Armillary Spheres and Scientific Instruments in Renaissance life and Art

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"The Earth can neither move in any of the aforesaid oblique directions, nor ever change at all its place at the center."[1]

Above is a quote from the Greek astronomer Claudius Ptolemy whose treatise the *Almagest* has been one of the most influential documents in history. Like the ancient physician Galen and the philosopher Aristotle, the works of Ptolemy were so highly regarded they actually managed to stifle new ideas that might have strayed from their established teachings. But this kind of conservative thinking is common to the human character. For instance, many American school children are taught that history follows a linear path of progression from the ancient civilizations of Babylon, Egypt and Palestine to Greece and then Rome. The Roman Empire is said to have fallen and the result was a thousand years of stagnation lasting until the arrival of the Renaissance. Of course this is a Eurocentric view, now generally dismissed, that ignores the Eastern Roman, or Byzantine, Empire, Islamic civilization, the Mongol Empire, which was the largest land empire in history and the many accomplishments of Western Europeans during the so-called "dark" ages. But even in this storybook view of history there is a bit of truth. It wasn't until the later part of the Renaissance that some ideas, including those of astronomy, reached the same level of understanding as in the first century.

Ptolemy's *Almagest* is primarily a compilation of all the astronomical knowledge of his day. He was born and lived in Egypt during the second century BCE. His writings are the only comprehensive work on astronomy to have survived from antiquity. His *Geography* is also the only classical book of cartography to have escaped oblivion. How true contemporary translations are to the original is debatable. Was it the Greek Ptolemy who referred to a "God invisible and unchanging"[2] or a later Islamic translator? The word Almagest itself is an anglicized version of the Latinized *Almagestum*, which is derived from the Arabic *Al Magisti*. *Al Magisti* means greatest composition. The original Greek name of the *Almagest* was *Great Composition* or *Mathematical Composition*. The book's influence is incalculable and "may fairly be regarded as the astronomical Bible of the Middle Ages."[3] In it he describes how to make several devices for measuring the stars and planets including the armillary sphere.

The armillary sphere gets its name from the Roman word *armillae*, which simply means brass ring in Latin. It is still a useful device for understanding the relative movements of the Sun, Moon, stars and planets and has long been a symbol in art for wisdom and to represent the intelligence of the subject who might be painted contemplating it. In Sandro Botticelli's Saint *Augustine in his Studio* (figure 1), Augustine's wisdom is represented by several books and the armillary sphere he seems to be meditating upon along with a mechanical clock and book of geometry on the shelf behind him. The Saint's attitude toward science and astronomy is clear in his book *The Literal Meaning of Genesis*. In the fifth century he wrote "even a non-Christian knows something about the motion and orbit of the stars and even their size and relative positions, about the predictable eclipses of the sun and moon… it is a disgraceful and dangerous thing for an infidel to hear a Christian…talking nonsense on these topics."[4]

(figure 1)

The armillary sphere is a map of the universe, as it was understood until the advent of modern astronomy. They are still used today as teaching devices, though the Sun is now at the center rather than the Earth. A highly educated man like Augustine would have been familiar with the works of Ptolemy and have no reason to suspect that the Earth revolved around the Sun rather than the opposite. Indeed Ptolemy, like Aristotle before him, makes a convincing and logical argument as to why the Earth must be at the center of the Universe in the *Almagest*. If the Earth was not in the center surely the stars could not move so uniformly across the sky. They would be skewed to one side or the other. Ptolemy ridicules other astronomers who proposed such a ridiculous idea as the Earth revolving around the Sun.

Of course we know today that the Sun is at the center of the Solar System with the planets revolving around it and the idea of a center of the Universe is a misunderstanding of modern cosmology. But Ptolemy's logic is sound unless one comprehends the vastness of space. According to William P. Blair of the Department of Physics and Astronomy at John Hopkins University if we imagine the distance from the Earth to the Sun, 93 million miles, to be the thickness of a sheet of paper the nearest star would be 73 feet away. The diameter of the Milky Way would be 310 miles, the closest galaxy, Andromeda, would be 6000 miles away and the "edge" of the known universe would be a stack of paper 31 million miles long. Given these incomprehensible distances there was no way to detect any variance in the positions of the stars from anywhere in Earth's orbit before the invention of the telescope.

