Galileo and the Telescope: Naturalistic Representations in Visual Astronomy

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Within the year following Hans Lipperhey's October 1608 patent application for the telescope, Galileo had devised his own three-powered version constructed from a tube filled with spectacle lenses. Initially, Galileo extolled the instrument's value for military reconnaissance, seizing the opportunity to improve his position at the University of Padua (he did receive tenure and an increase in salary from 480 to 1,000 florins per year)(1). However, it was not until the autumn of 1609 that the accomplished mathematician and natural philosopher would point his latest twenty-powered telescope toward the heavens. Indeed, his perennial ambition to improve his social status motivated the publication of his first observational results in March 1610, entitled *Sidereus Nuncius* (*The Starry Messenger*). With the hope of gaining a more prestigious position at the University of Pisa, he dedicated the brief book to the Grand Duke of Tuscany, Cosimo d'Medici II(2). While the astronomical discoveries hastily presented in this text lacked the eminence and influence of his later writings, particularly his *Dialogo*, the book's composition and visual evidence remain to this day a cornerstone in the field's methodology.

Graphical representations of scientific data persisted in the form of symbolic or geometrical diagrams until Galileo's unprecedented naturalistic depictions of the Moon in *Sidereus Nuncius*; they are the product of an artistically proficient imagination and the striving for a new means to persuasively argue unprecedented scientific results gleaned from the telescope. For the first time in the history of Western science, technology single-handedly determined the model for presenting scientific data, establishing the visual conventions of modern science. Inevitably, as Galileo's artistic training was cultivated by the naturalistic aims of Italian Renaissance art and the well-understood rules for the perspectival rendering of space and depth, the incipient scientific pictorial style formed in *Sidereus Nuncius* and the later *La Macchiae Solari* (Rome, 1613) endowed these realistic drawings with the same compelling value for the intellectual and the lay-person as religious art had already achieved.

In the opening passage of *Sidereus Nuncius*, he declares how "pleasing to the eye" it is to "look upon the lunar body…as if it were distant by only two of these measures [Earth diameters]… so that the diameter of the Moon appears as if it were thirty times…larger than when observed only with the naked eye"(3). Furthermore, Galileo emphasizes how the telescope enhances the senses and thus the intellect, as though the visual experience of telescopic observing alone reveals the workings of nature unequivocally to the human mind. He confidently asserts that through the lenses of his *perspicullum*(4),

"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."(5)

His observations adduce the "uneven" and "rough" terminator (the edge of the shadow on the Moon's surface) contrary to the expected uniform curve, but more importantly that light only reflects from the side of craters opposing the bright side of the Moon (fig. 1). Five engravings accompany the text as references or visual aids. At first glance with the modern eye, they unmistakably portray the familiar craters, valleys, and 'seas' of the Moon, yet when tasked with identifying the most prominent of these features, it becomes clear that Galileo's illustrations are in fact exaggerated graphic representations to enhance his bold hypothesis.(6) Moreover, they serve as rhetoric for the unique vision of the telescope. Their arguably secondary role as visual support is offset by the density of his "precise verbal pictures," as Mary Winkler and Albert Van Helden have described his scientific writing in "Representing the Heavens: Galileo and Visual Astronomy"(7). Galileo corroborates the centrality of prose in his letter to Cosimo d'Medici,

"For such is the condition of the human mind that unless continuously struck by images of things rushing into it from the outside, all memories easily escape from it. Others, however, looking to more permanent and long-lasting things, have entrusted the eternal celebration of the greatest men not to marbles but rather to the care of the Muses and to incorruptible monuments of letters."(8)

One must be suspect, however, of the potential motivations to diminish his 'lesser' mechanical arts background in deference to his increasing stature as an intellectual, considering the context of the letter in his desire to attain a position as the Grand Duke of Tuscany's chief philosopher and mathematician(9). Nevertheless, he recognized both the relevance and power of visually depicting what the eye was capable of sensing with the telescope.

