STEPHEN P. BLAKE

ASTRONOMY AND ASTROLOGY IN THE ISLAMIC WORLD

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Astronomy and Astrology in the Islamic World

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Preface

To compose a readable, nontechnical account of astronomy and astrology in the Muslim world is challenging. The topic is scientific (dependent on arcane mathematical and physical theories and concepts), the period is long (covering nearly 1,000 years), the geography is extensive (stretching from India in the East to Spain in the West), and the context is crucial. To make sense of the Islamic era (from the middle of the eighth century CE until the middle of the sixteenth century), the narrative must begin three millennia before (with the Egyptians) and continue through the century following (with Copernicus, Kepler, and Newton).

Up to now, the treatments that are available fall into one of two categories. On the one hand, the books and articles by historians of Islamic science are admirably complete and sophisticated – full of formulas, diagrams, and explanations. Men like E. S. Kennedy, David Pingree, and David King have studied the Arabic treatises, carefully laying out the contributions of Islamic astronomers and mathematicians. Other historians, George Saliba, Seyyed Hossein Nasr, and Julio Samso, for example, have written longer less mathematical studies of particular topics or regions – cosmology, planetary theory, or Andalusia. And Aydin Sayili has compiled an exhaustive history of the observatory in the Muslim world.

The second category is the general history. The best of these, like the surveys of John David North, are useful for their context, situating the Islamic achievement in the larger framework of astronomy worldwide, but they are necessarily brief. Muslim astronomers and mathematicians are given no more than a chapter or two – only the most illustrious mentioned at all.

This book, on the other hand, offers a different perspective. It aims, in the first place, to be complete, covering the entire range of the nearly one thousand years of Islamic astronomy and astrology – from the first translations and compositions in al-Ma'mun's House of Wisdom in mid-eighth century Baghdad to the observatories and treatises of Raja Jai Singh in mid-eighteenth century Shahjahanabad (Old Delhi). It also aspires to be inclusive – covering not only the famous and illustrious (Nasir al-Din Tusi, al-Biruni, and Ulugh Beg) but the comparatively neglected as well – the Ottoman Taqi al-Din, the Mughal Jai Singh, and the many other scholars and scientists from Spain, Egypt, Iran, Iraq, and India who played important roles in the development of both the science and the pseudoscience. To situate the individual astronomers and astrologers in the context of their own societies is another theme, to see them in the social, cultural, religious, and scientific milieu from which they sprang. Finally, there is a good deal of comparison across regions and through time. How, for example, did the *Alfonsine Tables* of Cardoba (1270) compare to the *Zij-i Ilkhani* of Nasir al-Din Tusi (1272)? And what impact did the work of the earlier astronomers have on the observational programs, instruments, and theories of the latter?

The second feature of this essay is the effort to place the Islamic millennium in the larger history of astronomy and astrology in Western Eurasia – from the Egyptians in the third millennium BCE to Copernicus, Kepler, and Newton in the sixteenth and seventeenth centuries CE. The first chapter traces the antecedents of the Muslim era – the Egyptians, Babylonians, Mesopotamians, Greeks, Indians, and Iranians. In order to pinpoint the Islamic achievement it is important to distinguish what the early Muslim scientists took from their forbearers. And the last chapter indicates the impact Muslim astronomers and mathematicians had on the revolutionary breakthroughs of the sixteenth and seventeenth century Europeans. Although the Muslim scientists questioned the details of the Ptolemaic, Earth-centred system they had inherited, pointing out contradictions and offering corrections, they never offered a thoroughgoing alternative. It was not until the heliocentric hypothesis of Nicholas Copernicus that a completely new model was put forward. But it is important to highlight the role that Muslim scientists played in this transformation. Until the late-sixteenth century, it was the astronomers and mathematicians of the Islamic world (not the European) who stood at the forefront of the science, and it was their insights and discoveries that paved the way for the grand revolution that followed.

Since, in the Muslim world, astrology was tightly intertwined with astronomy, both must be analysed in any overall treatment of the heavenly sciences. Throughout the Islamic era and beyond the bond between the two was indissoluble – the needs of the pseudoscience driving the observations, formulas, and hypotheses of the science. Ptolemy set the agenda – composing in the second century of the Common Era the definitive texts for both astronomy and astrology – and the connection between the two remained close throughout the Islamic and early European periods. In both worlds the best astronomers and mathematicians were often the most popular astrologers; many scientists made their living by casting horoscopes, predicting and interpreting eclipses and comets, and determining the best time for marriages, battles, and journeys. A scientist as brilliant as Johannes Kepler, for example, once described himself as a Lutheran astrologer.

Although historians of science – both those mentioned above and many others as well – provided the raw material for this essay, there has been no attempt here to emulate their command of mathematics, astronomy, and physics. Rather, the effort has been to simplify the scientific side of the story while expanding its social, cultural, and comparative aspects. Leaving out most of the complicated formulas and difficult diagrams, a general sense of the individual contribution has been given in nontechnical terms. Although important terms and concepts are described in the text and a glossary of instruments is appended, some difficulties must inevitably remain. Either the narrative has been simplified too much – incompletely or inaccurately describing the mathematics or physics – or it has not been simplified enough – leaving too many technical and scientific terms unexplained. The hope is that a middle ground between these two extremes has been reached so that the splendid achievement of the Islamic scientists is presented in a way that is both complete and comprehensible.

CHAPTER ONE

From Egypt to Islam

In order to understand the work of Muslim astronomers it is necessary to return to the beginning – not just to the early Egyptian and Babylonian stargazers – but to the first beginning of all: the Big Bang. It is only in the last fifty years or so that cosmologists and astrophysicists have come to an agreement about the origins of the universe. About fourteen billion years ago a hot, dense, primordial mix exploded, and the rapid expansion that followed led to the vast cosmic configuration that we find today. Cosmologists estimate that our universe contains approximately one hundred billion galaxies – our Milky Way is one. And each galaxy in turn contains about one hundred billion stars – our Sun, the centre of our solar system, is one. Formed about 4.6 billion years ago, our solar system includes planets, moons, dwarf planets, comets, meteors, and an asteroid belt. The Sun is the principal component of the solar system, containing 99.9 per cent of its mass and dominating its gravitational field. Eight planets orbit the Sun. In order they are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Until 2006 Pluto, the farthest from the Sun, had also been listed as a planet but it has now been reclassified as a dwarf planet. The planets differ in size, mass, composition, temperature, and distance from the Sun. The inner planets (Mercury, Venus, Earth, and Mars) are relatively small, composed mostly of rock and have few or no moons. The outer planets (Jupiter, Saturn, Uranus, Neptune, and the dwarf Pluto) are massive, mostly gaseous, and have rings and moons. The Earth is the densest planet and Jupiter is the largest.

