UNIT 4 HISTORY OF COSMOLOGY

Contents

4.0 OBJECTIVES

- To give a historical basis for scientific cosmology.
- To know the key contributions of some of the famous cosmologists of the previous centuries.
- To appreciate the origin of scientific or physical cosmology, as distinct from religious one.

4.1 INTRODUCTION

In the previous unit, we have traced the history of pre-scientific cosmology and gone into some of the important themes of contemporary scientific cosmology. In this unit, we shall primarily focus on the history of scientific cosmology.

4.2 BEGINNING OF SCIENTIFIC COSMOLOGY

Revolutions in science, as in politics, often go beyond the limited changes that the people who started the revolution had in mind. Let us see some great minds who have contributed to the emergence and growth of scientific cosmology.

Nicholas Copernicus (1473-1543)

In 1543 Nicholas Copernicus proposed to switch the places of the Earth and the Sun. He put the Sun in the center of the universe and placed the Earth in revolution around the Sun. To account for the daily motion of the heavens, he set the Earth rotating about its own axis. (CHP 2011) To calculate the positions of planets, Copernicus used elaborate geometrical schemes, much like his Greek and Islamic predecessors (historians are still trying to decide just what sources contributed to his ideas). Ptolemy's system was reasonably satisfactory in matching the observations. Copernicus did not have new and more accurate observations demanding the overthrow of the old theory. It was a yearning for greater mathematical harmony that made him seek something different. In Copernicus's opinion, when Ptolemy had violated the principle of uniform circular motion. Furthermore, from Copernicus's "heliocentric" (sun-centered) theory, several observed phenomena followed automatically, rather than needing to be adjusted as they were in the Ptolemaic theory (Coles 2001).

A heliocentric system was counter to long-established belief and seemed unimaginable to many. This is why Copernicus wrote in the preface to his book that he had "hesitated long whether I should give to the light these my Commentaries written to prove the Earth's motion." His friends, though, had "often urged and even importuned me to publish this work." Copernicus hoped that "my labors contribute somewhat even to the Commonwealth of the Church... For not long since the question of correcting the ecclesiastical calendar was debated." It was true for centuries, the difficult question of calculating the dates of future Easters had been a main motive of astronomical observations and calculations. (CHP 2011)

Further, he admitted: "To ascribe movement to the Earth must indeed seem an absurd performance on my part to those who know that many centuries have consented to the establishment of the contrary judgment, namely that the Earth is placed immovably as the central point in the middle of the Universe." Yet this logical consequence of Copernicus's innovation was not immediately realized, by Copernicus or by others. It was finally recognized by Thomas Digges, an English Mathematician and astronomer, who translated and paraphrased the key parts of Copernicus's work, he said, "to the end such noble English minds might not be altogether defrauded of so noble a part of Philosophie."

Copernican revolution led to the conclusion that the Earth was no longer unique. It was merely one of many similar objects in the solar system. If the Earth were but one of many similar planets, other planets might also have similar inhabitants (Coles 2001). The principle of "plenitude," which interpreted any unrealized potential in nature as a restriction of the Creator's power, further encouraged belief in a plurality of worlds. This conclusion was most dramatically emphasized by Galileo and his new telescopic observations.

Galileo Galilei (1564-1642)

Galileo's father wanted him to study medicine, and he did so briefly at the University of Pisa. But Galileo preferred mathematics. He studied with private tutors in Pisa and then at home, in Florence. Soon he was giving private lessons in mathematics and was later appointed to the vacant mathematics chair at the University of Pisa. Here he is said to have dropped iron balls from the leaning tower, as a public challenge to Aristotelian philosophers, who said that heavier balls should fall faster. They don't. While Galileo probably never acted as this legend tells, it is true to his spirit — challenging authority, thinking clearly, and relying upon actual observation.

