History

History of astronomy

Astronomy is the oldest of the natural sciences, dating back to antiquity, with its origins in the religious, mythological, and astrological practices of pre-history: vestiges of these are still found in astrology, a discipline long interwoven with public and governmental astronomy, and not completely disentangled from it until a few centuries ago in the Western World (see astrology and astronomy). In some cultures astronomical data was used for astrological prognostication.

Ancient astronomers were able to differentiate between stars and planets, as stars remain relatively fixed over the centuries while planets will move an appreciable amount during a comparatively short time.

Early history

Early cultures identified celestial objects with gods and spirits. They related these objects (and their movements) to phenomena such as rain, drought, seasons, and tides. It is generally believed that the first "professional" astronomers were priests (such as the Magi), and that their understanding of the "heavens" was seen as "divine", hence astronomy's ancient connection to what is now called astrology. Ancient structures with possibly astronomical alignments (such as Stonehenge) probably fulfilled both astronomical and religious functions.

Calendars of the world have usually been set by the Sun and Moon (measuring the day, month and year), and were of importance to agricultural societies, in which the harvest depended on planting at the correct time of year. The most common modern calendar is based on the Roman calendar, which divided the year into twelve months of alternating thirty and thirty-one days apiece. In 46 BC Julius Caesar instigated calendar reform and adopted a calendar based upon the 365 1/4 day year length originally proposed by 4th century BC Greek astronomer Callippus.

Mesopotamia

The origins of Western astronomy can be found in Mesopotamia, the "land between the rivers" Tigris and Euphrates, where the ancient kingdoms of Sumer, Assyria, and Babylonia were located. A form of writing known as cuneiform emerged among the Sumerians around 3500–3000 BC. Our knowledge of Sumerian astronomy is indirect, via the earliest Babylonian star catalogues dating from about 1200 BC. The fact that many star names appear in Sumerian suggests a continuity reaching into the Early Bronze Age. Astral theology, which gave planetary gods an important role in Mesopotamian mythology and religion, began with the Sumerians. They also used a sexagesimal (base 60) place-value number system, which simplified the task of recording very large and very small numbers. The modern practice of dividing a circle into 360 degrees, of 60 minutes each, began with the Sumerians. For more information, see the articles on Babylonian numerals and mathematics.

Classical sources frequently use the term Chaldeans for the astronomers of Mesopotamia, who were, in reality, priest-scribes specializing in astrology and other forms of divination.

The first evidence of recognition that astronomical phenomena are periodic and of the application of mathematics to their prediction is Babylonian. Tablets dating back to the Old Babylonian period document the application of mathematics to the variation in the length of daylight over a solar year. Centuries of Babylonian observations of celestial phenomena are recorded in the series of cuneiform tablets known as the *Enūma Anu Enlil*. The oldest significant astronomical text that we possess is Tablet 63 of the *Enūma Anu Enlil*, the Venus tablet of Ammi-saduqa, which lists the first and last visible risings of Venus over a period of about 21 years and is the earliest evidence that the phenomena of a planet were recognized as periodic. The MUL.APIN, contains catalogues of stars and constellations as well as schemes for predicting heliacal risings and the settings of the planets, lengths of daylight measured by a water-clock, gnomon, shadows, and intercalations. The Babylonian GU text arranges stars in 'strings' that lie along declination circles and thus measure right-ascensions or time-intervals, and also employs the stars of the zenith, which are also separated by given right-ascensional differences.[1]

A significant increase in the quality and frequency of Babylonian observations appeared during the reign of Nabonassar (747–733 BC). The systematic records of ominous phenomena in astronomical diaries that began at this time allowed for the discovery of a repeating 18-year cycle of lunar eclipses, for example. The Greek astronomer Ptolemy later used Nabonassar's reign to fix the beginning of an era, since he felt that the earliest usable observations began at this time.

The last stages in the development of Babylonian astronomy took place during the time of the Seleucid Empire (323–60 BC). In the third century BC, astronomers began to use "goal-year texts" to predict the motions of the planets. These texts compiled records of past observations to find repeating occurrences of ominous phenomena for each planet. About the same time, or shortly afterwards, astronomers created mathematical models that allowed them to predict these phenomena directly, without consulting past records. A notable Babylonian astronomer from this time was Seleucus of Seleucia, who was a supporter of the heliocentric model.

