History of Western Art and Civilization

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C O N N E X I O N S

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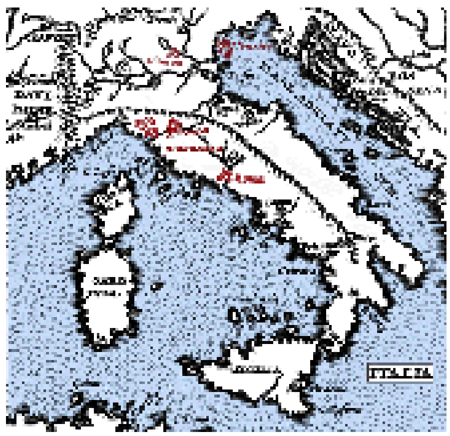


Figure 1: Italy[2] Map of Italy[3]

After the fall of the Roman Empire, the peninsula of Italy was not again politically unified until the nineteenth century. The region emerged from the so-called Dark Ages as an unorganized group of city states. Historically the most important of these were Venice (wealthy because of its trade with the Middle East) and Milan (an important manufacturing center) in the North, Florence (Section) (a center of commerce and manufacturing) and the Papal States in the center, and Naples and Sicily in the South. There were also many smaller and less important city states, such as Mantua, Genoa, and Verona.

During the high Middle Ages, ca. 1000-1450, the Italian region was economically and culturally the most advanced in Europe. Its wealth was based on trade with the Near East bringing spices, silk, and other desired Eastern commodities into Europe; manufacture, especially of finished cloth (Florence) and armaments (Milan), and banking. Italy's wealth attracted the attention of foreigners, and for several centuries there was a contest between the papacy and the Holy Roman (German) Empire to control the region, but neither side succeeded.

It is in the city states, Florence chief among them, that Italian art, architecture, letters, and engineering flourished as never before, but in the long run these states were too small to be viable in a world increasingly dominated by the new, larger, nations states.

[1] This content is available online at <http://cnx.org/content/m11960/1.2/>.
[2] http://cnx.org/content/m11960/latest/italy.gif
[3] http://cnx.org/content/m11960/latest/italy_map.bmp

As the city states emerged independent from both Pope and Emperor, at the end of the Middle Ages, their never ending wars and intrigues against each other opened the door to other foreign intervention. Italy now became the victim of the ambitions of the new nation states of France and Spain. Sicily and Naples came under the rule of Spain and remained there until the nineteenth century, while Milan and Florence fell under the influence of France. Perhaps the most symbolic event was the sack of Rome by the troops of the Emperor, Charles V, in 1527. Moreover, with the voyages of Columbus and Vasco da Gama (partially financed by Italian capital) the economic center of Europe shifted away from the Mediterranean to the Atlantic coast. The new economic powers were, first, Portugal and Spain, and then France, the Netherlands, and England. Beginning in the sixteenth century, then, Italy began to slip with respect to Northern Europe, and by the end of the seventeenth century it had become a region of secondary economic and cultural importance.

During the Middle Ages the papal monarchy had claimed to be a supraregal political power (a claim the Popes did not give up until recently): the Pope claimed political primacy over counts, dukes, kings, and even the emperor. This struggle ended disastrously when the papacy was captured by the French king and moved to Avignon, where it remained from 1302 to 1378. From that date until 1417 there were, in fact, two popes, one in Rome and one in Avignon, and for a brief period, 1409-1415, there were three! With a single pope now again established in Rome, the papacy entered a period of unparalleled venality. The Renaissance popes were, it seemed at times, more interested in their pet projects in art and architecture or the careers of their relatives than in the well being of the Catholic Church. Reform was slow in coming. The occasion of the start of the Protestant Reformation, in 1517, was the selling of indulgences to raise money for the building of the cathedral of St. Peter in Rome.

There was, in Italy, a crisis of confidence in the sixteenth century. Many sought law, order, and security; republics fell, princes became more powerful; authority and titles were stressed (even if the latter had to be made up). The papal court became more Italian, and the Popes themselves gathered more and more power onto themselves, taking it away from the cardinals and bishops. At the same time the Church girded its loins for the battle against the Protestants. In 1540 Ignatius of Loyola founded the Society of Jesus, an order which owed obedience to the Pope; intermittently, from 1545 to 1563, the Council of Trent met and made a number of important pronouncements on the issues that separated the Protestants from the Catholic church. By the end of the sixteenth century the church was regaining territories that it had lost to Protestants.

The intellectual climate at this time was rather more restricted than it had been in earlier centuries. Orthodoxy was enforced; heterodoxies were combated. Giordano Bruno[4], an apostate monk who espoused the Copernican system (Section) and the infinitude of worlds (and inhabitants) was burned at the stake in 1600. It was in this climate that Galileo argued for the Copernican theory.

[4]"Giordano Bruno (1548-1600)" <http://cnx.org/content/m11935/latest/>

Florence and Tuscany[5]

Figure 1: Florence

Tuscany is located in the western part of the boot of Italy (Section), north of Rome and south of Genoa. It is bounded by the Apennines to the North and East and by the Mediterranean on the West. Its land area is about 9,000 square miles. Its major cities are Florence, Pisa, Siena, Lucca, Arezzo, and Pistoia. Its major river is the Arno, on which Florence and Pisa are located.

It was the home land of the Etruscans, which was annexed by Rome in 351 BC. After the fall of the Roman empire, the region, which became known as Tuscany (Toscana in Italian) came under the rule of a succession of rulers (Herulians, Ostrogoths, etc.) and emerged as a political entity with its own rulers. By the twelfth century the Tuscan cities were gradually gaining their independence as republics and forcing the nobility to live in the cities. By the high Middle Ages the cities of Pisa, Siena, Arezzo, Pistoia, Lucca, and especially Florence had become wealthy because of textile manufacture, trade, banking, and agriculture. Gradually Florence came to overshadow and conquer all other cities in the region.

After several experiments with representative government, Florence was ruled by an oligarchy of wealthy aristocrats, among whom the Medici (Section) family became dominant in the fifteenth century. Under the patronage of these wealthy families the arts and literature flourished as nowhere else in Europe. Florence was the city of such writers as Dante, Petrarch, and Macchiavelli, and artists and engineers such as Boticelli, Brunelleschi (who built the magnificent dome on the church of St. Mary of the Flowers), Alberti, Leonardo Da Vinci, and Michelangelo. Because of its dominance in literature, the Florentine language became the literary language of the Italian region and is the language of Italy today. Lorenzo de' Medici, who ruled Florence in the late fifteenth century was perhaps the greatest patron of the arts in the history of the West.

But times changed. After Lorenzo the friar **Savonarola** ruled Florence, and the Medici were exiled.

[5]This content is available online at <http://cnx.org/content/m11936/1.3/>.

With the shift of commerce away from the Mediterranean and toward the Atlantic, after 1492, the economy of Tuscany went into a slow decline. In 1530 the Holy Roman Emperor Charles V conquered Florence and reestablished the Medici family in power. They were now dukes of Florence, and within a few decades Cosimo de Medici was made Grand Duke of Tuscany. Cosimo aggressively pursued a policy of economic revival, building the great harbor at Livorno because the harbor of Pisa had silted up.

Galileo was born under the rule of Cosimo in 1564. It was during this period that the Medici court increasingly firmly established its hold over the city. The court came to dominate all aspects of civic life, and for the Galilei family the route to success lay through the patronage structure in which the Court was central. In the seventeenth century Florence and Tuscany increasingly faded into obscurity and did not revive until the nineteenth century. It is today a major cultural center and attracts millions of tourists each year.

The Medici Family[6]

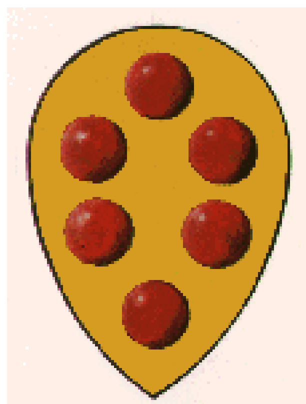


Figure 1: The Medici Coat of Arms

The Medici family of Florence can be traced back to the end of the 12th century. It was part of the **patrician class**, not the nobility, and through much of its history the family was seen as the friends of the common people. Through banking and commerce, the family acquired great wealth in the 13th century, and political influence came along with this wealth. At the end of that century, a member of the family served as gonfaliere, or standard bearer (high ceremonial office) of Florence. In the 14th century the family's wealth and political influence increased until the gonfaliere Salvestro de' Medici led the common people in the revolt of the ciompi (small artisanate). Although Salvestro became the de facto dictator of the city, his brutal regime led to his downfall and he was banished in 1382. The family's fortune then fell until it was restored by Giovanni di Bicci de' Medici (1360-1429)[7] , who made the Medici the wealthiest family in Italy, perhaps Europe. The family's poltical influence again increased, and Giovanni was gonfaliere in 1421.