Aristotelian professors were certainly not friendly to Galileo, and he soon moved to the University of Padua. Galileo built a telescope and was the first to use this new instrument to systematically explore the heavens, making astonishing discoveries. For example, he discovered four satellites of Jupiter early in 1610. Later in 1610 Galileo returned to Florence as mathematician and philosopher to the grand duke and chief mathematician of the University of Pisa, without obligation to teach. Nothing was so disturbing to old ideas as what Galileo saw when he turned his telescope on the Moon. His observations of the Moon's surface inspired the revolutionary conclusion that the Moon was not a smooth sphere, as Aristotelians had maintained. He wrote: ""The surface of the Moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it to be, but is uneven, rough, and full of cavities and prominences, being not unlike the face of the Earth, relieved by chains of mountains and deep valleys." Aristotle's assumption that only matter below the sphere of the Moon was earthy and imperfect was proved to be wrong.

Another similarity, this one between Jupiter and the Earth, was furnished by Galileo's discovery of four satellites of Jupiter, similar to the Earth's single moon. How would they possibly fit into the system of spheres used by everyone since Plato? Galileo considered the "four planets never seen from the creation of the world up to our own time" to be his most important discovery.

In 1613, in a long unpublished letter, Galileo began arguing that Bible and Copernicanism were compatible. Aristotelians tried to bring the power of the Church against Galileo, pointing to Bible passages that clearly described the Earth as unmoving. Galileo argued that while the reconciliation of scientific facts with the Bible was a matter for theologians, they should not interfere with scientists studying nature. In 1616 the Church ordered Galileo not to hold or defend Copernicanism. In 1624, Pope Urban VIII, a friend of Galileo, gave him permission to discuss the Copernican system in a book if he gave the Ptolemaic system equal time. The Dialogue Concerning the Two Chief World Systems was published in Florence in 1632, after some changes required by the Pope. This is usually considered Galileo's masterpiece. Despite his claims to the contrary, the Dialogue represents Galileo's strongest endorsement of the Copernican system over its Ptolemaic counterpart, giving devastating refutations of many central tenets of Aristotelian physics.

There were complaints, and the Inquisition ordered Galileo to appear before it in Rome. He was forced, probably under threat of torture, to acknowledge that he had gone too far in his arguments for Copernicus, and to abjure the Copernican "heresy." His book was put on the Index of forbidden books, where it remained until 1835. In 1633, Galileo himself was sentenced to life in prison. The sentence was immediately commuted to permanent house arrest. He spent his remaining years in his villa in the hills above Florence, writing another masterpiece — not on cosmology but on physics and mechanics (CHP 2011). Till the end, he kept close contact with his friends in the Church.

Aristotelian cosmology envisioned spheres carrying the planets around the Earth—solid crystalline spheres, according to some, which provided the physical structure of the universe. Late in the 16th century, Tycho Brahe observed comets moving through the solar system. This fact shattered the crystalline spheres. Tycho was still conservative, however. He was reluctant to set the Earth in motion. As an alternative to the Copernican universe with all planets circling the sun in the center, Tycho had his own system of the world. In it other planets circled the Sun while the Sun circled a stationary Earth at the center.

From his observations of the 1572 nova and 1577 comet, Tycho was convinced of the falsity of the Ptolemaic system. In Tycho's system the Earth is absolutely fixed, so that the daily motion of the fixed stars is ascribed to a daily rotation of the outermost sphere, as in the Ptolemaic system. (A similar planetary system was proposed in antiquity by Heraklides of Pontus (ca. 388-310 BCE) who, however, ascribed to the Earth a daily axial rotation.)

From the standpoint of apparent planetary motions as seen from Earth, this system is observationally indistinguishable from the Copernican model, yet maintains the fixity of the Earth. The latter belief was held by Tycho to the end of his life. A main reason was that he had been unable to detect the annual parallax of the fixed stars predicted by the Copernican model, despite the unprecedented accuracy of the observations carried out with his giant instruments at Uraniborg. Tycho could measure parallax down to 2 minutes of arc (1/30 of a degree). The failure to see parallax for fixed stars implied that they would have to be located hundreds of times farther away than Saturn, the outermost planet known at the time. (CHP 2011)

Johannes Kepler (1571-1630)

Born into an undistinguished and poverty-stricken family, Kepler attended the University of Tübingen (now in Germany) on scholarship, studying mathematics and astronomy. He went on to the theological school, intending to become a Lutheran minister. Soon he was asked to leave and teach mathematics at a school in Graz (now in Austria). It was here that he imagined his quixotic world model based on Platonic solids. The theory was wrong, but it made him famous. After Tycho Brahe moved from Denmark to Prague, Kepler visited him there. Kepler recognized the value of Tycho's voluminous observations, more accurate than any previous. He inherited both Tycho's data and the favor of the Emperor following Tycho's death in 1601. Studying the data, Kepler found what later became famous as his three laws, along with many other supposed regularities, some correct and others now forgotten (Levy 2000).