(figure 2)

In Jan Provost's painting *A Christian Allegory* (figure 2) from the early sixteenth century one can see that the universe is presented as a sphere with the Earth at the center and the Sun and Moon in orbit around it. The celestial equator and the tropics of Cancer and Capricorn can be made out along with the line of the celestial latitude. These are common features of the armillary sphere and show that the artist's understanding of the shape of the Universe encompasses a familiarity with the instrument. Also it can be inferred that his audience would have been somewhat accustomed with this model.

(figure 3)

Geurcino's *Personification of Astronomy* (figure 3) depicts the goddess Venus Urania holding a typical armillary sphere. Since antiquity Urania was commonly depicted with some form of globe representing the cosmos. Sometimes this globe would be an armillary sphere detailing the relative movements of the heavenly bodies or it might be a celestial globe, which is solid and maps out the positions of the major stars and constellations. In Giamblogna's *Venus Uranis* (figure 4) from around 1573 one can see the map of the universe at the figure's feet. The ecliptic can be clearly seen along with latitudinal lines and the tropics.

(figure 4)

The ecliptic is the apparent path of the Sun in relation to a viewer on the Earth. Though there are numerous constellations, the zodiac refers to those constellations within the ecliptic. The twelve signs of the zodiac each occupy an equal 30-degree section of the circle of the ecliptic. The moon's orbit is generally within the ecliptic though it crosses to outside the path of the Sun twice a month. If this happens during a new moon it will produce a solar eclipse. If the moon crosses the path of the Sun during a full moon there will be a lunar eclipse. The armillary sphere has proven to be an excellent tool for predicting the eclipses of both the Sun and the Moon. The planets also generally follow the path of the ecliptic.

The utility of the armillary sphere only added credence to Ptolemy's dogmatic assertion that the Earth was at the center with the Sun, Moon and "fixed" stars circling it. In addition to being a practical tool and teaching aid the armillary sphere also became a symbol for an understanding of the heavens. Its use as a decorative element in architecture expanded widely during the voyages of discovery, particularly in Portugal. An armillary sphere can clearly be made out in the windows of the Convent of the Order of Christ or Castle of the Knights Templar in Tomar, Portugal (figure 5). This is a typical example of the Manueline style or Late Portuguese Gothic. One of the characteristics of the Manueline style is the use of astronomical and navigational instruments in the ornamentation. The style is named for King Manuel I who reigned over Portugal from 1495 to 1521 and clearly celebrates the Portuguese navel accomplishments of the time. Even today the Portuguese flag depicts an armillary sphere and can be seen as an evolution from Manuel I's personal flag.


(figure 5)

Another use of scientific instruments in the architecture of this time can be found at Santa Maria Novella in Florence, Italy. Ingnazio Danti, who could claim priest, astronomer, mathematician, cartographer and tutor for the Medici family among his accomplishments, added an armillary sphere and quadrant to Leon Battista Alberti's famous façade in 1572. Danti lived in the convent at Santa Maria Novella when he installed the functional armillary sphere with its fixed position to accurately measure the movement of the sun by measuring its shadow. Along with Cosimo I de' Medici, known as the Great, Ingnazio Danti campaigned Pope Gregory III for a revisiting of the Julian calendar. Though extremely accurate the Egyptian calendar established in the West by Julius Caesar, with its 365.25 daylong year, had slowly shifted the seasons by ten days over the course of fifteen hundred years.