Babylonian astronomy was the basis for much of what was done in Greek and Hellenistic astronomy, in classical Indian astronomy, in Sassanian Iran, in Byzantium, in Syria, in Islamic astronomy, in Central Asia, and in Western Europe.[2]

Egypt

The precise orientation of the Egyptian pyramids affords a lasting demonstration of the high degree of technical skill in watching the heavens attained in the 3rd millennium BC. It has been shown the Pyramids were aligned towards the pole star, which, because of the precession of the equinoxes, was at that time Thuban, a faint star in the constellation of Draco.[3] Evaluation of the site of the temple of Amun-Re at Karnak, taking into account the change over time of the obliquity of the ecliptic, has shown that the Great Temple was aligned on the rising of the midwinter sun.[4] The length of the corridor down which sunlight would travel would have limited illumination at other times of the year.

Astronomy played a considerable part in religious matters for fixing the dates of festivals and determining the hours of the night. The titles of several temple books are preserved recording the movements and phases of the sun, moon and stars. The rising of Sirius (Egyptian: Sopdet, Greek: Sothis) at the beginning of the inundation was a particularly important point to fix in the yearly calendar.

Writing in the Roman era, Clement of Alexandria gives some idea of the importance of astronomical observations to the sacred rites:

> And after the Singer advances the Astrologer (ὡροσκόπος), with a *horologium* (ὡρολόγιον) in his hand, and a *palm* (φοίνιξ), the symbols of astrology. He must know by heart the Hermetic astrological books, which are four in number. Of these, one is about the arrangement of the fixed stars that are visible; one on the positions of the sun and moon and five planets; one on the conjunctions and phases of the sun and moon; and one concerns their risings.[5]

The Astrologer's instruments (*horologium* and *palm*) are a plumb line and sighting instrument. They have been identified with two inscribed objects in the Berlin Museum; a short handle from which a plumb line was hung, and a palm branch with a sight-slit in the broader end. The latter was held close to the eye, the former in the other hand, perhaps at arms length. The "Hermetic" books which Clement refers to are the Egyptian theological texts, which probably have nothing to do with Hellenistic Hermetism.[6]

From the tables of stars on the ceiling of the tombs of Rameses VI and Rameses IX it seems that for fixing the hours of the night a man seated on the ground faced the Astrologer in such a position that the line of observation of the pole star passed over the middle of his head. On the different days of the year each hour was determined by a fixed star culminating or nearly culminating in it, and the position of these stars at the time is given in the tables as in the centre, on the left eye, on the right shoulder, etc. According to the texts, in founding or rebuilding temples the north axis was determined by the same apparatus, and we may conclude that it was the usual one for astronomical observations. In careful hands it might give results of a high degree of accuracy.

Greece and Hellenistic world

The Ancient Greeks developed astronomy, which they treated as a branch of mathematics, to a highly sophisticated level. The first geometrical, three-dimensional models to explain the apparent motion of the planets were developed in the 4th century BC by Eudoxus of Cnidus and Callippus of Cyzicus . Their models were based on nested homocentric spheres centered upon the Earth. Their younger contemporary Heraclides Ponticus proposed that the Earth rotates around its axis.

A different approach to celestial phenomena was taken by natural philosophers such as Plato and Aristotle. They were less concerned with developing mathematical predictive models than with developing an explanation of the reasons for the motions of the Cosmos. In his *Timaeus* Plato described the universe as a spherical body divided into circles carrying the planets and governed according to harmonic intervals by a world soul.[7] Aristotle, drawing on the mathematical model of Eudoxus, proposed that the universe was made of a complex system of concentric spheres, whose circular motions combined to carry the planets around the earth.[8] This basic cosmological model prevailed, in various forms, until the 16th century AD.

Greek geometrical astronomy developed away from the model of concentric spheres to employ more complex models in which an eccentric circle would carry around a smaller circle, called an epicycle which in turn carried around a planet. The first such model is attributed to Apollonius of Perga and further developments in it were carried out in the 2nd century BC by Hipparchus of Nicea. Hipparchus made a number of other contributions, including the first measurement of precession and the compilation of the first star catalog in which he proposed our modern system of apparent magnitudes.