Kepler believed that God the Creator had created an orderly and harmonious world. Kepler was committed to Copernicus's heliocentric system both for its technical advantages, which made it possible to dispense with some of the complications of Ptolemy's system, and on philosophical grounds, including a symbolic identification of the Sun with God at the center of all things. Kepler's colorful life was marred in the end by, among other things, his mother's trial for witchcraft, and a periodically nomadic and economically uncertain existence under the stress of wars and political upheavals. (CHP 2011)

Belief in uniform circular motion had been a fundamental aspect of Western astronomy for two millennia. This belief was broken early in the 17th century. Kepler, using Tycho's observational data, showed that the Earth and the other planets all travel around the Sun in elliptical orbits. This was the first of Kepler's three laws. It was published in 1609 in Kepler's book on his new astronomy, Astronomia nova. The laws Kepler found for the motions of the planets applied equally to the orbit of the Earth. He had abandoned the ancient distinction between the physics of our earthy sphere below the Moon and the celestial physics of a higher realm (Levy 2000 CHP 2011).

Aristotelian physics no longer worked in the universe of Copernicus and Kepler. A new explanation of how the planets continued to retrace the same paths forever around the Sun remained a central problem of cosmology until Isaac Newton explained how objects move under gravity. He accomplished this by showing how motions in the heavens obey the same laws that determine the movement of bodies on Earth. This led the way to understanding what was increasingly seen as a mechanical universe.

Check Your Progress I

Note: Use the space provided for your answers.

1) What was Galileo's opinion on Bible and science?

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2) Briefly mention the contribution of Kepler to cosmology?

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4.3 THE MECHANICAL UNIVERSE

The mechanical universe was initiated by Newton and taken up by other scientists.

Isaac Newton (1642-1727)

Since his father died before his birth and his mother remarried within 3 years, Newton was left in the care of a grandmother. Difficult early years may have contributed to his difficult personality as an adult. He graduated from Trinity College, Cambridge, and served there as Lucasian Professor. Later Newton was warden of the mint in London and president of the Royal Society. Newton's remarkable intellectual accomplishments include creation of the calculus, invention of the reflecting telescope, development of the corpuscular theory of light, and development of the principles of gravity and terrestrial and celestial motion. A "Newtonian" worldview came to permeate understanding not only of the physical world, but also of such intellectual fields as politics and economics— in which people sought simple and universal laws of the type demonstrated by Newton in physics and astronomy. (CHP 2011)

The omnipresence of God pervaded the Newtonian cosmos. The divine presence operated as an immaterial "*aether*" that offered no resistance to bodies, but could move them through the force of gravitation. Newtonian gravitational theory practically demanded a continual miracle to prevent the Sun and the fixed stars from being pulled together. Newton envisioned an infinitely large universe, in which God had placed the stars at just the right distances so their attractions cancelled, as precisely as balancing needles on their points. Another possible solution was to place the fixed stars at such vast distances from one another that they could not attract each other perceptibly in the few thousand years since the Creation.

The ancient assumption that the stars were fixed in position was not seriously questioned until 1718, when the English astronomer Edmond Halley reported a remarkable discovery. Three bright stars were no longer in the positions determined by ancient observations. The stars were freed to move like normal physical objects. (CHP 2011) Newton treated the motions of the stars and planets as problems in mechanics, governed by the same laws that govern motions on Earth. He described the force of gravity mathematically.

Descartes, Laplace and other Critics

The French philosopher René Descartes, on the other hand, had proposed a non-mathematical model. He suggested that the universe consists of huge whirlpools ("vortices") of cosmic matter. Our solar system would be only one of many such whirlpools. Descartes banned from scientific investigation "occult" phenomena, or causes hidden from the senses. He had celestial matter circulating about the Earth, pushing all terrestrial matter toward the Earth. Descartes' followers distrusted Newton's alternative, a mysterious gravitational force acting at a distance.