From the dawn of human history man has gazed at the heavens and wondered at the spectacle: the rising and setting of the Sun, the shifting phases of the Moon, the movements of the planets, and the patterns of the night-time stars. The Sun was probably the first celestial body to be studied. Its apparent annual motion on the ecliptic (the apparent path of the Sun on the celestial sphere) was always eastward, but not perfectly uniform. The length of the tropical year was 365¼ mean solar days, but the Sun's apparent angular speed eastward on the ecliptic varied, from a maximum of sixty-one minutes per mean solar day on 1 January to a minimum of fifty-seven minutes per mean solar day on 4 July. As a result, the length of the seasons also varied: winter (eighty-nine days), spring (ninety-three), summer (ninety-four), and autumn (eighty-nine). Because the Earth rotated on its axis at an angle of about 23.5 degrees as it travelled around the Sun, the hours of daylight also varied. In the northern hemisphere when the

Sun crossed the celestial equator at the spring (20 or 21 March) and autumn (20 or 21 September) equinoxes, the twenty-four hours were equally divided – twelve hours of light and twelve hours of darkness. As spring advanced to summer the Sun moved progressively north and the hours of daylight increased, until at the summer solstice (20 or 21 June) it was light for fifteen hours or more. From the summer solstice the Sun reversed direction and moved south until at the winter solstice (20 or 21 December) it reached its maximum southern point, leaving only about nine and a half hours of daylight. From the earliest period of settled civilisation the connection of these movements to the agricultural year was well known, and the important solar positions were tracked, recorded, and marked. Many prehistoric monuments seem to have been oriented toward the midsummer and midwinter risings and settings of the Sun: Stonehenge is one example.[1]

At many of these early monuments the Moon was also an object of scrutiny, its more complex movements captured in the various orientations and alignments. Revolving around the Earth in approximately 29½ days, the Moon changed shape as it went – swinging from new (almost invisible) to full (completely round) and back again. Like the Sun it also shifted its position of rising and setting, moving eastward along the ecliptic in a non-uniform motion that varied from about eleven degrees to about fifteen degrees a day, averaging thirteen. The orbit of the Moon was inclined to the ecliptic at an angle of 5 degrees, 8 minutes, and its path showed a number of irregularities or perturbations, due mostly to the gravitational force of the Sun. The size of the largest irregularity was first estimated by the early Greek astronomer, Hipparchus. Eclipses of the Sun and Moon occurred periodically. A lunar eclipse took place when the Earth passed between the Moon and the Sun, and the Earth's shadow obscured the Moon. It happened at night and was relatively frequent. A solar eclipse, on the other hand, occurred when the Moon passed between the Earth and the Sun blocking all or a portion of the Sun. Happening during the day, it was much rarer and could only be seen in a restricted area and for a short time.[2]

The motions of the planets and all other bodies in the solar system were governed by Newton's law of universal gravitation: two bodies attract one another with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. Since the Sun was by far the most massive object in the solar system, it had the strongest gravitational force, and the orbits of the planets depended, for the most part, on their individual mass and their distance from the Sun. According to Kepler's first law of planetary motion, the planets circled the Sun in elliptical orbits – the Sun at one focus of the ellipse. In such an orbit a planet's distance from the Sun and its speed varied, moving faster the closer it got to the Sun, slowing down as it moved farther away. The distance from the Sun and period of the five visible planets were: Mercury (36 million miles away, 88 days), Venus (67 million miles, 226 days), Earth (93 million miles, 365 days), Mars (142 million miles, 686 days), Jupiter (778 million miles, 12 years), and Saturn (887 million miles, 29.5 years).

From the perspective of the earthbound observer the motions of the heavenly bodies were difficult to decipher. The Sun moved with a nearly constant angular speed always toward the east, and the Moon's motion was also eastward but more complicated – faster and more variable. The apparent paths of the planets, however, were much more complex – reversing direction, looping and zig-zagging, speeding up, slowing down, and even stopping. This weird activity perplexed the ancients. To the Egyptians, Mars was 'one who travels backward', and to the Babylonian the planets were 'wild sheep'. And the English word itself ('planet') came from the Greek 'wanderer'. Although, from the Earth-centred point of view the motions of the planets were bizarre, from the Sun-centred, Newtonian perspective they were completely intelligible. The Earth circled the Sun more quickly than the superior planets – Mars, Jupiter, and Saturn. Like a faster car on a freeway, the Earth overtook and passed these slower planets. As the Earth sped past Mars, for example, the Red Planet appeared first to stop and then to drop back or recede, finally resuming its original direction but making a loop in the process. For the inferior planets (Mercury and Venus), orbiting more quickly than Earth, the process was reversed. They moved rapidly west of the Sun during their retrograde motion, then slowly overtook the Sun after their motion became direct. They appeared as morning stars when on the west side of the Sun and as evening stars when on the east. To describe planetary motion astronomers adopted a special vocabulary. The longer-lasting eastward motion was called progression or direct motion, and the shorter westward motion was retrogression or retrograde motion. The time and place when direct motion changed to retrograde was called the stationary point or simply the station of the planet.[3]

To the naked eye the Sun, Moon, and planets moved against a fixed background of innumerable twinkling stars. Of the one hundred billion or so stars in the Milky Way, some of the closest or brightest were visible from the Earth, and they seemed to form clusters or constellations. Over the centuries these constellations were identified and given names. In the northern hemisphere some of the most prominent were Ursa Major (or the Big Dipper), Ursa Minor (or the Little Dipper), Cassiopeia, Andromeda, Cancer, Capricorn, Gemini, and Orion. No one knows how many of the other stars in the Milky Way have planets or how many of those other planets (if there are any) are capable of sustaining life.[4]

Although in northern Europe the evidence for early astronomy was primarily archaeological, in Egypt there were written records going back to the third millennium BCE. The great god of the early Egyptians was Ra, the Sun god, and the first pyramids (c. 2800 BCE) were oriented toward the Sun. Many of the rituals of the early pharaohs were also Sun-based. Some myths, however, were lunar, centred on the full Moon, and were associated with fertility because the thirty-day cycle of the Moon was the same length as the female menstrual cycle. For the early Egyptians, though, the most important astronomical event seems to have been the first sighting of the star Sirius, the brightest in the sky. Its heliacal rising or first appearance, which took place in mid-July, coincided with the beginning of the Nile flood – which, irrigating the entire valley, was the focal event of the agricultural year. Reconciling the three interlocking temporal systems – solar, stellar, and lunar – was an extremely difficult task that occupied Egyptian astronomers for many centuries. The festival of Sirius followed the solar year of 365 ¼ days but the lunar year (12 months of 29.5 days) was only 354 days. As a result, from about the middle of the third century BCE the Egyptians created one of the oldest calendrical systems – the lunisolar. They added an extra or intercalary month to the calendar every three years or so, bringing the lunar and solar years into rough equivalence. With time, this scheme was further refined: the year was set at 365 days and the 12 months were divided into three ten-day 'weeks'. The problem of the extra quarter day was at first ignored.[5]

Although the Egyptians paid close attention to the heavens and venerated certain celestial bodies, they did not keep any systematic records of cosmic activities – movements of planets, eclipses, or the like. The Babylonian dynasties of Mesopotamia, in contrast, kept meticulous records and developed sophisticated mathematical techniques for analysing the movements of the heavenly bodies. Mesopotamian astronomy and astrology can be divided into four periods. The first centred on the reign of the great Babylonian ruler Hammurabi (c. 1792–1750 BCE). During this period the Babylonians took over the cuneiform script and number system of the Sumerians, who had ruled the Mesopotamian city states for centuries. Using a mixture of phonetic spelling and Sumerian ideograms, the Babylonians developed their own script and left a large collection of documents on fragments of dried clay. The Sumerian number system was crucial because it employed place-value notation. That is, like our present-day decimal system, but unlike the numeral system of the Romans, a number's significance depended on its position. In the number 222, for example, the individual digits represent different values depending on their location in the sequence. The Sumerian and Babylonian systems, however, differed from the decimal in that they were based on a scale of sixty rather than ten. Although deciphering the meaning of a number in the sexagesimal (base 60) system can be difficult for the uninitiated, the legacy of the Babylonian system has persisted to the present-day: in our reckoning of time – hours, minutes, and seconds – and measuring of angles – degrees, minutes, seconds. To help ease the burden of calculation the Babylonians also devised a computational system employing number tables – multiplication tables and tables for reciprocals, squares, and square roots.[6]

