

# Chapter 14

## Galileo's Astronomy

### Galileo, *Sidereus Nuncius* [1610]<sup>1</sup>

ASTRONOMICAL MESSAGE Containing and Explaining Observations  
Recently Made, With the Benefit of a New Spyglass, About the Face of the  
Moon, the Milky Way, and Nebulous Stars, about Innumerable Fixed Stars and  
also Four Planets hitherto never seen, and named COSMIC STARS

In this short treatise I propose great things for inspection and contemplation by every explorer of Nature. Great, I say, because of the excellence of the things themselves, because of their newness, unheard of through the ages, and also because of the instrument with the benefit of which they make themselves manifest to our sight.

Certainly it is a great thing to add to the countless multitude of fixed stars visible hitherto by natural means and expose to our eyes innumerable others never seen before, which exceed tenfold the number of old and known ones.

It is most beautiful and pleasing to the eye to look upon the lunar body, distant from us about sixty terrestrial diameters, from so near as if it were distant by only two of these measures, so that the diameter of the same Moon appears as if it were thirty times, the surface 900 times, and the solid body about 27,000 times larger than when observed only with the naked eye. Anyone will then understand with the certainty of the senses that the Moon is by no means endowed with a smooth and polished surface, but is rough and uneven and, just as the face of the Earth itself, crowded everywhere with vast prominences, deep chasms, and convolutions.

Moreover, it seems of no small importance to have put an end to the debate about the Galaxy or Milky Way and to have made manifest its essence to the senses as well as the intellect; and it will be pleasing and most glorious to demonstrate clearly that the substance of those stars called nebulous up to now by all astronomers is very different from what has hitherto been thought. But what greatly exceeds all admiration, and what especially impelled us to give notice to all astronomers and philosophers, is this, that we have discovered four wandering stars, known or observed by no one before us. These, like Venus and

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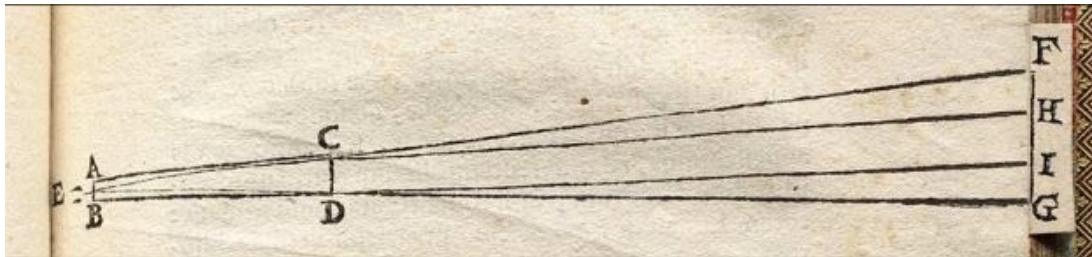
1. Translated by Albert Van Helden, University of Chicago Press: Chicago, 1989

Mercury around the Sun, have their periods around a certain star notable among the number of known ones, and now precede, now follow, him, never digressing from him beyond certain limits. All these things were discovered and observed a few days ago by means of a glass contrived by me after I had been inspired by divine grace.

Perhaps more excellent things will be discovered in time, either by me or by others, with the help of a similar instrument, the form and construction of which, and the occasion of whose invention, I shall first mention briefly, and then I shall review the history of the observations made by me.

