

The Assayer
(1623)

(abridged, translation by Stillman Drake)

by Galileo Galilei

Don Virginio Cesarini[1]:

I have never understood, Your Excellency, why it is that every one of the studies I have published in order to please or to serve other people has aroused in some men a certain perverse urge to detract, steal, or deprecate that modicum of merit which I thought I had earned, if not for my work, at least for its intention. In my *Starry Messenger* there were revealed many new and marvelous discoveries in the heavens that should have gratified all lovers of true science; yet scarcely had it been printed when men sprang up everywhere who envied the praises belonging to the discoveries there revealed. Some, merely to contradict what I had said, did not scruple to cast doubt upon things they had seen with their own eyes again and again.

My lord the Grand Duke Cosimo II, of glorious memory, once ordered me to write down my opinions about the causes of things floating or sinking in water, and in order to comply with that command I put on paper everything I could think of beyond the teachings of Archimedes, which perhaps is as much as may truly be said on this subject. Immediately the entire press was filled with attacks against my *Discourse*. My opinions were contradicted without the least regard for the fact that what I had set forth was supported and proved by geometrical

demonstrations; and such is the strength of men's passion that they failed to notice how the contradiction of geometry is a bald denial of truth.

How many men attacked my Letters on Sunspots, and under what disguises! The material contained therein ought to have opened to the mind's eye much room for admirable speculation; instead it met with scorn and derision. Many people disbelieved it or failed to appreciate it. Others, not wanting to agree with my ideas, advanced ridiculous and impossible opinions against me; and some, overwhelmed and convinced by my arguments, attempted to rob me of that glory which was mine, pretending not to have seen my writings and trying to represent themselves as the original discoverers of these impressive marvels.[2]

I say nothing of certain unpublished private discussions, demonstrations, and propositions of mine which have been impugned or called worthless; yet even these have sometimes been stumbled upon by other men who with admirable dexterity have exerted themselves to appropriate these as inventions of their own ingenuity. Of such usurpers I might name not a few. I shall pass over first offenders in silence, as they customarily receive less severe punishment than repeaters. But I shall no longer hold my peace about one of the latter, who has too boldly tried once more to do the very same thing he did many years ago when he appropriated the invention of my geometric compass, after I had shown it to and discussed it with many gentlemen years before, and had finally published a book about it. May I be pardoned if on this occasion—against my nature, my custom, and my present purpose—I show resentment and protest (perhaps too bitterly) about something I have kept to myself all these years.

I speak of Simon Mayr of Guntzenhausen. He it was in Padua, where I resided at the time, who set forth in Latin the uses of my compass and had one of his pupils publish this and sign it. Then, perhaps to escape punishment, he departed immediately for his native land and left his pupil in the lurch. In Simon Mayr's absence I was obliged to proceed against his pupil, in the manner described in the *Defense* which I published at the time.

Now four years after my *Starry Messenger* appeared, this same fellow (in the habit of trying to ornament himself with other people's works) unblushingly made himself the author of the things I had discovered and printed in that book. Publishing under the title of *The World of Jupiter*, he had the gall to claim that he had observed the Medicean planets which revolve about Jupiter before I had. . . . But note his sly way of attempting to establish his priority. I had written of making my first observation on the seventh of January, 1610. Along comes Mayr, and, appropriating my very observations, he prints on the title page of his book (as well as in the opening pages) that he had made his observations in the year 1609. But he neglects to warn the reader that he is a Protestant, and hence had not accepted the Gregorian calendar. Now the seventh day of January, 1610, for us Catholics, is the same as the twenty-eighth day of December, 1609, for those heretics. And so much for his pretended priority of observation.

After such clear proofs as these, there was no longer any room for doubt in my mind about the ill feeling and stubborn opposition that existed against my works. I considered remaining perfectly silent in order to save myself any occasion for being the unhappy target of such sharpshooting, and to remove from others any material capable of exciting these reprehensible talents. I have certainly not lacked opportunities to put forth

other works that would perhaps be no less astonishing to the schools of philosophy and no less important to science than those published previously. But the reason cited above was so cogent that I contented myself merely with the opinion and judgment of a few gentlemen, my real friends, to whom I communicated my thoughts. In discussions with these men I have enjoyed that pleasure which accompanies the opportunity to impart what one's mind brings forth bit by bit, and at the same time I avoided any renewal of those stings which I had previously experienced with so much vexation. Demonstrating in no small degree their approval of my ideas, these gentlemen have managed for a variety of reasons to draw me away from the resolution I had made.

At first they tried to persuade me not to be upset by obstinate attacks, saying that in the end those would rebound upon their authors and merely render my own reasoning more lively and attractive, furnishing as they did clear proof that my essays were of an uncommon nature. They pointed out to me the familiar maxim that vulgarity and mediocrity receive little or no attention and are soon left in the cold, while men's minds turn to the revelation of wonders and transcendent things—though these indeed may give rise in ill-tempered minds to envy, and thereby to slander. Now these and similar arguments, coming to me on the authority of those gentlemen, almost took away my resolve to write no more; yet my desire to live in tranquility prevailed. And, fixed in my resolve, I believed that I had silenced all the tongues that once had shown such eagerness to contradict me. But it was in vain that I had reached this frame of mind, and by remaining silent I could not evade the stubborn fate of having to concern myself continually with men who write against me and quarrel with me. It was useless to hold my peace, because those who are so anxious to make trouble for me have now had recourse to attributing to me the

works of others. In that way they have stirred up a bitter fight against me, something that I believe never happens without indicating some insane passion.

One might have thought that Sig. Mario Guiducci would be allowed to lecture in his Academy, carrying out the duties of his office there, and even to publish his Discourse on Comets without "Lothario Sarsi" a person never heard of before, jumping upon me for this. Why has he considered me the author of this *Discourse* without showing any respect for that fine man who was? I had no part in it beyond the honor and regard shown me by Guiducci in concurring with the opinions I had expressed in discussions with him and other gentlemen. And even if the entire *Discourse* were the work of my pen[5] - a thing that would never enter the mind of anyone who knows Guiducci - what kind of behavior is this for Sarsi to unmask me and reveal my face so zealously? Should I not have been showing a wish to remain incognito?

Now for this reason, forced to act by this unexpected and uncalled-for treatment, I break my previous resolve to publish no more. I am going to do my best to see that this act shall not escape notice, and to discourage those who refuse to let sleeping dogs lie and who stir up trouble with men that are at peace.

I am aware that this name Lothario Sarsi, unheard of in the world, serves as a mask for someone who wants to remain unknown. It is not my place to make trouble for another man by tearing off his mask after Sarsi's own fashion, for this seems to me neither a thing to be imitated nor one which could in any way assist my cause. On the contrary, I have an idea that to deal with him as a person unknown will leave me a clearer field when I come to make my reasoning clear and explain my notions freely. I realize that often those who go about in masks are low persons who attempt by disguise to gain esteem

among gentlemen and scholars, utilizing the dignity that attends nobility for some purpose of their own. But sometimes they are gentlemen who, thus unknown, forgo the respectful decorum attending their rank and assume (as is the custom in many Italian cities) the liberty of speaking freely about any subject with anyone, taking whatever pleasure there may be in this discourteous raillery and strife. I believe that it must be one of the latter who is hidden behind the mask of "Lothario Sarsi," for if he were one of the former it would indeed be poor taste for him to impose upon the public in this manner. Also I think that just as he has permitted himself incognito to say some things that he might perhaps repress to my face, so it ought not to be taken amiss if I, availing myself of the privilege accorded against masqueraders, shall deal with him quite frankly. Let neither Sarsi nor others imagine me to be weighing every word when I deal with him more freely than he may like.

During the entire time the comet was visible I was confined by illness to my bed. There I was often visited by friends. Discussions of the comets frequently occurred, during which I had occasion to voice some thoughts of mine which cast doubt upon the doctrines that have been previously held on this matter. Sig. Guiducci was often present, and one day he told me that he had thought of speaking on comets before the Academy; if I liked, he would include what he had heard from me along with things he had gathered from other authors or had thought himself. Inasmuch as I was in no condition to write, I regarded this courtesy as my good fortune, and I not only accepted but I thanked him and acknowledged my debt.

Meanwhile from Rome and elsewhere there came insistent requests to know whether I had anything to say on this subject, from friends and patrons who perhaps did not know that I was ill. I replied to them that I had only some questions to raise,

which I was unable to write down because of my infirmity, but that I hoped these ideas of mine would soon be included in a discourse by a friend who had taken the trouble to collect them. That is as I said, and it has been told in several places by Guiducci. There was no need for Sarsi to pass him off as a mere copyist. But since Sarsi wants it so, let it be; meanwhile let Guiducci accept my defense of his treatise in return for the honor he did me.

I have never claimed (as Sarsi pretends) that my opinion was certain to be swiftly carried by the winds to Rome. That usually happens only with the words of great and celebrated men, which really far exceeds the bounds of my ambition. It is true, though, that in reading Sarsi's book I have wondered that what I said never did reach Sarsi's ears. Is it not astonishing that so many things have been reported to him which I never said, nor even thought, while not a single syllable reached him of other things that I have said over and over again? But perhaps the winds that blow the clouds and those chimeras and monsters that tumultuously take shape in them had not the strength to carry solid and weighty things.

In Sarsi I seem to discern the firm belief that in philosophizing one must support oneself upon the opinion of some celebrated author, as if our minds ought to remain completely sterile and barren unless wedded to the reasoning of some other person. Possibly he thinks that philosophy is a book of fiction by some writer, like the *Iliad* or *Orlando Furioso*, productions in which the least important thing is whether what is written there is true. Well, Sarsi, that is not how matters stand. Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of

mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth.

