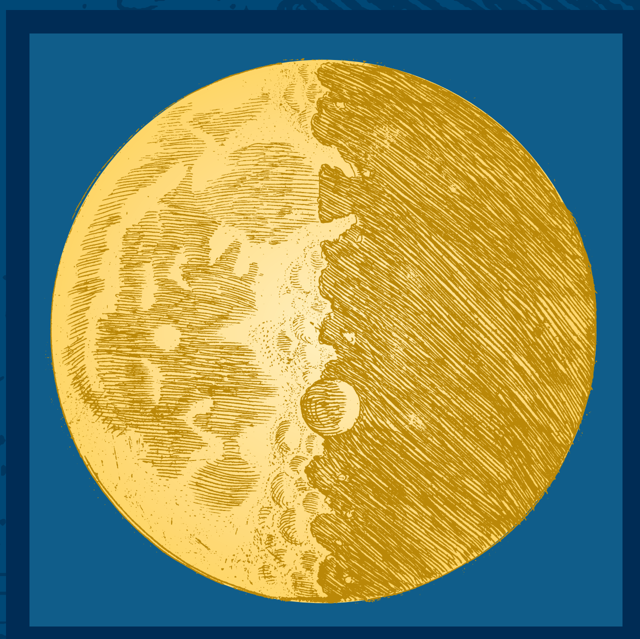
GALILEO GALILEI

The Starry Messenger

Venice 1610



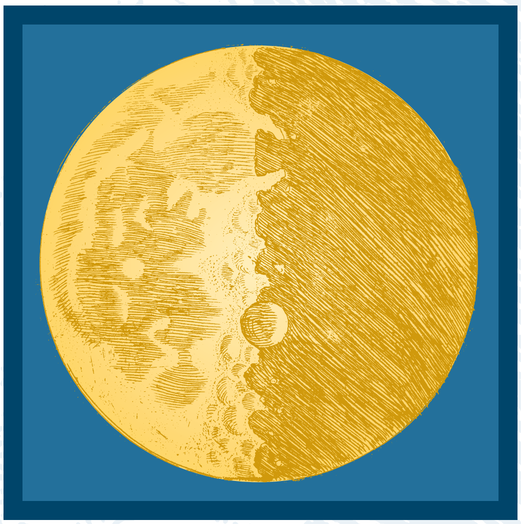
LIBRARY OF CONGRESS

'From Doubt to Astonishment'

GALILEO GALILEI

The Starry Messenger

Venice 1610



LIBRARY OF CONGRESS

'From Doubt to Astonishment'

with the symposium proceedings of
Owen Gingerich ✲ John W. Hessler ✲ Peter Machamer
David Marshall Miller ✲ Paul Needham ✲ Eileen Reeves

John W. Hessler and Daniel De Simone
Editors

Contents

SCHOLARSHIP

'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.'

Seeing and Believing: Galileo, Aristotelians, and the Mountains on the Moon

David Marshall Miller

When Galileo first heard about and constructed a telescope, sometime in the middle of 1609, one of the first things he aimed it at was the moon. The moon, of course, was an obvious target. It is, after all, the brightest and biggest celestial body one can directly observe without blinding oneself, which also made it something on which to practice using an unfamiliar instrument. The moon itself was, on all accounts, the earth's closest celestial neighbor, so telescopic observation of the moon offered a novel path of enquiry into the nature of the heavens. Anyone with a serious interest in natural philosophy would have been curious about the telescopic view of the lunar body.[1] Indeed, what Galileo saw amazed him, and he almost immediately began preparing a report of his findings for publication.[2] This appeared in 1610, as the *Sidereus nuncius*—the *Starry Messenger*—which reported Galileo's lunar observations, as well as the marvelous discovery of the moons of Jupiter and other telescopic discoveries.

What did Galileo see when he pointed his telescope at the moon? At the beginning of the *Sidereus nuncius*, he tells us:

> **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.… 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.[3]**

With "the certainty of the senses," Galileo says, the telescope reveals the uneven texture of the lunar surface. Looking through his telescope, Galileo saw a rough and uneven world, a second earth. Galileo saw mountains on the moon.

As Galileo indicates in this passage, the *montuosità* (mountainousness) of the moon was a significant discovery. According to the prevailing Aristotelian-Scholastic natural philosophy, the terrestrial realm was constituted by imperfect and corruptible substances subject to all sorts of changes in quality, quantity, and location. The heavens, by contrast, were a realm of quasi-divine perfection that shared nothing of terrestrial imperfection and mutability. The heavenly bodies, including the moon, were supposed to be incorruptible, impenetrable, unchanging, perfectly solid spheres of aether. Moreover, all the heavenly bodies had to be perfectly spherical. Inasmuch as unevenness and roughness were attributes of the corruptible terrestrial elements, they could therefore *not* be attributes of the celestial substance. The moon, therefore, was necessarily a perfect aethereal sphere, smooth and unblemished. As a heavenly body, it shared nothing of the terrestrial nature. It certainly could not and did not have mountainous protuberances or vacuous cavities.

A moon actually covered with mountains and valleys would therefore contradict the Aristotelian learning of the schools and its insistence on this strict dissimilarity and opposition between terrestrial and celestial. As Galileo himself noted, his lunar observations seemed to constitute a direct, empirical refutation of the Aristotelian "philosophers":

> **By oft-repeated observations of [the spots on the moon] 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.[4]**

The "great crowd" of Aristotelian philosophers may have insisted on the smoothness of the moon, but "the certainty of the senses" had shown this to be false.

Or so Galileo said. Upon closer examination, it is not clear that Galileo's observations were, in fact, an empirical refutation of Aristotelian natural philosophy. Was Galileo entitled to conclude that there were mountains on the moon? And, furthermore, were Galileo's observations sufficient to convince his opponents and force them to abandon the Aristotelian view of nature? Could an Aristotelian philosopher rationally maintain his belief in a smooth moon, even in the face of Galileo's observations?

Observers could and did maintain that the lunar observations described in the *Sidereus nuncius* were compatible with the Aristotelian view. Galileo's sensory evidence was not the "certain" refutation of Aristotelian physics it might at first seem. In the first place, one does not *see* mountains on the moon. One must *infer* their existence, and that inference depends on a form of analogical reasoning that is deeply problematic. Galileo's inference, therefore, could be and was rejected by his opponents. Second, the Aristotelians already had an alternative interpretation of the appearances that was compatible with their view. In light of this, Aristotelians could reasonably maintain their commitment to a smooth moon.