Giovanni's son, Cosimo (1389-1464), Cosimo il Vecchio (the old or first Cosimo), is considered the real founder of the political fortunes of the family. In a political struggle with another powerful family, the Albizzi, Cosimo initially lost and was banished, but because of the support of the people he was soon recalled, in 1434, and the Albizzi were banished in turn. Although he himself occupied no office. Cosimo ruled the city as uncrowned king for the rest of his life. Under his rule Florence prospered.

[6]This content is available online at <http://cnx.org/content/m11975/1.2/>.
[7]http://cnx.org/content/m11975/latest/Medici_fam.gif

Figure 2: Cosimo il Vecchio

Cosimo spent a considerably part of his huge wealth on charitable acts, live simply, and cultivated literature and the arts. He amassed the largest library in Europe, brought in many Greek sources, including the works of Plato, from Constantinople, founded the Platonic Academy and patronized Marsilio Ficino, who later issued the first Latin edition of the collected works of Plato. The artists supported by Cosimo included Ghiberti, Brunelleschi, Donatello, Alberti, Fra Angelico, and Ucello. During his rule and that of his sons and grandson, Florence became the cultural center of Europe and the cradle of the new Humanism. Cosimo's son Piero (1416-1469) ruled for just a few years but continued his father's policies while enjoying the support of the populace.

Piero's sons, Lorenzo (1449-1492) and Giuliano (1453-1478) ruled as tyrants, and in an attack in 1478 Giuliano was killed and Lorenzo wounded. If the family fortunes dwindled somewhat and Florence was not quite as prosperous as before, under Lorenzo, known as the Magnificent, the city surpassed even the cultural achievements of the earlier period. This was the high point of the Florentine Renaissance: Ficino, Giovanni Pico della Mirandola, Boticelli, Michelangelo, etc. But Lorenzo's tyrranical style of governing and hedonistic lifestyle eroded the goodwill of the Florentine people. His son Piero (1472-1503) ruled for just two years. In 1494, after accepting humiliating peace conditions from the French (who had invaded Tuscany), he was driven out of the city and died in exile. For some time, Florence was now torn by strife and anarchy and, of course, the rule of Savanarola[8] .

Upon the defeat of the French armies in Italy by the Spanish, the Spanish forced Florence to invite the Medici back. Piero's younger brother Giuliano (1479-1516) reigned from 1512 to 1516, and became a prince; he was followed by Lorenzo (1492-1519), son of Piero, who was named Duke of Urbino by Pope Leo X (himself a Medici, son of Lorenzo the Magnificent); and upon Lorenzo's death, Giulio (1478-1534), the illigitimate son of Lorenzo the Magnificent's brother Giuliano, became rule of the city but abdicated in 1523 in favor of his own illegitimate son, Alessandro (1510-1537), to become Pope Clement VII. Alessandro became hereditary Duke of Florence.

If the rulers since Lorenzo the Magnificent had been weak and ineffective, this changed when Cosimo I (1519-1574) ascended the throne in 1537 at the age of 18. Cosimo was a descendant not of Cosimo il Vecchio but from Cosimo's brother. He quickly consolidated his power, and under his rule Tuscany was transformed into an absolutist nation state. Although politically ruthless, Cosimo was highly cultured and promoted letters and arts as well as the Tuscan economy and navy. He founded the Accademia della Crusca, a body charged with the promotion of the Tuscan language (which has become the standard Italian of today), the Accademia del Disegno (Academy of Design), renewed the university of Pisa, and conquered Siena and Lucca.

[8]http://cnx.org/content/m11975/latest/#savon

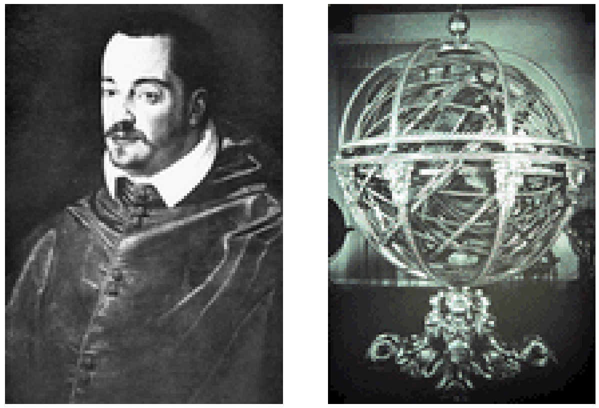
Figure 3: Cosimo I

In 1569 Cosimo was named Grand Duke of Tuscany. He set the style for the new absolute rule by concentrating the administration of Florence in a new office building, the Uffizi (where he also began a small museum for art works; the entire Uffizi is now a museum), and moving his residence across the river to the Pitti Palace, bought in 1549 and enlarged and remodeled several times by Cosimo and his descendants. He built a private corridor between the Pitti Palace and the Palazzo Vecchio in the city, where the government met. Vincenzo Galilei[9] moved his family, including the ten-year old Galileo, from Pisa to Florence in the year of Cosimo's death.

Cosimo's son, Francesco I (1541-1587) was an ineffectual ruler under whom Tuscany languished. His younger brother, Ferdinand (1549-1609), who had been made a cardinal at the age of fifteen, became Grand Duke upon Francesco's death in 1587. Ferdinand II was a capable administrator under whom Tuscany flourished again.

Ferdinand was an admirer of Tomasso Campanella and tried to protect him as best he could. He was interested in scientific matters, and had a great **armillary sphere** constructed by Antonio Santucci, his cosmographer.

[9]"Vincenzo Galileo" <http://cnx.org/content/m11934/latest/>



(a) (b)

Figure 4: (a) Ferdinand I (b) Armillary Sphere of Santucci

Ferdinand appointed Galileo to the professorship of mathematics at the university of Pisa in 1588. In the year of his accession, Ferdinand married Christina of Lorraine (1565-1637), who was the grand daughter of Catherine de' Medici, Queen of France. Christina was well-disposed to Galileo and as a favor in return for some services rendered by Galileo when he was still in Padua found a position for his brother in law Benedetto Landucci. It was to Christina that Galileo later wrote his letter on science and scripture, "Letter to the Grand Duchess Christina of Lorraine."

Ferdinand and Christina had four sons and four daughters. The eldest son, Cosimo II, ascended the throne upon his father's death in 1609. Galileo had tutored Cosimo in mathematics during some summers, and therefore the young Grand Duke knew him well and admired him enough to offer him a court position in 1610, after Galileo had dedicated *Sidereus Nuncius* to him and his family. After a bout of fever, in 1615, Cosimo's health deteriorated, and he died in 1620.

Figure 5: Christina of Lorraine

Figure 6: Cosimo II

Cosimo's son, Ferdinand II (1610-1670) was just ten years old when he became Grand Duke, and until his majority the government was carried on by the two Grand Duchesses, Cosimo's mother Christina of Lorraine, and Cosimo's wife, Maria Magdalena of Austria, the sister of the Holy Roman Emperor Ferdinand II.

Figure 7: Ferdinand II

During the outbreak of the plague, in 1630, Ferdinand distinguished himself, but he was not a strong ruler and was unable to protect Galileo from the Inquisition[10] in 1633. In 1657, together with his brother Leopold, Ferdinand established the Accademia del Cimento, or Academy of Experiment, a forerunner of more permanent scientific academies, such as the Royal Society of London (1665) and the Royal French Academy of Sciences (1666). The Accademia del Cimento stopped functioning in 1667.

The Florentine and Tuscan economy had been slowly stagnating since the end of the sixteenth century. Under Ferdinand II, his son, Cosimo III (1642-1723), and his grandson, Gian-Gastone (1671-1737), the city country slipped into insignificance. Cosimo III's rule was one of incompetence and religious intolerance. Gian-Gastone's rule was too short to repair the damage. In 1735, an arrangement was made between Austria, France, England, and the Netherlands that a swap should be made with Lorraine going to France and Tuscany to Austria in return. In 1737 Austrian troops occupied Tuscany. One of Gian Gastone's last acts was to erect a memorial to Galileo in the church of Santa Croce and to inter Galileo remains there. During the transference, several parts of Galileo's skeleton were taken as relics by various people. One of Galileo's fingers is now housed in the Museum of History of Science in Florence.

Gian-Gastone had no male heir, and the House of Medici died with him.

[10] "The Inquisition" <http://cnx.org/content/m11944/latest/>

Figure 8: Maria (Marie), Queen of France

The Medici family dominated Florentine politics for two and a half centuries and presided over a cultural achievement that is equalled only by Athens in the golden age. The family also got its genes mixed with those of most royal families in Europe. Medici women included Catherine (1519-1589) who married Henry II, King of France and ruled the coutry after her husband's death; Maria (1573-1642) married Henry IV, King of France. Maria's daughters became queens of Spain and England. Cosimo II's wife, Maria Magdalena, was the sister of Ferdinand II, Holy Roman Emperor.

