# Classical cosmology: from Aristotle to Copernicus

In this chapter, we consider early ideas about the universe, from creation myths to the geocentric universe of Pythagoras, Aristotle and Ptolemy. We recall the heliocentric universe of Copernicus, Kepler, and Galileo and consider the paradoxes posed by Newtonian cosmology.

Cosmology is the branch of science concerned with the study of the universe or *cosmos*. It is the oldest of the sciences, as the questions posed by cosmologists have been pondered through the ages. Does our world and everything we see in the night sky comprise all that exists? How big is the universe? Has it always been there or how old is it? How did it come into being?

Our oldest records suggest that the earliest civilizations made simple observations of the motions of objects in the night sky, and each had its own view of the nature of the universe. Although such cosmologies differed in their details, most were based on the existence of deities and creation myths. Thus the Babylonians imagined the world as a giant oyster immersed in an immense sea, with the earth being created from the body of the sea-goddess Tiamat, while the Chinese believed that the universe began as a giant egg, shattered by the giant Pan Gu. Some parts of the egg rose to become the heavens while other heavier parts formed the earth.

*The universe of Ancient Greece*

It is generally agreed that the idea that one could study the universe using logic, observation and mathematical reasoning first emerged in the sixth century BC, in the context of the considerations of the Ionian scholars of ancient Greece (the word *kosmos* means universe in Greek). In particular, the famous Greek philosopher Pythagoras of Samos believed that all of nature could be described by numbers and mathematics, just as the different notes of the musical scale could be produced by different lengths of the strings of a lyre in simple ratios. As regards cosmology, Pythagoras envisioned a geometrical, *geocentric* universe in which a spherical, stationary earth was orbited by planets moving in concentric circles, surrounded by an outer sphere comprising the fixed stars (figure 1). He imagined that the motion of each celestial body through the air would produce a musical note, the relative distances of the planets from earth corresponding to the intervals of the musical scale (the hypothetical sound of the ensemble became known as the ‘music of the spheres’).

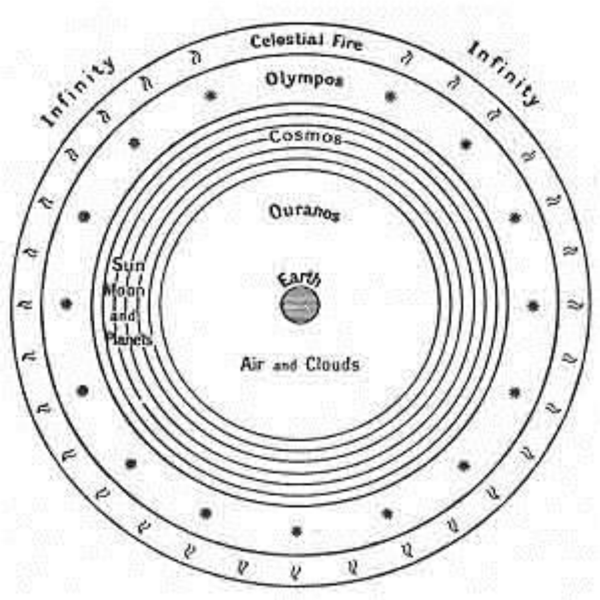


Figure 1. The Pythagoran universe.

Many of Pythagoras’s followers also had ideas about the cosmos; the philosopher Philolaus imagined a universe where the earth, the moon, the sun and the five planets revolved around a central fire, while Heraclides retained the earth as the centre of all things but proposed that night and day were caused by a rotation of the Earth on its axis.

The Pythagoran brotherhood was eventually disbanded by the authorities due to some radical ideas on society and politics (not least the emancipation of women), but some of the school’s scholarship survived. In particular, the original Pythagoran model of the cosmos was adopted by the famous Greek philosopher Plato, who lived in the fifth century BC. It was a central tenet of Plato’s philosophy that the natural world could be described in terms of simple universal principles, and he proposed axiomatic philosophical arguments for the spherical shape of the earth and the circular motion of celestial bodies. The model was further refined by Plato’s pupil Aristotle, who imagined a motionless earth at the centre of nine concentric transparent spheres representing the motion of the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn and the fixed stars (in that order), all surrounded in turn by a divine sphere associated with God. An important feature of this cosmology was the assumption that everything above the lunar sphere was perfect and changeless, while everything below it was imperfect and subject to change, a concept that became known as the two-sphere universe.