Nevertheless, the *Sidereus nuncius* was an important moment in the Scientific Revolution, and helped overthrow Aristotelian explanations of nature. It did so not by disproving Aristotelian theory by direct empirical test, but by changing the audience's expectations of what scientific theories should do. Galileo's book was incredibly successful in simply getting people to look at the heavens. It generated excitement and interest, and Galileo's rhetorical skill—including the problematic analogies—guided the observations of his readers. Galileo led his audience to *see* the moon, if not its mountains, in a new way. As a result, Galileo put natural philosophy in contact with careful, technical, and particular experiences. Natural philosophical theories were now expected to explain what was seen. Observations demanded interpretation by a theory, and competing theories could be judged by how well they accommodated an observation. In other words, theories came to be evaluated according to their empirical adequacy. The *Sidereus nuncius* ultimately changed the epistemic norms by which natural philosophical theories were judged.

Galileo's lunar observations alone were insufficient to topple Aristotelian natural philosophy, but their conjunction with other telescopic and experimental discoveries did eventually undermine it, since Aristotelian interpretations proved less satisfactory than those offered by Galilean and Copernican science. Galileo's lunar observations were not an empirical refutation of Aristotelian celestial physics, but they made such empirical refutations possible. By establishing a demand for empirical adequacy, the *Sidereus nuncius* helped give birth to modern science.

Galileo's assertion that he *saw* the moon "crowded everywhere with vast prominences, deep chasms, and convolutions" was something of an overstatement. Galileo could not and did not *see* the mountains on the moon. As he admitted in 1611:

> **Not only do I say that the cavities and eminences of the moon (as eminences) are not seen and cannot be seen from such a distance [as the moon's], but also that they could not be seen even from 100 miles; just as nothing of our [terrestrial] hills and highest mountains can be seen to rise above the plains from a height and distance of 50 miles and even less.[5]**

"How then," Galileo continues, "do we know the moon to be mountainous? We know it not by sense alone, but by the accompaniment and conjunction of argument [*discorso*] with observation and sensory appearance…."[6] The *montuosità* of the moon, in other words, is Galileo's *interpretation* of the telescopic appearances of the moon. The "discovery" of the mountains on the moon is not a direct observation, but sensory appearance supplemented by rational argument. It is an *inference* based upon experience.

As several authors have noted, the arguments conjoined to the "sensory appearances" are cases of analogical reasoning.[7] Galileo draws upon the similarity between lunar and terrestrial *appearances* to infer a similarity between the moon and the earth themselves. Analogical arguments along these lines appear throughout the *Sidereus nuncius*, in various states of elaboration. We have already seen the statement at the beginning of the text that the moon is rough and uneven, "like the face of the Earth." The *Sidereus nuncius* also describes how a careful telescopic examination of the terminator—the boundary of the sun's illumination—reveals that bright spots, illuminated by the sun, appear on the darkened side of the moon, gradually expand toward the boundary, and then are incorporated into the general solar illumination:

> **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 2 or 3 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.[8]**

Galileo then compares this to the appearance of mountains on the earth:

> **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?[9]**

The unstated conclusion, of course, is that the bright spots are mountains on the moon, just as the bright spots at dawn are mountains on the earth.

It is worthwhile to tease apart the reasoning further. Galileo notes that observations of the moon present the sensory appearance of bright spots that appear on the dark side of the terminator, completely surrounded by darkness. Over the course of a few hours, these gradually expand toward the terminator and are eventually incorporated into the general illumination of the bright portion of the moon. Galileo notes that this appearance is similar to an appearance we experience on the earth. At dawn, mountain peaks are first illuminated. This illumination expands as the sun, rising in the sky, illuminates more of the mountains, until the sun is high enough to illuminate the entire landscape. In other words, we interpret the similar terrestrial appearance as the effect of mountains illuminated by the sun, and say that we are looking at mountains illuminated by the sun. By analogy, Galileo concludes, we should interpret similar lunar appearances in the same way.[10] We should say that we are looking at mountains being illuminated by the sun—that we are looking at the mountains on the moon. The terrestrial interpretation is simply applied, by analogy, to the case of the moon. The similar effects, the appearances, have similar causes, the mountains.

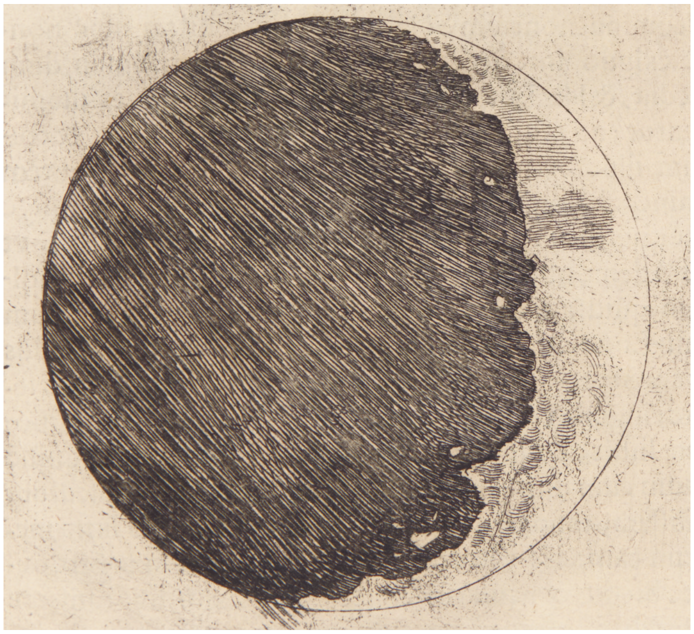


Figure 1. Engraving showing the "bright spots" along the darkened side of the terminator. The "bright peak" like a "huge promontory" is near the bottom of the image (f. 8r)

The *Sidereus nuncius* repeats this form of argument several times. Galileo notes that, as bright spots appear on the dark side of the terminator, dark spots appear on the illuminated side:

> **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. . . . 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.[11]**

Just as the bright spots in the dark can be interpreted as mountains in sunlight, the dark spots in the light are interpreted as valleys in shadow.

Galileo goes on to compare other aspects of the moon's appearance to terrestrial phenomena, progressively becoming more and more specific as he guides the observer's attention to individual features of the moon's appearance. We are directed, both by verbal descriptions and by engraved illustrations, to a "bright peak" in the southern part of the moon; to some "huge projections" that arise "around a certain spot in the upper, northern part of the Moon"; and to "a certain cavity larger than all others and of a perfectly round figure" found "around the middle of the Moon." In each of these cases, Galileo argues that the lunar appearance is similar to terrestrial appearances. The "bright peak" is "like a huge promontory," the "huge projections" are "like a ridge of very high mountains," and the round "cavity" (probably the crater Albategnius) "offers the same aspect to shadow and illumination as a region similar to Bohemia would offer on Earth, if it were enclosed on all sides by very high mountains, placed around the periphery in a perfect circle."[12]

Note also that in some of these instances, Galileo collapses the entire analogical argument and simply uses terrestrial-topographical terms to describe the visual appearance. Consider the following passage:

> **Moreover, in the Moon the large spots are seen to be lower than the brighter areas, for in her waxing as well as waning, on the border between light and dark, there is always a prominence here or there around these large spots, next to the brighter part, as we have taken care to show in the figures; and the edges of the said spots are not only lower, but more uniform and not broken by creases or roughness.[13]**

Here, Galileo uses topographical language to describe the pattern of light and dark he observes. "Prominences" border the "brighter part" and the edges of the spots are "lower," "not broken by creases or roughness." Elsewhere, as noted above, Galileo speaks of "peaks" that "light up, as if they are sprouting" on the dark side of the terminator, and another "bright" peak that appears like a "huge promontory." That is, Galileo writes *as if* he sees the mountains on the moon, and this is how he presents his observations at the opening of the book. This is, however, misleading—the mountains are really seen only through an *interpretation* of what actually appears, an interpretation based on an analogy to the earth.