The impact of Galileo's art training is altogether clear in a concluding argument regarding the Moon's perfectly circular appearance to the naked eye, despite the evidently super-terrestrial heights of lunar mountains. First, a diagram recalling demonstrations of the first artistic theories of shadows, postulated by Leonardo da Vinci and Albrecht Dürer, accompanies a geometrical argument claiming a lunar mountain to stand over four "Italian miles" in height. Such an argument makes his unconventional pictorial assertions from telescopic data more plausible by appealing to the prevalent scientific language, mathematics. Another optical 'visual ray' diagram posits the Moon's circular appearance as the manifestation of an inhibited "passage of vision" from atmospheric darkening(10). Galileo most likely proposed these standard geometric counterarguments to supply familiar evidence for his more controversial telescopic findings, anticipating the reactions of conservative astronomers. Principally, the dubious reliability of the telescope, the instrument this entire work so radically depended upon, opened debate over the legitimacy of its problematic discoveries.

Harold Brown cites Galileo as the first scientist to doubt the reliability of human vision in celestial observation, instead preferring the telescope as a purifying medium for science(11). After the release of *Sidereus Nuncius*, many scientists questioned Galileo's unwavering confidence in the instrument's function, including Giovanni Magini who in 1610 reported seeing triple images of the Sun with his telescope(12). In response, Galileo empirically demonstrated defects of human perception in resolving the angular size of stars, where "the naked eye distinguishes none of these shapes without the telescope, and all are seen encumbered with alien rays in the same radiant shape"(13). In the telescope's defense, he had adduced purely observational evidence in *Sidereus Nuncius* to demonstrate that the Milky Way comprised innumerable distinct stars through the optical, as opposed to its nebulous appearance to unaided vision. Nevertheless, while the Tuscan philosopher was satisfied with his instrument as a 'black box,' a more concrete geometric optical theory of the telescope was required to substantiate his results(14).

Soon, mathematicians and philosophers such as Johannes Kepler and Galileo as well as virtuosos of telescope construction like Christian Huygens and Johan Hevelius had formulated much of the necessary optics; as such instruments became more available, Galileo's observational discoveries were quickly verified(15). Newer telescopes offered broader fields of view and corrective optics like the Huygenian eyepiece (which eliminated chromatic aberrations), appealing to both astronomers and the military(16). Galileo's Moon drawings were corroborated by previously conflicting observers, such as the Englishman Thomas Harriot who previously had pointed his telescope at the lunar surface months before the Italian astronomer and had reported no craters or mountains. The five engravings in *Sidereus Nuncius* became the pictorial standard for representing the Moon, as evident in Hevelius' later lunar atlas, *Selenographia* (1647). Even Galileo's close friend, the Florentine artist Lodovico Cigoli, painted the Moon in this new 'style' below the feet of the Virgin in a 1612 fresco of the Assumption for Santa Maria Maggiore's Pauline Chapel. As the artist had difficulty reading Latin and the detail in the fresco lacks convincing resemblance to any individual Galileo drawing, it is likely that he observed the Moon through his own telescope and subsequently interpreted his rendition of the pockmarked surface(17). Curiously, Pope Paul V approved this 'maculate' moon on the ceiling of his tomb despite its ostensibly problematic context in the theme of the Virgin's immaculate birth. Steven Ostrow has proposed that this single ramification of Galileo's lunar discovery paled in comparison to the implications of his evidence for Copernican theory in discovering Jupiter's orbiting satellites, and was therefore tolerable given the unequivocal appearance of the Moon visible with the telescope(18). Additionally, he cites alternative exegetical traditions which may have been applied to align Church teachings with scientific results, suggesting that the Virgin is to be represented crushing heresy and humanity's fallen nature in the way that Heraclius defeats Chosroes in an adjacent scene(19). In fact, Galileo desired the compatibility of science and religion; as a Catholic and firm believer in the scientific method, he was convinced that the mystery of Scripture could be confirmed in nature. He once responded to an opposing theological argument that,

"Granting… two truths can never be contrary to each other, it is the task of wise expositors to try to find the true meanings of sacred passages in accordance with natural conclusions which have been rendered certain and secure … by necessary demonstrations"(20).

