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Excellent account of Kuhn's book, well documented, interesting extra thoughts

# The Copernican Revolution

Nicolaus Copernicus was an early astronomer that left a lasting impact on the scientific world. His development of the heliocentric model was known as the Copernican Revolution and was the starting point for an even more significant period in the history of science called the Scientific Revolution (Stars). The Copernican theory was so revolutionary at the time because it uprooted prior astronomical theories and played a tremendous role in non-scientific thought as well (Kuhn 4). Its influence is among the ranks of Darwin's theory of evolution, Einstein's theory of relativity and Freud's psychoanalytic theories (Kuhn 4). A closer look at prior and subsequent theories as well as the history behind the revolution truly puts its magnitude into perspective.

The Copernican Revolution completely reformed fundamental concepts of astronomy during its time and took part in a major transition in the sense of values held by the common man (Kuhn 2). It is important to analyze astronomical theories prior to that of Copernicus' to understand the significance of his findings (Kuhn 3). Cosmology, the study of the structure of the universe and its relation to man, fascinated the ancient man for centuries (Kuhn 4). Many primitive theories of the universe were proposed during this time. The Egyptians, for example, believed the Earth was shaped as an elongated platter bounded by platters for the skies, the water and the universe (Kuhn 5). While this theory may seem absurd to us today, it was considered equally as valid during that time. Just like modern scientists, the Egyptians based their theories on what they knew and what they saw (Kuhn 5). The Egyptians lived alone the Nile, their land was shaped like a platter, and the sky did have a dome-like shape (Kuhn 5). The ancient Egyptians, along with other ancient civilizations, truly believed in the theories they proposed, just as we have no doubt in our theories of the universe. It is this strong belief that makes the transition from primitive to modern theories difficult. Furthermore, the ancient man used cosmology to fulfill a psychological need (Kuhn 6). Explaining the relationship between where man lived and the external world makes man feel “at home” in the universe, giving his thoughts and actions meaning (Kuhn 6). Rejection of a theory that provided man with such a strong sense of spirituality and belonging would be no easy feat. Core values and beliefs, especially those ingrained since birth, are considerably difficult to alter.

The theories developed during the Copernican Revolution overthrew many existing world views that made the universe meaningful for the general population (Kuhn 7). The ancient two-sphere universe, developed by Greek astronomers in the fourth century B.C., was the first conception of the astronomical universe taken seriously by the largest number of people, especially astronomers (Kuhn 27). The two-sphere universe contained an interior, terrestrial sphere for man and an exterior, celestial sphere for the stars (Kuhn 27). The Earth was believed to be a stationary sphere at the center of a larger moving sphere, containing the stars (Kuhn 27). The Sun moved in the space between the Earth and the stars, but outside of the outer sphere there is only empty space (Kuhn 27). Like the ancient Egyptians, astronomers relied on what they observed and what they could comprehend to develop their theory for the two-sphere universe (Kuhn 28). The stars were the farthest objects they could see in the skies and appeared to move together, so assuming the stars were on the outermost edge of the universe was not irrational (Kuhn 28). The movement of the stars was also ceaseless and regular, suggesting that it must be moving around a symmetric surface. The Greeks postulated that this surface must be a sphere using arguments that, at the time, were indisputable (Kuhn 30). They believed that it was no coincidence that the Earth possesses the same perfect spherical form as the universe that surrounds it (Kuhn 29). Additionally, they believed that because the Earth was at the center of the universe and its spherical nature did not allow there to be a discernable “up” or “down,” it must be stationary (Kuhn 30). Similar to the Egyptians, these theories had heavy implications on spiritual thought as well. It is comforting to imagine a universe that revolves around the Earth, the habitat of man. Therefore, it is not difficult to understand why the Greeks held the two-sphere universe in such high esteem and why it was so difficult to renounce.