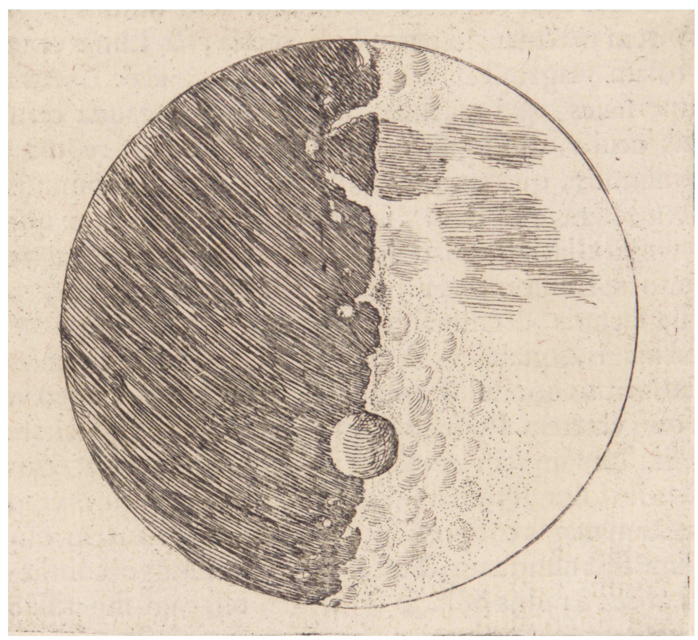


Figure 2. Engraving showing the "huge projections" in the upper part of the moon and the "cavity larger than all others and of a perfectly round figure" said to be found "around the middle of the Moon," but depicted along the terminator south of the moon's center (f. 9v)

What did Galileo's readers make of this? In particular, did the *Sidereus nuncius* successfully convince his Aristotelian opponents? In fact, many were immediately converted, but some of Galileo's audience noted difficulties with Galileo's reasoning. One problem with analogical argument in general is that it is difficult to control the extent of the analogy.[14] If you use the similarity between two things to establish the commonality of one feature, such as *montuosità*, it is hard to prevent the inference that there should also be other common features. Put simply, analogies can run amok.

When Johannes Kepler, the Imperial Astronomer, first read the *Sidereus nuncius*, he was elated. Kepler was a Copernican, and had long rejected the Aristotelian view of the heavens, so the book accorded with many things he had considered over the years. When he read it, he immediately penned a long letter to Galileo, published shortly thereafter as the *Dissertatio* *cum Sidereo Nuncio*, in which he enthusiastically endorsed everything Galileo had written, even without confirming the observations himself, since he lacked a good telescope. But Kepler took the analogy between earth and moon much further than Galileo. If the moon is mountainous, he said, it follows that it is also inhabited—by giants, in fact: "It surely stands to reason that the inhabitants express the character of their dwelling place, which has much bigger mountains and valleys than our earth has."[15] Furthermore, says Kepler, the inhabitation of the moon explains the round cavities (i.e., the craters):

> **Consequently, being endowed with very massive bodies, [the moon's inhabitants] also construct gigantic projects. Their day is as long as 15 of our days, and they feel insufferable heat. . . . Their usual building plan, accordingly, is as follows. Digging up huge fields, they carry out the earth and heap it in a circle. . . . In this way they may hide deep in the shade behind their excavated mounds and, in keeping with the sun's motion, shift about inside clinging to the shadow. They have, as it were, a sort of underground city. They make their homes in numerous caves hewn out of that circular embankment.[16]**

The craters, Kepler says, are moonlings' houses, built in a circle to shade them from the sun.

Of course, this takes the analogy too far, and Kepler came in for some ridicule. For example, the Aristotelian professor of philosophy at La Sapienza, Giulio Cesare La Galla, spoofed Kepler's interpretation of the lunar craters in order to criticize Galileo. In *De Phaenomenis in Orbe Lunae* (1612), La Galla sarcastically extends the analogy even further. "I would freely admit" all Kepler says, writes La Galla,

> **only I hold that the vast crypt would contain casks of wine, as in Italy, where we dig out our subterranean cellars and crypts more to preserve wine than to capture shade. But by what ship is Cretan or Neapolitan or, if you please, Alban wine carried thither? Could I describe the wings or sails? This business I leave to Kepler: the best is always made plain only with the greatest difficulty.[17]**

Kepler's giant moonlings and their caves, La Galla concludes, are utterly ridiculous. Yet Kepler had inferred their existence on the basis of an analogy with the earth, insofar as it is inhabited. But if it stretches the similarity between earth and moon too much to say that there are giant oenophile moonlings living in circular berms, why is it not too much of a stretch to say that there are mountains on the moon? Might any similarity be merely apparent? How can Galileo draw the line between an acceptable analogical inference and an unacceptable one?

Kidding aside, this exchange points to a second, more fundamental problem with Galileo's analogical reasoning. In order for Galileo's argument to work, he needs to *presume* that there is a fundamental similarity between the earth and the moon. Galileo presupposes that similar visual appearances are caused by, and can be interpreted as, similar topographical features on a surface. But this similarity between causes is explicitly *denied* by Aristotelian natural philosophy when it comes to the celestial and terrestrial realms. The celestial and terrestrial are, as noted earlier, supposed to be entirely dissimilar and opposed. Each is subject to a different physics, and thus to different chains of cause and effect. So, if a mountain causes a certain terrestrial appearance, it follows that a similar celestial appearance is definitely *not* caused by a mountain. Galileo's argument is circular in this respect: he is entitled to the conclusion that the moon is mountainous, and thus like the earth, only if he *supposes* that the moon is like the earth.[18]

Of course, in the sixteenth century, Copernicus had famously argued that the earth was not the center of the universe, but orbited the sun. He had thus cast the earth into the heavens, breaking the Aristotelian opposition between celestial and terrestrial. Copernicanism supports the hypothesis that the moon and earth are alike, and thus might both be mountainous. Though there is no overt declaration in the *Sidereus nuncius*, there are clear indications that Galileo had become a Copernican by 1610, or at the very least harbored Copernican sympathies.[19] It is reasonable to suspect that Galileo's interpretation of the lunar appearances was colored by his adherence to Copernicanism. He interpreted his observations as mountains on the moon because he already thought the moon was similar to the earth. But this was not convincing to an Aristotelian.[20]

