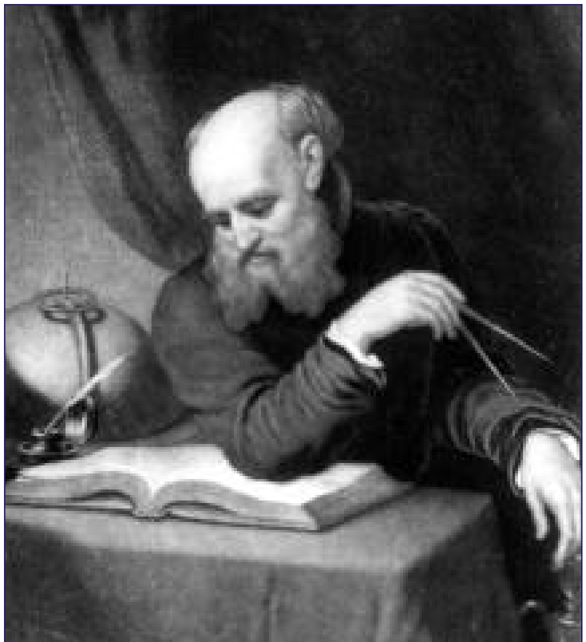
Galileo's

LUNAR LANDSCAPES

BRIAN S. BAIGRIE

When Galileo turned his telescope to the heavens in late 1609, astronomy was a science filled with diagrams but lacking actual pictures. The moon, for example, often portrayed as a crescent in medieval and Renaissance works of art, was not pictured as it actually appeared to the naked eye. Prevailing astronomical opinion held that the moon was in fact a perfect sphere.

European intellectual society was therefore shocked when Galileo's *Sidereus nuncius (The Starry Messenger)* was published in 1610. Among other discoveries, Galileo reported that the moon was a rugged body with earth-like features—a claim that was punctuated with five naturalistic copperplate engravings of the moon with its warts and blemishes intact (Fig. 1).



Galileo Galilei. (*Courtesy of AIP Emilio Segrè Visual Archives, Physics Today Collection.*)

Galileo's use of mathematics to predict experimental results is considered a cornerstone of modern science. He made significant contributions to the physical sciences, and his defense of the Copernican system brought him into conflict with the Catholic Church, which found him guilty of heresy, banned his works in 1633 and placed him under house arrest.

Although Galileo employed pictorial devices in his *Letters of Sunspots* of 1613, he later abandoned naturalistic forms of representation. Indeed, his celebrated work on cosmology, the *Dialogue Concerning the Two Chief World Systems* of 1623, contained not a single picture. This lack of pictorial representation was in step with the times. In printed astronomical works of this period, pictures were rare and made no attempt at naturalistic representation.

It was not until the 1640s, with the emergence of physical astronomy as an autonomous discipline, that a pictorial language began to be developed in astronomy.

This brief recounting of the circumstances surrounding Galileo's copper engravings of the moon raises a number of questions. First, since astronomy was a science with diagrams at the beginning of the seventeenth century, what role did Galileo's pictures of the moon serve in the *Sidereus nuncius*? It is clear that diagrams played an epistemic role in Renaissance astronomy, often imparting critical pieces of information to the reader. Were Galileo's copper engravings of the moon meant to play a similar role? Second, did Galileo's pictures of the moon signal a natural evolution of the traditional role played by diagrams as repositories of information—an evolution that emerged as a result of the invention of the telescope and the opportunity it afforded for more naturalistic representations of the heavens? If so, why did it take another 30 years for a visual language to emerge for astronomy? And third, what role did Galileo's contributions play in the development of a visual language for astronomy?

Galileo's observations

Until 1604, astronomy was something of a departure for Galileo. But later he suddenly became interested in two astronomical questions. The first was why if earth moved in space, as Copernicus contended, only one hemisphere of the sky was visible. Proponents of the traditional astronomy of Aristotle insisted that moving away from the celestial sphere brought one closer to one side, therefore rendering more than half the sphere visible. Galileo was certain that this attempted rebuttal of the Copernican system was groundless, but he possessed no physical proof for the hypothesis of a moving earth. He wrote to Johannes Kepler, the imperial mathematician at Prague, to tell him that he supported the Copernican hypothesis, but Kepler was already one of the converted.

The second question Galileo addressed was why if the heavens were immutable,as Aristotle had argued, a new star appeared in 1604. Aristotelians demurred that the phenomenon was meteorological, occurring in the changeable region below the surface of the moon. However, Galileo and others were beginning to suspect that the star of 1604 and an earlier nova of 1572 lay beyond the sphere of the moon, as Tycho Brahe had claimed many years earlier.

