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Copernicus' Role in the Scientific Revolution: Philosophical Merits and Influence on Later Scientists

Today, Copernicus is one of the most familiar names among Renaissance scientists, but his role in the Scientific Revolution is misunderstood. He is commonly known as the man who introduced the idea of a heliocentric universe, but is not his theory itself that was transformational. In truth, he did very little to advance the proof of his claim. His value is not in what he said, but what it caused later scientists like Brahe, Kepler, Galileo and later Newton, to develop as a result of what he proposed. Copernicus' work was ultimately most significant because it changed the way people used physics and astronomy to understand the universe. Despite its lack of scientific rigor, Copernicus' heliocentric model presented a harmonious solution to the increasingly complex Ptolemaic model that, when studied by 16th through 18th century scientists, led to important developments in the fields of astronomy and physics.

In order to understand the effect of Copernicus' theory, it is important to understand two aspects of astronomy leading up to the time of Copernicus. First, until Copernicus' theory gained acceptance, astrology was the primary motivation for astronomical research. Astrology served as a guide to the rulers and their people, and even through part of the Renaissance, the most well supported astronomers were those who could give the best astrological predictions. Kepler and Brahe, who I discuss later, were supported because they were believed to cast the best horoscopes, and Ptolemy, who was considered the astronomical authority up to the Renaissance, was just as well known for his astrological contributions in *Tetrabiblos* as his astrological ones in *Almagest* (The Copernican Revolution 93-94).

Astrology loses its credibility if earth is viewed as a planet, considered equal to other celestial bodies. Astrological technique rests on the assumption of an earth with extraordinary celestial power. When Copernicus replaced the Earth with the Sun at the center of the universe, it changed the role of astronomy in society. A lot of the resistance to Copernicus' theory came not only from within the scientific community but also a result of the social implications of a heliocentric universe. Copernicus was in a minority of astronomers who did not cast horoscopes, and the importance of astrology declined after Copernicanism gained acceptance. (The Copernican Revolution 94-95).

Secondly, space under Ptolemaic and Aristotelian astronomy was understood in terms of relations between different objects and areas, rather than through concrete laws of physics. To understand this concept it helps to look at an excerpt from Aristotle's *Physics* that discusses motion.

> Further, the typical locomotions of the elementary natural bodies-namely, fire, earth, and the like-show not only that place is something, but also that it exerts a certain influence. Each is carried to its own place, if it is not hindered, the one up, the other down. ... It is not every chance direction which is 'up', but where fire and what is light are carried; similarly, too, 'down' is not any chance direction but where what has weight and what is made of earth are carried-the implication being that these places do not differ merely in relative position, but also as possessing distinct potencies. (Gaye).

Space was a place that provided the drive for objects to move, where each section of space had distinct characteristics that affect the behavior of an object. Each part of space had "distinct potencies" and exerted a "certain influence". This concept seems unfamiliar to someone in the

21st century but it was the common view at the time of Copernicus Comparing the vagueness and mythical quality of Aristotle's language to the concrete laws of physics and astronomy that I describe later in the work of scientists like Kepler and Newton highlights a contrast between pre and post Copernican thought.

It is important to understand why Copernicus chose to revise the Ptolemaic system in order to understand the significance of his work. Rising criticisms of Aristotelian and Ptolemaic science, the need for calendar reform, and the rise in Neoplatonism were the three major motivators for Copernicus (The Structure of Scientific Revolutions 69).

One of the earliest scholars to criticize science from antiquity was Nicole Oresme, who lived in 14th century Paris. Oresme wrote an analysis of Aristotle's *On the Heavens* which includes a critique of Aristotle on two points which appear during the Copernican revolution (Grant 210-211). Oresme disagreed with Aristotle's arguments for the special status of Earth. Aristotle argued that if there were two earths, they would naturally combine at the center of the universe, because it is in earth's nature to move towards the center. Oresme argued that no theory of motion existed that could prove this (The Copernican Revolution 116-117). Additionally, he was critical of Aristotle's refutation of proof for earth rotating on its axis. Though Oresme himself did not believe in a rotating earth, he was adamant that there was no way of proving that this wasn't true. Many of Copernicus' key arguments likely came from Oresme. Though Oresme himself did not propose any radical changes to Aristotelian science, he made the discussion of earth's motion legitimate, and called into question the evidence for earth's unique status (Grant 210-211).

