The New Astronomy and Cosmology of the Scientific Revolution: Nicolaus Copernicus, Tycho Brahe, and Johannes Kepler

Introduction

The sixteenth and seventeenth centuries are notable for a significant shift in orientation toward the natural world. Previously, the study of nature had been dominated by the metaphysical speculations of Aristotle. In Aristotelian metaphysics, abstractions dominated. All entities were understood as following rules based on their essences. Each substance had a proper or natural place.

In astronomy, space was divided into two main regions. The stars resided in the higher region and were fixed in space. The planets and the moon resided in the lower region and revolved around the Earth. The sun also revolved around the Earth. Celestial and earthly motion was understood in terms of bodies seeking their natural resting places.

By the completion of the Scientific Revolution, most Aristotelian notions were overthrown. Space was reconceived as isotropic and non-hierarchical. Matter was seen as compositionally consistent throughout the universe. Motion was understood in terms of forces acting upon otherwise inert bodies. Finally, with Isaac Newton, a single constant called “gravity” was introduced as the fundamental operative force of the entire universe.

The New Natural Philosophy

During this period and well into the nineteenth century, investigations of nature fell under the rubric of “natural philosophy” rather than the modern term “science.” Natural philosophy had been considered a part of philosophy itself, which was understood as the sole means to gaining knowledge in all scholarly areas. While the study of nature continued to be referred to as “natural philosophy,” in the sixteenth and seventeenth centuries, natural philosophy began to distinguish itself from philosophy. The new approach included an emphasis on experimentation, a reliance on induction (the collection of observations), a mechanistic view wherein complex phenomena were reduced to their constituent parts, and the use of mathematics for the expression of experimental findings.

Within the new natural philosophy, some degree of specialization became apparent, as natural philosophers devoted themselves to one more areas of investigation. Astronomy, chemistry, mathematics, and what we call “physics” and “biology” were delineated as fields of investigation.† Nothing like modern scientific

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1 The English word “scientist,” for example, was not coined until 1834.

2 The fields of physics and biology were not formally identified as such until the late nineteenth century.
specialization or professionalization was evident during this period, however. Many natural philosophers also considered alchemy to be a legitimate scientific pursuit.

Nicolaus Copernicus

The transformations in astronomy that took place during this period, which bore on cosmology, began with the work of Nicolaus Copernicus (1473–1543). Copernicus was an extraordinary polymath, a master of numerous fields of study. He was a mathematician, lawyer, physician, and classicist. He was also a polyglot, a fluent speaker and writer in several languages, including Latin, Polish, German, Greek, and Italian. Most importantly for posterity, Copernicus was the astronomer credited with founding the field of modern astronomy.

Copernicus’s major work, *On the Revolutions of the Heavenly Spheres*, was published in 1543, the year of his death. In this great work, Copernicus effected a radical transformation of the system developed by Ptolemy (ca. 87–150 CE). Contrary to the Ptolemaic system, Copernicus posited a heliocentric model wherein the Earth and other planets, including Mercury, Venus, Mars, Jupiter, and Saturn, were carried by spheres around a stationary sun. In the Ptolemaic system, the Earth had been figured as the stationary center of the universe around which the planets and sun revolved. In the Copernican system, on the other hand, the Earth was merely “another planet,” that is, a “wandering star.”

Because his philosophy and theology held that God created only perfect order and harmony, Copernicus envisioned the planetary revolutions as perfectly circular. In order to account for some locations of planets and moons, he retained the auxiliary theory of epicycles that had been a part of the Ptolemaic system. In Copernicus’s use of epicycles, the planets also circled the Earth while circling the sun. The number of epicycles from the Ptolemaic system that Copernicus was able to eliminate is a subject of some disagreement.

Like a majority of Europeans of his time, Copernicus was an adherent of the Catholic Church. Yet a heliocentric universe ran contrary to the Christian, Earth-centered cosmology. Accordingly, Copernicus withheld publication of *On the Revolutions of the Heavenly Spheres* until he was literally on his deathbed. An introductory insertion in the text made by a friend or editor suggested that his writings ought to be understood as hypotheses only.