The study of astronomy by the ancient Greeks was not limited to Greece itself but was further developed in the 3rd and 2nd centuries BC, in the Hellenistic states and in particular in Alexandria. However, the work was still done by ethnic Greeks. In the 3rd century BC Aristarchus of Samos was the first to suggest a heliocentric system, although only fragmentary descriptions of his idea survive.[9] Eratosthenes, using the angles of shadows created at widely separated regions, estimated the circumference of the Earth with great accuracy.[10]

The Antikythera mechanism, an ancient Greek astronomical observational device for calculating the movements of the Sun and the Moon, possibly the planets, dates from about 150-100 BC, and was the first ancestor of an astronomical computer. It was discovered in an ancient shipwreck off the Greek island of Antikythera, between Kythera and Crete. The device became famous for its use of a differential gear, previously believed to have been invented in the 16th century AD, and the miniaturization and complexity of its parts, comparable to a clock made in the 18th century. The original mechanism is displayed in the Bronze collection of the National Archaeological Museum of Athens, accompanied by a replica.

Depending on the historian's viewpoint, the acme or corruption of physical Greek astronomy is seen with Ptolemy of Alexandria, who wrote the classic comprehensive presentation of geocentric astronomy, the *Megale Syntaxis* (Great Synthesis), better known by its Arabic title *Almagest*, which had a lasting effect on astronomy up to the Renaissance. In his *Planetary Hypotheses* Ptolemy ventured into the realm of cosmology, developing a physical model of his geometric system, in a universe many times smaller than the more realistic conception of Aristarchus of Samos four centuries earlier.

India

Ancient Indian astrology is based upon sidereal calculation. The sidereal astronomy is based upon the stars and the sidereal period is the time that it takes the object to make one full orbit around the Sun, relative to the stars. It can be traced to the final centuries BC with the Vedanga Jyotisha attributed to Lagadha, one of the circum-Vedic texts, which describes rules for tracking the motions of the Sun and the Moon for the purposes of ritual. After formation of Indo-Greek kingdoms, Indian astronomy was influenced by Hellenistic astronomy (adopting the zodiacal signs or *rāśis*). Identical numerical computations for lunar cycles have been found to be used in India and in early Babylonian texts.[11]

Aryabhata (476–550), in his magnum opus *Aryabhatiya* (499), propounded a computational system based on a planetary model in which the Earth was taken to be spinning on its axis and the periods of the planets were given with respect to the Sun. He accurately calculated many astronomical constants, such as the periods of the planets, times of the solar and lunar eclipses, and the instantaneous motion of the Moon.[12] [13] Early followers of Aryabhata's model included Varahamihira, Brahmagupta, and Bhaskara II.

Astronomy was advanced during the Sunga Empire and many star catalogues were produced during this time. The Sunga period is known as the "Golden age of astronomy in India".

Brahmagupta (598-668) was the head of the astronomical observatory at Ujjain and during his tenure there wrote a text on astronomy, the *Brahmasphutasiddhanta* in 628. He was the earliest to use algebra to solve astronomical problems. He also developed methods for calculations of the motions and places of various planets, their rising and setting, conjunctions, and the calculation of eclipses.

Bhāskara II (1114–1185) was the head of the astronomical observatory at Ujjain, continuing the mathematical tradition of Brahmagupta. He wrote the *Siddhantasiromani* which consists of two parts: *Goladhyaya* (sphere) and *Grahaganita* (mathematics of the planets). He also calculated the time taken for the Earth to orbit the sun to 9 decimal places. The Buddhist University of Nalanda at the time offered formal courses in astronomical studies.

Other important astronomers from India include Madhava of Sangamagrama, Nilakantha Somayaji and Jyeshtadeva, who were members of the Kerala school of astronomy and mathematics from the 14th century to the 16th century. Nilakantha Somayaji, in his *Aryabhatiyabhasya*, a commentary on Aryabhata's *Aryabhatiya*, developed his own computational system for a partially heliocentric planetary model, in which Mercury, Venus, Mars, Jupiter and Saturn orbit the Sun, which in turn orbits the Earth, similar to the Tychonic system later proposed by Tycho Brahe in the late 16th century. Nilakantha's system, however, was mathematically more effient than the Tychonic system, due to correctly taking into account the equation of the centre and latitudinal motion of Mercury and Venus. Most astronomers of the Kerala school of astronomy and mathematics who followed him accepted his planetary model.[14] [15]

China

The astronomy of East Asia began in China. Solar term was completed in Warring States Period. The knowledge of Chinese astronomy was introduced into East Asia.

