7

Galileo and the Telescope

Wide differences of opinion have been—and are—expressed about Galileo's role in the invention, development, and astronomical use of the telescope. Some of the issues perennially raised are illusory, as when he is reproached for having claimed the original invention of the instrument, a claim he never made. Others are genuine problems, capable of more precise solutions than they are generally given; for example, the chronology of Galileo's first involvement with the instrument. Still other issues must remain in the area of probability and conjecture; among these is the question of the extent of Galileo's knowledge of the optical principles involved in the construction of his telescopes. The present essay is concerned principally with the order of events in Galileo's early work with the telescope, though some light may be shed on other issues in the course of that discussion.

Galileo's first published account of his own connection with the telescope, given in March 1610, ran as follows:

> About ten months ago a report reached my ears that a certain Fleming had constructed a spyglass by means of which visible objects, though very distant from the eye of the observer, were distinctly seen as if nearby. Of this truly remarkable effect several experiences were related, to which some persons gave credence while others denied them. A few days later the report was confirmed to me in a letter from a noble Frenchman at Paris, Jacques Badovere, which caused me to apply myself wholeheartedly to inquire into the means by which I might arrive at the invention of a similar instrument. This I did shortly afterwards, my basis being the theory of refraction. First I prepared a tube of lead, at the ends of which I fitted two glass lenses, both plane on one side while on the other

> side one was spherically concave and the other convex. Then, placing my eye near the concave lens, I perceived objects satisfactorily large and near, for they appeared three times closer and nine times larger than when seen with the naked eye alone. Next I constructed another one, more accurate, which represented objects as enlarged more than sixty times [that is, of about eight power, equivalent in magnification to the usual field glass of today].[1]

It was this instrument that he presented to the Venetian government late in August 1609.

Galileo made no claim to the original discovery, but only to its independent duplication and subsequent improvement, in this first printed narrative. In his letter of presentation to the Venetian government, however, he spoke of his instrument as having been developed by reflection on the principles of perspective, without mentioning the work of others. That statement is often portrayed as a false representation and deserves comment in passing.

It was impossible for Galileo to pretend successfully to the Venetian government, late in August 1609, that the telescope as such was his own invention. This is so evident from existing documents that it would scarcely be worth mentioning, were that preposterous idea not frequently put forth as a part of the evidence against Galileo's integrity and honesty. Numerous letters of the period show not only that word of the Dutch invention had reached Italy by the first of August 1609, but that an unidentified person visited Padua in July with a telescope in his possession, and then traveled on to Venice in the hope of selling it.[2] The Venetian government referred the matter to Fra Paolo Sarpi for his opinion, and on his recommendation the offer was refused. All this was known to Galileo, whose instrument was accepted by the same government a short time afterward. In addressing them, he claimed only that *his own* instrument had been devised on optical principles, and this was quite consistent with what he wrote and published elsewhere, though his terminology varied.

The change from the word "perspective" in the letter of presentation to the word "refraction" in the *Starry Messenger* to identify the optical basis of his telescope has given rise to doubts about Galileo's own knowledge of the theoretical principles involved. Such doubts are in part created by misunderstanding of the

sense of the word "perspective" at the time. The name "perspective glasses" had been applied in England for at least thirty years to single lenses or concave mirrors capable of enlarging the images of distant objects. The word "perspective" was the standard Latin synonym for the Greek "optics" in the nomenclature of mathematical sciences during the Middle Ages and throughout the sixteenth century. Tartaglia, in his preface to Euclid, included under "Perspective Science" the works of both Witelo and Albrecht Dürer, whereas we should be inclined to speak of Witelo's optics and Dürer's perspective. Hence there exists no suitable basis in the words alone for concluding that Galileo was either ignorant or was bluffing. His knowledge of perspective was at least equal to that of the ordinary professor of mathematics in any Italian university of the time, and his knowledge of refraction equaled that of any other professor of astronomy. In order to move from a three-power to an eight-power instrument in a very short time—a move that Dutch and French makers had not made in several months—Galileo probably did apply his knowledge of optics. If he did not, he certainly had extraordinary luck in improving the instrument to eight power, to say nothing of incredible luck about the end of the year in moving on to a thirty-power telescope, which he applied to the heavens. Others were still unable to produce an equivalent instrument for a very long time afterward.