Finding answers to these questions began to be possible with the invention of the telescope. Although many papers have been written on this subject, nobody knows who actually invented the telescope. Regardless, this amazing instrument that made distant objects appear both larger and nearer created a stir in the Netherlands in 1608. A report of this instrument reached Galileo the following year. After confirming the telescope's existence and acquiring the basic information on its construction, Galileo proceeded to build his first refracting telescope in July 1609. By the end of that year, he had succeeded in creating an instrument that represented objects 1,000 times larger and 30 times nearer than they appeared to the naked eye.

Galileo turned this comparatively simple instrument to the skies in January 1610. In a very short time, he made three sets of observations that challenged the prevailing astronomical opinions of Aristotle. First,Galileo asserted rightly that the moon was unique among heavenly bodies in possessing features discernible to the naked eye (sunspots were often large enough to be seen with the naked eye, but prior to the seventeenth century, the dominant Aristotelian cosmology closed the door to sunspot investigation). The moon's features caused difficulties for Aristotelian cosmology, which was based on a distinction between the perfection of the celestial realm and the corruption of the terrestrial realm. A number of clever theories were devised to explain the spottiness of the moon, the prevalent opinion being that the perfectly spherical lunar surface appeared blemished as a consequence of lunar density variations.

With his telescope, Galileo was able to observe the familiar spots of the moon and many smaller spots previously not seen. (It should be noted that Galileo was not the first scientist to observe the moon with a telescope. Earlier, the English astronomer Thomas Harriot observed the moon for several years, and it was he who produced the first rough maps of its surface). Galileo noticed that these bright and dark areas changed in size as he watched—a phenomenon that previously had been invisible. In particular, he noted that the width of the dark lines defining these spots varied with the angle of solar illumination. As the dark lines changed, he saw light spots in the dark part of the moon gradually merge with the illuminated part of the moon.

Galileo reasoned that the best explanation for the changing patterns of light and dark was that the changing dark lines were shadows projected by features on the surface of the moon. His reasoning implied that the surface of the moon was "everywhere full of vast protuberances, deep chasms, and sinuosities," like earth's surface. Noting that the summits of the highest elevations were illuminated at a considerable distance from the edge of the lunar crescent, Galileo applied simple geometrical reasoning to estimate that the lunar mountains were at least four times higher than the mountains on earth. Contrary to traditional belief, Galileo concluded that the moon was far from perfect; indeed, it was not even spherical.

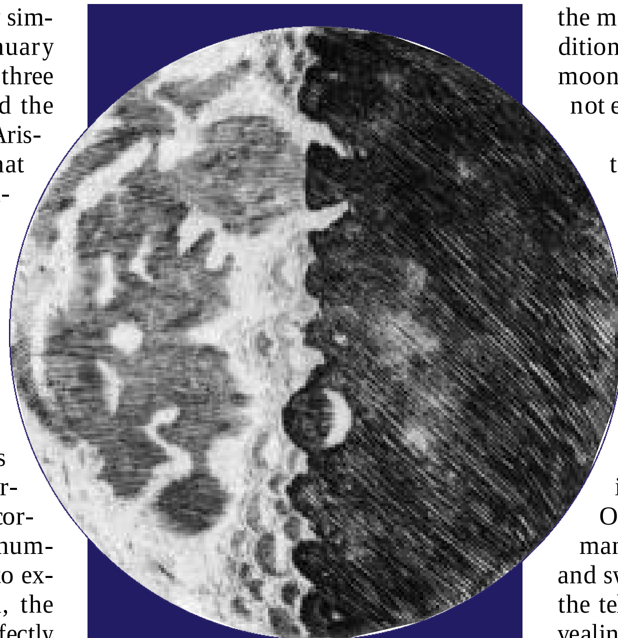
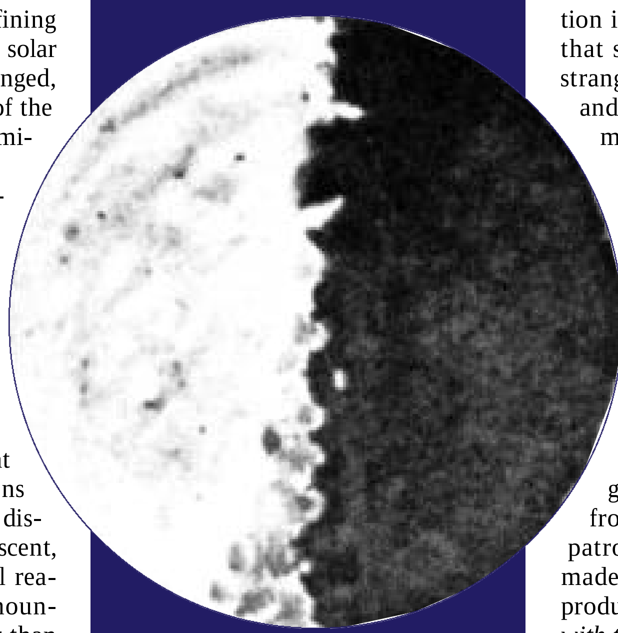


