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Physics in Perspective

The Scientific Revolution in Art

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In the continuing spirit of narrowing the gap between the "two cultures," this essay illustrates, quite literally through representative works of Western art, the striking parallels between the visual arts and the discoveries made during the Scientific Revolution, the period between Copernicus's 1543 *De revolutionibus* and Newton's 1687 *Principia* when the foundations of modern science swept away the scientific heritage of the ancient and medieval worldviews, a period that, though underrepresented in art–science studies, marked the birth of the modern mind and, indeed, the modern world.

Key words: History of science; history of physics; scientific revolution; art history; art–science connections.

> *The historical process that led to Alamogordo and to the moon is known as the Scientific Revolution.*
> – Yuval Noah Harari, *Sapiens: A Brief History of Humankind* (2011)

Introduction

The Scientific Revolution is the name historians give to the period in European history when, during the long seventeenth century, focusing on age-old questions concerning the architecture of the solar system and the motion of the planets, the conceptual, methodological, and institutional foundations of modern science swept away the scientific heritage of the ancient and medieval worldviews.[1] It has been proclaimed "the most profound revolution achieved or suffered by the human mind,"[2] indeed "a turning point in the history of the world."[3] A civilization organized around Christianity was transformed into a modern world centered on science through the important work of some of the most notable scientists in history including Nicolaus Copernicus, Tycho Brahe, Johannes Kepler, Galileo Galilei, René Descartes, Robert Boyle, Robert Hooke, Christiaan Huygens, and, standing on the shoulders of them all, Isaac Newton, whose crowning tour de force, *Philosophiae naturalis principia mathematica* (*Mathematical Principles of Natural Philosophy*), established, at last, *the* principles of natural philosophy in

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1687, formulating the framework for a clockwork, mechanical universe (figure 1) that set the game plan of physics until supplemented by the sciences of thermodynamics and electromagnetism in the nineteenth century, and subsequently modified by the new physics of relativity and the quantum early the following century.

Although some have questioned the revolutionary nature of a process that unfolded over the course of more than a century,[4] no other was as revolutionary as this one in transforming the way science is done. It was a total reformation of science, a major re-building with new materials—new methodologies, especially, and in particular, the novel use of experimentation and mathematics to understand and describe nature—rather than a quick-fix internal reworking of a pre-existing structure. It entailed a wholesale dismantling and replacement, as opposed to a minor renovation, of entrenched orthodoxy, resulting in the establishment of a clearly recognizable new order noticeably distinct from its precursor and having no antecedents, *in*novative as opposed to *re*novative. Newtonian mechanics, for example, was not built upon Aristotelian physics; it replaced it. Most historians and scientists today recognize, just as surely as did eighteenth-century Europeans, that something clearly extraordinary occurred in the sciences.

Nevertheless, despite its importance for the birth of modern science—and, indeed, for the birth of the modern world and the making of the modern mind[5]—the artwork of the Scientific Revolution has been notably underrepresented in art–

Fig. 1. Joseph Wright of Derby's *A Philosopher Giving a Lecture on the Orrery* (1766), now in England's Derby Museum and Art Gallery. The orrery was an eighteenth-century device used to illustrate Newton's clockwork, mechanical universe. *Credit*: Courtesy of Wikimedia Commons

Fig. 2. *The Sciences and the Arts* (before 1650) by the Flemish painter Adriaen van Stalbent, now in Madrid's Museo de Prado. Gallery paintings such as this represent a new pictorial genre of collectors' curiosity cabinets (*Wunderkammer*) popular during the Renaissance, forerunners of today's art and science museums. Here, a spacious and richly decorated room contains representations of the wonders of the natural world (animals, plants, and minerals) along with examples of human creativity (painting and sculpture). During this early "encyclopedic" phase, the genre reflected the Baroque period's culture of curiosity and enthusiasm for collecting, when art works, scientific instruments, *naturalia* (things made by nature) and *artificialia* (things made by humans) were equally the object of study and admiration. These paintings, like the world they were a part of, were typically populated by persons as interested in discussing scientific instruments as in admiring paintings. *Credit*: Courtesy of Wikimedia Commons

science studies, appearing only sporadically in general studies,[6] typically discipline specific (for instance, astronomy)[7] and spanning centuries if not millennia, and in detailed treatments of specific period pieces.[8] In the wake of Renaissance revolutions in artistic visualizations, such as the invention of linear perspective, artists and natural philosophers shared a culture of reciprocally influential ways of seeing and depicting nature, intellectually as well as visually, as artistic taste and the study of nature moved along one and the same course (figure 2).[9] Satisfying the new craving for realism and exactness, this new method of "painting by numbers," rationalizing the representation of space, was the result of a carefully calculated mathematical fusion of art and science to give the *trompe-l'œil* illusion of real three-dimensional space on an otherwise two-dimensional surface. With the rise in importance of empiricism, perspective construction as the science of seeing became a vital meeting point between scientists and artists, each group focused on observing and recording visual phenomena. Never again was art so essential to science, or science so important to art. Indeed, although the two are distinct in the modern ordering of culture, they were at this time aspects of a single endeavor concerning the "rationalization of sight."

These revolutionary artistic attitudes and practices helped pave the path for the equally revolutionary sciences developed during the early modern period. In their realistic depiction of the natural world, the visual acuity of Renaissance artists, a key creative influence on Western science, was central to the establishment of "the new [empirical] attitudes that characterized the Scientific Revolution."[10] Social barriers between manual and intellectual labor crumbled as the new artifactual knowledge of artists and artisans challenged the old textual knowledge of scholars. Painterly practitioners led the transformation, soon emulated by the new experiential sciences, from reflective and contemplative to active and exploratory ways of knowing. This new "independence of artists from the authority of ancient explanations of natural phenomena helped to create a milieu in which the scientific revolution could take place."[11] Not surprisingly, the art of the Scientific Revolution beautifully reflects the revolutionary science of the period.