Copernican System[11]

Figure 1: Copernicus

The first speculations about the possibility of the Sun being the center of the cosmos and the Earth being one of the planets going around it go back to the third century BCE. In his *Sand-Reckoner*, Archimedes (d. 212 BCE), discusses how to express very large numbers. As an example he chooses the question as to how many grains of sand there are in the cosmos. And in order to make the problem more difficult, he chooses not the geocentric cosmos generally accepted at the time, but the heliocentric cosmos proposed by Aristarchus of Samos (ca. 310-230 BCE), which would have to be many times larger because of the lack of observable stellar parallax. We know, therefore, that already in Hellenistic times thinkers were at least toying with this notion, and because of its mention in Archimedes's book Aristarchus's speculation was well-known in Europe beginning in the High Middle Ages but not seriously entertained until Copernicus.

[11] This content is available online at <http://cnx.org/content/m11938/1.3/>.

Figure 2: Copernicus

European learning was based on the Greek sources that had been passed down, and cosmological and astronomical thought were based on Aristotle and Ptolemy (Section). Aristotle's cosmology of a central Earth surrounded by concentric spherical shells carrying the planets and fixed stars was the basis of European thought from the 12th century CE onward. Technical astronomy, also geocentric, was based on the constructions of excentric circles and epicycles codified in Ptolemy's *Almagest* (2d. century CE).

In the fifteenth century, the reform of European astronomy was begun by the astronomer/humanist Georg Peurbach (1423-1461) and his student Johannes Regiomontanus (1436-1476). Their efforts (like those of their colleagues in other fields) were concentrated on ridding astronomical texts, especially Ptolemy's, from errors by going back to the original Greek texts and providing deeper insight into the thoughts of the original authors. With their new textbook and a guide to the *Almagest*, Peurbach and Regiomontanus raised the level of theoretical astronomy in Europe.

Several problems were facing astronomers at the beginning of the sixteenth century. First, the tables (by means of which to predict astronomical events such as eclipses and conjunctions) were deemed not to be sufficiently accurate. Second, Portuguese and Spanish expeditions to the Far East and America sailed out of sight of land for weeks on end, and only astronomical methods could help them in finding their locations on the high seas. Third, the calendar, instituted by Julius Caesar in 44 BCE was no longer accurate. The equinox, which at the time of the Council of Nicea (325 CE) had fallen on the 21st, had now slipped to the 11th. Since the date of Easter (the celebration of the defining event in Christianity) was determined with reference to the equinox, and since most of the other religious holidays through the year were counted forward or backward from Easter, the slippage of the calendar with regard to celestial events was a very serious problem. For the solution to all three problems, Europeans looked to the astronomers.

Nicholas Copernicus (1473-1543) learned the works of Peurbach and Regiomontanus in the undergraduate curriculum at the university of Cracow and then spent a decade studying in Italy. Upon his return to Poland, he spent the rest of his life as a physician, lawyer, and church administrator. During his spare time he continued his research in astronomy. The result was *De Revolutionibus Orbium Coelestium* ("On the Revolutions of the Celestial Orbs"), which was published in Nuremberg in 1543, the year of his death. The book was dedicated to Pope Paul III and initially caused litle controversy. An anonymous preface (added by Andreas Osiander, the Protestant reformer of Nuremberg) stated that the theory put forward in this book was only a mathematical hypothesis: the geometrical constructions used by astronomers had traditionally had only hypothetical status; cosmological interpretations were reserved for the philosophers. Indeed, except for the first eleven chapters of Book I, *De Revolutionibus* was a technical mathematical work in the tradition of the *Almagest*.

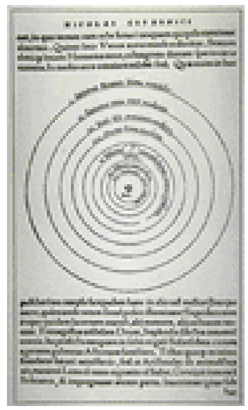


Figure 3: Diagram of the Copernican system, from De Revolutions[12]

But in the first book, Copernicus stated that the Sun was the center of the universe and that the Earth had a triple motion [13] around this center. His theory gave a simple and elegant explanation of the retrograde motions of the planets (the annual motion of the Earth necessarily projected onto the motions of the planets in geocentric astronomy) and settled the order of the planets (which had been a convention in Ptolemy's work) definitively. He argued that his system was more elegant than the traditional geocentric system. Copernicus still retained the priviledged status of circular motion and therefore had to construct his planetary orbits from circles upon and within circles, just as his predecessors had done. His tables were perhaps only marginally better than existing ones.

The reception of *De Revolutionibus* was mixed. The heliocentric hypothesis was rejected out of hand by virtually all, but the book was the most sophisticated astronomical treatise since the *Almagest*, and for this it was widely admired. Its mathematical constructions were easily transferred into geocentric ones, and many astronomers used them. In 1551 Erasmus Reinhold, no believer in the mobility of the Earth, published a new set of tables, the *Prutenic Tables*, based on Copernicus's parameters. These tables came to be preferred for their accuracy. Further, *De revolutionibus* became the central work in a network of astronomers, who dissected it in great detail. Not until a generation after its appearance, however, can we begin point to a community of practicing astronomers who accepted heliocentric cosmology. Perhaps the most remarkable early follower of Copernicus was Thomas Digges (c. 1545-c.1595), who in *A Perfit Description of the Coelestiall Orbes (1576)* translated a large part of Book I of *De Revolutionibus* into English and illustrated it with a diagram in which the Copernican arrangement of the planets is imbedded in an infinite universe of stars.

[12]http://cnx.org/content/m11938/latest/copernican_universe.gif

[13]A daily rotation about its center, an annual motion around the Sun, and a conical motion of its axis of rotation. This last motion was made necessary because Copernicus conceptualized the Earth's annual motion as the result of the Earth being embedded in a spherical shell centered on the Sun. Its axis of rotation therefore did not remain parallel to itself with respect to the fixed stars. To keep the axis parallel to itself, Copernicus gave the axis a conical motion with a period just about equal to the year. The very small difference from the annual period accounted for the precesion of the equinoxes, an effect caused by the fact that the Earth's axis (in Newtonian terms) precesses like a top, with a period of about 26,000 years. (Copernicus's ideas about this precession were more cumbersome and based on faulty data.)

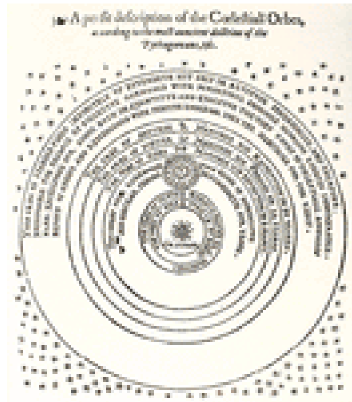


Figure 4: Diagram of the universe by Thomas Digges[14]

The reason for this delay was that, on the face of it, the heliocentric cosmology was absurd from a common-sensical and a physical point of view. Thinkers had grown up on the Aristotelian division between the heavens and the earthly region, between perfection and corruption. In Aristotle's physics, bodies moved to their natural places. Stones fell because the natural place of heavy bodies was the center of the universe, and that was why the Earth was there. Accepting Copernicus's system meant abandoning Aristotelian physics. How would birds find their nest again after they had flown from them? Why does a stone thrown up come straight down if the Earth underneath it is rotating rapidly to the east? Since bodies can only have one sort of motion at a time, how can the Earth have several? And if the Earth is a planet, why should it be the only planet with a moon?

For astronomical purposes, astronomers always assumed that the Earth is as a point with respect to the heavens. Only in the case of the Moon could one notice a parallactic displacement (about $1\,^{\circ}$) with respect to the fixed stars during its (i.e., the Earth's) diurnal motion. In Copernican astronomy one now had to assume that the **orbit of the Earth** was as a point with respect to the fixed stars, and because the fixed stars did not reflect the Earth's annual motion by showing an annual **parallax**, the sphere of the fixed stars had to be immense. What was the purpose of such a large space between the region of Saturn and that of the fixed stars?

[14] http://cnx.org/content/m11938/latest/digges_universe.gif

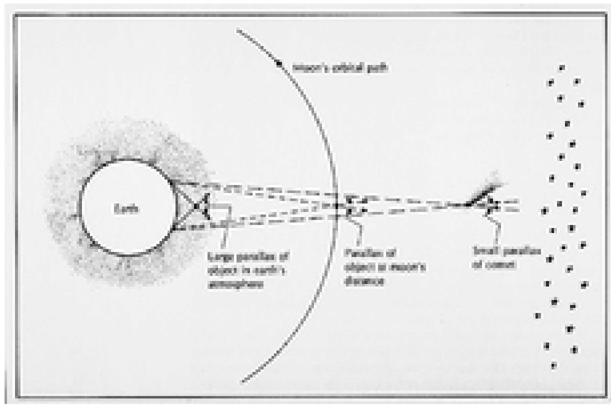


Figure 5: Parallax[15]

These and others were objections that needed answers. The Copernican system simply did not fit into the Aristotelian way of thinking. It took a century and a half for a new physics to be devised to undegird heliocentric astronomy. The works in physics and astronomy of Galileo and Johannes Kepler (Section) were crucial steps on this road.