Under Hammurabi the calendar was unified and Babylonian names were given to the months. Intercalary rules were also adopted, deciding whether a month would have twenty-nine or thirty days and whether a year would have thirteen rather than twelve months. The Babylonians also had an interest in what would come to be known as astrology. Many of their omens were concerned with the planet Venus, and there are tables going back nearly to the reign of Hammurabi giving the time and place of the rising and setting of the planet. These tables were particularly important because they showed that the Babylonians realised that Venus' motions shifted periodically.[7]

The second period of Babylonian history was the Assyrian (1000–612 BCE). During this period the early astronomers compiled a record of the rising and setting of some thirty-six stars. Inscribed on a series of clay tablets, these lists contained the names of constellations and star patterns and their related omens. They were also reports of lunar eclipses, rules for calculating the rising and setting of the Moon, and data on the height of shadows cast by a one-foot gnomon.[8]

The third era of Babylonian history encompassed a time of independence (612–539 BCE) followed by a period of Persian rule (539–331 BCE). During this era omens gave way to a new kind of divination based on the horoscope (see Glossary), and, as a result, systematic observation began of all the planets – not just of Venus. These records, known as astronomical diaries, began as early 652 BCE and listed planetary positions, lunar eclipses, solar halos, earthquakes, epidemics, water levels, market prices, and weather changes. The Babylonians calculated the 18-year or 223-month period over which the cycle of solar and lunar eclipses repeated itself. They determined the equivalent periods of the lunisolar calendar: nineteen solar years equalled 235 lunar months, and they computed the periods of the planets – Venus, for example, made five circuits of the Sun and eight returns to the same place in the stars over an eight-year period. By the early fifth century BCE the Babylonians had come up with the beginnings of a coordinate system. They divided the sky into the familiar twelve signs of the zodiac, each encompassing a thirty-degree segment of the great circle. Each of the zodiacal signs was named after one of the familiar constellations or star groups. In order, beginning with the vernal equinox, they were: Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricorn, Aquarius, and Pisces.[9]

The last period of Babylonian astronomy was the Seleucid (331–247 BCE). The establishment of a system of celestial coordinates was of great importance for mathematical astronomy, essential for an accurate and systematic analysis of planetary motion. The motives of the Babylonians were partly scientific but also partly religious and astrological. Of particular interest was Zoroastrianism, at this period the dominant religion of Iran. Its teachings located the home of the human soul in the heavens and asserted that the heavens influenced terrestrial activities and events. To practice horoscopic astrology, however, there needed to be a method for tracking planetary movement. The oldest known cuneiform horoscope (dated to 410 BCE) depended on clay tablets that were early versions of an ephemerides – tables listing the positions of the Sun, Moon, and planets at specific intervals (monthly, weekly, or daily). The Babylonians developed two separate methods for calculating and predicting the odd, seemingly erratic movements of the heavenly bodies – both of which were mathematical rather than geometrical.[10]

Babylonian astronomical tablets showed evidence of two processes: first, the creation of theories attempting to explain planetary motion, and, second, rules specifying how to predict astronomical phenomena using these theories. Most of the surviving tables represented the results of the second process – that is, the compilation of ephemerides. Greek astronomy seems to have developed in roughly the same way but at a much later date, beginning in about the second century BCE. By this time the Greeks had adopted a different approach to astronomy – geometrical rather than strictly mathematical. They modelled the heavens on a sphere containing the Sun, Moon, planets, and stars and explained heavenly variation as the result of the rotation of the celestial sphere. Using this model the Greeks were able to explain the workings of the universe on a rational basis.[11]

The discovery that the Earth was a sphere has been ascribed to Parmenides in the sixth century BCE, and he is thought to have proved that the Moon was illuminated by the Sun. But Greek astronomy of the fifth century BCE was primarily concerned with meteorological phenomenon – clouds, winds, thunder, lightning, rainbows, and so on. The planetary theory of Eudoxus (c. 408–355 BCE) was the exception. Interested in music and arithmetic from an early age, Eudoxus travelled to Athens to study with Plato. He visited Egypt a few years later and calculated an eight-year calendar cycle. It was, however, his contributions to arithmetic, geometry, and astronomy that made his reputation. Although Eudoxus was responsible for major advances in number theory and for some of the finest sections in Euclid's *Elements of Geometry*, it was his planetary theory that attracted the greatest interest. His planetary model was constructed of transparent spherical shells, one within the other, concentric with a fixed spherical Earth. The shells rotated uniformly at different speeds. With this system Eudoxus was able to describe the direct and retrograde motions of both the Sun and the Moon with three spheres each. For the planets four spheres were required and for the background of fixed stars one – bringing the total number of spheres to twenty seven. Eudoxus himself made no attempt to connect the various spheres with one other. To him the thickness and size of the spheres, their suspension and their order – all were immaterial. He was not concerned with numerical accuracy either. It seems likely that Eudoxus regarded his system as an abstract, theoretical construct, a testing ground for geometrical theorems. Despite these shortcomings, however, the planetary theories of Eudoxus were the first serious attempt to explain the retrograde motions of the celestial bodies in a rational, non-mythological manner.[12]

Although Plato (427–347 BCE), the giant of Greek philosophy, had been the teacher of Eudoxus and later of Aristotle, he contributed little to the development of Greek astronomy. His primary influence was his theory of the universe. According to Plato, the world was closed and finite and everything was interior – the seven planets, the sublunar region, and the Earth. The cosmos as a whole had a soul and so did the other heavenly bodies. The fixed stars were spherical, rotating balls of cold fire, each possessed of a soul that made it forever follow its twenty-four hour circular course about the Earth, the centre of the cosmos. The planets were also made of cold fire, free from gravity, mass, and other sublunar imperfections. Each had a soul that caused it to naturally follow its complicated path through the heavens. The souls (and movements) of the heavenly bodies had been given to them by the Great Artificer or Prime Mover. According to Plato (and later Eudoxus and Aristotle) the seven planets orbited the Earth in the following order: Moon, Sun, Venus, Mercury, Mars, Jupiter, and Saturn.[13]

Aristotle (384–22 BCE), the most influential ancient philosopher of the sciences, defended the Platonic theory of the universe, representing the planets and stars as eternal substances in unchanging motion. He took the theories of Eudoxus and others and turned an abstract set of geometrical concepts into a unified system of natural philosophy that held sway for two thousand years. Aristotle studied under Plato in Athens and later had Alexander the Great as a pupil. His writings were extensive and highly systematic and covered a large part of human knowledge. His most important work on astronomy and cosmology was *On the Heavens*. In it he depicted a celestial sphere with a spherical Earth at its centre. Aristotle had two kinds of motion: celestial motion (which applied to the massless celestial bodies composed of ether) and terrestrial motion (which applied to the ponderous sublunar bodies composed of the four elements: earth, air, fire, and water). For celestial bodies the natural tendency was to move in circles; for sublunar materials it was to move in straight lines. For heavy bodies, natural movement was toward the centre of the universe; for light bodies it was away from the centre. Since bodies on the Earth fell straight down, and fire ascended vertically, the Earth could not be rotating. If it were, the individual particles would have a natural circular motion.

