JHA, xxxvi (2005)

THE EARLY SEARCH FOR STELLAR PARALLAX: GALILEO, CASTELLI, AND RAMPONI

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Histories of astronomy tell us that Robert Hooke (1635–1703) is seen as the first Copernican to have tried with a telescope to discover annual parallax and so prove the motion of the Earth.[1] Curiously enough, this came to pass almost two generations after the invention of that revolutionary instrument. Indeed, we know very little about previous such attempts at providing proof of the heliocentric hypothesis. Around the same time as Hooke did his work, Robert Moray, one of the founders of the Royal Society of London, recalled another project of this kind. In a letter to Christiaan Huygens in November 1663, he mentions that ten years before, Robert Neile and Christopher Wren had planned to measure the altitude of stars in order to discover a parallax, using an aerial telescope up to 80 feet in length.[2] This brings us back to a time in Rome when the Jesuit polymath Athanasius Kircher (1602–80) was writing his *Itinerarium exstaticum* (1656), a space itinerary in the form of a dialogue relating the details of an imaginary voyage that takes the reader to all planets, to the newly detected moons, and beyond our own system, even travelling throughout the whole universe.[3] Presenting the traditional fixed stars as differing in size, and no longer motionless but circling each other in systems, Kircher invalidates beforehand stellar parallax as decisive evidence for the heliocentric model:[4] it might actually be the star itself that we see moving, and not the reflection of the motion of the orbiting Earth as Copernicus had expected.[5] Kircher's refutation of the crucial test would make sense only if stellar parallax had actively been sought in the first half of the seventeenth century.

Twenty years before the appearance of Kircher's work, Galileo Galilei had been condemned for supporting heliocentrism in his *Dialogo* (1632), the *Dialogue concerning the two chief world systems – Ptolemaic and Copernican*.[6] Determined to support Copernicus at great risk to himself, it would be no surprise if Galileo had also sought to observe a parallactic shift. This seems all the more likely, as Copernicans had nothing to lose by performing that experiment. Their failure to detect stellar parallax had been the most obvious and longest-standing objection against the motion of the Earth, whereas it became only one among many in the course of the cosmological controversy.[7] On the other hand, despite the many arguments against Copernicus, stellar parallax remained the only way to prove the heliocentric model. Geocentrists, too, would have to recognize Copernicus once a parallactic shift was observed, whereas its absence could be conveniently explained by the great distance of the stars.[8] Thus Copernicans were actually placed in a win–win situation to resolve the dispute over the true world system. They had in hand the 'experimentum crucis'

0021-8286/05/3603-0251/$10.00

of the debate, and Galileo himself, as he tells us in his *Dialogo*, was fully aware of this unequal balance in favour of the Copernican side:

> SALV[IATI]. I wish you had said that if such a variation were perceived, nothing would remain that could cast doubt upon the Earth's mobility, since no counter could be found to such an event. But even though this may not make itself visible to us, the Earth's mobility is not thereby excluded, nor its immobility necessarily proved. It is possible, Copernicus declares, that the immense distance of the starry sphere makes such small phenomena unobservable.[9]

It would seem rather strange, therefore, if Galileo had never tried himself to detect the parallax of a star. Nonetheless, this is exactly the impression he gives as Salviati in the following passages of the *Dialogo*. Without referring to any personal experience, he theorizes on how such an observation might be best organized.[10] It is however only a plan we read about: Galileo has gone down in history for outlining this project while entrusting future generations with the actual work of searching for stellar parallax.

On the other hand, as long as annual parallax had not yet been detected, this topic would hardly have been compelling enough for inclusion in a book meant to convince and persuade its readers of the true system of the world. Taking this into account, Galileo wrote extensively on this crucial point.[11] His *Dialogo* makes it clear that the question of annual parallax is the critical issue in the cosmological controversy. Furthermore, the search for this phenomenon is viewed as a problem in its own right. This problem, Galileo declared, had not so far been tackled or even comprehended by anyone.[12]

Galileo blames Tycho and the Tychonics for never having tried to detect such an apparent change in the position of a star.[13] This reproach was hardly justified, since those rejecting Copernicus were not bound to prove him right by searching for stellar parallax. On the contrary, this task was for those who believed the heliocentric hypothesis to be correct. Nevertheless, Galileo maintains that no one had ever attempted to make this observation.[14] According to him there was no doubt that whoever might have carried out this crucial experiment, would have reported its result in favour of one or other hypothesis.[15] And in any case, such an observation would be successful only if performed the way Salviati-Galileo describes it in the *Dialogo*.[16]

The lack of reports concerning the search for annual parallax, which Galileo takes as evidence for his conclusion, has however alternative explanations: either no one ever tried to detect the parallax of a star, as Galileo suggests, or they all chose not to communicate their lack of success. Indeed, confirming the failure to detect stellar parallax might not have been seen by the Copernicans as suitable for publication — all the more so as in any case this result was taken for granted by their opponents. Moreover, in view of the great issue at stake, as well as the unequal chance given by this crucial experiment to win the cosmological dispute, it seems likely that exactly the opposite of Galileo's conclusion may be true: that there had been attempts to discover stellar parallax, but that these had not been reported for the very reason that all had failed. Even the greatest stellar distance assumed at that time by Copernicans was many times too small when compared with the real dimensions of the stellar universe.[17]

In spite of his having examined the sky more accurately than anyone before him, Tycho Brahe had not detected a parallactic shift in any of the 777 stars he catalogued. On the basis of his values for star magnitudes, he calculated how big a Copernican universe must be: if the Earth circled around the Sun without resulting in an observable change in the position of the stars, the latter must lie at a distance more than 700 times greater than that of Saturn.[18] Tycho considered it absurd to assume such an enormous gap between the outermost known planet and the fixed stars.[19] Cosmic harmony meant that this inconceivably huge void served as an argument against the heliocentric system.[20]

Tycho's values were taken up and discussed by both sides in the cosmological controversy.[21] From the star magnitudes on which Tycho's calculation was based, Copernicans were able to deduce support for their own point of view: the tiny angle of stellar parallax would necessarily fall below the threshold of Tycho's measurements. Hence the parallactic shift would be observable only with instruments more accurate than those of Tycho, who had measured a value of 20 arcseconds for the apparent diameter of sixth magnitude stars.[22] Actually, Michael Mästlin (1550–1631), one of the first Copernicans, expected an annual parallax below Tycho's threshold, which he estimated at 24 arcseconds ("ultra duas quintas").[23] In refuting Tycho's arguments, he further reminds us that Copernicus had not excluded this phenomenon's being just beyond the capacity of our eyesight ("oculorum iudicium").[24]

Notwithstanding Galileo's criticism, Tycho had tried to detect a stellar parallax in 1586. This was reported in print thirty years later by Johannes Kepler, the former student of Mästlin and Tycho's former assistant.[25] Even before joining Tycho in Prague, Kepler himself had wanted to carry out this observation. However, while at Graz he lacked instruments, according to the letter he wrote to Galileo on 13 October 1597. In an earlier letter thanking Kepler for a copy of the *Mysterium cosmographicum* (1596), Galileo declared that he had been a Copernican for many years, albeit in secret.[26] Taking him at his word, Kepler called on Galileo to perform the crucial observation, which he himself could not make in Graz. If Galileo had at his disposal a quadrant capable of reading arcminutes and quarter minutes of arc (15″), he should determine the position of the Pole Star as well as of the first star in the tail of the (Little) Bear on two nights around the winter solstice. In addition, Kepler tells his senior colleague when to repeat both observations, fixing the dates as well as the time for Galileo's next sessions. And even if a parallactic shift was not detected in this way, together ("communiter") they would be the first to win renown in this most famous problem in astronomy.[27]

We probably will never know if Galileo did indeed begin his search for stellar parallax, as Kepler requested, around the winter solstice of 1597. Kepler's letter was left unanswered.[28] Perhaps Galileo knew already that the attempt would be futile: the quadrant was of course not accurate enough to detect the apparent shift in the position of a star due to the Earth's revolution. Yet thirteen years later the chance to observe such a parallactic shift was no longer limited by the capacity of eyesight. Galileo it was who first published the telescopic view of our world, and reported discoveries wholly unexpected. Thus, with this new instrument in his hands, nothing would seem more likely than that he should try to detect the phenomenon that the Copernicans were expecting, in order to demonstrate the truth of the heliocentric hypothesis and so complete the revolution in astronomy.

This next step had been foreseen by those who were able to appreciate the Copernican undertones of Galileo's *Sidereus nuncius* (1610). Shortly after its publication the rumour spread among enlightened readers in Bologna that Galileo had made a decisive observation in astronomy that settled many arguments. One of these readers, Lodovico Ramponi (baptized in 1577), a member of the circle of Giovanni Antonio Roffeni,[29] assumed that Galileo had in fact established heliocentrism by detecting the annual parallax of a star.[30] Since this proved not to be the case, Ramponi in his next letter to Galileo explicitly asked him to use the new instrument for such observations. After all, Copernicus would not be refuted by a failure to detect stellar parallax. On the other hand, a single parallactic shift would necessarily demonstrate the heliocentric hypothesis to be correct.[31] We see from Ramponi's letter, dated 23 July 1611, that Galileo was not the only one to be aware of this win-win opportunity to prove Copernicus right: Copernicans had recognized this unequal chance in favour of heliocentrism twenty years before Galileo's *Dialogo* appeared.