The cosmology of Plato and Aristotle dominated western ideas about the universe for centuries, but one aspect of the model was troubling. Even with the simple navigation instruments of antiquity, it could be seen that some of the planets did not move in perfect circles around the earth. Several planets seemed to travel in one direction, then in another, for no apparent reason, an anomaly that was known as *retrograde motion*. An explanation for the phenomenon was offered by the Greek astronomers Apollonius and Hipparchus, whose writings contain the suggestion that each planet moves in a small circle (known as an epicycle), the centre of which moves around the around the earth in a much larger circle.  This model was perfected in the second century by Ptolemy of Alexandria, who provided a detailed and quantitative description of the motion of the planets in his famous book *The Almagest,* although his model was rather complicated (figure 2).

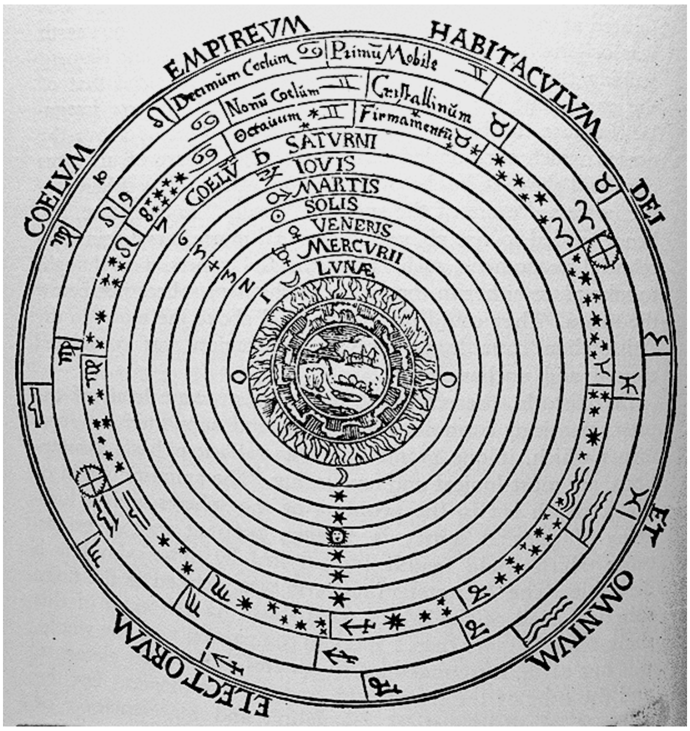


Figure 2. The Aristotelian-Ptolemaic universe

It’s worth noting that an alternative solution to the puzzle of retrograde motion was offered many years before Ptolemy. In the third century BC, the philosopher Aristarchus of Samos considered a universe in which the earth and the planets orbited the sun – the first *heliocentric* model of the cosmos. Little else is known about the Aristarchan model, except that he also adopted Heraclides’ idea that the earth rotated on its axis.[1] Thus, Aristarchus can be seen as a true forerunner of Copernicus, although his cosmology did not gain support amongst his contemporaries. Many historians have asked why not; the simplest answer is that no evidence for the motion of the earth existed at the time and the idea was no doubt inconceivable to most.[2] Thus the Aristarchan universe can be cited as a stunning example of a brilliant idea that was far too far ahead of its time!

With the fall of Greek and Roman civilizations and the onset of the Dark Ages, much of the knowledge of antiquity was lost to western cultures. However, some Greek scholarship was acquired and preserved by Islamic scholars and eventually made its way back to Europe via Moorish influences in Spain. Thus by the twelfth century, texts such as Aristotle’s *Physics*, Euclid’s *Elements* and Ptolemy’s *Almagest* were once again established as important texts for the medieval scholar. In particular, the famous cleric and philosopher Thomas Aquinas forged a synthesis of Greek cosmology with Christian teaching that became the dominant cosmology of Christian Europe until the 16th century.

[1] Aristarchus is best known for deriving surprisingly accurate measurements of the distances and sizes of the sun and the moon from simple geometry; we only know of his cosmology from the writings of contemporaries such as Archimedes.