Within the two-sphere universe, there were various different models proposed by astronomers. By the end of the fourth century B.C., astronomers laid out the planets based on their observed orbital periods in the vast region between the Earth and the stars (Kuhn 52). The Greek philosopher and scientist Aristotle believed that the universe contained within the sphere of stars was filled with an element called "aether" (Kuhn 78). Aether was considered a crystalline solid, unlike any substances found on Earth because it is pure, unalterable and weightless properties (Kuhn 78). This substance made up the planets, stars and concentric spherical shells to which the planets and other celestial objects were attached (Stars). Aristotle believed that there were fifty-five concentric spheres in total that all moved at different velocities and revolved around the Earth (Kuhn 80). The celestial objects attached to the spheres were always the same distance from Earth (Stars). Because the universe was full the shells were in contact with one another, one shell would rub against its neighboring shell, driving it and its next interior shell to rotate (Kuhn 80). The outermost sphere was termed the "Prime Mover," which drove the entire system and made the all the spheres turn at a constant angular velocity (Stars). The Aristotelian Universe is noteworthy because it provided fuel for cosmological thought during the Middle Ages and even the Renaissance (Kuhn 78). Even with its apparent problems, the structure of the universe was considered predominately Aristotelian during this time.

Although the two-sphere universe was widely accepted by scholars for many years, it provided no information about the location of the planets (Kuhn 52). The crude conception of the location of the planets produced problems that astronomers tried in vain to explain. The main problem was that the motion of the planets was highly irregular (Kuhn 47). Even though the average number of days for a planetary cycle could be estimated based on observations by the naked eye, the planets did not move at a uniform rate and distinct journeys differed from the average period (Kuhn 47). Additionally, while the planets usually move eastward, there were noticeable periods of westward motion (Kuhn 47). This was known as "retrograde motion" and only occurred among the five planets, excluding the moon and the Sun (Kuhn 47). Finally, there were observations of varying planetary brightness (Stars). The Greek astronomers and mathematicians Apollonius and Hipparchus developed the epicycle and deferent as a mathematical solution to the problem of the planets (Kuhn 59). The epicycle is a small circle that rotates around a point on the circumference of the deferent, a larger rotating circle (Kuhn 59). The Earth was thought to be the center of the deferent and planets were attached to the epicycles rather than the concentric spheres (Stars). The centers of the epicycles moved around the deferent with constant angular velocity while planets along the epicycles had their own circular motion (Stars). Retrograde motion is explained by this model because a planet can appear to be moving backwards in its revolution around the point on the deferent (Stars). Additionally, this rotation also explains variations in brightness because the distance of the planet from the Earth varies with time (Stars). However, this model was far too simple to explain the more detailed motion of the planets (Kuhn 64).

The astronomer Ptolemy, in 150 A.D., attempted to build upon this simple epicycle-deferent system to further explain the observed motion of the planets (Kuhn 66). His work is significant because all his successors, including Copernicus, modeled their theories on the framework he laid out (Kuhn 66). He developed the concept of the equant, a point directly opposite of the Earth from the center of the deferent (Kuhn 71). A planet moves with uniform speed with respect to the equant, but at an inconsistent speed with respect to the deferent (Kuhn 71). Ptolemy used this concept to solve the problem of irregular planetary motions but many astronomers, especially Copernicus, criticized his theory because it violated the idea that all planets had uniform circular motion (Kuhn 71).

Although Copernicus appears to build upon where Ptolemy left off, there was a great deal of scientific activity between when these two astronomers worked (Kuhn 100). This time period was crucial in providing the foundation for the Copernican Revolution (Kuhn 100). It is interesting to note how historical events influenced Copernicus and his work. Scientific activity and traditional learning began to decline after the second century B.C. with the decline of Roman authority in the Mediterranean. (Kuhn 101). The works of scholars such as Aristotle of Ptolemy were virtually unknown and incomprehensible (Kuhn 101). During the Middle Ages, the tradition of learning was revived, but scientific advances were scarce because of the influence of the Catholic Church (Kuhn 106). During the early centuries of the Christian era, the church believed science to be useless, secular learning because all the knowledge necessary for salvation could be found in Scripture (Kuhn 107). When the Roman Catholic Western Europe reestablished ties with the Orthodox Eastern Europe, the Church felt less threatened by "pagan wisdom" (Kuhn 109). A vast range of knowledge became acceptable for intensive study, given that the church could maintain their monopoly over learning (Kuhn 109). By the end of the Middle Ages, the Christian doctrine was modified to incorporate the idea of an Aristotelian universe (Kuhn 109). The philosopher and theologian Thomas Aquinas was a central figure in the synthesis of science and religion (Stars). He took passages from scriptural texts and, while upholding their literal meanings, applied them to cosmological theories (Kuhn 110). God, for example, was said to be the Prime Mover, which caused all changes in the heavens (Stars). From this period on, science was heavily involved in theology (Stars). Any contention with the Aristotelian Universe would not be a purely scientific dispute, but a theological one as well (Stars). This had a direct effect on the reception of Copernicus' theory and brings to light the significance of the Copernican Revolution.