La Galla's *De Phaenomenis* points out this flaw in Galileo's argument, as well. One should not be deceived, La Galla says, by the "similarity of speech and homonymy"[21] Galileo uses to describe the lunar and terrestrial appearances. Galileo might *call* the lunar appearances mountains, but that does not mean they actually *are* mountains. If Copernicanism "were true or possible, it would not be surprising if, seeing the moon up close by telescope, we saw mountains, valleys, lakes, seas, islands, promontories, and these somewhat larger than those on our Earth."[22] Yet, La Galla holds, Copernicanism is *not* "true or possible," and his treatise presents a blizzard of peripatetic arguments against the Copernican system, and in particular against any commonality between heavens and earth. To give but one example, La Galla discusses the generation of terrestrial fire. On earth, La Galla says, fire is caused by fire: one burning stick ignites another. But fire can also be caused by the sun, using a burning lens or mirror. No one, however (including Galileo himself), thinks that the sun is the same thing as terrestrial fire. For one thing, terrestrial fire is corruptible; the sun is not. Despite the similarity of the effect—i.e., fire—one cannot infer the similarity of causes—fire and sun—across the celestial-terrestrial divide.[23]

He interpreted his observations as mountains on the moon because he already thought the moon was similar to the earth.

By the same token, Galileo's interpretation of the lunar appearances as mountains, based on an analogy to terrestrial mountains, is fallacious. "Heaven is not of the same nature as the inferior things"—i.e., the terrestrial realm—so "it is therefore impossible that these phenomena [i.e., the lunar appearances] be attributed to some body capable of alteration, which would have inequalities, arising from its various generable and corruptible parts (as our Earth has), and thus mountains or valleys or rugged or pumice-like porous parts."[24] Heavens and earth are essentially dissimilar, so the similarity between lunar and terrestrial appearances does not imply a similarity between their causes. La Galla denies precisely what Galileo must presume: a similarity between heaven and earth.

Moreover, Galileo's "mountains" were not the only available interpretation of the moon's appearance. There was an alternative available that preserved the smooth moon demanded by Aristotelian natural philosophy. In fact, this was an old view, stemming from the fact that, even without a telescope, the moon does not look like a "smooth, uniform, and perfectly spherical" aethereal orb. It is covered with irregular spots—the "large and ancient" spots we call the man in the moon. These, by themselves, make the moon look rough and uneven. In antiquity, in fact, the poet Plutarch argued that the moon was mountainous, noting the wavy and irregular boundary between light and dark spots. That the moon was a "second earth" was also a widely reported view of the Pythagoreans and of Heraclides. Nevertheless, these accounts were superseded by a standard interpretation developed by medieval Aristotelian philosophers. This seems to have originated with Alhazen or Averroës, but the view was repeated by all the usual authorities: Buridan, Oresme, Albert of Saxony, and in the numerous commentaries on Sacrobosco's *Sphere* and Aristotle's *De Caelo*.[25] It was even discussed in verse by Dante.[26]

On this account, the celestial element, though one in nature, could vary its optical properties. In the medieval terminology, some aether was "rare" because it could absorb and re-emit light, thus appearing luminescent, while other aether was "dense," since it could not absorb light and remained dark and transparent. This was seen, for instance, in the sphere of the fixed stars, which was supposed to be a single solid shell of mostly non-luminescent, dense aether in which were embedded a scattering of luminescent, "rare" orbs that are seen as the stars. Likewise, the planets were thought to be luminescent orbs embedded in their own dark, transparent spheres. Thus, the appearances of bright spots in an otherwise dark sky was caused by a difference in "rarity" and "density" in the parts of the aether.[27] In the case of the moon, this interpretation simply said that it consisted of aether with varying degrees of density and rarity in its parts. And, though the moon did not shine on its own, when these parts were illuminated by the sun, they absorbed light and luminesced differently, giving the appearance of light and dark spots.

Nothing in Galileo's telescopic observations changed the basic nature of the available evidence. After all, like everyone else, he saw only light and dark spots, just in more detail. There was one novel datum, though: the telescope reveals that the smaller spots change their appearance, even over the course of a few hours. This could not be accounted for by patterns of light and dark on a smooth surface. Still, this novelty could be easily accommodated by a straightforward modification of the standard account. Rarity and density were simply held to vary within the lunar body, as well as on the surface, so the telescope revealed variations in three dimensions. Even in light of Galileo's observations, Aristotelians could maintain that the moon was actually a perfect, smooth, homogeneous sphere, and that only accidental differences in rarity and density gave it an uneven appearance.

Like everyone else, he saw only light and dark spots, just in more detail.

This was quickly adopted as the leading alternative to Galileo's "mountains." Christoph Clavius, the leading Catholic astronomer of the time, adopted this view. When the leading inquisitor and theologian in Rome, Robert Bellarmine, asked the mathematics faculty of the Collegio Romano, including Clavius, to confirm Galileo's observations, they replied that:

> **One cannot deny the great inequality of the moon; but it appears to Father Clavius more probable that it is not an uneven surface, but more likely that the lunar body is not of uniform density and that it has parts more dense and more rare; as are the ordinary spots, which are seen with natural vision.[28]**

Ludovico delle Colombe, one of Galileo's regular opponents, also proposed this interpretation in his response to *Sidereus nuncius*, the *Contro il Moto della Terra* of 1611.[29] There, Delle Colombe envisions the moon as a smooth sphere of transparent aether encasing a rough and uneven core of opaque aether, like "a big ball of the clearest crystal, inside of which a little earth is formed out of white enamel…." Because we see through the transparent part on the outside to the opaque part within, which has "all the corporeal dimensions…in the same way as would mountains and valleys," the moon appears "unequal, toothed, and mountainous, even if it is not."[30] Thus, differences in rarity and density could account for the appearances, and the moon might still be smooth, as Aristotelian philosophy required.[31]

In the end, then, the *Sidereus nuncius* did not constitute an immediately convincing, empirical refutation of Aristotelian natural philosophy. Galileo's contemporary opponents could and did quite reasonably reject Galileo's interpretation of the appearance of the moon. To draw his conclusion, one had to abandon the dissimilarity between heaven and earth, one of the fundamental tenets of Aristotelian natural philosophy. And in any case, the Aristotelians had a plausible alternative interpretation that did fit with their view. To simply accept the mountains on the moon would have been precipitous, at the very least.

This is not to say, though, that the *Sidereus nuncius* failed to undermine Aristotelian natural philosophy. Quite to the contrary, Galileo's book was ultimately an essential cause of the collapse of Aristotelianism over the course of the seventeenth century, since it helped change expectations about the relationship between theory and observation.