We may doubt whether Kepler's and Ramponi's letters had been necessary to sow in Galileo's mind the idea of settling the cosmological question by performing the famous crucial experiment. But if so, he may have benefited from Ramponi's further explanation. In his letter of 23 July 1611, Ramponi sets out the method of double stars for detecting stellar parallax.[32] This is the very method that later won Galileo renown and for which he was to be remembered by parallax hunters in the centuries that followed.[33] While it is generally thought that Galileo never tried to detect stellar parallax himself,[34] he is credited with this legacy to future generations. Ultimately, in the nineteenth century, the parallactic shift of a star was first measured by an adaptation of the technique of double stars, which Galileo presents quite briefly as an alternative method in his *Dialogo*:[35] instead of measurement of the absolute position of a star, the change in its angular distance from a nearby star could equally well reveal its annual parallax. This measurement would most easily be made if both stars appeared close together in the sky but were in fact at very different distances from the observer. In the case of such an 'optical double star', the annual revolution of the Earth would result in a greater shift of the nearer star, and this might well be measurable.

This technique of relative measurement, also known as Galileo's second method, had been explained to him in detail by Ramponi in 1611. Ramponi further describes his method by a sketch similar to Galileo's drawing in the *Dialogo* (see Figure 1).[36] Nonetheless, Galileo may well have had the same idea independently of Ramponi. Either way, by 1611 he was aware of this method which he considered worth explaining

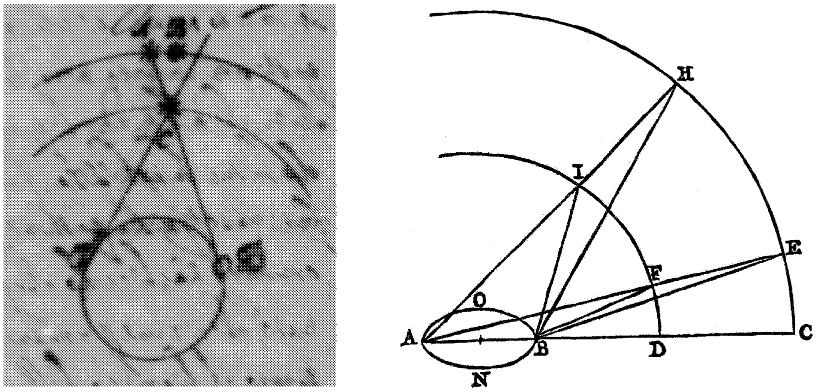

FIG. 1. The use of double stars to detect annual parallax: (*left*) Ramponi's sketch in his letter to Galileo, 23 July 1611, Fondo Galileiano, Gal. 89, f. 28v, Biblioteca Nazionale Centrale di Firenze, courtesy of the Biblioteca; (*right*) Galileo's drawing in *Dialogo*, in *Opere* (ref. 6), vii, 412.

in print twenty years later. Yet there was one thing Galileo could surely learn from Ramponi's letter advocating the crucial experiment and suggesting a method by which it might be carried out: there were others besides himself who were not only searching for but who might even succeed in detecting stellar parallax.

How should Galileo have known that even with a telescope, this newly-invented instrument of astronomical revolution, which sharpened human eyesight 30 times,[37] the angle of annual star shift was still out of reach? Because of his technological lead in constructing telescopes, Galileo had the best chance to be the first to detect stellar parallax. Thus, Galileo had no need to wait for someone else to perform this most important observation. Furthermore, his sense of priority was offended shortly after Ramponi's second letter, for meanwhile Christoph Scheiner (1575–1650) had discovered sunspots independently of Galileo. Whereas Scheiner published his observations in 1612 without explicitly claiming priority,[38] Galileo published his later the same year claiming that he had made the discovery before the Jesuit astronomer.[39] This was the beginning of a lifelong argument between these two men over the discovery, despite the fact they were not the only ones to have observed them.[40] Galileo heard immediately about Scheiner's observations, which were published on 5 January 1612.[41] Thus, five months at the latest after having received Ramponi's letter on stellar parallax, Galileo knew that he had been anticipated in print over a quite different discovery, for which he claimed nonetheless to be the only true discoverer. The triumph of this much greater discovery was one that Galileo would hardly have been willing to leave for anyone else.

In this context of astronomical competition and claims to priority, it may even make sense that Galileo in fact made no answer to Ramponi's valuable second letter.[42] Ramponi's third letter to Galileo was also left unanswered. In both Ramponi asked whether Galileo had observed the apparent shift of a star due to the Earth's orbit.[43]

Galileo, however, preferred not to reply at all, which allowed him not to admit, even implicitly, his failure to detect stellar parallax.[44] It had not been evident either to Ramponi or to Galileo that stellar parallax was out of their reach as long as they were using instruments of only 20 or 30 magnification. Nevertheless, in fact it would be another two generations before the first (telescopic) search for annual parallax was published.[45]

Even in the early 1610s, others had thought of using the newly invented instrument for proving Copernicus's hypothesis. A friend of Galileo's, the painter Passignano (Domenico Cresti, also called Passignani, 1558/60–1638), applied the telescope to this purpose: by observing the stars, he had 'seen' the Earth circling around the Sun. This is what a mutual friend, the fellow painter Cigoli (Lodovico Cardi, 1559–1612), reported to Galileo in June 1612. Passignano had defended his observation against Cigoli's objections by referring to things he had heard from Luca Valerio (1552–1618), a friend of Galileo and professor of mathematics in the Sapienza, or from the Jesuit astronomer and mathematician Christoph Grienberger (1564–1636), successor to Christoph Clavius (1538–1612) at the Collegio Romano.[46]

Cigoli did not believe his colleague. He accepted neither the results of his observations nor his authorities ("à sentito da non so chi"). However, it is remarkable that a prominent Jesuit was mentioned in this context at all. This may indicate that both sides of the controversy understood the value of the new astronomical instrument in the search to discover a decisive answer to the cosmological question. Hence, it seems unlikely that Galileo never tried to realize its potential himself. Nonetheless, there is no evidence that Galileo made such an attempt in the years immediately following the invention of the telescope.

Two decades later, Galileo would try to make out that nobody had ever thought of proving the Copernican theory by performing the decisive observation. His *Dialogo* knowingly portrays a background to the question that is incorrect. In this setting, his own efforts to explain and promote the crucial experiment make him appear to be the only true Copernican among his contemporaries — a pretence contradicted both by the 1611 letter from Ramponi and by the much earlier first letter to Galileo from Kepler, both left without answer.[47]

In the *Dialogo*, it was now Galileo's turn to give instructions on how to search for stellar parallax. He was here the first to publish a detailed explanation of the phenomenon, and he describes how such an observation should be performed in practice.[48] Having demonstrated *more geometrico* that the greatest parallax must occur in stars near to the pole of ecliptic,[49] Salviati-Galileo singles out a star in the (Little) Bear ("una delle stelle del Carro"). Next he seeks an appropriate location from which to observe: a large plain bordered by a very high mountain in the north. On the top of the mountain is a tiny church. Salviati would fix a thin plank to its roof and then choose a place in the plain from which to view it with a telescope. This observational post must be such as to let the star appear bisected by the plank. By fixing this mark, Salviati-Galileo hoped that even a tiny shift in the star's position would be noticeable.

Observations, he says, should always be made from the same spot in the plain and repeated monthly from the summer solstice until the winter solstice. Salviati recommends for this experiment a telescope able to magnify the Sun's disk a thousand times. He admits having used such an instrument for other observations.[50] Indeed, Galileo had managed to make a 30-power telescope long before, by March 1610.[51] Moreover, Galileo actually made such observations of the Sun's setting and rising position on the solstices, and he reported them to Cesare Marsili (1592–1633) in 1631.[52] Galileo was also acquainted with the location his alter ego Salviati alluded to: the mountains of Pietrapana and the villa near Florence mentioned by Salviati identify this place as Galileo's Villa Bellosguardo. Here he spent the summers of the years 1616–31.[53]

The villa near Florence is not only described in the *Dialogo* as a suitable location for a search for stellar parallax, it was, indeed, the place where Galileo himself performed observations attempting to detect a parallactic shift, using a second and quite different method. In November 1616, Benedetto Castelli (1577–1643), professor of mathematics in Pisa and Galileo's former student, reminded him of their session in Bellosguardo earlier that summer, when they observed three stars in the tail of the Great Bear that formed a right angle. Having recommenced his observations in November of that year, Castelli reported to Galileo that he thought their relative position had now changed.[54] From Castelli's description and illustration (see Figure 2 (left)) in his letter, it is clear which features of these stars had mainly attracted their attention in Bellosguardo. The first star after the beginning of the Great Bear's tail ("post eductionem caudae") is Mizar, famous for forming a double star with Alcor (they are not physically related but are a chance alignment); they appear very close together though still resolvable with the naked eye ("vicinissima con la vista naturale"). The third star in question, visible only through a telescope ("visibile solo con l'occhiale"), became notorious a century later for being pretentiously baptized Stella Ludoviciana by its self-declared discoverer.[55]

These three stars in the Great Bear's tail (Mizar, Alcor and Stella Ludoviciana) may well have seemed appropriate choices to use for the detection of stellar parallax by Ramponi's method. All three stars lay within the field of view (15 arcminutes) of a Galilean telescope.[56] Furthermore, the vertex of the almost right-angled asterism