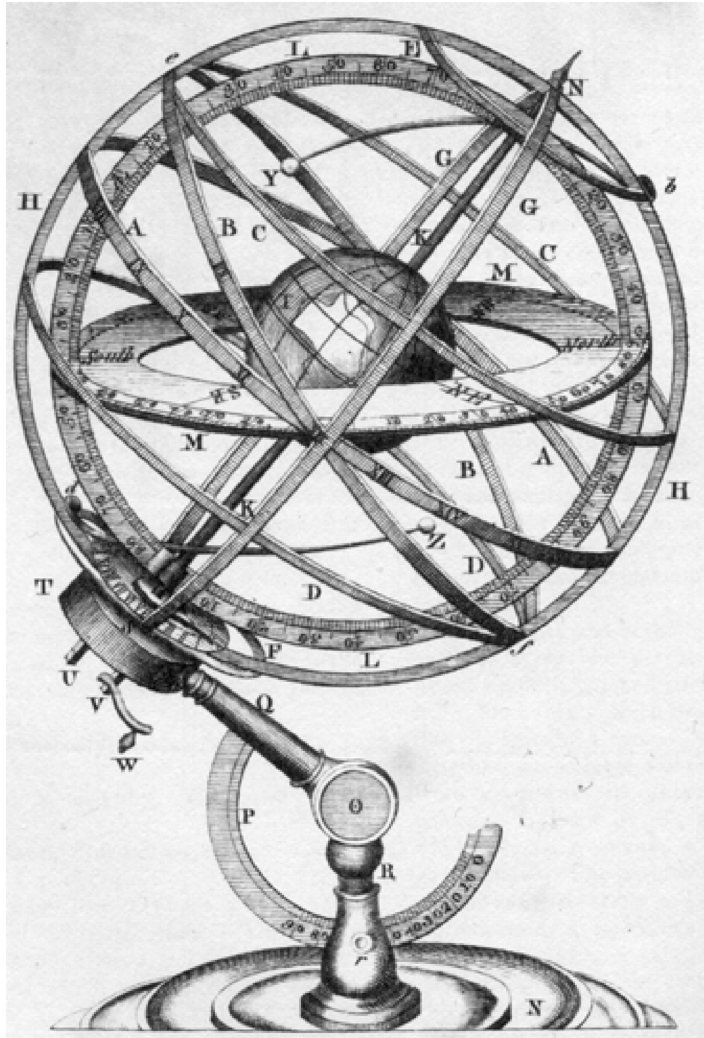
Contrary to the conventional wisdom that the Church has always been an adversary of science, it was for religious reasons that the correction of the calendar was of vital importance. "Although a centur(ies)-old problem, the measurement of the tropical year, on which to base a reform of the calendar, acquired new urgency in the Renaissance…the Christian world had been fragmented and divided…Renaissance popes did not fail to recognize the symbolic value of the dating of the calendar."[5] The dating of Easter has been a complicated task since the First Council of Nicaea decreed in 325 BCE that all Christians should celebrate the resurrection of Christ on the same day. This date has historically been the first Sunday after the Paschal Full Moon, which is not a full moon at all but rather the fourteenth day of a lunar month. To fix this anomaly, ten days would need to be eliminated from the calendar and the leap year and leap century implemented.

The correction was approved by the Council of Trent in 1563 and began implementation in 1582 though it wouldn't be adopted by England and America for another two hundred years. Many Eastern Orthodox churches still date Easter with the Julian calendar. In addition to the armillary sphere Ingnazio Danti also added an ornamental quadrant to the façade of Santa Maria Novella and built an enormous terrestrial globe for Cosimo I's Ducal palace.

Arguably the most spectacular armillary spheres constructed were those by Antonio Santucci an astronomer and mathematician from the University of Pisa. The first was commissioned by Philip I of Spain and built around 1582. Santucci completed a second colossal armillary sphere (figure 6) between 1588 and 1593 for Ferdinando I de' Medici, which is now housed in the *Museo Storia della Scienza* in Florence along with numerous other scientific instruments from the Medici collection. Carvings of the coats of arms of the Medici family and house of Lorraine are part off the elaborate design. "It may have been the largest armillary sphere, but it was among the last of its kind. Within a few years Ptolemy's …view of the cosmos began to disintegrate under a barrage of scientific breakthroughs."[6] Santucci's armillary spheres are certainly atypical and more decoration than tool. The common Renaissance armillary sphere would have been much smaller and portable. The instrument was often held aloft in front of the viewer so to be able to align it with the horizon.