Descartes' mechanical, mechanistic cosmology was highly acceptable within the general seventeenth-century conception of the world as a machine. His explanations, though, were but qualitative re-descriptions of phenomena in mechanistic terms. During the course of the eighteenth century, vortex theory proved unable to calculate the observed planetary motions. Meanwhile, the rival Newtonian theory advanced from one precise quantitative success to another (Hollar 2011).

The solar system contains many bodies, and the calculation of the orbit of any planet or satellite is not simply a matter of its gravitational attraction to the body around which it orbits. In addition, other bodies have smaller, but not negligible, effects (called "perturbations"). For example, the Sun alters the Moon's motion around the Earth, and Jupiter and Saturn modify the motions of each other about the Sun. A Swiss mathematician, Leonhard Euler, helped develop the mathematical techniques needed to compute perturbation effects. First he applied them to the Moon, and then, in 1748, to Jupiter and Saturn, with partial success (CHP 2011 and Hollar 2011).

Still unexplained were large anomalies in the motions of Jupiter and Saturn, and an acceleration of the Moon's orbital speed around the Earth. The French mathematical astronomer Pierre-Simon Laplace resolved these in 1785 and 1787. In his book Mécanique Céleste, published in five volumes between 1799 and 1805, Laplace summarized his studies of celestial mechanics. Here he proposed that all physical phenomena in the universe could be reduced to a system of particles, exerting attractive and repulsive forces on one another.

Laplace's writings were not just for scientists. His 1796 book Exposition du Système du Monde summarized for lay people the general state of knowledge about astronomy and cosmology at the close of the 18th century. In the book, Laplace advanced an idea that became known as the "nebular hypothesis." He suggested that our solar system, and indeed all stars, were created from the cooling and condensation of a massive hot rotating "nebula" (a gassy cloud of particles). The nebular hypothesis strongly influenced scientists in the 19th century, as they sought to confirm or challenge it. Elements of the idea remain central to our current understanding of how the solar system was formed. (CHP 2011)

Writers of the Romantic period in the early 19th century— for example William Wordsworth in England and Friedrich Schelling in Germany — reacted against Newtonian cosmology. Convinced that the cosmic order was beyond scientific explanation, they sought to breathe divine life back into what seemed an overly mechanized and increasingly godless universe.

The German philosopher Immanuel Kant argued against the Romantics, insisting that metaphysics could not provide an account of the foundations of physical, corporeal nature, and that the issue of the existence of God was completely divorced from direct sense experience. For him, the Newtonian solar system provided a model for the larger stellar system. Kant reasoned that the same cause which gave the planets their centrifugal force, keeping them in orbits around the Sun, could also have given the stars the power of revolving. And whatever made all the planets orbit in roughly the same plane could have done the same to the stars. Nebulous-appearing objects in the heavens became, in Kant's mind, island universes, like colossal solar systems.

Kant's thoughts about the universe had little observational content. The foundations of his cosmological hypotheses were philosophical and theological. Observation first entered cosmology in a major way late in the 18th century, thanks to an English amateur astronomer, William Herschel (Dougherty 1953).

William Herschel and the Construction of the Heavens

The Newtonian solar system offered a model for the larger stellar system. The arrangement of the stars might well be similar to that of the planets. Furthermore, the Newtonian system provided by analogy a physical explanation for a disk structure. The same cause which gave the planets their motion and directed their orbits into a plane could also have given the power of revolving to the stars and brought their orbits into a plane (CHP 2011).

In the late 18th century, observation at last entered stellar cosmology in a major way, in the person of the English amateur astronomer William Herschel. His discoveries were made possible by large telescopes of his own construction. From his observations, William Herschel reported in 1784: "A very remarkable circumstance attending the nebulae and clusters of stars is that they are arranged into strata, which seem to run to a great length; and some of them I have already been able to pursue, so as to guess pretty well at their form and direction. It is probably enough, that they may surround the whole apparent sphere of the heavens, not unlike the milky way, which undoubtedly is nothing but a stratum of fixed stars" (CHP 2011).