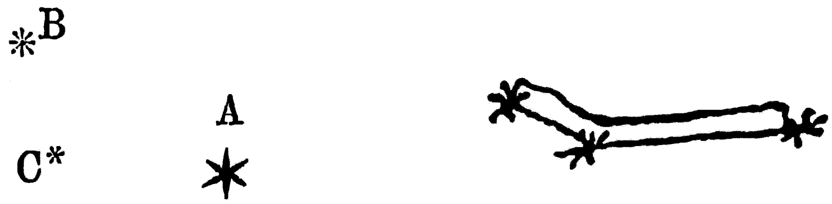

FIG. 2. (*left*) Castelli's angular asterism in the Great Bear's tail: Mizar (A), Alcor (B), "Stella Ludoviciana" (C), in Galileo, *Opere* (ref. 6), xii, 296; (*right*) Galileo's sketch of an aperture mask for an angular asterism, in *Opere* (ref. 6), iii.2, 879.

is formed by the eighth magnitude Stella Ludoviciana with Mizar and Alcor, which were of second and fourth magnitude respectively. On the plausible assumption that fainter stars are farther away, the three stars would be at different distances from the Earth; hence the orbit of the Earth would cause each of the three stars to yield a different parallactic angle, so distorting their rectangular formation. That this was the reason why Castelli and Galileo paid attention to these three stars during the summer of 1616 is clear from Castelli's check on their possible change of position when he re-examined them in November. Galileo's reply to Castelli's report is lost, but there are other letters he received from his former student documenting their continued search for fixed stars ("busca di stelle fisse"[57]). Galileo's part in this exchange of stellar information can be seen from his observational notes ("Analecta astronomica"). Since these minutes mostly match Castelli's letters of the years 1616 and 1617, it is very likely that they were all taken down around the same time, although the only dated entry is of 4 February 1617.[58]

On one of these manuscript sheets, Galileo had sketched down three stars forming an angle. This stellar angle is much more obtuse than the one pictured by Castelli in his letter of 16 November 1616. The point of interest in this asterism, however, is obviously the same for both astronomers. Commenting on his sketch, Galileo suggests cutting out a cardboard in the form of the angle — to illustrate his idea he draws a frame around the three stars (see Figure 2 (right)) — and placing it on the top of the telescope ("nella cima del telescopio").[59] Thus, Galileo builds an aperture mask that would permit him to detect more easily a distortion in the original stars' formation as Castelli had (mistakenly of course) thought he had observed for Mizar, Alcor and the Stella Ludoviciana.

On the same sheet of paper, Galileo recorded three Sirius observations, noting for each the zodiacal position of the Sun. From this detail, we can determine the day and month when Galileo observed Sirius ("Canicula"). In the light of Castelli's letter of 7 January 1617, we may presume that Galileo's first Sirius session took place in 1616: Castelli starts his letter by reporting on his own preparation for such an observation.[60] Therefore, Galileo may have earlier mentioned his own Sirius observation to Castelli, in which case he would have performed it on 22 December 1616.[61] This being so, it must have been Castelli's remark on the possibly changed positions of Mizar, Alcor and the Stella Ludoviciana that made Galileo conceive and sketch down on the same sheet of paper his aperture mask, as a means of detecting such a change in an asterism.

In his letter of 7 January 1617, Castelli returns to Mizar, the middle star in the tail of the Great Bear: he wishes Galileo to consider it one of the beautiful objects in the sky. Castelli is further convinced that there will be nothing better to be found for their purpose ("per il nostro servizio").[62] Castelli's cryptic wording may be intended as a precaution, since Copernicus had been condemned the year before. Indeed, the purpose of their search for suitable fixed stars would not be clear to anyone else reading his letter unless the reader knew not only the telescopic appearance of Mizar, but also the related method of detecting stellar parallax. This beautiful thing that Castelli had seen through his telescope is nothing less than a new class of celestial objects: Mizar is the first visual double star ever observed, and Castelli was the first to report such a doubling (which he considered to be a chance alignment of two independent stars).[63] The Jesuit Giambattista Riccioli (1598–1671) published Mizar's special nature in 1651, mentioning it in passing,[64] but by then the new phenomenon of multiple stars had already been reported in print, by the Capuchin friar Anton Maria Schyrleus de Rheita (1604–60), in 1645.[65]

Castelli, however, like apparently all Copernicans during the cosmological controversy, believed that double stars were only optical phenomena, i.e. chance alignments of stars that were in reality very distant from each other and from Earth.[66] The alternative interpretation (i.e. stars physically bound together) was suggested only by a few non-Copernicans in the seventeenth century, among them Rheita, Giovan Battista Hodierna (1597–1660) and Kircher.[67] In a Copernican view, however, the idea of stellar systems containing two or more associated stars seemed *a priori* excluded by heliocentrism: all stars in the universe are suns like our own, all being equal in size and resting at the centre of other possible solar systems. Given these premises, there cannot be a system with more than one star. In addition, the optical nature of double stars seemed to be evident in the case of Mizar. Because of its division into two components of different magnitudes (2.2 and 3.9) the two Mizar stars appear to be differently remote from us. This of course is true only if all stars of the universe are uniform in size ("faintness means farness"[68]), an assumption that was taken for granted by Copernicans until the end of the eighteenth century.[69]

Regarded as an optical double star, Mizar should reveal annual parallax by displaying parallactic orbits of different sizes in its two components. Two generations later, Huygens cited Mizar as the best example for detecting stellar parallax in this way.[70] For this very same reason, Castelli brought this newly-detected double star to Galileo's attention in his letter of 7 January 1617. Their shared interest in examining the fixed stars becomes clear from Castelli's following letter of 22 February, in which he refers to the expected phenomenon of differential parallax.[71] Galileo, however, seems immediately to have deciphered Castelli's cryptic wording and got down to work.

On 15 January, Galileo himself observed Mizar. The day and month of his observations can be read from the Sun's zodiacal position that he recorded.[72] Given the context of Castelli's letters dated 7 January and 22 February 1617, we may presume the same year for Galileo's own Mizar observation. Galileo meticulously takes the measurements necessary for detecting stellar parallax by the method of double stars: he records that the angular radius of the component stars is three and two arcseconds respectively, while their circumferences are separated from each other by a gap of ten arcseconds. In this way Galileo arrives at an angular distance of 15 arcseconds between the centres of Mizar A and B.[73] (Of course the closeness of this to the modern value of 14.43 arcseconds[74] is an accident.) Furthermore, Galileo deduces from the apparent diameter of Mizar A ($2 \times 3''$) its distance from Earth: if this star is as big as our Sun (which has an apparent diameter of 30 arcminutes), it must lie

300 times farther away.[75] In other words, Mizar A would be at a distance of 300 astronomical units. This, however, is all Galileo noted about the double star Mizar. It was enough to make him optimistic about his chances of detecting stellar parallax. If he had continued his reckoning, he would have expected Mizar A to shift its position by almost twelve arcminutes over three months.[76] This change would be all the more easily detected, since Mizar B appeared smaller, hence farther away, and was therefore expected to shift its position considerably less.[77] The combined effect of these different parallactic shifts would be manifest from the position of Mizar A relative to Mizar B, an angular separation that should change by around an arcminute over one month.[78]

A month later, Galileo was preoccupied with double stars other than Mizar. In the Orion constellation, north of the point of Orion's sword, he was observing an "apposite asterism" ("apposita fixarum constitutio"). This time, however, he had found it himself, which he emphasizes when noting down his observation ("reperta est a me", "observata sunt a me"). He further recorded it as a true discovery by taking the unusual step of stating explicitly its date and place of observation. [79] What he saw on 4 February 1617 in the sky above Bellosguardo is described by him in more detail than any other observation recorded in the papers that were published posthumously as "Analecta astronomica". In a sketch (see Figure 3) and in words, Galileo depicts four stars representing the parallel sides (*a*, *b* and *c*, *i*) of a trapezoid wherein is situated a fifth star (*g*) forming an isosceles triangle together with the stars of the upper side (*c*, *i*). Galileo determines the relative position of these five stars by expressing their proportion in terms of brightness and distance. Further, he provides the ecliptic coordinates (–30 , 78) for the point of Orion's sword. Thus, Galileo's description allows us to identify this asterism as one of the most spectacular multiple star systems in the entire night sky, the Trapezium in the heart of the Orion Nebula (M 42).[80]

However, by following Galileo's description strictly we would not find his triple star: his triangle (*c*, *g*, *i*) whose ground-line represents the upper parallel side of the trapezoid in the sketch. Probably, this was the reason why Castelli could not make out the Orion stars, which Galileo may have reported to him the same way he had recorded them in his own papers.[81] Actually, Galileo was observing a larger asterism than today's Orion Trapezium, since his three biggest stars (*a*, *b*, *g*) are too remote

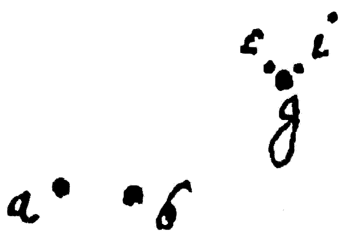

FIG. 3. Galileo's trapeziform asterism in Orion's sword, in *Opere* (ref. 6), iii/2, 880.

from each other to match it.[82] According to his measurements, we do indeed find a larger trapezoid in the sky.[83] Thus, within this bigger asterism Galileo's triangle (*c*, *g*, *i*) could represent stars of the Orion Trapezium. However, he notes that these three stars (*c*, *g*, *i*) lie very close together and vary considerably in brightness, which is actually not the case for the three brightest stars of the Trapezium. Hence, Galileo either did not record the features of his stellar triangle correctly, or he must have succeeded in resolving one of the three brightest stars of the Orion Trapezium, which is itself a double star and forming an optical triple together with another variable star.[84] In any case, the sketch he refers to in describing the asterism is either incomplete — at least one bright star of the Orion Trapezium is missing[85] — or incorrect — the stars forming the Orion Trapezium are not so close nor do they vary so much in brightness as in Galileo's stellar triangle (*c, g, i*).