About ten months ago a rumor came to our ears that a spyglass had been made by a certain Dutchman by means of which visible objects, although far removed from the eye of the observer, were distinctly perceived as though nearby. About this truly wonderful effect some accounts were spread abroad, to which some gave credence while others denied them. The rumor was confirmed to me a few days later by a letter from Paris from the noble Frenchman Jacques Badovere. This finally caused me to apply myself totally to investigating the principles and figuring out the means by which I might arrive at the invention of a similar instrument, which I achieved shortly afterward on the basis of the science of refraction. And first I prepared a lead tube in whose ends I fitted two glasses, both plane on one side while the other side of one was spherically convex and of the other concave. Then, applying my eye to the concave glass, I saw objects satisfactorily large and close. Indeed, they appeared three times closer and nine times larger than when observed with natural vision only. Afterward I made another more perfect one for myself that showed objects more than sixty times larger. Finally, sparing no labor or expense, I progressed so far that I constructed for myself an instrument so excellent that things seen through it appear about a thousand times larger and more than thirty times closer than when observed with the natural faculty only. It would be entirely superfluous to enumerate how many and how great the advantages of this instrument are on land and at sea. But having dismissed earthly things, I applied myself to explorations of the heavens. And first I looked at the Moon from so close that it was scarcely two terrestrial diameters distant. Next, with incredible delight I frequently observed the stars, fixed as well as wandering, and as I saw their huge number I began to think of, and at last discovered, a method whereby I could measure the distances between them. In this matter, it behooves all those who wish to make such observations to be forewarned. For it is necessary first that they prepare a most accurate glass that shows objects brightly, distinctly, and not veiled by any obscurity, and second that it multiply them at least four hundred times and show them twenty times closer. For if it is not an instrument such as that, one will try in vain to see all the things observed in the heavens by us and enumerated below. Indeed, in order that anyone may, with little trouble, make himself more certain about the magnification of the instrument, let him draw two circles or two squares on paper, one of which is 400 times larger than the other, which will be the case when the larger diameter is twenty times the length of the other diameter. He will then observe from afar both sheets fixed to the same wall, the smaller one with one eye applied to the glass and the larger

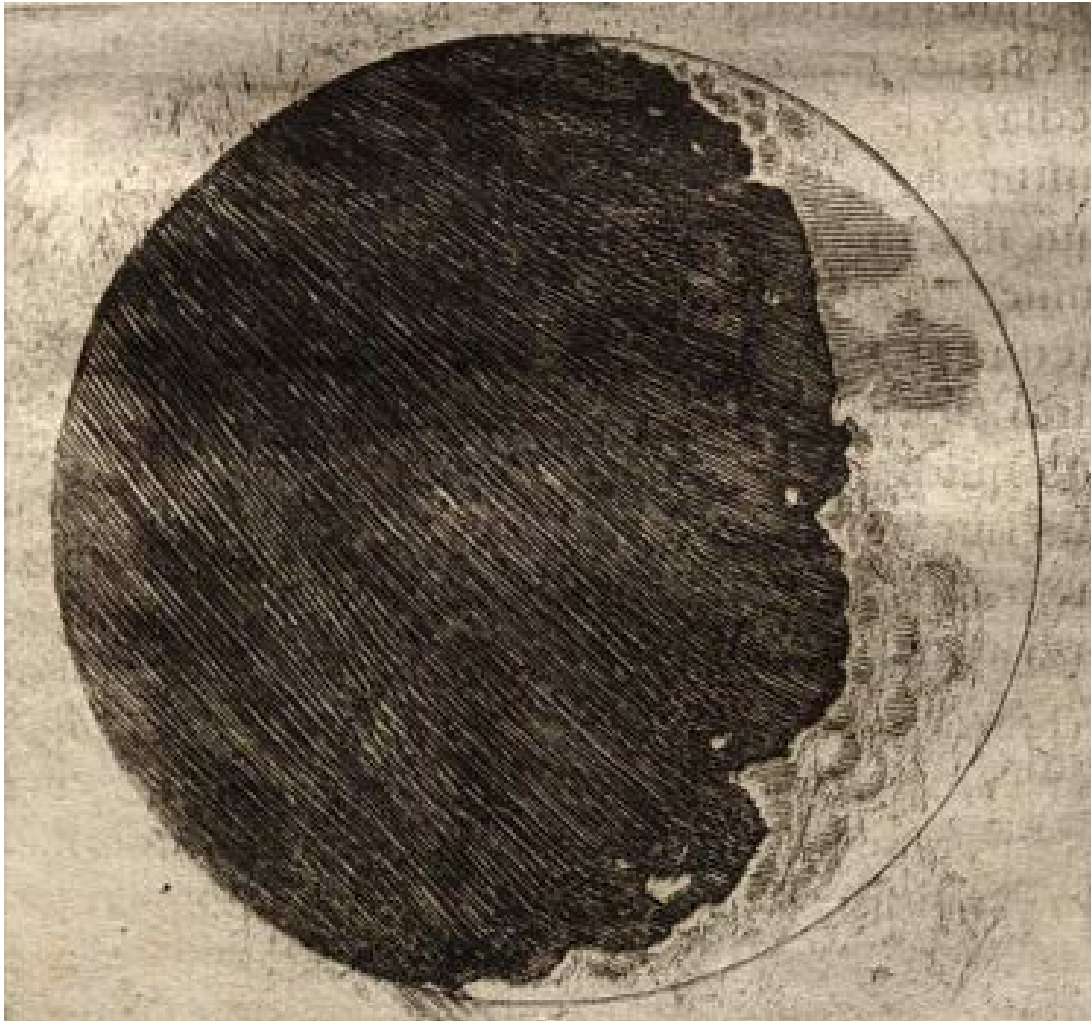
one with the other, naked eye. This can easily be done with both eyes open at the same time. Both figures will then appear of the same size if the instrument multiplies objects according to the desired proportion. After such an instrument has been prepared, the method of measuring distances is to be investigated, which is achieved by the following procedure. For the sake of easy comprehension, let ABCD be the tube and E the eye of the observer. When there are no glasses in the tube, the rays proceed to the object FG along the straight lines ECF and EDG, but with the glasses put in they proceed along the refracted lines ECH and EDI. They are indeed squeezed together and where before, free, they were directed to the object FG, now they only grasp the part HI.