Astronomy in China has a long history. Detailed records of astronomical observations were kept from about the 6th century BC, until the introduction of Western astronomy and the telescope in the 17th century. Chinese astronomers were able to precisely predict comets and eclipses.

Much of early Chinese astronomy was for the purpose of timekeeping. The Chinese used a lunisolar calendar, but because the cycles of the Sun and the Moon are different, astronomers often prepared new calendars and made observations for that purpose.

Astrological divination was also an important part of astronomy. Astronomers took careful note of "guest stars" which suddenly appeared among the fixed stars. They were the first to record a supernova, in the Astrological Annals of the Houhanshu in 185 A.D. Also, the supernova that created the Crab Nebula in 1054 is an example of a "guest star" observed by Chinese astronomers, although it was not recorded by their European contemporaries. Ancient astronomical records of phenomena like supernovae and comets are sometimes used in modern astronomical studies.

The world's first star catalogue was made by Gan De, a Chinese astronomer, in 4th century BC.

Mesoamerica

Maya astronomical codices include detailed tables for calculating phases of the Moon, the recurrence of eclipses, and the appearance and disappearance of Venus as morning and evening star. The Maya based their calendrics in the carefully calculated cycles of the Pleiades, the Sun, the Moon, Venus, Jupiter, Saturn, Mars, and also they had a precise description of the eclipses as depicted in the Dresden Codex, as well as the ecliptic or zodiac, and the Milky Way was crucial in their Cosmology.[16] A number of important Maya structures are believed to have been oriented toward the extreme risings and settings of Venus. To the ancient Maya, Venus was the patron of war and many recorded battles are believed to have been timed to the motions of this planet. Mars is also mentioned in preserved astronomical codices and early mythology.[17]

Although the Maya calendar was not tied to the Sun, John Teeple has proposed that the Maya calculated the solar year to somewhat greater accuracy than the Gregorian calendar.[18] Both astronomy and an intricate numerological scheme for the measurement of time were vitally important components of Maya religion.

Islamic astronomy

The Arabic world under Islam had become highly cultured, and many important works of knowledge from Greek astronomy and Indian astronomy were translated into Arabic, used and stored in libraries throughout the area. An important contribution by Islamic astronomers was their emphasis on observational science and observational astronomy[19] This led to the emergence of the first astronomical observatories in the Muslim world by the early 9th century.[20] [21] Zij star catalogues were produced at these observatories.

The late 9th century Persian astronomer Ahmad ibn Muhammad ibn Kathīr al-Farghānī wrote extensively on the motion of celestial bodies. His work was translated into Latin during the Latin translations of the 12th century. In the 9th century, Ja'far ibn Muhammad Abu Ma'shar al-Balkhi (Albumasar) developed a planetary model which has been interpreted as a heliocentric model.[22] This is due to his orbital revolutions of the planets being given as heliocentric revolutions rather than geocentric revolutions, and the only known planetary theory in which this occurs is in the heliocentric theory. His work on planetary theory has not survived, but his astronomical data was later recorded by al-Hashimi and Biruni.[22]

In the 10th century, Abd al-Rahman al-Sufi (Azophi) carried out observations on the stars and described their positions, magnitudes, brightness, and colour and drawings for each constellation in his *Book of Fixed Stars*. He also gave the first descriptions and pictures of "A Little Cloud" now known as the Andromeda Galaxy. He mentions it as lying before the mouth of a Big Fish, an Arabic constellation. This "cloud" was apparently commonly known to the Isfahan astronomers, very probably before 905 AD.[23] The first recorded mention of the Large Magellanic Cloud was also given by al-Sufi.[24] [25] In 1006, Ali ibn Ridwan observed SN 1006, the brightest supernova in recorded history, and left a detailed description of the temporary star.

In the late 10th century, a huge observatory was built near Tehran, Iran, by the astronomer Abu-Mahmud al-Khujandi who observed a series of meridian transits of the Sun, which allowed him to calculate the obliquity of the ecliptic, also known as the tilt of the Earth's axis relative to the Sun. In 11th-century Persia, Omar Khayyám compiled many tables and performed a reformation of the calendar that was more accurate than the Julian and came close to the Gregorian.