These shortcomings are revealing of Galileo's purpose in recording his asterism. It would not be surprising if the triple star itself had to a large extent absorbed his attention: its two smaller component stars (*c*, *i*) forming the triangle (*c*, *g*, *i*) are just one-fourth or one-fifth the size of the bigger star (*g*) while being very close to it, as Galileo notes.[86] In contrast, the components of the double star Mizar are less variable in brightness and farther away from each other. These two features, however, are significant for the detection of stellar parallax by measuring relative star positions. Thus, it is this method, described by Galileo in the *Dialogo* and explained to him long before by Ramponi (and shared with Castelli), that makes the Orion triple star much more appropriate ("apposita") than Mizar for the search of annual parallax. Hence, directing the telescope to the Orion triple could offer a more promising outcome. The significance of this seems to be confirmed by the fact that Galileo noted down in detail the date and place of his observation as if it were a discovery in its own right.

In spite of not finding the "beautiful thing" that this time Galileo had discovered in their joint parallax hunt, Castelli reported having detected a stellar triangle on 30 January of the same year. It lay halfway between Orion's left shoulder and the Little Dog (Canis Minor). In the eastern angle of this triangle, he first suspected a double star, though for a long time he had been unsure about it. Coming back to it later, he could clearly see two distinct stars.[87] Meanwhile, Castelli had rechecked the double star Mizar. Knowing best the former relative position of its components, Castelli had no doubt now when writing to Galileo that they had moved away from each other.[88] He had still "certain other sightings" to report on, but preferred to discuss them in a meeting. When Galileo visited him in Pisa, they could also make further observations, namely regarding the Greater Dog (Canis Maior), and reach some conclusions. Although Castelli gives a few interesting details about this forthcoming session in Pisa, he is nevertheless too cryptic to be clearly understood by a third party reading his letter to Galileo.[89] Here again, we see caution as the Copernican theory had been forbidden the year before.

The background for this early search of stellar parallax is the great cosmological controversy. The debate escalated in 1616 and thereafter became more and more polemical. In this contentious context, we cannot really expect Galileo to admit to his search for stellar parallax nor to his failure in detecting it. Thus, in response written in 1624 to an attack on him by the Jesuit Francesco Ingoli (1578–1649), Galileo alleges that the tiny stellar shift of annual parallax "with other instruments, being much bigger and much more perfect and rather various, might be seized perhaps one day".[90] Notwithstanding this, Galileo, as we have seen, had been confident that this tiny shift was within his reach. Hence, he speaks from his own experience when admitting implicitly the failure to detect stellar parallax in 1624. By then, despite his telescopes, Ramponi's method, and Castelli's double stars, it had not been possible to detect a parallactic shift. In his response to Ingoli, and likewise later in his *Dialogo*, he talks of making the search of stellar parallax a future project. Indeed, he could reasonably, and from his own experience, have given up hope already in 1624. If he really had been resigned at that time to failure in the hunt for parallax, he would have been less confident or less ambitious than his fellow searcher Castelli.

In 1626, Castelli became the Pope's advisor on river channelization,[91] and professor of mathematics in Rome. Nonetheless, he continued his pursuit of stellar parallax. On 7 August 1627 he reported yet another double star to Galileo:

> I have observed the northern one of the three stars in the head of Scorpius, which has a very close tiny star north to it in continuation of the arc formed by the three of the head [see Figure 4].... You would grant me a favour in writing me which play it must make while the Earth is moving in case of its being sufficiently more remote from Earth than its fellow that can be seen with naked eye.[92]

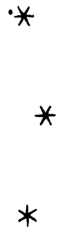

FIG. 4.

Here again, Castelli thinks he had caught sight of an optical double star. This time, however, he was right.[93] Indeed, the fainter star, being farther, should reveal the apparent motion of the nearer one while the Earth circles the Sun: having a parallax negligible in comparison, it would serve as a quasi-fixed marker making the greater parallactic shift of the nearby star detectable. In his letter to Galileo, Castelli seems to ask him for his estimate on how the relative position of these two differently remote stars would change. Likewise, we have seen traces of such a reckoning in Galileo's notes on Mizar from January 1617.

The letter of Castelli shows that in 1627 the underlying idea of identifying suitable quasi-fixed stars for the detection of parallax was still the method that Ramponi had explained to Galileo. The use of optical double stars was practised by Castelli and Galileo long before William Herschel began to collect such stars by the hundred. Galileo's so called 'method of double stars' had already been used in the early seventeenth century, in a long forgotten first chapter in the history of telescopic search for annual parallax. When the search was at last brought to a successful conclusion in 1838 by Friedrich Wilhelm Bessel, the technique he employed — the use of quasi-fixed background stars — was essentially that envisaged by Ramponi in 1611, and put into practice by Castelli and Galileo in the first decade of telescopic astronomy.

Acknowledgements

I thank Andrea Prange for her help with editing this article, and Barbara Gerard for her assistance with the English. I am grateful to the Biblioteca Nazionale Centrale di Firenze for permission to reproduce the diagram by Rampoli, and to Maurizio Sangalli for his help.

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2. Robert Moray (Whitehall) to Christiaan Huygens (Paris), 29 Nov. 1663, in *Oeuvres complètes de Christiaan Huygens* (22 vols, Paris, 1888–1950), iv, 443–5 (no. 1173): "Mais il y a long temps que Monsieur Wren en parlant de la façon de tuyau dont il faut se servir aux lunettes qui requierent une longueur de 60. 80. pieds ou d'avantage il s'est proposé la mesme chose que vous me descrivez [*ibid.*, 431–3 (no. 1167)]. Voicy qu'entre Monsieur Neile, pendant que J'escris ce que dessus, et me dit qu'il y a 10. Ans que Monsieur Wren et luy ont parlé de cette affaire. Mais ils n'ont pas songé à employer cette invention pour l'usage ordinaire. seulement il se proposoyent de placer un verre obiectif sur quelque grande hauteur et le fixer là pour observer et comparer les altitudes meridionales de quelque estoile afin de tascher de decouvrir sil y a quelque paralaxe &c." Aerial telescopes were also constructed by Johannes Hevelius and the most powerful ones were built by Huygens himself and by Giuseppe Campani (1635–1715). See Rolf Willach, "Schyrl de Rheita und die Verbesserung des Linsenfernrohres Mitte des 17 Jahrhunderts", *Sterne und Weltraum*, xxxiv (1995), 102–10 and 186–92, pp. 104, 105, 107–8.
3. Athanasius Kircher, *Itinerarium exstaticum* (Rome, 1656), reissued in a revised, augmented and annotated version by his friend Kaspar Schott under the title: *Iter ex[s]taticum coeleste* (Würzburg, 1660, ²1671). Barbara Bauer [Mahlmann], "Copernicanische Astronomie und cusanische Kosmologie in Athanasius Kirchers «Iter exstaticum»", *Pirckheimer Jahrbuch*, v (1989/90), 69–107; Carlos Ziller Camenietzki, "L'Extase interplanétaire d'Athanasius Kircher: Philosophie, cosmologie et discipline dans la Compagnie de Jésus au XVIIe siècle", *Nuncius*, x (1995), 3–32; Harald Siebert, "Vom römischen *Itinerarium* zum Würzburger *Iter*: Kircher, Schott und die Chronologie der Ereignisse", in *Spurensuche: Wege zu Athanasius Kircher*, ed. by Horst Beinlich, Hans-Joachim Vollrath and Klaus Wittstadt (Dettelbach, 2002), 163–88; and Trevor Johnson, "Jesuit space-travel in the age of Galileo: Athanasius Kircher's *Ecstatic voyage* of 1656", unpublished paper presented to the Reformation Studies Colloquium, Warwick University, April 2000.
4. Kircher, *Itinerarium* (ref. 3), 266–8, 275, 347–9; Kircher, *Iter* (ref. 3), 348–50, 355, 409–11; Harald Siebert, "Die große kosmologische Kontroverse: Rekonstruktionsversuche anhand des Itinerarium exstaticum von Athanasius Kircher SJ" (Ph.D. dissertation, Technische Universität Berlin / Université de Paris I, 2004), 208–15, 278–307.
5. Copernicus, *De revolutionibus orbium coelestium libri sex* (Nuremberg, 1543), f. 10r: "... quae [*sc.* the distance of the stars] faciat etiam annui motus orbem sive eius imaginem ab oculis evanescere."
6. Galileo Galilei, *Dialogo sopra i due massimi sistemi del mondo Tolemaico e Copernicano* (Florence, 1632) = *Le opere di Galileo Galilei*, ed. by Antonio Favaro (20 vols, Florence, 1890–1909; hereafter: Galileo, *Opere*), vii, 21–520.