Jacques Badovere had been a pupil of Galileo's at Padua, residing in his house in 1598. He was a frequent visitor from France. In 1607 he provided an affidavit, for use in legal proceedings, concerning the manufacture of the proportional compass by Galileo. But no correspondence between Galileo and Badovere is known to exist. Badovere (more properly Badoer) was the son of a rich Venetian merchant who had been converted to Protestantism and migrated to France. Jacques returned to the Catholic faith and became closely associated with the French Jesuits, for whom he undertook various risky enterprises. For a time he held a diplomatic post with the French government, abruptly terminated by vigorous opposition from Sully and other important ministers. Scandalous rumors were circulated against him, but he remains a shadowy figure. If he ever wrote to Galileo about the telescope, or anything else, the letter is lost. Yet one would expect Galileo

to have kept such a letter if he had received it, particularly in view of his having referred to it in print.

The Fleming referred to by Galileo was Hans Lipperhey (originally the family name was La Prey), who had obtained a patent from Count Maurice of Nassau for his invention. Fra Paolo Sarpi, who was appointed to report on the foreigner's instrument to the Venetian government and was the pivotal figure in its rejection, had been the first man in Italy to learn of the Flemish invention. His information came from Francesco Castrino in November of 1608, only a month after Lipperhey applied for the patent. In a letter to Castrino dated 9 December 1608, Sarpi acknowledged receiving "a month ago" a report of the embassy of the king of Siara to Count Maurice and news of the new "spectacles."[3] Writing to Jerome Groslot de L'Isle on 6 January 1609, Sarpi said:

> I have had word of the new spectacles more than a month, and believe it sufficiently not to seek further, Socrates forbidding us to philosophize about experiences not seen by ourselves. When I was young I thought of such a thing, and it occurred to me that a glass parabolically shaped could produce such an effect. I had a demonstration, but since these are abstract matters and do not take into account the fractiousness of matter, I sensed some difficulty. Hence I was not much inclined to the labor, which would have been very tiresome, so I did not confirm or refute my idea by experiment. I do not know whether perhaps that [Flemish] artisan has hit upon my idea—if indeed that matter has not been swelled by report, as usual, in the course of its journeys.[4]

Probably a similar account of Sarpi's own speculations had been sent to Badovere, with whom Sarpi (unlike Galileo) was definitely in correspondence at this time. Sarpi maintained an extensive correspondence with foreigners, Protestant and Catholic alike, concerning every kind of political and religious development in Europe and every important item of news. On 30 March 1609 he wrote to Badovere:

> . . . I have given you my opinion of the Holland spectacles. There may be something further; if you know more about them, I should like to learn what is thought there. I have

> practically abandoned thinking about physical and mathematical matters, and to tell the truth my mind has become, either through age or habit, a bit dense for such contemplations. You would hardly be able to believe how much I have lost, both in health and in composure, through attention to politics.[5]

There is little doubt that Badovere replied to this letter, confirming the effectiveness of the instrument. Perhaps he also described the two lenses employed in it, particularly if Sarpi had sent to him the same conjecture about a parabolic glass that he sent to Groslot de L'Isle. Since there is no known correspondence between Galileo and Badovere about any subject, and there was a correspondence between Sarpi and Badovere about this particular matter, the chances are that what Galileo saw (and reported in his *Starry Messenger*) was Badovere's letter to their common friend Sarpi. Galileo's account does not exclude this course of events, for he says that the truth of the reports was "confirmed to me from Paris in a letter from the noble Frenchman Jacques Badovere," not "confirmed in a letter to me . . . from Jacques Badovere."[6] Nor is it said that he was at Padua when he received that confirmation. In all probability he was at Venice, for in a later account he wrote:

> . . . At Venice, where I happened to be at the time, news arrived that a Fleming had presented to Count Maurice a glass by means of which distant objects might be seen as distinctly as if they were nearby. That was all. Upon hearing this news I returned to Padua, where I then resided, and set myself to thinking about the problem. The first night after my return I solved it, and on the following day I constructed the instrument and sent word of this to those same friends at Venice with whom I had discussed the matter the previous day. Immediately afterward I applied myself to the construction of another and better one, which six days later I took to Venice, where it was seen with great admiration by nearly all the principal gentlemen of that Republic for more than a month on end, to my considerable fatigue.[7]

Thanks to the labors of Professor Antonio Favaro, who edited and published the definitive edition of Galileo's works between the years 1890 and 1910, there are easily accessible not only Galileo's published works but virtually every scrap of writing in

his hand that has been preserved. Among these are accounts of grocery bills, payments to servants, and records of his dealings with instrument makers, copyists, boarders, and private students. These seemingly trivial documents are not devoid of interest to the historian, since it is safe to say that the 700-odd entries made in Galileo's journals between 1599 and 1610 supply us with dates on which he was physically present in Padua. A careful comparison of entry dates with surviving correspondence and other sources of information discloses but two entries in conflict with this assumption. One is the implied absurd date of 30 February 1610, which can clearly be shown to mean 30 March, the error arising from the mistaken use of the word *detto*. The other appears to be a slip in which *7mbre* was written for *9mbre*. In any case, two errors in seven hundred entries might occur in dates put down by a bookkeeper, let alone a professor keeping his own accounts.