The Copernican Revolution occurred after the Middle Ages, during the Renaissance and Reformation periods (Kuhn 124). Revolutionary developments in science have often occurred during periods of drastic change on the national and international level (Kuhn 124). During the Renaissance, for example, European countries were concerned with exploration of unexplored lands (Kun 125). This period of voyages called for improved maps and navigational techniques, creating a demand for expert astronomers (Kuhn 125). Voyages also led the Europeans to new territories where they discovered new products, new people and new ideas (Kuhn 125). The limitations of the Ptolemaic Universe became evident and computational techniques of the period were challenged (Kuhn 125). The Church took on the project of reforming the calendar in the early sixteenth century (Kuhn 125). Copernicus was asked to assist in this reform but he refused, stating that the current astronomical theories were insufficient for designing an accurate calendar (Kuhn 126). Even intellectual aspects of the Renaissance paved a way for Copernicus' revolutionary theory (Kuhn 126). The Neoplatonists pointed science in a new direction during the Renaissance (Kuhn 128). Their philosophy transcended reality, focusing on an eternal, perfect world (Kuhn 128). Mathematics, for example, was important to the Neoplatonists because it consisted of shapes and numbers that had eternal, perfect properties that surpassed the imperfections of the terrestrial world (Kuhn 128). Additionally, Neoplatonists began associating the Sun with "the Good," which they considered to be God (Kuhn 130). They believed that the

Sun was created before anything else and its location was in the center of the universe (Kuhn 131). This view contradicted the location of the Sun in the Ptolemaic Universe, influencing Copernicus to create a new system that revolved around the Sun (Kuhn 131). These developments during the Renaissance, though not scientific, set the stage for a transformation in astronomy to occur (Kuhn 126).

In 1543, Nicolaus Copernicus published the *De Revolutionibus Orbium Caelestium* (*On the Revolutions of the Heavenly Spheres*), its main goal being to solve the problems of the planets and to reform computational techniques to determine planetary position (Kuhn 137). He believed that the Ptolemaic system could not accurately describe the observed motion of the planets (Kuhn 139). Therefore, in the *De Revolutionibus*, Copernicus proposed that the Earth was a moving planet because this would explain irregular planetary motion (Kuhn 150). In addition, he rediscovered the heliocentric cosmology of Aristarchus and displaced the Earth as the center of the universe, replacing it with the Sun (Anderson). The heliocentric model was effective in explaining retrograde motion as well as the varying brightness of planets (Stars). As the Earth moves around the Sun, it will move faster than an outer planet, regularly passing it and making it appear to move backwards (Anderson). Additionally, because the planets were not always the same distance from the Earth, they varied in their brightness (Stars). Although the heliocentric model proved to be a simple solution to many of the problems that Ptolemy failed to effectively solve, Copernicus still utilized the epicycle-deferent system because he continued to assume that planets had uniform circular motion (Stars). He attempted to simplify Ptolemy's complicated system of epicycles on epicycles, but his use of the epicycle-deferent system was only slightly more simplified (Kuhn 171). The actual text of the *De Revolutionibus* was not especially revolutionary because it did not truly solve the problem of the planets and did little to simplify computational techniques, but the framework it created was revolutionary because it shifted science into a whole new direction and influenced the predecessors of Copernicus to completely eliminate the church-sponsored Aristotelian Universe and to develop a modern view of astronomy (Stars).