Ptolemy's *Almagest* was the standard of astronomical truth up until Copernicus' time. The Ptolemaic system placed Earth at the center of the universe with the sun and all other planets orbiting it. It was very successful at predicting changes in the stars and planets, however it came under increasing criticism leading into the Renaissance. With the beginning of the age of exploration, explorers began to realize the inaccuracies of the theories of ancient astronomers. Explorers had the knowledge to correct errors in Ptolemy's geography, which led to challenges of Ptolemaic astronomy. Direct reexamination of classical tests from 15th century mathematicians and astronomers revealed flaws in the formulas created by Ptolemy. The recognition of the shortcomings of Ptolemaic and Aristotelian science made contemporaries reconsider the work of their predecessors (The Scientific Revolution 126-127).

Copernicus attributed these increasing inaccuracies to an inherent flaw in Ptolemy's system (The Structure of Scientific Revolutions 69), which he makes clear in the introduction to *De Revolutionibus*.

> "So in the course of their exposition, which the mathematicians call their system, we find that they have either omitted some indispensable detail or introduced something foreign or wholly irrelevant. This would of a surety not been so bad had they followed fixed principles; for if their hypotheses were not misleading, all inferences based thereon might be surely verified" (Munitz 151)

Copernicus believed that a geocentric model for the universe was unworkable, and a new model was necessary.

During Copernicus' time, there was the push for calendar reform as a result of the errors that compounded for the Julian calendar (The Structure of Scientific Revolutions 69).

Copernicus advised the church not to reform the calendar because astronomical observations were not accurate enough, arguing that "For, first, the mathematicians are so unsure of the movements of the Sun and Moon that they cannot even explain or observe the constant length of the seasonal year" (Munitz 150). In *De Revolutionibus*, Copernicus offered a solution to help with calendar reform, and the Gregorian calendar, introduced in 1582, was based largely on Copernican calculations (The Copernican Revolution 11, 126).

The last major factor was the rise in Neoplatonism, a philosophy that believed in the mathematical nature of god and the importance of finding mathematical harmonies to understand the universe. Consider the way mathematics are described in this text from Proclus, a Neoplatonist from the 5th century:

> " All mathematical species, therefore, have a primary subsistence in the soul; so that before sensible numbers, there are to be found in her inmost recesses, self-moving numbers; vital figures; prior to the apparent; ideal proportions of harmony previous to concordant sounds...".

The search for numerical relations and numerical harmony is the distinguishing feature of Copernicus' work. Brahe and Kepler also shared this Neoplatonist ideal, which is what led them to consider Copernicus' work (The Copernican Revolution 129-130).

In 1543, just before his death, Copernicus' work *De Revolutionibus Orbium Coelestium* (On the Revolutions of the Celestial Spheres) was published, where he offered an alternative to the Ptolemaic model. Copernicus placed the sun at the center of the universe, and had earth orbit the sun. Even with all the criticisms that had risen towards Aristotelian and Ptolemaic science, it was hard for Copernicus to break from their thinking. The rest of the physics governing the movement of the planets was largely the same as that of Ptolemy (Hawking xvii). Copernicus' heliocentric model did not offer a more accurate prediction of the movement of the planets, and as a result, it took nearly half a century before people began to consider what he had written (Butterfield 17-18). Given that Copernicus was brought up with training and observations based on antiquity, he lacked a basis for challenging the geocentric model (Butterfield 27).

The appeal of Copernicus' system was aesthetic rather than pragmatic (Butterfield 32). Future astronomers, including Brahe, Kepler, and Galileo, considered what Copernicus wrote because of its mathematical harmonies and neatness (Butterfield 65). Copernicus describes this inherent neatness in the preface to De Revolutionibus when he writes that "the orders and magnitudes of all stars and spheres ... become so bound together that nothing in any part thereof could be moved from its place without producing confusion of all the other parts and of the universe as a whole" (Munitz 151). Copernicus' created a model where the movements of one planet are tied to the movements of every other planet. Additionally, he could explain the movements of the planets with fewer equations than his predecessors (Grant 214). The stylistic preference of mathematical harmonies, especially in the rising Neoplatonist community, is what let astronomers to consider his theory (The Copernican Revolution 201).