There was another potential problem with the *Sidereus nuncius*. At the beginning of the seventeenth century, natural philosophy was more or less divorced from empirical research. Philosophy was meant to be universal and certain, so it trafficked only in what was *generally* experienced, such as the fact that heavy bodies fall or that the planets move overhead. As Aristotle had put it, natural philosophy treated what was true "always or for the most part."[32] It did not, however, concern itself with *particular* phenomena, such as the fall of *this* ball or the motion of *that* planet. Consequently, explanatory theories were not subject to empirical tests. Theories were not expected to explain particular phenomena, so particular observations simply did not have the standing to contest, let alone refute, a philosophical theory. Observations made in particular circumstances, especially those involving specialized instruments, could not refute a theory's insistence on what was generally the case. So Galileo's empirical refutation of the Aristotelian view might have failed simply because his observations might have passed beneath the notice of his intended opponents.[33]

Galileo's book was ultimately an essential cause of the collapse of Aristotelianism over the course of the seventeenth century.

As it happened, though, Galileo's terrestrial analogies were remarkably successful in getting his audience to *see* the moon. The comparison to terrestrial appearances taught the readers of the *Sidereus nuncius* what to look for. By calling up images of terrestrial mountains in light and shadow, Galileo established what an observer might expect to see with the telescope, and his careful descriptions of ever greater particularity guided the gaze of his readers. The terrestrial analogies served a pedagogical purpose, alongside their suspect advocacy of the metaphysical existence of mountains.

The pedagogical role of the book was further aided, of course, by its engravings. As some have noted, the diagrams in the book are not exactly faithful reproductions of the appearance of the moon, but they do depict the kinds of appearances one sees, and thus help the observer know what to look for. The same can be said of Galileo's comparisons of the lunar appearances to *non*-topographical objects. Galileo says that "this lunar surface, which is decorated with spots like the dark blue eyes in the tail of a peacock, is rendered similar to those small glass vessels which, plunged into cold water while still warm, crack and acquire a wavy surface, after which they are commonly called ice-glasses."[34] Obviously, these comparisons are not meant to show that the moon *is* peacock feathers or Venetian glass, in the way that the comparisons to terrestrial mountains are meant to show that the moon *is* mountainous, but rather what the moon looks like and thus what an observer should be looking for.

We get a vivid impression of the *Sidereus nuncius*'s pedagogical effect from the English observer Sir William Lower. Before hearing of the *Sidereus nuncius*, Lower hunted about for an apt description of the moon seen through his telescope in 1610:

> **Neare the brimme of the gibbous parts towards the upper corner appeare luminous parts like starres, much brighter then the rest, and the whole brimme along, lookes like unto the description of coasts, in the dutch bookes of voyages. In the full she appeares like a tarte that my cooke made me the last weeke. Here a vaine of bright stuffe, and there of darke, and so confusedlie al over.[35]**

But later, once Lower had heard of Galileo's book, his observations are framed with a newfound coherence and significance:

> **Me thinkes my diligent Galileus hath done more in his threefold discoverie [concerning the Moon, Jupiter's moons, and the Milky Way] than Magellane in opening the straights to the South Sea or the Dutchmen that were eaten by beares in Nova Zembla.[36] I am sure with more ease and safetie to him selfe & more pleasure to mee. … [I]n the moone I had formerlie observed a strange spottedness al over, but had no conceite that anie parte thereof mighte be shadowes; since I have observed three degrees in the darke partes, of which the lighter sorte hath some resemblance of shadiness but that they grow shorter or longer I cannot yet perceive.[37]**

Lower's observation, which had previously yielded only a "strange spottedness al over," now revealed "shadowes" and "some resemblance of shadiness" that he had not before seen. And he was still looking for the changing spots Galileo had described. The *Sidereus nuncius* had shown Lower what to look for.[38]

Lower, of course, was not alone. Indeed, the publication of the book set off a clamor for telescopes as readers sought to see what Galileo had reported. Galileo gladly obliged, gifting his instruments to possible patrons across Europe and personally setting up demonstrations around northern Italy. Galileo's pedagogical and rhetorical skill, both in the book and in person, made the lunar appearances a big deal—something that could not be ignored. The excitement penetrated the learned public's imagination to the point that lunar observation was portrayed in art, verse, and on stage.[39] This had a proportionate effect among the natural philosophers. It is of no little significance that people like the theologian Bellarmine and the philosophy professor La Galla cared at all what was seen through the telescope, let alone felt compelled to respond. And the reams of correspondence and the numerous treatises written in response are further evidence of the book's success in ensnaring the attention of the philosophically inclined.

The publication of the book set off a clamor for telescopes as readers sought to see what Galileo had reported. Galileo gladly obliged.

Furthermore, those that observed the moon almost universally agreed that the moon *looked* rough and uneven in appearance. Whereas there was some dispute over the legitimacy of Galileo's other telescopic discoveries, especially regarding the moons of Jupiter, there was no suggestion, even among Galileo's opponents, that the appearance of the moon was not like that of terrestrial mountains. For example, the Aristotelian La Galla was present at one of Galileo's demonstrations in Rome, and his book repeatedly affirms the reliability of the telescope and the moon's uneven appearance, even as it disputes Galileo's interpretations. Thus, one of the chapter titles asks "Whether the Moon is one of the planets, of the same substance and nature as the rest of the heavens, that is, inalterable and incorruptible, as the Peripatetics hold, or whether there can truly be mountains and valleys [on the Moon], *as the telescope shows*."[40] Also, recall the Collegio Romano's response to Bellarmine, that "One cannot deny the great inequality of the moon" in its appearance. And Clavius, though he always hesitated to accept the actual unevenness of the moon's surface, wrote that:

> **This instrument [i.e., the telescope] shows…when the moon is a crescent or half full, it appears so remarkably fractured and rough that I cannot marvel enough that there is such unevenness in the lunar body. Consult the reliable little book by Galileo Galilei, printed at Venice in 1610 and called *Sidereus nuncius*, which describes various observations of the stars first made by him.**[41]

Thus, the leading astronomer of the period endorsed the Moon's uneven appearance, if not the assertion that it actually was so.

In this way, the *Sidereus nuncius* engendered widespread excitement and wonder, as well as a general consensus as to what the appearances were. Galileo did succeed in getting his audience to look at the moon, and to see the spots of light and dark he described—the spots that appeared *like* the illumination and shadow caused by mountains on the earth. Aristotelians such as La Galla and Delle Colombe were compelled to respond. They had to offer their own interpretations of the observations, and these interpretations could then be judged against competing alternatives, such as Galileo's.

