Newton's Telescope in Print: The Role of Images in the Reception of Newton's Instrument

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While Newton tried to make his telescope into a proof of the supremacy of his theory of colours over older theories, his instrument was welcomed as a way to shorten telescopes, not as a way to solve the problem of chromatic aberration. This paper argues that the image published together with the report on Newton's telescope in Philosophical Transactions *(1672) encouraged this reception. The differences between this visualization and other images of Newton's telescope, especially that published in* Opticks *(1704), are discussed. This paper shows that the image in* Opticks *adopted characteristics of a Cartesian program of visualization of machines and instruments which complemented a rhetoric which attributed primacy to theory over practice. The differences between the images in* Philosophical Transactions *and* Opticks *are also considered within the broader institutional context of Newton's attitude towards the Royal Society.*

Introduction

In a seminal article on the telescope in the seventeenth century Albert Van Helden complained that "the traditional treatment of the telescope is replete with optical diagrams . . . with the result that one is left with the impression that the telescope was an instrument which, if not invented through science, was at any rate turned into the sophisticated instrument it became by science—the science of optics" (Van Helden 1974, p. 38). Van Helden convincingly argued for the important contribution of craft skills—which could not be represented in optical diagrams—to the development of the telescope in the seventeenth century. Moreover, as I will argue here, the modernized optical diagrams also hardly do justice to the vi-

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sualizations which historical actors used to communicate on the telescope with patrons, mathematicians, and craftsmen. A lack of attention to the historical and visual particulars of the communication on this instrument deprives us of information on the conceptualization and reception of the telescope in the seventeenth century.

In this paper I will focus on Newton's telescope. I will consider three different drawings of Newton's telescope: (1) the drawing based on the formal description by Henry Oldenburg, which was checked by Newton and published in a modified version in the *Philosophical Transactions* of 25 March 1672 (Newton 1672)[1]; (2) an unfinished draft of a description of the telescope in Newton's papers at the Cambridge University Library; and (3) the drawing of Newton's telescope published in the *Opticks* (1704).[2] Earlier comments on these drawings explained the differences between these drawings in terms of *assumed* inaccuracies in the engravings or in terms of differences in the instruments themselves (Mills and Turvey 1979, p. 136; Hall 1995, p. 76).

Such comments are based on analyses of the drawings which—implicitly or explicitly—aimed at a reconstruction of the state of the technology. Unlike such analyses my approach will try to understand the function of the visualizations of Newton's telescope for the historical actors themselves.[3] I will ask questions about how the maker of the drawing, the message, and the audience of the drawing interacted in the communication of the drawing. It is my aim to understand the differences between the visualizations of Newton's telescope in terms of the different functions of the drawings. What did the maker of the drawing try to communicate? How did the audience understand the message communicated by the drawing? My analysis will stress the role of images of Newton's telescope in the reception of the instrument.

In following this approach I am not looking for the development of some presumed 'correct' representation of the telescope. The way of representing a telescope was a problem whose solutions depended on the function of the representation. In the seventeenth century the telescope

1. Oldenburg sent a verbal description and a picture of Newton's telescope—based on the telescope which Newton had presented to the Royal Society—to Newton for corrections on 2 January 1671/2. Newton replied with corrections, which Oldenburg included in the formal description published in *Philosophical Transactions,* on 6 January 1671/2. Oldenburg sent the description and picture to Huygens on 15 January 1671/2 (Turnbull 1959, pp. 72–76, pp. 79–82).

2. A fourth drawing of Newton's telescope (by Newton) is now in the Bernouilli papers in Basel, but in the 18th century it was in the possession of Johann Jacob Huber who worked at the Royal Observatory in Greenwich (Cohen 1993). As the original function of this drawing is unclear, I will leave it out of the discussion here.

3. This approach is indebted to Popplow 2004.

presented problems of representation which were specific to this *optical* instrument. The problems were different from those involved in depicting *mathematical* instruments, which had received attention in the sixteenth century. With mathematical instruments the boundary between the 'illustration' of the instrument in the book and the actual instrument was often blurry. The boundary case was, of course, *paper instruments* (Bennett 2003).[4] However, with the telescope the visual description of the construction and manipulation of the instrument did not coincide with a description of the mathematical or optical knowledge embodied in the instrument. In brief, there were no such things as *paper telescopes.*

This is not to say that the solutions given to the problems of representing telescopes in the seventeenth century did not show any continuity with those already found in representing mathematical instruments in the sixteenth century. In *Selenographia* (1647) and—even more obviously—in *Machina coelestis* (1673) Johannes Hevelius presented pictures of the telescopes, shown in the context of his observatory Stellaeborg in Danzig, which were modelled on Tycho Brahe's (Figure 1). Such pictures were supposed to vouch for the quality of the instruments (Winkler and Van Helden 1993; Van Helden 1994). This type of visualization—which, according to Martin Kemp (1996), allows mathematics to partake in the *rhetoric of the real*—had become the most *authoritative* one in a process that extended over the past two centuries. In Dupré 2006 I have argued that there were more options available in the representation of optical instruments in the fifteenth and sixteenth century than this one.

There were also more possibilities in the representation of telescopes than the one aimed at *virtual witnessing* chosen by Hevelius.[5] First, I will discuss the visualization of lens-grinding machines in the seventeenth-century. The depiction of machines is hardly new to the seventeenth century, but the legacy of Descartes' program for the mechanisation of lens-grinding had specific visual characteristics which complemented a rhetoric which attributed primacy to theory over practice.[6] I will show that this type of visualization and rhetoric was adopted by Newton in the representation of his telescope in *Opticks.* In the second part of my paper I will look at the differences with the representation in *Philosophical Transactions.*

4. On paper instruments, see Gingerich 1993.

5. The term *virtual witnessing* is used in this context in Winkler and Van Helden 1993, pp. 99, 111.

6. The scholarship on early modern machine drawings is extensive. A good, recent starting point is the various contributions to Lefèvre 2004. Leonardo's drawings of machines for making mirrors from the late fifteenth and early sixteenth centuries are the exception to the general observation that no drawings of mirror or lens-grinding machines pre-dating the invention of the telescope are preserved (Dupré 2005).

1. A Cartesian Program of Visualization and Newton's Telescope in 'Opticks'

Recently, Graham Burnett (2005) has discussed Descartes' program of the mechanisation of lens-grinding and its legacy in the seventeenth century in detail. I will rely here on Burnett's account, but I will focus, in particular, on the issues of visualization which were involved in the communication of the machines devised to grind (hyperbolic) lenses. Burnett has convincingly shown that Descartes' program relied on a distrust of the lens-grinding skills of artisans.[7] I will show that this rhetoric and style of visualization return in Newton's *Opticks.*

In the 1620s Descartes found a solution to the problem of the anaclastic (Shea 1991, pp. 149–163). He showed that the shape of the curved surface necessary to refract a set of parallel rays to a single point was hyperbolic. With this solution to the problem of the anaclastic Descartes stood at the beginning of a tradition which considered the grinding of hyperbolic lenses the main route to the perfection of the telescope until Newton's discovery of the compound nature of light. The grinding of hyperbolic lenses was difficult and Descartes' mathematics did not play any role in the improvement of the telescope in the seventeenth-century. In fact, the best telescopes of the seventeenth century—those of Campani—had spherical lenses (Righini Bonelli and Van Helden 1981). Nevertheless, Descartes' program of mechanisation of lens-making was very influential in the seventeenth century.

Descartes discussed his machine to grind hyperbolic lenses in *La Dioptrique* (1637), where it was presented as a proposal to the community of artisans (AT 1897, 6: 211–228) (Figure 2). The project was a failure—a failure for which Descartes blamed 'his' artisans. The failure is most clearly shown in Descartes' correspondence with the Parisian craftsman Jean Ferrier. Burnett has discussed the Descartes-Ferrier correspondence more extensively, but I will focus here on three letters of 1629 which are particularly revealing of the role of visualisation in the communication (and the lack of understanding) between Descartes (in Holland) and Ferrier (in Paris) (Burnett 2005, pp. 41–59).

While Descartes printed a perspectival image of the lens-grinding machine in *La Dioptrique,* his first letter to Ferrier showed a diagram (Figure 3) on the basis of which Descartes explained to Ferrier the basic mathematical principle behind the machine to trace the hyperbola.[8] Descartes

7. For Descartes' changing image of the artisan, see also Gauvin 2006. I would like to thank the author for allowing me to see his work before publication.