Copernicus' theory led to critical developments in physics and astronomy by three of his successors, Tycho Brahe, Johannes Kepler, and Galileo Galilei. As a result of their work, the Copernican model had near unanimous support within 150 years of the publication of *De Revolutionibus*. (The Copernican Revolution 227).

Tycho Brahe (1546-1601) was a Danish astronomer who is considered the dominant astronomical authority for the 50 years following the death of Copernicus. Though he considered himself an opponent of Copernicanism, he played an essential role in the development of the Copernican Revolution, and applied the mathematical principles developed by Copernicus to create his own model for the universe, the Tychonic system (Butterfield 24, 69-71).

Brahe was no innovator in terms of astronomical concepts. He is responsible, however, for immense changes in the techniques of astronomical observations, and the standards of accuracy in astronomy (Butterfield 63). Brahe invented many instruments that were better calibrated and more accurate than those before, and with that, was able to create a system of observation and collection of the position and of planets and stars more rigorous and detailed than his predecessors. He also made the pattern of regular observation of the heavenly bodies, as opposed to selective observation at convenient points, the standard in astronomy. He freed European astronomers from relying on data from antiquity, and introduced data that allowed later astronomers, notably his apprentice Johannes Kepler, to develop theories that supported the Copernican model. (The Copernican Revolution 201-202).

Brahe was not convinced by the heliocentric model posited in *De Revolutionibus*, but Copernicus contributed to Brahe's discontent with the Ptolemaic system. Brahe proposed a system where the Earth was at the center of the system, with the Sun and moon orbiting earth, and the remaining fives heavenly bodies orbiting the sun. The mathematical harmonies introduced by Copernicus used to determine the motion of the planets are nearly identical to those in the Tychonic system. His system retained the mathematical advantages of the Copernican system without any of its philosophical disadvantages (The Copernican Revolution 205).

Brahe's system of observations forced his successors to reconsider the foundations of Aristotelian and Ptolemaic astronomy that had dominated the field for so long. Now aware of the limitations of a Ptolemaic universe, many of Brahe's contemporaries begin to consider the Copernican model (Butterfield 62-63). Even those opposed to Copernicanism could not help promoting astronomical and cosmological reform. Additionally, Brahe familiarized astronomers with the harmonious mathematical concepts in *De Revolutionibus*, which appealed many in the field, most notably, Johannes Kepler (The Copernican Revolution 208).

Johannes Kepler (1571-1630) was a German astronomer and student of Brahe, who became convinced by the Copernican model during the mid 1590s after studying under Maestlin at the University of Tubingen. In 1596, he published *Cosmographical Mystery*, where he developed Copernicus' mathematical explanations using observations since the time of Brahe to defend a heliocentric system. In this text, Copernicus demonstrated the power of mathematical arguments for Copernicanism (Butterfield 83).

Kepler's belief in the causal role of the sun was critical in the development of his laws. In *Cosmological Mystery,* Kepler describes the sun as the

> "producer, conserver, and warmer of all things; a fountain of light, rich in fruitful heat, most fair, limpid, and pure to the sight, the source of vision, portrayer of all colors, though himself empty of colour, called king of the planets for his motion, heart of the world for his power, its eye for his beauty ... the Sun, who alone appears, by virtue of his dignity and power, suited for this motive duty and worthy to become the home of God himself, not to say the first mover (The Copernican Revolution 214)."

His agreement with Copernicus on a philosophical level, with the sun as the dominant force in the universe, part of what led him to consider Copernicus' theory.