This rhetorical dynamic was something new. The particular observations of the moon, made using a specialized instrument, now had the standing to demand interpretation by a natural philosophical theory. Theory now had to respond to individual observations. They could not be set aside as exceptions to what was true "for the most part." That made empirical tests possible. Observations that could be satisfactorily interpreted according to a theory served to support that theory. But an observation eliciting only unsatisfactory interpretations would constitute an empirical refutation—a reason to abandon the view.[42]

We can see this dynamic at work in Galileo's riposte to Delle Colombe's response to the *Sidereus nuncius*. Delle Colombe, compelled to offer an Aristotelian interpretation of the appearances, interpreted the lunar observations as the effect of differences in (optical) "rarity and density" in the lunar body. Specifically, Delle Colombe posited a smooth, clear shell surrounding a rugged opaque core. Yet, once this explanation had been proposed, it could be judged according to the norms by which natural philosophical theories were deemed satisfactory. Hence Galileo's retort:

> **Truly the imagination is beautiful; its only lack is that it is neither demonstrated nor demonstrable. And who does not see that this is a pure and arbitrary fiction, that puts nothing in being, and only offers something simply non-repugnant [to the theory]….I would voluntarily concede [Delle Colombe's sphere], if only that, with equal courtesy, I would be permitted to say that this crystal has on its surface a very large number of immense mountains, thirty times larger than the earth's, which, since they are of a diaphanous substance, cannot be seen by us; and thus I would draw another Moon ten times more mountainous than the first. And who will want to judge my assumption chimerical, without condemning by the same token the position of the adversary?**[43]

Beneath Galileo's snark lies an important argument. Delle Colombe's interpretation makes the Aristotelian account of the heavens consistent with the appearances. The crystalline shell is "non-repugnant" to the theory. But the interpretation runs afoul of a more basic principle: satisfactory theories should not posit entities that cannot be demonstrated. By this standard, Galileo says, the interpretation of the appearance should be rejected, and the Aristotelian theory upon which it is based is impugned by extension. Galileo also notes that Delle Colombe's view violates the Aristotelian's own demand for celestial simplicity: it posits *four* celestial materials—the lighter and darker opaque matter of the moon, the clear aether surrounding the moon, and the aether composing the rest of the heavens. This essential diversity comports less with celestial simplicity, Galileo argues, than the merely accidental irregularity of the lunar surface that Galileo posits.[44] Thus, the lunar observations form an empirical test of the interpretation, including the theory it is based upon. But this evaluation of Aristotelian theory in light of its accommodation to appearances would not have been possible at all had the appearance not demanded any interpretation.[45]

Galileo's terrestrial analogies, in their pedagogical mode, helped change the character of natural philosophy. The *Sidereus nuncius* put natural philosophy in contact with observation and empirical research. One now expected a theory to explain particular observations. For all the reasons noted earlier, as well as some others not here discussed,[46] Galileo's own interpretations of the appearances as mountains were not sufficiently convincing for some Aristotelians. They could be reasonably dismissed, and there was a passable Aristotelian alternative available. As more and more new phenomena were discovered, however, Aristotelian interpretations became more and more strained. Lunar spots might be acceptably accommodated, but what about the moons of Jupiter, the phases of Venus, the rings and moons of Saturn, and so on? These observations also demanded interpretations, which were not forthcoming. At some point, it became reasonable to reject the Aristotelian account, but only because that account was now expected to be empirically adequate.

It has long been argued that modern science emerged because of a general seventeenth-century trend in the direction of an empirical picture of science. The appearances established by the *Sidereus nuncius* were some of the first to move natural philosophy along this path. The interest they generated was one of the avenues by which intellectual culture came to value empirical research. The *Sidereus nuncius* had a palpable effect on the way in which explanations of the natural world were judged. Theory was now expected to account for particular phenomena, not just what was generally known. Insofar as we demand such empirical adequacy of scientific theories today, the *Sidereus nuncius* helped create modern science. Galileo's mountainous moon went unseen, but the *Sidereus nuncius* taught science to *see* the moon.

1 In fact, Galileo was not the first to observe the moon using a telescope. In July 1609, months before Galileo built his own device, the English naturalist Thomas Harriot turned a Dutch spyglass moonward, though he never published his findings. See Stephen Pumfrey, "Harriot's Maps of the Moon: New Interpetations," *Notes & Records of the Royal Society* (2009): 163-68. In the centuries leading to the advent of the telescope, Leonardo da Vinci, William Gilbert, and Johannes Kepler are also known to have observed the moon.

2 Owen Gingerich and Albert Van Helden, "From Occhiale to Printed Page: The Making of Galileo's *Sidereus Nuncius*," *Journal for the History of Astronomy* 34 (2003): 251-67; Owen Gingerich, "The Curious Case of the M-L *Sidereus Nuncius*," *Galilaeana* 6 (2009):141-65.

3 Galileo Galilei, *Sidereus Nuncius, or, The Sidereal Messenger*, trans. Albert Van Helden (Chicago: University of Chicago Press, 1989), pp. 35-36.

4 Galilei, *Sidereus Nuncius*, p. 40.

5 Galileo to Grienberger, 1 September 1611, in Galileo Galilei, *Le Opere di Galileo Galilei*, ed. Antonio Favaro (Florence: G. Barbera Editrice, 1890-1909), vol. 11, p. 183.

6 Galileo to Grienberger, 1 September 1611, in Galilei, *Opere*, vol. 11, p. 183. See also Galileo to Cigoli, 26 June 1612, in *Opere*, vol. 11. p. 341: "We know depth, then, not as an object of sight, *per se* and absolutely, but by accident in relation to light and to dark." Discussed in William R. Shea, "Looking at the Moon as Another Earth: Terrestrial Analogies and Seventeenth-Century Telescopes," in *Metaphor and Analogy in the Sciences*, ed. Fernand Hallyn (Dordrecht: Kluwer, 2000), pp. 83-103, at 88.

7 Peter K. Machamer, "Feyerabend and Galileo: The Interaction of Theories, and the Reinterpretation of Experience," *Studies in the History and Philosophy of Science* 4 (1973): 1-46; Roger Ariew, "Galileo's Lunar Observations in the Context of Medieval Lunar Theory," *Studies in the History and Philosophy of Science* 15 (1984): 213-26; Roger Ariew, "The Initial Response to Galileo's Lunar Observations," *Studies in the History and Philosophy of Science* 32 (2001): 571-81; Marta Spranzi, "Galileo and the Mountains of the Moon: Analogical Reasoning, Models and Metaphors in Scientific Discovery," *Journal of Cognition and Culture* 4 (2004): 451-83; Shea, "Looking at the Moon as Another Earth: Terrestrial Analogies and Seventeenth-Century Telescopes."