8. Descartes to Ferrier, 8 October 1629 (AT 1897, 1: 34). There is no autograph or manuscript copy of the Descartes-Ferrier correspondence preserved. Therefore, we cannot

also provided Ferrier with an image of the grinding wheel being cut by the hyperbolic plate (Figure 4), shown face on and edge on, "so that you will understand it better" (AT 1897, 1: 35). Ferrier's response not only revealed a lack of understanding of the mathematical principles, but it showed, above all, that Descartes' machine would not stand the test of practice. Ferrier pointed out, for example, that the glass blank would be harder than the grinding wheel and the hyperbolic plate, and they would thus be deformed by the spinning glass blank.[9] Grinding down a glass blank was only possible if abrasive between the glass blank and the grinding wheel was applied, Ferrier instructed Descartes. This was the kind of practical knowledge that an artisan with even a minimum of lens-grinding experience had. Descartes sorely lacked it. Moreover, Ferrier corrected the drawing of the grinding wheel, which Descartes had drawn precisely to help his craftsman in understanding the machine, by pointing out that "you drew the wheel in this first illustration seen face on, and not the edge, and that is why you should only show the plate *LM* seen from the side and not lying flat" (AT 1897, 1: 42). In response to another practical criticism of Ferrier Descartes felt obliged to defend his choice of visualization in his second letter to Ferrier.

> I had traced for you the lines *AB* and *CD* fully naked as mathematical lines so that you would better understand the principles of the machine . . . Although I am a very bad painter, you might understand my pictures [*figures*] better.[10]

Descartes' second letter was illustrated with a perspectival image of the machine instead of a mathematical diagram (Figure 5). Thus, under the pressure of communication with his craftsman, Descartes made a choice for a perspectival representation or a *picture* of the complete machine. When Descartes realized that such a representation might not be sufficiently informative on how the different parts of the machine fitted together, he made the effort to provide Ferrier with a partial view (more of the *plan* type), but the artisan was quick to point out—openly correcting Descartes' visualization—that this was done rather clumsily.[11] Moreover, it is obvious that Descartes' pictures do not contain any more of the craft

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but rely on the images redrawn in the edition of Adam and Tannery on the basis of Claude Clerselier's edition of Descartes' correspondence (Paris, 1667), and assume that these drawings are faithful to the original. I would like to thank professor Theo Verbeek and Erik-Jan Bos for the confirmation that no originals of the Descartes-Ferrier correspondence are known to be preserved.

9. Ferrier to Descartes, 26 October 1629 (AT 1897, 1: 46).

10. Descartes to Ferrier, 13 November 1629 (AT 1897, 3: 55).

11. For the distinction between a picture and a plan, see Lefèvre 2003.

knowledge, which Ferrier could bring to the project, than the diagrams with which Descartes began the exchange.

The legacy of Descartes' program of the mechanisation of lens-grinding and its style of visualisation is evident throughout the seventeenth century. One place where the program and the visualisation style surfaced was the early Royal Society of the 1660s. Under the presidency of Sir Robert Moray, in 1661 the Royal Society set up a committee, which included—among others—Sir Paul Neile, Jonathan Goddard and Christopher Wren, to evaluate tools and instruments to make telescope lenses (Hunter 1989, pp. 80–82; Bryden and Simms 1993; Copeman 1960; Ronan and Hartley 1960). Also, the early issues of *Philosophical Transactions* showed considerable interest in the making of telescope lenses. In the pages of *Philosophical Transactions* projects were mentioned, such as the one of the inventor Monsieur de Son to grind non-spherical lenses (Anonymous 1665/6b) and similar work for Francis Smethwick (Anonymous 1668a).[12] The journal also published a book review of Carlo Antonio Manzini's *L' occhio all' occhiale,* an Italian manual on telescope lens-making based foremost on the practice of Eustachio Divini (Anonymous 1668b).

One of the rumours that made it to the pages of *Philosophical Transactions* was that the lenses of the best telescopes of the moment—those of Campani—were made with a kind of mechanical system for shaping lenses directly on the lathe without the use of a forming pan (Anonymous 1665/6a). The rumour was not based on facts—there is no evidence that Campani used a machine—but the published rumour gave rise to the development of a machine to grind spherical lenses (Figure 6), which was published in the preface of the *Micrographia* (1665) of Robert Hooke (Bonelli and Van Helden 1981, p. 27).[13] Immediately, Adrien Auzout criticized Hooke's device as being mere theory and Hooke for publishing a machine design that had never been tested. Auzout was convinced that, although the principles upon which the machine was based were sound, practice would be different:

> Though it be true in the *Theory,* that a Circle whose Plain is inclined to the Axis of the Sphere by an Angle, whereof half the Diameter is the Sine, and which touches the Sphere in its Pole, will touch in all its parts a Spherical Surface, that shall turn upon that Axe. But it is true also that that must be but a Mathematical Circle, and without Breadth, and which precisely touches the body in

12. On De Son, see Keblusek 2005.

13. For the role of pictures in Hooke's *Micrographia,* see Dennis 1989. For a discussion of Hooke's lens-grinding machine, see also Riekher 1990, p. 69.

the middle: Whereas in the practice a Circle capable to keep Sand and Putty, must be of some breadth (Auzout 1665/6, p. 58).[14]

That such visualizations of machines did not contain any craft knowledge became very clear when Christopher Wren published his design for a machine for grinding hyperbolic lenses in the *Philosophical Transactions* of 1669.[15] In June of this year Wren showed that a section through the axis of a cylinder was a hyperbolic surface. Wren only hinted at the practical application of this principle, but he added that he hoped to soon publish a description of his machine to grind hyperbolic lenses "cum Icone" (Wren 1669a, p. 962). Wren showed only a mathematical diagram (Figure 7). The reader of *Philosophical Transactions* had to wait for the November issue, in which Wren (1669b) revealed his machine proposal, illustrated "cum Icone" as promised (Figure 8).

It is evident that the "icon" of Wren's *engine* did not visualize a machine, but only its mathematical principle. The image—in fact, little more than a shaded diagram—omitted "wheels, cogs, straps," that is, everything that makes a machine a machine (Wren 1669b). For Wren the addition of shading, suggestive of a resemblance with a possible machine, was sufficient to speak of an icon instead of a diagram. He also contrasted this type of visualization with a picture (or perspectival representation, such as that found together with his diagram on the same page in Figure 7). About the function and usefulness of a picture Wren wrote that "to describe this thing by an elaborate picture and a prolix explanation would be more troublesome to myself and my craftsman than for some clever Daedalus to invent the same thing" (Wren 1669b, p. 1060). In fact, Wren's visualization of his 'machine' suggested to the readers of *Philosophical Transactions* that the "icon" could easily—and without additional craft knowledge—be translated in an operating machine. When this translation would fail, it would be the craftsman who was to be blamed. While drawings and models were used in the communication with craftsmen,[16] and Descartes tried to communicate his design by providing Ferrier with pictures—albeit without success—Wren did not attempt to make a *picture* or perspectival representation of his machine.

Newton's earliest work in optics was triggered by his reading of Descartes' *La dioptrique.* It then comes as no surprise that Newton designed machines to grind hyperbolic lenses in unpublished notes *Of Refractions*

14. For Auzout's involvement with the making of telescopes, see McKeon 1965, pp. 99–136. I would like to thank Albert Van Helden for allowing me to see his copy.

15. On the background, see Bennett 1975, pp. 148–184.

16. For the important role of models and drawings in Hooke's communication with craftsmen, see Iliffe 1995, pp. 293–298.

(1665/6).[17] Although Newton appears to have purchased a lathe and lens-grinding equipment during this period—and thus might have been involved in actual lens-grinding—there is no evidence that he built machines to his paper designs (Shapiro 1984, pp. 10–11). Not only was the mathematical principle of Newton's machine similar (and prior) to Wren's design published in *Philosophical Transactions* of 1669, Newton also borrowed the style of visualisation which was characteristic of the Cartesian lens-grinding program. Newton's machine on fol. 26v (Figure 9)[18] was not a diagram strictly speaking (like the one below the image of the machine on the same folio), but—like Descartes' and Wren's—Newton's representation does little more than show the mathematical principle—the generation of the hyperboloid by means of a straight edge inclined to the axis of the cylinder—on which the machine was based. There is little in the image to remind us that this device had an ambition to be a real machine.

With Newton's discovery of the compound nature of light, published in *Philosophical Transactions* of 1671/2, prior to the appearance of Newton's telescope in the same pages, projects—including Newton's—to grind hyperbolic lenses lost their appeal (Newton 1671/2). Newton's early work on machines to grind hyperbolic lenses in the Cartesian tradition had, however, familiarized him with the style of visualization typical for this tradition. I will show that Newton used this style in the representation of his telescope in *Opticks.* As a point of reference (Figure 10), it is interesting to look at the diagram of a reflecting telescope in James Gregory's *Optica promota* (1663, pp. 92–95).

Gregory discussed his design in the *epilogus* of the *Optica promota* which stands apart from the rest of the treatise. In fact, it has been suggested that this section was added later to the *Optica promota* after Gregory had arrived in London and realized the possibility of actually constructing a telescope (Simpson 1992). A so-called *trial* of the design was made by the London optician Richard Reeve after the publication of the treatise.[19] Interestingly, the trial was made with a spherical concave mirror, because Gregory was well aware that the making of non-spherical mirrors and lenses had been "vainly attempted by others." Notwithstanding the knowledge which Gregory had gathered in the London workshops, the diagram in the

17. For a partial edition of Newton's *Of refractions,* see Whiteside 1967, 1: 559–576. For discussion, see Hall 1955.

18. There are more drawings of lens-grinding machines on fols. 26r, 29v, 30v (Cambridge University Library, Add. 4000). Some are reproduced in Burnett 2005, pp. 104–106. Burnett correctly noted the connection between Newton's machine and Wren's, but he is confused about the source of the drawings on fol. 30v, which he claims to be "in another Newton manuscript" (p. 105). In fact, all these drawings are in the same manuscript.