Assuming, then, that Galileo's journal entries and the dates on his letters provide us with accurate information about his presence in Padua, it is possible to establish with considerable confidence the chronology of production of his first telescopes and of the exhibition at Venice of one of these.

During that summer one of Galileo's university students, Count Montalban, remained to complete his work for a doctorate. He resided at Galileo's house and paid for room and board monthly. Normally these payments were entered toward the end of the month, as in April and June of 1609, but collections were made early in August and in September, suggesting that Galileo was absent from Padua at the end of July and again at the end of August. Montalban had studied with Galileo since 1604 but had never previously remained in the summer. A student's presence would have made it difficult for Galileo to be away for extended periods. Journal entries show that he was in Padua on the twenty-third, twenty-eighth, and twenty-ninth of June. On the third of July he wrote from Padua mentioning an illness; on the eleventh and eighteenth of July he again made account entries, as he did also on the twentieth of August and on the first and third days of September.

Toward the end of June, Galileo had spoken with Pietro Duodo at Padua concerning the possibility of improving his salary. Duodo was discouraging about the prospects. It is evident that

Galileo was not yet on the track of a new and wonderful discovery late in June 1609, but that he was anxious to increase his income. We know that he was in Venice twice during the next two months, hearing of the new instrument on the first visit and exhibiting his own on the second, having returned to Padua between the two visits.

The first of these visits may have begun at any time after 18 July. It was probably at Venice during his first visit that the rumors of the new instrument were discussed in Galileo's presence, some believing them and some rejecting them. It would be quite natural for Galileo to visit Paolo Sarpi when in Venice, where he was accustomed to discuss scientific problems with him. It has already been shown that Sarpi was in correspondence with Badovere on the topic, and it was probably in response to Galileo's inquiry for his opinion on the rumors that Sarpi showed him a letter from Badovere, amply confirming the truth of the rumors. Galileo was then seeking an increase in salary, and it would be in keeping with all that is known about him if he saw at once the possibility of utilizing the new device for the purpose.

It was precisely at this time, toward the end of July, that a foreigner visited Padua with one of the instruments in hand.[8] He showed it to Lorenzo Pignoria, a friend of Galileo's, who wrote on the first of August to another friend of Galileo's, Paolo Gualdo, about it. Gualdo was then at Rome. The rumors had spread all over Italy in that month; for example, Federico Cesi at Rome wrote to Giovanni Battista Porta at Naples for his opinion, probably in July. Porta replied on the first of August with a sketch of the device and his contemptuous dismissal of it as a mere toy. I believe that word of the presence of the foreigner at Padua with an actual instrument could not fail to reach nearby Venice swiftly. Galileo says that he left Venice immediately after discussions of the device with friends there. Very likely he had also heard of the visit of the stranger, and his motive was to find him and to examine the instrument for himself.

But here he was disappointed; when Galileo arrived back in Padua on the third of August, the stranger had already left for Venice to sell the "secret" to the government. Galileo's situation was now one in which he had to act with great speed or lose all hope of benefit from the opportunity. And he did act with speed.

It appears that he promptly verified his first conjecture about the construction of the instrument. He recounted this later as follows:

> My reasoning was this. The device needs either a single glass or more than one. It cannot consist of one glass alone, because its shape would have to be convex . . . concave . . . or bounded by parallel surfaces. But the last-named does not alter visible objects in any way, either by enlarging or reducing them; the concave diminishes them; and the convex, though it does enlarge them, shows them indistinct and confused. . . . Knowing that a glass with parallel faces alters nothing . . . I was confined to considering what would be done by a combination of the convex and the concave. You see how this gave me what I sought.[9]

Galileo's account, written much later, may or may not be historical. It certainly has no logical force, and in fact the combination of two convex lenses can produce much better telescopes than the combination he chose. No "principles of perspective" or "doctrines of refraction" are involved in any way in Galileo's own account of his actual (and feverish) procedure in hitting on the nature of the device. Very likely they were only minimally considered in its immediate improvement.[10] This now occupied him for several days, during which he obtained a tube and ground, or had his instrument maker grind, spherical lenses of different radii of curvature. It was not difficult to divine some connection between the ratio of those radii and the degree of magnification. At any rate, within two weeks Galileo was ready for his return to Venice on a trip that brought him undying fame, and incidentally secured him an increase in salary far beyond anything he had aspired to in June.