Figure 1. Copper engraving of the last quarter moon. (*Source: Galileo Sidereus nuncius, 1610.*)

Figure 2. Ink wash of the last quarter moon, 1609-1610. (*Source: Le opere di Galileo Galilei.)*



Galileo then turned the telescope to the stars to make his second observation. Although the stars appeared brighter through the telescope, they were not enlarged and instead looked even smaller (unlike the planets, which gave the appearance of small disks). Galileo's only explanation was that the stars were situated at immense distances from earth, much farther than the planets. By focusing the telescope on the constellation Orion, he discovered and recorded many stars never seen before in the belt and sword of the hunter. He then swung the telescope through the Milky Way, revealing that a universally believed luminous cloud in the sky was in fact a collection of individual stars.

Galileo's final set of observations proved to be the most dramatic, at least in terms of their pro-Copernican potential. He observed tiny stars near Jupiter. On successive nights, he noticed that these little stars stayed with Jupiter as the planet wandered through the fixed stars. He concluded that these four attendants must be moons circling Jupiter, and named them the Medicean stars in honor of the Medici family that ruled Tuscany. Here was a Copernican system in miniature, which discredited the Aristotelian contention that there could only be one center of motion in the universe, namely earth. Later that same year, Galileo observed that a strange oval satellite surrounded Saturn, and that Venus exhibited phases as the moon did.

Galileo wasted little time and reported his observations in a small, heavily illustrated treatise that was published in 1610 with the title *Sidereus nuncius*. It caused a sensation, making Galileo a celebrity overnight. When the initial run of 550 copies sold out, a reissue appeared in Frankfurt within months. In Prague, Giuliano de' Medici, the Tuscan ambassador, gave Kepler a copy with a request from Galileo for comments. Kepler's patron, the Emperor Rudoph II, soon made a similar request and Kepler soon produced a pamphlet called *A Discussion with the Starry Messenger*. This pamphlet extolled Galileo's work, even though at the time Kepler had no telescope and had never looked through one.

Soon afterwards, Kepler was afforded the opportunity to observe through one of Galileo's telescopes and he thereupon published a second pamphlet. Kepler became so intrigued with the instrument that he temporarily broke off his own research to publish a book in 1611 on lenses. Kepler even designed an alternative telescopic arrangement featuring a biconvex lens combination that had many advantages over the Galilean arrangement. Although the biconvex lens combination produced an inverted image, its field of view was much larger, permitting the development of telescopes with higher magnifications.

For the first time there was physical evidence that something was amiss in the Aristotelian universe. If Galileo's observations were sound, then the many followers of Aristotle (who dominated intellectual life in and around the universities) would have to revise Aristotelian astronomy, physics, and the entire edifice of Aristotelian philosophy. Each of Galileo's three sets of observations undermined objections to the Copernican system, and suggested that the universe was more congenial to the new astronomy than anyone had believed.

While the discovery of Jupiter's satellites was perhaps the most telling blow in the debate between the old and new astronomy, the discovery that the moon had a rugged surface was scientifically the most remarkable. The satellites of Jupiter, the rings of Saturn, the phases of Venus, and the individual stars in the Milky Way could not be observed with the naked eye. These observations were achievements of the telescope. As a supporter of the Copernican system, Galileo was caught up with these observations because he was convinced that they only made sense if the Copernican system did in fact represent reality. These observations and the Copernican system, in other words, buttressed each other.