19. On Richard Reeve, see Simpson 1985.

Optica promota clearly showed a parabolic mirror. The practice of the workshops and the theory of Gregory's treatise are two worlds apart. Gregory followed another path than the "vain attempts" of the Cartesian program and this shows in his image of the telescope—unambiguously, a diagram.

Newton's diagram of his reflecting telescope (Figure 11) in *Opticks* is more equivocal (Newton 1704, pp. 79–80). The diagram shows a concave mirror *abcd* "quick-silvered over on the backside"—thus made of glass—and fixed in a tube blackened on the inside. This primary mirror reflects the rays to a prism of glass or crystal *gcf* attached to a handle of brass or iron *k* which holds the prism in the middle of the tube. This prism brings the rays to *t* which is the common focus of the concave mirror and the plano-convex lens *h,* through which the image is viewed. The image is inverted, but Newton noted that it could be erected by making the prism's sides, *ef* and *eg,* convex. Newton did not specify any dimensions (relevant to the diagram of his telescope in *Opticks*) nor was there any indication of a mounting or a mode of focusing.[20]

Newton never built a telescope to this design (at least, evidence of this is lacking) (Mills and Turvey 1979). As we will see, the telescope which was presented to the Royal Society in 1672 had a small plane mirror instead of a prism. Moreover, the primary mirror was not made of glass, but of metal. In *Opticks* Newton explained that "because Metal is more difficult to polish than Glass and is afterwards very apt to be spoiled by tarnishing, and reflects not so much Light as Glass quick-silvered over does", he thought of using a glass mirror to make a reflecting telescope (Newton 1704, p. 77). An attempt by "one of our London Artists"—most likely the lens-grinder Christopher Cock—in 1683 had been unsuccesful.[21] Repeating a topos of practice and theory which was typical of the Cartesian lens-grinding tradition, Newton was convinced that "there wants nothing but a good Artist to bring the design to Perfection" (Newton 1704, pp. 77–78; Shapiro 1993, pp. 154–155). Moreover, like the images of lens-grinding machines but unlike Gregory's diagram, Newton's representation in *Opticks* suggests the *possibility* of realizing the mathematical principle of the design. While Wren's image of his *engine* used shading, Newton's image—look at the mirror, the handle, the prism—is a cross-section.

20. The only dimensions given in *Opticks* were in the historical account of the happenings of 1672. He specified that the concave mirror was ground to a sphere of 25 inches so that its focal length was about 6 1/4 inches. The diameter of the sphere to which the convex side of the plano-convex ocular was ground was 1/5 of an inch. See Newton 1704, p. 75.

21. On Christopher Cock, see Simpson 1989.

2. The Reception of Newton's Telescope

The image of Newton's telescope in *Opticks* was different from the one that had appeared in *Philosophical Transactions* when Newton presented his telescope to the Royal Society in 1672 (Figure 12). The latter image was also different from other contemporary images of telescopes which I have discussed above. Unlike Hevelius' pictures of his telescopes (see Figure 1) the image in *Philosophical Transactions* presented Newton's telescope without a context (a landscape—the city of Danzig—or an architectural context—Hevelius' observatory). Moreover, in the image in *Philosophical Transactions* the path of the light rays through the telescope is visualized—optical design information which was not visualized in Hevelius' representations of telescopes. Hevelius' pictures of his telescope had a different function than the image in *Philosophical Transactions.* Hevelius' aimed at making his readers into *virtual witnesses.* The function of the image in *Philosophical Transactions* was to establish Newton's priority.

The *Philosophical Transactions* was considered an extension in the public sphere of the Royal Society's Register in which inventions, instruments and theories were recorded to establish priority and, as such, the *Philosophical Transactions* also took over practices established around the Register (Johns 1998, pp. 476–485, pp. 501–502; Iliffe 1992). The Royal Society had the right, for example, to illustrate an invention in the Register with a drawing of its own making. This also happened with Newton's telescope in *Philosophical Transactions.* Henry Oldenburg had a drawing of the telescope made (Figure 13) and sent to Christiaan Huygens to claim priority for Newton.[22] An engraving of the instrument also illustrated the publication of the verbal account of Newton's telescope in *Philosophical Transactions* (Figure 12).[23] It is clear that this engraving was based on the drawing which Oldenburg had sent to Huygens. The only difference was in the representation of the mounting.

Indeed, in *Philosophical Transactions* the telescope is presented as a three-dimensional object with a system of focusing and a mounting. At Newton's request the dimensions of the optical components were also given (Turnbull 1959, p. 79).[24] It is also informative to point out the differences

22. Oldenburg wrote to Newton on 2 January 1671/2 that "they [the Philosophers at the Royal Society] think it necessary to use some meanes to secure this Invention from ye Usurpation of forreiners; And therefore have taken care to represent by a scheme that first Specimen, sent hither by you, and to describe all ye parts of ye Instrument, together wth its effect, compared wth an ordinary, but much larger, Glasse; and to send this figure, and description by ye Secretary of ye R. Soc. . . . in a Solemne letter to Paris to M. Hugens, thereby to prevent the arrogation of such strangers . . ." (Turnbull 1959, p. 73). On Oldenburg's role in the management of scientific communication, see Avramov 2002.

23. On the printing of *Philosophical Transactions,* see Rivington 1984; Andrade 1965.

24. In the account of Newton's telescope in *Philosophical Transactions,* it is noted that

between this image and the one presumably used by Newton in communication with a telescope tube maker (Figure 14) (Simpson 1989, p. 52). The latter drawing shows the telescope as a three-dimensional object—but with indications of the dimensions of the different parts of the tube, and with a mounting and a (albeit different) mode of focusing. Moreover, in contrast to the drawing in *Philosophical Transactions,* the path of the light rays is not visualized in the drawing intended for the craftsman. Indeed, such information is of little value to the craftsman who—drawing in hand—makes the telescope, but it is of interest to the mathematically informed readers of *Philosophical Transactions.* The dimensions of the different parts of the tube, however, are relevant for the craftsman, but not when establishing priority in the community of mathematicians. It might even be important to keep material information hidden when an inventor wanted to win a priority dispute.

There is no doubt that the image in *Philosophical Transactions* was of a specific instrument, and that the image in *Opticks* was not. That dimensions were specified in *Philosophical Transactions* and not in the *Opticks* was consequential for the reception of Newton's instrument. The image in *Philosophical Transactions,* I claim, supported a reception of Newton's telescope in which dimension was the crucial factor—a reception that went against Newton's intentions. In *Philosophical Transactions* Newton's "New Theory about Light and Colors" was published first. The description of Newton's telescope appeared only after the publication of the theory on the compound nature of light. The sequence of the papers reversed the order in which Oldenburg received Newton's letters.[25] The reversed sequence should have made it obvious to the readers of *Philosophical Transactions* that this new type of telescope design was the outcome of Newton's theoretical optical research.[26] This was the reception which Newton intended for his instrument. However, this was not the reception that it received.

While Newton tried to make his instrument into a proof of the supremacy of his theory of colours over older theories, his telescope was wel-

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the focal length of the primary mirror is 6 1/3 inches (against 6 1/4 inches in *Opticks*) (Newton 1672, p. 4005).

25. To Oldenburg's request to publish an account of Newton's telescope in *Philosophical Transactions,* Newton responded: "I am puprosing them [Royal Society], to be considered of & examined, an accompt of a Philosophicall discovery wch induced mee to the making of the said Telescope, & wch I doubt not will prove much more gratefull then the communication of that instrument, . . .". Newton to Oldenburg, 18 January 1671/2 (Turnbull 1959, p. 82).

26. On the reception of Newton's theory of light and color, see Shapiro 1996; Shapiro 1980.

comed as a way to shorten telescopes, not as a way to solve the problem of chromatic aberration (Bechler 1975). The drawing sent to Huygens and the engraving published in *Philosophical Transactions* encouraged this response. The figures of the crown—*A* as magnified through Newton's telescope, *B* as magnified through "a common tube of 25 inches long"—were included in the drawing and engraving to make the point that Newton's short telescope allowed for a magnification which—at least—equalled that of longer telescopes. Tellingly, Newton had to inform Oldenburg that "perhaps it may give some satisfaction to Mounsieur Hugens to understand in wt degree it represents things distinct & free from colours".[27] The bottom line of Oldenburg's description of Newton's telescope was not that the image was free from chromatic aberration, but that Newton's shorter instrument magnified as much as ordinary, longer telescopes.