Sarsi seems to think that our intellect should be enslaved to that of some other man. . . . But even on that assumption, I do not see why he selects Tycho. . . . Tycho could not extricate himself from his own explanation of diversity in the apparent motion of his comet; but now Sarsi expects my mind to be satisfied and set at rest by a little poetic flower that is not followed by any fruit at all. It is this that Guiducci rejected when he quite rightly said that nature takes no delight in poetry. That is a very true statement, even though Sarsi appears to disbelieve it and acts as if acquainted with neither nature nor poetry. He seems not to know that fables and fictions are in a way essential to poetry, which could not exist without them, while any sort of falsehood is so abhorrent to nature that it is as absent there as darkness is in light.

Guiducci wrote that "people who wish to determine the location of a comet by means of parallax must first establish that the comet is a fixed and real object and not a mere appearance, since reasoning by parallax is indeed conclusive for real things but not for apparent ones." . . . Sarsi says that no author worth considering, ancient or modern, has ever supposed a comet to be a mere appearance; hence that his teacher, who was disputing only with such men and did not aspire to victory over any others, did not need to remove comets from the company of mere images. To this I reply in the first place that for the same reason Sarsi might let Guiducci and me alone, as we are outside the circle of those worthy ancient and modern authors against whom his teacher was contending. We meant only to address those men, ancient or modern, who try in all their

studies to investigate some truth in nature. We meant to steer clear of those who ostentatiously engage in noisy contests merely to be popularly judged victors over others and pompously praised. . . . Guiducci, in the hope of doing something that would be welcome to men studious of truth, proposed with all modesty that henceforth it would be good to consider the nature of a comet, and whether it might be a mere appearance rather than a real object. He did not criticize Father Grassi or anyone else who had not previously done this. Now Sarsi rises up in arms and passionately strives to prove that this suggestion is beside the point and false to boot. Yet in order to be prepared for anything (lest the idea appear worthy of some consideration), he robs me of any possible credit by calling this "an ancient notion of Cardan and Telesio," which his teacher disparages as a fantasy of feeble philosophers who had no followers. And under this pretense, without the least shame for his disrespect, he robs those men of their reputations in order to cover up a slight oversight of his teacher's. . . . But I must not neglect to show, for his benefit and in their defense, how implausible is his deduction that their science was poor from their having had few followers.

Perhaps Sarsi believes that all the host of good philosophers may be enclosed within four walls. I believe that they fly, and that they fly alone, like eagles, and not in flocks like starlings. It is true that because eagles are rare birds they are little seen and less heard, while birds that fly like starlings fill the sky with shrieks and cries, and wherever they settle befoul the earth beneath them. Yet if true philosophers are like eagles they are not [unique] like the phoenix. The crowd of fools who know nothing, Sarsi, is infinite. Those who know very little of philosophy are numerous. Few indeed are they who really know some part of it, and only One knows all.

To put aside hints and speak plainly, and dealing with science as a method of demonstration and reasoning capable of human pursuit, I hold that the more this partakes of perfection the smaller the number of propositions it will promise to teach, and fewer yet will it conclusively prove. Consequently the more perfect it is the less attractive it will be, and the fewer its followers. On the other hand magnificent titles and many grandiose promises attract the natural curiosity of men and hold them forever involved in fallacies and chimeras, without ever offering them one single sample of that sharpness of true proof by which the taste may be awakened to know how insipid is the ordinary fare of philosophy. Such things will keep an infinite number here of men occupied, and that man, will indeed be fortunate who, led by some unusual inner light, can turn from dark and confused labyrinths in which he might have gone perpetually winding with the crowd and becoming ever more entangled.

Hence I consider it not very sound to judge a man's philosophical opinions by the number of his followers. Yet though I believe the number of disciples of the best philosophical may be quite small, I do not conclude conversely that those opinions and doctrines are necessarily perfect which have few followers, for I know well enough that some men hold opinions so erroneous as to be rejected by everyone else. But from which of those sources the two authors mentioned by Sarsi derive the scarcity of their followers I do not know, for I have not studied their works sufficiently to judge.

If I accept Sarsi's charge of negligence because various motions that might have been attributed to the comet did not occur to me, I fail to see how he can free his teacher from the same criticism for not considering the possibility of motion in a straight line. . . . There is no doubt whatever that by introducing irregu-

lar lines one may save not only the appearance in question but any other. Yet I warn.

Sarsi that far from being of any assistance to his teacher's case, this would only prejudice it more seriously; not only because he did not mention this, and on the contrary accepted the most regular line there is (the circular), but because it would have been very flippant to propose such a thing. Sarsi himself may understand this if he will consider what is meant by an irregular line. Lines are called regular when, having a fixed and definite description, they are susceptible of definition and of having their properties demonstrated. Thus the spiral is regular, and its definition originates in two uniform motions, one straight and the other circular. So is the ellipse, which originates from the cutting of a cone or a cylinder. Irregular lines are those which have no determinacy whatever, but are indefinite and casual and hence undefinable; no property of such lines can be demonstrated, and in a word nothing can be known about them. Hence to say, "Such events take place thanks to an irregular path" is the same as to say, "I do not know why they occur." The introduction of such lines is in no way superior to the "sympathy," "antipathy," occult properties," "influences," and other terms employed by some philosophers as a cloak for the correct reply, which would be: "I do not know." That reply is as much more tolerable than the others as candid honesty is more beautiful than deceitful duplicity.

Guiducci has written, "Many stars completely invisible to the naked eye are made easily visible by the telescope; hence their magnification should be called infinite rather than nonexistent." Here Sarsi rises up and, in a series of long attacks, does his best to show me to be a very poor logician for calling this enlargement "infinite." At my age these altercations simply make me sick, though I myself used to plunge into them with

delight when I too was under a schoolmaster. So to all this I answer briefly and simply that it appears to me Sarsi is showing himself to be just what he wants to prove me; that is, little cognizant of logic, for he takes as absolute that which was spoken relatively.

No one ever seriously claimed that the magnification of fixed stars is infinite. Rather, Father Grassi wrote that it was nil, and Guiducci, having noted that this is not correct inasmuch as many totally invisible stars are brought to visibility, remarked that such enlargement should be called infinite rather than nil. Now who is so simple-minded as not to understand that if we call a profit of one thousand ducats on a capital of one hundred "large," and not "nil," and the same upon a capital of ten "very large," and not "nil," then the acquisition of one thousand upon no capital at all should be called "infinite" rather than "nil"? . . . And even if Guiducci called the magnification "infinite" without any relative term, I should not have expected such carping criticism as this, for the word "infinite" in place of the phrase "extremely large" is a way of talking that is used every day. Here, indeed, Sarsi has a large field in which to show himself a better logician than all the other authors in the world; for I assure him that he will find the word "infinite" chosen in place of "extremely large" nine times out of ten. Nor is that all, Sarsi. If the Preacher should confront you and say: *Stultorum infinitus est numerus* ("the number of fools is infinite"),[8] what would you do? Would you argue with him and maintain his proposition to be false? You could prove on equal scriptural authority that the world is not eternal, and that having been created in time there cannot have been and cannot be an infinite number of men; and since foolishness reigns only among men, the above proposition could never be true even if all men—past, present, and future—were fools. For there could never be an in-

finite number of human beings even if the world were to endure eternally.

I did not mean to spend so many words on this trifling, Your Excellency, but since the more has been done, the less remains to do. Now for this other charge of violating the laws of logic. Guiducci, in his discussion of the telescope, is said either to have included an effect which does not exist or to have left out one that should be given. He said, "The telescope renders stars visible either by enlarging their images or by illuminating them," whereas Sarsi will have it that he should have said, "by enlarging them or by uniting the images and the rays." I reply that Guiducci had no intention of dividing what is one, and so far as he and I are concerned there is but one operation of the telescope in representing objects. What he said was, to be exact, "If the telescope does not render stars visible by enlarging them, then by some unheard-of means it must illuminate them." He did not introduce "illumination" as an effect that he believed in, but counterpoised it against the other as an obvious impossibility, intending in this way to make the truth of the alternative still more evident. This is quite a common figure of speech, as when one says: "If our enemies did not scale the fortress, they must have rained here from the sky." Now if Sarsi thinks he can win acclaim by condemning this idiom, then in addition to his animadversions on the word "infinite" he has another road open to him for winning a battle of logic against all the other writers on earth. But in hying to show himself off as a great logician, let him beware lest he make himself appear a still greater sophist.- I seem to see Your Excellency grin, but what can I do? It is Sarsi who has taken it into his head to write against Guiducci's treatise, and in the process he has been forced to grasp at skyhooks. For my part I do not merely excuse him, I praise him; for to me it appears he has accomplished the impossible.

Immediately after this, though perhaps not very appositely, Sarsi is induced to call the telescope my "foster child," and to disclose that it is not my offspring in any other way. Now how is this, Sig. Sarsi? First you try to place me under great obligations by showering new virtues upon this supposed child of mine, and next you ten me it is only an adopted one. Is this rhetorically sound? I should have thought that on such an occasion you would have tried to make me believe it was my very own child, even if you had been certain it was not.