The Copernican Revolution: From a Closed World to an Infinite Universe

Historians conventionally mark the start of the Scientific Revolution with Copernicus's *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*), the title itself proclaiming a revolution of sorts, published in 1543 (figure 3).[12] Copernicus's heliocentric system moved the earth and shattered the outer walls of the compact, medieval cosmos. Michelangelo's Sistine Chapel *Last Judgment* (figure 4), completed in 1541, analogizes Christ as a classical Apollonian sun god superimposed over a brilliant radiant sun positioned at the center of a decidedly circular composition.[13] Described as a "pictorial vision of heliocentrism,"[14] the fresco was in fact commissioned in 1533 by Pope Clement VII, who had expressed in that same year an interest in the Copernican heliocentric proposal, news of which spread across Europe decades before its publication in 1543 following the circulation of his ideas in manuscript form. The *Allegory of Divine Wisdom* ceiling fresco (1629–33) by the Italian painter Andrea Sacchi in Rome's Palazzo Barberini has also been interpreted as a depiction of the sun-centered Copernican universe.[15]

The absence of stellar parallax—the small shift in the position of nearby stars relative to more distant stars due to earth's motion around the sun (indeed, so small—less than one arcsecond for even the nearest stars—that it was not detected until 1838 with sophisticated telescopes)—implied that the universe is much larger than previously imagined, possibly infinite in size. Filling up of infinite space with

Fig. 3. A statue of Copernicus in front of Chicago's Adler Planetarium "erected in 1973 by the Copernicus Foundation & the Polish American Congress to commemorate the 500th anniversary of his birth." Copernicus holds in one hand a heliocentric armillary sphere, symbol of astronomy, and sits, appropriately, on the reflection of the early morning sun rising over Lake Michigan. Inscribed on the platform are the words: "By reforming astronomy he initiated modern science." Just as the rising sun announces a new day, the sun-centered Copernican cosmology inaugurated a new science. One recent visitor must have thought the whole business a bunch of bananas: a barely noticeable banana is impaled on the dividers held in the astronomer's other hand—"*Sun*kist" brand, no doubt! A similar monument to Copernicus can be found in Warsaw, Poland. *Credit*: Photo by the author

stars finds its counterpart, even if only coincidentally, in the characteristically crowded compositions of the Baroque period's principle of plenitude in paint (figure 5): if the universe is infinite, might as well populate it with a pile of people or putti; otherwise, what a tremendous waste of space. In music, an infinity of notes slid glissando-like off the strings of the violin, the archetypal Baroque instrument, as if to sanction in sound the infinite expanse in space of the new Copernican universe. The Renaissance invention of linear perspective was an earlier attempt to portray the notion of infinity in pictorial space.[16]

Sounding much like his Italian contemporary, the artist and pioneer art historian Georgio Vasari, Copernicus compared his interlinked, unified system, wherein "all the phenomena proceed from the same cause, which is in the Earth's motion," to the nonintegrated geocentric system of the ancients: "With them it is as though an artist were to gather the hands, feet, head, and other members for his images from diverse models, each part excellently drawn, but not related to a single body, and since they in no way match each other, the result would be monster rather than man."

Compare Copernicus's words here to those of Vasari, offering in his *Lives of the Most Excellent Painters, Sculptors, and Architects* advice very similar to that tendered a century earlier by the Italian Renaissance humanist author and artist, Leon Battista Alberti: "The artist achieves the highest perfection of working by

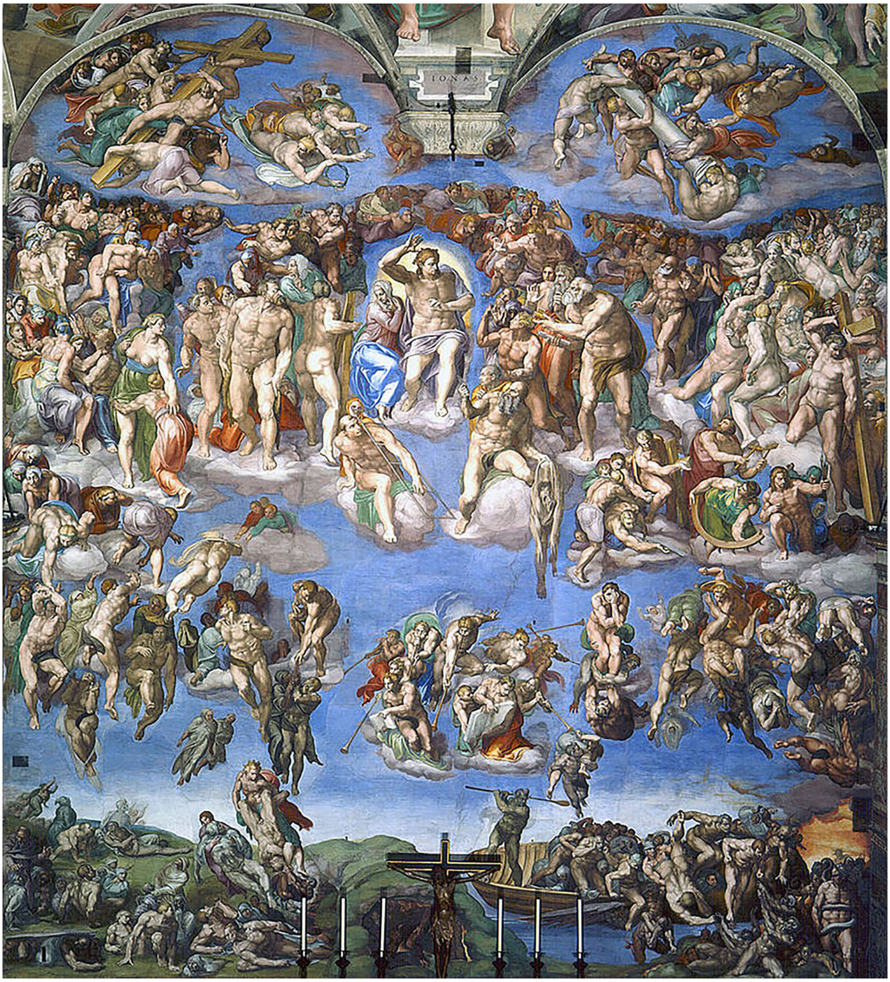

Fig. 4. Michelangelo's Sistine Chapel *Last Judgment* analogizes Christ as a classical Apollonian sun god—*Christos Helios*—positioned at the center of a decidedly circular composition. *Credit*: Courtesy of Wikimedia Commons