[2] Objects thrown upward fell toward the earth, not the sun, while a person standing on a mountain peak did not experience the sensation of the earth rushing through the air.

*The Renaissance universe*

Cosmology underwent a major paradigm shift during the European Renaissance. The first step in this process was achieved by the mathematician and astronomer Nicolaus Copernicus, who was born in Poland in 1473. Early in his career, Copernicus became convinced that a heliocentric model of the universe could account for celestial observations more simply than geocentric cosmology.[3] He did not formally publish his ideas at first, fearing ridicule, but circulated a manuscript outlining his ideas known as the *Commentariolus* amongst friends. Years later, Copernicus presented a detailed mathematical model of the universe in his famous book *De Revolutionibus Orbium Coelestium* (*The Book of Revolutions*). This book contained an unambiguous, clear account of a universe in which the sun lies at rest at the centre of the spheres of the fixed stars, orbited by the planets, including the earth (see figure 3). In addition, the earth turned on itself, accounting for day and night. However, it should be noted that the final model was not much simpler than that of Ptolemy; because Copernicus retained the notion of circular orbits for the planets, his model also featured a large number of complicated epicycles. In addition the book, which was published as Copernicus lay on his deathbed, included a preface by a clergyman to the effect that the model should not be taken literally!

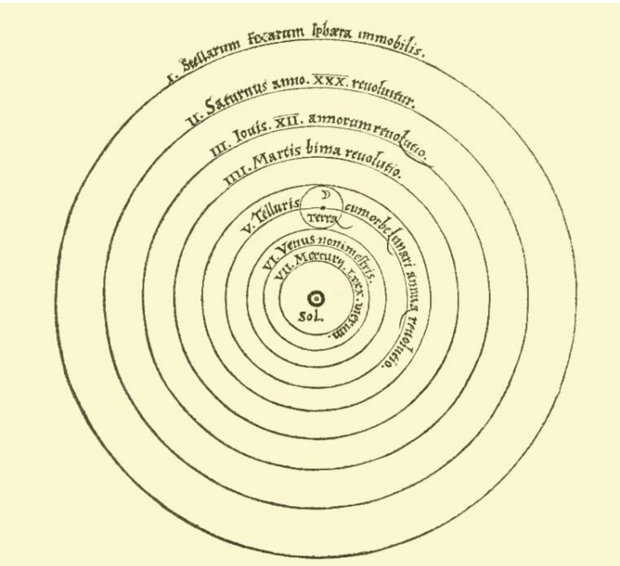


Figure 3. The Copernican universe

[3] Some of the early writings of Copernicus suggest that he was aware of the ideas of Aristarchus.

Another important advance was supplied by the German mathematician Johannes Kepler. In 1600, Kepler was employed by the famous Danish astronomer Tycho de Brahe to help analyse a great store of astronomical data the latter had accumulated at his observatories. In particular, Tycho hoped that Kepler would be able to show that the data supported his own model of the universe, a compromise cosmology in which the planets orbited the sun which in turn orbited the earth. At first, Kepler was only given observational data pertaining to Mars; however, he was granted access to all of Tycho's astronomical data following the unexpected death of Tycho.[4]After a long struggle, Kepler discovered that the motion of Mars, and the other planets, fitted the Copernican model beautifully if one more assumption was dropped; the planets did not orbit the sun in perfect circular paths, but traced out elliptical orbits with the sun at one focus! It took Kepler eight long years to make this important mathematical breakthrough, but the resulting model, published in 1609 in the book *Astronomia Nova*, provided a simple, satisfactory account of the motion of the planets.

Around this time, an important advance occurred in observation with the emergence of the telescope. An arrangement of optical lenses that enabled the observer to view distant objects clearly for the first time, the telescope is thought to have been invented in Holland sometime around 1608.[5] Famously, the Italian scientist and polymath Galileo Galilei constructed his own version and pointed it at the heavens.[6] This resulted in some ground-breaking astronomical observations such as the discovery of sunspots, the moons of Jupiter and the phases of Venus. Some of these observations were published in 1610 in Galileo's early book *Sidereus Nuncius (The Starry Messenger)*; they were clearly in conflict with a model of the universe in which the distant stars and planets execute perfect circular motions around a motionless earth, and Galileo became a convinced supporter of the Copernican worldview. As is well known, Galileo's observations brought him into conflict with university academics and with the Catholic Church, as the notion of an earth in motion conflicted

[4] Tycho de Brahe was a larger-than-life figure given to throwing extravagant parties, and died from a distended bladder shortly after one such event. For this reason, he is the patron saint of many student astronomical societies.