Aristotle's planetary system was that of Eudoxus with the addition of twenty-two more crystalline spheres. Aristotle's perfect celestial realm was unique, ungenerated, and eternal. In his *Metaphysics*, Aristotle spelled out the technical details of his system. In addition to the spheres which reproduced the motions of the heavenly bodies, Aristotle also postulated a series of counteracting spheres which were needed to neutralise the effects of the spheres above them – Jupiter for Saturn, Mars for Jupiter, and so on. In his model there were fifty-five spheres, a grand total that included the direct and counteracting spheres of each planet. Aristotle's mechanistic model was a universe of spherical shells. Motions were no longer postulated as though they were items in a geometry book but were now explained in terms of a physics of motion, of cause and effect. The first sphere of all, the first heaven, exhibited perpetual circular motion, which it transmitted to all lower spheres. The mover of the first heaven, however, was itself unmoved and eternal, the Unmoved Mover or First Cause.[14]

Apollonius of Perga (c. 262–190 BCE), a Greek mathematician, was a key figure in the development of the epicycle concept. Although the theory was expanded and refined by Ptolemy several centuries later, Apollonius worked through the details of using a second, smaller circle (epicycle) rotating around a larger original circle (deferent) as a way of modelling a planet's movement. Apollonius, however, did not seem to be interested in actual observation, and the first Greek astronomer to apply mathematical methods to geometrical astronomical theory was Hipparchus (fl. 150–125 BCE).

Hipparchus was one of the most original and creative of Greek astronomers. He put astronomy on the path that eventually led to the synthesis of Ptolemy three centuries later. Hipparchus fundamentally changed the role of observation in Greek astronomy by making a series of observations himself and by insisting on the importance of numerical accuracy and precision. He played a large role in making Babylonian observations available to Greek astronomers and showed how to use comparisons between old and new observations to reveal astronomical changes too slow to be detected within a single lifetime. He was the first astronomer to systematically employ the eccentric (a point near the Earth around which the heavenly bodies rotate) and the epicycle to represent the motions of the Sun and the Moon. Hipparchus also invented or greatly advanced trigonometry, radically improving the methods of numerically computing the sides and angles of plane and spherical geometrical figures. He wrote a treatise on chords (a chord is a line joining two points on a circle) and drew up a simple table of chords (similar to a table of sines). He worked out problems of spherical geometry by translating them into problems involving circles and triangles on a plane. This form of stereographic projection (a projection that pictures a sphere as a plane) became important in the early development of astronomical instruments, especially the astrolabe (see Glossary). It also made possible the mapping of stars on a plane surface and the creation of lines representing the local horizon, the meridian, and other relevant coordinates.[15]

To represent the motion of the Sun Hipparchus employed the epicycle and eccentric of Appollinus. He discovered the length of the solar year and the variability of the Sun's progress along the ecliptic. He predicted the time of eclipses to within an hour and their terrestrial latitude. For the Moon he assumed a simple epicyclic model similar to that he had used for the Sun. His theory was based on Babylonian and Alexandrian lunar eclipse observations. Hipparchus improved on Aristarchus' estimate for the Moon's distance from the Earth and discovered the second inequality in the Moon's motion (evection), determining its maximum amount to be 1 ¼ degrees (the modern measurement is 1 degree, 16 minutes). He also measured the inclination of the lunar orbit to be five degrees eight minutes. Hipparchus, however, left no detailed theory of planetary motion. He was hindered, Ptolemy later explained, by the paucity of accurate observations.[16]

After his discovery of a new star in c. 134 BCE, Hipparchus began to catalogue the fixed stars. He determined the positions of more than 1,000 stars and introduced the concept of stellar magnitudes. Comparing his own observations with those of the Alexandrian astronomers Timocharis and Aristyllus more than 150 years earlier, Hipparchus realised that the celestial longitudes had all increased by about the same amount, while celestial latitudes had remained about the same. This was most apparent for the stars near the ecliptic, such as Spica, which showed an increase in longitude of 2 degrees over 150 years or an average increase of about 48 seconds per year. He thought that this slow westward drift of the stars, or the precession of the equinoxes, was parallel to the ecliptic and common to all stars. Although there was some evidence that Hipparchus had originally proposed a precession rate fairly close to the now accepted value (50 seconds per year), he was later content to state a lower limit of 1 degree per century (36 seconds per year). This slower rate was adopted by Ptolemy.[17]

After the conquest of Alexander the Great (356–323 BCE) in 332 BCE, Egypt was ruled by Ptolemy I Soter, one of Alexander's generals. Ptolemy's successors moved the Egyptian capital from Memphis to Alexandria and founded two important scholarly institutions (the Museum and the Library) that served to introduce knowledge from Mesopotamia and the East into the Greek and Mediterranean worlds. In 30 BCE the future Roman Emperor Augustus defeated Marc Anthony and deposed Queen Cleopatra, Anthony's lover and the last of the Ptolemies, and Egypt became a province of the Roman Empire.[18]

Claudius Ptolemy (c. 100–170 CE.), the most famous Eurasian astronomer and mathematician before Nicholas Copernicus, was born and lived in Alexandria under Roman rule. His name suggests his heritage: Claudius, a Roman name, shows that he was a Roman citizen, and Ptolemy, a Greek name, reveals his ethnicity. His fame rests on three works: the *Geography*, a survey of the Greco-Roman world; the *Almagest*, on astronomy; and the *Tetrabiblos*, on astrology.

The *Almagest* (*Greatest*) is the major surviving text on ancient astronomy. Its title suggests its status. In the original Greek it was *The Mathematical Compilation*. Later it became the *The Great* [or *Greatest*] *Compilation* and finally ended up in Arabic as *al-Majisti* or *The Greatest*. In Latin (translated from the Greek in 1160 and from the Arabic in 1175) it became the *Almagest*. One of the most influential scientific texts of all time, its geocentric model of the universe held sway for more than 1,400 years, from its completion in the mid-second century until *On the Revolution of the Celestial Spheres* of Copernicus in the mid-sixteenth century.[19]

The *Almagest* comprised thirteen books. Book One contained an outline of Aristotelian cosmology. The celestial realm was spherical. The Earth was also spherical and rested motionless at the centre of the universe. The heavenly bodies were spherical and circled the Earth in the following order: Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn, and, finally, a sphere of fixed stars. Book One also described the cardinal circles and points on the celestial sphere. In an introductory mathematical section Ptolemy explained how Menelaus' theorem – which dealt with triangles in plane geometry – could be generalised to apply to great circles in spherical geometry. There was an account of chords and a table of chords to three sexagesimal places (the equivalent of five-place logarithmic tables). Ptolemy also calculated the obliquity of the ecliptic, that is the angle between the ecliptic and the celestial equator, and arrived at a value of 23 degrees, 51 minutes, 20 seconds. This was a relatively poor result (the modern value is about 23 degrees, 40 minutes).[20]

Book Two covered the daily motions of the heavens: rising and setting of celestial bodies, length of daylight, determination of latitude by observing the semidiurnal arcs of the Sun, points at which the Sun was vertical, and the shadows of the gnomon at the equinoxes and solstices.

Book Three dealt with the length of the year and the motion of the Sun. Ptolemy accepted Hipparchus' solar theory and his figure for the year – 365 ¼ days minus $1/300$. He included tables that allowed a rapid calculation of the two angles needed to settle the Sun's position. Extended and refined, these techniques were also used to calculate the more complicated movements of the planets. His solar theory was a simple eccentric model: one table calculated the mean motion of the Sun on the deferent circle and the other the angle of eccentricity. An additional equation (the equation of time) was an angle to be added or subtracted, enabling the astronomer to correct the mean position of the Sun, thereby arriving at its true position – that is, what an observer would see when he looked at the sky. For chronology, Ptolemy adopted the era of the Babylonian king Nebuchadnezzar, which began 26 February 747 BCE.