The after-life of the drawing sent to Huygens shows that this was a widely shared reception of Newton's telescope. The drawing was engraved (Figure 15) to illustrate a description of Newton's telescope—together with Huygens' response to it—in *Journal des Sçavans* of 29 February 1672.[28] The *Journal des Sçavans* singled out among the many advantages of Newton's telescope that "it shortens the tubes of telescopes without diminishing their magnification and this makes them thus much easier to manipulate" (Anonymous 1672, p. 52). Moreover, it was stressed that "the figure which I give here is of the same size as the Telescope which is represented" (Anonymous 1672, p. 53). Surely, the picture of the instrument, claimed not only to be to scale, but actually real life size, was meant to emphasize how small the instrument was. Moreover, in a contemporary Italian account of Newton's invention, it was again the shortness of the instrument which was emphasized, already in its title "Description of a small telescope through which remote objects are seen as distinctively as with the larger telescopes".[29] The small dimensions of Newton's instrument were additionally stressed by placing a depiction of Giuseppe Campani's aerial telescopes (of very long lengths) next to a drawing of Newton's telescope (Figure 16).[30]

27. Newton to Oldenburg, 6 January 1671/2 (Turnbull 1959, p. 79).

28. Huygens forwarded Oldenburg's drawing and description to Gallois in February 1672. See Huygens [1672] 1888–1905, 7: 134–136.

29. "Descrittione d' un piccolo occhiale mediante il quale si vedono l' ogietti remoti tanto distintamente quanto si puo fare colli maggiori telescopi", Ms. 1496 (Biblioteca Universitaria, Bologna).

30. Bonelli and Van Helden note that Campani suggested the form of mounting pictured in Figure 16 when he sent lenses—with which Cassini discovered Tethys and Dione in 1684—to Paris in the early 1680s. They also suggest that "this sheet was probably printed separately before 1684" and that the picture was "the frontispiece of Francesco Bianchini's *Hesperi et Phosphori,* Rome, 1728" (Bonelli and Van Helden 1981, p. 41).

Conclusion

In conclusion I would like to point to the importance of institutional context for understanding the differences between the images of Newton's telescope in *Philosophical Transactions* and in *Opticks.* These differences should be considered within the broader context of Newton's attitude towards the early Royal Society. It was in those early years of the Royal Society that a commission for the improvement of telescopes co-existed with a natural history project, the publication of Francis Willughby's *Historia Piscium* (Hunter 1989, pp. 80–82).[31] It has been argued that the hostile reaction (foremost of Hooke) to Newton's paper on color was caused by the experimental and natural history tradition of the Royal Society which clashed with Newton's belief in the primacy of mathematics in natural philosophy (Feingold 2001).[32] The visual way in which Newton's telescope was communicated in *Philosophical Transactions* fitted the experimental and natural history tradition of the early Royal Society rather than Newton's own belief in the primacy of mathematics. One could say that the image of the telescope in *Opticks* finally set the record straight for Newton in its faithfulness to his triumphing belief in the primacy of mathematics.

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31. On the publication history of the *Historia Piscium,* see Kusukawa 2000.
32. As a background, see also Malet 1997.

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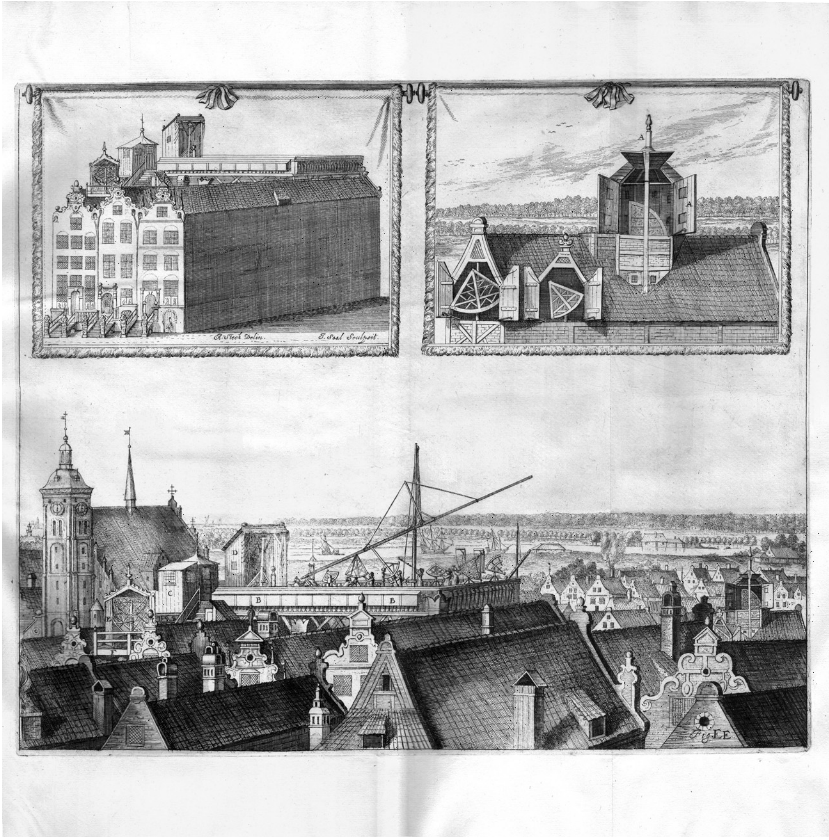
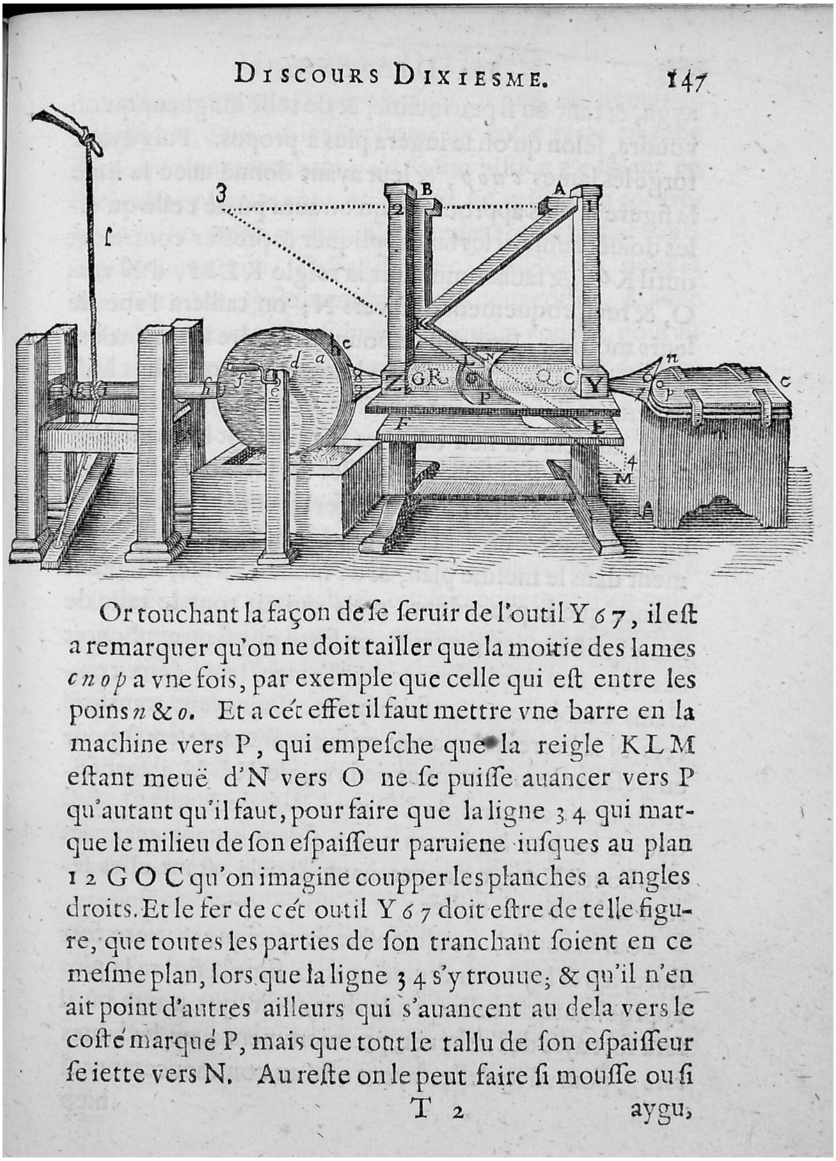


Figure 1. View of Hevelius' observatory. From Johannes Hevelius, *Machinae coelestis* (Gedani, Simon Reiniger, 1673). Ghent University Library, Ma 30, between pp. 444 and 445.



DISCOURS DIXIESME. 147

Or touchant la façon de ſe ſeruir de l'outil Y 6 7, il eſt a remarquer qu'on ne doit tailler que la moitie des lames *c n o p* a vne fois, par exemple que celle qui eſt entre les poins *n* & *o*. Et a cét effet il faut mettre vne barre en la machine vers P, qui empeſche que la reigle KLM eſtant meuë d'N vers O ne ſe puiſſe auancer vers P qu'autant qu'il faut, pour faire que la ligne 3 4 qui marque le milieu de ſon eſpaiſſeur paruiene iuſques au plan 1 2 G O C qu'on imagine coupper les planches a angles droits. Et le fer de cét outil Y 6 7 doit eſtre de telle figure, que toutes les parties de ſon tranchant ſoient en ce meſme plan, lors que la ligne 3 4 s'y trouue; & qu'il n'en ait point d'autres ailleurs qui s'auancent au dela vers le coſté marqué P, mais que tout le tallu de ſon eſpaiſſeur ſe iette vers N. Au reſte on le peut faire ſi mouſſe ou ſi

T 2 aygu,

Figure 2. Descartes' lens-grinding machine. From René Descartes, *Discours de la méthode. . . . Plus la dioptrique. . . .* (Leyde, Jan Maire, 1637), p. 147. By permission of the Royal Library Albert I of Belgium (Brussels).