Meanwhile, however, the foreigner had arrived in Venice with his instrument. There can be little question that the person to whom Galileo immediately sent word of his initial success in divining the "secret" was Paolo Sarpi. Sarpi was very close to the Venetian government as its theological adviser, having recently refuted Cardinal Bellarmine over the rights of Rome and counseled defiance of the interdict placed on Venice by Paul V. Before this appointment, Sarpi was already noted as a scientific expert. It was therefore natural that he was put in a position to referee the foreigner's demands. The foreigner would not allow Sarpi to do

more than look through the instrument, refusing anyone the right to take it apart. His price was a thousand florins. Sarpi, confident that Galileo could make at least as good an instrument and probably better, advised the government to reject the offer, and the foreigner departed. It is highly improbable that Galileo ever met him or saw his instrument.

The events, according to this reconstruction, took place as follows:

About 19 July 1609	Galileo leaves Padua to visit friends at Venice.
20–27 July	He hears rumors of the Dutch instrument and discussions of their veracity. Visitor arrives at Padua with a telescope.
About 27 July	Galileo visits Sarpi, asks his opinion of the rumors, and is shown Badovere's confirming letter.
1 August	Pignoria writes to Gualdo concerning the visitor. Galileo hears at Venice of the same event.
3 August	Galileo arrives in Padua, learns that the foreigner has gone to Venice to sell his "secret," and forms his own conjecture as to its nature.
4 August	Verifies his conjecture by trial and sends word to Sarpi that he has the "secret."
5–20 August	Sarpi advises Venetian government to reject the foreign instrument. Galileo succeeds in constructing an eight-power telescope.
21 August	Galileo returns to Venice and exhibits his telescope to officials from the campanile of St. Mark.
24–25 August	Exhibits telescope to the Signoria and presents it to the Senate, receiving life tenure and increased salary.

Galileo's later statement that he had exhibited the telescope to the principal dignitaries of Venice for more than a month on end is surely mistaken. There was no period in the summer of 1609 during which Galileo could have been in Venice for an entire month. By the first of September he had returned to Padua and

was making preparations for a speedy trip to Florence before the beginning of the new academic year. In the account written more than ten years later, Galileo recollected that he had demonstrated his new instrument to distinguished people for more than a month on end, to his considerable fatigue. But not all these dignitaries were at Venice; some were at Florence.

There is a third account of the events, written by Galileo right at the time. Addressed to his brother-in-law at Florence, and extant only in a contemporary copy, the letter embodying this account has been questioned as to authenticity on various grounds. Edward Rosen has argued very strongly for acceptance of the letter, and I agree entirely with his conclusions, though not with his interpretation of the circumstances.[11] It reads as follows:

> Dear and Honored Brother-in-Law:
>
> I did not write after receiving the wine you sent me, for lack of anything to say. Now I write to you because I have something to tell you which makes me question whether the news will give you more pleasure or displeasure, since all my hope of my returning home is taken away, but by a useful and honorable event.
>
> You must know, then, that it is nearly two months since news was spread here that in Flanders there had been presented to Count Maurice a spy-glass, made in such a way that very distant things are made by it to look quite close, so that a man two miles away can be distinctly seen. This seemed to me so marvellous an effect that it gave me occasion for thought; and as it appeared to me that it must be founded on the science of perspective, I undertook to think about its fabrication; which I finally found, and so perfectly that one which I made far surpassed the reputation of the Flemish one. And word having reached Venice that I had made one, it is six days since I was called by the Signoria, to which I had to show it together with the entire Senate, to the infinite amazement of all; and there have been numerous gentlemen and senators who, though old, have more than once scaled the stairs of the highest campaniles in Venice to observe at sea sails and vessels so far away that, coming under full sail to port, two hours or more were required before they could be seen without my spy-glass. For in fact the effect of this instrument is to represent an object that is, for example, fifty miles away, as large and near as if it were only five.