Books Four and Five covered the motion of the Moon, lunar parallax, the motion of the lunar apogee, and the sizes and distances of the Sun and Moon relative to the Earth. With the Moon as with the Sun, Ptolemy began with Hipparchus but here he improved greatly on the earlier theory. He introduced a uniform motion in the geo-centred deferent that tracked the Moon's motion more closely – to an accuracy of about 10 seconds, a small quantity in the astronomy of his day. And he more fully elucidated and calculated evection (the modification of the lunar orbit due to the gravitational effect of the Sun). Unfortunately, his model suffered from the enormous discrepancy it suggested in the distance of the Earth from the Moon, implying that the apparent diameter of the Moon varied by about a factor of two during a single revolution. Patently false, but apparently overlooked by Ptolemy, this flaw bedevilled Islamic astronomers for centuries. Book Five contained an account of the construction and use of astronomical instruments, including armillary spheres (see Glossary). It also discussed the parallax (difference in apparent position of an object when viewed along two different sight lines) of the Sun and Moon. Although the lunar parallax was fairly well determined, Ptolemy could not measure the position of the Sun with sufficient accuracy to tell anything about its parallax or distance.

Book Six dealt with solar and lunar eclipses. Although Ptolemy did not add much to Hipparchus, he did explain how the observation and timing of eclipses at two different locations would enable an observer to determine differences in longitude. This was Ptolemy's recommended method, but for ancient geographers the difficulty of simultaneous observations rendered the method more theoretical than practical.

Books Seven and Eight contained a star catalogue, listing the longitudes, latitudes, and magnitudes of 1,022 stars in thirty-eight constellations. He rated the stars in six classes – one the brightest and six the faintest. This catalogue served as the framework for all other work in the field until the seventeenth century. Ptolemy's system (both the positions and magnitudes) was based on that of Hipparchus (although his is no longer extant). He also followed Hipparchus' theory of precession (the motion of the eighth sphere) and used it to update his stellar locations.

Books Nine to Eleven provided the longitudes of the planets – both inferior (Mercury and Venus) and superior (Mars, Jupiter, and Saturn). Two different epicycle arrangements were needed for these two groups of planets. Mercury had additional difficulties and was treated in Book Nine by itself. For the planets Ptolemy had much less material from his predecessors than he had had for the Sun and the Moon. From Hipparchus he had the concept of the epicycle and some information about planetary periods. With this data he was able to construct tables of mean motions. In the Greek models of planetary motion the Sun played an important role. For the inferior planets (Mercury and Venus) the mean Sun was the centre of the deferent and the epicycle, but for the superior planets (Mars, Jupiter, and Saturn) another point (the equant) was added as the centre of the epicycle. Ptolemy introduced this new concept so as to accurately track and predict planetary positions. But his introduction of the equant broke the traditional Aristotelian principle of uniform circular motion, and this inconsistency troubled later Islamic astronomers. Ptolemy wanted not only to account for the changing motions of the planets – retrograde as well as direct – but he also wanted to make it easy to calculate their positions at any time – past, present, or future. To accomplish this he devised a series of rules (tables of special equations) that allowed the skilled practitioner to correct the tabulated mean motions, thereby arriving at the true position of the planet. Although Ptolemy's system is no longer regarded as correct, his prediction mechanisms were quite successful in describing the apparent motion of each body. For each planet the relative size of the epicycle and the deferent were determined with exceptional accuracy.

After finishing the *Almagest*, Ptolemy drafted two shorter astronomical tracts. In the *Planetary Hypotheses* he went beyond the longer treatise to present a physical realisation of the universe as a set of nested spheres, transforming his geometrical models into three dimensional spheres. This was a more sophisticated version of Aristotelian cosmology and was based on the assumption that there were no empty spaces in the universe. The circles and epicycles of the successive planets could not overlap those above, and thus the scale of the entire universe was now fixed – from the inner most circle of the Moon up to the circles and epicycles of Saturn. Since Ptolemy had a figure for the distance of the Moon from the Earth he could now estimate the distances of the other planets. This scheme was elaborated by Islamic astronomers and passed on to the scholars and poets of medieval Europe – seen most famously in the nine circles of hell in Dante's 'Inferno'.

In the *Handy Tables* Ptolemy picked from the *Almagest* the tables needed for astronomical calculation and republished them, prefacing the volume with an introduction explaining how the calculations were to be made. His aim was to make his work more accessible to the practicing astronomer/astrologer, and the *Handy Tables* became the model for the later Islamic astronomical treatises (sing., *zij*).[21]

In addition to his treatise on astronomy, Ptolemy also wrote the most important early work on astrology – the *Tetrabiblos* (*Four Books*).[22] Although the geocentric model in the *Almagest* was later superseded by the heliocentric system of Copernicus, Ptolemy's work on astrology has never really been supplanted, remaining influential not only in the universities and courts of medieval and early-modern Europe but in the newspaper columns and internet sites of today. As begun by the Greeks in the first century BCE and perfected by Ptolemy in the second century CE, astrology had four main branches. Genethlialogy (the science of births) focused on celestial configurations at the time of birth. After constructing a horoscope or birth chart, the astrologer was able (it was believed) to predict the person's character and eventual fate. Catarchic (or beginning) astrology determined the proper moment to launch an activity. It was the opposite of genethlialogy. Instead of deducing an outcome from a particular horoscope, the astrologer specified the heavenly configuration that would most likely lead to success. Interrogatory astrology, the third branch, offered answers to various questions – based on the individual's horoscope. The fourth branch was historical astrology. Developed in Sassanid Iran and dependent on Iranian cosmological theories, historical or conjunction astrology pinpointed important turning points (birth of prophet or ruler, birth or fall of a dynasty, natural cataclysm) on the basis of planetary conjunctions (apparent passing of two planets as seen from the Earth).[23]

Ptolemy wrote the *Tetrabiblos* sometime between 139 and 161, after he had completed the *Almagest*. In Book One he differentiated between two kinds of astronomical study – the first (astronomy proper) discovered the movements of the heavenly bodies and the second (astrology) examined the changes which these movements brought about. The two topics were complementary, and Ptolemy offered several justifications for the latter. As the Sun influenced the seasonal and daily cycles of nature and the Moon affected the tides and other natural rhythms, so too the stars and planets affected meteorological and natural patterns. If the knowledge of celestial cycles could help to predict weather and its effects on plants and animals, why could not an astronomer:

> with respect to an individual man, perceive the general quality of his temperament from the ambient [surrounding environment] at the time of his birth . . . and predict occasional events, by the fact that such and such an ambient is attuned to such and such a temperament and is favorable to prosperity, while another is not so attuned and conduces to injury . . .[24]

Ptolemy also argued that astrological prediction was natural and beneficial. In the matter of fate versus free will he took a balanced position. Although an individual could not escape the greater cycles of change – for example, a man with a favourable horoscope might still die in times of war – many other events were not so greatly determined, and an individual, if properly warned, might be able to avoid disaster. An astrologer, like a physician, could recognise beforehand which events or ailments were inevitable or fatal and which were contingent or treatable and could be prevented or treated.