There was another problem. A stationary Sun and moving Earth also clashed with many biblical passages. Protestants and Catholics alike often dismissed heliocentrism on these grounds. Martin Luther did so in one of his "table talks" in 1539, before *De Revolutionibus* had appeared. (Preliminary sketches had circulated in manuscript form.) In the long run, Protestants, who had some freedom to interpret the bible personally, accepted heliocentrism somewhat more quickly. Catholics, especially in Spain and Italy, had to be more cautious in the religious climate of the **Counter Reformation**, as the case of Galileo clearly demonstrates. Christoph Clavius[16], the leading Jesuit mathematician from about 1570 to his death in 1612, used biblical arguments against heliocentrism in his astronomical textbook.

The situation was never simple, however. For one thing, late in the sixteenth century Tycho Brahe[17] devised a hybrid geostatic heliocentric system in which the Moon and Sun went around the Earth but the planets went around the Sun. In this system the elegance and harmony of the Copernican system were married to the solidity of a central and stable Earth so that Aristotelian physics could be maintained. Especially after Galileo's telescopic discoveries, many astronomers switched from the traditional to the Tychonic cosmology. For another thing, by 1600 there were still very few astronomers who accepted Copernicus's cosmology. It is not clear whether the execution of Giordano Bruno[18], a Neoplatonist mystic who knew little about astronomy, had anything to do with his Copernican beliefs. Finally, we must not forget that Copernicus had dedicated *De Revolutionibus* to the Pope. During the sixteenth century the Copernican issue was not considered important by the Church and no official pronouncements were made.

Galileo's discoveries changed all that. Beginning with *Sidereus Nuncius* in 1610, Galileo brought the issue before a wide audience. He continued his efforts, ever more boldly, in his letters on sunspots, and in his letter to the Grand Duchess Christina (circulated in manuscript only) he actually interpreted the problematical biblical passage in the book of Joshua to conform to a heliocentric cosmology. More importantly, he argued that the Bible is written in the language of the common person who is not an expert in astronomy. Scripture, he argued, teaches us how to go to heaven, not how the heavens go. At about the same time, Paolo Antonio Foscarini[19], a **Carmelite** theologian in Naples, published a book in which he argued that the Copernican

[15]http://cnx.org/content/m11938/latest/parallax.gif
[16]"Christopher Clavius" <http://cnx.org/content/m11958/latest/>
[17]"Tycho Brahe" <http://cnx.org/content/m11946/latest/>
[18]"Giordano Bruno (1548-1600)" <http://cnx.org/content/m11935/latest/>
[19]"Paolo Antonio Foscarini" <http://cnx.org/content/m11966/latest/>

theory did not conflict with Scripture. It was at this point that Church officials took notice of the Copernican theory and placed *De Revolutionibus* on the Index of Forbidden Books[20] until corrected.

Galileo's *Dialogue Concerning the Two Chief World Systems* of 1632 was a watershed in what had shaped up to be the "Great Debate." Galileo's arguments undermined the physics and cosmology of Aristotle for an increasingly receptive audience. His telescopic discoveries, although they did not **prove** that the Earth moved around the Sun, added greatly to his argument. In the meantime, Johannes Kepler (Section) (who had died in 1630) had introduced physical considerations into the heavens and had published his *Rudolphine Tables*, based on his own elliptical theory and Tycho Brahe's[21] accurate observations, and these tables were more accurate by far than any previous ones. The tide now ran in favor of the heliocentric theory, and from the middle of the seventeenth century there were few important astronomers who were not Copernicans.

[20]"The Congregation of the Index" <http://cnx.org/content/m11974/latest/>
[21]"Tycho Brahe" <http://cnx.org/content/m11946/latest/>

Ptolemaic System[22]

Figure 1: Ptolemaic System

In his *Dialogue Concerning the Two Chief World Systems, Ptolemaic and Copernican* of 1632, Galileo attacked the world system based on the cosmology of Aristotle (384-322 BCE) and the technical astronomy of Ptolemy (ca. 150 CE).

In his books *On the Heavens*, and *Physics*, Aristotle put forward his notion of an ordered universe or cosmos. It was governed by the concept of place , as opposed to space, and was divided into two distinct parts, the earthly or sublunary region, and the heavens. The former was the abode of change and corruption, where things came into being, grew, matured, decayed, and died; the latter was the region of perfection, where there was no change. In the sublunary region, substances were made up of the four elements, earth, water, air, and fire. Earth was the heaviest, and its natural place was the center of the cosmos; for that reason the Earth was situated in the center of the cosmos. The natural places of water, air, and fire, were concentric spherical shells around the sphere of earth. Things were not arranged perfectly, and therefore areas of land protruded above the water. Objects sought the natural place of the element that predominated

[22]This content is available online at <http://cnx.org/content/m11943/1.3/>.

in them. Thus stones, in which earth predominated, move down to the center of the cosmos, and fire moves straight up. Natural motions were, then, radial, either down or up. The four elements differed from each other only in their qualities. Thus, earth was cold and dry while air was warm and moist. Changing one or both of its qualities, transmuted one element into another. Such transmutations were going on constantly, adding to the constant change in this sublunary region.

Figure 2: Ptolemy

The heavens, on the other hand, were made up of an entirely different substance, the aether [23] or quintessence (fifth element), an immutable substance. Heavenly bodies were part of spherical shells of aether. These spherical shells fit tightly around each other, without any spaces between them, in the following order: Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, fixed stars. Each spherical shell (hereafter, simply, sphere) had its particular rotation, that accounted for the motion of the heavenly body contained in it.

[23] The traditional English spelling, aether, is used here to distinguish Aristotle's heavenly substance from the modern chemical substance, ether.

Outside the sphere of the fixed stars, there was the prime mover (himself unmoved), who imparted motion from the outside inward. All motions in the cosmos came ultimately from this prime mover. The natural motions of heavenly bodies and their spheres was perfectly circular, that is, circular and neither speeding up nor slowing down.

It is to be noted about this universe that everything had its natural place, a privileged location for bodies with a particular makeup, and that the laws of nature were not the same in the heavenly and the earthly regions. Further, there were no empty places or vacua anywhere. Finally, it was finite: beyond the sphere of the fixed stars and the prime mover, there was nothing, not even space. The cosmos encompassed all existence.

Figure 3: Christian Aristotelian Cosmos. From Peter Apian, Cosmographia[24]

Now, ingenious as this cosmology was, it turned out to be unsatisfactory for astronomy. Heavenly bodies did, in fact, not move with perfect circular motions: they speeded up, slowed down, and in the cases of the planets even stopped and reversed their motions. Although Aristotle and his contemporaries tried to account for these variations by splitting individual planetary spheres into component spheres, each with a component of the composite motion, these constructions were very complex and ultimately doomed to failure. Furthermore, no matter how complex a system of spheres for an individual planet became, these spheres were still centered on the Earth. The distance of a planet from the Earth could therefore not be varied in this system, but planets vary in brightness, a variation especially noticeable for Venus, Mars, and Jupiter. Since in an unchangeable heaven variations in intrinsic brightness were ruled out, and since spheres did not allow for a variation in planetary distances from the Earth, variations in brightness could not be accounted for in this system.

Thus, although Aristotle's spherical cosmology had a very long life, mathematicians who wished to make geometrical models to account for the actual motions of heavenly bodies began using different constructions within a century of Aristotle's death. These constructions violated Aristotle's physical and cosmological principles somewhat, but they were ultimately successful in accounting for the motions of heavenly bodies. It is in the work of Claudius Ptolemy, who lived in the second century CE, that we see the culmination of these efforts. In his great astronomical work, *Almagest*, [25] Ptolemy presented a complete system of mathematical constructions that accounted successfully for the observed motion of each heavenly body.

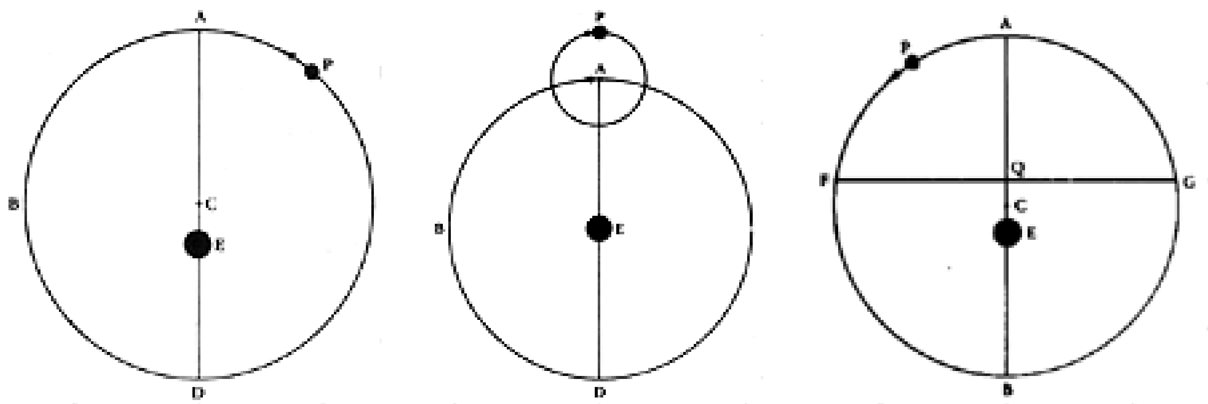
Ptolemy used three basic constructions, the eccentric, the epicycle, and the equant. An eccentric construction is one in which the Earth is placed outside the center of the geometrical construction. Here, the Earth, E, is displaced slightly from the center, C, of the path of the planet. Although this construction

[24] http://cnx.org/content/m11943/latest/ptolematic_universe.gif

[25] The title is one given to this book by Islamic translators in the ninth century. Its original Greek title is Mathematical Syntaxis.

violated the rule that the Earth was the center of the cosmos and all planetary motions, the displacement was minimal and was considered a slight bending of the rule rather than a violation. The eccentric in the figure below is fixed; it could also be made movable. In this case the center of the large circle was a point that rotated around the Earth in a small circle centered on the Earth. In some constructions this little circle was not centered in the Earth.