The lunar observations were another matter altogether: scientists and laypeople alike did not need a Galilean telescope to know that the moon had discernible features. The fact that these features were fixed made it obvious that the moon always kept the same face turned towards earth. The telescope enabled Galileo to study the changing patterns of these features, particularly at the interface between the shaded and illuminated portions. In order to make sense of these patterns, Galileo invoked a method of argument he referred to as "in virtu di perspettiva." Fluent in the method of representing space according to geometrical rules elaborated by Filippo Brunelleschi (1377-1446), Galileo argued that the changing patterns of light and dark were caused by shadows cast by huge topographical features, including mountains and craters. The Copernican theory was consistent with the claim that the lunar surface was rugged, but it did not provide him with an interpretation for the spottiness of the moon. It was the common language of European art that provided Galileo this interpretation.

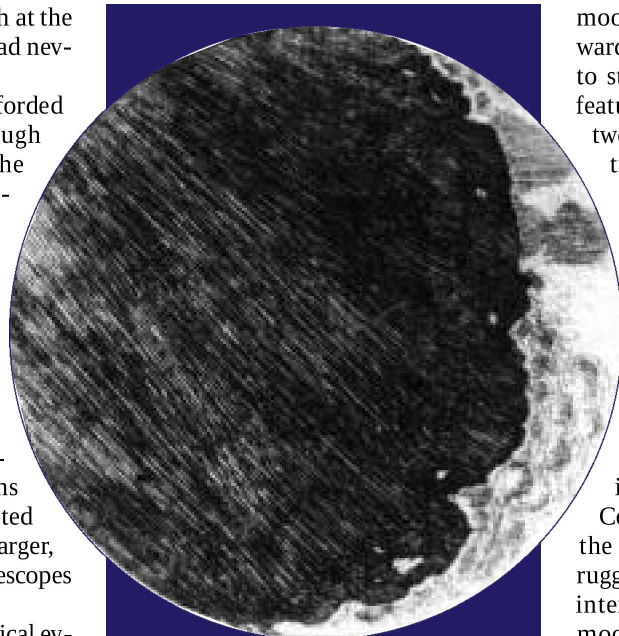
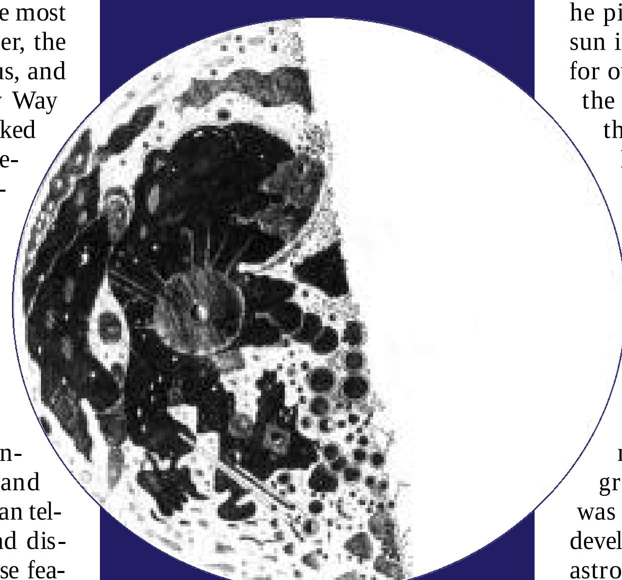


Figure 3. Copper engraving of the moon, four or five days old. (*Source: Galileo Sidereus nuncius, 1610.*)

Figure 4. Copper engraving of the last quarter moon. (*Source: Hevelius, Selenographia:sive, Lunae Descriptio, 1647.*)



Galileo exploited the artist's understanding of cast shadows not only in the text of the *Sidereus nuncius* but also in the five copperplate engravings (one of which was a duplicate) that accompanied the text. Traditionally, astronomy had been a science of diagrams that lacked pictures. The sole exceptions were the rough sketches in the notebooks of Leonardo da Vinci (ca. 1500) and a drawing of the moon by William Gilbert, which he left at his death in 1603. These illustrations were never printed.

Galileo continued this style of representation in *Letters of Sunspots* in 1613. Here, he pictured the daily appearances of the sun in an almost uninterrupted sequence for over a month so the reader could see the changing shapes of the spots and their progress across the sun's face. However, there is not a single picture in his *Dialogue Concerning the Two Chief World Systems* of 1623. Although one might except that pictorial representations in astronomy would become standard fare in the years following 1610, this was not the case. The few pictures that appeared in works by his contemporaries contained none of the elements that made Galileo's copper engravings such a sensation. Indeed, it was not until the 1640s that astronomy developed its own pictorial language and astronomers began to use art as science (i.e., as sources of information).