Herschel's telescopes, culminating in 1789 with an awkward monster forty feet tall, were one of the wonders of the world. These powerful telescopes not only revealed more moons about planets and resolved some fuzzy-appearing nebulae into clusters of stars, but also enabled Herschel to reach farther into space than anyone had done before, and to begin to outline the structure of our galaxy. Herschel observed stars seemingly lying between two parallel planes and running on to great distances. He concluded that the Milky Way (a luminous band of light circling the heavens) is the appearance of the projection of the stars in the stratum (CHP 2011 and Coles 2001).

In his 1785 paper "On the Construction of the Heavens," Herschel wrote that our Milky Way is a very extensive, branching, compound Congeries of many millions of stars. Herschel's drawing shows a cross section through the Milky Way, our galaxy, as determined from his observations. In the course of time, remarkable new observational techniques, photography and spectroscopy, did address cosmological questions, but indecisively. In 1835, the prominent French philosopher Auguste Comte, remarked that humans would never be able to understand the chemical composition of stars. He was soon proved wrong, because spectroscopy and photography helped bring about a revolution in people's understanding of the cosmos. For the first time, scientists could investigate what the universe was made of. This was a major turning point in the development of cosmology, as astronomers were able to record and document not only where the stars were but what they were as well. Amateur astronomers — the professionals by definition were already engaged in well-defined research projects such as mapping stars — made photographs that showed some nebulae were made up of many stars. But other nebulae remained obdurately nebulous. And nobody was able to decisively show changes in nebulae over time. (CHP 2011)

Spectroscopy held out a promise of differentiating between nebulae made of many stars and those made of glowing gases, and also of determining if nebulae were rotating . But here also the conclusions were questionable. As, indeed, was cosmology itself as a scientific endeavor. Advances in cosmology during the nineteenth century were considerable, but only in the twentieth century would cosmology be transformed from speculation, based on a minimum of observational evidence and a maximum of philosophical predilection, into a respectable observational science.

Approaching the beginning of the 20th century, the worldview pioneered by Herschel was vastly different from that of Aristotle or even Copernicus. No longer were human beings necessarily at or very near the center of the universe (Coles 2001). The Milky Way was now understood to be an optical effect, with our solar system immersed in a much larger stratum of stars, a roughly disk-shaped stellar system. Possibly other island universes were scattered throughout a possibly infinite space.

Changing cosmological understanding is manifested in changing social views. Now that we Earthlings were but one of possibly many intelligent inhabitants of a possibly infinite universe, there was less reason to believe that we had been created in the best of all possible worlds, and perhaps more sympathy for discontent with the established social hierarchy.

Check Your Progress II

Note: Use the space provided for your answers.

1) How did Kant's contribution differ from other scientists?

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2) Briefly mention the contribution of William Herschel?

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4.4 FROM OUR GALAXY TO ISLAND UNIVERSES AND MORE

At the beginning of the 20th century, astronomers were unsure of the size of our galaxy. Generally, they believed it was not much greater than a few tens of thousands of light years across, and perhaps considerably less. (A light year, nearly six trillion miles, is the distance traveled in a year moving at the speed of light in a vacuum.) Also, observations early in the 20th century made it seem that our solar system was near the center of the galaxy. (CHP 2011). Therefore the English astronomer Arthur Eddington said in 1914: "It is believed that the great mass of the stars … are arranged in the form of a lens- or bun-shaped system … considerably flattened towards one plane … the Sun occupies a fairly central position."

Shapley's New Model of the Universe

This vision of the universe was soon replaced with a revolutionary new conception, based largely on the observations of the American astronomer Harlow Shapley at the Mount Wilson Observatory. The astronomer and scientific entrepreneur George Ellery Hale had founded the observatory on a mountain peak overlooking Los Angeles in 1904, and four years later master instrument-builder George Ritchey completed a 60-inch reflecting telescope designed specifically for astronomical photography.