Fig. 5. *Minerva Protects Peace from Mars* or *War and Peace* (1629–30), a typical Baroque painting by the archetypal Flemish Baroque painter Peter Paul Rubens, now in London's National Gallery. As if endorsing a painter's principle of plenitude, this style's characteristically crowded composition filling all of space, of which there was plenty in the increasingly popular and possibly infinite Copernican universe, certainly, if only coincidentally, resonates with the new science. Pictorial space in painting opened up at the same time the finitude of the cosmos was put into question. *Credit*: Courtesy of Wikimedia Commons

copying the most beautiful things in nature and combining the most perfect members, hands, head, and torso and legs, to produce the finest possible model."[17] Copernicus, educated in the humanist tradition and an amateur painter (the astronomer Tycho Brahe considered himself the proud possessor of an alleged self-portrait by Copernicus), could very well have read Alberti and been exposed to this philosophy during his period of study in Italy, which included the study of anatomy during his training as a physician, and he certainly would have seen Italian paintings.

Here, at one of the most pivotal periods in the history of science, Copernicus makes "a direct comparison with the art of painting in one of its finest hours … an interesting meeting point between Renaissance art theory on the one hand, and the beginning of the so-called Scientific Revolution on the other."[18] As Copernicus himself recognized, the appeal of his heliocentric astronomy was aesthetic rather than pragmatic: the Copernican achievement was, in a very real sense, much like that of an accomplished draftsman. And just as in art, coherence, not proof, became the arbiter in science, which strives for a “self-consistent description of nature that hangs together in a convincing way … building an evermore intricately linked explanatory system.”[19]

Kepler and the Baroque

The birth of modern science, born of the fusion of observation and theory, teetered on the precipice of the mutual mistrust of an extravagant Danish extrovert and a pious German introvert (figure 6). The circles and epicycles that were for so

Fig. 6. Astronomers Tycho Brahe (holding the sextant) and Johannes Kepler, two men as complementary in their personalities as in their scientific skills, by the Czech sculptor Josef Vajce on the former site of Tycho’s summer home in Prague, very close to the city’s castle district. Strangely, although Brahe was the observationalist and Kepler the theoretician, it is the nearsighted Kepler who strains to look up to the sky. *Credit*: Photo by the author

Fig. 7. Like Kepler's elliptical orbits, Caravaggio's Mannerist/Baroque style, with its elongations, exaggerations, and other deformations and distortions that upset the harmony and stability of idealist Renaissance sensibilities, represents a realist depiction of nature based on a bold submission to empirical facts often far removed from dreamed perfection. *Credit*: National Gallery, London, courtesy of Wikimedia Commons

long the staples of astronomy were finally discarded early in the seventeenth century by the "new astronomy" (*Astronomia nova*, 1609) of Johannes Kepler, which was based fundamentally on the careful observations of Tycho Brahe, the most accurate made before the invention of the telescope. Working together at the court of Emperor Rudolf II in Prague, Kepler, using Brahe's observations of the planet Mars, discovered that Mars moves around the sun in an elliptical orbit, not, as was believed since antiquity, a circular orbit.[20] Not even Copernicus had challenged the ancient Platonic principle of circularity.

Caravaggio's *Supper at Emmaus* (figure 7) was painted at the time Kepler was engaging in his quest to unravel the mysteries of planetary motion (ca. 1600), and exhibits the same foreshortening—notice the extended arm that seems to protrude out of the picture plane—as Kepler's proposed elliptical orbits for the planets. (That a circle, representing the ideal in geometry, becomes an ellipse in foreshortened projection was proved by Apollonius of Perga in the third century BC.) Kepler's "distorted" planetary orbits resonated with the curvilinear distortions characterizing contemporary Baroque architecture (figure 8), and shared features of earlier Mannerist art, distinguished by exaggerated and distorted forms, all in reaction against the idealized, restrained, and ordered style associated with the High Renaissance.[21]

In the first serious challenge to the classical canon of uniform circular motion, Kepler also discovered that a planet's orbital speed varies inversely with its distance from the sun, traveling faster when closer to the sun, slower when farther out, sweeping out equal areas in its orbit around the sun in equal intervals of time, a geometrization, we now know, of conservation of angular momentum. Kepler reasoned that a force emanating from the sun, becoming stronger when a planet is closer to the sun and weaker when it moves farther out in its orbit, must be responsible for moving the planets in their orbits. Although he incorrectly attributed this force to magnetism acting between a planet and the sun, he was the first to suggest that a *physical* force moved the planets.[22] He was the last scientific astrologer and the first astrophysicist.

While working on the problem of the promenade of the planets, Kepler managed to publish two important works on the science of optics, including a detailed

Fig. 8. Aerial view showing the elliptical plan of Saint Peter's Square, the large plaza located directly in front of St. Peter's Basilica in Vatican City, the papal enclave inside Rome. Designed by the Italian sculptor and architect Gian Lorenzo Bernini and constructed between 1656 and 1667, two granite fountains are located at each focus of the ellipse delineated by Bernini's famous colonnade with an ancient Egyptian obelisk marking the center of the ellipse. In 1817 circular stones were set to mark the tip of the obelisk's shadow at noon as the sun enters each of the signs of the zodiac in turn through the year, making the obelisk a gigantic meridional gnomon. *Credit*: Google Earth

treatment of the *camera obscura* and, in the first major physiological discovery in the history of science, the first correct explanation of retinal vision, both of which displayed his debt to artistic visualization, relying in particular on famed German Renaissance artist Albrecht Dürer's visualization of optical problems a century earlier, yet another connection between art and physics in the Scientific Revolution: Kepler clearly transformed the "visualization" of Dürer from art to science.[23] The information carried by light is important to both the artist and the astronomer, and advances in Renaissance naturalistic painting reflect those in both pre-telescopic and telescopic astronomy.