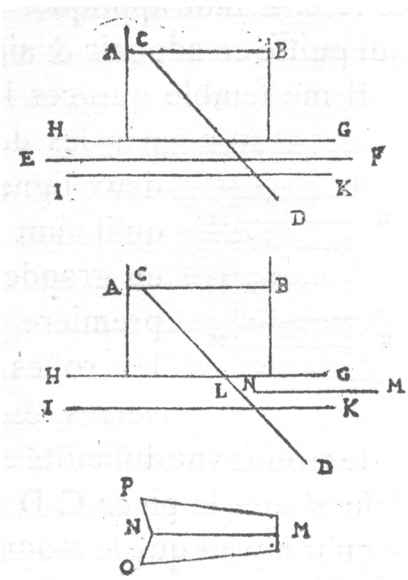


Figure 3. Diagram of Descartes' lens-grinding machine. From René Descartes to Jean Ferrier, 8 October 1629 (AT 1897, 1:34).

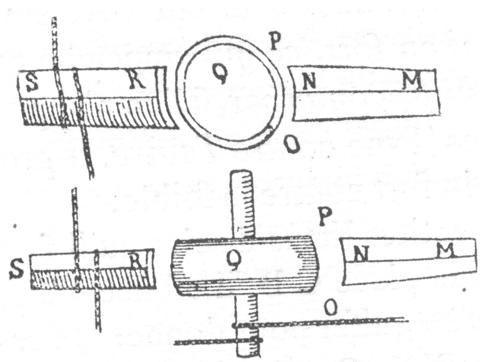


Figure 4. The grinding wheel of Descartes' machine. From René Descartes to Jean Ferrier, 8 October 1629 (AT 1897, 1:35).

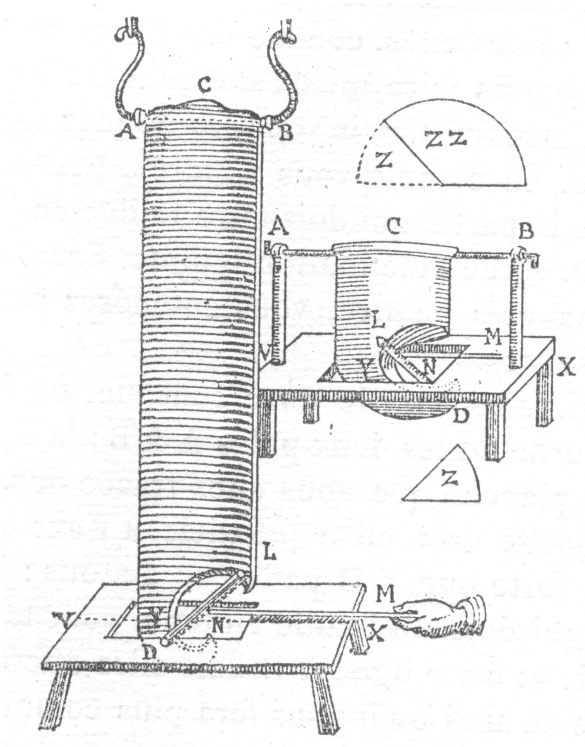


Figure 5. Picture of Descartes' lens-grinding machine. From René Descartes to Jean Ferrier, 13 November 1629 (AT 1897, 1:56).

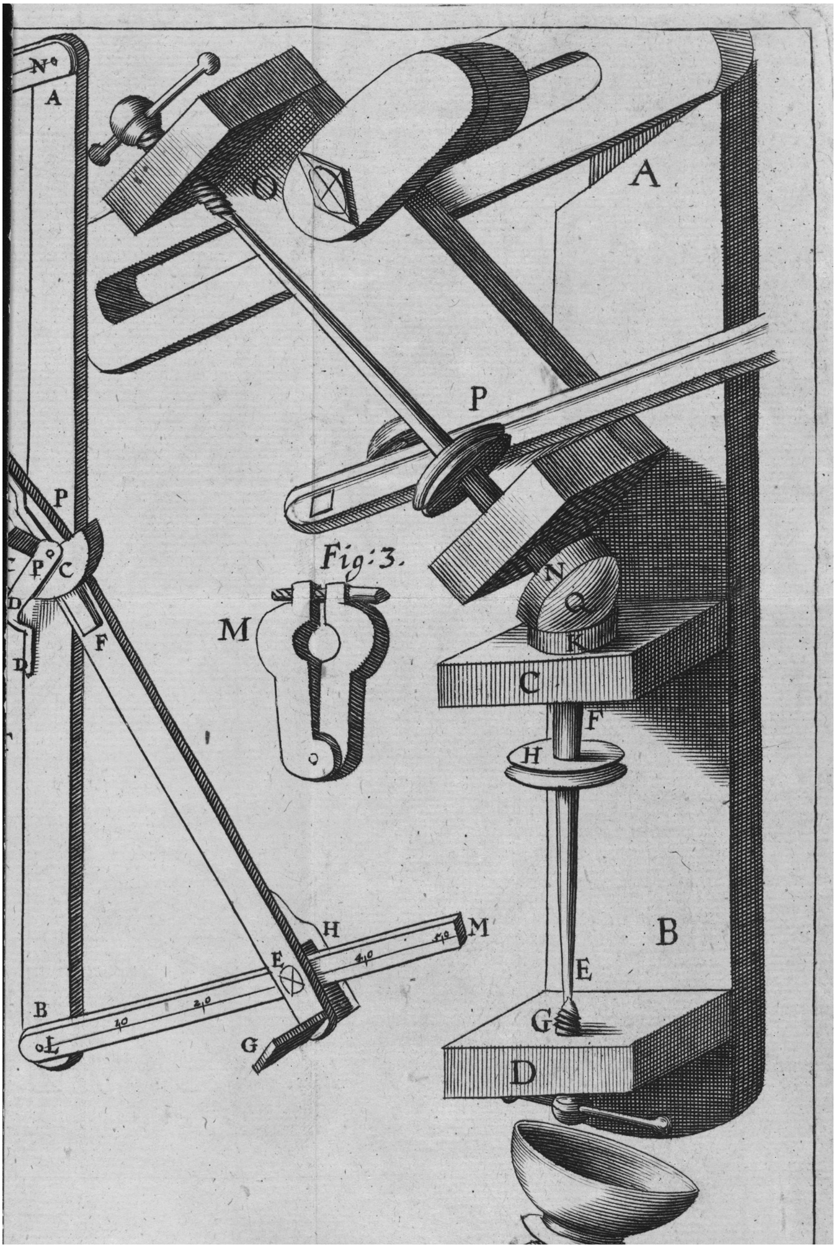


Figure 6. Hooke's lens-grinding machine. From Robert Hooke, *Micrographia* (London, I. Martyn and J. Allestry, 1665), shelfmark G1524, figure 3. By permission of The British Library.

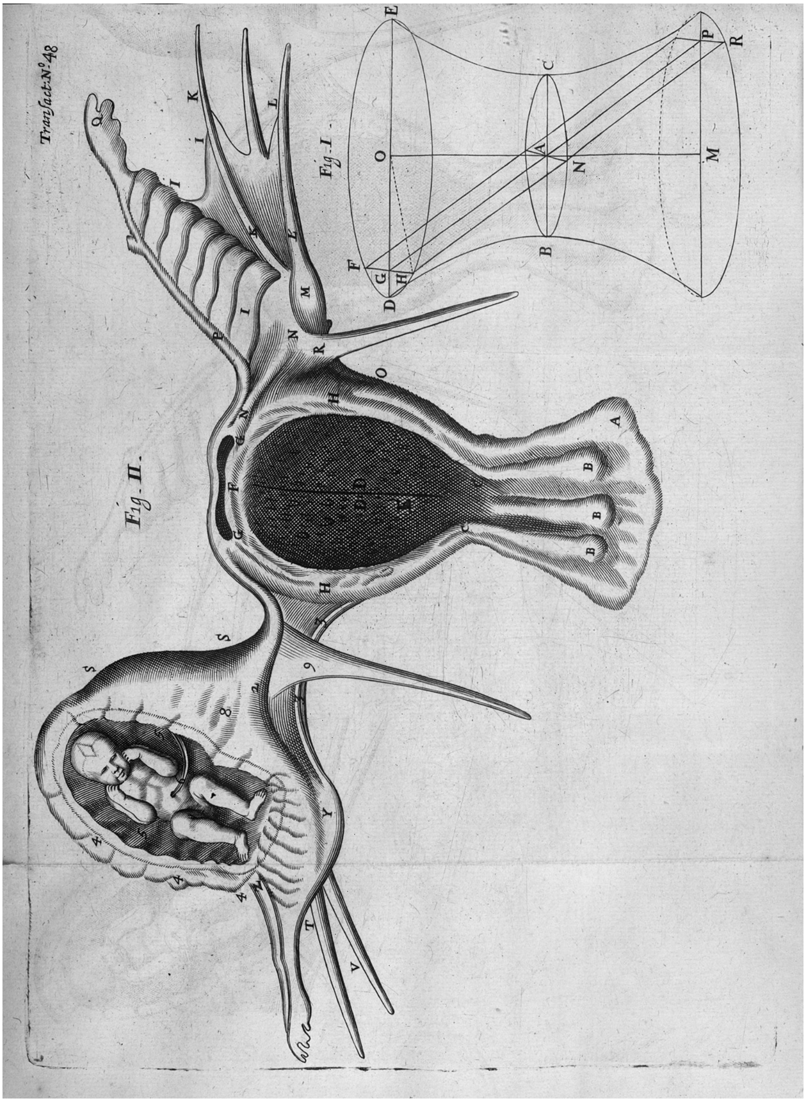


Figure 7. Christopher Wren's diagram. From (Wren, 1669a), shelfmark (P) BX80–43, opposite p. 976. By permission of The British Library.

