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THE DEVELOPMENT OF COMPOUND EYEPIECES, 1640–1670

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Between Hans Lipperhey's patent application of 1608[1] and the end of the seventeenth century, the refracting telescope developed from a simple all-purpose spyglass into a sophisticated and specialized astronomical research instrument. The compound eyepiece played an important role in this development because its larger field of view helped make possible the very long telescopes which came into use after 1660. Although almost nothing is known about the actual composition of compound eyepieces before about 1665, it is now possible to comment on their genesis in Augsburg in the early 1640s and their spread to Northwest Europe over the next two decades. The invention of the Huygenian eyepiece, *ca.* 1662, can therefore be placed in historical perspective. Like its predecessors, it was the result of trial and error, not theory.

In his *Dioptrice* of 1611 Johannes Kepler showed that the telescopic effect can be obtained not only by combining a convex and a concave lens in the configuration made famous by Galileo, but also by combining two convex lenses. This combination results in an inverted image, but Kepler pointed out that the addition of a third convex lens, appropriately placed, will make the image erect again.[2] But his suggestions were not immediately translated into practice because telescopes consisting of convex lenses had no readily apparent advantages over the "Dutch" or "Galilean" type, and certain obvious disadvantages. One would have to put up with an inverted image or suffer the compounding of lens imperfections caused by the third lens. Only in the study of sunspots was the telescope with two convex lenses used sometimes because it yields an erect *projected* image, while the Galilean combination gives an inverted projected image.[3]

The advantages of the telescope with two convex lenses, a larger field of view and a brighter image, were first mentioned in print by Christoph Scheiner, in his *Rosa ursina* of 1630. Scheiner had used such a combination from time to time for projecting the Sun's image and had recognized its merits when he happened to look through it.[4] When the increasing lengths and magnifications of telescopes made the small field of view of the Galilean combination an ever-greater handicap, the Keplerian form offered a solution to which astronomers could turn because in practice the inverted image turned out to be no particular disadvantage. The telescope with two convex lenses, therefore, replaced the Galilean type in astronomical research, first in Italy in the late 1630s and then north of the Alps in the middle 1640s.[5]

But the small field of view of the Galilean combination was an equally serious handicap in viewing objects on Earth as magnifications increased. And since the simple Keplerian form gives an inverted image, it offered no solution in this case. For terrestrial purposes, therefore, men turned to Kepler's suggestion that the inverted image can be erected by adding yet a third convex lens. We may speculate that experimentation to find the best place for the erector lens led to the development of the compound eyepiece.

In 1643 a Capuchin monk named Antonius Maria Schyrlaeus de Rheita published a tract entitled *Novem stellae circa Iovem, circa Saturnum sex, circa Martem nonnullae*, in which he claimed to have discovered a number of new satellites of the superior planets. He informed the reader that these new stars could not be seen through ordinary telescopes, but would only be revealed by a new telescope recently invented by him (*nuper a me reperto*).[6] Two years later he published his much larger *Oculus Enoch et Eliae*, in which he described telescopes with two convex lenses for astronomical purposes and with three convex lenses for terrestrial purposes. In a cryptogram he mentioned a telescope with *four* convex lenses without giving details as to its construction.[7] The three-lens telescope was, of course, a Keplerian combination with an erector lens; the four-lens instrument (as it turned out) consisted of an objective, an erector lens, a field lens, and an eye lens. If Rheita did not give the reader much information about the construction of the telescope with four lenses, he did mention that all instruments described by him could be obtained, at an appropriate price, from Johannes Wiesel, an optician in Augsburg.[8] The new instrument aroused great curiosity.

In England Sir Charles Cavendish, brother of William Cavendish, Marquess of Newcastle, had been working together with the mathematician John Pell and the instrument maker Richard Reeves at least since 1641, trying to make Galilean telescopes with hyperbolic objective lenses, inspired by Descartes's *Dioptrique*.[9] But this was a very difficult business, as the correspondence between Cavendish and Pell shows.[10] Descartes himself, when he heard about their efforts, admitted that it was impossible to grind such lenses.[11] Sir Charles was also familiar with telescopes consisting of two convex lenses through his acquaintance with William Gascoigne who was "providore" to his brother's army.[12] But he did not entirely approve of these instruments:

> I onlie mislike his glass next the eye which he makes convex on both sides: I tolde him it woulde make confused sight, if De Cartes his doctrine be true, but upon triall it proved more distinct than I expected, yet I thinke a concave on that side next the eye would doe better. . . .[13]

After the battle of Marston Moor in July 1644 (at which Gascoigne died), Sir Charles left England with his brother. In Hamburg he heard about Father Rheita's celestial discoveries and the new type of telescope with which these discoveries were made. He promptly began making inquiries about these telescopes.[14] A letter to Augsburg produced information about Father Rheita's whereabouts—he was in Antwerp, seeing his *Oculus Enoch et Eliae* through the press—and about the prices of Wiesel's telescopes. On 27 December Sir Charles wrote to Pell:

> I have little to adde, but this inclosed concerning Reieta's glass. I desire you will be pleased to inquire if he be at Antwerp, and if he be, to inquire of him if one of those glasses may be had both sooner and at an easier rate.[15]

A few months later Sir Charles, on his way to Paris, met Father Rheita in Antwerp, and he reported the meeting to Pell:

> We met heere with the famous Cappuchin Rieta . . . . He teaches allso in this booke *Oculus Enoch et Eliae* the making of his new tellescope; his tube for his best glass was spoiled so that wee could not see it, but wee saw another made by his directions, but had not the opportunitie of looking at a convenient object far distant, but as I guess it is not better than myne, it represents objects even [*i.e.*, erect]. I had not discourse enough with him alone to aske manie quaeres, but douteless he is an excellent man and verie courteous, and I found him free and open in his discourse to me.[16]

It appears that Rheita, and Wiesel as well,[17] considered the composition of these new telescopes a professional secret. The only way to find out how they were composed was to buy one.

It is not known whether Sir Charles Cavendish finally bought one of these new telescopes from Wiesel. We do know, however, that information about these instruments quickly found its way to England. A pricelist of Wiesel's telescopes dated 25 September 1647 is preserved among the manuscripts in the British Museum. Besides Galilean telescopes Wiesel could deliver several other types:

> Another [type] is of more recent [tubes], and first composed of several glasses, with which objects are seen inverted, and which are usually employed for contemplating the stars. Nevertheless, they may also be of excellent use on Earth in the daytime because through them a very large space and very many things contained in that space are shown, while, on the contrary, through those older ones hardly a thirtieth part of these things appears. The length of them does not exceed 10 or 14 feet and their minimum price amounts to 50 or 60 ducats.
>
> There follows a third type: These are very recent, and are composed of several glasses. With these an entire army of about 7 or 8 thousand may be beheld clearly at one time and be examined very distinctly indeed. And, indeed, not in an inverted position as with the previous type, but in an erect and natural [position]. Through these marvellous figures are perceived in the Full Moon and around Jupiter not merely 4 but indeed nine smaller stars. The length of these tubes, drawn out and fitted for use, is 10, 12, or even 14 feet, and the price is not below 120 ducats. Nor has any tube of this type yet become known or been sold up to now, for it was invented very recently.[18]

Since both types of telescopes described here consisted of several, *i.e.*, more than two, lenses, we may assume that Wiesel was referring to Keplerian telescopes with a field lens in the first instance and with an added erector lens in the second instance.

Wiesel also made telescopes with more lenses, and actually delivered his telescopes to English customers. Among the papers of Samuel Hartlib there is a copy of a letter from Wiesel to Johannes Morian, a member of the Hartlib circle, dated 17 December 1649. This letter, containing instructions for the assembly and use of a four-lens "nightlie starrie tubo", one which showed things inverted, is reproduced in its entirety in the appendix below. From this letter we can reconstruct the telescope in question to some extent.

It consisted of 11 drawtubes and, as was the rule with Wiesel's telescopes, the objective was in the smallest tube. A large ocular, a field lens, was positioned in the next to the largest tube, and a compound eyepiece, put together as a unit in a small separate tube, was fitted into the back of the largest drawtube. The two lenses in this eyepiece were as large as the white of one's eye, that is, about $\frac{3}{4}''$ in diameter, and all three ocular lenses were plano-convex and had their flat sides turned towards the eye. Since the images seen through this instrument were inverted, we may surmise that Wiesel used two field lenses, and this raises the possibility that the combination in the separate little tube had as its function more than just the enlargement of the field of view. Perhaps Wiesel had already found that a certain combination of oculars improved the quality of the images.