The second construction, the epicycle, is geometrically equivalent to the simple movable eccentric. In this case, the planet moved on a little circle the center of which rotated on the circumference of the large circle centered on the on theEarth. When the directions and speeds of rotation of the epicycle and large circle were chosen appropriately, the planet, as seen from the Earth, would stop, reverse its course, and then move forward again. Thus the annual retrograde motion of the planets (caused, in heliocentric terms by the addition of the Earth's annual motion to the motion of the planet) could roughly be accounted for.



(a) (b) (c)

Figure 4: From Michael J. Crowe, Theories of the World from Antiquity to the Copernican Revolution. (a) Eccentric[26] (b) Epicycle[27] (c) Equant[28]

But these two constructions did not quite bring the resulting planetary motions within close agreement with the observed motions. Ptolemy therefore added yet a third construction, the equant. In this case, the center of construction of the large circle was separated from the center of motion of a point on its circumference, as shown below, where C is the geometrical center of the large circle (usually called in these constructions the excentric circle) but the motion of the center of the epicycle, P (middle of Figure 4), is uniform about Q, the equant point (righthand side of Figure 4).

Ptolemy combined all three constructions in the models of the planets, Sun, and Moon. A typical construction might thus be as in the picture below, where E is the Earth, C the geometric center of the eccentric circle, Q the equant point, F the center of the epicycle, and P the planet. As mentioned before, the eccentric was often not fixed but moved in a circle about the Earth or another point between the Earth and the equant point.

[26] http://cnx.org/content/m11943/latest/eccentric_p.gif
[27] http://cnx.org/content/m11943/latest/epicycle_p.gif
[28] http://cnx.org/content/m11943/latest/equant_p.gif

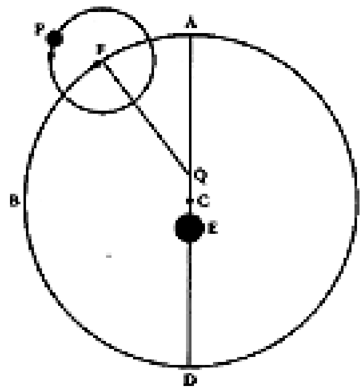


Figure 5: Typical Ptolemaic planetary model (From Michael J. Crowe, Theories of the World from Antiquity to the Copernican Revolution.)[29]

With such combinations of constructions, Ptolemy was able to account for the motions of heavenly bodies within the standards of observational accuracy of his day. The idea was to break down the complex observed planetary motion into components with perfect circular motions. In doing so, however, Ptolemy violated the cosmological and physical rules of Aristotle. The excentric and epicycle meant that planetary motions were not exactly centered on the Earth, the center of the cosmos. This was, however, a "fudge" that few objected to. The equant violated the stricture of perfect circular motion, and this violation bothered thinkers a good deal more. Thus, in *De Revolutionibus* (see Copernican System (Section)), Copernicus tells the reader that it was his aim to rid the models of heavenly motions of this monstrous construction.

Aristotelian cosmology and Ptolemaic astronomy entered the West, in the twelfth and thirteenth centuries, as distinct textual traditions. The former in Aristotle's *Physics and On the Heavens* and the many commentaries on these works; the latter in the *Almagest* and the technical astronomical literature that had grown around it, especially the work of Islamic astronomers working in the Ptolemaic paradigm. In the world of learning in the Christian West (settled in the universities founded around 1200 CE), Aristotle's cosmology figured in all questions concerned with the nature of the universe and impinged on many philosophical and theological questions. Ptolemy's astronomy was taught as part of the undergraduate mathematical curriculum only and impinged only on technical questions of calendrics, positional predictions, and astrology.

Copernicus's innovations was therefore not only putting the Sun in the center of the universe and working out a complete astronomical system on this basis of this premise, but also trying to erase the disciplinary boundary between the textual traditions of physical cosmology and technical astronomy.

[29]http://cnx.org/content/m11943/latest/combined_p.gif

Johannes Kepler[30]

Figure 1: Johannes Kepler

Johannes Kepler was born in Weil der Stadt in Swabia, in southwest Germany. His paternal grandfather, Sebald Kepler, was a respected craftsman who served as mayor of the city; his maternal grandfather, Melchior Guldenmann, was an innkeeper and mayor of the nearby village of Eltingen. His father, Heinrich Kepler, was "an immoral, rough and quarrelsome soldier," according to Kepler, and he described his mother in similar unflattering terms. From 1574 to 1576 Johannes lived with his grandparents; in 1576 his parents moved to nearby Leonberg, where Johannes entered the Latin school. In 1584 he entered the Protestant seminary at Adelberg, and in 1589 he began his university education at the Protestant university of T\x{00FC}bingen. Here he studied theology and read widely. He passed the M.A. examination in 1591 and continued his studies as a graduate student.

Kepler's teacher in the mathematical subjects was Michael Maestlin (1580-1635). Maestlin was one of the earliest astronomers to subscribe to Copernicus's heliocentric theory, although in his university lectures he taught only the Ptolemaic system. Only in what we might call graduate seminars did he acquaint his students, among whom was Kepler, with the technical details of the Copernican system (Section). Kepler stated later that at this time he became a Copernican for "physical or, if you prefer, metaphysical reasons."

In 1594 Kepler accepted an appointment as professor of mathematics at the Protestant seminary in Graz (in the Austrian province of Styria). He was also appointed district mathematician and calendar maker. Kepler remained in Graz until 1600, when all Protestants were forced to convert to Catholicism or leave the

[30]This content is available online at <http://cnx.org/content/m11962/1.2/>.

province, as part of **Counter Reformation** measures. For six years, Kepler taught arithmetic, geometry (when there were interested students), Virgil, and rhetoric. In his spare time he pursued his private studies in astronomy and astrology. In 1597 Kepler married Barbara Muller. In that same year he published his first important work, *The Cosmographic Mystery*, in which he argued that the distances of the planets from the Sun in the Copernican system were determined by the five regular solids, if one supposed that a planet's orbit was circumscribed about one solid and inscribed in another.