Now having known how useful this would be for maritime as well as land affairs, and seeing it desired by the Venetian government, I resolved on the 25th of this month to appear in the College and make a free gift of it to His Lordship. And having been ordered in the name of the College to wait in the room of the Pregadi, there appeared presently the Procurator Priuli, who is one of the governors of the University. Coming out of the College, he took my hand and told me how that body, knowing the manner in which I had served for seventeen years in Padua, and moreover recognizing my courtesy in making such an acceptable gift, had immediately ordered the Honorable Governors [of the University] that, if I were content, they should renew my appointment for life and with a salary of one thousand florins per year; and that since a year remained before the expiration of my term, they desired that the salary should begin to run immediately in the current year, making me a gift of the increase for one year, which is 480 florins at 6 lire 4 soldi per florin. I, knowing that hope has feeble wings and fortune swift ones, said I would be content with whatever pleased His Lordship. Then Signor Priuli, embracing me said: "Since I am chairman this week, and can command as I please, I wish after dinner to convene the Pregadi, that is the Senate, and your reappointment shall be read to you and voted on." And so it was, winning with all the votes.[12] Thus I find myself here, held for life, and I shall have to be satisfied to enjoy my native land sometimes during the vacation months.

Well, that is all I have for now to tell you. Do not fail to send me news of you and your work, and greet all my friends for me, remembering me to Virginia and the family. God prosper you.

From Venice, 29 August 1609.

Your affectionate brother-in-law

GALILEO GALILEI[13]

Antonio Favaro neglected to state the reasons for which he felt the style of this letter to be not Galilean at certain points, but that objection seems pointed at the opening and closing paragraphs. These are quite extraordinarily awkward, so much so that at first sight they seem to exclude Galileo as the writer. But they may be readily reconciled with his authorship if those two paragraphs are considered as having been hurriedly tacked on to the body of the

letter, which itself had been very carefully drafted, simply to supply Galileo with a pretext for sending it to Landucci and having its contents conveyed to friends. Galileo was never on good terms with Landucci, even though he had exerted himself to obtain a minor government post for him a short time before. Certainly Landucci did not care whether Galileo ever returned to Florence, and (as Favaro observed) Galileo had other correspondents at Florence who would normally have been more suitable recipients of this stirring news.

The main body of the letter makes it very plausible to suppose that it was written for other eyes than those of Galileo's brother-in-law. To Landucci's eyes, the parade of dignitaries and the high salary offered would have been an intolerable display of boasting. As Galileo well knew, Landucci's own job carried no salary and brought him fees amounting to no more than sixty florins a year. There could be no sense in Galileo's telling him that when offered a salary of one thousand florins a year for life, he had accepted it only because "hope has feeble wings and fortune swift ones." What more, Landucci might exclaim, could a man possibly want? But this phrase would have a very real significance to the grand duke, who had delayed too long in acting on Galileo's appeals for employment, and for whose eyes I believe the letter was really intended.

If my reconstruction of the events is correct, Galileo was embarrassed to admit to Cosimo de' Medici that he had suddenly committed himself to remain in the service of the Venetian Republic for life while negotiating for a post at the Court of Tuscany. Nevertheless, he felt a need to have this news reach the Florentine court from himself before word got there from others. Accordingly he sent his message as a family letter to his brother-in-law, who held a minor government post, with specific instructions to greet all his friends for him. Landucci did convey the news promptly, and the interest that was immediately shown at the court in the topic doubtless accounts for the survival of this letter in a contemporary manuscript copy, whereas any other letters Galileo may have written to Landucci are lost.

Galileo's phrase "if I were content," coupled with his insistence on the impossibility of his ever returning permanently to Florence, implies that he had accepted as a condition of the in-

crease in salary the stipulation that he remain for life. If we accept the letter as genuine, and consider how soon after the events it was written, we are obliged to believe that such a promise was exacted. In that way a great deal of light is thrown upon some subsequent events, especially upon the bitterness that was created at Venice by Galileo's later departure. The letter implies also that Galileo had been given to understand by Priuli that the increase in salary would take place immediately, and that he was not told of any restriction against future increases. In the official award, the increase was made effective in the following year, not the academic year about to begin, and it was stipulated that no further increase could ever be made. It is possible that Priuli misunderstood these stipulations when he conveyed the offer to Galileo, or that Galileo misunderstood Priuli concerning them. In any event, differences between the terms of the subsequent contract and their description in the letter do not condemn the letter as unauthentic. On the other hand, once we accept the letter as genuine, it becomes easier to understand Galileo's subsequent behavior, his mounting irritation at the university, and his final departure from Venice within the year.