At any rate, it is clear that there was nothing haphazard about Wiesel's compound eyepieces. He had taken pains to work out the best positions of the lenses, even discovering, no doubt through experimentation, that in the particular combinations used by him it was best to have the flat sides of the three ocular lenses turned towards the eye. We find this practice again in the Huygenian eyepiece fifteen years later.

As the letter to Morian shows that at least two Wiesel telescopes found their way into the Hartlib circle in England where they were, no doubt, examined by a number of people, we may assume that amateur and professional telescope makers in England became familiar with compound eyepieces over the next few years. In the Netherlands the situation was much the same.

When Christiaan Huygens turned his attention to the buying or making of good telescopes in 1652, he made inquiries about the telescopes made in Germany. He quickly found out that Jacobus Edelheer, a renowned legal scholar and Pensionary of the city of Antwerp, was in possession of a telescope made by Wiesel. Edelheer sent his four-lens instrument to The Hague so that Huygens could examine it.[19] A relative of Huygens bought a Wiesel telescope with *five* lenses shortly afterwards and sent him information as to its construction.[20] Huygens was, therefore, familiar with compound eyepieces even before he began making his own telescopes. But he did not pursue the subject at that time, no doubt because he had as yet little need for lenses which enlarge the field of view. His first good telescope, finished early in 1655, was a 12ft effort with a single convex ocular.[21] It magnified fifty times and had a field of view of about 30′,[22] which was quite large, and we may surmise that Huygens saw little sense in the unnecessary "multiplication of lenses".[23] In his more ambitious telescope of 23 feet, finished a year later, which magnified 100 times and had a field of view of about 17′,[24] he used an eyepiece consisting of two *contiguous* plano-convex lenses, in an effort to minimise the optical thickness of the ocular.[25] Since this telescope could not show the entire Moon at one time, we might expect that Huygens was becoming aware of the restrictions which the field of view of a simple Keplerian telescope placed on increases in magnification. But he did not begin to use field lenses for another five years.

When, in connection with his discoveries about Saturn, Huygens wrote to

John Wallis about the construction of his 23ft telescope with the two contiguous eye lenses, Wallis replied (28 February 1659, n.s.):

> What you thought worthy to disclose to us about the arrangement of the lenses in your tubes, I shall make known to Mr. Neile as soon as an occasion presents itself. He arranges his lenses in completely the same way, except that he has the two lenses which are near the eye not contiguous but somewhat separated. . . . But he has the lenses, like yours, plano-convex.[26]

Whereas by 1659 Huygens was still using telescopes with a maximum length of 22 or 23 feet, Sir Paul Neile had already made instruments of up to 35 feet by this time.[27] And being familiar, through his scientific connections, with the construction of Wiesel's telescopes, he had adopted the compound eyepiece in order to enlarge the field of view of these long telescopes. When he heard about Huygens's contiguous eye lenses, he suspected that they were, in fact, separated by a small distance,[28] but Huygens assured him that these lenses were indeed contiguous.[29]

News of advances in telescope making in England also reached Huygens from another direction. In the summer of 1660 he was notified by Pierre Guisony that in Italy a comparison had been made of a telescope made by Eustachio Divini and " . . . un de Reeves de la methode du Chevalier Neal . . ." which had been sent to Italy. In the opinion of Guisony, the English instrument was better.[30] In 1660 Reeves was thus already offering telescopes with compound eyepieces for sale, and we may surmise that they were becoming popular in England.

When Huygens left The Hague, in the autumn of 1660, for a visit to Paris and then London, he must have been curious about the construction and quality of the telescopes of Neile and Reeves. When he arrived in London, he found that city in the midst of the preparation for the coronation of Charles II, while the English astronomical community was getting ready to observe the predicted transit of Mercury across the Sun; the two events were to occur on the same day. Henry Powers, intent on observing the transit, inquired about suitable telescopes for this event and Richard Reeves wrote him on 21 March 1661:

> Sr
>
> according to yr brothers request who was lately with mee I shall give you an account wt telescopes I have wch I conceive are fittest to yr intent for the observation of the eclipse of the sunn by Mercury. The Longest glasses are the best in regard they greten the object most & soe discover the minute parts of it more particularly. But Galilaeus that hee observed with were made with a Concave glasse next the eye & a convex glasse next the object, wch because if the tube be of much lenght they take in but a little Compasse, & are not therefore soe usefull in observing the Heavenly Bodyes as those mor lately invented wch are made with 3 or 4 Convexes & never a Concave: because these sorts of Tellescopes (as it demonstrable by reason & confirmed by experience) will take in 40 times more of an object then the other. I have here indorsed sent you for yr satisfaction all the

prices of my glasses both microscopes & telescopes and shall be glad to serve yow with any yow please to write for, assureing yow they shall be as good & as well whrought as any England can afford, Sr I presume there will be some long observations of this strang Eclipse made at my house severall men of art in town determining to meet there that day to the same purpose, wt observations they make I shall (if you desire it) send yow an account of. & shall in lieu thereof begg the like favour of yow.

The enclosed pricelist listed "Tellescopes wth Convexes inverted & erected" in lengths up to 36 feet.[31] The form which Reeves used to grind the objectives of these longest telescopes was no doubt the same in which he ground the objective for Neile's 35ft instrument several years earlier.

Huygens made a number of observations with Neile's telescope, but judged the objectives of his own telescopes to be better. He had his favourite 22ft instrument sent over from The Hague and showed it to the members of the Royal Society. He also demonstrated his method of grinding and polishing lenses.[32] It appears that Neile in turn taught this method to Reeves and his son some time later.[33]

On the day of the coronation Huygens, whose high connections could easily have secured him a good seat for the ceremony, was in the shop of Richard Reeves on Longacre, where he observed the transit of Mercury with several astronomers, to the great amusement of his father.[34] We are, therefore, certain that during his visit to England Huygens saw not only the telescopes of Sir Paul Neile but also the various instruments made by Richard Reeves and his son John. And it appears that at this time he became impressed with the advantages of compound eyepieces. That his interest in English telescopes continued is shown by a letter written to him by John Reeves later in 1661 (when Huygens was back in The Hague) in which Reeves informed him of the prices of his telescopes.[35]

Between his return from London, in June 1661, and the spring of 1662, Huygens was engaged in researches unconnected with telescopes, but then he resumed his astronomical observations, his telescope making, and his study of optics. For some time he had equipped some of his telescopes with erecting mirrors,[36] and now he sent some of these to Paris equipped also with field lenses.[37] In October 1662 he wrote to his brother Lodewijk in Paris:

. . . as to the oculars, you will see that I have found something new there, which causes that clarity in the telescopes for daytime [use] and the same in the longer ones, giving them at the same time a large field.[38]

We may assume, then, that Huygens had found the special relationship between the strengths and separation of the lenses of the compound eyepiece by October 1662.

But his terrestrial telescopes with a field lens, an eye lens, and an erecting mirror were nothing particularly new in the autumn of 1662. Pierre Petit wrote to Huygens:

As to those with a mirror, which you have recently sent, they reveal a great expanse of land but they magnify little. I have not seen their construction, but this cannot be anything else than two convex oculars instead of a single one, put together at a proportional distance, such as the ones I have seen some time ago, which came from England, but without mirror, which therefore inverted things.[39]

The telescopes of Neile and Reeves had thus already made their appearance in Paris. (In this connection it is to be noted that although Huygens repeatedly mentioned his new compound eyepieces in letters to Paris, he was entirely silent on this subject in his letters to London.) And telescopes with compound eyepieces also reached Paris from a different direction. Earlier in 1662 Balthasar de Monconys had already shown a telescope with five lenses in Paris which he probably brought from Italy.[40] And by November terrestrial telescopes with four lenses made by Giuseppe Campani of Rome had made their appearance in Paris.[41] These instruments drew praise from everyone, including Huygens.[42]

Huygens described the advantages of his eyepiece as follows:

> . . . if to the great [objective] lens we add two oculars which have a certain proportion and a determined distance between them, then not only is the field of the telescope enlarged admirably, so that in one single glance much more is embraced than when the instrument is constructed with a single ocular lens, but also the images appear less deformed. And finally, every impurity caused by the irregularities of the oculars are removed from sight to such an extent that, although there are two lenses, one does not see them at all, while otherwise, with a single lens, they are a great inconvenience.[43]