Kepler addressed difficulties with existing theories of planetary orbits. Brahe's observations had made the inaccuracies of the Ptolemaic and Copernican systems more obvious. In his 1609 publication *On the Motion of Mars,* Kepler proposed that planets had an elliptical orbit, as opposed to a circular orbit as previously thought. The elliptical orbits were far simpler and predicted planetary movements with far greater accuracy than any movement before. The problem of planetary motion had been solved, and was solved within the frame of a Copernican universe (The Copernican Revolution 212).

Kepler's discovery led to the first two laws of planetary motion, which remain fundamental in the field of astronomy today. The first law stated that all planets had an elliptical orbit around the sun. The second law, derived from this observation, states that the orbital speed of the planets varies so that they sweep out equal areas in equal periods of time. Copernicus got rid of many of the components required for previous theories, and created a simplified and accurate explanation for planetary motion within the Copernican universe (Butterfield 64-65).

Galileo (1564-1642) was an Italian astronomer who helped popularize the argument for heliocentrism by making it both scientifically and philosophically plausible. In 1609, Galileo heard of a Dutch lens grinder who had combined two lenses to create a powerful lens that could magnify distant objects. Using a lower powered telescope, Galileo made a number of observations about the sun, moon, planets, celestial bodies, which supported the Copernican system.

Galileo did not provide any major modifications to heliocentric system. His work holds significance because his observations confirmed the predictions of earlier Copernican astronomers. The most significant example of this comes with his observations of Venus. Until Galileo, no one had the tools to view the planet in detail. When Galileo pointed his telescope towards Venus, he was able to see for the first time the phases of the planet. The phases he observed were only possible with a sun-centered orbit. Copernicans had also predicted the phases of Venus exactly as they were before Galileo observed them, which proved to the scientific community the power of the Copernican system (The Copernican Revolution 222-224).

Galileo also made a heliocentric system credible on a conceptual level. When Galileo saw the moon through his telescope, he observed pits, valleys, craters, and mountains on its surface. By measuring measurements of the shadows cast on or by these features, he was able to create a description for the moon's topography, which turned out to be very similar to that of the Earth. This helped mitigate the traditional distinction between the earth and other bodies, an area where Copernicus' system initially met a lot of resistance (The Copernican Revolution 221).

Galileo's observations of the sun and Jupiter had a similar effect in making the Copernican model conceptually possible. His observations of moving dark spots on the surface of the sun, sunspots, challenged ideas of the perfection of celestial bodies and the unchanging nature of the heavens, where Copernicus faced resistance to his theories. His observations of the sunspots also proved the axial rotation of the sun, providing a visible model for the axial rotation of the earth. When Galileo observed Jupiter, he found four bright points around the planet. Continual observation of these points showed that they rearranged themselves in a way that could only be explained by those four bodies rotating around the planet. It was a blow to the Ptolemaic world system which stated that celestial bodies all orbited Earth (Butterfield 69-70).

Most importantly, Galileo popularized the field of astronomy beyond the circle of astronomers. Telescopes became a popular item during the later half of the seventeenth century. People who had never shown an interest in astronomy were now beginning use a telescope and observe the same things Galileo saw. The beginnings of popular science and science fiction can be found in the seventeenth century, and the discoveries of the telescope made a major contribution to both areas. Galileo's telescope helped popularize astronomy, and the astronomy that was being popularized was Copernican (The Copernican Revolution 228).

The telescope made astronomy more accessible, but also made the consequences of a Copernican universe more tangible. Accepting Copernicanism meant a rejection of cosmology that governed many aspects of practical and spiritual life. Had there not been so many implications of a universe governed by the sun rather than earth, it wouldn't have taken as long for the Copernicanism to gain widespread popularity (The Copernican Revolution 95). Heliocentrism spread quickly in the astronomical community, with near every astronomer accepting Copernicanism by the mid 17th century. The transition was slower in university and popular settings, but definite nonetheless. By the 18th century, Ptolemaic and Tychonic teaching was dropped in Protestant universities, with Copernicanism the exclusive model. In popular science, it took to the end of the 18th century for Copernicanism to become the standard in the Western world (The Copernican Revolution 227).