The occasion for Galileo's having written this letter becomes clear when the presence of the foreigner at Padua and Venice is taken into account. Had there been no immediate pressure to act swiftly, Galileo might have taken his new instrument to Florence rather than to Venice. Negotiations for his employment by the grand duke of Tuscany, a former pupil, had been in progress for some time but showed no signs of coming to a head. The presentation of a telescope, useful for military purposes, would have been a good inducement to conclude them. But as things stood, Galileo could not delay. He knew that others already had similar instruments, and if none were yet as good as his, he had no reason to think that others would not soon equal or better his achievement. At best, by the time he could reach Florence, it would be known there that a similar instrument was being shown at Venice, and any claim of superiority for his telescope would be difficult to establish. Hence his best procedure was to devote all his efforts to forestalling action at Venice on the rival instrument, produce a better one himself, and hurry back with it to Venice, a mere twenty-five miles from Padua. Thus, from the moment he learned

that the stranger had left Padua for Venice, Galileo may be presumed to have worked only at beating him at his own game.

When he succeeded in doing so, however, the next thing he had to do was to communicate the news to the grand duke, his natural prince and former pupil. This was embarrassing. To the duke, he had to present the circumstances in a light that would explain his failure to return to Florence and would justify his gift of the new and important device to a foreign government. The recital of events he prepared was plausible, if not precise in all regards. He said it was nearly two months since the rumors spread, but he did not say that he himself had heard the rumors at that time. He said that word had reached Venice of his having penetrated the secret, but not that it was he himself who had promptly sent news of his success to friends there. The manner in which he recounted events for the ears of Florentines was designed to make it appear that he was the victim of circumstances, and had acted from that time under orders of the government which employed him. "It is six days since I was called by the Signoria," he wrote, making the context imply that this elite body had called him to Venice from Padua; in fact, on the twenty-third of August he was already in Venice and had shown the instrument to others before he was officially called to show it to the Signoria. On the two succeeding days it was shown first to them and then to the whole Senate. The offer made to him was generous; had he refused it, he could not have been sure of doing so well at Florence. Such was the story as written for the eyes of Cosimo. It may, in the light of later events, have been an oblique reopening of Galileo's application for a court position.

If Galileo tried by this letter to be first to get the news to Florence, however, he did not succeed. On the same day that his letter was posted at Venice, Eneas Piccolomini wrote from Florence at the request of the grand duke to inquire about the instrument and solicit the gift of one or instructions for making one. Galileo did more than comply with this request; he personally made a hurried trip to Florence. There he repaired any damage that had been done, and paved the way for negotiations the following spring that culminated in his long-desired appointment by Cosimo.

Why did Galileo, after his spectacular success in wresting from the Venetian government a lifetime appointment at a large

increase in pay, continue to improve the telescope? It seems to be widely assumed that he expected a still stronger telescope to reveal discoveries in the heavens. I cannot see the slightest reason for him to expect such a thing, even if he had been interested in astronomy at the time. The idea of using a telescope at night would not have occurred to any sensible person on rational grounds. A point of light, magnified many times, is still a point of light. Nevertheless, Galileo did apply himself to the improvement of his telescope and even brought it to the practicable limit of power, for the lens-system he employed, by the beginning of 1610. It is possible that he had previously observed the moon with a weaker instrument and wished to enlarge that body still more, but there is no mention of any lunar (or other astronomical) observations before 1610 in his notes or correspondence.

It is my opinion that there was no specific scientific purpose in Galileo's mind when he resumed the improvement of the telescope late in 1609. He was still pressing for a post at Florence, and he may have wished to present to the grand duke a better telescope than anyone else then had. Galileo undoubtedly liked to tinker, and he had a well-equipped workshop. The clue to higher power was implicit in the eight-power and three-power telescopes he had already built. His later lenses bear the radii of curvature scratched in the glass, and the "secret" of their ratio to the power was not a hard one to find. It is indeed surprising that other makers had not hit on it. The widespread production of three-power toys suggests that they used spectacle lenses. The real reason that Galileo's were for a long time the only telescopes adequate for celestial observations was probably that he concentrated on the grinding of short-focus concave eyepieces. The production of such lenses entailed considerable technical difficulties.

In any case, Galileo's first celestial observations appear to have been made early in January 1610. Probably they were accidental in their origin. A glimpse of the moon, low in the heavens, during terrestrial observations made about dusk, would have been sufficient to start him on them. Two months later they were the talk of Europe.