Unfortunately, this meaningful union of Church and science could not withstand the inescapable Copernican ramifications of his subsequent discoveries of Venus' Moon-like phases in 1610 and the revolving solar surface exhibited by the enigmatic sunspots(21).

Harriot and the German astronomer Christoph Scheiner observed sunspots with telescopes between late 1610 and autumn of 1611, producing a body of observing reports with drawings of the Sun. The former sketches several small black spots on each, but does not mention them in the accompanying written report. Scheiner, a mathematician like Galileo, published *Tres Epistolae* in

1612 with composite plates of observations demonstrating the orbiting behavior of point-like black dots over the course of weeks. Acknowledging the sensitive theological issue regarding the Sun as an immaculate body equated with Christ's, he authored the works under the pseudonym, *Apelles latens post tabulam, (*"Apelles hiding behind the painting")(22). Unfortunately, owing to the painful process of observing sunspots which involved staring at a magnified Sun through a telescope, the drawings are, as Scheiner describes, "not terribly exact, but rather hand drawn on paper as they appeared to the eye without certain precise measurement." He further warned that "the proportion of the spots to the sun should not be taken from the drawing"(23). Nonetheless, the visual component of *Tres Epistolae* stands alone as evidence, reliable or not, for the theory of solar satellites that he outlines in writing. With a small image size, he more convincingly renders the spots as orbiting planets and permits the neglect of their observable dynamic morphology within his admittedly deficient precision.

Galileo received a copy of Scheiner's publication in early 1612 and immediately disputed the German's observational methods and conclusions. Applying one of his pupil's ingenious ideas, he projected the image of the Sun onto a flat paper surface and traced the shadow-like forms of sunspots, thus drastically increasing the precision of solar observations and allowing for safe observing whenever the Sun was not obscured by clouds(24). Not surprisingly, Scheiner's argument was "vanquished by this sense experience," as friend, patron and *Accademia de Lincei* founder Federico Cesi praised the drawings(25). In 1613, Galileo wrote three letters in response to *Tres Epistolae* and published them together with 38 engravings of sunspots in a volume entitled, *La Macchiae Solari*; both Cesi and Cigoli were so awestruck by the drawings that they sponsored the first edition's publication of 1,400 copies, allowing the images to be published as large as possible on the printed page(26) (fig. 2). As Cesi anticipated, the visual figures alone were a coup de grace to Scheiner's theory. A decade later, the German astronomer published new results in concurrence with Galileo's observations. Indeed, visual evidence had become a primary force in telescopic astronomy, but also a stage for interpretation and controversy. Galileo's sunspot drawings are the matured progeny of the exaggerated Moon engravings, formed into pictures of naturalistic exactitude. As a prophetic prelude to the nascent scientific revolution, the recently promoted Lyncean Philosopher and Mathematician of the Grand Duke of Tuscany included one of the first ephemerides of Jupiter, predicting in clear, visual form the precise location of the Medicean stars for late April and early May, 1613 (figs. 3, 4). The visual conventions established in *La Macchiae Solari* for mapping the status of evolving sunspots and the position of celestial objects persist to this day.

