 2.9:
Diagram showing the telescopic appearance of the double star Mizar, according to observing notes by Galileo from 1617.

Galileo recorded the components of Mizar as having diameters of 6 and 4 seconds of arc, and a separation of 15 seconds of arc. He assumed that these were two stars at differing distances along a line of sight. On the assumption that stars were of the same physical size as the Sun, he calculated that since the larger component was 1/300th the apparent diameter of the Sun, it must be 300 times more distant than the Sun. At such a distance these two stars would reveal prominent differential parallax were the Earth in motion. They do not, which would have suggested to Galileo that either the Earth is not in motion or the stars are at vast distances-and thus enormous, by virtue of their 6 and 4 second apparent diameters. Thus the star size problem, Tycho Brahe's "principal argument" against Copernicus, remained in force.

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