Those who argue that Galileo knew nothing of optics and was unable himself to explain properly the construction and theory of the telescope may be assuming absence of knowledge where

there was only unwillingness to give away advantages. His critics also point out that Galileo never built a Keplerian telescope, with its superior field of view and higher limit of power. They overlook the fact that Galileo had a good deal of trouble convincing others that what the telescope disclosed in the heavens was really there, and was not just an illusion created by the lenses. In arguing the contrary, Galileo was much assisted by the fact that his telescopes gave an erect image, so that objects observed close at hand were in no way altered (except as to size) by the instrument. An inverting lens system would only have made his task harder in this regard. Nor was higher power any advantage in making the initial discoveries; high-power telescopes need rather elaborate supports.

There are many debated points concerning the invention and improvement of the telescope. Credit for the original invention was early in dispute and has been widely debated ever since. The safest attribution is to Hans Lipperhey, who first applied for a patent on the device in October 1608. Descartes, however, credited the invention to Jacob Metius. In 1634 Isaac Beeckman entered in his journal the claim of Zacharias Janson, as put forth by his son, under whom Beeckman was then learning the technique of lens-grinding. His journal entry was discovered early in the present century, and reads as follows:

> Johannes, son of Zacharias, says that his father made the first telescope here in the year 1604, after an Italian one on which was written "anno 190 [i.e., 1590?]."[14]

The credence due to Beeckman, a highly intelligent and upright man, has been unreasonably transferred to the story he heard from Johannes. Beeckman accurately reported what he had been told, but his informant was unreliable, not only as an interested party, but as a man who later submitted a palpably false sworn affidavit on the same matter. The story is itself improbable to the highest degree. Johannes was born in 1611, seven years after the claimed events, and was accordingly obliged to rely on a family story for his information. His father, the claimant, was born in 1588, and was thus but sixteen years of age in 1604. Later a convicted counterfeiter, the father is hardly a credible witness on his own behalf. His son's later affidavit, in 1655, claimed the invention by his father for the year 1590, when in fact his father was

an infant of two years, and Johannes deliberately falsified his father's age.

Yet it is by no means impossible that a telescope was built in Italy in 1590, or even earlier. Either Giambattista Porta or Marcantonio de Dominis would have been quite capable of constructing one. Porta, however, later regretted that he had never done more than to describe it as a toy, so it is unlikely that he had ever built an instrument worthy of having the date engraved on it. The relevant work of de Dominis, supposed to have been composed in 1590, was not published until 1611. Moreover, if a worthy instrument was made in Italy, dated, transported as far as Holland, and copied there, it seems to have escaped mention in any letter or book. The case was quite different in 1608–9. Then the instrument, from its very first public mention, became the subject of widespread correspondence and printed reports in journals. None of this correspondence appears to have called forth memories of a predecessor instrument (or report of one) four years earlier, or of a more remote one in 1590.

Reports of optical experiments by Leonard Digges and John Dee in England as early as the 1570s have occasioned speculations that telescopes were made and used there long before 1590. Those speculations are not idle with respect to the history of the reflecting telescope, introduced astronomically much later by Sir Isaac Newton. But the idea of a combination of lenses enclosed in a tube appears not to have been involved in the English experiments. William Bourne left a manuscript account of them that is probably reasonably complete.[15] It is clear from this document that the concave mirror alone, or its combination with plane or with other concave mirrors, was the basis of the magnifying effects obtained by Digges and Dee. An effective portable magnifying device such as the Galilean or Keplerian lens system would not be likely to have gone unremarked or neglected, particularly in a seafaring nation. Bourne suggested that a series of concave mirrors might be arranged for greater magnification. He also suggested, in his *Inventions or Devices* of 1578, the use of a single large convex lens (burning glass) in combination with a plane mirror. The passage is of considerable interest, and since the book is rare, it deserves citation:

> For to see any small thing a great distance of[f] from you, it requireth the aid of two glasses, and one glasse must be made of purpose, and it may be such sort, that you may see a small thing a great distance of[f], as this, to reade a letter that is set open neare a quarter of a myle from you, and also to see a man foure or five myles from you. . . . [It must be] like the small burning glasses of that kind of glasse, and must be round, and set in a frame as those bee, but that it must bee made very large, of a foote, or 14 or 16 inches broade. . . . But now to use this glasse, to see a small thing a great distance, then doo this, the thing or place that you would view and discerne, set that glasse fast, and the middle of the glasse to stand [at] right [angles] with the place assigned, and be sure that it doo not stand oblique or awry by no means, and that done, then take a very fayre large looking glasse that is well polished, and set that glasse directly right with the side against i.e., towards ye first glasse, to the intent to receive the beame or shadow that cometh thorow the first placed glasse, and set it at such a distance off, that the thing shall marke the beame or shadowe so large, that it may serve your turne, and so by that meanes you shall see in the looking glass a small thing a great distance. . . .[16]

This description, I believe, precludes the possibility that Bourne, who was very well informed about the state of the arts at his time, had ever heard of any kind of portable telescope.