Despite the worldwide success of these two works and their enduring impact on visual astronomy, such visual representations are to be found nowhere else in Galileo's work after 1613. In fact, his most famous works, *The Assayer* and *Dialogue Concerning the Two Chief World Systems* (1623, 1632 respectively), together contain one diagram(27). Considering his rapidly climbing academic prominence, his increasing distance from the mechanical arts may not be so surprising. As Winkler and Van Helden highlight, this period of Galileo's career (1610-1613) lies before the Church's banning of Copernican literature in 1616, along with which *Sidereus Nuncius* and *La Macchiae Solari* were included, and the final battle between the Ptolemaic and Copernican systems in which the aging Italian's discoveries delivered the final blow to the system of the ancients. Visual astronomy would later rise to preeminence in the 1640s with the works of Hevelius, once the aesthetic and scientific conventions of displaying such pictorial information had been founded in precise depictions of natural experience.

The source of this motivation to represent natural phenomena visually, especially in the case of Galileo's astronomical work, stemmed from the naturalist ethos of the Renaissance, pithily summarized by Dürer as, "Art is in nature. Who can extract it, has it"(28). In particular, both the lay-person and the intellectual were perceptually prepared for pictures imitating the world of experience by the spatial theory of linear perspective that was already ubiquitous in religious painting. Galileo's artistic talents, honed by pictorial exercises of depth and shadow on complex geometrical figures(29), made him sensitive to certain visual cues in the telescope's two-dimensional image; therefore, he was able to intuit the mountainous lunar landscape.

The theory of propagating visual rays at the heart of linear perspective also convinced Galileo and his pupil Benedetto Castelli why their initial sunspot tracings had to be reflected and transferred to another sheet of paper to account for the telescope's inverted image(30). In the visual debate on sunspots, the Italian artist-scientist would not only have been aware of the changing shape of the enigmatic solar features, but he was able to identify their foreshortened forms as they receded toward the solar limb in close, successive observations.

Thus, as Alberti's window linked human vision to the theoretical framework of illusionistic depth in painting, Galileo's application of artistic spatial theory to the enhanced sensory experience of telescopic observing established the perceptual apparatus with which the geometry of Copernicus' *De Revolutionibus* was subsequently realized. In between perspective and science, Galileo forged a new faith in the telescope, and hence the discoveries made with the instrument.
Thomas Kuhn describes telescopic evidence as "propaganda" for modern science, in the sense that each of Galileo's breakthroughs was a visual model (in Kuhnian terminology, a "visual paradigm") for

the solar system and a rotating Earth, the two fundamental principles of Copernican theory(31). The phases of Venus imitated the orbit of our Moon, the Medicean stars modeled the whole solar system as a body whose behavior could be predicted mathematically, and the periodic rotation of sunspots meant revolvement within the Sun itself, as well as with the planets around it including the Earth; not only was the notion of the solar system demonstrated and confirmed by visual observation, but the idea that the same physical theory of motion applied to both Earth and the heavens became fundamental to science, as Newton would later formulate in classical mechanics. The Church's immaculate universe and the conception of a real heaven and hell began to fade as a metaphor, and Galileo's telescopic discoveries, indebted to his perceptive abilities developed from artistic training in Renaissance Florence, catalyzed the birth of modern science and the increasing secularism of the 17th and 18th centuries.

In 1846, U. Leverrier in France and J.C. Adams in England independently predicted the existence of Neptune before it was observed with telescopes(32), demonstrating that the dynamic theory of the solar system intuited all of its creation before the Church or even observational astronomers could account for its existence. After Galileo – and the development of linear perspective by Renaissance artists - there was no turning back.

Acknowledgments

I would like to express my gratitude to Prof. Samuel Edgerton for introducing me to the fascinating dynamic between art and science in Renaissance Europe and its indelible marks on Western civilization. I am also greatly indebted to Prof. Jay M. Pasachoff of the Williams College Astronomy Department for availing his remarkable collection of original Galileo texts and virtually every other pivotal scientific document of Western science.