In the early 11th century, Ibn al-Haytham (Alhazen) wrote the *Maqala fi daw al-qamar* (*On the Light of the Moon*) some time before 1021. This was the earliest attempt at applying the experimental method to astronomy and astrophysics, and thus the first successful at combining mathematical astronomy with "physics" (which then referred to natural philosophy) for several of his astronomical hypotheses. He disproved the universally held opinion that the moon reflects sunlight like a mirror and correctly concluded that it "emits light from those portions of its surface which the sun's light strikes." In order to prove that "light is emitted from every point of the moon's illuminated surface," he built an "ingenious experimental device." Ibn al-Haytham had "formulated a clear conception of the relationship between an ideal mathematical model and the complex of observable phenomena; in particular, he was the first to make a systematic use of the method of varying the experimental conditions in a constant and uniform manner, in an experiment showing that the intensity of the light-spot formed by the projection of the moonlight through two small apertures onto a screen diminishes constantly as one of the apertures is gradually blocked up."[26]

Other Muslim advances in astronomy included the collection and correction of previous astronomical data, resolving significant problems in the Ptolemaic model, the development of the universal latitude-independent astrolabe by Arzachel,[27] the invention of numerous other astronomical instruments, the beginning of astrophysics and celestial mechanics after Ja'far Muhammad ibn Mūsā ibn Shākir theorized that the heavenly bodies and celestial spheres were subject to the same physical laws as Earth,[28] the first elaborate experiments related to astronomical phenomena, the introduction of exacting empirical observations and experimental techniques,[29] and the introduction of empirical testing by Ibn al-Shatir, who produced the first model of lunar motion which matched physical observations.[30]

In the 12th century, Fakhr al-Din al-Razi criticized the idea of the Earth's centrality within the universe, and instead argued that there are more than "a thousand thousand worlds (*alfa alfi 'awalim*) beyond this world such that each one of those worlds be bigger and more massive than this world as well as having the like of what this world has."[31]

The first empirical observational evidence of the Earth's rotation was given by Nasīr al-Dīn al-Tūsī in the 13th century and by Ali Qushji in the 15th century, followed by Al-Birjandi who developed an early hypothesis on "circular inertia" by the early 16th century.[32] Natural philosophy (particularly Aristotelian physics) was separated from astronomy by Ibn al-Haytham (Alhazen) in the 11th century, by Ibn al-Shatir in the 14th century,[33] and Qushji in the 15th century, leading to the development of an independent astronomical physics.[32]

It is known that the Copernican heliocentric model in Nicolaus Copernicus' *De revolutionibus* employed geometrical constructions that had been developed previously by the Maragheh school,[34] [35] and that his arguments for the Earth's rotation were similar to those of Nasīr al-Dīn al-Tūsī and Ali al-Qushji.[32] Some have referred to the achievements of the Maragha school as a "Maragha Revolution", "Maragha School Revolution", or "Scientific Revolution before the Renaissance".[36]

Medieval Western Europe

After the significant contributions of Greek scholars to the development of astronomy, it entered a relatively static era in Western Europe from the Roman era through the Twelfth century. This lack of progress has led some astronomers to assert that nothing happened in Western European astronomy during the Middle Ages.[37] Recent investigations, however, have revealed a more complex picture of the study and teaching of astronomy in the period from the Fourth to the Sixteenth centuries.[38]

Western Europe entered the Middle Ages with great difficulties that affected the continent's intellectual production. The advanced astronomical treatises of classical antiquity were written in Greek, and with the decline of knowledge of that language, only simplified summaries and practical texts were available for study. The most influential writers to pass on this ancient tradition in Latin were Macrobius, Pliny, Martianus Capella, and Calcidius.[39] In the Sixth Century Bishop Gregory of Tours noted that he had learned his astronomy from reading Martianus Capella, and went on to employ this rudimentary astronomy to describe a method by which monks could determine the time of prayer at night by watching the stars.[40]

In the Seventh Century the English monk Bede of Jarrow published an influential text, On the Reckoning of Time, providing churchmen with the practical astronomical knowledge needed to compute the proper date of Easter using a procedure called *computus*. This text remained an important element of the education of Clergy from the Seventh

Century until well after the rise of the Universities in the Twelfth Century.[41]

