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Introduction

For thousands of years, ever since humankind came of age, people imagined the heavens as a spherical dome, blue by day and black at night, enclosing Earth like a cap. The dome seemed to be made of a clear substance studded with stars. Above the celestial dome, they imagined an infinite store of water, the source of rain, giving the dome its blue hue. The dome turns around the Earth, and the Sun and the planets travel in the space between the dome and Earth. The book before you describes the scientific revolution that led scientists and eventually also humankind to realize that the motions of the dome and the Sun are imaginary, the result of the Earth turning both on its axis and around the Sun. The celestial sphere is an optical illusion; the stars cruise over infinite spans of space and it is Earth that circles the Sun.

The revolution was sparked by the book *On the Revolutions of the Heavenly Spheres* (*De Revolutionibus Orbium Coelestium*) published in 1543 when its author, Nicolaus Copernicus (1473–1543), was on his deathbed. His revolutionary theory required people to change their fundamental conception of science – their paradigm – and mandated a profound change in mindset. A change in worldview is cataclysmic for anyone, particularly when the earlier conviction is deep-seated. The scientific community experienced just such a cataclysm when faced with the new theory that toppled the pillars of ancient cosmology.

The invention of the telescope by Galileo Galilei (1564–1642), about sixty years after Copernicus' death, allowed astronomers at the time to make new observations of the planets and begin the tortuous process of accepting Copernican theory.

The waves of the revolution that *De Revolutionibus* started reverberated far beyond the world of astronomy. Its shockwaves drove the creation of a new physics, impacting both natural science as a whole and humanity's perception of its place in the universe. The unfolding of the Copernican revolution is an important part of Western civilization's intellectual history, encompassing the development of the natural sciences and in particular the circumstances of one of the most important revolutions in physics and astronomy.

The understanding that Earth is not at the hub, but, on the contrary, travels around the Sun, brought in its wake the notion that the universe is vast and stretches far beyond the boundaries of the solar system. Within less than one hundred years, the heliocentric model, which places the Sun (Helios) at the center, led astronomers to hypothesize that the stars are actually suns that radiate heat and light just like our Sun, and it is their great distance from us that makes them look so faint. The *solar system*, a fundamental concept in modern astronomy, is a Copernican term. It is an idea that allows us to observe the world from the outside and view the Sun and planets as a single system. Outside of the solar system there is a vast space in which there are other stars and other suns.

It is a small leap from here to considering the possibility of planets outside our solar system that are orbiting other suns elsewhere in the universe. Thoughts of objects in space could only have appeared once Copernican theory had been internalized. Giordano Bruno (1548–1600) proposed such

daring ideas; he believed in the infinite universe less than one hundred years after *De Revolutionibus* was published. At the turn of the seventeenth century, the Catholic Church burned Bruno at the stake in the name of the Christian God. Burning Bruno failed to prevent his ideas from continuing to percolate in the minds of astronomers.

Indeed, by the nineteenth century, astronomers succeeded in collecting conclusive evidence that the stars are suns like ours and by the end of the twentieth century, almost four hundred years after Bruno was executed, astronomers discovered planets orbiting distant suns. We might like to view the discoveries made in recent years as a second Copernican revolution – in that we are finding observational proof that the Copernican solar system is not unique. The long, drawn-out process of acceptance that the Copernican revolution underwent is much like human maturation, in which a baby learns through a slow, painstaking process that the world does not revolve around her.

Furthermore, recent studies are driving us to recognize that most suns have planets in orbit around them, and that some of these planets are similar to the ones orbiting our Sun. Given our current realization that our galaxy contains close to one hundred billion suns, it is fair to assume that some of these planets harbor life-friendly conditions. Astronomy could be on the cusp of a breathtaking breakthrough – the identification of planets outside the solar system showing signs of other life, just like Bruno's vision of four hundred years ago when he adopted Copernican theory. Are we facing a third Copernican revolution in which we will find that life, perhaps even intelligent life, is not as unique as we tended to believe? The implications for human thinking of such discoveries are beyond imagination.