8 Galilei, *Sidereus Nuncius*, p. 42.

9 Galilei, *Sidereus Nuncius*, p. 42.

10 Note that the analogy is not straightforward. Galileo, in effect, asks his reader to imagine what the earth *would* look like, if it were observed from a great height, so the similarity of the appearances is established only by an act of imagination, not direct observation. For the purposes of this discussion, we can set aside the problems that arise in this context. Note that the appearance of terrestrial mountains from a great height could be constructed via the laws of perspective and optics familiar to Galileo and many of his audience, though Galileo did have to further explain this to some of his correspondents—e.g., in a long letter to Christopher Grienberger. (Galileo to Grienberger, 1 September 1611, in Galilei, *Opere*, vol. 11, pp. 178-208.) This issue was related to the measurement of the height of the lunar mountains, which also depended on the laws of optics, and came up in discussions of that calculation. See Galileo to Brengger, 8 November 1610, in *Opere*, vol. 10, pp. 466-73; "*De Lunarium Montium Altitudine*," in *Opere*, vol. 3, part 1, pp. 299-307. See also Samuel Y. Edgerton Jr., "Galileo, Florentine 'Disegno,' and the 'Strange Spotednesse' of the Moon," *Art Journal* 44 (1984): 225-32; Spranzi, "Galileo and the Mountains of the Moon," 463.

11 Galilei, *Sidereus Nuncius*, pp. 40-41.

12 Galilei, *Sidereus Nuncius*, pp. 42-43, 44-45, 47. Galileo also suggests (p. 43): "if anyone wanted to resuscitate the old opinion of the Pythagoreans that the Moon is, as it were, another Earth, its brighter part would represent the land surface while its darker part would more appropriately represent the water surface. Indeed, for me there has never been any doubt that when the terrestrial globe, bathed in sunlight, is observed from a distance, the land surface will present itself brighter to the view and the water surface darker." This comparison is far more suggestive than the others, of course, though it is stated tentatively. Note also the imagined transposition of the observer, here made explicit.

13 Galilei, *Sidereus Nuncius*, pp. 43-44.

14 See Shea, "Looking at the Moon as Another Earth: Terrestrial Analogies and Seventeenth-Century Telescopes."

15 Johannes Kepler, *Kepler's Conversation with Galileo's Sidereal Messenger*, trans. Edward Rosen (New York and London: Johnson Reprint Corp., 1965), p. 28.

16 Kepler, *Conversation*, p. 28.

17 *Quae omnia et ipse libenter admitterem; modo crypta adeo ingens vini dolia contineret Italico more, quo potius ad vinum asservandum, quam ad umbram captandam, subterraneas nobis cellas et cryptas excavamus. Sed quonam navigio eo afferretur vinum Creticum aut Neapolitanum, vel etiam, si lubet, Albanum? Numquid alis an velis instructo? Hoc Keplero relinquo negotium: nobis absque difficultate optimum semper in promptu est*. Julio Cesare La Galla, *De Phaenomenis in Orbe Lunae* (Venice, 1612; repr., Galilei, *Opere*, vol. 3, part 1, pp. 309-99), at 329.

18 See Ariew, "Galileo's Lunar Observations in the Context of Medieval Lunar Theory"; Owen Gingerich, "*Dissertatio cum Professore Righini et Sidereo Nuncio*," in *Reason, Experiment, and Mysticism in the Scientific Revolution*, ed. M. L. Righini Bonelli and William R. Shea (New York: Science History Publications, 1975), pp. 77-88. Spranzi and Wilson have separately tried to absolve Galileo of this circularity, without—in the author's view—much success. See Ariew, "The Initial Response to Galileo's

Lunar Observations"; Spranzi, "Galileo and the Mountains of the Moon"; Fred Wilson, "Galileo's Lunar Observations: Do They Imply the Rejection of Traditional Lunar Theory?," *Studies in the History and Philosophy of Science* 32 (2001): 557-70.

19 Famously, Galileo had explicitly declared himself a Copernican in a 1597 letter to Kepler, though there is some debate about the extent of Galileo's Copernicanism before 1610.

20 In the earlier *De Motu* manuscripts, Galileo proposed an anti-Aristotelian matter theory in which all bodies are held to be essentially similar insofar as they are all heavy (and would thus descend in a void). Thus, Galileo may have had an additional physical reason, outside of any commitment to Copernicanism, to dissolve the Aristotelian distinction between heavens and earth. (Thanks to Peter Machamer for stressing this point.)

21 *…ex similitudine loquendi et homonymia qua utitur decepti…* La Galla, *De Phaenomenis*, p. 328.

22 La Galla, *De Phaenomenis*, p. 332.

23 La Galla, *De Phaenomenis*, p. 368.

24 La Galla, *De Phaenomenis*, p. 377.

25 Willy Hartner, "Terrestrial Interpretations of Lunar Spots," in *Reason, Experiment, and Mysticism in the Scientific Revolution*, eds. M. L. Righini Bonelli and William R. Shea (New York: Science History Publications, 1975), pp. 89-94; Ariew, "Galileo's Lunar Observations in the Context of Medieval Lunar Theory."

26 Eileen Reeves, "From Dante's Moonspots to Galileo's Sunspots," *MLN* 124 (2009): S190-S209, S198-S202.

27 The terms were sometimes reversed (as in Delle Colombe), so that "dense" aether was luminescent and "rare" aether dark, but the principle remained the same. It should be remembered that these terms did not connote anything to do with the terrestrial properties of rarity and density. They were properties of luminescence only, not a relation of matter and volume. Note also that "aether" refers specifically to the classical element, which the ancients supposed constituted the heavens. It is distinct from terrestrial and modern "ethers."

28 *Non si può negare la grande inequità della luna; ma pare al P. Clavio più probabile che non sia la superficie inequale, ma più presto che il corpo lunare non sia denso uniformemente et che abbia parti più dense et più rare, come sono le macchie ordinarie, che si vedono con la vista naturale.* Mathematicians of the Collegio Romano to Bellarmine, 24 April 1611, in Galilei, *Opere*, vol. 11, pp. 92-93.

29 Ludovico delle Colombe, "Contro il Moto della Terra," in Galileo, *Opere,* vol. 3, part 1, pp. 251-90.

30 *Applicando adunque al proposito nostro, diciamo che, essendo il corpo lunare ripieno di parti più dense e più rare (le quali densità non sono nella superficie di quel corpo solamente, come i colori nelle tavole dipinte, ma ancora per entro tutto quel corpo sparse, ed hanno tutte le dimensioni corporee perchè sono larghe, lunghe, e profonde, nel modo stesso che sarebbono i monti e le valli, se fossero in quel corpo)… e perciò, non si vedeno l'altre parti di quel corpo che lo fanno sferico, rotondo e liscio (perchè, essendo rare, non reflettono il raggio del Sole nè si fanno luminose), appar che egli sia ineguale, dentate e montuoso, se bene non è. Essemplo manifesto ne sia il vedere, che se altri piglia una palla grande di chiarissimo cristallo, dentro a cui sia formato di smalto bianco una picciola Terra con selve, valli e monti*. Delle Colombe, "Contro il Moto della Terra," pp. 286-87. Note that Delle Colombe was perhaps inspired by Clavius's response to Bellarmine. See Colombe to Clavius, 27 May 1611, in Galilei, *Opere*, vol. 11, p. 118.