In Book One Ptolemy related the planets to certain humoral qualities, dividing them into pairs of opposites. They might be benefic (warming or moistening) or malefic (cooling or drying), masculine (drying) or feminine (moistening), active and diurnal (suited to the day and aligned to the Sun) or passive and nocturnal (suited to the night and aligned with the Moon). Mars, for example, was associated with destruction because it was dry and cold; Jupiter was temperate and fertilising because of its warmth and humidity. Ptolemy adopted the Chaldean personification of the planets. Jupiter and Venus were friendly while Saturn and Mars were hostile. Saturn, the farthest planet from Earth, ruled Saturday and caused those born under it to be petty, malicious, solitary, deceitful, harsh, lazy, and unhappy. Jupiter, nearest Saturn, governed Thursday and brought to those born under it love, friendship, abundance, justice, honor, security, and freedom. Ptolemy also took over the Babylonian division of the Zodiac. The twelve signs were divided into four triplicities: Fire – composed of Aries, Leo, and Sagittarius; Earth – Taurus, Virgo, and Capricorn; Air – Gemini, Libra, and Aquarius; and Water – Cancer, Scorpio, and Pisces.[25]

In Book Two Ptolemy took up the topic of earthly or mundane astrology. He offered a comprehensive review of eclipses, comets, wars, epidemics, natural disasters, ethnic stereotypes, and weather patterns. He described the genetic differences between peoples of different climates – those near the equator were short with black skin and those farther north were lighter and taller – and argued that any astrological assessment must rest on the knowledge of an individual's ethnic and national background. Given his interest in geography, it is not surprising to find him assigning astrological significance to the various countries of the inhabited world. Britain and Spain, for example, were ruled by Jupiter and Mars. The horoscope of a city (at the time of its founding) or of a ruler (at the time of his coronation) could be used to establish the characteristics and experiences of the city or rule. Book Two also dealt with the topic of eclipses – whether they foretold beneficial or destructive outcomes for nations or individuals. Meteorological matters were also important and the stars and planets affected weather patterns in predictable ways.

Books Three and Four explored genethlialogical astrology or the interpretation of individual birth horoscopes. The chart yielded three kinds of prediction: of generic qualities established prior to birth (family and parental influences), of qualities at birth (sex of child and birth defects), and of post-natal aspects (length of life, quality of mind, illnesses, marriage, children, and worldly success.) Ptolemy also discussed how to predict psychological outcomes or the quality of the soul from the birth horoscope. Book Four took up predictions of material, marital, and professional success and the topics of children, friends, enemies, and death. The book ended with a discussion of the seven ages of man. Each age was associated with one of the planets: age 0–3 with the Moon, 4–14 with Mercury, 15–22 with Venus, 23–41 with the Sun, 42–56 with Mars, 57–68 with Jupiter, and 69–death with Saturn. It was impossible to properly interpret an astrological chart without taking into consideration the age of the particular individual.[26]

Although the principal influence on Islamic astronomy and astrology was Greek, India and Iran also made significant contributions to the work of the early Muslim astronomers. The Indian and Iranian scientific traditions were themselves complex, both had absorbed the teaching of the *Almagest* and the *Tetrabiblos*, and so the indigenous astronomy in both civilisations was an intricate mix. In India astronomical beliefs and practices could be traced back to the middle of the second millennium BCE. In the *Rigveda* (c. 1500–1000 BCE), the oldest of the Hindu sacred texts, astral gods were mentioned along with various time periods – half months of fourteen to fifteen *tithis* or lunar days (the bright half was the fifteen days from new moon to full and the dark half the fifteen days from full moon to new), months of thirty days, and *yugas* or eras of great length. Because sacrifice was the principal ritual of the *Vedas*, time reckoning was of the utmost importance. The priest must chant the exact words and perform the specified actions at the precise moment. An early text advised the Vedic astronomer:

> The person having correct knowledge of the movements of the sun, moon and other planets, accrues dharma which will take care of his future world; artha which will ensure his prosperity in this world; and fame that will perpetuate his memory. But a bad astronomer who misleads people by his (incorrect) calculations will surely have to go to hell and dwell there.[27]

At this early period, however, there was no clear evidence of complicated calendrical schemes or advanced mathematical techniques for calculating planetary motions.[28]

With the conquest of north-western India by the Achaemenid Dynasty (r. 558–330 BCE) in the late fifth century, Babylonian instruments and ideas reached the subcontinent: Chaldean omen literature and calendar procedures along with the gnomon. In the *Puranas*, a collection of religious texts from the second half of the first millennium BCE, the *yuga* was defined as an era of 4,320,000 years, a figure derived from a Babylonian calculation of the time it took the planets to rotate completely through the heavens.

In the first millennium CE, as trade between western India and the Roman Empire increased, Greek astronomy and astrology began to enter the subcontinent. In 149/50 a Greek astrological work, probably written in Alexandria about 100, was translated into Sanskrit prose. About one hundred years later (269/70) the astronomer Sphujidhvaja turned this prose version into a shorter poetic work entitled *Yavanajataka* (*Greek Astrology*). In the early fourth century a Greek astronomical text was translated into Sanskrit as the *Romakasiddhanta* (*Roman Astronomical Treatise*). During this period astronomy outgrew its original purpose of providing a calendar for the Vedic priests. No longer confined to the study of the Sun and Moon, Indic astronomers began to analyse the movements of the five planets – first and last visibility, duration of appearance and disappearance, distance from the Sun, retrograde motion, and movement through the various signs of the zodiac.[29]

In the succeeding centuries Indian scientists began compiling their own astronomical treatises (*siddhantas*). Undoubtedly influenced by Ptolemy's *Handy Tables* and a forerunner of the Arabic *zij* (astronomical treatise), the Indic *siddhanta* treated the usual topics: measures of time, planetary theory, arithmetic and algebraic procedures, positions of stars and planets, and astronomical instruments. In the traditional account of Indian astronomy the first of these works was the *Surya Siddhanta*. While both the author and original date of composition are unknown, the treatise is said to have been finished c. 400 CE, with the earliest recension dating to the eighth–twelfth centuries CE. Reflecting the Greek and Babylonian theories of the *Yavanajataka* and the *Romakasiddhanta*, the *Surya Siddhanta* replaced the outdated Vedic and Puranic concepts and theories. In 500 verses spread over fourteen chapters it dealt with solar and lunar eclipses, mean and true positions of the stars and planets, phases of the Moon, heliacal risings and settings, and latitudes of the stars and planets. It also treated cosmology, measures of time, and astronomical instruments. According to the treatise, a cosmic wind had initiated planetary motion, and an invisible, divine force (pushing or pulling) caused the motions of the planets to vary. For most Indic astrologers and almanac makers the *Surya Siddhanta* has remained the central text – even to the present day.[30]

The most famous early Indian astronomer was Aryabhata (c. 476–550). He completed two of the most important works in early Indic science: *Aryabhatiya*, on mathematics and astronomy; and *Arya Siddhanta*, an astronomical treatise. The *Aryabhatiya* comprised 121 Sanskrit verses divided into four chapters. Chapter One covered large units of time – *kalpa* (4.32 billion years) *maha-yuga* (4.32 million years), and *yuga* (redefined to 432,000 years). According to Aryabhata, the epoch of the present *yuga* (the Kali Yuga) was midnight 17–18 February 3102 BCE. The Sun, Moon, and planets were in conjunction at zero longitude on this date. He described the orbits and diameters of the Sun, Moon, and planets and the obliquity of the ecliptic. Book Two dealt with measurement, arithmetic and geometric progression, shadow lengths, and various algebraic equations. Book Three presented the eccentric and epicyclic methods for determining the daily positions of the Sun, Moon, and planets. It also explained the timing of the intercalary month. Book Four looked at the ecliptic and the equator, the trigonometry of the celestial sphere, and the signs of the zodiac. His definitions of sine, cosine, versine, and inverse sine influenced the early development of trigonometry. In fact, the modern terms sine and cosine were mistranscriptions of the words *jya* and *kojya* as used by Aryabhata. Transcribed in Arabic as *jiba* and *kojiba* they were misunderstood by Gerard of Cremona in eleventh century Spain as *jaib*, or fold, and translated into Latin as sine (cove or bay). Aryabhata also calculated π to five figures (3.1416) – at that time the closest approximation.