While Copernicus’s ideas were revolutionary at the time, they did not cause a revolution in the study of astronomy until taken up by Galileo Galilei and Johannes Kepler several years later.

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3 Contrary to common conceptions of his model, Copernicus saw the planets as carried around the sun by celestial spheres. Furthermore, the sun itself was not the absolute center of the system. Rather, Copernicus posited a “mean sun,” or average location, around which the spheres carried the planets.
Tycho Brahe

Tycho Brahe (1546–1601) was the court astronomer to Holy Roman Emperor Rudolf II. Tycho’s impact on astronomy was considerable. He developed numerous instruments to improve the accuracy of astronomical observation, and conducted extremely meticulous empirical observations of the heavens. He discovered a new star, witnessed the motion of a comet, and vastly improved the mapping of the planets.

Tycho’s acute observations of planetary positions, drawn on by his student Johannes Kepler, made possible Kepler’s reconceptualization of the Copernican revolutions as ellipses rather than perfect circles. Tycho’s observation of a falling star also made possible the conception of space as isotropic and non-hierarchical. Thus, Tycho greatly advanced the scientific revolution.

Yet Tycho adhered to the Ptolemaic model of the universe. His reservations about the Copernican system were based on philosophical presuppositions drawn from Aristotle. The Earth, he believed, could not be mobile because it was naturally heavy and thus must be the center of space. Further, the improvements of the heliocentric model were not apparent until Kepler refigured the system in terms of elliptical revolutions, thus allowing for greater accuracy in the prediction of planetary positioning.

Johannes Kepler

Johannes Kepler (1571–1630) may be seen as the fulfillment of the Copernican revolution. But Kepler accomplished far more than the mere realization of the Copernican system. While accepting the central feature of Copernicus’s model—a stationary sun and revolving planets—Kepler jettisoned the remainder of the complex and cumbersome auxiliary theories, including epicycles. In their place, he introduced a wholly new conception of the universe that is still essentially accepted today.

Kepler was a student of Tycho’s and gained a great deal from his exposure to Tycho’s methods and findings. His investigations of the planet Mars as a student of Tycho’s effectively forced him to develop a theory that could account for the data. He drew from Tycho’s yet unpublished notes and data to develop a picture of planetary positions that finally led to his major breakthrough, the accepted model of planetary motion. In his “elliptical thesis,” first propounded in his book The New Astronomy (1609), Kepler boldly declared that the planets, including the Earth, revolve around a stationary sun in ellipses, rather than in perfect circles.

Kepler’s other revolutionary contribution to astronomy was his introduction of a new celestial physics, one that aimed to explain the natural causes of the motions of celestial bodies. That is, with Kepler, we see the final overthrow of Aristotelian metaphysics, in which motion was based on the essence of the object itself. Under Aristotle’s metaphysics, an object’s movement toward its “natural” resting place accounted for its motion. Instead, Kepler introduced the modern notion of physical forces as the causes of motion. For Kepler, a planet or other lifeless object is without an internal or active force of its own. Motion is derived only from external forces acting on the object. This particular insight was essential for Isaac Newton’s breakthrough formulation of the law of gravity.
Summary:

- The sixteenth and seventeenth centuries saw the emergence of a new approach to, and new theories about, the natural world that have been since recognized as the Scientific Revolution.
- The Scientific Revolution involved the overthrow of ancient and medieval explanations of the universe and the behavior of the bodies within it.
- In place of Aristotle’s metaphysics, new “naturalistic” theories of space, motion, and matter were introduced, finally resulting in the theory of gravity as introduced by Isaac Newton.
- Nicolaus Copernicus’s work marked the birth of modern astronomy. His theory of a heliocentric universe initiated what would become, with Kepler and Galileo, a revolution in astronomy.
- Tycho Brahe’s observations in astronomy permitted a major breakthrough that would result in what is essentially the modern conception of the solar system.
- Johannes Kepler introduced what has become the modern model of the solar system with the elliptical orbit of the planets, including Earth, around the sun.
- Kepler also introduced the modern notion of natural causes for the motion of otherwise inert bodies, both earthly and celestial. Likewise, Kepler prepared the way for Isaac Newton’s introduction of gravity as the universal force in nature.