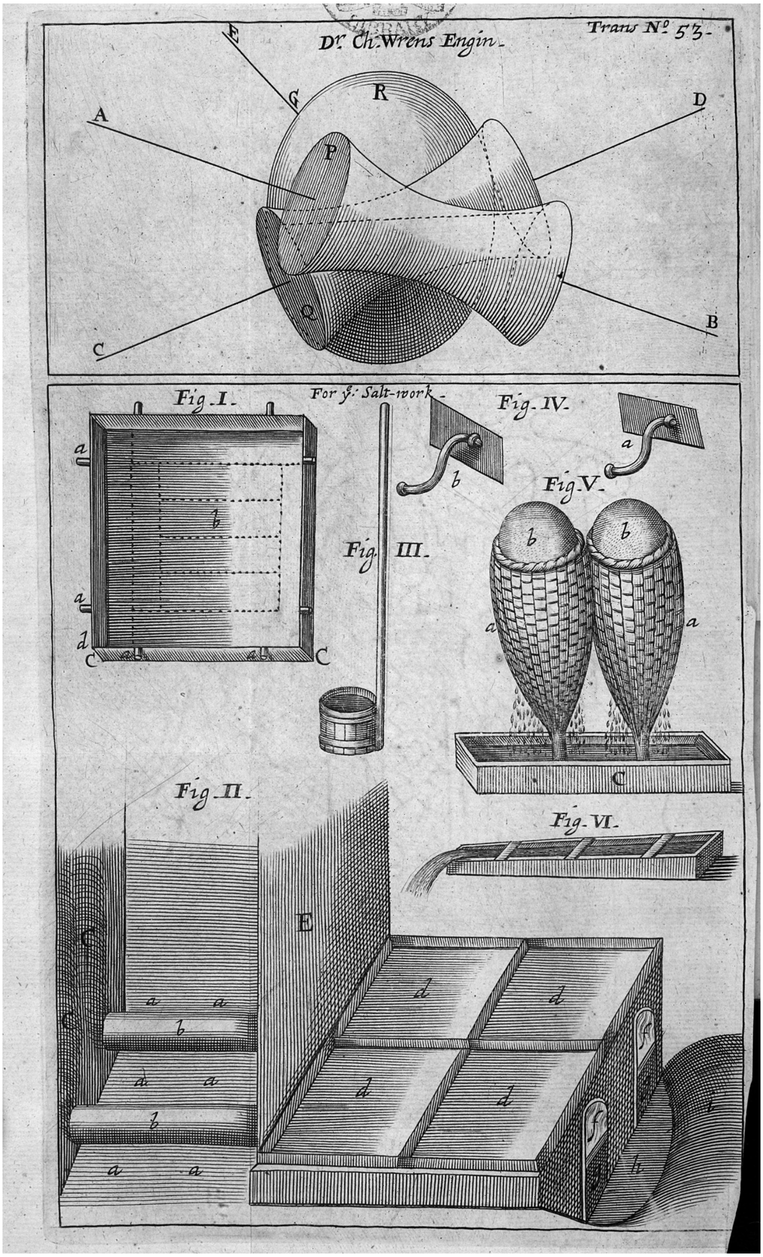


Figure 8. Christopher Wren's lens-grinding machine. From (Wren, 1669b), shelfmark (P) BX80-E43(4), no. 53. By permission of The British Library.

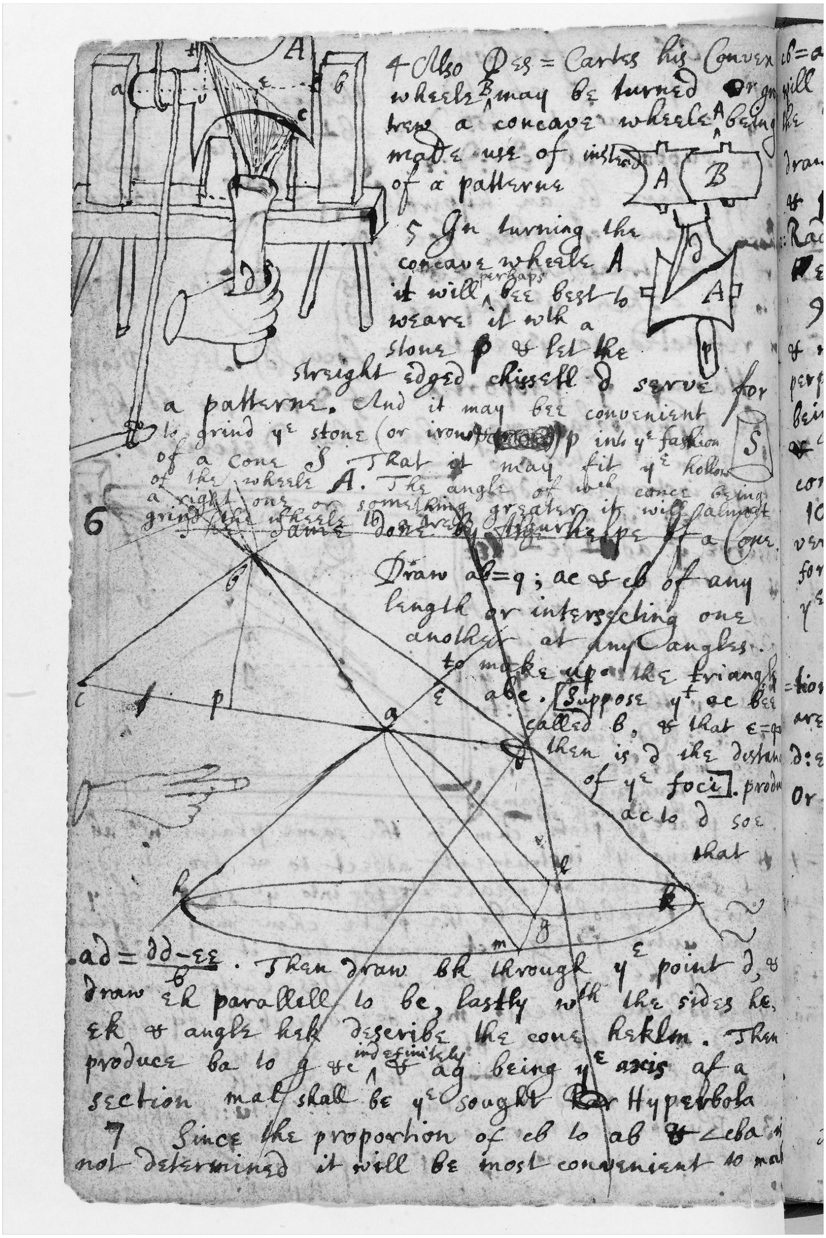


Figure 9. Isaac Newton's lens-grinding machine. From University Library (Cambridge), Ms. Add. 4000, fol. 26v. By permission of the Syndics of Cambridge University Library.