(figure 6)

Surprisingly almost as old as Denis Diderot's famous *Encyclopedie*, the *Encyclopedia Britannica* published a superb engraving (figure 7) detailing the workings of a typical armillary sphere in its 1771 edition. In this engraving one can see that *A* represents the celestial equator. *B* is the ecliptic. The small *b* is the nut that controls the wire attached to the Sun, which is represented by *Y*. When the small *b* is turned the Sun moves along the ecliptic. *C* is the tropic of Cancer. The tropic of Cancer represents the farthest north that the Sun travels along the ecliptic. The classic armillary sphere is a model of the Ptolemaic universe and the earth is at the center. For all practical purposes, such as navigation, finding one's position in relation to the Sun or predicting eclipses, the armillary sphere is a very reliable tool. The Small *d* is the nut that holds the wire controlling the position of the Moon, which is *Z*. *D* is the tropic of Capricorn. This is the farthest south that the Sun will appear to a viewer on the Earth. When the sun reaches the small *f* it is at the winter solstice. At point small *e* it is at the summer solstice. The large *E* represents the Arctic Circle. Above this point there is at least one 24 hour period a year of both total daylight and total night. The same is true for below the Antarctic Circle at *F*. *G* is the equinox ring. When the sun is parallel to *G* it will be directly above the equator and either the vernal or autumnal equinox. *I* shows the Earth at the center of the Universe as balance on *K*, the terrestrial axis. *L* is the meridian ring with the latitude degrees engraved on it. *M* is a flat disk that travels along the meridian ring to show the angle of the horizon. The tilt of the Earth's axis can be set at *P* and by turning the lever *W* the entire cosmos would move with the clockwork precision of the Ptolemaic universe.



(figure 7)

To truly understand the armillary sphere as a model of the Universe, one has to imagine the Greek Universe that it represented. In the very center are the four elements. First there is earth, then water. Above this is air and above that is the most mysterious element of all, fire. If one presupposes that the world is made of these four elements this is exactly how it should be perceived. Certainly the oceans rest on the land, which is encompassed by the dome of the sky and fire, by nature, rises upward to the heavens. Above the fire is the Moon. Next come the planets Mercury and Venus. One can only be impressed that the Greeks had, through careful observation, realized that the two planets between the Earth and the Sun were different from the other three. Next comes the Sun, which is below the planets Mars, Jupiter and Saturn. Finally, furthest away are the "fixed" stars including all 48 constellations mentioned by Ptolemy.

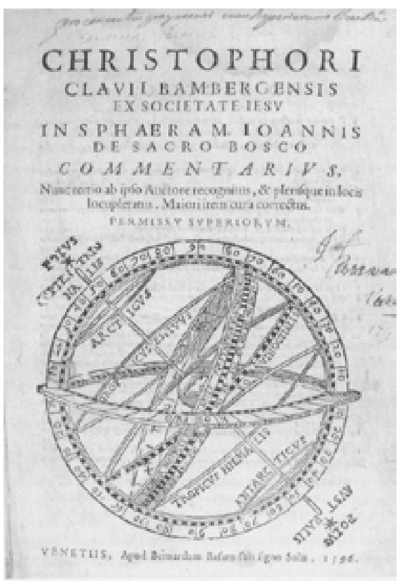
Who actually invented the armillary sphere is debatable. Traditionally it is attributed to the Greek astronomer Eratosthenes around 225 BCE, but this a Western tradition and there are some Scholars who would give the credit to the Chinese astronomers Shi Shen and Gan De from the fourth century BCE. The Chinese certainly have a long history of careful astronomical measurements and claim to have accurately measured the obliquity of the ecliptic, or angle at which the ecliptic cuts the equator, as early as 1100 BCE.[7] There is also a school of thought that credits the invention of the armillary sphere much later to the Islamic astrologer Al-Nayrizi in the tenth century. Truly objective history seems to be a rarity and because of the delicate nature of the armillary spheres themselves, none have survived from antiquity to give insight as to their origin.