The proportion and distance between the lenses was given as follows: the focal length of the field lens was four times greater (or a bit more) than that of the eye lens, and their separation was equal to twice the focal length of the eye lens. The combination was placed so that the focal point of the objective fell at a point between the field- and eye lens, and this point was removed from the eye lens by a distance equal to two-thirds the focal length of the eye lens.[44] At other times Huygens made the ratio of focal lengths of field- and eye lens as great as 5:1 and as small as 3:1, but he always kept the separation between the lenses equal to twice the focal length of the eye lens (see Figure 1).[45]

In fact, the optimum configuration of the Huygenian eyepiece is a ratio of focal lengths between 2:1 and 3:1 and a separation equal to half the sum of the focal lengths.[46] This configuration is derived from theoretical principles which were not available to Huygens. Even the conceptual foundation for the treatment of chromatic aberration was not available until Newton published his first paper on colours in 1672.[47] And Huygens was fully aware of the limitations of contemporary optics. In the draft of his *Dioptrica* composed not long before 1667,[48] he introduced his discovery as follows:

> We describe here, if not the best combination of lenses among all those that are possible—which would be tedious and perhaps impossible to discover—at least that one which experience has shown us to be useful.[49]

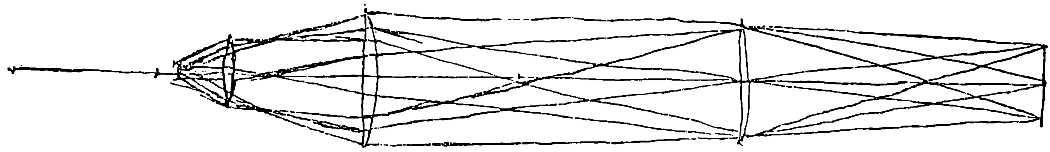

FIG. 1. Ray diagram of a telescope with a Huygenian eyepiece. From the 1666 manuscript copy of Huygens's *Dioptrica: Oeuvres complètes*, xiii (1), 254.

He summed up the state of the art a few pages further in the same draft:

> But different men combine the ocular lenses differently with regard to each other, seeking, with only the guide of experience, which combination is best. And, to be sure, it would not be easy to teach something about this by means of certain precepts since the consideration of colours cannot be reduced to the laws of geometry, nor, except with great difficulty, can that curvature of straight lines often seen near the edges of lenses.[50]

We may, therefore, agree with the editors of Huygens's *Oeuvres complètes:* "On doit donc admettre que l'experience a eu la plus grande part dans l'invention de son oculaire . . . ."[51]

Huygens, then, did not invent the compound eyepiece named after him *ex nihilo*. Compound eyepieces had been around for nearly twenty years before he took a serious interest in them, and when he took up their development he was following the lead of others. In all likelihood there were a number of eyepieces which alleviated transverse chromatic aberration to different degrees in 1662, and Huygens's particular form of that eyepiece, which was better than most combinations, was found by the same methods which other investigators used to determine good combinations. Huygens's invention must, therefore, be seen in the context of the increased popularity of compound eyepieces occasioned by the increasing lengths and magnifications of telescopes.

The recurrent theme in the development of the telescope between 1640 and 1670 is the limitation placed on magnifications by the progressive restriction of the field of view. A Galilean telescope which magnified 20 times had a field of view of 10′ to 15′.[52] Further increases in magnification would rapidly give this type of telescope a field of view so small as to render the instrument virtually useless.[53] When, because of improved lens making techniques, higher magnifications became possible, around 1640, the Keplerian telescope with its larger field of view rapidly replaced the Galilean type. Magnifications could now be increased, but only up to a point.

Christiaan Huygens was a newcomer to the field of telescope making in 1654, and his first efforts were of comparably modest lengths. His 12ft instrument of 1655, which magnified about 50 times, had a field of view of about 30′, and his 23ft telescope of 1656, which magnified 100 times, had a field of view of 17′.[54] In Italy much longer telescopes were already being made.[55] Sir Paul Neile's 35ft instrument could not have had a field of view much larger than 10′, which must have been a severe handicap. And surely for *this* reason Neile adopted the compound eyepiece, known in England because Wiesel telescopes had been sent there, for his own use. When Huygens visited England in 1661 he had not yet been impressed with the need for field lenses because his longest telescope was only 22 or 23 feet long and had a reasonable field of view. But his observations through Neile's 35ft instrument (no doubt with and without field lens) made him see the need for compound eyepieces in these longer telescopes. Without giving Neile any credit, he put the fears of others who despaired of the usefulness of very long telescopes to rest. In June 1662 he wrote to his brother Lodewijk in Paris concerning Pierre Petit's apprehensions:

> His fear that with telescopes of 50 or 100 feet one would perhaps only see one star at a time is ridiculous, and if he uses a convex [eye] lens I am surprised that he is not better acquainted with the effect. Assure him that with my telescope of 22 feet I see the entire Moon at one time, but not with one simple lens near the eye, but rather by means of that new way which I mentioned before; so that if he procures for me a good glass of 100 feet we shall still see at least a quarter of the diameter of the Moon.[56]

With compound eyepieces finding rapid acceptance during the 1660s, men could now continue their efforts to make longer and longer telescopes, with the knowledge that these instruments would still have useful fields of view. The practical development of the compound eyepiece (preceding any theoretical treatment by at least a generation) should, therefore, be seen as a necessary step in the progression from the low-powered Galilean telescope of the 1630s to the long, high-powered astronomical research instrument of the last few decades of the seventeenth century.

APPENDIX

Johannes Wiesel to Johannes Morian, 17 Dec. 1649 (Samuel Hartlib Papers, Bundle 8, iii).[57]

Copie of a letter from Johan Weissel opticus 17 December 1649 from Augsburg, directed to D. Johan Morian.

Honoured Sir [,] my last was y^{t} I would deliver y^{e} starrie telescopium to Hern von Stetten & of him recive 100 rix dollers by yo^{r} ordre, w^{ch} was this day effected [.] thoug w.th last tubo a large direction how to fitt y^{e} same were sent y^{t} following y^{t} said direction one could scarce erre yet requires also this nightlie starrie tubo another direction w^{ch} followes [.]

first there bee eleven pipes or drawers & every one of these pipes marked wth 2 letters as A and B [.] there be fower glases [.] as before in y^{e} small pipe screwed in y^{e} great objectivum. In y.^{e} great leather pipe there is a shorter tubus w.th two convex glases screwed in in the black wood w.th a strong screw, whereof y^{e} one glas is part of a circle y.^{e} other of a section as yet unknown [.] this small pipe is screwed in at y.^{e} ende of y.^{e} great & are these two glases a y.^{e} white of ones ey and also both of them w.th theyr flatt sides against or towards y.^{e} ey well fitted & fastned w.th these screwes so that herin cannot bee erred [.] thirdly there is also a great ocular glass in y.^{e} great pipe w^{ch} followes y.^{e} leather one, there screwed in [.] this is alwayes layd in so that y^{e} flatt side therof bee towards te[*sic*] eye [.] now when all these glases by long usage grow durtie may y^{e} same bee taken out & very well cleansed w.th y.^{e} whitest linning & without spott every one layd in againe in due place & screwed up [.] Sir you may bee assured this is y.^{e} first starrie tubus w^{ch} I have made of this manner & so good y^{t} it goes farre beyond all others wherof my selfe also doe not little rejoyce [.] When I looked first throug y^{e} same y^{e} moone seemed to my eyes exceeding bigg & not above y.^{e} length of a foote of from my eyes & have found out others [*sic*] things besides what ever observed & brought to sight [.] also I have observed last night being 16 december 1649 in y.^{e} evening about 7 a clocke Saturnus in such figur as herover [.][58] While by triall observed that by day (though when y.^{e} sonne shineth) y.^{e} nerer objects therew.th more increased then w.th my other former perspectives, so could not obmitt y^{e} use therof in y^{e} particuler [.] by night to y.^{e} starrs must alle y.^{e} pipes bee drawen out to y.^{e} letter A and for y.^{e} nerer objects by day when y.^{e} sonne shines must they bee drawen out all to y.^{e} letter B [.] there may bee a perspective picture of y.^{e} bignes of a sheet of papper hanged up or fastned upside downe[59] to a white wall in a shining sonne & y^{t} y.^{e} distance from y.^{e} pipe or tubus to y.^{e} pictue bee of 32½ ells augsburger mesure, there all will appeare to y.e bigness of living persons in sd picture delightfull to behold [.] I have now also a great tubus in hand wch I use by day for y.e land this also is made & fitted w.th this new manner of glasses wth this doe I trust to worke wonderfull things & all objects lost out of sight because of y.e great distance to increase & bring into sight againe [.] by my next will I write of som what rares how that wth a small instrument & help of a particular object all y.e inward defects of y.e eye may bee seene as if y.e same were painted upon a papper wch is a worke never yet in being before much less knowne & described & is of great & benefitiall use [.] thus sir you have in briefly wth my respects &c. Augsburg y.e 17 december 1649 Yo.r humble servant Johan. Wiessel opticus.

it were good that a light canal holed out halfe, were made for y.e telescopium there to rest & to keepe y.e same from bowing throug y.e length therof.