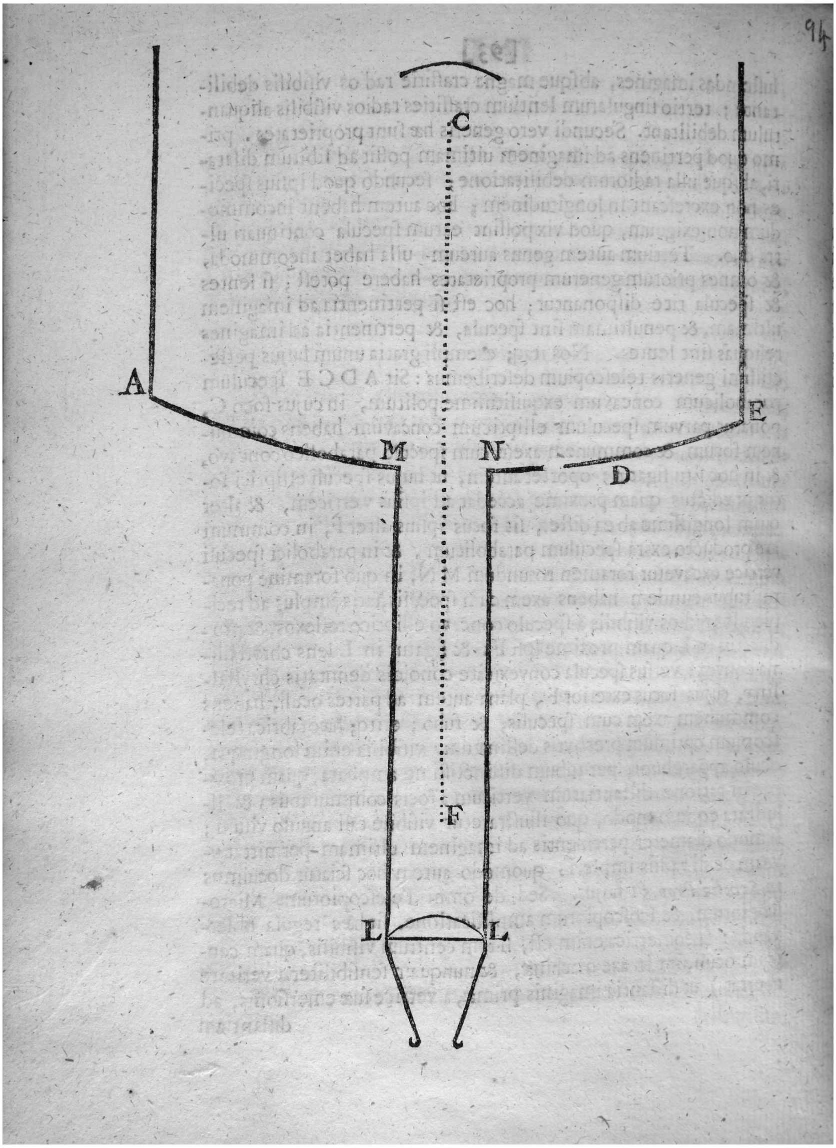


Figure 10. Gregory's telescope. From James Gregory, *Optica promota* (Londini, 1663). Shelfmark 537.f.40, p. 94. By permission of The British Library.

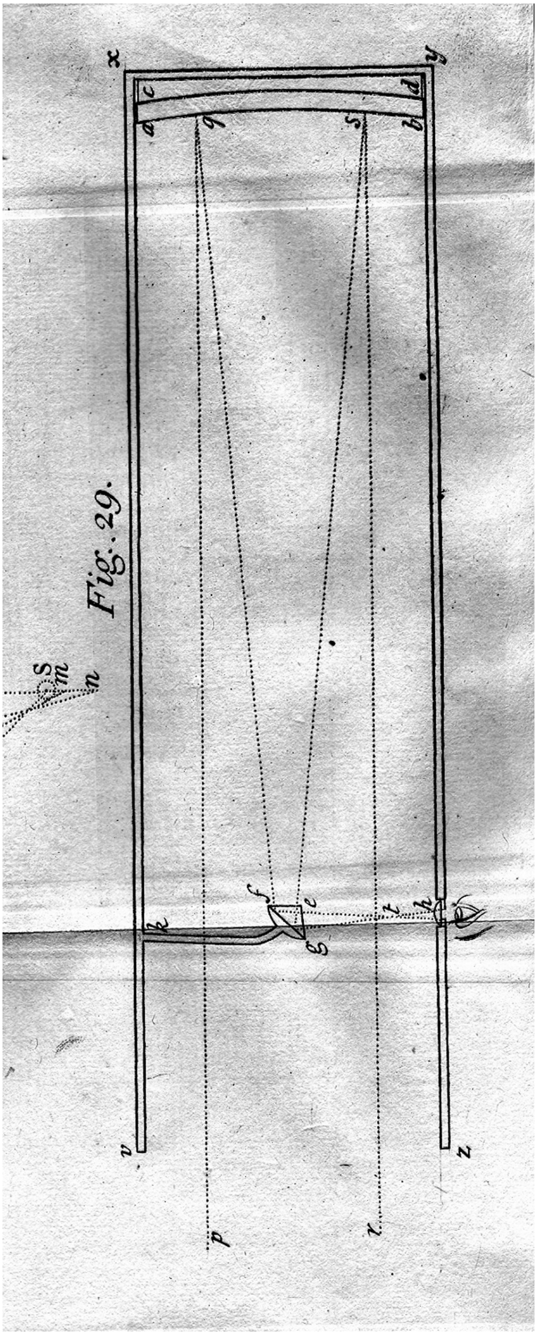


Figure 11. Newton's telescope. From Isaac Newton, *Optice, sive de reflexionibus, refraxionibus, inflexionibus et coloribus lucis libri tres* (Londini, S. Smith & B. Walford, 1706). Ghent University Library, Math. 428, Lib. I. Par. I, Tab. V., fig. 29.

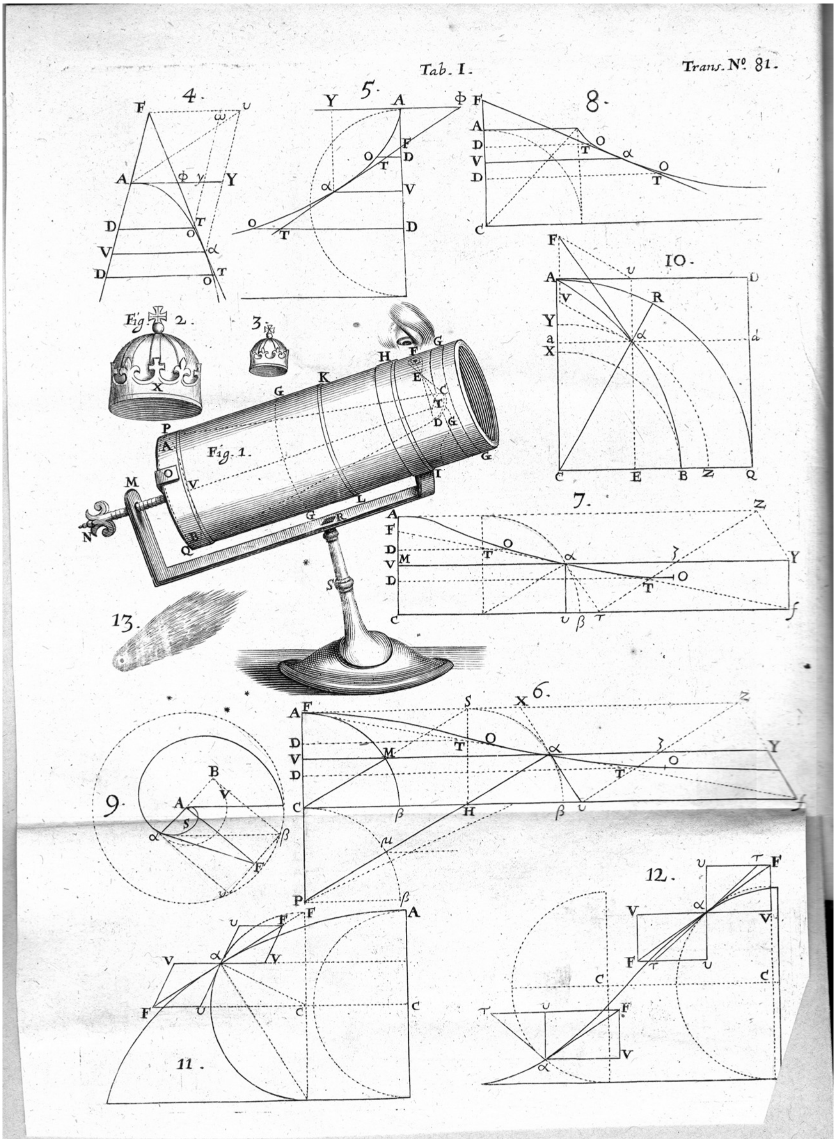


Figure 12. Newton's telescope. From (Newton 1672), Ghent University Library, P26, page following frontispiece.

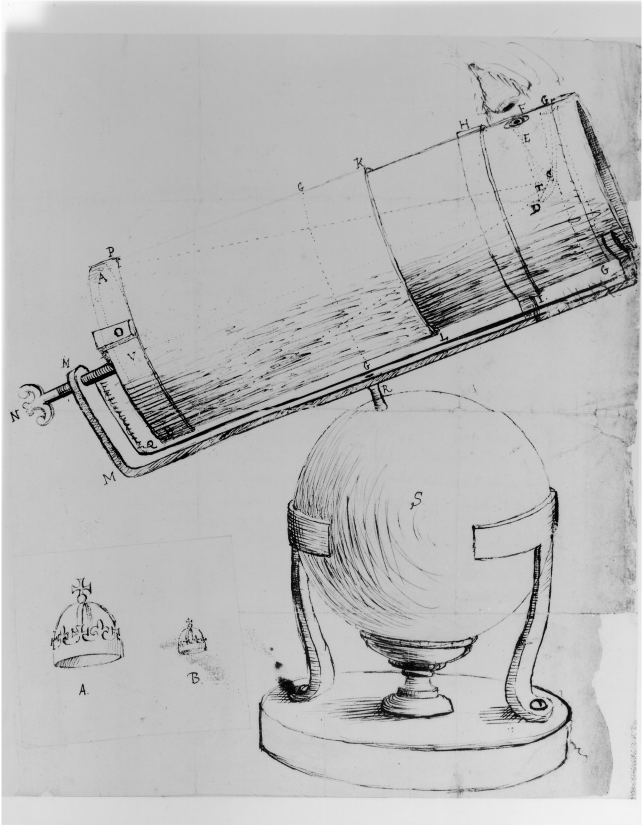


Figure 13. Newton's telescope. From Henry Oldenburg to Christiaan Huygens, 15 January 1671/2. © The Royal Society.