The book before you tells the story of the Copernican

revolution, spinning three separate strands into one yarn: the appearance and reception of the heliocentric theory, which placed the Sun at the center and planets in orbit around it; Galileo's development of the telescope, a tool that contributed to the acceptance of the Copernican model and which has since then remained the workhorse of modern astronomy; and, the conflict between science and religion, rooted in Copernicus' book and continuing to the present day. During the fifteenth to the seventeenth century, it was impossible to uncouple the scientific outlook from the spiritual milieu that astronomers occupied. The detachment we have today did not exist at the time, and the history of the Copernican revolution is difficult to understand without some grasp of those scientists' religious and spiritual world. This is why our discussion diverges briefly to discuss the spiritual world of our protagonists.

De Revolutionibus is about the planets in the solar system, and its complicated technical arguments held interest for few sixteenth-century astronomers. The book you are reading presents Copernicus' arguments in simple terms and accessible language to the present-day reader who is not an astronomer in an attempt to bridge the chasm that divides scientists from scholars of the humanities.

The first part of the book, chapters one to three, describes pre-Copernican astronomy. It is technical by nature, so readers anxious to follow the action can skim these sections and head straight to the second part. Following a description of Copernicus' cultural environment in chapter four, chapters five through nine outline the new heliocentric model. These chapters follow the convoluted path that eventually led Copernicus to publish his book.

The third part, chapters ten to thirteen, examines the adjustments and changes in the heliocentric theory as

later astronomers tweaked and modified it, as well as the new measurements collected using advanced equipment, particularly the telescope, which eventually led to the acceptance of the new theory. This part of the book also describes how in the seventeenth century the Catholic Church became bitterly opposed to the heliocentric model, and how it was driven to fight Galileo.

In the fourth part (chapters fourteen and fifteen), this book describes how astronomers confirmed that the stars are indeed suns much like our own and how in the 1990s they finally discovered planets orbiting other, distant suns. As an astronomer investigating binary stars and exoplanets (planets outside the solar system), I was fortunate enough to be part of this chapter of the unfolding story from its start. This is why part of the second stage of the revolution is described from my own personal perspective. Finally, this book makes brief mention of the possibility of a third Copernican revolution, perhaps a few generations away, in which life will be found outside of Earth.

All biblical quotations in this book are taken from the Jewish Publication Society Tanakh (1985 edition), and all the quotations from the Talmud are from Rabbi Adin Even-Israel Steinsaltz, *The William Davidson Talmud*, Jerusalem: Koren Publishing, 2017.

Chapter 4

The Times of Copernicus

To understand the background to the appearance of a revolutionary astronomical theory destined to reshape our conception of the universe, we need to get a sense of the intellectual milieu of the fifteenth and sixteenth centuries when Copernicus lived. This chapter presents a brief overview of the spirit of that time.

Copernicus was born right into the period we call the early Modern era, a time during which Europe changed profoundly through four intense processes. One was the Renaissance in Italy, when people's interest in the classical worldview was reanimated and man and his intellectual freedom became the focus of European thinking and creativity. Next, the printing revolution, which started in Germany, gained ground and created new and faster channels for the exchange of information and ideas. Third was the discovery and subsequent colonization of new lands, a process led by the two Iberian kingdoms, Portugal and Spain. Fourth and somewhat later was the Protestant Reformation – also in Germany – which resulted in Europeans being offered a choice of two established religions, one Catholic and the other Protestant. Italy, Germany, and the Iberian Peninsula were the vertices of a turbulent triangle where these four processes played out.

At the same time, outside this geographical triangle,

on the shores of the Baltic Sea, far away from any center of intellectual activity, there grew, almost in secret, an astronomical theory destined to upend humanity's conception of the universe. This was the theory developed by Copernicus, a church cleric working almost alone for nearly forty years. This chapter offers a glance at the four processes that prepared the ground for Copernican theory to be catapulted on to the center stage of the sixteenth-century intellectual arena in Europe.

The Renaissance

The Renaissance era emerged in Italy and spread to Western Europe over the fourteenth to sixteenth centuries. During this period, Europe slowly rose up from the decay of the Middle Ages, which had followed the collapse of the Roman Empire. The cultural elite of the times named their own period "the Renaissance," meaning rebirth. Their choice of name is witness to the ethos that leaders of this cultural change believed in; they perceived themselves as experiencing a rebirth of civilization and culture. They saw in this rebirth a restoration of the former glories of ancient Greece and Rome in place of the medieval creeds that had ruled Europe for one thousand years.