Kepler's first model of the universe, published in 1597 as *Mysterium cosmographicum* (*The Cosmographic Mystery*), was a reworking within the Copernican framework of the ancient Pythagorean "harmony of the spheres," a metaphysic that regarded music, a quadrivial member of the seven liberal arts of antiquity, as an embodiment of the harmonic structure of the universe.[24] One of the earliest endorsements of heliocentrism, it was an elaborate model for the solar system based on six spheres, one for each of the six planets known in Kepler's time, inscribed and circumscribed around the five perfect Platonic solids nested one within the other (figure 9) that may have been inspired also by the ornamental ivory turnings that were quite popular as decorative art at the time (figure 10).[25] It was an idea that Kepler carried with him through life (he published a second edition in 1621), and inspired even his discovery, quite possibly guided by his interest in practical music,[26] published in his 1619 *Harmonices mundi libri V* (*Five Books on the Harmony of the World*), that the ratio of a planet's orbital period squared to its average distance from the sun cubed is the *same* for *all* planets, a real harmony in the clockwork motion of the solar system, later labeled Kepler's third law of planetary motion and shown by Newton to contain the essence of universal gravitation.

Galileo Galilei: Scientist, Artist, Artisan

Just as so much has been written about him,[27] Galileo has been the focus—and sometimes the creator and inspirator—of much art, from his time to ours (figure 11). His ink-wash drawings of the lunar craters, announced to the world in his *Sidereus nuncius* (*Starry Messenger*) in 1610, expertly rendered with special attention to the chiaroscuro effects of light and shadow, led him "to the opinion and conviction that the surface of the moon is not smooth … but is uneven, rough, and full of cavities and prominences, being not unlike the face of the earth, relieved by chains of mountains and deep valleys."[28] Art historian Samuel Edgerton comments: "With the deft brushstrokes of a practiced watercolorist, [Galileo] laid on a half-dozen grades of washes, imparting to his images an attractive soft and luminescent quality. Remarkable indeed was Galileo's command of the Baroque painter's convention for contrasting lighted surfaces, and his ability to marshal dark and light washes to increase their mutual intensities.…

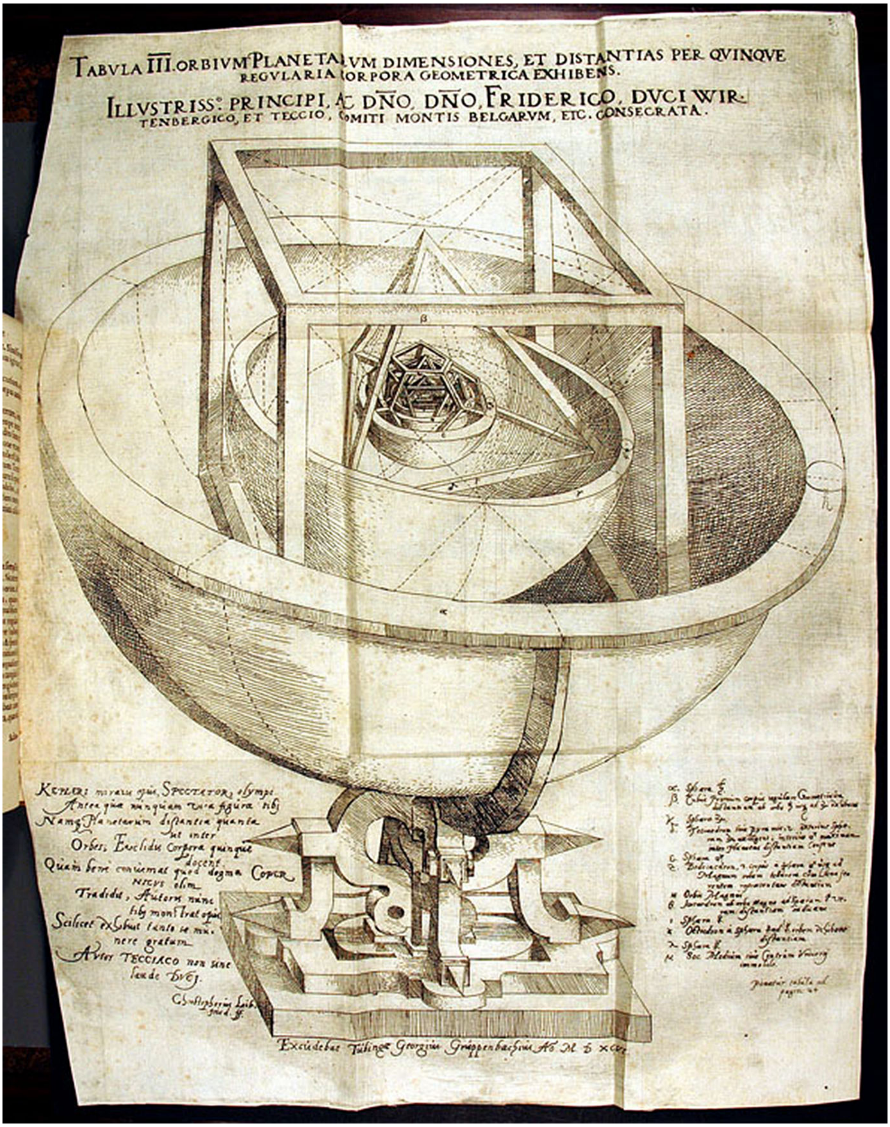

Fig. 9. Illustration from Kepler's 1596 *Mysterium cosmographicum*, a geometrical archetype of the solar system showing the spheres of the planetary orbits bounded by the five regular solids (working outward from the central sun: the octahedron, the icosahedron, the dodecahedron, the tetrahedron, and the cube). Not believing that these spheres or solids had a physical existence, Kepler regarded the regular solids as archetypes with a kind of physical efficacy, mathematicals that abided with the Creator since the beginning of time shaping the structure of the visible heavens. Interestingly, modern cosmology posits a cosmic octahedral or possibly dodecahedral topology for the universe. *Credit*: Courtesy of Wikimedia Commons

Fig. 10. *Cabinet of Curiosities* (1690s), a *trompe-l'oeil* painting by Domenico Remps, now in Florence, Italy's Opificio delle Pietre Dure, that blurs the boundary between real and fictitious space in its representation of a cabinet of curiosities (recall figure 2). Note the elaborately nested geometric figure at the right end of the middle shelf. Frederick I, Duke of Württemberg, and Holy Roman Emperor Rudolf II, Kepler's first and second patrons, had such collections, Rudolf's being unrivaled north of the Alps. *Credit*: Courtesy of Wikimedia Commons

With artistic economy worthy of Tiepolo, Galileo indicated the concave hollow [of a crater] with a single stroke of dark, leaving a sliver of exposed white paper to represent the crater's glowing brim."[29]

His carefully drawn sketches of sunspots, shown increasingly foreshortened as they neared the limb of the sun, thus indicating that they are actually on the surface of a rotating sphere, betray the skill of an artist experienced in the Mannerist tradition.[30] Galileo studied mathematics in Pisa with a former teacher from the Accademia del Disegno (Academy of Drawing), a Florentine art school—the world's first official academy of art—founded in 1563 by Giorgio Vasari. The telescope-toting Tuscan was himself elected a member of this prestigious academy in 1613; his one-time math mentor, Ostilio Ricci, was its first permanent lecturer in mathematics. Galileo was certainly no stranger to the arts: his father was an accomplished musician and music theorist.