Well, my part in the discovery of this instrument (and whether I may reasonably claim to be its parent) was long ago set forth in my *Starry Messenger*. There I wrote that in Venice, where I happened to be at the time, news arrived that a Fleming had presented to Count Maurice [of Nassau] 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 men of that republic for more than a month on end, to my considerable fatigue. Finally, at the suggestion of one of my patrons, I presented it to the Doge at a meeting of the Council. How greatly it was esteemed by him, and with what admiration it was received, is testified by ducal letters still in my possession. These reveal the munificence of that serene ruler in compensation for the invention presented to him, for I was reappointed and confirmed for life in my professorship at the University of Padua with double my previous salary, which was already three times

that of some of my predecessors. These acts did not take place in some forest or desert, Sig. Sarsi; they happened in Venice, and if you had been there you would not be dismissing me thus as a simple schoolmaster. But most of those gentlemen are still living there, by the grace of God, and you may be better informed by them.

Yet perhaps some will say that in the discovery and solution of a problem it is of no little assistance first to be conscious in some way that the goal is a real one, and to be sure that one is not attempting the impossible, and hence that my knowledge and certainty of the telescope having already been made was of so much help to me that without this I should never have made the discovery. To this I shall reply by making a distinction. I say that the aid afforded me by the news awoke in me the will to apply my mind to the matter, and that without this I might never have thought about it, but beyond that I do not believe any such news could facilitate the invention. I say, moreover, that to discover the solution of a stated and fixed problem is a work of much greater ingenuity than to solve a problem which has not been thought of and defined, for luck may play a large part in the latter, while the former is entirely a work of reasoning. Indeed, we know that the Fleming who was first to invent the telescope was a simple maker of ordinary spectacles who, casually handling lenses of various sorts, happened to look through two at once, one convex and the other concave, and placed at different distances from the eye. In this way he observed the resulting effect and thus discovered the instrument. But I, incited by the news mentioned above, discovered the same thing by means of reasoning. And this reasoning, easy as it is, I wish to reveal to Your Excellency, for if set forth where it is to the purpose it may by its simplicity reduce the incredulity of those who (like Sarsi) try to diminish whatever praise there may be in this that belongs to me.

My reasoning was this. The device needs either a single glass or more than one. It cannot consist of one glass alone, because the shape of this would have to be convex (that is, thicker in the middle than at the edges) or concave (that is, thinner in the middle), 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 indistinctly and confusedly. Passing then to two, and knowing as before that a glass with parallel faces alters nothing, I concluded that the effect would still not be achieved by combining such a glass with either of the other two. Hence I was restricted to discovering what would be done by a combination of the convex and the concave [9]. You see how this gave me what I sought; and such were the steps in my discovery, in which I was assisted not at all by the received opinion that the goal was a real one.

If Sarsi and others think that certainty of a conclusion extends much assistance in the discovery of some means for realizing it, let them study history. There they may learn that Archytas made a dove that flew, that Archimedes made a mirror which kindled fires at great distances and many other remarkable machines, that other men have kindled perpetual fires, and a hundred more inventions no less amazing. By reasoning about these they may easily discover, to their great honor and profit, how to construct such things. Or, if they do not succeed, at least they will derive some benefit in the form of a clarification of their ideas about the help which they expect from a foreknowledge of the effects. That help will be a good deal less than they have imagined.

Sarsi now prepares with admirable boldness to maintain, by means of acute syllogisms, that objects seen through the telescope are the more enlarged the closer they are, and he is so

confident that he practically promises I shall come to admit this to be true, though at present I deny it. Now I make a very different forecast. I believe that in the weaving of this cloth, Sarsi is going to get himself so entangled—far more than he supposes now, while he is laying the warp—that in the end he will voluntarily admit himself defeated. This will become apparent to anyone who will notice that he ends by saying precisely the same things that Guiducci wrote, though he disguises this and fits it in piecemeal among such a variety of wordy ornaments and arabesques that those who merely glance at his statements may take them to be something different from what they really are.

Meanwhile I say, in order not to discourage him, that if what he is attempting turns out to be correct, then this reasoning which his teacher and his astronomer friends use to determine the location of the comet is not only the most ingenious argument of all, but such an employment of the telescope far transcends all others in the importance of its consequences. I cannot help being astonished that Sarsi and his teacher, thinking it to be true, should have regarded it less highly than their others—which, if I may say so, are not fit to hold a candle to this one. Your Excellency, if this thing is true, Sarsi has a clear road to the most admirable inventions ever thought of. Not only may any distance on earth be measured from a single place, but the distances of the heavenly bodies may also be established exactly. For once we have observed a circle through a telescope at a distance of one mile and found it to be thirty times as large as when viewed with the naked eye, we need only find a tower that is magnified ten times and we may be sure that it is three miles distant. If this telescope merely triples the moon's diameter, we may say that the moon is ten miles away, and the sun would be fifteen if its diameter is but doubled. Conversely, if the moon is tripled by some excellent telescope when it is more

than one hundred thousand miles away (as Father Grassi says), then the ball on a cupola at a distance of one mile would be enlarged more than a million times. Now to add what I can to so astounding a venture, I shall set forth some trifling questions which arose in me as Sarsi proceeded. Your Excellency may, if you like, show them to him some time so that he may by replying establish his position more solidly.

Sarsi wishes to persuade me that the fixed stars receive no appreciable enlargement from the telescope. He begins with objects in my room, and asks me whether I need to lengthen my telescope very much in order to view them [11]. I answer, yes. Now, letting the objects pass out the window to a great distance, he tells me that in order to look at them it is necessary to shorten the telescope a good deal; and I affirm this. Next I concede to him that this comes about from the very nature of the instrument, which must be made longer for observing nearby objects and shorter for those that are more distant. Moreover, I confess that the longer tube shows the objects larger than the shorter; and finally I grant him for the present his whole syllogism, the conclusion being that in general nearby objects are more enlarged and farther ones less so. This implies that the fixed stars, which are remote objects, are less enlarged than things within a room or a courtyard, for it appears to me that Sarsi includes things which he calls "nearby" within those limits, he not having specifically removed this boundary to any greater distance.

But the statement made thus far is still a long way from proving Sarsi's point. For next I ask him whether he places the moon in the class of "nearby" objects, or in that of "distant" ones? If he puts it with distant objects, then he must conclude for it the same thing he concludes for the fixed stars; namely, slight enlargement. But this is in direct contradiction to his

teacher, who, in order to situate the comet beyond the moon, requires that the moon be one of those objects which are greatly magnified. He even wrote that the moon viewed through the telescope is much enlarged, and the comet was but little. On the other hand if Sarsi places the moon among nearby objects, then I shall reply to him that he should not have restricted such objects to the walls of a room at the outset; he should have extended this boundary at least as far as the moon. But having extended it that far, let Sarsi return again to his original questions, and ask me whether I need to lengthen my telescope very much in order to see "nearby" objects—that is, objects which are not beyond the orbit of the moon. I answer no, and the archer's bow is broken and the shooting of syllogisms is over.

If we go back to examine his argument more closely, we find it to be defective because it takes as absolute that which must be understood relatively, or as bounded that which is unbounded. In a word, Sarsi has created an incomplete dichotomy (as logicians call this error) when he divided visible objects into "far" and "near" without assigning limits and boundaries between these. He has made the same mistake as a person who should say, "Everything in the world is either large or small." This proposition is neither true nor false, and neither is the proposition "objects are either near or far." From indeterminacy of this sort it will come about that the same objects may be called "quite close" and "very remote"; that the closer may be called "distant" and the farther "close"; that the larger may be called "small" and the smaller "large." Thus one may say "This is a very small hill," and "this is a very large diamond." A courier calls the trip from Rome to Naples very short, while a great lady grieves that her house is so far from the church.

In order to avoid equivocation Sarsi needed to give his classification at least three parts, and say: "Of visible objects, some are near, some far, and others are situated at a medium distance." Nor should he even stop there; he should give an exact determination of this limit, saying for example: "I call 'medium' a distance of one league; 'far,' that which is more than one league; and 'near,' that which is less." I fail to see why he did not do this, unless it was that he realized his case would be stronger if he advanced it by cleverly juggling equivocations in front of the simpleminded than by reasoning it soundly for the more intelligent. Well, it truly is a great advantage to have one's bread buttered on both sides, and to be able to say: "Because the fixed stars are distant, they are not much magnified, whereas the moon is, because it is close," and then to say, if necessity arises, "Objects in a room, being close, are magnified a great deal, but the moon, because it is distant, is little enlarged."

Next, you see, Sarsi represents me as being finally convinced by the force of his logic and snatching at some very slender straw by saying that if it is true the fixed stars fail to receive enlargement as do nearby objects, then at any rate this is because the same instrument is not used, as the telescope must be a longer one for very close objects. He adds, with a "get thee hence," that I am seizing at trifles. But it is you, Sig. Sarsi, and not I who take refuge in these minutiae and in "at any rate." It was you who had to say that in the very subtle concepts of geometry "at any rate", the fixed stars require more shortening of the telescope than does the moon. Later it turned out that if the moon were magnified one thousand times, the fixed stars would be magnified nine hundred and ninety-nine, whereas to support your position they could not be allowed to be enlarged by even one-half. This is indeed resorting to "at any rate." It is like insisting that something is still a serpent when, scotched

and trampled, it has no longer any life left outside the tip of its tail, which goes on twitching to fool the passersby into thinking it is still healthy and strong.