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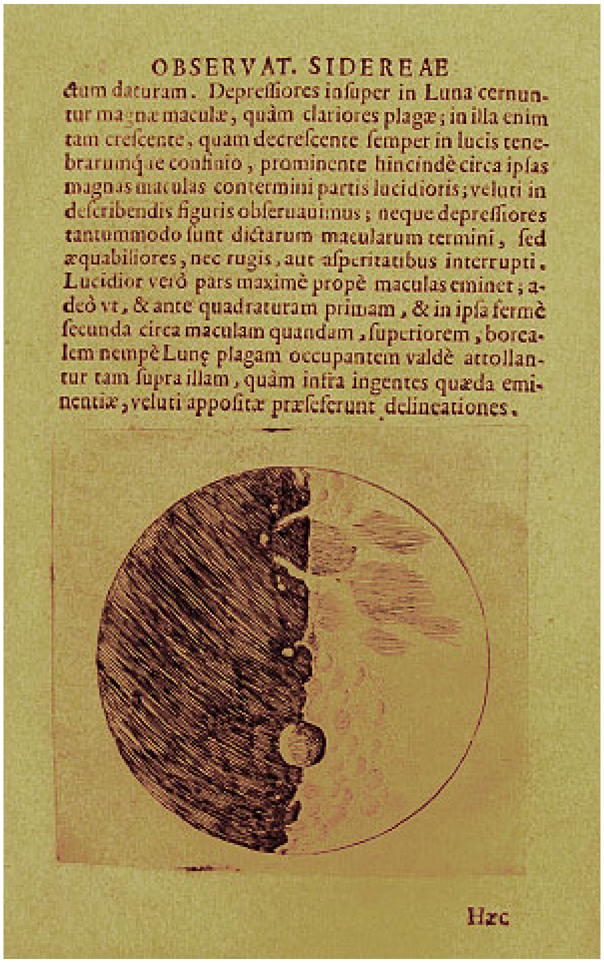
Note

All images were taken by the author of original Galileo texts from the collection of Professor Jay M. Pasachoff, of the Williams College Department of Astronomy and the Hopkins Observatory.

