13.1: Some History

Learning Objectives

- You will understand some context for our place in the Universe according to Western traditions.

Center of the Universe

Cosmology is the study of the large-scale structure and evolution of the Universe. People in early and isolated societies had a wide range of ideas concerning the formation of the Universe. The Western tradition of cosmology began with the ancient Greeks, and below we give a very condensed version of the development of cosmological ideas in Europe and the Mediterranean region, starting with Ancient Greece.

The Greeks applied logic and geometry to the study of astronomy. Starting around 600 BCE, the Greeks began developing a geocentric model of the Universe. In their model, Earth was at the center of a series of shell-like spherical domains carrying the Sun, Moon, planets, and stars around Earth. They built upon this idea for many centuries, culminating in a model made by Claudius Ptolemy (100–170). The Ptolemaic model worked well at predicting astronomical phenomena and was in use for hundreds of years. In addition to their model of the heavens, the Ancient Greeks also knew that Earth was round, and its size was measured by the Greek astronomer Erastosthenes (276–196 BCE).

When the Roman Empire superseded the Greek civilization that came before it, there was little advancement of cosmological ideas. The Roman interest in science tended more to the practical, like the building of roads and water transport systems, metallurgy and other pursuits with more immediate application. The Romans adopted the Greek ideas and, through their vast Empire, were able to spread them all around the lands they controlled.

Classical civilization in Europe and the Western Mediterranean came to an end with the fall of the Western Roman Empire in the 5th century AD. After the destruction of the Library of Alexandria in 415, which housed millions of volumes of ancient books, much of classical learning was lost. However, some of the ancient knowledge was preserved by Islamic scholars working in Baghdad and other Islamic cities. While Western Europe was experiencing the Dark Ages, the Middle East was a center of enlightenment.

Islamic scholars of many religions and cultures worked together. They created algebra and made detailed observations and maps of the sky, and this knowledge was shared with learned people in the Eastern Mediterranean. After the fall of Constantinople in 1453, which put an end to the Eastern Roman Empire (The Byzantine Empire), many scholars moved to Europe. The influx of trade and knowledge spurred the European Renaissance.

Among the pieces of knowledge preserved was the spherical shape of Earth. It is a common myth that this information was not known at the time of Columbus and other European explorers, but that is not true. Scholars certainly knew that Earth is spherical, although the average person, illiterate and uneducated at that time, probably did not.

Over the centuries, using the old Ptolemaic ideas to predict celestial motions became increasingly difficult. The discrepancies between observations and predictions became too big to ignore. Nor could they be explained away by simple means. Eventually, it became implausible to explain the observed motions of the planets while insisting that they were traveling around Earth. A better idea was needed.

Nicolaus Copernicus (1473–1543) provided a simpler explanation for planetary behavior. He postulated that the planets (including Earth) orbit the Sun. Copernicus imagined the planets to move on giant, concentric circular paths with the Sun at their common center. Thus, he displaced humans from the center of the Universe. Such a Sun-centered model is known as heliocentric. The Greek astronomer Aristarchus (310–230 BCE) had proposed a heliocentric model centuries before. He was not taken seriously at the time, and the details of his model were lost when Classical civilization collapsed.

Despite being simpler conceptually, the Copernican heliocentric model had its challenges. For example, it did not work any better than the Earth-centered model it replaced. Furthermore, it was not very intuitive. If Earth is moving, why do we not see any of the stars appear to move as a result of that motion? These were questions that made people doubt the Copernican model when it was first proposed.

The answer to their questions is obvious to us now, but it was not at the time; the stars are so far away that their apparent displacements due to Earth's orbital motion are tiny, well beyond the technical capabilities of any ancient or medieval observers to measure. Eventually, however, the invention and development of telescopes allowed measurements of stellar parallax, and from those measurements it was possible to calculate stellar distances. In addition, Johannes Kepler (1571–1630), who lived in the century after Copernicus, showed that planetary orbits are actually ellipses, not circles. Kepler's elliptical orbits provided an excellent fit to the careful observations made by Tycho Brahe (1546–1601) - and they still are an excellent fit to any observations of planets or asteroids made now, no matter how good the precision. This is because the Keplerian model of elliptical orbits with the Sun occupying one of the foci of the ellipse is the correct description of orbits.

If Copernicus and Kepler displaced people from the center of the Universe, subsequent observations that explored space beyond the solar system soon demoted the Sun as well. Slowly the picture emerged of the Sun as an average star among a huge population of similar bodies. Each star is so far away from its neighboring stars that even light requirs years to travel between them. Beyond the nearby stars, those few with distances we can measure geometrically, lie many others: the great band of the Milky Way was resolved by telescopes into millions more stars. The band was recognized by Thomas Wright (1711–1786) and Immanuel Kant (1724–1804), among others, as the effect of our being located within a huge disk of stars—a galaxy. By the early years of the last century, our Galaxy was the largest structure known, but some scientists were proposing that many fuzzy blobs (then known as nebulae) might be other galaxies. It is at this point that our current ideas about the cosmos begin to take root.