It is perfectly true that the lengthened telescope is a "different" instrument from what it was before, and this was essential to our point. Sarsi would not have thought otherwise if he had not equivocated from the subject matter of our meaning to the form of our argument, as may easily be shown from the very example he himself uses. I ask Sarsi why it is that some organ pipes produce deep tones and some high. Will he say that this comes about because they are made of different materials? Surely not; they are all of lead. They sound different tones because they are of different lengths; and as to the material, this plays no part whatever in the formation of the sound. Some pipes are made of wood, some of pewter, some of lead, some of silver, and some of paper, but all will sound in unison when their lengths and sizes are equal. But on the other hand one may make now a larger and now a smaller tube with the same quantity of material, say the same five pounds of lead, and form different notes from it. With regard to the production of sound those instruments are different which are of different sizes, not those which are of different materials. Now if by melting down one pipe and remolding the same lead we make a new tube that is longer, and therefore of lower pitch, will Sarsi refuse to grant that this is a different pipe from the first? I think he will not. And if we find a way to make this longer tube without melting down the shorter, would not this come to the same thing? Surely it would. The method will be to make the tube in two pieces, one inserted in the other. This may be lengthened and shortened at will, making diverse pipes which will produce different notes; and such is the construction of the trombone. The strings of a harp are all of the same material, but they produce different sounds because they are of various

lengths. On a lute, one string will do what many strings on a harp will do; for in fingering the lute the sound is drawn now from one part of the string and now from another, which is the same as lengthening and shortening it, and making of it different strings so far as relates to the production of sound. The same may be said of the tube of the throat, which, varying in length and breadth, accommodates itself to the formation of various notes and may be said to become various tubes. Now since a greater or less enlargement depends not upon the material of a telescope but upon its shape, the tube constitutes different instruments when the same material is used but the separation of the lenses is altered. . . .

At the end of this argument Sarsi says that a telescope which is now long and now short may be called "the same instrument, but differently applied." If I am not mistaken, this is a quibble, and it seems to me that matters stand quite the opposite—the instrument is altered while its application remains the same. The same instrument is said to be differently applied when it is employed for different uses without any alteration; thus the anchor was the same when used by the pilot to secure the ship and when employed by Orlando to catch a whale[12], but it was differently applied. In our case the reverse is true, for the use of a telescope is always the same, being invariably applied to looking at things, whereas the instrument is varied in an essential respect by altering the interval between its lenses. This makes Sarsi's quibble apparent.

Next Sarsi patches together an argument out of various fragments of propositions designed to prove that the comet was situated between the moon and the sun. Guiducci and I may concede the whole thing to him without prejudice, as we have never said anything about the location of the comet, nor have we denied that it might have been beyond the moon. We

merely said that the proofs thus far set forth by other authors are not free from objections. Sarsi would fail to remove these objections no matter how many new proofs of his own he added, even if they were themselves conclusive. . . . Still, since I like to see mysterious things brought to light, and since I wish to discover the truth, I shall consider his argument; and for a clearer understanding let me first reduce it to as few words as possible.

Sarsi says he has it from my *Starry Messenger* that the fixed stars are widely irradiated with a fulgor which is not real but only apparent, as they shine with their own light; that the planets, having no light of their own, are not similarly irradiated- especially the moon, Jupiter, and Saturn, which are seen to be almost devoid of any such splendor; and that Venus, Mercury, and Mars, though they have no light of their own, are nevertheless irradiated by reason of their proximity to the sun and their consequent bright illumination by it. He goes on to say that in my opinion a comet receives its light from the sun, and he adds that he himself and other reputable authors for a while regarded the comet as a planet. Hence they reasoned about it as about the other planets, to the effect that the closer Of these to the sun are the more irradiated and consequently are less enlarged when observed through the telescope. Now, since the comet was enlarged little more than Mercury and much less than the moon (he says), it might be very reasonably concluded that it was not much farther from the sun than Mercury is, and very much closer to the sun than to the moon. This is his argument, which so smoothly fits his needs and so neatly assists him that it almost looks as if his conclusion had been made before his premises, and the latter depended upon the former instead of vice versa. It is as if the premises had been prepared not by the bounty of nature but by the precision of the subtlest art. But let us see how conclusive they are.

First of all, it is quite false that I said in my *Starry Messenger* that Jupiter and Saturn have little or no irradiation, while Mars and Venus and Mercury are grandly crowned with rays. It was the moon alone that I sequestered from the rest of the stars and planets.

Second, I am not so sure that in order to make a comet a quasi-planet, and as such to deck it out in the attributes of other planets, it is sufficient for Sarsi or his teacher to regard it as one and so name it. If their opinions and their voices have the power of calling into existence the things they name, then I beg them to do me the favor of naming a lot of old hardware I have about my house, -gold." But names aside, what attribute induced them to regard the comet as a quasi-planet for a time? That it shone like other planets? But what cloud, what smoke, what wood, what wall, what mountain, touched by the sun does not shine equally? Sarsi has seen it proved in my *Starry Messenger* that the earth itself shines more brightly than the moon. And why should I speak of the comet as shining like a planet? I myself believe that the light of a comet may be so weak and its material so thin and rare that if anyone could get close enough to it he would completely lose it from view, as happens with some fires which glow on earth and are seen only at night and from afar, being lost when close at hand. Thus also we see distant clouds as sharply bounded, but later, from close by, they show no more than a misty shadowiness, so indefinitely bounded that a person entering within them will fail to distinguish their limits or to separate them from the surrounding air. . . . Comets may be dissolved in a few days, and they are not of a circular and bounded shape, but confused and indistinct-indicating that their material is thinner and more tenuous than fog or smoke. In a word, a comet is more like a toy planet than the real thing.

Up to this point Sarsi has gone along arbitrarily shaping his premises to fit the conclusions he meant to prove; now it seems to me that he proceeds to shape conclusions for the purpose of opposing them to Guiducci and mine, for they are certainly different from those set forth in the *Discourse*, or at least they are differently construed. That the comet was a mere image and appearance was never positively affirmed by us; it was merely raised as a question and offered for the consideration of philosophers, along with various arguments and conjectures that appeared suitable to show them this possibility. Here are Guiducci's words: "I do not say positively that a comet is formed in this way, but I do say that just as doubts exist concerning this, so doubts exist concerning the origins suggested by other authors; and if they claim to have established their ideas beyond doubt, they are under an obligation to show that this (and any other theory) is vain and foolish."

Once more distorting things, Sarsi represents us as having definitely declared that the motion of a comet must necessarily be straight and perpendicular to the earth's surface - a thing which was not said in that way at all, but was merely brought under consideration as explaining the observed changes in position of the comet more simply and in better agreement with the appearances. The notion was put forth so temperately by Guiducci that at the end he said, "Hence we must content ourselves with what little we can conjecture thus among shadows." Sarsi, however, has attempted to represent me as firmly believing these opinions, and himself as being able to annihilate them. Well, if he succeeds I shall be the more obliged to him, as in the future I shall have one less theory to worry about when I set my mind to philosophizing on such matters. But since it seems to me that there is still some life left in Guiducci's conjectures, I shall make a few remarks upon the strength of Sarsi's refutations.

Attacking the first conclusion with great boldness, he says that to anyone who once looked at the comet, no other argument is necessary to prove the nature of its light, for by comparison with other true lights it clearly showed itself to be real and not spurious. Your Excellency will note the great confidence which Sarsi places in the sense of sight, deeming it impossible for us to be deceived by a spurious object whenever that may be set beside a real one. I confess that I do not possess such a perfect faculty of discrimination. I am more like the monkey that firmly believed he saw another monkey in a mirror, and the image seemed so real and alive to him that he discovered his error only after running behind the glass several times to catch the other monkey.

Assuming that what Sarsi sees in his mirror is not a true and real man at all, but just an image like those which the rest of us see there, I should like to know the visual differences by which he so readily distinguishes the real from the spurious. I have often been in some room with closed shutters and seen on the wall a reflection of sunlight coming through some tiny hole; and so far as vision could determine, it seemed to be a star no less bright than Venus. When we walk over a field into the sunlight, thousands of straws and pebbles that are smooth or moistened will reflect the sun in the aspect of the most brilliant stars. Sarsi has but to spit upon the ground and undoubtedly he will see the appearance of a natural star when he looks from the point toward which the sun's rays are reflected. And any object placed at a great distance and struck by the sun will appear as a star, particularly if it is placed so high as to be visible at nightfall when other stars appear. Who could distinguish between the moon seen in daylight and a cloud touched by the sun, were it not for differences of shape and size? If simple appearance can determine the essence of a thing, Sarsi must be-

lieve that the sun, the moon, and the stars seen in still water are true suns, real moons, and veritable stars.

Long experience has taught me this about the status of mankind with regard to matters requiring thought: the less people know and understand about them, the more positively they attempt to argue concerning them, while on the other hand to know and understand a multitude of things renders men cautious in passing judgment upon anything new.

Once upon a time, in a very lonely place, there lived a man endowed by nature with extraordinary curiosity and a very penetrating mind. For a pastime he raised birds, whose songs he much enjoyed; and he observed with great admiration the happy contrivance by which they could transform at will the very air they breathed into a variety of sweet songs.

One night this man chanced to hear a delicate song close to his house, and being unable to connect it with anything but some small bird he set out to capture it. When he arrived at a road he found a shepherd boy who was blowing into a kind of hollow stick while moving his fingers about on the wood, thus drawing from it a variety of notes similar to those of a bird, though by quite a different method. Puzzled, but impelled by his natural curiosity, he gave the boy a calf in exchange for this flute and returned to solitude. But realizing that if he had not chanced to meet the boy he would never have learned of the existence of a new method of forming musical notes and the sweetest songs, he decided to travel to distant places in the hope of meeting with some new adventure.

The very next day he happened to pass by a small hut within which he heard similar tones; and in order to see whether this was a flute or a bird he went inside. There he found a small boy who was holding a bow in his right hand and sawing upon

some fibers stretched over a hollowed piece of wood. The left hand supported the instrument, and the fingers of the boy were moving so that he drew from this a variety of notes, and most melodious ones too, without any blowing. Now you who participate in this man's thoughts and share his curiosity may judge of his astonishment. Yet finding himself now to have two unanticipated ways of producing notes and melodies, he began to perceive that still others might exist.