Then, having found the ratio of the distance EH to the line HI, the size of the angle subtended at the eye by the object HI is found from the table of sines, and we will find this angle to contain only some minutes, and if over the glass CD we fit plates perforated some with larger and some with smaller holes, putting now this plate and now that one over it as needed, we form at will angles subtending more or fewer minutes. By this means we can conveniently measure the spaces between stars separated from each other by several minutes with an error of less than 1 or 2 minutes. Let it suffice for the present, however, to have touched on this so lightly and to have, so to speak, tasted it only with our lips, for on another occasion we shall publish a complete theory of this instrument. Now let us review the observations made by us during the past two months, inviting all lovers of true philosophy to the start of truly great contemplation.

Let us speak first about the face of the Moon that is turned toward our sight, which, for the sake of easy understanding, I divide into two parts, namely a brighter one and a darker one. The brighter part appears to surround and pervade the entire hemisphere, but the darker part, like some cloud, stains its very face and renders it spotted. Indeed, these darkish and rather large spots are obvious to everyone, and every age has seen them. For this reason we shall call them the large or ancient spots, in contrast with other spots, smaller in size and occurring with such frequency that they besprinkle the entire lunar surface, but especially the brighter part. These were, in fact, observed by no one before us. By oft-repeated observations of them we have been led to the conclusion that we certainly see the surface of the Moon to be not smooth, even, and perfectly spherical, as the great crowd of philosophers have believed about this and other heavenly bodies, but, on the contrary, to be uneven, rough, and crowded with depressions and bulges. And it is like the face of the Earth itself, which is marked here and there with chains

of mountains and depths of valleys. The observations from which this is inferred are as follows.



On the fourth or fifth day after conjunction, when the Moon displays herself to us with brilliant horns, the boundary dividing the bright from the dark part does not form a uniformly oval line, as would happen in a perfectly spherical solid, but is marked by an uneven, rough, and very sinuous line, as the figure shows. For several, as it were, bright excrescences extend beyond the border between light and darkness into the dark part, and on the other hand little dark parts enter into the light. Indeed, a great number of small darkish spots, entirely separated from the dark part, are distributed everywhere over almost the entire region already bathed by the light of the Sun, except, at any rate, for that part affected by the large and ancient spots. We noticed, moreover, that all these small spots just mentioned always agree in this, that they have a dark part on the side toward the Sun while on the side opposite the Sun they are crowned with brighter borders like shining ridges. And we have an almost entirely similar sight on Earth, around sunrise, when the valleys are not yet bathed in light but the surrounding mountains facing the Sun are already seen shining with light. And just as the shadows of the earthly

valleys are diminished as the Sun climbs higher, so those lunar spots lose their darkness as the luminous part grows.