Copernicus' influence was not limited to the field of astronomy. He and his successors forced a reexamination of the concept of matter and space. One issue that came about was the question of what force governed the movement of celestial bodies around the sun. The search for an answer to this question led to a revolution in the field of physics.

English physicist Isaac Newton (1642-1727) suggested that the force that caused an object to fall to the ground on earth was the same force that caused celestial bodies to orbit the sun. From this idea he wrote two laws that are fundamental to physics today. First, that all bodies have a gravity that affects surrounding matter, and second, the law of inertia. Together, these two laws governed the motion of all celestial and terrestrial objects (The Copernican Revolution 255). In order to more accurately explain the effect of gravity on the movement of the planets, he later developed the law of universal gravitation. The law of universal gravitation, along with Newton's laws of motion, dominated the physical interpretation of the universe to this day (Hawking xvi). Just like Copernicus caused scientists to reevaluate the concept of matter and space, Newton forced scientists to reconsider the significance of weight in physics.

Many would argue that Copernicus' importance is overstated, and consider him to be the last great Ptolemaic astronomer rather than the first great astronomer of the Scientific Revolution. Copernicus is considered by many to be too conservative in his science to have had an impact. He relied heavily on data from antiquity to come to his conclusions, and insisted on using many Ptolemaic principles without considering their validity, such as his insistence on a perfect circular orbit for each of the planets (Haden 81-82).

One academic who holds this view is Herbert Butterfield, known for writing *On the Origins of Modern Science: 1300-1800*. He considers Copernicus' work to be "only a modified form of the Ptolemaic system" (Butterfield 28). He also dismisses Copernicus' work as largely irrelevant stating that

> "of those individual makers of world-systems like Aristotle and Ptolemy, who astonish us by the power which they showed in producing a synthesis so mythical-and so irrelevant to the present day-that we should regard their work almost as a matter for aesthetic judgment alone. Once we have discovered the real character of Copernicanly thinking, we can hardly help recognizing the fact that the genuine scientific revolution was still to come" (Butterfield 32).

The scientific revolution had not yet occurred with Copernicus, and, as he argues later, the discoveries during the scientific revolution would have come even without *De Revolutionibus* (Butterfield 30).

Butterfield and similar critics are right in some regard. Copernicus' model was not rigorous enough to cause an immediate revolution in the field of astronomy, and a majority of the elements in *De Revolutionibus* come directly from Aristotelian and Ptolemaic science. However, Butterfield ignores the significant philosophical implications of Copernicus' work, which played a huge role in motivating future scientists to find a solution to the movement of the planets. It is important to remember that scientists often adopt new theories because of reasons outside of science, and Brahe, Kepler, and Galileo, as I described earlier, are no exception.

The fact that Copernicus and Brahe were able to apply the mathematical harmonies in *De Revolutionibus* to the movement of the planets is nothing short of revolutionary. Were Copernicus not able to create those mathematical harmonies, it's possible that Kepler and Galileo would have never considered a heliocentric universe (The Copernican Revolution 129).

Copernicus by no means provided empirical evidence of a heliocentric universe, but was revolutionary because he planted the philosophical framework which guided the work of astronomical revolutionaries like Brahe, Kepler, and Galileo.

The discoveries made during the Scientific Revolution with Brahe, Kepler, Galileo and Newton began with the thinking of Copernicus 150 years earlier. It is important to remember that for most of the time between Ptolemy and Copernicus, people were as certain about the structure of the solar system as we are about the fundamental science of our universe today. As observations get more complex and old models fail, a new idea will inevitably come about to address the issue, as was the case with Copernicus and the scientists that follow him. What we get from Copernicus, and the development of similarly revolutionary theories today~~,~~ is that the way we perceive our relationship to the universe through science is never static, despite our certainty. In 2009, NASA launched the Kepler spacecraft, which has discovered over one hundred earth-like planets around distant stars that exist in what are known as the Goldilocks zone, regions with just the right conditions for life. It is estimated that there could be as many as 40 billion habitable Earth-like planets in the galaxy (Overbye). As the Kepler spacecraft gathers more information about extrasolar planets, society may begin to rethink its role in the context of the universe, as it did during the Copernican Revolution.

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