The first hint of a drastically revised understanding of our galaxy came in 1916. Studying a "globular cluster,"—a group of hundreds of thousands of stars—Shapley noticed faint blue stars. If they were similar to bright blue stars near the Sun, they must be about 50,000 light years away to explain why they looked so faint. He pushed ahead to establish distances more conclusively using a new and ingenious method of measuring the universe (CHP 2011 and Coles 2001)

Shapley built a new understanding of the universe by measuring distances to stars based on properties of a type of variable stars called "Cepheids" (named after the constellation Cepheus, in which a typical such star was first noticed). They are giant stars, and thus visible to great distances. Each Cepheid varies in brightness over time. In 1908 the American astronomer Henrietta Leavitt had pointed to a remarkable rule that Cepheids obey. During routine comparisons of photographs she discovered variable stars, brighter on some photographs and fainter on other photographs taken at different times. Leavitt noticed that the brighter the variable star, the longer its period.

Shapley used the period-luminosity relation to estimate distances. First, he collected all the available data on Cepheid stars, from his own observations and from other astronomers including Leavitt. The distance to some of the nearer Cepheids had been measured, and thus Shapley could figure out their absolute magnitudes. The only physics he needed was the simple rule that brightness decreases with the square of the distance. Then Shapley graphed period versus absolute magnitude (CHP 2011 and Coles 2001).

Shapley made the reasonable assumption that Cepheids in distant globular clusters obey the same physics as nearby Cepheids. He observed the periods of distant Cepheids, read off their presumed absolute magnitudes from his graph of period versus luminosity, and compared that absolute magnitude with the observed apparent magnitude. This produced distances to many far-away Cepheids—and to the globular clusters in which they resided. (Some globular clusters did not have Cepheids he could measure, and he used other, cruder methods to estimate their distances.)

Shapley found that the globular clusters are arranged symmetrically around the galaxy, about as many above the plane of the galaxy as below. The clusters seemed to avoid the plane itself, the Milky Way. Shapley wrote that "this great mid-galactic region, which is peculiarly rich in all types of stars, planetary nebulae, and open clusters, is unquestionably a region unoccupied by globular clusters." Shapley acknowledged that there was an alternative explanation. Maybe globular clusters were not, as he believed, actually missing from the region, but instead were hidden by clouds of absorbing matter along the spine of the Milky Way (CHP 2011).

The dwindling significance of humans and their particular planet had dwindled further still. Shapley noted a historical progression from belief in a small universe, with humankind at its center, to a larger universe with the Earth further from the center. The geometry had been transformed from geocentric to heliocentric to a-centric. The psychological change was no less, he insisted, from homocentric to a-centric. Some astronomers had long doubted that the solar system was near the center of the galaxy and that people enjoyed a privileged place in the universe. They felt that the odds, given a random distribution, were small. Now Shapley gave this philosophical position scientific basis.

Hubble's Important Discoveries

Shapley's galaxy was far larger than any previous estimate (aside from earlier guesses of an infinite stratum of stars). It might indeed be the entire universe. For Shapley had showed that globular clusters were clearly part of the galaxy, not independent island universes. Other nebulae (concentrations of stars and dust), especially spiral-shaped ones, might still lie outside our galaxy. But if they were similar in size to our now enormous galaxy, they seemed implausibly large. Separate island universes were not impossible, but they seemed less likely now that Shapley had multiplied the size of our galaxy many fold. (CHP 2011)

Shapley defended his conclusions in the so-called "Great Debate" before the National Academy of Sciences on 26 April 1920. His major concern was the size of the galaxy. His model of a drastically larger galaxy, with the solar system far from its center, was largely correct. But he was on less solid ground when he argued that the spiral nebulae, which seemed to be much smaller, were part of our galaxy. His opponent, Heber Curtis, argued that the galaxy could be as large as Shapley said, yet still be only one of many island universes, if it happened by chance to be several times larger than the average. Ultimately observations would prove Curtis correct, but in 1920 Shapley had the stronger position (CHP 2011 and Coles 2001).