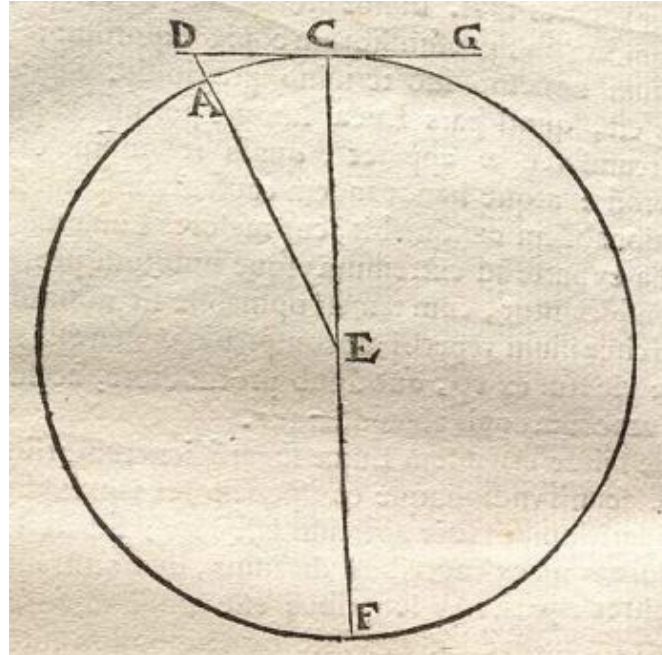
Not only are the boundaries between light and dark on the Moon perceived to be uneven and sinuous, but, what causes even greater wonder, is that very many bright points appear within the dark part of the Moon, entirely separated and removed from the illuminated region and located no small distance from it. Gradually, after a small period of time, these are increased in size and brightness. Indeed, after two or three hours they are joined with the rest of the bright part, which has now become larger. In the meantime, more and more bright points light up, as if they are sprouting, in the dark part, grow, and are connected at length with that bright surface as it extends farther in this direction. An example of this is shown in the same figure. Now, on Earth, before sunrise, aren't the peaks of the highest mountains illuminated by the Sun's rays while shadows still cover the plain? Doesn't light grow, after a little while, until the middle and larger parts of the same mountains are illuminated, and finally, when the Sun has risen, aren't the illuminations of plains and hills joined together? These differences between prominences and depressions in the Moon, however, seem to exceed the terrestrial roughness greatly, as we shall demonstrate below.

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As has often been observed by me, with the Moon in various aspects to the Sun, some peaks within the dark part of the Moon appear drenched in light, although very far from the boundary line of the light. Comparing their distance from that boundary line to the entire lunar diameter, I found that this interval sometimes exceeds the twentieth part of the diameter. Assuming this, imagine the lunar globe, whose great circle is CAF, whose center is E, and whose diameter is CF, which is to the Earth's diameter as 2 to 7. And since according to the most exact observations the terrestrial diameter contains 7,000 Italian miles,<sup>2</sup> CF will be 2,000 miles, CE 1,000, and the twentieth part of the whole of CF will be 100 miles. Now let CF be the diameter of the great circle [Illustration] dividing the luminous from the dark part of the Moon (because of the very great distance of the Sun from the Moon this circle does not differ sensibly from a great circle), and let A be distant from point C one-twentieth part of it. Draw the semidiameter EA, which, when extended, intersects the tangent GCD (which represents a ray of light) at D. The arc CA or the straight line CD will therefore be 100 parts of the 1,000 represented by CE, and the sum of the squares of CD and CE is 1,010,000, which is equal to the square of ED. The whole of ED will therefore be more than 1,004, and AD more than 4 parts of the 1,000 represented by CE. Therefore the height AD on the Moon, which represents some peak reaching all the way up to the Sun's rays GCD and removed from the boundary line C by the distance CD, is higher than 4 Italian miles. But on Earth no mountains exist that reach even to a perpendicular height of 1 mile. It is evidence, therefore, that the lunar prominences are loftier than the terrestrial ones.

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2. There was no Italian mile strictly speaking. The miles of Florence, Venice, and Rome were all within 10% of the modern English mile.



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The difference between the appearance of planets and fixed stars also seems worthy of notice. For the planets present entirely smooth and exactly circular globes that appear as little moons, entirely covered with light, while the fixed stars are not seen bounded by circular outlines but rather as pulsating all around with certain bright rays. With the glass they appear in the same shape as when they are observed with natural vision, but so much larger that a little star of the fifth or sixth magnitude appears to equal the Dog Star, which is the largest of all fixed stars. Indeed, with the glass you will detect below stars of the sixth magnitude such a crowd of others that escape natural sight that it is hardly believable.