7. The absence of observable parallax was no longer a major argument of anti-Copernicans in the seventeenth century: Ludovico Delle Colombe, "Contro il moto della Terra" (Ms., 1610/ 1611), Galileo, *Opere*, iii/1, 251–90, pp. 281–3; and Francesco Ingoli, "De situ et quiete terrae contra Copernici systema disputatio" (Ms., 1615), *ibid*., v, 403–12, p. 409. Giambattista Riccioli (1598–1671) quotes it among his 77 arguments against the motion of the Earth: Riccioli, *Almagestum novum* (2 vols, Bologna, 1651), ii, 450b–4a (Lib. 9, sect. 4, cap. 28). The Copernican explanation for its absence is granted by Anton Maria Schyrleus de Rheita (*Oculus Enoch et Eliae sive radius sidereomysticus* (2 vols, Antwerp, 1645), i, 194b) and implicitly also by Kircher (*Itinerarium* (ref. 3), 267–8, 350 and *Iter* (ref. 3), 349–50, 411).
8. Copernicus, *De revolutionibus* (ref. 5), 21.
9. Galilei, *Dialogo*, in *Opere*, vii, 413: "SALV[IATI]. Vorrei che voi diceste, che quando una tal diversità [*sc.* parallactic shift] si scorgesse, niuna cosa resterebbe più che potesse render dubbia la mobilità della Terra, atteso che a cotal apparenza nissun altro ripiego assegnar si potrebbe. Ma quando bene anco ciò sensibilmente non apparisse, non però la mobilità si rimuove, nè la immobilità necessariamente si conclude, potendo esser (come afferma il Copernico) che l'immensa lontananza della sfera stellata renda inosservabili cotali minime apparenze...." Translation from Stillman Drake, *Galileo: Dialogue concerning the two chief world systems* (Berkeley, ^{3}1962), 386–7.
10. Galileo, *Dialogo*, in *Opere*, vii, 409–12, 414–16.
11. Galileo, *Dialogo*, in *Opere*, vii, 399–416. In contrast Kepler's report on Tycho's failure to detect stellar parallax is given in only a single page: Johannes Kepler, *Epitome astronomiae Copernicanae* (Linz, 1618), 493.
12. Galileo, *Dialogo*, in *Opere*, vii, 399, 400, 404, and 413–14.
13. Galileo, *Dialogo*, in *Opere*, vii, 399.
14. Galileo, *Dialogo*, in *Opere*, vii, 404.
15. Galileo, *Dialogo*, in *Opere*, vii, 416: "SALV[IATI]. A me par tutto l'opposito, perchè non ha del verisimile che, se alcuno l'avesse sperimentata, non avesse fatto menzione dell'esito, se succedeva in favore di questa o di quella opinione; oltre che nè per questo nè per altro fine si trova che alcuno si sia valso di tal modo di osservare, il quale anco, senza telescopio esatto, malamente si potrebbe effettuare."
16. Galileo, *Dialogo*, in *Opere*, vii, 414, l. 36.
17. Kepler suggests a distance of 60 million Earth radii (*Epitome* (ref. 11), 492), and this is the greatest distance a Copernican assumed explicitly in the first half of the seventeenth century; *cf*. the table in Riccioli, *Almagestum novum* (ref. 7), i, 419a. On the basis of Gottfried Wendelin's measure for the apparent diameter of the Sun, Riccioli (*ibid*., i, 419b) calculates a distance of 604,589,312 Earth radii.
18. Tycho Brahe, *Epistolae astronomicae* (Uraniburg, 1597), 167, cites 7,850,000 [Earth radii]. Tycho's calculation (2284 E.r. / tan (1/60) = 7,851,813.4 E.r.) is based on the apparent diameters of stars of almost third magnitude ($1\frac{1}{12}$: see Tycho, *Astronomiae instauratae progymnasmata* (Prague, 1602), 482; for Saturn's distance he assumes 10,550 E.r. (*ibid*., 476)).
19. The same calculation is in his *Progymnasmata* (ref. 18), 481, where Tycho concludes: "quod absurdum est credere."
20. Christian S. Longomontanus, *Astronomia Danica* (Amsterdam, 1622), ii, 19, 21; and Libertus Fromondus (Froidmont), *Ant-Aristarchos sive orbis-terrae immobilis* (Antwerp, 1631), 64–71. Overall the anti-Copernican arguments of Tycho's *Epistolae astronomicae* (ref. 18) were widely used by geocentrists. See Massimo Bucciantini, *Galileo e Keplero: Filosofia, cosmologia e teologia nell'Età della Controriforma* (Turin, 2003), 57–62.
21. Christoph Scheiner, *Disquisitiones mathematicae, de controversiis et novitatibus astronomicis* (Ingolstadt, 1614), 27; Michael Mästlin's comments on Rheticus's *Narratio prima* (^{2}1541) as reprinted in the second edition of Kepler's *Mysterium cosmographicum* (Frankfurt, 1621), 113, 114–15; and Galileo, *Dialogo*, in *Opere*, vii, 389.
22. Tycho Brahe, *Progymnasmata* (ref. 18), 482. Combining the measurement of several instruments,

Tycho determined with an accuracy of 25″ the positions of several bigger stars: Walter G. Wesley, "The accuracy of Tycho Brahe's instruments", *Journal for the history of astronomy*, ix (1978), 42–53, p. 51.

23. Mästlin's comments in Kepler's *Mysterium cosmographicum* (ref. 21), 114: "Nec enim ulla necessitas exigit, illam Infinitatis similitudinem eousque ampliari, donec Orbis Terrae Magnus ad Stellatum Orbem prorsus, ut Tycho putat, euanescat (licet idem Orbis Magnus etiam secundum Tychonis numeros nondum prorsus euanesceret, siquidem in Stellis fixis in parallaxin ultra duas quintas, hoc est, ferme ad semissem unius scrupuli primi procrearet) quia etiam longe restrictior eius altitudo, immensa, hoc est imperscrutabilis, et nullis instrumentis, nulloque artificio inuestigabilis est...."
24. *Ibid*., 114: "Ergo Copernicum ad oculorum iudicium, non ad universalem omnis parallaxeos exclusionem respexisse, extra dubium est...."
25. Galileo, *Dialogo*, in *Opere*, vii, 399; Kepler, *Epitome* (ref. 11), 493.
26. Galileo (Padua) to Kepler (Graz), 4 Aug. 1597, in Galileo, *Opere*, x, 67–68 (no. 57). For a 'Microstoria' of this letter, see Bucciantini, *op. cit.* (ref. 20), 49–68.
27. Kepler (Graz) to Galileo (Padua), 13 Oct. 1597, Galileo, *Opere*, x, 69–71 (no. 59): "Nunc abs te placet aliquid observationum postulare: scilicet mihi, qui instrumentis careo, confugiendum est ad alios. Habes quadrantem in quo possis notare singula scrupula prima et quadrantes primorum? Observa igitur, circa 19 Decembris futurum, altitudinem eductionis caudae in Ursa [*sc.* ε UMi] maximam et minimam eadem nocte. Sic circa 26 Decembris observa similiter utramque stellae polaris [*sc.* α UMi] altitudinem. Primam stellam observa etiam circa 19 Martii anni 98, altitudine nocturna, hora 12; alteram, circa 28 Septembris, etiam hora 12. Nam si, quod opto, differentia quaedam inter binas observationes intercedet unius atque alterius scrupuli, magis si decem aut quindecim, rei per totam astronomiam latissime diffusae argumentum erit; sin autem nihil plane differentiae deprehendemus, palmam tamen demonstrati nobilissimi problematis, hactenus a nemine affectatam, communiter reportabimus. Sapienti sat dictum."
28. Galileo writes his next letter to Kepler thirteen years later, on 19 Aug. 1610 (Galileo, *Opere*, x, 421–3, no. 379), having himself received two letters: Kepler (Prague) to Galileo (Padua), 19 April 1610 (Galileo, *Opere*, x, 319–40 (no. 297)), and 9 Aug. 1610 (*ibid*., 413–17 (no. 347)). Arthur Koestler explains this silence by Galileo's taking offence at Kepler's exhortations, whereas Massimo Bucciantini alleges Galileo's prudence because of Kepler's being the disciple of Michael Mästlin whose books were put on the Index and who was in public dispute with Christoph Clavius over the Gregorian Calendar Reform: see respectively A. Koestler, *The sleepwalkers* (London, [6]1968), 359–60, and Bucciantini, *op. cit.* (ref. 20), 74–81.
29. About Ramponi little is known; he had been baptized in Bologna on 19 June 1577 (Galileo, *Opere*, xx, 515b). On Roffeni see Denise Aricò, "Giovanni Antonio Roffeni, un astrologo bolognese amico di Galileo", *Il carrobbio*, xiv (1998), 67–96.
30. Ramponi (Bologna) to Galileo (Florence), 1 July 1611 (Galileo, *Opere*, xi, 133–6 (no. 548)). Ramponi reveals his initial assumption concerning Galileo's detection of stellar parallax in his next letter: Ramponi to Galileo, 23 July 1611 (*ibid*., 159–62 (no. 561)).
31. Ramponi (Bologna) to Galileo (Florence), 23 July 1611 (Galileo, *Opere*, xi, 159–62 (no. 561)); *cf.* the passage quoted above (ref. 9) from Galileo, *Dialogo* (*Opere*, vii, 413).
32. Ramponi to Galileo, 23 July 1611 (ref. 31): "Per far questo, giudicarei che fussero molto a proposito quei luoghi ne i quali si veggiono le stelle frequentissime, come V. S. ha di già dissegnato nel Nuntio, perciò che per la loro quasi contiguità, per la quale sono comprese con lo stromento tenuto immobile, potrebbesi vedere con più facilità e sicurezza se mutino le configurationi e distanze tra loro; il che se fia, ecco dimostrata a un tratto la mobilità della terra, la distanza delle stelle fisse, da molti per la grande vastità abhorrita, e il sito delle stelle fisse, l'una più lontana dell'altra dalla congerie di questi nostri corpi, che solo credo poter essere cagione di questo truovamento, come appare qui accennato: dove, al sito della terra in D vedesi la stella A congiunta con la C, et la B antecedere la C; là dove poi nel sito E vedensi le due A et C disgiunte, et la B seguire alla C. Quando in quelle stelle così frequenti apparisse una tale disordinanza nelle figure e distanze

loro, parmi che la hipothesi Copernicana sarebbe dimostrata."