One easily dispelled myth is the idea that pre-modern peoples imagined the Earth to be flat. There were a number of astronomical treatises in circulation during the Middle Ages. The most popular of which was that of Johannes de Sacrobosco, also known as John of Holywood, the English-born astronomer who taught at the University of Paris in the thirteenth century. His major work, *Tractatus de Sphaera*, was readily available throughout Europe after its publication around 1230. Sacrobosco was clearly familiar with the use of the armillary sphere and was fully aware that the Earth is round. He also recognized the problems with the Julian calendar and is credited with being the first Westerner to use Hindu-Arabic numbers. The spherical Earth was explained in the "Latin versions of the cosmological works of both Ptolemy and Aristotle.

Though later criticized as inaccurate, these translations remained influential down to the sixteenth century.”[8] Certainly no educated person of the time would have imagine the Earth to be flat and there is no reason to think the uneducated would have second-guessed them.


(figure 8)

William Cunningham’s book The *Cosmographicall Glasse* (figure 8), printed in London in 1570 shows the god Atlas holding up a universe that is presented in the form of an armillary sphere. This is the first English language work on the subject of cosmography. The cover of Christoph Clavius’ *Commentaries on the Sphere of Sacrobosco* (figure 9) also shows the Universe as an armillary sphere. Christoph Clavius was the most influential astronomer involved in the calculation of the Gregorian calendar. This further illustrates how precise measurements such as the length of the year could be made without ever straying from the idea that the Earth was at the center. In the sixteenth century engraving after a painting by FranciscoVillamena (figure 10) Christoph Clavius is depicted posed in front of an armillary sphere, quadrant and astrolabe. As a Jesuit, Clavius illustrates that the conventional wisdom of the Church’s opposition to science has been exaggerated. He was an early supporter of Galileo, who would have been familiar with Clavius’



(figure 9)


(figure 10)

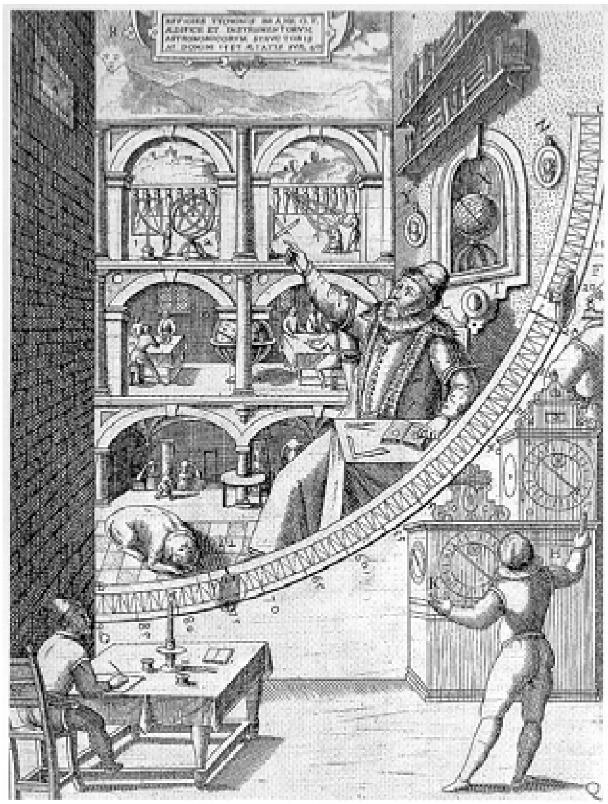
Commentaries. The myth that Galileo was tortured for his heliocentric views is contrary to all evidence and it appears to be his indiscrete and insulting writings that mocked his onetime supporter Pope Urban VIII that resulted in his eventual problems with the inquisition and house arrest.