Conclusions

What, then, are we to make of Galileo's copper engravings? Galileo used the term *figura* to denote both diagrams and his pictures of the moon, and once used *de - lineatio* to refer to the copper engravings. It is therefore possible to conclude that the copper engravings are not scientific illustrations in the ordinary sense that a visual element imparts knowledge to the reader. The *Sidereus nuncius* describes changes of light and dark over time that would have required an extended series of pictures and not the few drawings of the moon prepared by Galileo. If anything, Galileo's engravings are less informative than the schematic diagrams that frequent astronomical treatises in the Renaissance. The engravings are therefore not scientific, but instead are visual impressions geared toward bolstering the claim that the lunar surface is rugged and earth-like—a point elaborated at great length in the text.

Galileo's intended distortions in the lunar landscapes also point to the notion that the engravings were meant as textual aids. Consider, for example, the ink wash of the last quarter moon (Fig. 2) that was prepared at roughly the same time as the copper engraving of the same object (Fig. 1) as it appeared subsequently in *Sidereus nuncius*. The ink wash testifies that Galileo was more than capable of executing a descriptively accurate picture of the moon, but comparison with the copper engraving reveals that he was prepared to sacrifice descriptive accuracy for the sake of his argument. In order to shore up his claim that lunar cavities resemble such large earthly valleys as Bohemia, the large cavity just below the middle of the terminator (presumably Albategnius) is greatly exaggerated. More caricature than description, a cavity of this size would have been visible from earth, which of course,it was not. It seems to have been lost on Galileo's contemporaries that a crater of this size would undermine his claims.

Galileo's engravings (Fig. 3) stand in stark contrast to Hevelius' *Selenographia* (1647), which contained copper engravings of 40 different lunar phases and four views of the full moon (Fig. 4). These pictures were intended as accurate descriptions of the moon, a purpose that is explicitly stated in the book. The engravings are informative independently of the associated text, as are scientific illustrations in the proper sense of the expression. It is with Hevelius that astronomy became a visual science. However, this concession does not undermine the importance of Galileo's contributions to the emergence of astronomy as a visual science. Before scientists could take interest in the moon's features,they had to first accept the claim, made credible by *Sidereus nuncius*, that the moon was a terrestrial body. Only when the identification with earthly features was established could standard cartographic techniques be extended to the moon.

This acceptance of a rugged moon took some time in the making. Although Galileo opened up the possibility of a new branch of visual astronomy concerned with the actual anatomy of the components of the planetary system, it was not until the 1640s that physical astronomy emerged as an autonomous discipline. A number of reasons could be cited for this delay, but clearly the most important factor was that the Copernican system did not come to enjoy widespread support in the mainstream scientific community until the 1630s and 1640s. Only then did astronomers have good reason to systematically explore the physical characteristics of the moon and other planetary bodies.

Further reading

1. R.Ariew, Studies in History and Philosophy of Science **15**, 213-26 (1984).
2. S.Y. Edgerton Jr., Art Journal **44**, 225-48 (1985).
3. P. Feyerabend,"Problems of Empiricism,Part II," In R.G.Golodny, ed.,The Nature and Function of Scientific Theories, Pittsburgh:University of Pittsburgh Press,275-353 (1975).
4. G.Galileo, Sidereus nuncius, Venice (1610),English translation:Sidereus nuncius,or the Sidereal Messenger, trans.A.V. Helden.Chicago, University of Chicago Press (1989).
5. G.Galileo, Le opere di Galileo Galilei, ed.A.Favaro, Florence:G.Barbera (1890-1909).
6. O. Gingerich,"Dissertatio cum Professore Righini et Sidereo Nuncio," In M.R.Righini Bonelli and W. R. Shea,ed.,Reason,Experiment,and Mysticism in the Scientific Revolution,New York,Science History Publications, 77-88 (1975).
7. J.Hevelius,Selenographia:sive, lunae descriptio. Gdansk (1647).
8. M. Kemp, The Science of Art:Optical Themes in Western Art from Brunelleschi to Seurat,New Haven,Yale University Press (1992).
9. G.Reaves and C. Pedretti, J.History of Astronomy **18**, 55-8 (1987).
10. E.A.Whitaker, "Selonography in the Seventeenth Century," In M.A.Hoskin,ed.,The General History of Astronomy. Cambridge:Cambridge University Press, vol.2, 119-43 (1983).
11. M.G.Winkler and A. V. Helden,Isis **83**, 195-217 (1992).

Brian Baigrie is associate professor at the Institute for History and Philosophy of Science and Technology, University of Toronto, Toronto, Canada. He can be reached by e-mail at baigrie@attcanada.net.