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We have briefly explained our observations thus far about the Moon, the fixed stars, and the Milky Way. It remains for us to reveal and make known what appears to be most important in the present matter: four planets never seen from the beginning of the world right up to our day, the occasion of their discovery and observation, their positions, and the observations made over the past two months concerning their behavior and changes. And I call on all astronomers to devote themselves to investigating and determining their periods. Because of the shortness of time, it has not been possible for us to achieve this so far. We advise them again, however, that they will need a very accurate glass like the one we have described at the beginning of this account, lest they undertake such an investigation in vain. Accordingly, on the seventh day of January of the present year 1610, at the first hour of the night, when I inspected the celestial constellations through a spyglass, Jupiter presented himself. And since I had prepared for myself a superlative instrument, I saw (which earlier had not happened because of the weakness of the other instruments) that three little stars were positioned near him—small but yet very bright. Although I believed them to be among the

number of fixed stars, they nevertheless intrigued me because they appeared to be arranged exactly along a straight line and parallel to the ecliptic, and to be brighter than others of equal size. And their disposition among themselves and with respect to Jupiter was as follows:



That is, two stars were near him on the east and one on the west; the more eastern one and the western one appeared a bit larger than the remaining one. I was not in the least concerned with their distances from Jupiter, for, as we said above, at first I believed them to be fixed stars. But when, on the eighth, I returned to the same observation, guided by I know not what fate, I found a very different arrangement. For all three little stars were to the west of Jupiter and closer to each other than the previous night, and separated by equal intervals, as shown in the adjoining sketch. Even though at this point I had by no means turned my thought to the mutual motions of these stars,



yet I was aroused by the question of how Jupiter could be to the east of all the said fixed stars when the day before he had been to the west of two of them. I was afraid, therefore, that perhaps, contrary to the astronomical computations, his motion was direct and that, by his proper motion, he had bypassed those stars. For this reason I waited eagerly for the next night. But I was disappointed in my hope, for the sky was everywhere covered with clouds.

Then, on the tenth, the stars appeared in this position with regard to Jupiter. Only two stars were near him, both to the east.



The third, as I thought, was hidden behind Jupiter. As before, they were in the same straight line with Jupiter and exactly aligned along the zodiac. When I saw this, and since I knew that such changes could in no way be assigned to Jupiter, and since I knew, moreover, that the observed stars were always the same ones (for no others, either preceding or following Jupiter, were present along the zodiac for a great distance), now, moving from doubt to astonishment, I found that the observed change was not in Jupiter but in the said stars. And therefore I decided that henceforth they should be observed more accurately and diligently. And so, on the eleventh, I saw the following arrangement:





There were only two stars on the east, of which the middle one was three times as far from Jupiter than from the more eastern one, and the more eastern one was about twice as large as the other, although the previous night they had appeared about equal. I therefore arrived at the conclusion, entirely beyond doubt, that in the heavens there are three stars wandering around Jupiter like Venus and Mercury around the Sun. This was at length seen clear as day in many subsequent observations, and also that there are not only three, but four wandering stars making their revolutions about Jupiter.

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These are the observations of the four Medicean planets recently, and for the first time, discovered by me. From them, although it is not yet possible to calculate their periods, something worthy of notice may at least be said. And first, since they sometimes follow and at other times precede Jupiter by similar intervals, and are removed from him toward the east as well as the west by only very narrow limits, and accompany him equally in retrograde and direct motion, no one can doubt that they complete their revolutions about him while, in the meantime, all together they complete a 12-year period about the center of the world. Moreover, they whirl around in unequal circles, which is clearly deduced from the fact that at the greatest separations from Jupiter two planets could never be seen united while, on the other hand, near Jupiter two, three, and occasionally all four planets are found crowded together at the same time. It is further seen that the revolutions of the planets describing smaller circles around Jupiter are faster. For the stars closer to Jupiter are often seen to the east when the previous day they appeared to the west, and vice versa, while from a careful examination of its previously accurately noted returns, the planet traversing the largest orb appears to have a semimonthly period. We have moreover an excellent and splendid argument for taking away the scruples of those who, while tolerating with equanimity the revolution of the planets around the Sun in the Copernican system, are so disturbed by the attendance of one Moon around the Earth while the two together complete the annual orb around the Sun that they conclude that this constitution of the universe must be overthrown as impossible. For here we have only one planet revolving around another while both run through a great circle around the Sun: but our vision offers us four stars wandering around Jupiter like the Moon around the Earth while all together with Jupiter traverse a great circle around the Sun in the space of twelve years.