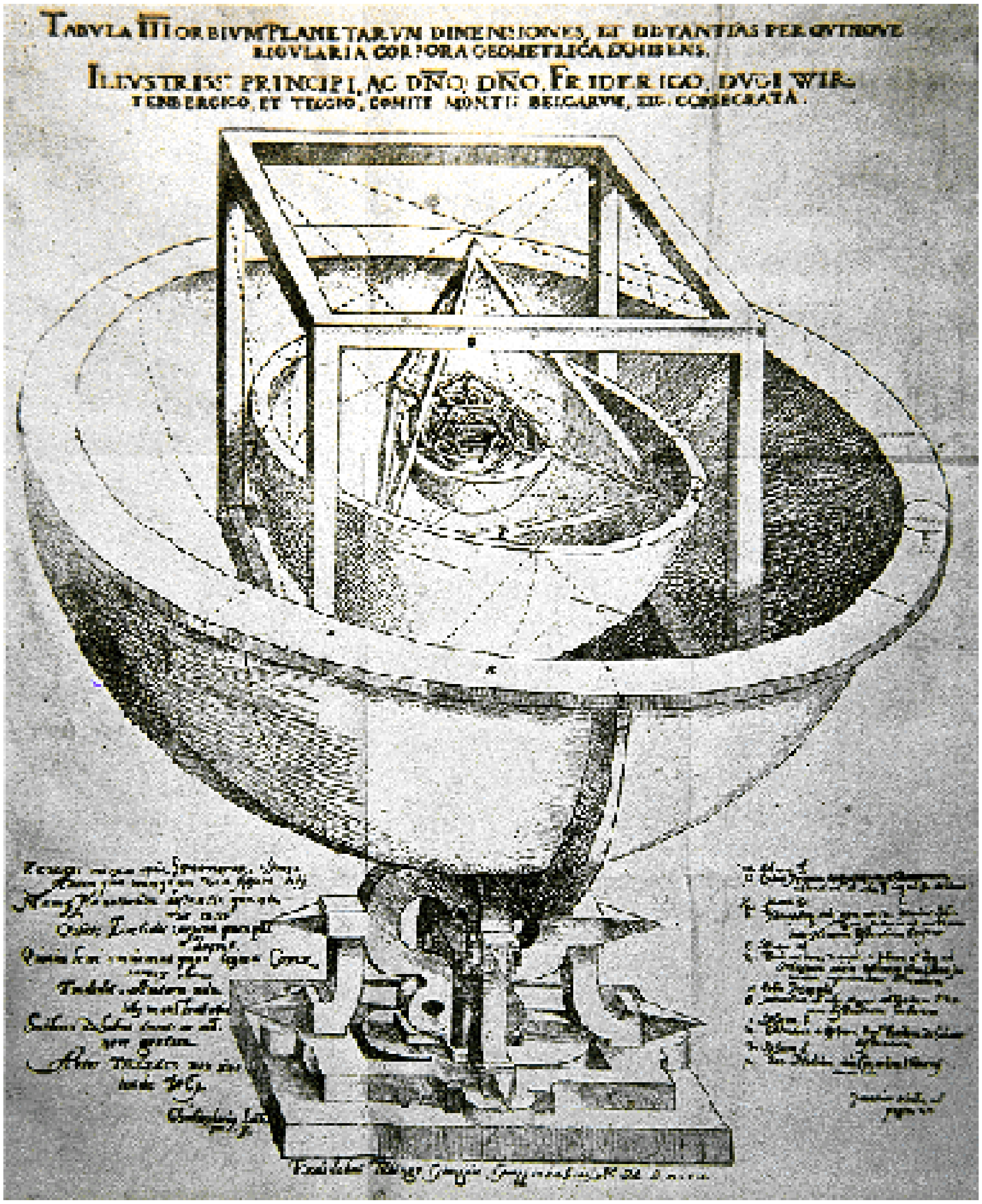


Figure 2: Kepler's model to explain the relative distances of the planets from the Sun in the Copernican System.

Except for Mercury, Kepler's construction produced remarkably accurate results. Because of his talent as a mathematician, displayed in this volume, Kepler was invited by Tycho Brahe[31] to Prague to become

[31]"Tycho Brahe" <http://cnx.org/content/m11946/latest/>

his assistant and calculate new orbits for the planets from Tycho's observations. Kepler moved to Prague in 1600.

Kepler served as Tycho Brahe's assistant until the latter's death in 1601 and was then appointed Tycho's successor as Imperial Mathematician, the most prestigious appointment in mathematics in Europe. He occupied this post until, in 1612, Emperor Rudolph II was deposed. In Prague Kepler published a number of important books. In 1604 *Astronomia pars Optica* ("The Optical Part of Astronomy") appeared, in which he treated **atmospheric refraction** but also treated lenses and gave the modern explanation of the workings of the eye; in 1606 he published *De Stella Nova* ("Concerning the New Star") on the new star that had appeared in 1604; and in 1609 his *Astronomia Nova* ("New Astronomy") appeared, which contained his first two laws (planets move in elliptical orbits with the sun as one of the foci, and a planet sweeps out equal areas in equal times). Whereas other astronomers still followed the ancient precept that the study of the planets is a problem only in kinematics, Kepler took an openly dynamic approach, introducing physics into the heavens.

In 1610 Kepler heard and read about Galileo's discoveries with the spyglass. He quickly composed a long letter of support which he published as *Dissertatio cum Nuncio Sidereo* ("Conversation with the Sidereal Messenger"), and when, later that year, he obtained the use of a suitable telescope, he published his observations of Jupiter's satellites[32] under the title *Narratio de Observatis Quatuor Jovis Satellitibus* ("Narration about Four Satellites of Jupiter observed"). These tracts were an enormous support to Galileo, whose discoveries were doubted or denied by many. Both of Kepler's tracts were quickly reprinted in Florence. Kepler went on to provide the beginning of a theory of the telescope in his *Dioptrice*, published in 1611.

During this period the Keplers had three children (two had been born in Graz but died within months), Susanna (1602), who married Kepler's assistant Jakob Bartsch in 1630, Friedrich (1604-1611), and Ludwig (1607-1663). Kepler's wife, Barbara, died in 1612. In that year Kepler accepted the position of district mathematician in the city of Linz, a position he occupied until 1626. In Linz Kepler married Susanna Reuttinger. The couple had six children, of whom three died very early.

In Linz Kepler published first a work on chronology and the year of Jesus's birth, In German in 1613 and more amply in Latin in 1614: *De Vero Anno quo Aeternus Dei Filius Humanam Naturam in Utero Benedictae Virginis Mariae Assumpsit* (Concerning the True Year in which the Son of God assumed a Human Nature in the Uterus of the Blessed Virgin Mary"). In this work Kepler demonstrated 0 Kepler heard and read about Galileo's discoveries with the spyglass. He quickly composed a long letter of support which he published as Dissertatio cum Nuncio Sidereo ("Conversation with the Sidereal Messenger"), and when, later that year, he obtained the use of a suitable telescope, he published his observations of Jupiter's satellites under the title Narratio de Observatis Quatuor Jovis Satellitibus ("Narration about Four Satellites of Jupiter observed"). These tracts were an enormous support to Galileo, whose discoveries were doubted or denied by many. Both of Kepler's tracts were quickly reprinted in Florence. Kepler went on to provide the beginning of a theory of the telescope in his Dioptrice, published in 1611.that the Christian calendar was in error by five years, and that Jesus had been born in 4 BC, a conclusion that is now universally accepted. Between 1617 and 1621 Kepler published *Epitome Astronomiae Copernicanae* ("Epitome of Copernican Astronomy"), which became the most influential introduction to heliocentric astronomy; in 1619 he published *Harmonice Mundi* ("Harmony of the World"), in which he derived the heliocentric distances of the planets and their periods from considerations of musical harmony. In this work we find his third law, relating the periods of the planets to their mean orbital radii.

In 1615-16 there was a witch hunt in Kepler's native region, and his own mother was accused of being a witch. It was not until late in 1620 that the proceedings against her ended with her being set free. At her trial, her defense was conducted by her son Johannes.

1618 marked the beginning of the Thirty Years War, a war that devastated the German and Austrian region. Kepler's position in Linz now became progressively worse, as **Counter Reformation** measures put pressure on Protestants in the Upper Austria province of which Linz was the capital. Because he was a court official, Kepler was exempted from a decree that banished all Protestants from the province, but he nevertheless suffered persecution. During this time Kepler was having his *Tabulae Rudolphinae*

[32]"Satellites of Jupiter" <http://cnx.org/content/m11971/latest/>

("Rudolphine Tables") printed, the new tables, based on Tycho Brahe's accurate observations, calculated according to Kepler's elliptical astronomy. When a peasant rebellion broke out and Linz was besieged, a fire destroyed the printer's house and shop, and with it much of the printed edition. Soldiers were garrisoned in Kepler's house. He and his family left Linz in 1626. The *Tabulae Rudolphinae* were published in Ulm in 1627.

Kepler now had no position and no salary. He tried to obtain appointments from various courts and returned to Prague in an effort to pry salary that was owed him from his years as Imperial Mathematician from the imperial treasury. He died in Regensburg in 1630. Besides the works mentioned here, Kepler published numerous smaller works on a variety of subjects.

Galileo's Telescope[33]

Figure 1: Johannes Hevelius observing with one of his telescopes.[34] (Source: Selenographia, 1647)

The telescope was one of the central instruments of what has been called the Scientific Revolution of the seventeenth century. It revealed hitherto unsuspected phenomena in the heavens and had a profound influence on the controversy between followers of the traditional geocentric astronomy (Section) and cosmology and those who favored the heliocentric system of Copernicus[35]. It was the first extension of one of man's senses, and demonstrated that ordinary observers could see things that the great Aristotle had not dreamed of. It therefore helped shift authority in the observation of nature from men to instruments. In short, it was the prototype of modern scientific instruments. But the telescope was not the invention of scientists; rather, it was the product of craftsmen. For that reason, much of its origin is inaccessible to us since craftsmen were by and large illiterate and therefore historically often invisible.

Although the magnifying and diminishing properties of convex and concave transparent objects was known in Antiquity, lenses as we know them were introduced in the West [36] at the end of the thirteenth century. Glass of reasonable quality had become relatively cheap and in the major glass-making centers of Venice and Florence techniques for grinding and polishing glass had reached a high state of development. Now one of the perennial problems faced by aging scholars could be solved. With age, the eye progressively loses its power to accommodate, that is to change its focus from faraway objects to nearby ones. This condition, known as **presbyopia**, becomes noticeable for most people in their forties, when they can no longer focus on letters held at a comfortable distance from the eye. Magnifying glasses became common in the thirteenth century, but these are cumbersome, especially when one is writing. Craftsmen in Venice began

[33]This content is available online at <http://cnx.org/content/m11932/1.4/>.
[34]http://cnx.org/content/m11932/latest/hevelius_telescope.gif
[35]"Introduction" <http://cnx.org/content/m11838/latest/>
[36]They may have developed independently in China.

making small disks of glass, convex on both sides, that could be worn in a frame–spectacles. Because these little disks were shaped like lentils, they became known as "lentils of glass," or (from the Latin) **lenses**. The earliest illustrations of spectacles date from about 1350, and spectacles soon came to be symbols of learning.