33. Neither Ramponi in his letter ("quasi contiguità") nor Galileo in the *Dialogo* ("vicinissima") describes the nearby stars as double stars: Galileo, *Opere*, xi, 161, ll. 75–79, and vii, 409, ll. 31–35 respectively. For this reason William Herschel, despite knowing very well Galileo's methods of detecting stellar parallax, considered himself to be the first to apply Galileo's second method to double stars: W. Herschel, "On the parallax of the fixed stars", *Philosophical transactions*, lxxii (1782), 82–111, p. 88. However, as we will see below, the phenomenon of double stars turns up in Galileo's correspondance.
34. William Herschel surely contributed to this view by assuming that Galileo had only "pointed out" the method of direct measurement "first attempted by Hook" and had "suggested" a second method of relative measurement: *ibid*., 84 and 88. In contrast, Umberto Fedele (see ref. 63), 67, and, though without citing evidence, Emilio Bianchi ("Il problema delle parallassi stellari", *Rendiconti del seminario matematico e fisico di Milano*, iii (1929), 224–50, p. 225) take it for granted that Galileo used his telescopes for the search of stellar parallax.
35. Michael A. Hoskin, "Stellar distances: Galileo's method and its subsequent history", *Indian journal of history of science*, x (1966), 22–29, p. 28: "... it was fitting that two of the three successful measurements, and in particular the one that carried immediate conviction in the astronomical world, were made by the technique of double stars that Galileo had proposed more than two centuries before." Galileo describes this second method in *Dialogo* (*Opere*, vii, 409, and 411–12).
36. *Cf.* Ramponi to Galileo, 23 July 1611 (Galileo, *Opere*, xi, 161 (sketch)), and Galileo, *Dialogo* (*Opere*, vii, 412 (drawing)).
37. Stillman Drake, "Galileo's first telescopic observations", *Journal for the history of astronomy*, vii (1976), 153–68, p. 159: "I think it likely enough that by March 1610 he [*sc*. Galileo] had managed to make a 30-power telescope...."
38. Christoph Scheiner, *Tres epistolae de maculis solaribus: Scriptae ad Marcum Velserum* (Augsburg, 5 Jan. 1612) (Galileo, *Opere*, v, 21–33).
39. Galileo (Villa delle Selve) to Marcus Welser (Augsburg), 4 May 1612, published in Galileo, *Istoria e dimostrazioni intorno alle macchie solari e loro accidenti* (Rome, 1613) (Galileo, *Opere*, v, 94–113, p. 95). Galileo's claim to priority is confirmed by Angelo de Filiis, member of the Accademia dei Lincei, in his preface to this book: Galileo, *Opere*, v, 84. Galileo had mentioned his sunspot observations for the first time in print in Galileo, *Discorso intorno alle cose, che stanno in su l'acqua, o che in quella si muovono* (Florence, (May) 1612): Galileo, *Opere*, iv, 58–141, p. 64.
40. Thomas Harriot (1560–1621) never published his sunspot observations, which he had made in December 1610. David Fabricius (1564–1617) and his son Johannes (1587–1616), however, did publish theirs: Johannes Fabricius, *De maculis in Sole observatis, et apparente earum cum Sole conversione narratio* (Wittenberg, 1611). Kepler (Linz) reports this publication in his letter to Oddo van Maelcote (Brussels), 18 July 1613 (Galileo, *Opere*, xi, 536–7 (no. 902)). For the chronology of these observations see especially Galileo, *Dialogo*, ed. by Ottavio Besomi and Mario Helbing (Padua, 1998), ii, 720–35. See also William R. Shea, "Galileo, Scheiner, and the interpretation of sunspots", *Isis*, lxi (1970), 498–519; Rivka Feldhay, *Galileo and the Church: Political inquisition or critical dialogue?* (Cambridge, 1995), 256–91; and Mario Biagioli, "Picturing objects in the making: Scheiner, Galileo and the discovery of sunspots", in *Wissensideale und Wissenskulturen in der Frühen Neuzeit*, ed. by Wolfgang Detel and Claus Zittel (Berlin, 2002), 39–96, pp. 53–96.
41. Giovanni Faber (Rome) to Galileo (Pisa), 15 Dec. 1611 (Galileo, *Opere*, xi, 238–9 (no. 614)); Marcus Welser (Augsburg) to Faber (Rome), 16 Dec. 1611 (Galileo, *Opere*, xi, 246 (no. 622)); Welser (Augsburg) to Galileo (Florence), 6 Jan. 1612 (Galileo, *Opere*, v, 93 and xi, 257 (no. 637)). The day of publication of Scheiner's *Tres epistolae de maculis solaribus* is given on the title page ("M.DC.XII. Non. Ian.").
42. See Ramponi's third letter to Galileo where he refers to his unanswered second letter of 23 July

1611: Ramponi (Bologna) to Galileo (Florence), 21 May 1612 (Galileo, *Opere*, xi, 299–300 (no. 679)).

43. Ramponi to Galileo, 23 July 1611 (Galileo, *Opere*, xi, 160 (no. 561)), and 21 May 1612 (*ibid.*, 300 (no. 679)).
44. From Ramponi's four letters to Galileo published in Galileo, *Opere* and cited in this paper, there is evidence for only one reply from Galileo (to Ramponi's first letter). In his last letter Ramponi begs farewell to Galileo, declaring that he will never write to him again, because he has not received replies: Ramponi (Bologna) to Galileo (Florence), 11 July 1612 (Galileo, *Opere*, xi, 359–60 (no. 727)).
45. Hooke, *op. cit.* (ref. 1).
46. Lodovico Cardi/Cigoli (Rome) to Galileo (Florence), 30 June 1612: "Il Pasigniano, huomo molto di sua oppinione, à sentito da non so chi questa sua; et l'altra sera me la diceva, che lo avete chiaro, tenendo ancora duro la sua, et che non guarda più sole, ma che attende ai movimenti delle stelle, et che vede visibilmente che la terra si move in 24 ore, et d'altro moto che fa la state e 'l verno, et il sole sta fermo: dove li soggiunsi che V. S. dice che si rivolgie in sè stesso ancora lui; dove egli se ne rise, et io ancora delle sue sentenzie così dintornate e risolute, senza mai dire altro che le cose ch'egli sente da il Signior Lucha o 'l Padre Gambergier, e le vole lucidare, e le storpia, che è cosa ridicola, et che si fa fare uno ochiale a Venezia, che sarà lungho tre braccia, con il quale spera da avere a vedere e speculare cose minimissime et nella luna e nel cielo." Galileo, *Opere*, xi, 347–9 (no. 718), p. 348. My thanks to Giulia Giulianelli for verifying this passage. Cigoli had already reported on Passignano's telescopic activities in 1611: Cardi/Cigoli to Galileo, 16 Sept. 1611 (Galileo, *Opere*, xi, 208–9 (no. 582)), and 23 Sept. 1611 (*ibid.*, 212–13 (no. 587)). Galileo answered both letters: 1 Oct. 1611 (Galileo, *Opere*, xi, 213–14 (no. 588)).
47. See Ramponi, *op. cit.* (ref. 44) and Kepler, *op. cit.* (ref. 28).
48. Galileo, *Dialogo* (*Opere*, vii, 414–15).
49. Galileo, *Dialogo* (*Opere*, vii, 409–11).
50. Galileo, *Dialogo* (*Opere*, vii, 415).
51. Drake, "Galileo's first telescopic observations" (ref. 37), 159. In one of his undated observation notes Galileo mentions a 32-power telescope: Galileo, "Analecta astronomica" [Ms.] (Galileo, *Opere*, iii/2, 872–80, p. 878; later references to this work will cite the page from *Opere*).
52. Galileo (Bellosguardo) to Cesare Marsili (Bologna), 5 April 1631 (Galileo, *Opere*, xiv, 239–41 (no. 2137)).
53. For the year 1616 see below. For the years 1617 to 1631 see Galileo, *Dialogo* (ref. 40), ii, 795–6. The owner of the villa was Lorenzo Segni.
54. Benedetto Castelli (Pisa) to Galileo (Florence), 16 Nov. 1616 (Galileo, *Opere*, xii, 296 (no. 1236)): "Ho osservata di novo la constellazione della prima delle tre stelle nella coda dell'Orsa maggiore *post eductionem caudae*, e mi è parsa tale la constituzione con quella che se li vede vicinissima con la vista naturale e quell'altra visibile solo con l'occhiale: quella notata A è la prima delle tre etc.; quella notata B è la vicina etc., e finalmente quella notata C è la visibile con l'occhiale. Ma se mal non mi ricordo, questa estate a Bellosguardo la C era talmente situata con l'altre due, che in lei si formava un angolo retto, tirando le linee dalla C alla B et A. Però V. S. ci faccia un puoco di reflessione, quando ne habbia comodità...."
55. The third star in question is of the eighth magnitude (HD 116798, TYC 3850-00257-1) and no longer known as Stella Ludoviciana (Ludwigs-Stern, or Louis's Star), the name given it by Johann Georg Liebknecht (1679–1749), professor of mathematics and theology in Gießen, whose sovereign was Landgrave Ernst Ludwig (1678–1738) of Hesse-Darmstadt. Watching this star on 2 Dec. 1722, Liebknecht mistakenly believed he had detected not only a new star but even its proper motion. In the following year he published his discovery and defended it subsequently against objections from Ludwig Philipp Thümmig (1697–1728), a disciple of Christian Wolff: Johann Georg Liebknecht, *Sidus boreale stella noviter detecta stipatum et ... Ludovicianum nuncupatum* (Gießen, 1723), and *Uberior stellae Ludovicianae noviter detectae consideratio* (Gießen, 1723).
56. For a 30-power telescope of Galilean type the field of view is even more reduced. Mizar and Alcor

are about 12 arc-minutes distant from each other and respectively 9 and 6 arc-minutes from the Stella Ludoviciana.