Scientific exploration was rarely discouraged and usually celebrated throughout Renaissance Europe in all levels of society. Hans Holbein's famous painting *The Ambassadors* shows its subjects in front of a display of numerous scientific instruments. These include a globe of the earth, a celestial globe, a quadrant, a torquetum and a polyhedral sundial all of which represent the wisdom of the two men portrayed. Celestial globes are models of the Ptolemaic Universe as might be seen from the outside. One can imagine them as an armillary sphere with a cover around the outer layer displaying a map of the ‘fixed" stars. A quadrant is used for measuring a celestial body's altitude from the horizon or can be used to find the angles between objects. It could be used in navigation, surveying or architecture. Quadrants have long proved useful in finding the heights of buildings by using a plum line to ensure the device is level, then walking away until the quadrant indicates that the viewer is at a forty-five degree angle for the top of the structure. The distance from the building at this point will be the same as the height. A torquetum is a simpler version of an armillary sphere used to measure the horizon, equator and the ecliptic.

Another painting by Holbein depicting scientific instruments is his *Portrait of Nicolas Kratzer*. In this painting the subject can be seen working on the polyhedral sundial, which he invented. The polyhedral sundial could be used to tell time in a number of different ways. At this time sundials were getting more elaborate and complicated. New designs were becoming more common. In 1570 Giovanni Padovani, a Veronese mathematician and astronomer published a popular treatise on the sundial giving examples of a wide variety of the devices.

Perhaps the most familiar depiction of scientific instruments in a work of art is Raphael's fresco, the *School of Athens*. This fresco was painted from 1510 to 1511 in what is now called the Stanze di Raffaello, or Raphael Rooms in the Vatican. The identities of many of the figures in the painting are contested including the two philosophers holding aloft the terrestrial and celestial globes. Who exactly the figures are is debatable. The general consensus is that Ptolemy is the figure facing the viewer holding the celestial globe and the one facing away with the terrestrial globe is Zoroaster.[9] Giovan Pietro Bellori, writing at the end of the seventeenth century, identifies the figure as a "representative of the Chaldeans."[10] Neither Zoroaster nor the Chaldeans would have been associated with the actual school of Athens but then neither would Ptolemy. The Chaldeans were Babylonian and associated with astronomy in the biblical book of *Daniel*. "Zoroaster (and) Ptolemy…tracked divinity in the regular patterns of geometry and the stars."[11] Raphael is clearly not interested in painting a history but rather a symbolic and comprehensive collection of philosophical thought. Also one can only imagine how many compromises must have been made by the famously affable Raphael and the numerous intellectuals surrounding him who would have wanted to add their suggestions for the subject matter of such a public work.

Even during Raphael's lifetime the unquestioned authority of the Ptolemaic universe was coming to an end. Nicolaus Copernicus would have been a contemporary of the artist but the scientist's ideas would not have been widespread. Scientific instruments for measuring the relative movements celestial bodies were getting more sophisticated and accurate. The most successful and influential astronomer before the invention of the telescope was Tycho Brahe. In an engraving from his treatise *Astronomiae Instauratae Mechanica* (figure 11) one can see an armillary sphere, a celestial globe and the enormous quadrant he used for making his precise measurements of the stars and planets. An assistant appears on the far right of the engraving



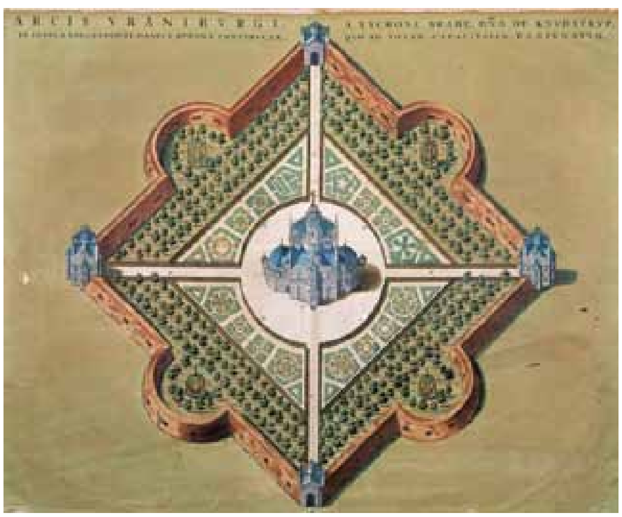
(figure 11)

working the quadrant, which appears to be several feet taller than him. The astronomer is depicted pointing toward a small window with which he could keep make the most careful measurements yet recorded. The *Astronomiae Instauratae Mechanica* also has a diagram of Tycho's Great Equatorial Armilla, (figure 12) a much larger version of a measuring device described by Ptolemy in the *Almagest*.