The centuries-old debate was resolved only by new scientific evidence, produced using larger telescopes and new observational techniques, including photography and spectroscopy. The key proponent of island universes was Edwin Hubble (1889-1953), who like Shapley did his revolutionary work at the Mount Wilson Observatory. Writing in his doctoral thesis in 1917, Hubble noted that catalogs already included some 17,000 small, faint nebulous objects that could ultimately be resolved into groupings of stars. Perhaps 150,000 were within the reach of existing telescopes. Yet, he wrote, “Extremely little is known of the nature of nebulae, and no significant classification has yet been suggested; not even a precise definition has been formulated.” The way Hubble discovered to classify nebulae is described here.

After serving in World War I, Hubble joined the Mount Wilson Observatory staff. There he took photographs of nebulae with the new 100-inch reflector, the most powerful telescope in the world. Hubble discovered variable stars in an irregular nebula. By now Shapley had left Mount Wilson for the Harvard College Observatory. Hubble wrote to Shapley in 1923 to tell him of the discovery. Hubble also said he was going to hunt for more variable stars and to investigate their periods. Shapley wrote back, “What a powerful instrument the 100-inch is in bringing out those desperately faint nebulae.” (CHP 2011)

Early in 1924 Hubble wrote to Shapley again. This time Hubble reported, “You will be interested to hear that I have found a Cepheid variable [star] in the Andromeda Nebula [M31]. I have followed the nebula this season as closely as the weather permitted and in the last five months have netted nine novae and two variables”. When he found a Cepheid variable, Hubble realized he held the key to distance. As Shapley had used the period-luminosity relation for Cepheids to find distances to globular clusters in our galaxy, so Hubble could find the distance to the spiral nebula M31. Hubble found that “the distance [to M31] comes out something over 300,000 parsecs.” This was roughly a million light years, and several times more distant than Shapley’s estimate of the outer limits of our own galaxy. Hubble continued: “I have a feeling that more [Cepheid] variables will be found by careful examination of long exposures” (CHP 2011).

On reading Hubble’s letter, Shapley remarked to a colleague who happened to be in his office, “Here is the letter that has destroyed my universe” (CHP 2011). Shapley admitted that the large number of photographic plates that Hubble had obtained were enough to prove that the stars were genuine variables. By August, Hubble had still more variables to report. Shapley was glad to see this definite solution to the nebula problem, even if it refuted earlier evidence against spiral nebulae as island universes. Hubble’s discovery of Cepheid variable stars in spiral nebulae, and the distance determination confirming that spiral nebulae are independent galaxies, were officially announced on New Year’s Day, 1925, at a meeting of the American Astronomical Society. He followed this preliminary paper by further work over the next four years, with convincingly voluminous detail. A good part of Hubble’s genius, and much of the acceptance that his revolutionary conclusions commanded, were due to lots of hard work.

Before the 1920s ended, astronomers understood that the spiral nebulae lie outside our own galaxy. In the previous decade Shapley had multiplied the size of the universe by about ten times. Hubble multiplied it by another ten - if not more. Hubble's universe was no longer the one all-comprehending galaxy envisioned by Shapley. Henceforth the universe was understood to be composed of innumerable galaxies spread out in space, farther than the largest telescope could see. Hubble next would show that the universe is not static, as nearly everyone then believed, but is expanding. What he had made infinite in space, he would make finite in time (CHP 2011). That was the cosmology till the beginning of 20th century. The story of the contemporary cosmology will be taken up in the following units.

Check Your Progress III

Note: Use the space provided for your answers.

1) What is an island universe?

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2) What are were some of the important discoveries of Shapley?

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4.5 LET US SUM UP

In this unit we traced the origin and development of scientific cosmology till the beginning of 20th century. This is to give a bird's eye-view of the cosmological journey and is a preparation for the coming units.

4.6 KEY WORDS

Aether : According to ancient and medieval science aether also spelled æther or ether, is the material that fills the region of the universe above the terrestrial sphere. Modern science has given up this notion.

Cepheid variable : Any of a class of pulsating, yellow, supergiant stars whose brightness varies in regular periods: from the period-luminosity relation, the distance of such a star can be determined

Island universe : Obsolete term used for the galaxies when it was first realised that they exist separately from our own galaxy and at great distances from each other. Now we do not hold on to this theory any more.

4.7 FURTHER READINGS AND REFERENCES

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