Figure 2: The Spectacle Vendor by Johannes Stradanus, engraved by Johannes Collaert, 1582[37]

These spectacles were, then, reading glasses. When one had trouble reading, one went to a spectacle-maker's shop or a peddler of spectacles (see Figure 2 and Figure 3) and found a suitable pair by trial and error. They were, by and large, glasses for the old. spectacles for the young, concave lenses [38] that correct the refractive error known as **myopia**, were first made (again in Italy) in the middle of the fifteenth century. So by about 1450 the ingredients for making a telescope were there. The telescopic effect can be achieved by several combinations of concave and convex mirrors and lenses. Why was the telescope not invented in the fifteenth century? There is no good answer to this question, except perhaps that lenses and mirrors of the appropriate strengths were not available until later.

In the literature of white magic, so popular in the sixteenth century, there are several tantalizing references to devices that would allow one to see one's enemies or count coins from a great distance. But these allusions were cast in obscure language and were accompanied by fantastic claims; the telescope, when it came, was a very humble and simple device. It is possible that in the 1570s Leonard and Thomas Digges in England actually made an instrument consisting of a convex lens and a mirror, but if this proves to be the case, it was an experimental setup that was never translated into a mass-produced device. [39]

Figure 3: The earliest known illlustration of a telescope. Giovanpattista della Porta included this sketch in a letter written in August 1609.[40]

[37]http://cnx.org/content/m11932/latest/spectacle_maker2.gif
[38]Note that the word lens was used only to denote convex lenses until the end of the seventeenth century.
[39]The claim for an "Elizabethan telescope" has recently been made by Colin Ronin, who has demonstrated an instrument based on the writings of Thomas Digges and William Bourne.
[40]http://cnx.org/content/m11932/latest/porta_sketch.gif

The telescope was unveiled in the Netherlands. In October 1608, the States General (the national government) in The Hague discussed the patent applications first of Hans Lipperhey[41] of Middelburg, and then of Jacob Metius of Alkmaar, on a device for "seeing faraway things as though nearby." It consisted of a convex and concave lens in a tube, and the combination magnified three or four times. [42] The gentlemen found the device too easy to copy to award the patent, but it voted a small award to Metius and employed Lipperhey to make several binocular versions, for which he was paid handsomely. It appears that another citizen of Middelburg, Sacharias Janssen had a telescope at about the same time but was at the Frankfurt Fair where he tried to sell it.

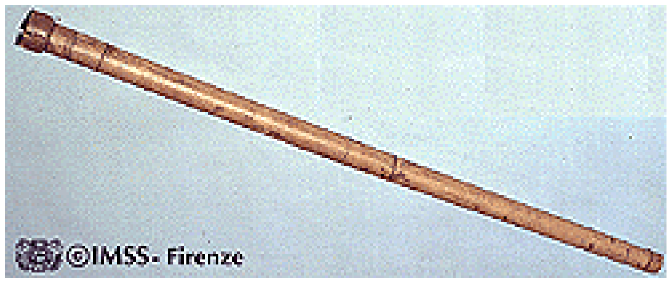


Figure 4: Galileo's telescopes[43]

The news of this new invention spread rapidly through Europe, and the device itself quickly followed. By April 1609 three-powered spyglasses could be bought in spectacle-maker's shops on the Pont Neuf in Paris, and four months later there were several in Italy. (Figure 4) We know that Thomas Harriot[44] observed the Moon[45] with a six-powered instrument early in August 1609. But it was Galileo who made the instrument famous. He constructed his first three-powered spyglass in June or July 1609, presented an eight-powered instrument to the Venetian Senate in August, and turned a twenty-powered instrument to the heavens in October or November. With this instrument (Figure 5) he observed the Moon, discovered four satellites of Jupiter[46], and resolved nebular patches into stars. He published *Sidereus Nuncius* in March 1610.

Verifying Galileo's discoveries was initially difficult. In the spring of 1610 no one had telescopes of sufficient quality and power to see the satellites of Jupiter, although many had weaker instruments with which they could see some of the lunar detail Galileo had described in *Sidereus Nuncius*. Galileo's lead was one of practice, not theory, and it took about six months before others could make or obtain instruments good enough to see Jupiter's moons. With the verification of the phases of Venus by others, in the first half of 1611, Galileo's lead in telescope-making had more or less evaporated. The next discovery, that of sunspots[47], was made by several observers, including Galileo, independently.

[41] "Hans Lipperhey" <http://cnx.org/content/m11940/latest/>
[42] Their optical system and magnification was the same as our traditional opera glasses.
[43] http://cnx.org/content/m11932/latest/g_telescope.gif
[44] "Thomas Harriot" <http://cnx.org/content/m11979/latest/>
[45] "The Moon" <http://cnx.org/content/m11945/latest/>
[46] "Satellites of Jupiter" <http://cnx.org/content/m11971/latest/>
[47] "Sunspots" <http://cnx.org/content/m11970/latest/>

Figure 5

A typical Galilean telescope with which Jupiter's moons could be observed was configured as follows. It had a plano-convex objective (the lens toward the object) with a focal length of about 30-40 inches., and a plano-concave ocular with a focal length of about 2 inches. The ocular was in a little tube that could be adjusted for focusing. The objective lens was stopped down to an aperture of 0.5 to 1 inch. , and the field of view was about 15 arc-minutes (about 15 inches in 100 yards). The instrument's magnification was 15-20. The glass was full of little bubbles and had a greenish tinge (caused by the iron content of the glass); the shape of the lenses was reasonable good near their centers but poor near the periphery (hence the restricted aperture); the polish was rather poor. The limiting factor of this type of instrument was its small field of view–about 15 arc-minutes–which meant that only a quarter of the full Moon could be accommodated in the field. Over the next several decades, lens-grinding and polishing techniques improved gradually, as a specialized craft of telescope makers slowly developed. But although Galilean telescopes of higher magnifications were certainly made, they were almost useless because of the concomitant shrinking of the field.

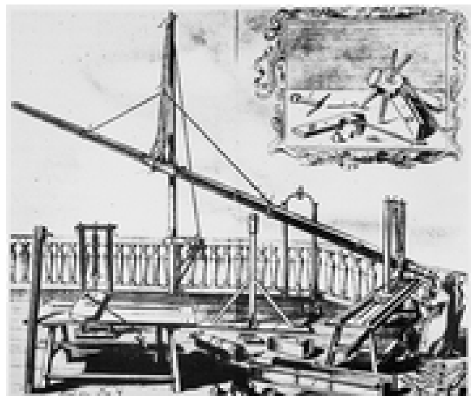
As mentioned above, the telescopic effect can be achieved with different combinations of lenses and mirrors. As early as 1611, in his *Dioptrice*, Johannes Kepler (Section) had shown that a telescope could also be made by combining a convex objective and a convex ocular. He pointed out that such a combination would produce an inverted image but showed that the addition of yet a third convex lens would make the image erect again. This suggestion was not immediately taken up by astronomers, however, and it was not until Christoph Scheiner[48] published his *Rosa Ursina* in 1630 that this form of telescope began to spread. In his study of sunspots, Scheiner had experimented with telescopes with convex oculars in order to make the image of the Sun projected through the telescope erect. [49] But when he happened to view an object directly through such an instrument, he found that, although the image was inverted, it was much brighter and the field of view much larger than in a Galilean telescope. Since for astronomical observations an inverted image is no problem, the advantages of what became known as the astronomical telescope led to its general acceptance in the astronomical community by the middle of the century.

The Galilean telescope could be used for terrestrial and celestial purposes interchangeably. This was not true for the astronomical telescope with its inverted image. Astronomers eschewed the third convex lens (the erector lens) necessary for re-inverting the image because the more lenses the more optical defects multiplied.

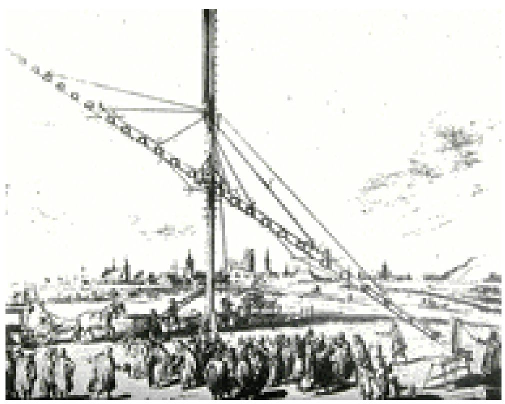
[48]"Christoph Scheiner" <http://cnx.org/content/m12126/latest/>

[49]The Galilean telescope produces an erect image of an object viewed directly but an inverted image of a projected object; by substituting a convex for the concave ocular, this situation is reversed.