All of these amazing instruments were housed in Tycho's s unprecedented observatory on the then-Danish island of Ven. Though it no longer stands there are still numerous engravings and paintings (figure's 13 and 14) of Tycho's observatory, Uranienborg or fortress of the heavens. Because of it uniqueness and historical importance, Uranienborg has remained an object of fascination and the now-Swedish island of Ven is still a place of pilgrimage for students of history and astronomy. Tycho built a second, more utilitarian, observatory nearby and called it Steirneborg or Castle of the Stars. Steirneborg was built mostly underground to avoid any shifting of the positions of his instruments and the careful measurements made there would lay the groundwork for the scientific revolution that was about to come. Tychos's obser-

(figure 12)

(figure 13)



(figure 14)

vations led him to the first deviation from the Ptolemaic model of the Universe since antiquity by having Mercury and Venus orbiting the Sun, which still revolved around an unmoving Earth at the center. He also realized that the orbits of the planets were not perfect circles.

The traditional Egyptian model of the Universe had predated Tychos revelations by millenniums. Long before Ptolemy, Egyptian astronomers and mathematicians had developed a model of the Universe with Mercury and Venus revolving around the Sun. One can see that in the case of astronomy there was an actual renaissance of ancient learning. Possibly Egyptian and Babylonian astronomers had devices as sophisticated as Tycho's. Evidence for this has yet to be discovered and it is currently impossible to know how these ancient peoples arrived at the conclusion that at least two planets orbited the Sun.

Giovanni Battista Riccioli's 1651 *Almagestum Novum* (figure 15) shows the goddess Venus Urania weighing the models of the Universe proposed by Tycho and Copernicus and finding Copernicus lacking. Ptolemy is depicted lying below and his version of the Universe is at the goddess' feet. He is saying "I am made erect by being made correct." The hand of God is repre-


(figure 15)

sented at the top with the words *numerus*, *mensura* and *pondus* to indicate that the Universe is created by numbers, measurement and weight. The goddess Urania is show holding an armillary sphere.

Because of the success of the Ptolemaic model in explaining the positions of the stars and planets and its practical use in navigation there was considerable resistance to change until the evidence became overwhelming. This posits the speculation as to what misguided assumptions about the Universe might modern man be innocently clinging onto that will someday be overturned by evidence. Today the armillary sphere is still a useful device for explaining the relative movement of the Earth and heavenly bodies and contemporary artwork, such as Lee Lawrie's *Atlas* in front of Rockefeller Center, utilize its design. The armillary sphere is also the most recognizable abstract symbol for the Universe and it has remained, since antiquity, a model for contemplation of man's place in the unimaginable vastness of the cosmos.

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4. John Hammond Taylor, ed., *Saint Augustine: The literal Meaning of Genesis* (Bryan, Texas: The Newman Press, 1982), 42-43.
5. Francesca Fiorani, *The Marvel of Maps* (New Haven and London: Yale University Press, 2005), 52.
6. Thomas F. Homer-Dixon, T*he Upside of Down: Catastrophe, Creativity, and the Renewal of Civilization* (Washington, D.C.: Island Press, 2006), 209.
7. Berry, *op. cit*., page 11.
8. Allen G. Debus, *Man and Nature in the Renaissance* (Cambridge, London, New York and Melbourne: Cambridge University Press, 1978), 78.
9. Marcia Hall, "Introduction," in *Raphael's School of Athens*, ed. Marcia Hall (Cambridge, New York, Madrid and Melbourne: Cambridge University Press, 1997), 34.
10. Ingrid D. Rowland, "The Intellectual Background," in *Raphael's School of Athens*, ed. Marcia Hall (Cambridge, New York, Madrid and Melbourne: Cambridge University Press, 1997), 156.
11. *ibid*., page 156.