Just as Galileo's scientific convictions were influenced by his aesthetic sensibilities, his new science, in turn, inspired contemporary art. The visual acumen of

Fig. 11. Flemish Baroque painter Peter Paul Rubens's *Self-Portrait in a Circle of Friends from Mantua* (ca. 1605), now in the Wallraf-Richartz Museum, Cologne, Germany. In the center of the painting are Galileo and, looking out directly toward the viewer, the artist, with his brother, Philip, in the background. At the left are two former students of the philosopher Justus Lipsius, shown standing behind the artist. At the time, artists were of a lower social class than scholars, and so including himself in such a learned circle may have been the primary motivation behind the painting. Rubens met Galileo in Italy and was a fan of astronomy (see, for example, his 1637 *Birth of the Milky Way*, Museo del Prado, Madrid, and ca. 1635–40 *Landscape by Moonlight*, Courtauld Gallery, London; see also figure 14) and of the general philosophical discussion that filled the air of the Dutch Golden Age. *Credit*: Courtesy of Wikimedia Commons

Galileo's illustrations of the lunar surface, marking the beginnings of astronomy as a visual science, so impressed his friend and fellow Ricci student, the leading Tuscan painter Lodovico Cardi da Cigoli, that the painter decided to incorporate Galilean discoveries in his fresco of *The Virgin of the Immaculate Conception* in the domed ceiling of the Pauline Papal Chapel in Rome's Basilica of Santa Maria Maggiore (figure 12). It is the first depiction in the history of Western art of the Madonna standing on a most maculate crater-pocked moon rather than the conventionally smooth and immaculate crescent consistent with most Marian associations (such as the Spanish Baroque artist Diego Velázquez's *The Immaculate Conception*, now in London's National Gallery, painted only a few years after Cigoili's version).[31] Adam Elsheimer's *The Flight into Egypt* (Alte Pinakothek, Munich), thought to be the first naturalistic rendering of the night sky in art complete with a realistic depiction of lunar maria (even if the diagonal band representing the Milky Way is too narrow, too bright, and located in the wrong part of the sky in comparison with several otherwise accurately rendered constellations), was painted in Rome at the same time Galileo announced his discoveries.[32]

Galileo's impressionistic technique for portraying the transient, almost transcendent, moonscape foreshadows the style of the great early nineteenth-century English landscape painter John Constable and that of his contemporary compatriot J. M. W. Turner, whose lesser-known works include a ca. 1826–27 Galileo-like wash drawing of *Galileo's Villa* in Arcetri outside Florence, now in the Tate London. Galileo's dreamy moonscapes, the first illustrations ever published recording the actual appearance of the surface of a celestial body, anticipated the genre of autonomous landscape painting in the history of art.

Other telescopic discoveries made by Galileo, all of which supported the Copernican hypothesis, appeared in the art of the Scientific Revolution, including a series of eight small canvases by the Italian artist Donato Creti, now in the Vatican Museum, depicting disproportionately sized celestial bodies painted by

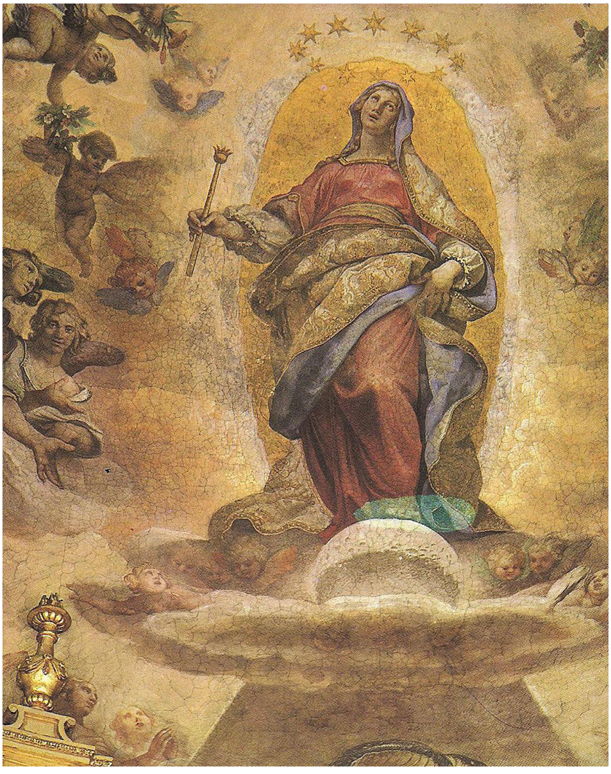

Fig. 12. Lodovico Cigoli's (ca. 1610–12) fresco of *The Virgin of the Immaculate Conception* in the domed ceiling of the Pauline Chapel in Rome's Basilica of Santa Maria Maggiore. *Credit*: Courtesy of Wikimedia Commons

the miniaturist Raimondo Manzini (figure 13).[33] Rubens, an acquaintance of Galileo (recall figure 11), painted *Saturn Eating One of His Children* (figure 14), depicting Saturn as a bright star flanked by the two moons Galileo thought he saw before the Dutch scientist Christiaan Huygens, using a much larger telescope in 1656, was able to identify the apparition as a ring. Astronomy themed paintings, such as Dutch painters Johannes Vermeer's *The Astronomer* (1668, Musée du Louvre, Paris) and Gerrit Dou's *Astronomer by Candlelight* (ca. 1665, Getty Museum, Los Angeles), and Italian painter Niccolò Tornioli's *Gli Astronomi* (*The*