Edwin Hubble's first major contribution to cosmology was to identify a few special stars—Cepheid variables—in a number of these "nebulae." The luminosity of Cepheids is correlated with their period of variability, a fact discovered by Henrietta Leavitt of Harvard Observatory. The more luminous the Cepheid, the longer its period of variation. Hubble was able to monitor the variability of several Cepheids and thus determine their luminosities. From the ratio of their apparent brightness to their calculated luminosity, he could deduce their distances and show that in many cases they were far beyond our own Galaxy. They must, therefore, be located within galaxies of their own. Figure 13.1 shows the first Cepheid star Hubble recognized in another galaxy. The star was in the Andromeda galaxy, our nearest large neighbor. It has a size similar to the Milky Way.

With this discovery, Hubble settled the debate about the structure and size of the Universe, at least for the time. He showed that the Milky Way is but one galaxy among many others filling the cosmos. Just how many galaxies exist, and out to what distances, remained unknown.

Figure 13.2 shows Edwin Hubble peering into the eyepiece of the 100-inch telescope at Mt. Wilson in California. This is something he did only when posing for photos like this one. Photographic film is a much more sensitive light detector than the human eye, and so astronomical observations were being done using film at that time. Essentially this turned the telescope into a giant telephoto lens for the camera mounted onto it.

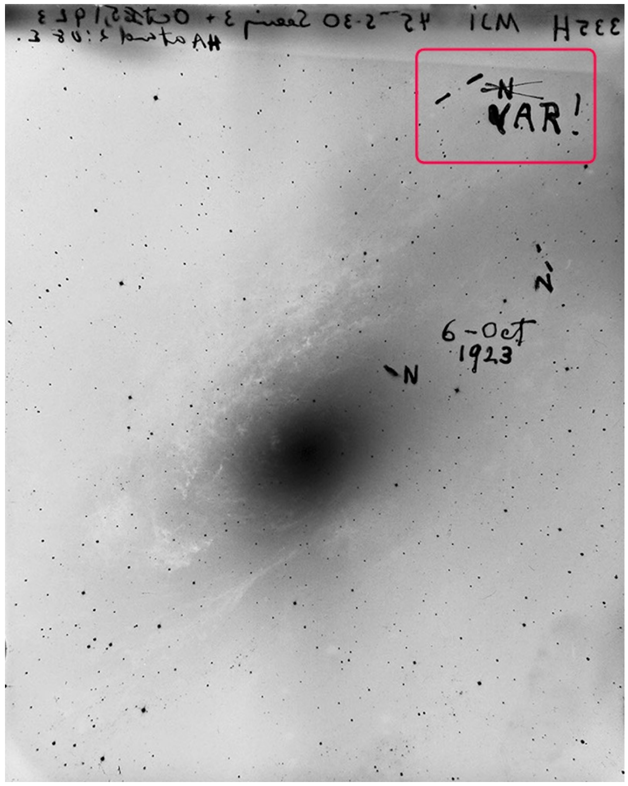

Figure 13.1: Edwin Hubble took this photographic image of a Cepheid variable star in the Andromeda galaxy in 1923 using the 100-inch telescope at Mount Wilson Observatory. The results were published in 1925 and revolutionized the cosmic distance scale. Credit: Mount Wilson Observatory Historical Archives

Figure 13.2: Edwin Hubble looks through the 100-inch telescope at Mount Wilson Observatory in 1937. Hubble used this telescope throughout the 1920's and 1930's and made several important discoveries. Credit: Margaret Bourke-White, Time & Life Pictures/Getty Images

Over a period of three thousand years the best human models for the cosmos evolved from being local, to geocentric, to heliocentric, to stellar, to galactic, to extragalactic. The scale of the models has grown from hundreds of kilometers to, as we will soon see, billions of light-years. Each light-year is approximately 10 trillion kilometers, so there has been a vast expansion of in the scale of the known Universe. Similarly, as we have grasped the great ages of stars by understanding their nuclear mechanisms and history, so has our estimate of the age of the Universe, determined by entirely independent means, grown from a few human generations to billions of years.

Humans, central to the early models they proposed, have become less and less conspicuous in each succeeding model. However, we still carry a special significance as the only part of the Universe we know of that engages in cosmology—we are the part of the

Universe that can think about the Universe. In the remainder of this chapter we will take the first steps on our journey to comprehend how the current view of the cosmos has come into being. We will start out by understanding the primary evidence underpinning the Big Bang theory: cosmic expansion.