The *Arya Siddhanta*, however, has been lost. An astronomical treatise, it was known only through the commentaries of later astronomer-mathematicians such as Brahmagupta and Bhaskara. Aryabhata advanced the theory that the apparent movement of the stars was actually due to the rotation of the Earth on its axis. As was true of the similar idea of the Greek philosopher Aristarchus (c. 310–230 BCE), Aryabhata's insight was ignored because it violated common sense – to the earthbound observer there was no sensation of rapid rotation. His planetary model was basically that of Ptolemy – geocentric, planets in the same order, and moving according to a similar system of epicycles and eccentrics. Aryabhata had a theory for predicting eclipses, and he calculated close approximations of several astronomical constants. He set the agenda for the work of later Indic astronomers. They covered the same ground – presenting the material in a slightly different manner or revising and updating his constants.[31]

Brahmagupta (c. 598–665) headed the astronomical observatory in Ujjain and completed his *Brahma-Sphuta Siddhanta* in 628. A voluminous treatise of 1,008 verses, it was divided into twenty-four chapters and covered planetary motions and conjunctions, the problems of direction, space, and time, lunar and solar eclipses, and the risings and settings of the planets. Brahmagupta was a talented mathematician and the first person (apart from some Mayan scientists) to treat zero as a number in its own right. Although the Babylonians had a sexagesimal positional numeral system, they had no true placeholder or positional value – thus 2 and 20, or 3 and 30, would look the same. Brahmagupta, on the other hand, considered zero to be a number and gave rules for using it with both positive and negative numbers. With this innovation he completed the modern decimal positional numeral system (incorrectly known today as the Arabic numeral system). The nine numbers plus zero derive from the Brahmi glyphs found in Indic inscriptions of the first centuries CE.

In his *Brahma-Sphuta Siddhanta* Brahmagupta introduced a number of advances in mathematical theory and practice. In algebra he gave the solution for the general linear equation and used it in his astronomical calculations. In arithmetic he described the four operations (addition, subtraction, multiplication, and division) in the newly completed decimal numeral system. In geometry he discovered the formula for cyclic quadrilaterals, and in trigonometry he presented a sine table for calculating the longitudes of the planets. Translated into Arabic in 770 as *Zij al-Sindhind (The Indian Treatise)*, the *Brahma-Sphuta Siddhanta* introduced Indian astronomy to the Islamic world.[32]

Bhaskara (c. 600–680), a contemporary of Brahmagupta, was the foremost early commentator on Aryabhata. He finished his treatise, the *Aryabhatiyabhasya*, in 629, one year after Brahmagupta's *Brahma-Sphuta Siddhanta*. In the *Aryabhatiyabhasya* Bhaskara's aim was to defend the master, clarifying the more abstruse parts of Aryabhata's mathematical astronomy and presenting a close approximation of the sine function. In his own *siddhanta*, the *Mahabhaskariya*, he dealt with mean motions of the planets; true positions as well as velocities and applications; space, time, and directions; the computation and graphical presentation of eclipses; heliacal and diurnal rising of the Moon; and heliacal rising and conjunction of the planets. In his planetary model he employed the epicyclic and eccentric models of Ptolemy.[33]

The third Indian astronomer of the medieval period was Aryabhata II (920–1000). So named to distinguish him from his illustrious predecessor, he composed the *Maha-Siddhanta* – an astronomical treatise in verse. Of its eighteen chapters, the first twelve dealt with the typical topics of the Sanskrit *siddhanta*. The last six chapters explored the geometry, algebra, and geography necessary for calculating the longitudes of planets. He also constructed a sine table accurate to five decimal places. Because of the development of the decimal numeral system, an important aspect of Indian astronomy was its computational character. The Indic astronomers were obsessed with accuracy: They calculated planetary motions (both mean and true), time reckonings of great length, and trigonometric tables of various sorts.[34]

Indic astrology, like Indic astronomy, was a mixture of the Greek and the indigenous. As we have seen, the first Greek text translated into Sanskrit, the *Yavanajataka*, was astrological. Thus, the early Indic astrologers began with the basics of Ptolemy's *Tetrabiblos*. Indic astrologers employed the twelve signs of the zodiac, assigned planets to the seven days of the week, and used Ptolemaic theories to draw up their horoscopes. However, in astrology, as in astronomy, the Indic imprint was unmistakable. A characteristic aspect was the *nakshatra* or lunar mansion. The ecliptic was divided into twenty-seven (sometimes twenty-eight lunar mansions), each named after a prominent constellation. The names themselves came from the *Vedanta Jyotisha*, a first century BCE text, and differed from the Greek. They included Ashvini (wife of the Ashvins), Bharani (the Bearer), Kritika (old name of the Pleiades), Punarvasu (two restorers or chariots), and Hasta (the Hand). Indic astrology also featured the twin concepts of karma and samsara. According to the law of karma, a person's status or station in life was determined by his past deeds (karma), as the individual soul had cycled through countless rounds of birth and rebirth (samsara). Thus, Indic astrology, in addition to being predictive, was also retrospective. In casting a horoscope the *jyotish* (astronomer/astrologer) not only calculated the individual's nativity (position of planets at birth) but also included in his interpretation the residue from his past lives.[35]

From the relevant *siddhanta* (usually the *Surya*), the local *jyotish* produced for his clients an annual almanac (*panchangam* or *panchanga*). As its name implied (*panchangam* means five limbs), the almanac had five parts: (1) *Tithi* (lunar day), (2) *Nakshatra* (stellar mansion of the Moon), (3) *Yoga* (angular relationship between Sun and Moon), (4) *Karana* (half of a *tithi*), (5) *Var* (day of week). In addition to the five attributes, the *panchangam* contained other astrological and religious information – on festivals, birthdays, and anniversaries of holy men, eclipses, auspicious and inauspicious days, planetary positions, rising and setting of the Sun and Moon, and latitudes and longitudes of important localities.[36]

In contemporary accounts the question of the Indian influence on Islamic astronomy/astrology was answered in the story of Kanaka al-Hindi (Kanaka the Indian). According to Abu Ma'shar (787–886), the famous astronomer/astrologer of the early Islamic period, Kanaka was the foremost Indian expert at the early Abbasid court. Heir to the great Indian scientists (Arbyabhata, Brahmagupta, and Bhaskara), Kanaka (in Abu Ma'shar's telling) was the one who carried Brahmagupta's *Brahma-Sphuta Siddhanta* to Baghdad and had it translated into Arabic.