Fig. 13. Donato Creti's *Jupiter* accompanied by three of the four satellites discovered by Galileo, one of eight nocturnal landscapes commissioned in 1711 as a gift to Pope Clement XI to convince him of the importance to the Church of an astronomical observatory. Others in the series depicting Galilean discoveries include a crescent-phased Venus and a spotted sun. *Credit*: Courtesy of Wikimedia Commons

Fig. 14. *Saturn Eating One of His Children* (1636) by Peter Paul Rubens, now in Madrid's Museo del Prado. *Credit*: Courtesy of Wikimedia Commons

Astronomers, ca. 1645, Galleria Spada, Rome) portraying a parade of astronomers through history, including Ptolemy, Aristotle, Copernicus, and Galileo, were popular in this new age of astronomy. Imaginary portraits of historical philosophers, such as Rembrandt's *Aristotle with a Bust of Homer* (1663, Metropolitan Museum of Art, New York), were also popular during the Scientific Revolution.

Galileo was directly involved with the development of several new scientific instruments besides the telescope (figure 15), including the microscope, the thermometer, the barometer, the pendulum clock, and the air pump (figure 16), all products of the craft tradition and explicit material manifestations of both the experimental and the mechanical philosophies associated with the new science that were instrumental, literally and figuratively, to this new understanding of nature.[34] These six important scientific instruments provided the solid, empirical foundation of the Scientific Revolution.

Fig. 15. *Allegory of Sight* (ca. 1615) by José (Jusepe) de Ribera el Españoleto ("the little Spaniard"), now in Mexico City's Museo Franz Mayer, appears to be the very first depiction of an astronomical telescope. A leading painter of the Spanish school, his mature work was all done in Italy, and it is quite possible that he met Galileo when both were in Rome between 1615 and 1616. Other early paintings to include the telescope are Jan Brueghel the Elder's 1617 *Allegory of Air* (with Peter Paul Rubens, Museo Nacional del Prado, Madrid) and various versions of *Allegory of Sight* (e.g., 1621, Paris Musée du Louvre), all from his series of paintings of the four elements and the five senses. *Credit*: Courtesy of Wikimedia Commons

Galileo was also a pivotal player in the development of the new physics that was necessitated by the adoption of the new astronomy.[35] Combining careful experimentation and mathematical analysis, Galileo discovered that all objects fall at the same rate, covering a distance proportional to the square of the time of fall (figure 17). Galileo's appreciation of the essentially temporal character of motion and his subsequent scientization of time marked the first time that time itself was mathematically quantified, a novelty that would profoundly influence the subsequent development of science. Addressing the problem of two-dimensional

Fig. 16. Joseph Wright of Derby's *An Experiment on a Bird in the Air Pump*, first exhibited in 1768 and now in London's National Gallery, is very similar in composition to his orrery painting (figure 1) referencing the new mechanical universe. Note the realistic depiction of the refracted light coming from the immersed slender rod; indeed, the overall realism of the entire composition is striking, particularly Wright's characteristic attention to light and shadow, with the concentration of light dramatically conveying the process of scientific enlightenment that is taking place here. The enigmatic, Newton-looking lecturer displays a most haunting expression, while the man seated at the right, perhaps pensively fretting the destructive power of the new science, wonders, as does his counterpart in figure 1, "What hath God wrought?" Depicting subjects new to British art, Wright's science-themed paintings exemplify best, in both style and subject matter, the enlightened spirit of the Scientific Revolution in the fine arts during the "Century of Light." (For more on this most science-minded painter in this most science-conscious century, see Stephen Daniels, *Joseph Wright*, Princeton University Press, 1999.) *Credit*: Joseph Wright of Derby, An Experiment on a Bird in the Air Pump, 1768. Presented by Edward Tyrrell, 1863, The National Gallery, London

motion, Galileo discovered that projectiles move along parabolic trajectories—"gravity's rainbow" he called it—and became identified with the parabola just as Kepler was with the ellipse, two of the conic sections that were first analyzed in antiquity by Apollonius. It is interesting to compare the unrealistic trajectory of blood from the wound of Holofernes in Caravaggio's *Judith Beheading Holofernes* (Galleria Nazionale d'Arte Antica at Rome's Palazzo Barberini), painted in 1598–99, a full decade before Galileo's discovery of the parabolic law, with the parabolic

Fig. 17. *Galileo Demonstrates the Laws of Gravity to the Medici*, a mid-nineteenth-century fresco by Giuseppe Bezzuoli in Florence, Italy's Tribuna di Galileo. Against a background of Pisa, Giovanni de Medici, the illegitimate son of Cosimo I, sits royally on the right, while, one might guess, Aristotelian sceptics thumb through books on the left. *Credit*: Wikimedia Commons, user Sailko, licensed under CC BY-SA 3.0

paths of blood in the similarly themed painting by the accomplished Italian Baroque painter Artemisia Gentileschi, painted ca. 1620 (figure 18).[36] Artemisia had met and communicated with Galileo, and both were members of the Accademia del Disegno.

The story of Galileo's conflict with the Church is well known and, not surprisingly, has been depicted in art through the years (figure 19), as were his last years living under house arrest in Arcetri outside of Florence (figure 20), punishment imposed by the Inquisition for "suspicion of heresy" in his support of the Copernican cosmos.[37]

Newton and the Mechanical Universe

Isaac Newton tells us that he was able to see "further … by standing on y^{e} shoulders of Giants."[38] This rather reserved and much revered Englishman, himself one of the greatest giants of science, saw all the way to the modern world. Our modern view of the world, indeed our modern civilization itself, is profoundly indebted to his insights. Whatever else he may have been, Newton was the culminating figure—the "Final Cause"—of the Scientific Revolution and the "First Cause" of modern science, completely altering the landscape of physical science. The man and his accomplishments continue to inspire artists even today (figure 21).