His amazement was increased when upon entering a temple he heard a sound, and upon looking behind the gates discovered that this had come from the hinges and fastenings as he opened it. Another time, led by curiosity, he entered an inn expecting to see someone lightly bowing the strings of a violin, and instead he saw a man rubbing his fingertip around the rim of a goblet and drawing forth a pleasant tone from that. Then he observed that wasps, mosquitoes, and flies do not form single notes by breathing, as did the birds, but produce their steady sounds by swift beating of their wings. And as his wonder grew, his conviction proportionately diminished that he knew how sounds were produced; nor would all his previous experiences have sufficed to teach him or even allow him to believe that crickets derive their sweet and sonorous shrilling by scraping their wings together, particularly as they cannot fly at all.

Well, after this man had come to believe that no more ways of forming tones could possibly exist- after having observed, in addition to all the things already mentioned, a variety of organs, trumpets, fifes, stringed instruments, and even that little tongue of iron which is placed between the teeth and which makes strange use of the oral cavity for sounding box and of the breath for vehicle of sound when, I say, this man believed he had seen everything, he suddenly found himself once more plunged deeper into ignorance and bafflement than ever. For

having captured in his hands a cicada, he failed to diminish its strident noise either by closing its mouth or stopping its wings, yet he could not see it move the scales that covered its body, Or any other thing. At last he lifted up the armor of its chest and there he saw some thin hard ligaments beneath; thinking the sound might come from their vibration, he decided to break them in order to silence it. But nothing happened until his needle drove too deep, and transfixing the creature he took away its life with its voice, so that he was still unable to determine whether the song had originated in those ligaments. And by this experience his knowledge was reduced to diffidence, so that when asked how sounds were created he used to answer tolerantly that although he knew a few ways, he was sure that many more existed which were not only unknown but unimaginable.

I could illustrate with many more examples Nature's bounty in producing her effects, as she employs means we could never think of without our senses and our experiences to teach them to us-and sometimes even these are insufficient to remedy our lack of understanding. So I should not be condemned for being unable to determine precisely the way in which comets are produced, especially in view of the fact that I have never boasted that I could do this, knowing that they may originate in some manner that is far beyond our power of imagination. The difficulty of comprehending how the cicada forms its song even when we have it singing to us right in our hands ought to be more than enough to excuse us for not knowing how comets are formed at such immense distances. Let us therefore go no further than our original intention, which was to set forth the questions that appeared to upset the old- theories, and to propose a few new ideas.

Sarsi should not have undue trouble in understanding that even if all the material involved in a comet is equally illuminated, sunlight might be reflected to the eyes of one particular observer only from some particular part of it. . . . In order to explain a point that is of the utmost importance, and perhaps to give someone (I shall not say Sarsi) a new idea, imagine yourself to be at the seashore when the sun is descending in the west. You will see a bright reflection of the sun on the surface of the sea near the line passing vertically through the solar disk. It will not spread over a large area; indeed, if the water is quite calm you will see a pure image of the sun as sharply bounded as in a mirror. Now let a slight breeze spring up and ruffle the surface of the water, when you will see the image of the sun begin to break up into many pieces and extend into a wider area. If you were close by, you might be able to distinguish the broken pieces of this image from one another. But from a greater distance you would not see that separation because of the narrow gaps between the pieces, or because the great brilliance of the shining parts would cause them to intermingle and behave as do several fires close together which from afar seem to be one. If the ruffling goes on to form greater and greater waves, the multitude of mirrors from which the image of the sun will be reflected will extend over wider and wider spaces. Now withdraw to a greater distance and climb some hill or other prominence in order to see the water better; the lighted field will now appear to be one and continuous. From a very high mountain about sixty miles from the Bay of Leghorn, on a clear and windy day about an hour before sunset, I have seen a very bright strip spreading out on both sides of the sun and extending for tens or perhaps hundreds of miles, this being a reflection of sunlight identical with those just described.

Now let Sarsi imagine most of the sea on both sides to be removed, leaving only a breadth of two or three miles in the center, pointing toward the sun. This would surely be illuminated, but it would not change place with every motion of the observer to one side, unless perhaps he were to move several miles. . . . Even then the image would not move with the same motion as the observer, but the whole of it would move so that its center would always be in line with the sun. . . .

Here I should like to suggest something that has occurred to me as a solution of a problem that concerns sailors. When they are experienced, they sometimes recognize that a wind will approach before long from a certain direction, and they say that a sure sign of this is to see the air brighter in that direction than it would normally be. Might this not come about from a wind in that quarter disturbing the waves at a distance? From such waves, as from many mirrors extending over a wide area, would result a much brighter reflection of the sunlight than would occur if the sea were calm. In turn, that region of the vapor-laden air would be made brighter by this new light and by the diffusion of that reflection. Such air, being high, would send some reflection of light to the sailors' eyes while they, being low and far off, would be unable to catch the primary reflection from that part of the sea that is already being ruffled by a wind some twenty or thirty miles away. Thus they might perceive and predict this wind from a distance.

It is true that smooth and polished surfaces such as those of mirrors send a strong reflection of the sun's light to us, so much so that we can hardly look at these without injury to the eyes; but it is also true that surfaces which are not so smooth make some reflection, less powerful in inverse ratio to the smoothness. Now Your Excellency may decide whether the brilliance of a comet belongs among things which dazzle the vision, or

among those so feeble as not to offend the eyes; then you may judge whether a mirror-like surface is required for its production or whether one much less smooth will suffice.

I want to teach Sarsi a method of representing a reflection very like a comet. Take a clean carafe and hold a lighted candle not far from it, and you will see in its surface a tiny image of the light, very sharp and bright. Next with the tip of your finger take a small quantity of any oily material that will adhere to the glass, and spread a thin coating where the image appears, dimming the surface a little. The image will promptly be dimmed too. Now turn the carafe so that the image emerges from the oiled spot and just touches its edge, and rub your finger once right across the oiled part. Instantly you will see a ray formed in imitation of the tail of a comet, cutting right across the place where you rubbed your finger. If you rub across this again, the ray will be led off in another direction. This happens because the skin on the ball of the finger is not smooth, but is marked with certain twisted lines which we use in sensing the slightest irregularity of objects by touch. These leave some tracks in moving over the oily surface, and the reflection of light takes place in their edges, and since they are numerous and regularly arranged this forms a light stripe. The image may be placed at the head of this stripe by moving the carafe, and will then appear brighter than the tail. The same effect may be produced by fogging the glass with the breath instead of using oil. But if you ever suggest this little game to Sarsi, and if he protests at great length, then I beg Your Excellency to tell him that I do not mean to imply by this that there is in the sky a huge carafe, and someone oiling it with his finger, thus forming a comet; I merely offer this as an example of Nature's bounty and variety of methods for producing her effects. I could offer many, and doubtless there are still others that we cannot imagine.

Only too clearly does Sarsi show his desire to strip me completely of any praise. Not content with having disproved our reasoning set forth to explain the fact that the tails of comets sometimes appear to be bent in an arc, he adds that nothing new was achieved by me in this, as it had all been published long ago, and then refuted, by Johann Kepler. In the mind of the reader who goes no more deeply than Sarsi's account, the idea will remain that I am not only a thief of other men's ideas, but a petty, mean thief at that, who goes about pilfering even what has been refuted. And who knows; perhaps in Sarsi's eyes the pettiness of the theft does not render me more blameworthy than I would be if I had bravely applied myself to greater thefts. If, instead of filching some trifle, I had more nobly set myself to search out books by some reputable author not as well known in these parts, and had then tried to suppress his name and attribute all his labors to myself, perhaps Sarsi would consider such an enterprise as grand and heroic as the other seems to him cowardly and abject. Well, I lack the stomach for this and I freely confess this cowardice. But poor as I am in courage and power, I am at least upright. I will not carry this undeserved wound, and I shall write frankly what you, Sarsi, have left out; and since I cannot divine what passion gave rise to the omission, I leave it to you to explain that later in your apology. . . .

Kepler tried to give a reason for the tail being really curved; Guiducci supposes it to be really straight, and seeks a cause for its bent appearance. Kepler reduced his reason to a diversity in refraction of the sun's rays occurring in the material from which the comet's tail is formed. . . . Guiducci introduces a refraction not of the sun's rays, but of the comet's image, and not in the material of the comet but in the vaporous sphere which surrounds the earth. Hence the cause, the material, the place, and the method all differ between the two, and no correspon-

dence exists except in both authors' use of the word "refraction." . . . Kepler has always been known to me as a man no less frank and honest than intelligent and learned. I am sure that he would admit our statement to be entirely different from the one which he refuted[13].

Before I proceed let me tell Sarsi that it is not I who want the sky to have the noblest shape because of its being the noblest body; it is Aristotle himself, against whose views Sig. Guiducci is arguing. For my own part, never having read the pedigrees and patents of nobility of shapes, I do not know which of them are more and which are less noble, nor do I know their rank in perfection. I believe that in a way all shapes are ancient and noble; or, to put it better, that none of them are noble and perfect, or ignoble and imperfect, except in so far as for building walls a square shape is more perfect than the circular, and for wagon wheels the circle is more perfect than the triangle.