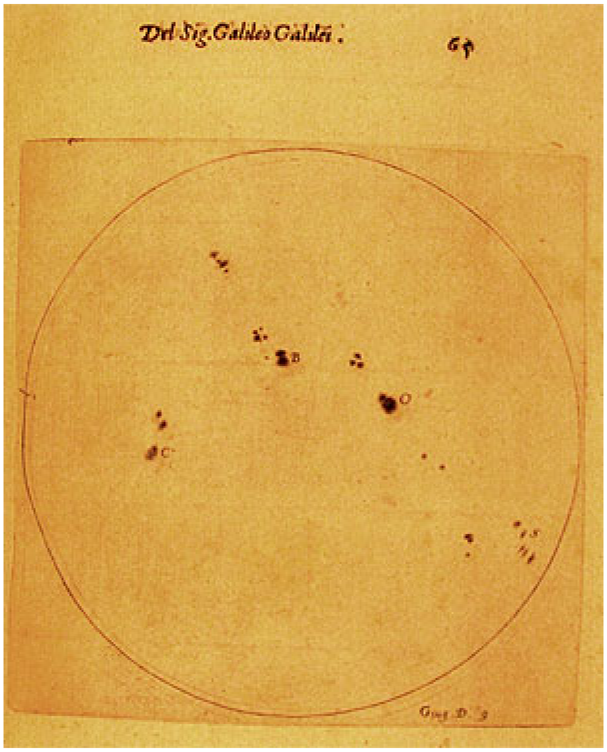


OBSERVAT. SIDEREAE

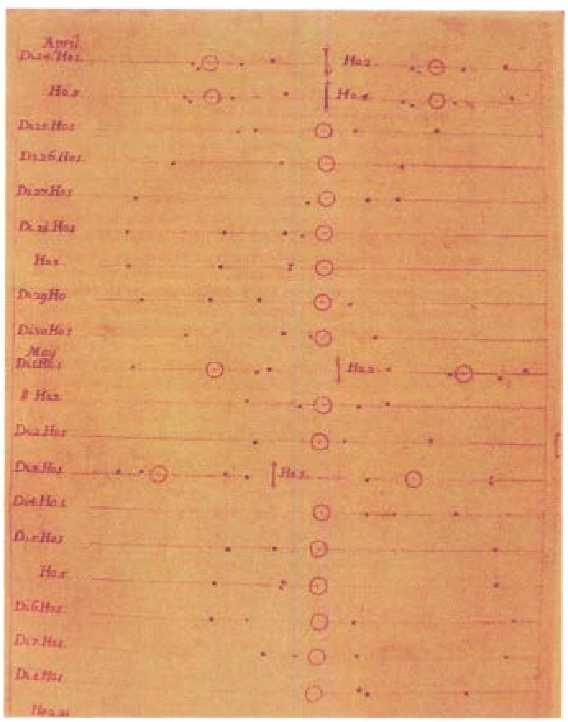
ctum daturam. Depressiores insuper in Luna cernuntur magnæ maculæ, quàm clariores plagæ; in illa enim tam crescente, quam decrescente semper in lucis tenebrarumque confinio, prominente hincindè circa ipsas magnas maculas contermini partis lucidioris; veluti in describendis figuris obseruauimus; neque depressiores tantummodo sunt dictarum macularum termini, sed æquabiliores, nec rugis, aut asperitatibus interrupti. Lucidior verò pars maximè propè maculas eminet; adeò vt, & ante quadraturam primam, & in ipsa fermè secunda circa maculam quandam, superiorem, borealem nempè Lunę plagam occupantem valdè attollantur tam supra illam, quàm infra ingentes quædam eminentiæ, veluti appositæ præseferunt delineationes.

Hæc

1. Moon engraving from *Sidereus Nuncius*, 1610.



2. Sunspot drawing from *La Macchiae Solari*, 1613.



[picture included from print edition]
3. Ephemeris for Jupiter and moons, April and May, 1613. From *La Macchiae Solari*.

4. Portrait of Galileo. Notice the putti figures at work in the upper register, especially the one with a perspicullum instead of the conventional horn. From *La Macchiae Solari.*

Footnotes

1 Galileo Galilei (trans., Van Helden, Albert), *Sidereus Nuncius* (Chicago: University of Chicago Press, 1989), 8.

2 The conventional translation of the title, "The Starry Messenger," is the product of the text's first translator, Stillman Drake (1957), and has for whatever reason become the accepted over the other possibility (suggested by Van Helden), "The Starry Message."

3 Galilei, 35,36.

4 Van Helden translates this as "spyglass," though it clearly derives from the Latin for "spectacles" or "lenses;" he points out that Galileo did use the Italian word *occhiale* (from 'eye' or 'to gaze') as well.

5 Ibid., 36.

6 Guglielmo Righini and Owen Gingerich have attempted to identify the date of these depicted observations, with much difficulty. The latter claims that the largest crater discussed in detail by Galileo is in fact Albategnius, one of the largest such features on the Moon's surface. Nevertheless, it is represented at such a size that it would be easily visible to the eye. See Ewen Whitaker's "Galileo's Lunar observations and the Dating of the Composition of 'Sidereus Nuncius,'" *Journal for the History of Astronomy* 9, (1978), 155-169.

7 Mary Winkler and Albert Van Helden, "Representing the Heavens: Galileo and Visual Astronomy," *Isis* 83, No. 2 (June, 1992): 207. Winkler and Van Helden present other such "transitional" visual arguments such as Apian's discovery of comet tails pointing away from the Sun (a major discovery for the Copernican system).

8 Galilei, 29. The antiquarian fervor of the Renaissance is remarkably clear in this letter, as Galileo likens his naming of the Medicean stars to a similar story involving Julius Caesar. He ends the letter with, "Written in Padua on the fourth day before the Ides of March, 1610." (33)

9 Ironically, Galileo was the first to condemn the published work of Fontana and Hevelius for relying solely on visual evidence. See Winkler, Van Helden, 216-217.