Fig. 18. *Judith Slaying Holofernes* (ca. 1620) by the court painter and Galileo confidant Artemisia Gentileschi, now in Florence's Uffizi Gallery. Note the conquered general's blood gushing out in parabolic paths. *Credit*: Courtesy of Wikimedia Commons

Newton's laws of motion and universal law of gravitation, announced in his *Principia*, established at last the mathematical basis for a new clockwork, mechanical universe, unifying Kepler's celestial physics with Galileo's terrestrial physics. Newton's first law of motion, the law of inertia, as well as the principle of conservation of momentum, one of many important conservation principles now recognized in physics, were originally developed earlier in the century by the French philosopher and mathematician René Descartes, the first to espouse the new mechanical philosophy in which everything was understood in terms of "matter in motion." Descartes's suggestion that animals are no more than machines of flesh led directly to the proliferation of intricately designed automata, material manifestations of the mechanical philosophy. One can easily trace a scientific method from the Copernican heliocentric hypothesis, through the

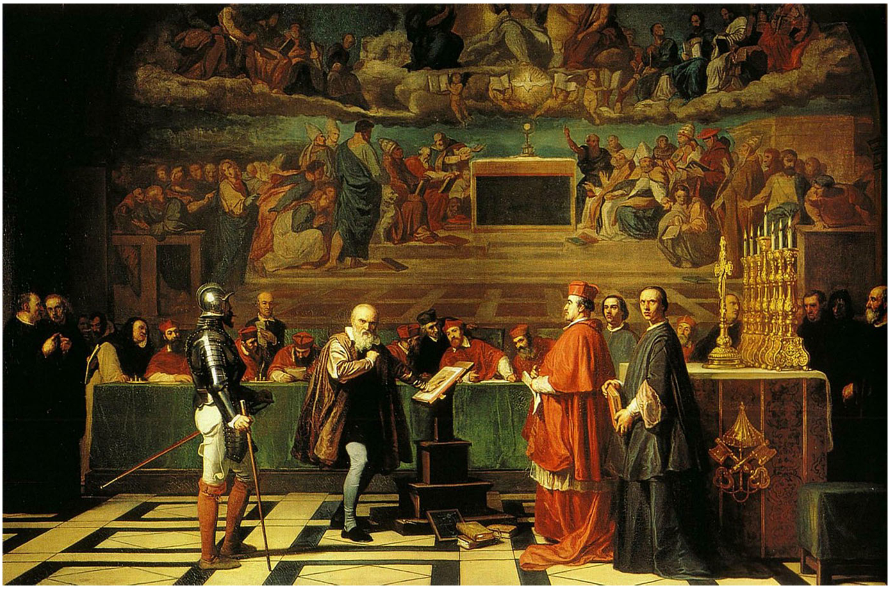

Fig. 19. *Galileo before the Inquisition* (1847) by the French painter Joseph Nicolas Robert-Fleury, now in the Paris Musée du Louvre. *Credit*: Courtesy of Wikimedia Commons

observations of Tycho Brahe and the empirical laws of Kepler, Galileo, and Descartes, to the Newtonian theoretical synthesis. Influenced by Descartes's new analytical geometry, a powerful synthesis of algebra and geometry that quantified space just as Galileo had earlier quantified time, the French mathematician and engineer Girard Desargues developed a new means to create the illusion of depth on the basis of projective geometry, replacing the old Renaissance "checkerboard floor" method with a more accurate, mathematically grounded scheme.[39]

Newton is memorialized by a Baroque monument in London's Westminster Abbey erected shortly after his death at the location of his interment in a prominent position in the nave near the entrance to the choir, indicative of Newton's high standing (figure 22). It depicts Newton reclining on a stack of books labeled "*Divinity*, *Chronology*, *Opticks*," and "*Philo. Prin. Math.*," attended by mathematically minded cherubs at his feet playing with all manner of things that were of interest to Newton during his long and productive life: a prism that lay at the heart of his study of light, a reflecting telescope of his invention, a furnace signifying his alchemical studies, newly minted coins recognizing his tenure as Warden and eventually Master of the Royal Mint, and a balance beam from which are suspended the sun and the planets, at last brought together into one grand, harmonious system by the laws Newton discovered. Surmounting the whole, a female figure representing Astronomy, the Queen of the Sciences, sits weeping on

Fig. 20. *Milton Visiting Galileo when a Prisoner of the Inquisition* by Solomon Alexander Hart, exhibited at London's Royal Academy in 1847, now part of the Wellcome Collection. The English poet John Milton visited Galileo at his villa near Florence. In Milton's words, "There it was that I found and visited the famous Galileo grown old a prisoner to the Inquisition, for thinking in Astronomy otherwise than the Franciscan and Dominican licensers thought." Several aspects of this episode made it attractive to later writers and painters: the contrast between the youth of Milton and the age of Galileo, the encounter of Europeans from north and south of the Alps, and the meeting of a poet and a philosopher. Milton described his experience of Galileo's house arrest in his book *Areopagitica*, an eloquent contribution to the historic English fight for freedom of speech. On the back wall of the painting is a reduced version of Titian's painting of the death of Saint Peter Martyr, the chief Dominican inquisitor and persecutor of heretics, an especially appropriate picture for Galileo to contemplate. Milton's epic poem, *Paradise Lost*, is replete with references to Galileo's telescopic discoveries ("like the Moon, whose Orb / Through optic glass the Tuscan Artist views / … to descry new Lands, / Rivers, or Mountains, in her spotty Globe"; "Starr's / Numerous, and every Starr perhaps a World / Of destind habitation"; "And hence the morning planet guilds her horns"), contributions from the literary arts inspired by the Scientific Revolution. Significantly, Galileo is the only person among Milton's contemporaries who is mentioned by name in this greatest of epic poems in the English language. *Credit*: Wellcome Collection, Attribution 4.0 International CC BY 4.0

a celestial globe showing the path of the comet of 1681 and the solstice position by which Newton dated the ancient Greek expedition of the Argonauts. The Latin inscription at the base, the eulogy to him who least needs praise, reads, in part: "Who by a vigor of Mind almost Divine, the Motions and Figures of Planets, the Paths of Comets, and the Tides of the Seas, first demonstrated.… Let Mortals