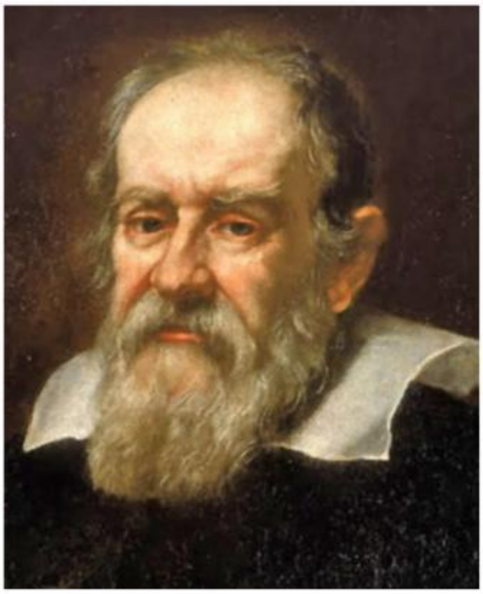
The range of surviving ancient Roman writings on astronomy and the teachings of Bede and his followers began to be studied in earnest during the revival of learning sponsored by the emperor Charlemagne.[42] By the Ninth Century rudimentary techniques for calculating the position of the planets were circulating in Western Europe; medieval scholars recognized their technical flaws, but texts describing these techniques continued to be copied, reflecting an interest in the motions of the planets and in their astrological significance.[43]

Building on this astronomical background, in the Tenth Century European scholars such as Gerbert of Aurillac began to travel to the Spain and Sicily to seek out learning which they had heard existed in the Arabic-speaking world. There they first encountered various practical astronomical techniques concerning the calendar and timekeeping, most notably those dealing with the astrolabe. Soon scholars such as Hermann of Reichenau were writing texts in Latin on the uses and construction of the astrolabe and others, such as Walcher of Malvern, were using the astrolabe to observe the time of eclipses in order to test the validity of computistical tables.[44]

By the Twelfth century, scholars were traveling to Spain and Sicily to seek out more advanced astronomical and astrological texts, which they translated into Latin from Arabic and Greek to further enrich the astronomical knowledge of Western Europe. The arrival of these new texts coincided with the rise of the universities in medieval Europe, in which they soon found a home.[45] Reflecting the introduction of astronomy into the universities, John of Sacrobosco wrote a series of influential introductory astronomy textbooks: the Sphere, a Computus, a text on the Quadrant, and another on Calculation.[46]

In the 14th century , Nicole Oresme, later bishop of Liseux, showed that neither the scriptural texts nor the physical arguments advanced against the movement of the Earth were demonstrative and adduced the argument of simplicity for the theory that the earth moves, and *not* the heavens. However, he concluded "everyone maintains, and I think myself, that the heavens do move and not the earth: For God hath established the world which shall not be moved."[47] In the 15th century, cardinal Nicholas of Cusa suggested in some of his scientific writings that the Earth revolved around the Sun, and that each star is itself a distant sun. He was not, however, describing a scientifically verifiable theory of the universe.

Renaissance Period



Galileo Galilei (1564–1642) crafted his own telescope and discovered that our Moon had craters, that Jupiter had moons, that the Sun had spots, and that Venus had phases like our Moon.

The renaissance came to astronomy with the work of Nicolaus Copernicus, who proposed a heliocentric system, in which the planets revolved around the Sun and not the Earth. His *De revolutionibus* provided a full mathematical discussion of his system, using the geometrical techniques that had been traditional in astronomy since before the time of Ptolemy. His work was later defended, expanded upon and modified by Galileo Galilei and Johannes Kepler.

Galileo was among the first to use a telescope to observe the sky and after constructing a 20x refractor telescope he discovered the four largest moons of Jupiter in 1610. This was the first observation of satellites orbiting another planet. He also found that our Moon had craters and observed (and correctly explained) sunspots. Galileo noted that Venus exhibited a full set of phases resembling lunar phases. Galileo argued that these observations supported the Copernican system and were, to some extent, incompatible with the favored model of the Earth at the center of the universe.[48]

Uniting physics and astronomy

Although the motions of celestial bodies had been qualitatively explained in physical terms since Aristotle introduced celestial movers in his Metaphysics and a fifth element in his On the Heavens, Johannes Kepler was the first to attempt to derive mathematical predictions of celestial motions from assumed physical causes.[49] [50] Combining his physical insights with the unprecedentedly accurate naked-eye observations made by Tycho Brahe,[51] [52] [53] Kepler discovered the three laws of planetary motion that now carry his name.[54]