REFERENCES

1. Minutes of the States-General of the Netherland, 2 October 1608. The Hague, Algemeen Rijksarchief, MSS. "Staten-Generaal", xxxiii, 169r. See A. Van Helden, "The Invention of the Telescope", *Transactions of the American Philosophical Society*, forthcoming.
2. *Johannes Kepler gesammelte werke* (Munich, 1938–), iv, 387–9.
3. *Ibid.*, 388–9. Galileo discussed the projection of the Sun's image through a Galilean telescope in his second letter on sunspots (*Le opere di Galileo Galilei. Ristampa della Edizione Nazionale* (Florence, 1929–39), v, 136–7). In tracing sunspots on a paper on which the Sun's image is projected, the use of a Galilean telescope will result in a tracing in which top and bottom are inverted but left and right are correct, while the use of a Keplerian telescope will give a tracing in which left and right are inverted but top and bottom are correct. In either case the paper has to be held up to the light and the image transferred to the back of it for all the orientations to be correct. The only advantage of the Keplerian configuration is in the continuous adjustment of the telescope to keep the Sun's image on the paper: one does not have to remind oneself to do the opposite of what seems to be indicated.
4. *Rosa ursina* (Bracciano, 1626–30), 129v–130r.
5. A. Van Helden, "The 'Astronomical Telescope', 1611–1650", *Annali dell' Istituto e Museo di Storia della Scienza*, forthcoming.
6. *Novem stellae circa Jovem* (Louvain, 1643), 9.
7. *Oculus Enoch et Eliae* (Antwerp, 1645), part 1, 336–56. Rheita's *secreta* is on p. 356.
8. *Ibid.*, 339.
9. Cavendish to Pell, 20 November 1641 (o.s.), in James Orchard Halliwell (ed.), *A collection of letters illustrative of the progress of science in England* (London, 1841, reprinted London, 1965), 74.
10. *Ibid.*, 72–74. Halliwell printed here six letters from Cavendish to Pell dated between 26 June 1641 and 5 February 1641/2 (o.s.). Apparently unaware that it was the custom to begin the new year on 25 March, Halliwell mixed up the chronological order of the letters.
11. *Oeuvres de Descartes publiées par Charles Adam & Paul Tannery* (Paris, 1897–1913), iii, 585–6.
12. Halliwell, *op. cit.*, 83.
13. *Ibid.*
14. *Ibid.*, 85.
15. *Ibid.*, 87. In order to avoid confusion I have rendered all dates in the new style in the text of this article. Note that Halliwell made the same mistake (see ref. 10) in printing the letters from Cavendish to Pell written between 26 July 1644 and 27 June 1645 (o.s.), 76–88.
16. *Ibid.*, 77–78.
17. Oldenburg to Hartlib, 23 July 1659 (o.s.). *The correspondence of Henry Oldenburg* (Madison, London, 1964–), i, 288.
18. British Museum, MSS. "Sloane" 651, 169–171. This document (in Latin) was reproduced in facsimile by Thomas H. Court and Moritz von Rohr in "New Knowledge of Old Telescopes", *Transactions of the Optical Society*, xxxii (1930–31), 113–22, pp. 118–9.
19. *Oeuvres complètes de Christiaan Huygens* (The Hague, 1888–1950), hereafter cited as *O.C.*, i, 215, 224.
20. *O.C.*, i, 308–9. This is a letter with instructions for assembling a telescope sent by Wiesel. Although Wiesel described the instrument in question as a telescope with *six* lenses, one of these is merely a coloured glass for observing the Sun.