[5] The invention of the telescope is usually attributed to the Dutch lensmaker Hans Lippershey.

[6] Galileo was not the first to do this; the English astronomer Thomas Digges made many telescopic observations of the heavens.

with the writings of antiquity and of scripture.[7] He was ordered to desist from teaching or publishing any material in favour of the Copernican model, a decree he obeyed for some years. Many years later, with the appointment of an erstwhile friend to the Papacy, Galileo felt it was safe to publish his views on cosmology in the book *Dialogue Concerning the Two Chief World Systems*. However, the Church did not agree. In 1633, Galileo was tried by the Inquisition and found to have defied Church decree; his book was banned and he was sentenced to house arrest for the rest of his life.[8]

It's worth noting that Galileo also turned his telescope to the Milky Way, the band of light across the sky known since ancient times, and found that it contains a myriad number of stars, as had been suggested by earlier astronomers such as Thomas Digges. Not only was the earth not the centre of our planetary system, it seemed our entire solar system might be only one of many in a whole galaxy of stars.

*The Newtonian universe*

In 1687, Isaac Newton published a number of universal laws that described all known motion, the culmination of his life's work. In particular, Newton postulated a law of gravity that predicted an attractive force between any two bodies due to their *mass* (the amount of matter in each body). This law successfully accounted for the observed motion of falling bodies. Even better, the same law accurately predicted the Keplerian orbits of the planets about the sun. In this manner, Newton gave the first physical explanation for both terrestrial and celestial gravity, showing them to be of common origin.

Newton's laws of mechanics set the foundations for three centuries of physics. However, one disappointment was that Newton's universal law of gravity did not appear to furnish a satisfactory description of the universe at large. As his contemporary Richard Bentley pointed out, if the attractive force of gravity was the only long-range force acting on neutral matter, it was hard to see why the

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[7] Astronomers also objected to the Copernican model at this time due to the absence of stellar parallax.

[8] See (McMullan 2002) for the definitive version of this story.

universe didn't collapse to a point. Newton's answer was to postulate a universe that is infinite in space, with the all the attractive forces on a given body effectively cancelling out (figure 4). However, Bentley noted that such an arrangement is unstable; the slightest increase in mass in a given region would cause an increase in gravitational force in that region, eventually leading to runaway collapse. Since just such a perturbation must have occurred for stars and planets to form, this created a paradox that became known as *Bentley's paradox*. Another problem was that if the universe contained an infinite number of stars, it was not obvious why the earth's sky is dark at night; this puzzle became known as *Olbers' paradox*.[9]As we shall see, these problems were to dog cosmology right up to the 1930s...

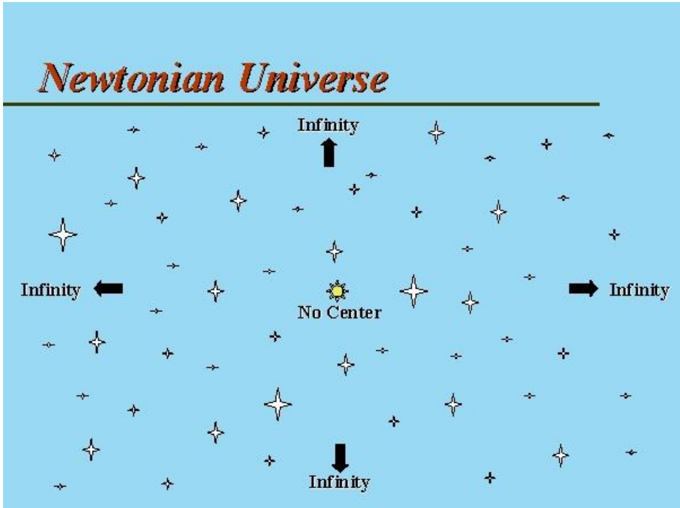


Figure 4. The Newtonian universe

[9] Simple mathematics suggested that the earth should always be in the line of sight of a star.