57. Castelli (Pisa) to Galileo (Florence), 7 Jan. 1617 (Galileo, *Opere*, xii, 301 (no. 1241)): "Non manco d'andar in busca di stelle fisse; ma non trovo cosa al proposito, fuor che le avvisate nelle passate."

58. Galileo, "Analecta astronomica" (ref. 51), 880.

59. *Ibid*., 879: "Facciasi un angolo di cartone, che, messo nella cima del telescopio, passi per le 3 stelle notate etc., come nell'esempio qui sotto: [sketch]."

60. Castelli (Pisa) to Galileo (Florence), 7 Jan. 1617 (Galileo, *Opere*, xii, 301 (no. 1241)): "Per l'osservazione della Canicola ho ritrovato un luogo nel quale si potrà collocare il lumicino, e di poi allontanarsi 150 braccia in circa per osservare: e quanto prima il tempo me ne dia licenza, mi metterò all'impresa."

61. These three Sirius observations are recorded together with Galileo's sketch of the aperture mask on the same sheet of paper: Galileo, "Analecta astronomica" (ref. 51), 879. For the Sun's position we read 0 ♑, 6 ♈ and 0 ♉ respectively. The exact day to be deduced from the zodiacal position depends on the year in question, i.e. whether it is a leap year or the first, second or third year after a leap year. Assuming the year 1616 for Galileo's first observation we obtain the following dates: 22 December 1616 (0 ♑), 27 March 1617 (6 ♉) and 21 April 1617 (0 ♉). We have used Clavius's tables for determining the dates of Galileo's zodiacal notation: Christoph Clavius, *In sphaeram Ioannis de Sacro Bosco commentarius*, *Opera mathematica* (5 vols, Mainz, 1611–12; reprinted, Hildesheim, 1999), iii, 159–62.

62. Castelli (Pisa) to Galileo (Florence), 7 Jan. 1617 (Galileo, *Opere*, xii, 301 (no. 1241)): "Non manco d'andar in busca di stelle fisse; ma non trovo cosa al proposito, fuor che le avvisate nelle passate. Desiderarei che V. S. Ecc.^{ma}, concedendoglielo la sanità, una sera desse un'occhiatina a quella stella di mezo delle tre che sono nella coda dell'Orsa maggiore, perchè è una delle belle cose che sia in cielo, e non credo che per il nostro servizio si possa desiderar meglio in quelle parti."

63. Umberto Fedele, "Le prime osservazioni di stelle doppie", *Coelum*, xvii (1949), 65–69 (reprinted in: *Coelum astronomia: Edizioni scientifiche Coelum*, liv (2002), 57–59). Fedele's almost forgotten article was brought to my attention by Leos Ondra, "Il volto nuovo de Mizar", *Coelum astronomia: Edizioni scientifiche Coelum*, liv (2002), 52–56, who has also provided an English version: http://leo.astronomy.cz/mizar/fedele.htm.

64. Riccioli, *Almagestum novum* (ref. 7), i, 422a (Lib. 6, cap. 9): "*Primus* modus observandi diametros stellarum nititur oculari aestimatione..., quae coniectura errori proculdubio exposita est..., adeo ut stella unica videatur illa, quae media est in cauda Ursae maioris, cum tamen sint duae, ut Telescopium prodidit...." Ronchi thinks that Martin Horky saw the doubling of Mizar already on 24/25 April 1610: Vasco Ronchi, *Galileo e il cannocchiale* (Udine, 1942), 266. However, Fedele, *op. cit.* (ref. 63), 67, shows that Horky referred to the optical double star formed by Alcor and Mizar and not to the binary Mizar A and B.

65. Anton Maria Schürle mentions a triple star ("stella tricorporea") described and illustrated as a multiple star, which he had observed in the Orion constellation: Rheita, *Oculus Enoch* (ref. 7), i, 198a and illustration (sheet G, figure 7) at the end of vol. ii. Johann Baptist Cysat (*Mathemata astronomica* (Ingolstadt, 1619), 75), had published an observation of five double or multiple stars in Praesepe, but he considered them star clusters: "... quini stellularum cumuli qui in unica Nebulosa Cancri per Tubum spectantur, ex nubilo lumine constantes intermicantibus aliquot stellulis." For Cysat's observation, see Siebert, *op. cit.* (ref. 4), Anhang (appendix).

66. Through statistical analysis John Michell (1724–93) demonstrated "with the highest probability ... that the stars are really collected together in clusters in some places, where they form a kind of systems": J. Mitchell, "An inquiry into the probable parallax, and magnitude of the fixed stars, from the quantity of light which they afford us, and the particular circumstances of their situation", *Philosophical transactions*, lvii (1767), 234–64, p. 249.

67. For their idea of stellar systems Rheita and Kircher were both criticized by the Copernican Otto von Guericke, *Experimenta nova (ut vocantur) Magdeburgica de vacuo spatio* (Amsterdam,

1672), 230a,b and 235b–236a respectively. G. B. Hodierna (*De systemate orbis cometici deque admirandis coeli characteribus* (2 vols, Palermo, 1654), ii, Sectio quarta, Corollaria 1, 3, 4) does not exclude the possiblilty of (physical) multiple stars (see Domenico Ognibene's Italian translation of this very rare book on http://www.orsapa.it/hodierna/index.htm). For these non-Copernican conceptions of stars and the forgotten stellar astronomy of the Tychonics see Siebert, "Die große kosmologische Kontroverse" (ref. 4), 208–77.

68. Owen Gingerich's aphorism.
69. Huygens and Newton were the most prominent astronomers who tried to gauge the distance of stars by measuring their brightness. This was to be another project of William Herschel's. Stellar uniformity, however, was contradicted by Kircher and questioned by Rheita and Hodierna.
70. Christiaan Huygens, ΚΟΣΜΟΘΕΩΡΟΣ (The Hague, 1698), *Oeuvres complètes* (ref. 2), xxi, 815.
71. Castelli (Pisa) to Galileo (Florence), 22 Feb. 1617 (Galileo, *Opere*, xii, 309 (no. 1248)): "Similmente le due della coda dell'Orsa si sono tra di loro allontanate, se ben poco; ma io che so benissimo come stavano, almeno quanto alla vicinanza tra di loro, non ho dubbio dell'essersi allontanate."
72. Galileo, "Analecta astronomica" (ref. 51), 877: "Media caudae Elicis incidit secundum latitudinem in gr. 9 ♍, et latitudo eius est gr. 56. Terra est modo in 25 ♋, ex quo locus ✶ ab ea distat gr. 44." Helice or Elice is another name for the Great Bear. Galileo measures for Mizar's position 56 ecliptical latitude and an ecliptical longitude of 159 (5 × 30 + 9 , Virgo being the sixth zodiacal constellation starting from the First Point of Aries). He deduces an angular distance of 44 between Mizar and the Earth whose position on the zodiac is 25 Cancer, which corresponds to an ecliptical longitude of 115 . The Sun's position in the zodiac is 180 , opposite to that of the Earth. Hence the zodiacal position of the Sun is 25 Capricorn. From Clavius's tables we read for this the date 15 January (for a year such as 1617, i.e. annus primus post bissextum): Clavius, *In sphaeram* (ref. 61), iii, 161. By taking as entry date of Capricorn 22 December (*ibid.*, 157) and adding (25 /360 365 =) 25 days we get the same date, which is also assumed for the year 1617 by Fidele (ref. 63), 68.
73. Galileo, "Analecta astronomica" (ref. 51), 877: "Inter mediam caudae Elicis et sibi proximam pono nunc gr. 0.0 ,15 . Semidiameter stellae maioris gr. 0.0.3 , minoris vero 2 , et intercapedo 10 ."
74. The Tycho Double Star Catalogue [TDSC], ed. by C. Fabricius *et al.*, 2002 (Mizar's TDSC Number is 35543), to be consulted on http://vizier.u-strasbg.fr/cgi-bin/VizieR (under Mizar's Henry Draper no. HD 116656).
75. Galileo, "Analecta astronomica" (ref. 51), 877: "Semidiameter orbis magni continet semidiametros ⊙ 226. Semidiameter ⊙ continet semidiametros stellae maioris 300. Distantia ergo stellae continet distantias ⊙ 300 (si stella ponatur tam magna ut ⊙), hoc est semidiametros ⊙ 67800."
76. Following the rule of stellar distances (*d*, in astronomical units) and stellar parallax (*p*, being half of the angle of a star's total shift in the sky) we obtain for Mizar A at a distance of 300 AU (*p* = arc tan 1 AU/300 AU =) 0.19 or 11.5 as parallactic shift due to the Earth's revolution over three months.
77. Gauging the distance of Mizar B the same way Galileo did for Mizar A, we obtain 450 AU and thus a parallax of 7.6 .
78. The relative distance between Mizar A and B would vary by (11.5 – 7.6 =) 3.9 over three months.
79. This is the only dated observation in Galileo's "Analecta astronomica" (ref. 51): "Apposita fixarum constitutio reperta est a me prope cuspidem ensis Orionis.... Haec observata sunt a me die 4 Februarii 1617 a Bellosguardo" (p. 880).
80. Galileo, "Analecta astronomica" (ref. 51), 880: "Incidit cuspis ensis Orionis in gr. 18 ♊ cum latitudine australi gr. 30." Hence Galileo had observed the θ^1 Orionis stars in the so-called Huygens Region before Giovanni Battista Hodierna (*De systemate orbis cometici deque admirandis coeli characteribus* (2 vols, Palermo, 1654), ii, 19) and long before Huygens himself (*Systema Saturnium* (The Hague, 1659), 8–9; *Oeuvres complètes* (ref. 2), xv, 237–8). Unlike Hodierna, however, who would be the first to discuss the Orion Nebula in print, Galileo did not even mention it.