31 Christoph Scheiner, soon to become Galileo's opponent in the *Sunspot Letters*, takes this view as well. (Welser to Galileo, 7 January 1611, in Galilei, *Opere*, vol. 11, pp. 13-14.) Even one of Galileo's converts, the Jesuit mathematician Odo van Maelcote, in a laudatory address delivered in Galileo's honor, leaves the door open to an interpretation based on density and rarity, rather than *montuosità*: "But if some of you hold that the [Moon's] aspect is instead caused by density and rarity in the parts of the lunar body, or something similar, I do not interpose my judgment. It suffices for me, as for the *Nuncius*, to have related what I saw and learned from the heavens regarding the Moon's spots. You [the audience] judge the outcome of these matters." *Quod si quis vestrum huius aspectus causam densitatem raritatemque variam corporis lunaris, vel quid simile, afferri posse putet, ego iudicium meum non interpono: mihi enim, utpote Nuncio, quae vidi et e Caelo accepi de Lunae maculis, narrasse sufficiat: vos de rerum consequentiis iudicate*. Odo van Maelcote, "Nuntius Sidereus Colegii Romani," in Galilei, *Opere*, vol. 3, part 1, pp. 291-98, at 295.

32 See, e.g., Aristotle, *Physics* II.8.

33 See Peter Dear, "Jesuit Mathematical Science and the Reconstitution of Experience in the Early Seventeenth Century," *Studies in the History and Philosophy of Science* 18 (1987): 133-75; Gingerich, *"Dissertatio cum Professore Righini et Sidereo Nuncio*." In fact, the lack of concern with empirical research was institutionalized in the social distinctions between practitioners of the practical and mathematically-informed "mixed" sciences, such as medical doctors, opticians, mechanical engineers, and astronomers, on

the one hand, and natural philosophers on the other. Only the former group was concerned with real-world observations and applications. The philosophers eschewed what was seen as menial or manual labor and remained book-bound. Galileo himself was a professor of mathematics at Padua. That he was able to secure employment as mathematician *and* philosopher in Tuscany upon the publication of the *Sidereus nuncius* further illustrates the transformative and transdisciplinary effect of the book.

34 Galilei, *Sidereus Nuncius*, p. 43.

35 Lower to Harriot, 6 February 1610 (OS), in Ewen A. Whitaker, "Selenography in the Seventeenth Century," in *Planetary Astronomy from the Renaissance to the Rise of Astrophysics, Part A: Tycho Brahe to Newton*, ed. René Taton and Curtis Wilson (Cambridge: Cambridge University Press, 1989), vol. 2A, pp.119-43, at 120.

36 I.e., the Russian archipelago Novaya Zemlya, where, in 1595, two sailors on an expedition led by the Dutch explorer Willem Barentsz were killed by a polar bear.

37 Lower to Harriot, dated "the longest day of 1610," in Whitaker, "Selenography in the Seventeenth Century," 120-21.

38 See Shea, "Looking at the Moon as Another Earth: Terrestrial Analogies and Seventeenth-Century Telescopes"; Mary G. Winkler and Albert Van Helden, "Representing the Heavens: Galileo and Visual Astronomy," *Isis* 83 (1992): 195-217.

39 Reeves, "From Dante's Moonspots to Galileo's Sunspots"; Sara Elizabeth Booth and Albert Van Helden, "The Virgin and the Telescope: The Moons of Cigoli and Galileo," *Science in Context* 13 (2000): 463-86.

40 Chapter 10. See Galilei, *Opere*, vol. 3, part 1, p. 377; italics added.

41 Christoph Clavius, *Opera Mathematica* (Bamberg, 1612; repr. http://mathematics.library.nd.edu/clavius/), vol. 5, p. 75; translation based on James M. Lattis, *Between Copernicus and Galileo: Christoph Clavius and the Collapse of Ptolemaic Astronomy* (Chicago: University of Chicago Press, 1994), p. 198.

42 This rhetorical demand could be quite literal, especially when embodied by the patronage system in which intellectual culture was embedded. Bellarmine makes such a demand on the mathematicians of the Collegio Romano, as we have seen. Kepler also provides an instructive case. In the *Dissertatio* he relates, "Three months ago [i.e., before the publication of *Sidereus nuncius*] the Most August Emperor [Rudolf II] raised various questions with me about the spots on the moon. He was convinced that the images of countries and continents are reflected in the moon as though in a mirror. He asserted in particular that Italy with its two adjacent islands seemed to him to be distinctly outlined. He even offered his glass for the examination of these spots on subsequent days, but this was not done." Kepler, *Conversation*, p.13. Rudolf had observed the moon, and now demanded an interpretation from his Imperial Mathematician, or an evaluation of his own. This demand was renewed a few months later, when the Emperor received a copy of the *Sidereus nuncius* and showed it to Kepler, asking for his opinion. Kepler, *Conversation*, p. 11.

43 *Veramente l'immaginazione è bella; solo gli manca il non essere nè dimostrata nè dimostrabile. Et chi non vede che questa è una pura et arbitraria finzione, che nulla pone in essere, et solo propone una semplice non repugnanza?…io volentieri lo concederò, pur che con pari cortesia sia permesso a me il dire che questo cristallo ha nella sua superficie grandissimo numero di montagne immense, et trenta volte maggiori che le terrene, le quali, per esser di sustanzia diafana, non possono da noi esser vedute; et così potrò io figurarmi un'altra dieci volte più montuosa della prima. Et chi vorrà giudicare questo mio assunto chimerico, senza condennare della medesima nota la posizione dell'avversario?* Galileo to Gallanzoni, 16 July 1611, in Galilei, *Opere*, vol. 11, pp. 142-43.

44 Galileo to Gallanzoni, 16 July 1611, in Galilei, *Opere*, vol. 11, p. 143.

45 Galileo is here appealing to an epistemic norm already contained in Aristotelian natural philosophy. The requirement that a natural philosophical theory be empirically "demonstrable" is enshrined in Aristotle's *Posterior Analytics*. Even an Aristotelian could agree that Delle Colombe's explanation was inadequate (though Galileo's own interpretation had problems, as well). In other words, Galileo co-opted fundamental Aristotelian principles regarding the nature of science itself in order to undermine the *content* of Aristotelian science. He did not browbeat Aristotelian natural philosophers into adopting a view they did not to some extent already hold.

46 For instance, Galileo could not satisfactorily explain why mountains are not seen at the edge of the moon. He first supposed the mountains were arranged in ranges so that individual peaks could not be seen. He also suggested that the moon had an atmosphere that refracted light in such a way as to make the mountains along the limbs of the moon invisible. Eventually, however, Galileo conceded that he did not have a clear understanding of this feature of the appearances.