Sarsi says that abundant arguments have been supplied by me for proving the roughness of the interior surface of the sky, since I will have it that the moon and other planets -bodies which are also celestial, and even more noble and perfect than the sky itself-are mountainous and rough. And if that is so, he asks, why shouldn't irregularity exist also in the shape of the sky? For an answer to this let him put down whatever it is that he would reply to a man who argued that the surface of the ocean should be bony and scaly, since the fish which inhabit it are.

As to his question why the moon is not smooth, I reply that it and all the other planets are inherently dark and shine by light from the sun. Hence they must have rough surfaces, for if they were smooth as mirrors no reflection would reach us from them and they would be quite invisible to us. . . . On the other hand almost equal disorder would ensue if the celestial orbs

were of a solid substance and had surfaces not perfectly smooth, since then refractions would be disturbed and the movements, shapes, and projections of rays from the planets would be most confused and irregular.

Sarsi tries to attribute to me something quite false; namely, that the water in a bowl remains as motionless as air when the bowl is rotated. Well, I am not surprised that he says this, for any man who is constantly reversing the sense of things that others have written and published will think it even more permissible to alter things he admits he has only on hearsay. Just the same, I do not consider it within the bounds of good breeding to print something that a man has merely heard from his neighbors, and the more so when (either deliberately or as a result of misunderstanding) his report is quite different from what was actually said. It is my affair to print my ideas for the world to read, Sarsi, not yours. And if in the course of an argument a man has said something foolish, as indeed does happen sometimes, why must you rush into print with it, and thus deprive him of the opportunity to think it over more carefully and amend his own error, preserving mastery over his own mind and pen?

What Sarsi may have heard-but, from what I see, did not understand very well- was a certain experiment which I exhibited to some gentlemen there at Rome, and perhaps at the very house of Your Excellency, in partial explanation and partial refutation of the "third motion"[14] attributed by Copernicus to the earth. This extra rotation, opposite in direction to all other celestial motions, appeared to many a most improbable thing, and one that upset the whole Copernican system. . . . I used to remove the difficulty by showing that such a phenomenon was far from improbable, and indeed would be in accordance with Nature and practically forced to occur. For any body resting

freely in a thin and fluid medium will, when transported along the circumference of a large circle, spontaneously acquire a rotation in a direction contrary to the larger movement. The phenomenon was seen by taking in one's hands a bowl of water and placing in it a floating ball. Then turning about on the toe with this hand extended, one sees the ball turn on its axis in the opposite direction, and complete this revolution in the same time as one's own. In this way the wonder was removed, and in place of it one would be astonished if the earth were not to acquire a contrary rotation when assumed to be a body suspended in a fluid medium and going around a large circle in a period of one year. What I said was designed to remove a difficulty attributed to the Copernican system, and I later added that anyone who would reflect upon the matter more carefully would see that Copernicus had spoken falsely when he attributed his "third motion" to the earth, since this would not be a motion at all, but a kind of rest. It is certainly true that to the person holding the bowl such a ball appears to move with respect to himself and to the bowl, and to turn upon its axis. But with respect to the wan (or any other external thing) the ball does not turn at all, and does not change its tilt, and any point upon it will continue to point toward the same distant object.

That is what I asserted, and you see it is very different from what Sarsi relates. This experiment, and perhaps others, may have induced someone who was present at our discussions to attribute to me what Sarsi mentions next that is, a certain natural talent of mine for explaining by means of simple and obvious things others which are more difficult and abstruse. He does not deny me praise for this, but I think this comes from courtesy rather than from his true feelings, for so far as I can see he is not easily persuaded of any talent on my part.

Well, now you have seen a great expenditure of words on the part of Sarsi and myself to determine whether the solid hollow of the lunar orb [15] (which does not exist in Nature), moving around (as it never has), sweeps along with it the element of fire (which is not proved to exist) and along with this the exhalations which in turn kindle the material of comets- a material whose location we cannot establish with certainty, and which we are positive is not combustible Sarsi here puts me in mind of the saying of a very witty poet:

*By Orlando's sword, which they have not
And perhaps which they never shall have
These blows of blind men have been given...* [16]

Sarsi next wants to make Guiducci agree with Aristotle, and to show that they have both stated the same conclusion when one of them says that motion is the cause of heat, and the other says that the cause is not motion but the brisk rubbing of two hard bodies. And since it is Guiducci's statement that is correct, Sarsi interprets the other one by saying that if indeed motion, as motion, is not the cause of heat, nevertheless friction is not created without motion, so that at least derivatively we may say that motion is the cause. But if that is what Aristotle meant, why didn't he say "friction"? When a man can say definitely what he means by using a simple and appropriate word, why employ an inappropriate one that requires qualification and ultimately becomes transformed into something quite different? But assuming that this was Aristotle's meaning, it still differs from Guiducci's; for to Aristotle any rubbing of bodies would suffice, even of tenuous ones or of the air itself, whereas Guiducci requires two solid bodies, for he considers that trying to pulverize the air is as great a waste of time as grinding water in the proverbial mortar.

It is my opinion that the original proposition may be quite true, taken in the simplest sense of the words it contains, and that perhaps it came from some good philosophical school of antiquity, but that Aristotle failed to fathom the mind of the ancients who propounded it, and deduced his false conception accordingly. Nor would this be the only proposition that is inherently true but is understood by the Peripatetics in a false sense. Of this I shall say more some other time...

Really, I do not believe that Guiducci would say (as Sarsi pretends) that in order to become hot, bodies must first be rarefied, and that rarefaction diminishes them, and that the thinner parts fly away. . . . In the process under discussion one must consider on the one hand the body that is to produce the heat, and on the other hand the body which is to receive heat. Sarsi thinks Guiducci would require the excitation and the consumption of parts to take place in the body receiving the heat, whereas I believe the body that is diminished would be the one that generates heat...

When Sarsi heated his bit of copper by pounding it many times, I can well believe that he detected no diminution in its weight even by the most delicate balance. But I do not think on that account that none can have taken place; it may have been too minute to be perceptible any balance whatever. Let me ask Sarsi whether he thinks any difference of weight could be detected in a silver button before and after it is gilded. He must say no, as we see gold reduced to such thin leaf that it will sustain itself upon the quiet air and drop with extreme slowness; and with such gold any metal may be gilded. Now this button may be used two or three months before the gilding will wear off, and yet since the gilt is ultimately consumed it must be diminishing every day and even every hour.

Or take a ball of musk and carry it with you for a fortnight; it will fill with odor a thousand rooms and streets which cannot happen without some diminution of material; yet you will find none by weighing it. Thus Sarsi may see that insensible reductions of weight do occur from consumption over a period of months on end, let alone the few minutes he may have persisted in hammering away at his bit of copper. And precisely by this difference we may measure the sensitivity of the assayer's balance in comparison with that of the philosopher's steelyard. And note that the tenuous material which produces heat is even more subtle than that which causes odor, for the latter cannot leak through a glass container, whereas the material of heat makes its way through any substance.

Here Sarsi objects, saying, "If testing with the balance is insufficient to reveal so small a consumption, how will you have it shown?" The objection is ingenious, though not so profound as to be incapable of solution by a little physical logic. Here are the steps of the argument. Of bodies that are rubbed together, some are certainly not consumed, others are quite perceptibly consumed, and still others are indeed consumed, but insensibly. Our senses show us that those which are not consumed at all by rubbing, such as two polished mirrors, are not heated by rubbing, either. We know that those are heated which are perceptibly consumed, as iron when it is being filed. Therefore when we are in doubt whether things are consumed by rubbing we may believe that they are if they are sensibly heated, while those which are not heated may be said not to be consumed.

Before going on I wish to add something for Sarsi's instruction. To say, "This body has not lost weight in the balance, and hence no part of it has been consumed," is fallacious reasoning. It is possible for part of something to be consumed and yet for it to

gain weight instead of losing it. This will happen when the specific gravity of that which is consumed is less than that of the medium in which it is being weighed. For instance a very knotty piece of wood taken from near the root may sink when placed in water. Under water let it weigh four ounces. Now cut away some of the lighter parts and leave the knotty portions; the former, being of less specific gravity than the water, gave some support to the entire mass. Hence I say it may happen that the parts left will weigh more in water than the entire piece of wood did. Now it may be that in filing or rubbing together pieces of iron, sticks, or stones, some particles of material less dense than air become separated from them; if nothing else is removed, this would leave the body heavier than before. What I say is not entirely improbable, or merely a refuge which will leave the adversary some trouble in refuting it. For if you carefully observe what happens in breaking glass or stones, you will see some perceptible fumes emerge and rise high in the air, which must be lighter than air. I first noticed this when breaking the corners off a piece of glass and rounding it with a key or some other piece of iron. Besides the little pieces of various sizes which flew off and fell to the ground, I saw a subtle smoke always arising. And apart from what we see, what we smell is a clear sign that some sulfurous or bituminous parts may be ascending which remain invisible but make themselves known by their odor.

Let Sarsi see from this how superficial his philosophizing is, except in appearance. But let him not think he can reply with additional limitations, distinctions, logical technicalities, philosophical jargon, and other idle words, for I assure him that in sustaining one error he will commit a hundred others that are more serious, and produce always greater follies in his camp. . . . Why must I attribute lightning to vehement motion when I see that fire is not excited without the rubbing of solid bodies

which do not exist among the clouds? And heat lightning occurs when no commotion is perceived in the air or in clouds. This theory of his, I think, is no more inherently true than the statements of these same philosophers when they attribute the rumbling of thunder to the tearing apart of clouds, or to their knocking together. Actually in the brilliance of the brightest flashes of lightning not the slightest movement or change of shape is discerned in the clouds, and this is just when thunder is being formed. I pass over in silence the fact that these philosophers say that no noise is produced by the striking of wool or hemp, and require the percussion of solid bodies to make sound; and then again when it suits their purposes they assert that mists and clouds striking together will render the loudest of all sounds. Tractable and benign indeed is such philosophy, so pleasantly and readily adapting itself to men's needs and wishes!