10 Galileo, 49-51. While incorrect in this case, atmospheric darkening is in fact why the Sun appears circular (limb darkening).

11 Harold Brown, "Galileo on the Telescope and the Eye," *Journal of the History of Ideas* 46, No. 4 (Oct.-Dec., 1985): 487-501.

12 Ibid., 488.

13 Le *Opere di Galileo Galilei*, ed. Antonio Favaro, (Florence, 1890-1909), VI, 359, "Assayer," 321.

14 The first published edition of *Sidereus Nuncius* (Venice, 1610) includes several short treatises on relevant optical problems like the rainbow (worked out in this edition by Marci Antonii) and more importantly, spherical aberrations from spherical lenses. Ironically, Magini addresses the latter issue in this volume, after seeing multiple images of stars through telescopes (*Breve Instruttione sopra L'Apparenze et Mirabili Effeti dello Specchio concavo sferico*, December, 1610).

15 Albert Van Helden, "The Telescope in the Seventeenth Century," *Isis* 65, No. 1, (March, 1974): 38-58.

16 Ibid.

17 Steven Ostrow, "Cigoli's Immacolata and Galileo's Moon: Astronomy and the Virgin in Early Seicento Rome," *The Art Bulletin* 78, No. 2, (June, 1996): 218, 229-231.

18 Ibid., 232.

19 Ibid., 233. 6th and 7th century theologians claimed that the Moon signified "the failings and faults of corrupt nature," or the eponymic lunacy. The Copernican debate is riddled with such exegetical twists. Though the Protestants reprimanded Galileo, it was Martin Luther who once wrote that "sacred Scripture tells us that Joshua [Joshua 10:13] commanded the Sun to stand still, and not the Earth." (from a 1539 "Table Talk" in Andrew D. White, *A History of the Warfare of Science with Theology in Christendom*, (New York: Appleton, 1896), I, 126.)

20 Ibid., 234-235. There are remarkable similarities between Galileo and the later Einstein's faith. The latter once remarked that faith "takes the form of a rapturous amazement at the harmony of natural law… This feeling is the guiding principle of his life and work." (see Albert Einstein, "About Religion," *Ideas and Opinions*, (New York: Three Rivers Press, 1982), 36-53.)

21 Though it was not questioned at the time, the Sun does not rotate as a rigid body like the planets or a rolling ball. The solar surface's gaseous composition leads to differential rotation, since the rotation of material differs with latitude.

22 Albert Van Helden, "Galileo and Scheiner on Sunspots: A Case Study in the Visual Language of Astronomy," *Proceedings of the American Philosophical Society* 140, No.3, (September, 1996): 369-372.

23 Ibid., 370-371.

24 Ibid., 375-376.

25 Ibid., 378.

26 Ibid., 378-379.

27 Winkler, Van Helden, 197.

28 Fritz Koreny, *Albrecht Dürer and the Animal and Plant Studies of the Renaissance*, (Little Brown & Company, 1988), 14.

29 Many such texts listed in Samuel Edgerton, "Galileo, Florentine 'Disegno,' and the 'Strange Spottednesse' of the Moon," *Art Journal* 44, No. 3, Art and Science: Part II, Physical Sciences (Autumn, 1984): 225-232.

30 Van Helden, 375-376. One can compare this development of a perceptual schema to the modern pictorial interpretations of Einstein's four-dimensional theory of general relativity and space-time.

31 Thomas Kuhn, *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought*, (Cambridge: Havard University Press, 1985), 222-224. Robert Westman provides an insightful critique of Kuhn's shifting perceptual paradigm in "Two Cultures or One?: A Second Look at Kuhn's *The Copernican Revolution*," *Isis*, 85, No. 1, (March, 1994), 79-115.

32 Kuhn, 261-265.