This new culture believed in humanity and its spirit and in its right to strive for an understanding of the natural world without the agency of the church or divine revelation. Renaissance intellectuals were both curious and passionate about understanding the material world and the human body, rather than angels and saints. An intense surge of faculty and boldness suddenly erupted first in the arts, and then in the sciences. Two classic examples from the medical field

are William Harvey (1578–1657), who discovered blood circulation, and Andreas Vesalius (1514–1564) who, like Copernicus, published a groundbreaking book about human anatomy in 1543.

Cultural revolutions frequently represent their revolutionary process as a return to the ancient ways. This is particularly true when the revolution involves a difficult-to-accept change that undermines some deep-seated conceptions. In such cases, the revolution dons a mask that camouflages the profound change by claiming, either knowingly or unconsciously, that the new ideas are neither as novel nor as revolutionary as they first appear. This was what the architects of the Renaissance claimed, too. They believed that they were leading a return to the classical, ideal world of Roman and Hellenistic culture. Copernicus followed the same practice. He argued that some Greek astronomers had already placed the Sun at the center of the universe.

Another revolutionary practice is to rely on rediscovered ancient manuscripts that embody an earlier culture to which the revolution is attempting to return. According to the revolutionary narrative, the disappearance of the ancient manuscripts represents a retreat from the ideal ancient culture. Their rediscovery means that people can experience firsthand the lost ideas that the revolution is seeking to reinstate.

Indeed, the Renaissance period saw a profusion of Hellenistic and Roman books translated from Greek and Arabic into Latin, the intellectual language of Western Europe. This process gained impetus when the Byzantine Empire fell to the Ottomans in 1453, twenty years before Copernicus was born, which resulted in the center of scholarship shifting westward, away from Byzantium where it had been in close

contact with the Islamic civilization. The Hellenistic bible of astronomy, the *Almagest*, experienced a similar fate. It was translated into Latin in 1460 by Regiomontanus (1436–1476), one of the greatest astronomers in the generation before Copernicus, thus opening a window into Hellenistic astronomy. Its appearance in Latin in Western Europe was instrumental in preparing the ground for the Copernican revolution.

Universities were another component of Renaissance culture. The first of these appeared in the Middle Ages, competing with the monasteries and the Church – which held a monopoly on knowledge in the Middle Ages – for the right to pass on and cultivate knowledge. The University of Padua in Italy is one example of this. In 1222, a group of students resigned from the University of Bologna after they had become disenchanted with the ecclesiastical and monarchical supervision and founded the free university of Padua whose motto was *Universa Universis Patavina Libertas* (Paduan freedom is for everyone). The University of Padua was famous for its advanced program in medicine; Andreas Vesalius, the man who revolutionized medicine during the new age, studied and taught at the University of Padua. In this same spirit of freedom, Padua was the first university to admit Jews as students; many Jewish doctors in the early Modern era indeed gained their general and medical education there.

The University of Padua was destined to have an influential role in the Copernican revolution. Copernicus himself studied there when he left his homeland of Poland to complete his studies in Italy. This was where he acquired some of his knowledge in astronomy, and most probably, it was where he breathed in the Renaissance ideas so characteristic of his thinking. Giordano Bruno, who played

a central role in the drama of the Copernican revolution, spent time in Padua, too. He was there for several years, trying to secure a teaching position at the university. When his efforts failed, he went to Venice as the guest of a local noble, the same one who eventually denounced him to the Inquisition, effectively sealing Bruno's fate.

Galileo Galilei, the man at the center of Copernican revolution in the post-Copernican generation, was a Paduan scholar too – he spent eighteen years in Padua, from 1592 to 1610, as a lecturer at the university. It was there that Galileo developed his first telescope and where he made the transformative astronomical discoveries that became the first proofs of the heliocentric theory. Unlike Bruno, Galileo left Padua of his own accord to take up a flattering position offered to him in Florence. Like Bruno, this move eventually led Galileo into the clutches of the Inquisition.

There is another university which played an important role in the history of modern thought. Wittenberg University was founded in 1502, about three hundred years after the University of Padua, when the winds of the Renaissance finally swept through Germany. Martin Luther (1483–1546), a religious reformer who we will discuss later, was a teacher at Wittenberg University; Philip Melanchthon (1497–1560), the primary theologian of the new religious movement, presided over the university, and Rheticus (1514–1574), a protagonist in our Copernican plot, had his first academic posting there.

The printing press

A seemingly technical invention, the printing press, radically changed the way the corpus of knowledge developed in the