81. Castelli (Pisa) to Galileo (Florence), 22 Feb. 1617 (Galileo, *Opere*, xii, 309 (no. 1248)): "L'osservazione accennatami da V. S. in Orione non m'è riuscita, perchè non ho mai ritrovate le stelle che lei mi nota."

82. Galileo, "Analecta astronomica" (ref. 51), 880: "Distantia inter *a*, *b* iudicatur 3 2 semidiametros, ad quam distantia *b g* videtur tripla." Thus the lower parallel side (*a*, *b*) of the trapezoid is three times Jupiter's apparent radius (3·33 /2); this length is approximately 50 while its uper side is about 2 30 away. In contrast, the θ^1 Orionis stars of the Trapezium are not more than 20 from each other.

83. The lower parallel side of this larger trapezoid is formed by the variable star TYC 4774-00934-1 (mag. 6.2) and 43 θ^2 Ori (mag. 5, TYC 4774-00933-1); these are separated by 52 and so represent Galileo's *a* and *b* stars respectively, for which he measured a relative distance of 50 (see ref. 82). In a range of 2 30 from *b* to the northeast as indicated by Galileo we actually find for his *g*-star 41 θ^1 Ori (mag. 6.5, TYC 4774-00953-1) at a distance of 2 27 from 43 θ^2 Ori (Galileo's *b*). Hence Galileo's *g*-star is one of the bright stars of the Orion Trapezium. Together with 41 θ^1 Ori (mag. 6.3, TYC 4774-00930-1) at a distance of 19 (missing in Galileo's sketch) it lies parallel to the lower (*a*, *b*) side of Galileo's trapezoid, whereas in his sketch the upper parallel side is made by the stars near *g*, i.e. *c* and *i* (forming a narrow isosceles triangle).

84. Galileo's *g*-star (see ref. 83), one of the Trapezium θ^1 Orion cluster, is itself a close binary (TYC 4774-00953-1, resolved in WDS 05353-0523 [AE] and in HIP 26220 [BH]) whose components (mag. 6.7 and 11.1) are separated by 4.1 today. They form a triple star together with the equally-near variable star (mag. 7.2, TYC 4778-01358-1), which is too bright to match Galileo's depiction, but is suspected to have an intrinsic variability. It is catalogued as an eighth-magnitude star (mag 8.2) in the *Bonner Durchmusterung* (1859–1903) and may have been still fainter in 1617. For the performance of Galileo's (mostly lost) telescopes, see the Galilean Telescope Homepage: http://www.pacifier.com/ tpope/index.htm.

85. On the line between Galileo's *b*-star (43 θ^2 Ori, TYC 4774-00933-1) and his *g*-star (41 θ^1 Ori, TYC 4774-00953-1) separated by 2 30 (see ref. 83) lies another bright star of the Orion Trapezium, 41 θ^1 Ori (mag. 5, TYC 4774-00931-1), 2 16 away from *b* and missing in Galileo's sketch.

86. Galileo, "Analecta astronomica" (ref. 51), 880: "... duae vero *c*, *i* admodum exiguae, nempe vix 4ª aut 5ª pars ipsius g.... Duae *c*, *i* aequaliter distant a *g*, quam fere tangunt.... Insuper intercapedo inter *g* et quamlibet ipsarum *c*, *i* vix caperet alteram *g*."

87. Castelli (Pisa) to Galileo (Florence), 22 Feb. 1617 (Galileo, *Opere*, xii, 309 (no. 1248)): "È ben vero che havendo ai 30 di Gennaio osservato tra 'l Cane maggiore e la spalla sinistra d'Orione circa 'l mezo un triangolo e nell'angolo orientale una stella, restai in dubbio, dopo diligente e replicata osservazione, se era una o due; et hora, ritornato alla medesima osservazione, le ritrovo chiaramente due, sichè il gioco si fa."

88. Castelli (Pisa) to Galileo (Florence), 22 Feb. 1617 (Galileo, *Opere*, xii, 309 (no. 1248)): "Similmente le due della coda dell'Orsa si sono tra di loro allontanate, se ben poco; ma io che so benissimo come stavano, almeno quanto alla vicinanza tra di loro, non ho dubbio dell'essersi allontanate."

89. Castelli (Pisa) to Galileo (Florence), 22 Feb. 1617 (Galileo, *Opere*, xii, 309 (no. 1248)): "Io ho ancora certe altre osservazioni, delle quali meglio trattaremo a bocca, compiacendosi lei di trasferirsi sin qua; e così ancora potrà dar ordine all'altro capo dell'osservazioni, il che riuscirebbe esquisitamente di qua e di là d'Arno, stando noi a osservare nel Long'Arno esposto al mezo giorno, et il segno sopra le case che sono di là d'Arno. Haverei ancora qua nel giardino de' Padri di S. Girolamo qualche sito per il Can maggiore, ma dubito che la distanza non basti; tuttavia, se lei si risolve di venire, trattaremo e concluderemo qualche cosa."

90. Galileo, "Lettera a Francesco Ingoli in risposta alla Disputatio de situ et quiete Terrae" [Ms., 1624], Galileo, *Opere*, vi, 509–61, p. 553: "... ed in tanto vi dico, che non avendo voi per voi stesso fatte tali osservazioni, non dovete prestar così ferma fede a Ticone ed a' suoi strumenti, inabili per avventura a poter distinguere tali minuzie, che forse con altri strumenti, e molto maggiori e molto più perfetti ed assai diversi, potrebbero un giorno esser comprese." Galileo refers to Francesco Ingoli, "De situ et quiete Terrae" [Ms., 1615], Galileo, *Opere*, v, 403–12, p. 409. On

Galileo's response see Massimo Bucciantini, *Contro Galileo: Alle origine dell'affaire* (Florence, 1995), 149–74.

91. Alessandra Fiocca, "I gesuiti e il governo delle acque del basso Po nel secolo XVII", in Maria Teresa Borgato (ed.), *Giambattista Riccioli e il merito scientifico dei gesuiti nell'età barocca* (Florence, 2002), 319–70, pp. 340–54.

92. Castelli (Rome) to Galileo (Florence), 7 Aug. 1627, Galileo, *Opere*, xiii, 372–3 (no. 1834): "Ho osservata la stella settentrionale delle tre della fronte del Scorpione, quale ha una stellina vicinissima, più settentrionale di essa, nella continovazione dell'arco delle tre della fronte, in questa maniera: [Castelli's sketch, see Fig. 6] [/] V. S. mi faccia grazia di scrivermi che gioco doverà fare, movendosi la terra, caso che lei sia assai più lontana dalla terra della altra compagna, visibile con la vista naturale."

93. The northern star in the head of Scorpius is 8 β Scorpii (also called Graffias or Acrab): Fedele, "Le prime osservazioni di stelle doppie" (ref. 63), 68; Ondra, "A new view of Mizar" (ref. 63). However, Castelli did certainly not mean the physical double star β Scorpii itself, whose components are visible without a telescope (mag. 4.5 and 2.5 respectively), whereas Castelli distinguishes only the brighter star with naked eye. Moreover the components are too distant from each other (separated by 24.7 in 1627) to match Castelli's description according to which the fainter star ("stellina") is most close ("vicinissima") to the brighter. Castelli's tiny star lying nearby north to Graffias (8 β^1 Sco) must be TYC 6208-00095-1, a star of almost eleventh magnitude (10.94). although it would be surprising if so faint a star were within reach of his telescope (see also ref. 84 above). In 1627 its distance to Graffias was about 9 and it continued the arc formed by the three stars in the head of Scorpius (6 π Sco; Dschubba, 7 δ Sco; Graffias, 8 β Sco) in accordance with Castelli's sketch). For recalculating the stars' position the software Redshift™5 from United Soft Media was used.