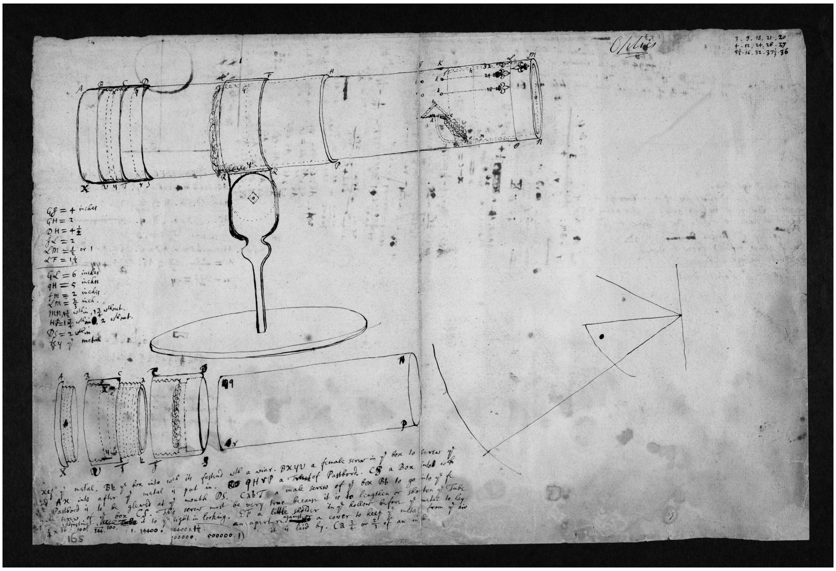


Figure 14. Drawing of Newton's telescope. From University Library (Cambridge), Ms. Add. 3970, fols. 591r and 592v. By permission of the Syndics of Cambridge University Library.

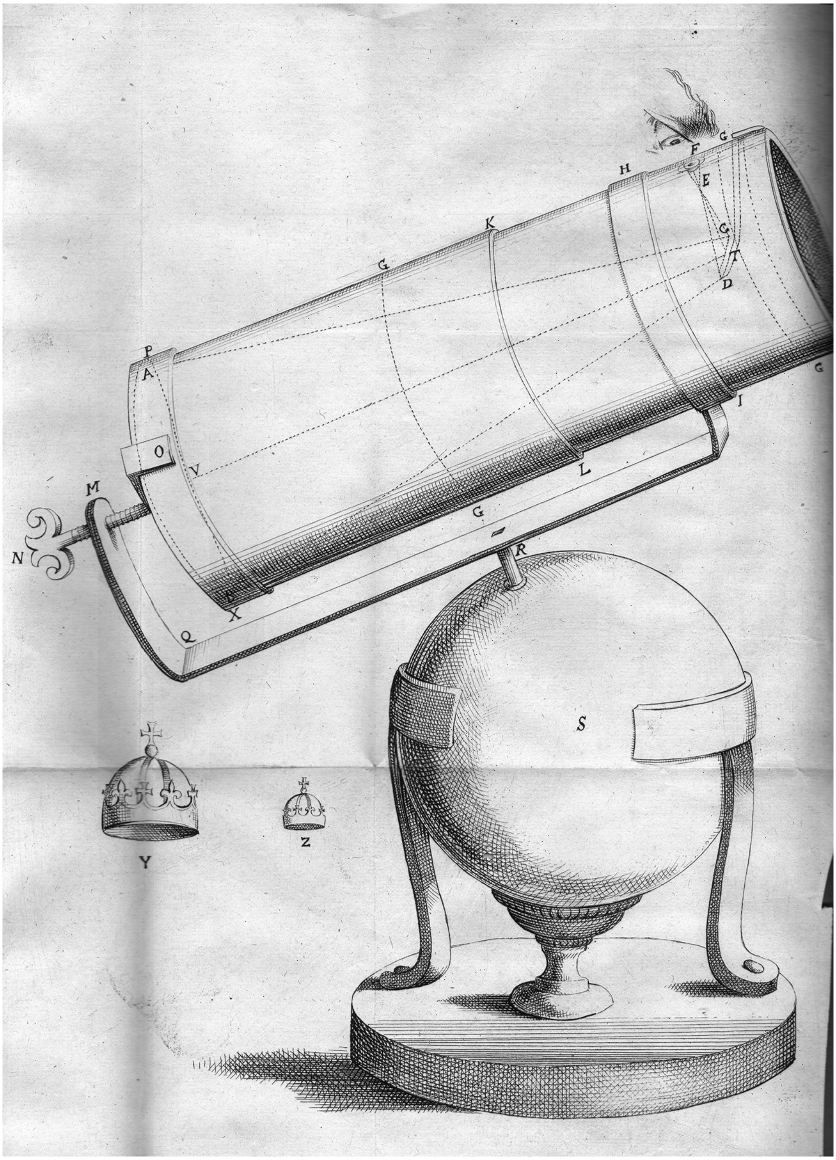


Figure 15. Newton's telescope. From (Anonymous 1672), Ghent University Library, P825, between pp. 52 and 53.

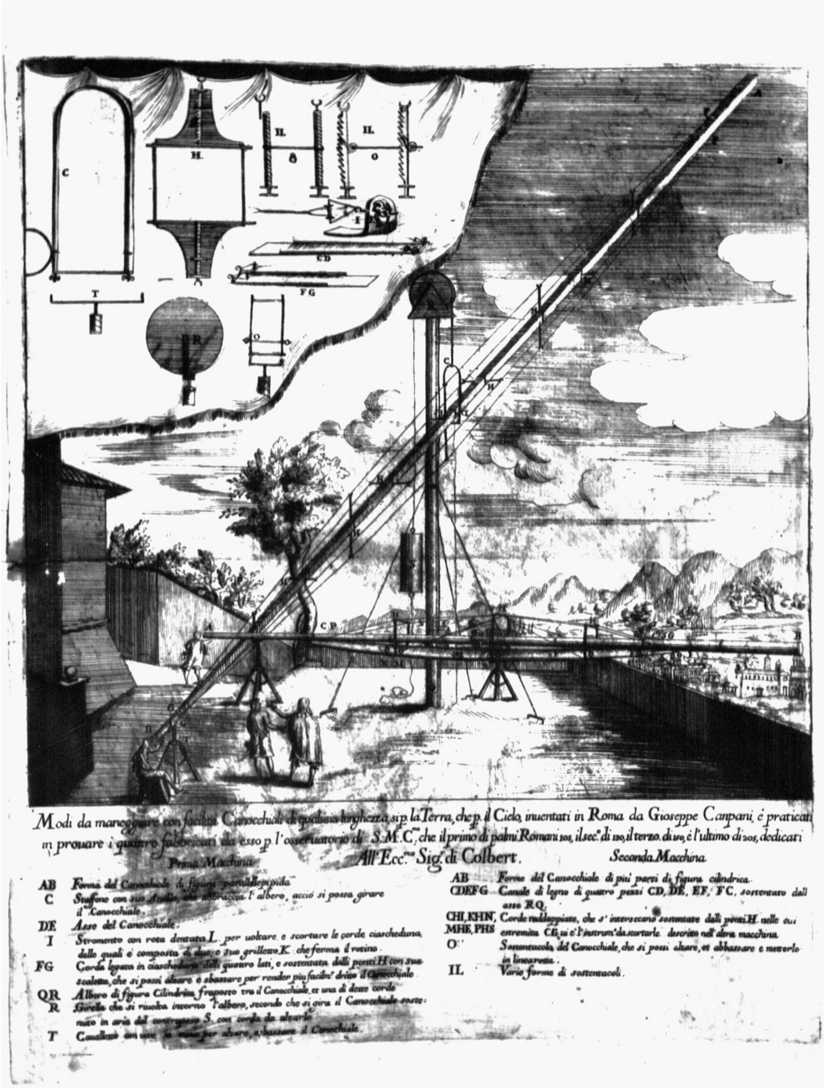


Figure 16. Giuseppe Campani's arial telescope. From "Descrittione d'un piccolo occhiale mediante il quale si vedono l'ogietti remoti tanto distintamente quanto si puo fare colli maggiori telescopi". Biblioteca Universitaria (Bologna), Ms. 1496.