Notes to Essay 7

1. Galileo, *Starry Messenger;* cf. *Discoveries,* pp. 28–29.
2. These letters will be found in *Opere,* X, 250–55.
3. *Atti del R. Ist. Veneto di Scienze, Lettere ed Arti,* 87 (1927), pt. 2, p. 1069. The embassy is usually said to have been from Siam. Siara (Ceará) was a province in northern Brazil that submitted to the Dutch in 1637.
4. *Sarpi, Lettere ai Protestanti,* ed. M. L. Busnelli (Bari, 1931), I, 58.
5. *Atti del R. Ist. Veneto* . . . , 87 (1927), pt. 2, p. 1160.
6. *Mihi per literas a nobili Gallo Iacobo Badovere ex Lutetia confirmatus est* (*Opere,* III, pt. 1, p. 60).
7. Galileo, *The Assayer;* cf. *Discoveries,* p. 244.

8. The visitor was probably the same one whose telescope was seen in Milan by Geronimo Sirturi in May 1609, as reported in his *Telescopium* (Frankfort, 1618). Sarpi had heard of a telescope brought to Italy by 21 July 1609, when he mentioned the news in a letter to a friend.
9. Galileo, *The Assayer;* cf. *Discoveries,* pp. 245–46.
10. In his *Starry Messenger,* Galileo mentions refraction in relation to the angle subtended by the visual image, which determines the apparent size. He does not discuss the lenses separately, but only their joint effect. The omission is more likely due to his desire to diminish competition than to ignorance on his part.
11. E. Rosen, "The Authenticity of Galileo's Letter to Landucci," *Modern Language Quarterly,* 12 (1951), 473–86; "When Did Galileo Make His First Telescope?" *Centaurus,* 2 (1951), 44–51.
12. The vote was not unanimous, which has contributed to doubts about the authenticity of this letter. But Galileo does not say "winning all the votes." "Winning with all the votes" may simply mean after all votes had been counted.
13. *Opere,* X, 252.
14. *Journal tenu par Isaac Beeckman,* ed. De Waard, vol. 3 (The Hague, 1945), p. 376.
15. Published by J. O. Halliwell-Phillips in *Rara Mathematica* (London, 1839), pp. 32–47, reprinted 1967.
16. William Bourne, *Inuentions or Deuices very necessary for all Generalles . . . as well by Sea as by Land* (London, 1578), pp. 96–97.

8

The Dispute over Bodies in Water

In June of 1611 Galileo returned from a visit to Rome, aptly described by a contemporary as a "tour of triumph," during which he exhibited his telescopic discoveries, was made a member of the Lincean Academy, and opened with Cardinal Bellarmine a discussion of the merits of the Copernican system. Accompanying him on the return to Florence were G. B. Strozzi and his young protégé Giovanni Ciampoli.

The journey was very tiring, and Galileo was ill for some weeks after his return. In the latter part of July he was present at a meeting of literati which probably took place at the house of Filippo Salviati in Florence. Here a dispute over floating bodies originated, but the matter of hydrostatic principles did not come up directly. The point argued was philosophical—that cold produced condensation—and ice was introduced as an example by Vincenzio di Grazia, professor of philosophy at Pisa.[1] Galileo countered with the paradoxical position that ice must be rarefied water, being lighter than water, as shown by its floating. Di Grazia attempted to explain the floating of ice by its shape. Galileo successfully answered di Grazia's arguments, but did not really convince him. It is probable that at this first philosophical argument there was present also Giorgio Coresio, professor of Greek at Pisa and a staunch Aristotelian.[2]

Three days later di Grazia told Galileo that in discussing the arguments with other friends, he had encountered one who had volunteered to demonstrate the falsity of Galileo's denial that shape played a role in the floating of bodies, and would do so by means of actual experiments. This new opponent was Ludovico delle Colombe, who first entered the dispute only in connection with this Aristotelian point. Galileo agreed to meet Colombe at the house