While the impulse to portray the Indian influence on Islamic astronomy/astrology as the work of a single individual is understandable, it was almost surely an invention, condensing a complex and longer-lasting process into the lifestory of a single individual. In the literature there were at least two Kanakas from Western India but Abu Ma'shar's subject was most likely the author of several Sassanid-influenced works: *Book of the Secret of Nativities* and *Book of Conjunctions*. While this Kanaka could have learned his astrology in India, the stronger likelihood is that he picked it up in Baghdad, the Abbasid (750–1258) capital. His horoscopes on Islamic history appear to have been cast by an astrologer at the court of Harun al-Rashid (786–809), following the chronology of Masha'allah (740–815), Abu Ma'shar's illustrious predecessor. Kanaka's various predictions – on early Islamic and Abbasid history – suggest that he wrote his works during the reign of al-Ma'mun (813–33), Harun's successor. Thus, while Kanaka probably was an Indian astronomer at the Abbasid court, he was almost surely not the omniscient savant who (in Abu Ma'shar's story) introduced the heavenly mysteries of the East to the Islamic world.[37]

As compared to the Indic tradition there was much less that was indigenous and original in Iranian astronomy/astrology, and so the impact of Iran on the development of the Islamic sciences was less significant. During the Achaemenid (550–330 BCE) and Parthian (247 BCE–224 CE) periods there is evidence that some concepts from Indic astrology and Babylonian mathematical astronomy had become influential but there is no systematic writing on these topics before the rule of the Sassanids (224–651 CE). During the third century CE the first two Sassanid rulers underwrote translations into Pahlavi of Greek and Sanskrit works on astronomy and astrology. In Greek these included the *Pentateuch* of Dorotheus of Sidon (c. 75) and the *Anthology* of Vattius Valens (120–75), both on astrology, and Ptolemy's *Almagest*. In Sanskrit the early translations comprised an astrological work by Farmasb and the *Romakasiddhanta*. Although the original Pahlavi versions have been lost, there remain Arabic translations of Dorotheus and of a Sassanid astrological treatise entitled *The Book of Zarathustra*. These works suggest that Iranian astronomy and astrology of the early first millennium was a complex mixture – Greek and Sanskrit concepts and theories intermingled with the indigenous Zoroastrian. In addition to these writings there was also an indigenous version of the *zij* or astronomical treatise. Three examples of the *Royal Tables (Zij-i Shahryaran)* have been found. The first, in 450, was mostly derivative, dependent on an early Sanskrit work. The second, in 556, was organised on the basis of the Indic *Zij al-Arkand*, employing the Indic methods for correcting mean longitudes. The final Pahlavi *zij* was compiled in the 630s or 640s under Yazdegird III (632–51) and used the Indic double epicycle model for planetary equations.[38]

Iranian views of the cosmos were heavily influenced by Zoroastrianism. In the *Avesta*, the collection of Zorastrian sacred writings, the Sun and Moon were represented as beneficent immortal beings. The planets, on the other hand, were wandering, unpredictable, and harmful, trying to steal the light and goodness from the two luminaries. The Zoroastrian calendar assigned patron deities to each day and month. The years too were given astrological meaning. The belief in a world year of 12,000 years, each millennium governed by a zodiacal sign, strongly reinforced indigenous doctrines of apocalypse. For the Sassanids the present age (that of Zoroaster) would witness the final defeat of the demonic forces of evil.

Thus far Iranian astronomy and astrology seem to have consisted mostly of an appropriation of Greek and Indic theories and concepts. The Iranian theory of astrological history, however, was *sui generis* and an extremely important contribution to Islamic astrology. The Sassanid astrologers combined the Zoroastrian concept of the world year with an indigenous notion about the meaning of the Jupiter–Saturn conjunctions to arrive at a theory of history. Zarathustra, the legendary founder of Zoroastrianism, was said to have been the author of a Pahlavi astrological work, called in its Arabic translation *The Book of Nativities*. It contained five books, the one on historical astrology reflecting Iranian theories of planetary conjunctions. And Book 14 of the Zoroastrian *Book of the Zodiac* contained annual political and economic predictions based on planetary conjunctions.[39]

Notes

1. John David North, *Cosmos: An Illustrated History of Astronomy and Cosmology* (Chicago: University of Chicago Press, 2008), ch. 1; Theodor Jacobsen, *Planetary Systems from the Ancient Greeks to Kepler* (Seattle: University of Washington Press, 1999), ch. 1.
2. Jacobsen, *Planetary Systems*, ch. 1.
3. Ibid.; Simon Singh, *Big Bang: The Origin of the Universe* (New York: HarperCollins, 2005), 26–9.
4. Singh, *Big Bang*, ch. 1.
5. North, *Cosmos*, ch. 2.
6. Ibid.
7. North, *Cosmos*, ch. 3.
8. Ibid.
9. Ibid.
10. Ibid.
11. North, *Cosmos*, ch. 4.
12. Ibid.; Jacobson, *Planetary Theories*, ch. 2.
13. Ibid. ch. 1.
14. Ibid.; North, *Cosmos*, ch. 4.
15. North, *Cosmos*, ch. 4; Jacobson, *Planetary Theories*, ch. 3.
16. Jacobson, *Planetary Theories*, ch. 3.
17. Ibid.
18. North, *Cosmos*, ch. 4.
19. For an overview see O. Peterson, *A Survey of the Almagest* (Odense, 1974); O. Gingerich, *The Eye of Heaven: Ptolemy, Copernicus, Kepler* (New York: American Institute of Physics, 1993).
20. Jacobson, *Planetary Theories*, ch. 4.
21. North, *Cosmos*, ch. 4.

22. Frank E. Robbins (ed.), *Ptolemy's Tetrabiblos* (Cambridge: Cambridge University Press, 1940).
23. Roger Beck, *A Brief History of Ancient Astrology* (London: Blackwell Publishing, 2007), ch. 1. David Pingree, *From Astral Omens to Astrology: From Babylon to Bikaner* (Roma: Istitute italiano per l'Africa et l'Oriente, 1997), ch. 2.
24. Available at <http://www.wikipedia.org/wiki/tetrabiblos> last accessed 3 March 2014.
25. Pingree, *From Astral Omens to Astrology*, ch. 2.
26. Derek & Julia Park, *A History of Astrology* (London: André Deutsch, 1983), 41–6; Beck, *A Brief History of Ancient Astrology*, 7.
27. Pingree, *From Astral Omens to Astrology*, 195.
28. Kripa Shankar Shukla, 'Main Characteristics and Achievements of Ancient Indian Astronomy in Historical Perspective', in G. Swarup, A. K. Bag, K. S. Shukla (eds), *History of Oriental Astronomy: Proceedings of an Internattional Astronomical Union Colloquium*, no. 91, New Delhi, India, 13–16 November 1985 (Cambridge: Cambridge University Press, 1987), 9–22; North, *Cosmos*, ch. 7.
29. Shukla, 'Main Characteristics', 9–22; Pingree, *From Astral Omens to Astrology*, ch. 3.
30. B. V. Subbarayappa (ed.), 'The Tradition of Astronomy in India, Jyotisastra' in D. P. Chattopadhyaya (ed.), *History of Science, Philosophy, and Culture in Indian Civilization* (New Delhi: Center for Studies in Civilisations, 2008), vol. IV, part 4, 20–1.
31. Shukla, 'Main Characteristics', 9–22.
32. Subbarayappa, 'Tradition of Astronomy in India', 29–31.
33. Ibid. 32–5.
34. North, *Cosmos*, ch. 7; Pingree, *From Astral Omens to Astrology*, 91–2.
35. Pingree, *From Astral Omens to Astrology*, 203–4.
36. Ibid.
37. Pingree, *From Astral Omens to Astrology*, ch. 5.
38. North, *Cosmos*, 186–8; 'Astrology and Astronomy in Iran', in *Encyclopaedia Iranica*.
39. 'Astrology and Astronomy in Iran', *Encyclopaedia Iranica*; Pingree, *From Astral Omens to Astrology*, ch. 4.