Finally, we must not neglect the reason why it happens that the Medicean stars, while completing their very small revolutions around Jupiter, are themselves now and then seen twice as large. We can in no way seek the cause in terrestrial vapors, for the stars appear larger and smaller when the sizes of Jupiter and nearby fixed stars are seen completely unchanged. It seems inconceivable, moreover, that they approach and recede from the Earth by such a degree around the perigees and apogeas of their orbits as to cause such large changes. For smaller circular motions can in no way be responsible, while an oval motion (which in this case would have to be almost straight) appears to be both inconceivable and by no account harmonious with the appearances. I gladly offer what occurs to me in this matter and submit it to the judgment and censure of right-thinking men. It



is well known that because of the interposition of terrestrial vapors the Sun and Moon appear larger but the fixed stars and planets smaller. For this reason, near the horizon the luminaries appear larger but the stars [and planets] smaller and generally inconspicuous, and they are diminished even more if the same vapors are perfused by light. For that reason the stars [and planets] appear very small by day and during twilight, but not the Moon, as we have already stated above. From what we have said above as well as from those things that will be discussed more amply in our system, it is moreover certain that not only the Earth but also the Moon has its surrounding vaporous orb. And we can accordingly make the same judgment about the remaining planets, so that it does not appear inconceivable to put around Jupiter an orb denser than the rest of the ether around which the Medicean planets are led like the Moon around the sphere of the elements. And at apogee, by the interposition of this orb, they are smaller, but when at perigee, because of the absence or attenuation of this orb, they appear larger. Lack of time prevents me from proceeding further. The fair reader may expect more about these matters soon.

### **First Letter of Galileo Galilei to Mark Welser Concerning the Sunspots, in Reply to his Letter<sup>3</sup>**

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Apelles goes on to suggest that this could be a means of establishing with certainty whether Venus and Mercury revolve around the Sun or between the Earth and the Sun, a point which he develops more fully in his second letter. I am somewhat surprised that he has not heard, or if he has, that he has not made use of the exquisite and convenient method of determining this which I discovered almost two years ago, and which has been communicated to so many people that it is now generally known, and which can be applied on many occasions. This is the fact that Venus changes its shape in the same way as the Moon. If Apelles will now observe Venus with his telescope, he will see that it is perfectly circular and very small, although not as small as it was when it first appeared in the evening. If he continues to observe it he will see that, at the point of its greatest elongation from the Sun, it appears semicircular, after which it will change into a horned shape, becoming thinner as it approaches the Sun again. Around its conjunction with the Sun it will be as thin as the Moon when it is two or three days old, and its visible circle will be so much increased that its apparent diameter, when it rises as an evening star, is less than a sixth of what it appears when it sets in the evening or rises in the morning. Hence its disc appears almost forty times larger in the latter position than in the former. These things leave no room for doubt about the orbit of Venus, but show with absolute certainty that it revolves around the Sun, which is the centre of the revolutions of all the planets, as the Pythagoreans and Copernicus maintain. Hence there is no need to wait for bodily

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3. Galileo Galilei, *Selected Writings*, transl. by William R. Shea and Mark Davie, Oxford: Oxford University Press, 2012.

conjunctions to confirm such a self-evident conclusion, or to produce arguments which are open to objections, however feeble, to gain the assent of those whose philosophy is strangely unsettled by this new structure of the universe. For these people, if they are not constrained by other evidence, will say either that Venus shines with its own light, or that it is of a substance that can be penetrated by the Sun's rays, so that it can be illuminated not just on its surface but also in depth. They will shield themselves with this response all the more boldly because there has been no lack of philosophers and mathematicians who have believed this to be the case (*pace* Apelles, who writes otherwise). Copernicus himself had to admit that one of these propositions was possible, indeed necessary, since he was unable to explain how it was that Venus does not appear horned when it is below the Sun; and indeed no other reply was possible until the telescope came to show us that Venus is naturally dark like the Moon, and that it changes its shape as the Moon does.

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