Fig. 21. Scottish artist Eduardo Paolozzi's larger-than-life 1995 bronze sculpture *Newton* displayed on a high platform outside London's British Library. Sometimes known as *Newton after Blake* due to it resemblance to William Blake's 1795 print *Newton: Personification of Man Limited by Reason* (Tate Gallery, London), it fancifully depicts the famous scientist, in a pose based on Michelangelo's Sistine Chapel *Abias*, inscribing geometric figures with a divider as if embarking upon the creation of his new rationally ordered and mathematically lawful universe. *Credit*: Photo by the author

rejoice That there has existed such and so great an Ornament to the Human Race." Newton's work in optics, in particular his theory of color, drew considerable interest from painters.[40]

Memorialized also in a painting in the year of his death, the imposing *An Allegorical Monument to Sir Isaac Newton* (1727–29; figure 23) by the Italian artist Giovanni Battista Pittoni with the assistance of brothers Guiseppe and Domenico Valeriani, who were responsible for the architectural setting, depicts the mourning figures of Minerva, Roman goddess of Wisdom, and other muses of science led by an angel towards a large urn containing Newton's ashes. In the middle ground, on either side of a pedestal supporting symbolic figures of Mathematics and Truth,

Fig. 22. Monument to Sir Isaac Newton, the first scientist to be knighted, in London's Westminster Abbey, executed by the sculptor Michael Rysbrack to the designs of the architect William Kent. *Credit*: Photo by the author

people study diagrams and instruments. A spectrum of light spreading across the center of the painting after passing through a prism recognizes Newton's celebrated experiments with light, itself a symbol of this enlightened age.

Concluding Remarks

Eighteenth-century Europeans appreciated that something extraordinary occurred in the sciences in the sixteenth and seventeenth centuries, and the art and science of the Scientific Revolution became a major part of the larger intellectual milieu

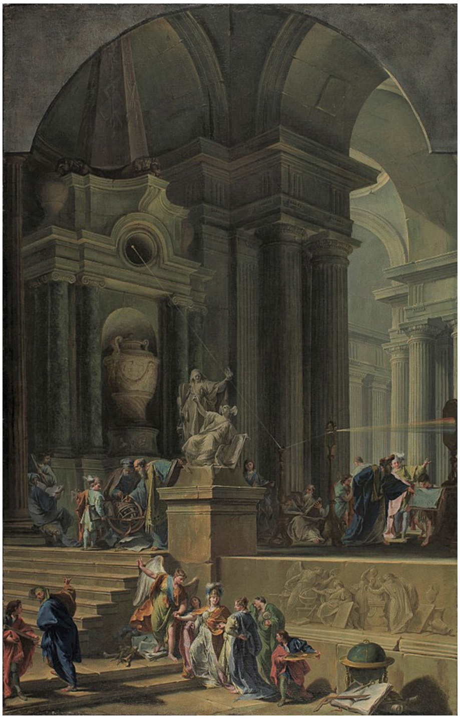

Fig. 23. *An Allegorical Monument to Sir Isaac Newton*. *Credit*: ©The Fitzwilliam Museum, Cambridge

during the eighteenth-century Enlightenment. Newton's influence dominated *all* areas of human concerns, scientific and otherwise, as scientific principles were applied to *all* aspects of life in the century the French called *le siècle de la lumière*, "the Century of Light," whence the Enlightenment.[41] It could just as well have been called "the Century of Newton": he was, after all, as the poet Alexander Pope had so confidently proclaimed in his epitaph intended for Newton, the "Light" of the new world.

Like painting, the architecture of the eighteenth century reflects a renewed interest in classical form with well-proportioned Newtonian symmetry and balance, an emphasis that earned it a periodization of its own called Neoclassicism which overlapped the French and English Baroque period in the second half of the century and extended well into the following century.[42] "The geometrical," wrote Christopher Wren, one of the most highly acclaimed English architects in history and Savilian Professor of Astronomy at Oxford University and founding member of London's scientific Royal Society, "is the most essential Part of Architecture."[43] (Wren and Robert Hooke together transformed the built environment of London

Fig. 24. Interior of the original Pennsylvania Supreme Court Chamber in Philadelphia's Independence Hall—itself symmetrical and balanced in design like much of Colonial American architecture—just across from the Assembly room where the signing of the American Declaration of Independence took place on July 4, 1776. The door on the left is real and functional; the one on the right, however, is fake: inoperable, but necessary to preserve the overall symmetry of the room. Neoclassical balance is evident in several monumental buildings of the period displaying on a rather ostentatious scale the century's vogue for mathematical regularity in buildings (and gardens), including the Royal Naval College, Greenwich, England, established in buildings designed by Wren and built between 1696 and 1712, the impressive Schloss Schönbrunn royal palace (after 1743) and gardens in Vienna, Austria, and Palacio Real de Madrid (begun 1735), Europe's largest by floor area. *Credit*: Photo by the author

after the heart of the city was destroyed by the Great Fire of 1666.) Through the course of the century, the fancifully over-decorated ornamentation of the gaudily ornate and busy Baroque, characterized by motion and movement—and thus an aesthetic reflection of the new Mechanical Philosophy (recall Descartes's definition of the world as one of matter in motion)—which nonetheless was itself often infused with a highly mathematical sense of proportion and symmetry manifested by a precise distortion of classical shapes into effable and emotional curvilinear forms (recall figure 8), assumed the unpretentious, balanced style of Neoclassicism, where the emphasis was on symmetry and the pureness of form (figure 24). In an age rebelling against excess, Cartesian swirls yielded to Newtonian balance and simplicity. As in painting and architecture, Baroque music, trending toward mechanical instrumental expression in the new mechanical universe, established formal and ordered "classical" patterns as well as the equally tempered "natural" scale that spaced all notes evenly on a logarithmic scale with a semitone interval of 21/12.[44]

And so, through works produced contemporaneously as well as later pieces that continue to reflect back on the period, the history of art beautifully reflects the achievements of the Scientific Revolution. For no other period before, and rarely since, has so much art focused on science, either directly in depicting scientists and their tools and discoveries, or indirectly in reflecting underlying themes and core principles shared in the arts and sciences. Clearly, artists appreciated—and continue to recognize—the revolutionary character of what occurred in the sciences in the early modern period, adding merit to understanding this era as truly revolutionary and therefore deservedly labeled *the* Scientific Revolution, written in the capitalized singular form of a proper noun modified by the definite article to proclaim its uniqueness in specifying a particular period of particular importance in history.

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