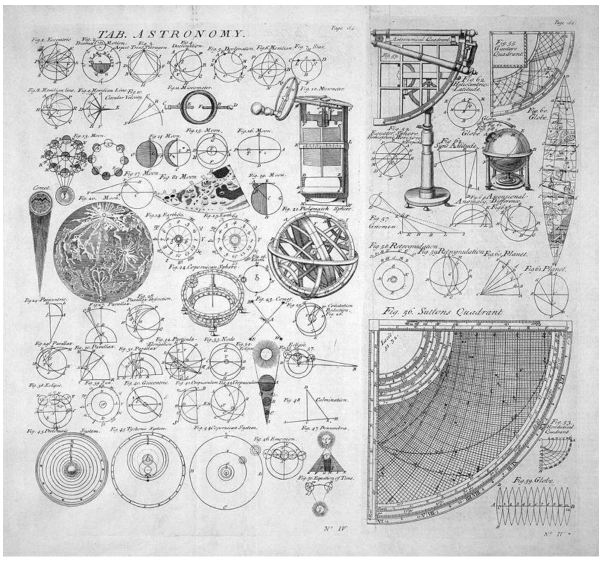


Plate with figures illustrating articles on astronomy, from the 1728 *Cyclopaedia*

Isaac Newton developed further ties between physics and astronomy through his law of universal gravitation. Realising that the same force that attracted objects to the surface of the Earth held the moon in orbit around the Earth, Newton was able to explain – in one theoretical framework – all known gravitational phenomena. In his Philosophiae Naturalis Principia Mathematica, he derived Kepler's laws from first principles. Newton's theoretical developments lay many of the foundations of modern physics.

Modern astronomy

At the end of the 19th century it was discovered that, when decomposing the light from the Sun, a multitude of spectral lines were observed (regions where there was less or no light). Experiments with hot gases showed that the same lines could be observed in the spectra of gases, specific lines corresponding to unique elements. It was proved that the chemical elements found in the Sun (chiefly hydrogen and helium) were also found on Earth. During the 20th century spectrometry (the study of these lines) advanced, especially because of the advent of quantum physics, that was necessary to understand the observations.

Although in previous centuries noted astronomers were exclusively male, at the turn of the 20th century women began to play a role in the great discoveries. In this period prior to modern computers, women at the United States Naval Observatory (USNO), Harvard University, and other astronomy research institutions began to be hired as human "computers," who performed the tedious calculations while scientists performed research requiring more background knowledge. [55] A number of discoveries in this period were originally noted by the women "computers" and reported to their supervisors. For example, at the Harvard Observatory Henrietta Swan Leavitt discovered the cepheid variable star period-luminosity relation which she further developed into the first method of measuring distance outside of our solar system. Annie Jump Cannon organized the stellar spectral types according to stellar temperature, and Maria Mitchell discovered a comet using a telescope. According to Lewis D. Eigen, Cannon alone, "in only 4 years discovered and catalogued more stars than all the men in history put together."[56] (See [57] for more women astronomers.) Most of these women received little or no recognition during their lives due to their lower professional standing in the field of astronomy. Although their discoveries and methods are taught in classrooms around the world, few students of astronomy can attribute the works to their authors or have any idea that there were active female astronomers at the end of the 19th century.

Cosmology and the expansion of the universe

Most of our current knowledge was gained during the 20th century. With the help of the use of photography, fainter objects were observed. Our sun was found to be part of a galaxy made up of more than 10^{10} stars (10 billion stars). The existence of other galaxies, one of the matters of *the great debate*, was settled by Edwin Hubble, who identified the Andromeda nebula as a different galaxy, and many others at large distances and receding, moving away from our galaxy.

Physical cosmology, a discipline that has a large intersection with astronomy, made huge advances during the 20th century, with the model of the hot big bang heavily supported by the evidence provided by astronomy and physics, such as the redshifts of very distant galaxies and radio sources, the cosmic microwave background radiation, Hubble's law and cosmological abundances of elements.

New windows into the Cosmos open

Late in the 19th century, scientists began discovering forms of light which were invisible to the naked eye: X-Rays, gamma rays, radio waves, microwaves, ultraviolet radiation, and infrared radiation. This had a major impact on astronomy, spawning the fields of infrared astronomy, radio astronomy, x-ray astronomy and finally gamma-ray astronomy. With the advent of spectroscopy it was proven that other stars were similar to our own sun, but with a range of temperatures, masses and sizes. The existence of our galaxy, the Milky Way, as a separate group of stars was only proven in the 20th century, along with the existence of "external" galaxies, and soon after, the expansion of the universe seen in the recession of most galaxies from us.

Notes

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