Now let us go on to examine the arrows in flight and the lead balls hurled by catapults which are supposed to be set afire and melted in the air, according to the authority of Aristotle, many famous poets, other philosophers, and historians. But it is wrong to say, as Sarsi does, that Guiducci and I would laugh and joke at the experiences adduced by Aristotle. We merely do not believe that a cold arrow shot from a bow can take fire in the air; rather, we think that if an arrow were shot when afire, it would cool down more quickly than it would if it were held still. This is not derision; it is simply the statement of our opinion.

Sarsi goes on to say that since this experience of Aristotle's has failed to convince us, many other great men also have written things of the same sort. To this I reply that if in order to refute Aristotle's statement we are obliged to represent that no other men have believed it, then nobody on earth can ever refute it,

since nothing can make those who have believed it not believe it. But it is news to me that any man would actually put the testimony of writers ahead of what experience shows him. To adduce more witnesses serves no purpose, Sarsi, for we have never denied that such things have been written and believed. We did say they are false, but so far as authority is concerned yours alone is as effective as an army's in rendering the events true or false. You take your stand on the authority of many poets against our experiments. I reply that if those poets could be present at our experiments they would change their views, and without disgrace they could say they had been writing hyperbolically-or even admit they had been wrong.

Well, if we cannot have the presence of your poets (who, as I say, would yield to experience), we do have at hand archers and catapultists, and you may see for yourself whether citing your authorities to them can strengthen their arms to such an extent that the arrows they shoot and the lead balls they hurl will take fire and melt in the air. In that way you will be able to find out just how much force human authority has upon the facts of Nature, which remains deaf and inexorable to our wishes. You say there is no longer an Acastes or a Mezentius [17] or other mighty paladin? I shall be content to have you shoot an arrow not with a simple longbow, but with the stoutest steel crossbow, or use a catapult drawn by lovers and windlasses that could not be managed by thirty of your ancient heroes. Shoot ten arrows, or a hundred; and if it ever happens that on one of them the feathers so much as slightly tan-let alone its shaft taking fire or its steel tip melting- I shall not only concede the argument but forfeit your respect, which I regard so highly. . . .

I cannot but be astonished that Sarsi should persist in trying to prove by means of witnesses something that I may see for my-

self at any time by means of experiment. Witnesses are examined in doubtful matters which are past and transient, not in those which are actual and present. A judge must seek by means of witnesses to determine whether Peter injured John last night, but not whether John was injured, since the judge can see that for himself. But even in conclusions which can be known only by reasoning, I say that the testimony of many has little more value than that of few, since the number of people who reason well in complicated matters is much smaller than that of those who reason badly. If reasoning were like hauling I should agree that several reasoners would be worth more than one, just as several horses can haul more sacks of grain than one can. But reasoning is like racing, and not like hauling, and a single Arabian steed can outrun a hundred plowhorses. So when Sarsi brings in this multitude of authors it appears to me that instead of strengthening his conclusion he merely ennobles our case by showing that we have outreasoned many men of great reputation.

If Sarsi wants me to believe with Suidas[18] that the Babylonians cooked their eggs by whirling them in slings, I shall do so; but I must say that the cause of this effect was very different from what he suggests. To discover the true cause I reason as follows: "if we do not achieve an effect which others formerly achieved, then it must be that in our operations we lack something that produced their success. And if there is just one single thing we lack, then that alone can be the true cause. Now we do not lack eggs, nor slings, nor sturdy fellows to whirl them; yet our eggs do not cook, but merely cool down faster if they happen to be hot. And since nothing is lacking to us except being Babylonians, then being Babylonians is the cause of the hardening of eggs, and not friction of the air." And this is what I wished to discover. Is it possible that Sarsi has never observed the coolness produced on his face by the continual change of

air when he is riding post? If he has, then how can he prefer to believe things related by other men as having happened two thousand years ago in Babylon rather than present events which he himself experiences? . . .

Sarsi says he does not wish to be numbered among those who affront the sages by disbelieving and contradicting them. I say I do not wish to be counted as an ignoramus and an ingrate toward Nature and toward God; for if they have given me my senses and my reason, why should I defer such great gifts to the errors of some man? Why should I believe blindly and stupidly what I wish to believe, and subject the freedom of my intellect to someone else who is just as liable to error as I am? [...]

Finally Sarsi is reduced to saying with Aristotle that if the air ever happened to be abundantly filled with warm exhalations in the presence of various other requisites, then leaden balls would melt in the air when shot from muskets or thrown by slings. This must have been the state of the air when the Babylonians were cooking their eggs. . . . and at such times things must go very pleasantly for people who are being shot But, Sarsi says, since to find such conditions is a matter of chance and one that does not occur too frequently, we must resort to experiments for settling such questions. So, Sarsi, if experiments are performed thousands of times at all seasons and in every place without once producing the effects mentioned by your philosophers, poets, and historians, this will mean nothing and we must believe -their words rather than our own eyes? But what if I find for you a state of, the air that has all the conditions you say are required, and till the egg is not cooked nor the lead ball destroyed? Alas! I should be wasting my efforts, ... for all too prudently you have secured your position by saying that "there is needed for this effect violent mo-

tion, a great quantity of exhalations, a highly attenuated material, and whatever else conduces to it." This "whatever else" is what beats me, and gives you a blessed harbor, a sanctuary completely secure.

What I had in mind, though, was to suspend our argument and wait quietly until some new comet came along. I imagined that while this lasted you and Aristotle would grant me that since the air was then properly disposed for kindling the comet, it would likewise be suitable for melting lead balls and cooking eggs, inasmuch as you seem to require the same condition for both effects. It was then that I would have had us set to work with our slings, eggs, bows, muskets, and cannons so that we might clear up this matter for ourselves. And even without waiting for a comet we might find an opportune time when in midsummer the air flashes with heat lightning, as you assign all these "burnings" to a single cause. But I suppose that when you failed to behold a melting of lead balls or even the cooking of eggs under such conditions you would still fail to give in; you would say that this "whatever else conduces to the effect" was lacking. If you would only tell me what this "whatever else" is, I should endeavor to provide it. But if not I shall have to abandon my little scheme, though I do believe it would turn out against you. . . .

It now remains for me to tell Your Excellency, as I promised, some thoughts of mine about the proposition "motion is the cause of heat," and to show in what sense this may be true. But first I must consider what it is that we call heat, as I suspect that people in general have a concept of this which is very remote from the truth. For they believe that heat is a real phenomenon or property, or quality, which actually resides in the material by which we feel ourselves warmed. Now I say that whenever I conceive any material or corporeal substance, I

immediately feel the need to think of it as bounded, and as having this or that shape; as being large or small in relation to other things, and in some specific place at any given time; as being in motion or at rest; as touching or not touching some other body; and as being one in number, or few, or many. From these conditions I cannot separate such a substance by any stretch of my imagination. But that it must be white or red, bitter or sweet, noisy or silent, and of sweet or foul odor, my mind does not feel compelled to bring in as necessary accompaniments. Without the senses as our guides, reason or imagination unaided would probably never arrive at qualities like these. Hence I think that tastes, odors, colors, and so on are no more than mere names so far as the object in which we place them is concerned, and that they reside only in the consciousness. Hence if the living creature were removed, all these qualities would be wiped away and annihilated. But since we have imposed upon them special names, distinct from those of the other and real qualities mentioned previously, we wish to believe that they really exist as actually different from those.

I may be able to make my notion clearer by means of some examples. I move my hand first over a marble statue and then over a living man. To the effect flowing from my hand, this is the same with regard to both objects and my hand; it consists of the primary phenomena of motion and touch, for which we have no further names. But the live body which receives these operations feels different sensations according to the various places touched. When touched upon the soles of the feet, for example, or under the knee or armpit, it feels in addition to the common sensation of touch a sensation on which we have imposed a special name, "tickling." This sensation belongs to us and not to the hand. Anyone would make a serious error if he said that the hand, in addition to the properties of moving and touching, possessed another faculty of "tickling," as if tickling

were a phenomenon that resided in the hand that tickled. A piece of paper or a feather drawn lightly over any part of our bodies performs intrinsically the same operations of moving and touching, but by touching the eye, the nose, or the upper lip it excites in us an almost intolerable titillation, even though elsewhere it is scarcely felt. This titillation belongs entirely to us and not to the feather; if the live and sensitive body were removed it would remain no more than a mere word. I believe that no more solid an existence belongs to many qualities which we have come to attribute to physical bodies-tastes, odors, colors, and many more.

A body which is solid and, so to speak, quite material, when moved in contact with any part of my person produces in me the sensation we call touch. This, though it exists over my entire body, seems to reside principally in the palms of the hands and in the finger tips, by whose means we sense the most minute differences in texture that are not easily distinguished by other parts of our bodies. Some of these sensations are more pleasant to us than others. . . . The sense of touch is more material than the other senses; and, as it arises from the solidity of matter, it seems to be related to the earthly element.