21. *O.C.*, xv, 10–15.
22. *O.C.*, ii, 7. Huygens mentions here that with this instrument he could see the entire Moon and a bit more at one time.
23. Huygens was always hesitant to add more lenses to his telescopes. For a long time he preferred an erecting mirror (at 45° to the optical axis) to an erector lens, even though terrestrial telescopes of this construction showed left and right reversed. He began the passage in his *Dioptrica* in which his compound eyepiece is described with the words: "Quanquam lentes non frustra sint multiplicandae . . ." (*O.C.*, xiii, 253, 463).
24. *O.C.*, ii, 7; xv, 56, 60, 350.
25. *O.C.*, ii, 362; xv, 230.
26. *O.C.*, ii, 358.
27. *O.C.*, iii, 417.
28. *O.C.*, ii, 521.
29. *O.C.*, iii, 58.
30. *O.C.*, iii, 45–46.
31. British Museum, MSS. "Sloane" 1326, 23r–24v. This letter, "transcribed into modern English", was first published by Court and von Rohr, *op. cit.* (ref. 18), 121.
32. *O.C.*, xxii, 568–76. This is Huygen's journal of his stay in England. See also *O.C.*, iii, 265–7.
33. *O.C.*, iii, 445.
34. *O.C.*, iii, 271–2; xxii, 575.
35. *O.C.*, iii, 445.
36. The first mention of these mirrors was in 1654, *O.C.*, i, 242. See also *O.C.*, xiii, 264, note 3.
37. When his father asked him to make a telescope with an erecting mirror for a highly placed person in Paris, Huygens sent such an instrument in May 1662 (*O.C.*, iv, 132–3). In September he sent another instrument which had three lenses and a mirror (*O.C.*, iv, 228–9). At that time he told his brother Lodewijk that he could have the first one ". . . car d'en faire present a quelqu'autre il n'a garde, a cause du secret de l'invention" (*O.C.*, iv, 224).
38. *O.C.*, iv, 242–3.
39. *O.C.*, iv, 250.
40. *O.C.*, iv, 125.
41. *O.C.*, iv, 266–9.
42. *O.C.*, vi, 48. Huygens described the construction of one of Campani's terrestrial telescopes in his *Dioptrica*, *O.C.*, xiii, 469–73, 607.
43. *O.C.*, xiii, 252.
44. *O.C.*, xiii, 252–3.
45. *O.C.*, xiii, L, note 4.
46. *E.g.*, Boris V. Barlow, *The astronomical telescope* (London & New York, 1975), 60–61.
47. In his *Traité de la lumière* of 1692 Huygens did not treat colours.
48. On the dating of the various drafts of his posthumous *Dioptrica*, see *O.C.*, xiii, I–XIII.
49. *O.C.*, xiii, 252.
50. *O.C.*, xiii, 262–4.
51. *O.C.*, xiii, L. Not until after 1685 did Huygens treat the size of the field theoretically (*ibid.*, 450–3, 457–61, 468–73).
52. John North, "Thomas Harriot and the First Telescopic Observations of Sunspots", in John W. Shirley (ed.), *Thomas Harriot, Renaissance scientist* (Oxford, 1974), 129–65, 146–7.
53. Thomas Harriot had a 50-powered Galilean telescope, but it is mentioned only once in the record of his observations (*ibid.*, 142). This telescope could not have had a field of view much larger than 5′. Note that such a small field was an even greater handicap in terrestrial observations. A telescope with a field of 15′ will show an area of about 12 feet at 1000 yards, while one with a field of 5′ will only show an area of about 4 feet at this distance.
54. *O.C.*, ii, 7; xv, 56, 60, 350.

55. In his *Novae coelestium terrestriumque rerum observationes* (Naples, 1646), Francesco Fontana mentioned telescopes of 50 Neapolitan palms, *i.e.*, about 40 feet (p. 21). Eustachio Divini mentioned telescopes of up to 45 Roman palms (about 35 feet) in length in an advertising sheet in 1649. See *Bullettino di bibliografia et di storia delle scienze matematiche e fisiche*, xx (1887), facing p. 614. From 1660 to 1662 Huygens was engaged in a controversy with Divini in which Divini claimed that his telescopes were better than those of Huygens because they were longer. See *O.C.*, xv, 406–14.
56. *O.C.*, iv, 152.
57. I thank Dr Marie Boas Hall for calling this letter to my attention.
58. In the margin of this copy is a little sketch of Saturn as observed by Wiesel.
59. This telescope, then, showed things inverted, and this raises a question as to the function of the "great ocular glas" in the second draw tube.