The *De Revolutionibus* was well-accepted by the astronomical world because it was the first text that could rival the thoroughness and detail of Ptolemy's *Almagest* (Kuhn 185). The majority of scientists still frowned upon its central thesis of an unstable Earth, but it was so widespread that it became inevitable that astronomers would begin to develop a favorable attitude towards it, especially with newly discovered evidence (Kuhn 188). Those who were not astronomers had a significantly more difficult time accepting Copernicus' proposal (Kuhn 188). Notable scholars, who were not scientists, wrote papers, books and even poems in rejection of Copernicus' radical theory (Kuhn 190). The general public looked to these individuals rather than the scientists for information about astronomy, making it difficult to convert an entire population of men already invested in the idea of a stable Earth (Kuhn 190). Religious leaders were especially averse to Copernicus because a moving Earth directly contradicted with passages from The Bible (Kuhn 192). Furthermore, the proposal that the Earth was just another planet had serious implications on Christian teahcings (Kuhn 193). If there were other planets like Earth, then God would have surely inhabited them as well (Kuhn 193). If this were the case, it would be difficult to conceive how men on these foreign planets could be descendents of Adam and Eve and how they could be subject to the consequences of the original sin as well (Kuhn 193). In 1616, the Church took extreme measures to suppress Copernican thought by banning the *De Revolutionibus,* publicly criticizing Copernicus and dismissing members of the Catholic Church that followed his beliefs (Kuhn 199). It was not until 1822 that the ban on the book was lifted, but by this time there was already a significant amount of evidence supporting Copernicus, harming the reputation of the Catholic Church (Kuhn 199).

The *De Revolutionibus* had direct affects on the immediate successors of Copernicus, notably Tycho Brahe, Johannes Kepler and Galileo Galilei (Kuhn 200). Brahe was able to make the most accurate measurements of the position and movement of stars and planets at that time (Stars). He did not believe that the Earth was the center of the universe because he was unable to observe stellar parallax, but this was due to the fact that the stars were too far away to observe with the naked eye (Anderson). Brahe's work was able to unite the work of Copernicus and Ptolemy into what was known as the Tychonic system (Kuhn 202). His student Johannes Kepler built upon his work and the Copernican system to develop three laws of planetary motion (Anderson). His laws were as follows: planets orbit in ellipses around the sun, which is at the focal point of the ellipse, planets cover equal areas of space in equal time, and the period required for a planet to orbit around the Sun increases with the radius of the orbit (Stars). Kepler was the first astronomer to truly solve the problem of the planets (Kuhn 219). When the telescope was invented by Galileo in 1609, he was the first astronomer that was able to clearly observe the heavens (Kuhn 219). His observations and calculations provided concrete support for the Copernican system (Anderson). One significant observation was of the phases of Venus, where it exhibited phases similar to those of the moon (Kuhn 221). This rejected the Ptolemaic system because Venus would always be in one phase if it revolved around an epicycle around the Earth (Stars). The collaborative work of Kepler, Brahe and Galileo was effective in eliminating the belief of a unique and stable Earth (Kuhn 227). The assimilation of the Copernican system was slow and gradual and its acceptance depended on status, profession and religious beliefs (Kuhn 227).By the end of the seventeenth century, it was virtually impossible to find an astronomer that did not believed in an Earth centered universe (Kuhn 227). By the eighteenth century, the common man began to accept the Copernican system as a part of his popular cosmology (Kuhn 227).

The Copernican Revolution was remarkable in its own right because of its lasting influence on the scientific world and its upheaval of a deeply rooted line of thought. It is interesting to compare this revolution to other just as significant revolutions in science. Many great revolutions seem to deemphasize the importance of man. Clearly, the Copernican Revolution did this by displacing the Earth as the center of the universe. The habitat of man was no longer the most important object of the heavens, but just another planet. Additionally, Darwin's theory of evolution challenged the Creationist view that man was created for a specific purpose by some supreme being. Darwin suggests that we evolved from apes and, by chance, developed characteristics that make us successful at surviving and reproducing. Our origins were not unique and our seemingly superior characteristics are not so significant. Heisenberg's Uncertainty Principle, although not revolutionary, questions the capability of man. It states that physical properties can never be predicted to precision, emphasizing the notion that man is not always in control. This trend appears to be strong within scientific innovations and it would be quite intriguing to examine future advances for this characteristic.

The magnitude of the Copernican Revolution can be put into perspective when prior astronomical theories and its influence on other disciplines are taken into account. For such a radical theory to become incorporated as common knowledge is astoundingly difficult and remarkable. His innovation even began to raise problems outside of the field of astronomy because it challenged traditional answers to questions early scientists had already solved (Kuhn 230). Questions of how the planets were kept in their orbits, why objects are not left behind when thrown in the air and what role the stars played in the universe were raised (Kuhn 230). There was a vacuum of unknown and undiscovered concepts that gave future scientists reason to explore their fields. The universe and the physical laws we are familiar with today are a result of a revolution that began with Copernicus.

## Works Cited

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