Perhaps the origin of two other senses lies in the fact that there are bodies which constantly dissolve into minute particles, some of which are heavier than air and descend, while others are lighter and rise up. The former may strike upon a certain part of our bodies that is much more sensitive than the skin, which does not feel the invasion of such subtle matter. This is the upper surface of the tongue; here the tiny particles are received, and mixing with and penetrating its moisture, they give rise to tastes, which are sweet or unsavory according to the various shapes, numbers, and speeds of the particles. And those minute particles which rise up may enter by our nostrils

and strike upon some small protuberances which are the instrument of smelling; here likewise their touch and passage is received to our like or dislike according as they have this or that shape, are fast or slow, and are numerous or few. The tongue and nasal passages are providently arranged for these things, as the one extends from below to receive descending particles, and the other is adapted to those which ascend. Perhaps the excitation of tastes may be given a certain analogy to fluids, which descend through air, and odors to fires, which ascend.

Then there remains the air itself, an element available for sounds, which come to us indifferently from below, above, and all sides - for we reside in the air and its movements displace it equally in all directions. The location of the ear is most fittingly accommodated to all positions in space. Sounds are made and heard by us when the air without any special property of "sonority" or "transonority" - is ruffled by a rapid tremor into very minute waves and moves certain cartilages of a tympanum in our ear. External means capable of thus ruffling the air are very numerous, but for the most part they may be reduced to the trembling of some body which pushes the air and disturbs it. Waves are propagated very rapidly in this way, and high tones are produced by frequent waves and low tones by sparse ones.

To excite in us tastes, odors, and sounds I believe that nothing is required in external bodies except shapes, numbers, and slow or rapid movements. I think that if ears, tongues, and noses were removed, shapes and numbers and motions would remain, but not odors or tastes or sounds. The latter, I believe, are nothing more than names when separated from living beings, just as tickling and titillation are nothing but names in the absence of such things as noses and armpits. And as these four senses are related to the four elements, so I believe that vision,

the sense eminent above all others in the proportion of the finite to the infinite, the temporal to the instantaneous, the quantitative to the indivisible, the illuminated to the obscure--that vision, I say, is related to light itself. But of this sensation and the things pertaining to it I pretend to understand but little; and since even a long time would not suffice to explain that trifle, or even to hint at an explanation, I pass this over in silence.

Having shown that many sensations which are supposed to be qualities residing in external objects have no real existence save in us, and outside ourselves are mere names, I now say that I am inclined to believe heat to be of this character. Those materials which produce heat in us and make us feel warmth, which are known by the general name of "fire," would then be a multitude of minute particles having certain shapes and moving with certain velocities. Meeting with our bodies, they penetrate by means of their extreme subtlety, and their touch as felt by us when they pass through our substance is the sensation we call "heat." This is pleasant or unpleasant according to the greater or smaller speed of these particles as they go pricking and penetrating; pleasant when this assists our necessary transpiration, and obnoxious when it causes too great a separation and dissolution of our substance. The operation of fire by means of its particles is merely that in moving it penetrates all bodies, causing their speedy or slow dissolution in proportion to the number and velocity of the fire-corpuscles and the density or tenuity of the bodies. Many materials are such that in their decomposition the greater part of them passes over into additional tiny corpuscles, and this dissolution continues so long as these continue to meet with further matter capable of being so resolved. I do not believe that in addition to shape, number, motion, penetration, and touch there is any other quality in fire corresponding to "heat"; this belongs so intimately to us that

when the live body is taken away, heat becomes no more than a simple name. . . .

Since the presence of fire-corpuscles alone does not suffice to excite heat, but their motion is needed also, it seems to me that one may very reasonably say that motion is the cause of heat. . . . But I hold it to be silly to accept that proposition in the ordinary way, as if a stone or piece of iron or a stick must heat up when moved. The rubbing together and friction of two hard bodies, either by resolving their parts into very subtle flying particles or by opening an exit for the tiny fire-corpuscles within, ultimately sets these in motion; and when they meet our bodies and penetrate them, our conscious mind feels those pleasant or unpleasant sensations which we have named heat, burning, and scalding. And perhaps when such attrition stops at or is confined to the smallest quanta, their motion is temporal and their action calorific only; but when their ultimate and highest resolution into truly indivisible atoms is arrived at, light is created. This may have an instantaneous motion, or rather an instantaneous expansion and diffusion [20] rendering it capable of occupying* immense spaces by its- I know not whether to say its subtlety, its rarity, its immateriality, or some other property which differs from all these and is nameless.

I do not wish, Your Excellency, to engulf myself inadvertently in a boundless sea from which I might never get back to port, nor in trying to solve one difficulty do I wish to give rise to a hundred more, as I fear may have already happened in sailing but this little way from shore. Therefore I shall desist until some more opportune occasion.

Finally I cannot resist speaking about Sarsi's amazement at my hopeless ineptitude in the employment of experiments, inasmuch as he himself errs as badly as a man can in that same activity. You, Sarsi, must show us that an interposed flame would

not suffice to hide the stars. In order to convince us by experiments, you say that if we look through flames at people, firebrands, coals, printed pages, and candles, we shall see all these quite plainly. Did it never enter your head to tell us to try looking at stars? Why did you not say to us at the outset, -Interpose a flame between the eye and some star, and the star will be made neither more nor less visible"? Surely there is no lack of stars in the sky. Now is this to be a skillful and prudent experimentalist?

I ask you whether the comet's flame is like our flames, or whether it has a different nature. If its nature is different, experiments made with our flames are not conclusive. If it is like our flames, then you might have made us look at stars through our flames and left out firebrands, candle-snuffs, and such things. Instead of saying that print may be read through a candle flame, you might have said that a star may be so perceived. . . . You are obliged to kindle a very distant flame as large as a comet and to make us see stars through it. . . . But in order to put you at your ease and give you every advantage, I shall be content with much less. Instead of placing the fire as far away as a comet, I am satisfied with a distance of one hundred yards. In place of the thickness of a comet, merely ten yards will suffice. And since you say the object to be seen gains an advantage from being bright, let it be one of the stars which was visible through the tail of the comet-for you maintain that stars are brighter than any flame.

And now, with all these conditions so advantageous to your cause, if you can make the star visible through the bonfire, I shall admit defeat and place you among the most prudent and expert experimenters in the whole world. But if you fail, I ask no more from you than silence, by which an end will be put to this dispute. And truly that is what I hope will now take place.

NOTES

[1] Cesarini (1595-1624) -as a brilliant man of letters at whose house in Rome Galileo had often debated in favor of Copernicus during his ill-starred visit in 3.615-3.6. He had served as confidential secretary to Pope Gregory XV and was appointed chamberlain by Urban VIII in 1623.

[2] This statement was believed by Scheiner to be unjustly aimed at him, and was probably the source of his disastrous enmity toward Galileo. But Galileo had already spoken of Scheiner in his reference to "attacks under disguises." Here he was probably speaking of another opponent, most likely Jean Tarde, who had published a book on sunspots at Paris while *The Assayer* was being written. Tarde had visited Galileo in 1614 and had discussed sunspots with him personally, yet in his book he completely ignored Galileo's conclusions and appropriated the earlier mistaken ideas of Scheiner. The charge of plagiarism from Galileo's books could not be aimed at Scheiner himself for obvious reasons, but judging from the bitter attack on Galileo in the *Rosa Ursina* and from its author's undoubted role in Galileo's final condemnation, Scheiner believed that to be the intention.

[5] So it was, to all intents and purposes, and most of the manuscript survives in Galileo's handwriting.

[8] Ecclesiastes 1:15.

[9] The reasoning is of course entirely post hoc, and in fact a combination of two convex lenses is much more satisfactory for astronomical purposes. Such telescopes were described by Kepler in 1611, and are said to have been first constructed and used by Scheiner some years later.

[11] Grassi's queries may have been responsible for Galileo's having taken up again his interest in the use of lenses to magnify very small objects. In the early days of the telescope he had experimented with such an application of it, but it was only when writing *The Assayer*

that he altered the lens system and produced a manageable compound microscope. The invention is, of course, contested in favor of several other men about this time.

[12] *Orlando Furioso*, c. xi, 37-38. The translation here is deliberately free. Orlando did not employ the anchor as a fishhook, but used it to prop open the mouth of a sea monster while he entered to kill it.

[13] Grassi had referred to the views which Kepler had set forth in an early optical work, and Galileo rightfully objected to the implication that these views were similar to his own. In 1619, however, Kepler had published a book on comets in which he changed his previous notion and foreshadowed the modern view that the tails of comets consist of material driven from their bodies by the sun's rays, and that their curvature arises from a composition of motions.

[14] Copernicus ascribed to the earth what he called a "motion in declination" in addition to the annual and diurnal motions. The purpose of this was to maintain the axis of the earth parallel to itself throughout the year in order to account for the seasons. Galileo, who had discovered the principle of inertia, saw that this did not require a special motion at all, but was a direct consequence of his principle. At first he used his discovery in support of Copernicus. After the theory was banned he utilized it to smuggle in the truth by pretending (as here) that Copernicus had spoken falsely in attributing a nonexistent motion to the earth. Resourcefulness of this sort made him a very hard man to silence.

[15] This expression refers not to the moon but to the imaginary crystalline sphere that was supposed to transport it around the earth. The inner surface of that sphere was supposed to be the boundary between the four terrestrial elements (fire, air, water, and earth) and the special fifth substance (aether) which composed all heavenly bodies.

[16] Boiardo, *Orlando Innamorato* iii, c. vi, 50, 3-5.

[17] Two powerful warriors of Virgil's *Aeneid*: "Acestes . . . discharged his shaft . . . ; the arrow, flying among the watery clouds, took fire and with flames marked out its path, till being quite consumed it van-

ished." (v, 525 f.) 'Mezentius himself, having laid aside his arms, thrice whirling about his head the thong, discharged a hissing sling, and with the half-melted lead clove asunder the temples of the son of Arcens." (ix, 585 ff.)