In the second half of the seventeenth century, therefore, the Galilean telescope was replaced for terrestrial purposes by the "terrestrial telescope," which had four convex lenses: objective, ocular, erector lens, and a field lens (which enlarged the field of view even further).



(a)



(b)

Figure 6: (Machina Coelestis, 1673) (a) Hevelius's 60 foot telescope[50] (b) Hevelius's 140 foot telescope[51]

With the acceptance of the astronomical telescope, the limit on magnification caused by the small field of view of the Galilean telescope was temporarily lifted, and a "telescope race" developed. Because of optical defects, the curvature of lenses had to be minimized, and therefore (since the magnification of a simple telescope is given roughly by the ratio of the focal lengths of the objective and ocular) increased magnification had to be achieved by increasing the focal length of the objective. Beginning in the 1640s, the length of telescopes began to increase. From the typical Galilean telescope of 5 or 6 feet in length, astronomical telescopes rose to lengths of 15 or 20 feet by the middle of the century. A typical astronomical telescope is the one made by Christiaan Huygens, in 1656. It was 23 feet long; its objective had an aperture of several inches, it magnified about 100 times, and its field of view was 17 arc-minutes.

[50]http://cnx.org/content/m11932/latest/hevelius_telescope_60ft.gif
[51]http://cnx.org/content/m11932/latest/hevelius_telescope_140ft.gif

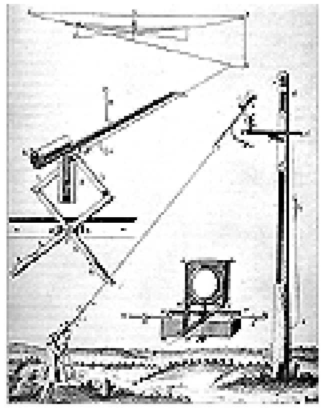


Figure 7: Aerial telescope (Christiaan Huygensm Astroscopium Compendiaria,1684)[52]

Telescopes had now again reached the point where further increases in magnification would restrict the field of view of the instrument too much. This time another optical device, the field lens came to the rescue. Adding a third convex lens–of appropriate focal length, and in the right place–increased the field significantly, thus allowing higher magnifications. The telescope race therefore continued unabated and lengths increased exponentially. By the early 1670s, Johannes Hevelius had built a 140-foot telescope.

But such long telescopes were useless for observation: it was almost impossible to keep the lenses aligned and any wind would make the instrument flutter. After about 1675, therefore, astronomers did away with the telescope tube. The objective was mounted on a building or pole by means of a ball-joint and aimed by means of a string; the image was found by trial and error; and the compound eyepiece (field lens and ocular), on a little stand, was then positioned to receive the image cast by the objective. Such instruments were called **aerial telescopes**.

Although some discoveries were made with these very long instruments, this form of telescope had reached its limits. By the beginning of the eighteenth century very long telescopes were rarely mounted any more, and further increases of power came, beginning in the 1730s, from a new form of telescope, the reflecting telescope.

Since it was known that the telescopic effect could be achieved using a variety of combinations of lenses and mirrors, a number of scientists speculated on combinations involving mirrors. Much of this speculation was fueled by the increasingly refined theoretical study of the telescope. In his *Dioptrique*, appended to his *Discourse on Method* of 1637, Renè Descartes addressed the problem of spherical aberration, already pointed out by others. In a thin spherical lens, not all rays from infinity–incident parallel to the optical axis–are united at one point. Those farther from the optical axis come to a focus closer to the back of the lens than those nearer the optical axis. Descartes had either learned the sine law of refraction from Willebrord Snell (Snell's Law) [53] or had discovered it independently, and this allowed him to quantify spherical aberration. In order to eliminate it, he showed, lens curvature had to be either plano-hyperboloidal or spherico-ellipsoidal. His demonstration led many to attempt to make plano-hyperboloidal objectives, [54] an effort which was doomed to failure by the state of the art of lens-grinding. Others began considering the virtues of a concave paraboloidal mirror as primary receptor: it had been known since Antiquity that such a mirror would bring parallel incident rays to a focus at one point.

[52] http://cnx.org/content/m11932/latest/aerial_telescope.gif

[53] The ratio of the sines of the angles of incidence and refraction is constant.

[54] The effect is most apparent for the objective; spherical aberration in the ocular affects the image much less.

Figure 8: Newton's reflecting telescope (1671)[55]

A second theoretical development came in 1672, when Isaac Newton published his celebrated paper on light and colors. Newton showed that white light is a mixture of colored light of different refrangibility: every color had its own degree of refraction. The result was that any curved lens would decompose white light into the colors of the spectrum, each of which comes to a focus at a different point on the optical axis. This effect, which became known as chromatic aberration, resulted in a central image of, e.g., a planet, being surrounded by circles of different colors. Newton had developed his theory of light several years before publishing his paper, when he had turned his mind to the improvement of the telescope, and he had despaired of ever ridding the objective of this defect. He therefore decided to try a mirror, but unlike his predecessors he was able to put his idea into practice. He cast a two-inch mirror blank of speculum metal (basically copper with some tin) and ground it into spherical curvature. He placed it in the bottom of a tube and caught the reflected rays on a 45° secondary mirror which reflected the image into a convex ocular lens outside the tube (see Figure 8). He sent this little instrument to the Royal Society, where it caused a sensation; it was the first working reflecting telescope. But the effort ended there. Others were unable to grind mirrors of regular curvature, and to add to the problem, the mirror tarnished and had to be repolished every few months, with the attending danger of damage to the curvature.

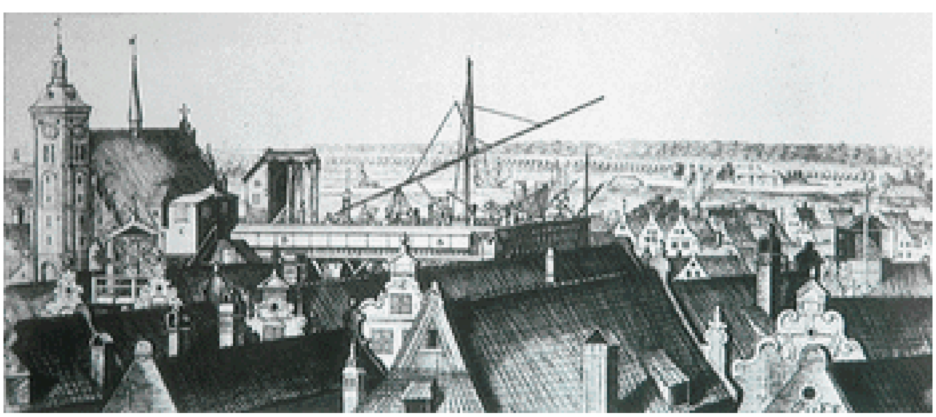


Figure 9: Hevelius's rooftop observatory, (Machina Coelestis, 1673)[56]

[55] http://cnx.org/content/m11932/latest/newton_telescope.gif

The reflecting telescope therefore remained a curiosity for decades. In second and third decades of the eighteenth century, however, the reflecting telescope became a reality in the hands of first James Hadley and then others. By the middle of the century, reflecting telescopes with primary mirrors up to six inches in diameter had been made. It was found that for large aperture ratios (the ratio of focal length of the primary to its aperture, as the f-ratio in modern cameras for instance), f/10 or more, the difference between spherical and paraboloidal mirrors was negligible in the performance of the telescope. In the second half of the eighteenth century, in the hands of James Short and then William Herschel, the reflecting telescope with parabolically ground mirrors came into its own.

[56]http://cnx.org/content/m11932/latest/hevelius_roof_obsry.gif

Chapter 1

(Untitled)

Glossary

A

armillary sphere

- An instrument consisting of an arrangement of rings, all of which are circles of the same sphere, used to show the relative positions of the celestial equator, ecliptic, and other circles of the clestial sphere.

atmospheric refraction

The change in direction of a ray of light as it passes from space into the atmosphere. This causes celestial objects to appear to be in a location different from their actual ones.

C

Carmelite Order

The Brothers of the Blessed Virgin Mary of Mount Carmel is one of the mendicant orders originating on Mount Carmel in Israel.

Counter Reformation

- As dissenting groups split off from the Catholic Church in what came to be known as the Protestant Reformation, the Church began a series of reform measures of their own. These reform measures aimed to keep Church members from becoming Protestants, and were known as the Counter Reformation.

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P

parallax

The change in the position of an object in the heavens due to the orbit of the earth. Observable parallax in the fixed stars is a proof of the rotation of the earth around the sun. See this explanatory diagram.

patrician class

- The aristocracy or nobles.

S

Savonarola, Girolamo

- A Dominican friar, prior of the convent of San Marco in Florence, Savonarola believed that he was sent as a watchman for God to warn people of impending doom. His power was such that when the Medici family was expelled in 1494, he ruled the city and became a major power in Italy. In 1496, he turned against the pope, after the pope attempted to control the prior's power by offering a cardinal's office. In 1497, the pope excommunicated Savonarola. Savonarola continued to practice as a priest, refuting the order. In the end, Savonarola was tortured and in 1498 was hanged.

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