ASTRONOMY IN ISLAMIC WORLD
A EUROPEAN PERSPECTIVE

Richard Kerner
Laboratoire de Physique Théorique de la Matière Condensée
Sorbonne-Université,, Paris, France

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Islamic science took its sources on both sides of its geographical spread, namely in Greek scientific tradition conserved in Byzantium and in Hellenistic Egypt, both Christianized since many centuries, and in Indian mathematical and astronomical traditions.

The Greeks owned much of astronomical knowledge to the earlier Babylonian and Egyptian civilizations; however, they enriched and extended them in unprecedented proportions.

The earliest acquaintance of Islamic world with mathematics and astronomy was due to Indian and Persian influence. From India, the Arabs took the decimal system with numerals and zero which we use today. The main Indian mathematical text by Brahmagupta ($598 - 670$ C.E.) was translated into arabic.

It contained, among others, the idea of negative numbers and their algebraical properties. They were called “debts”, in opposition to positive numbers called “fortunes”; not only algebraical addition was defined, but also the multiplication, with well-known rules, including the fact that a product of two negative numbers is positive.

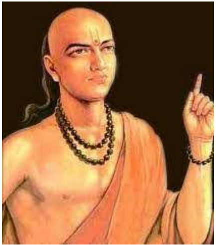


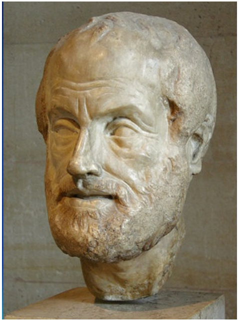
Figure: **Aryabhata** 476 – 550 **C.E.** **Aryabhata is the father of Indian mathematics. He was the greatest mathematician and astronomer of ancient India. His major work is known as Aryabhatiya. It consists of spherical trigonometry, quadratic equations, algebra, plane trigonometry, sums of power series, arithmetic.**

The three pillars of Greek science which were adopted by Arab and Islamic polymaths were Aristotle for physics and all natural sciences, Euclid for geometry, and Ptolemy for Astronomy. Their major works were translated, copied, edited and commented upon for centuries.

Aristotle would assume the title of "First Teacher", vouching for all the intellectual heritage of the Greeks, viewed as a systematic knowledge compatible with the Muslim worldview. Together with Aristotle's own works, the Arabs translated an equally great amount of commentaries tracing back to late Antiquity, particularly to the School of Alexandria.

Some of Plato's texts were translated at the same time.

Figure: **Plato and Aristotle, as they appear on Rafael Santi's monumental painting "The School of Athens"**



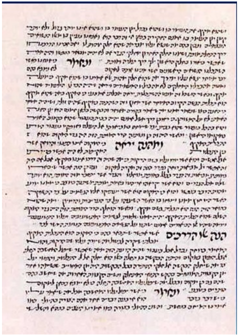


Figure: **Left: Aristotle's portrait in the Louvre; Right: A page from Aristotle's "Organon" in Hebrew translation**

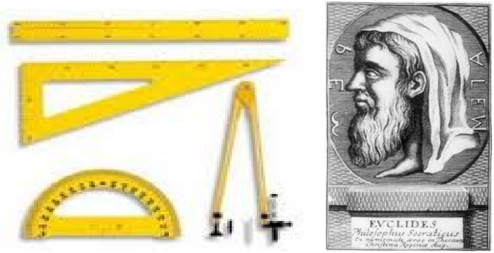


Figure: **Left: Tools of Euclidean geometry, Right: Euclid, 323 – 265 B.C.E. The great Greek mathematician Euclid united in the 13 books of his major work, "The Elements" the geometrical knowledge elaborated by his predecessors, Pythagoras (570 – 495 B.C.E., Hippocrates of Chios (470 – 410 B.C.E), Eudoxus of Cnidos (406 – 355 B.C.E.). Euclid's merit was not only the systematization of all known geometrical facts and theorems, but above all, the proof that they can be derived from only FIVE POSTULATES.**

Figure: **Left: One of the rare fragments of "Elements", Right: Euclid's statue in Oxford. The "Elements" were copied many times in Greek in Byzantium, and translated in Syriac. The Arabic translation from Syriac and Greek appeared around 800 C.E. under the Khalif Haroun al-Rachid. In 1120 English monk Adelard of Bath translated Euclid's book from Arabic into Latin.**

Claudius Ptolemy lived in the Egyptian city of Alexandria from 100 till 170 C.E. or even till 178 according to some Arab commentators and translators of his writings. At that time Egypt was a Roman province ruled by the Greek dynasty bearing the same family name, Ptolemaios. Ptolemy was the last great representative of Greek science, heir to a tradition eight centuries old.

Ptolemy lived and worked 400 years after Euclid, 600 years after Pericles and 700 years after Anaximander of Miletus who was the first to suggest the idea of the celestial sphere and to produce a map of the inhabited world known in his time.

Little is known about Ptolemy's life except that he probably spent it all in Alexandria, where he observed two solar eclipses: one in the ninth year of Hadrian's rule (125 C.E.) and in the fourth year of Antoninus' rule (141 C.E.). Besides his *Syntaxis Mathematicus*, known also as "Magnum Opus" due to its importance for astronomy, and mostly under the name of its arabic translation *Almagest*. Ptolemy was also a renowned geographer in his time.

The geocentric system elaborated in *Syntaxis* was universally accepted during Hellenic and Roman antiquity, and later on by medieval Christian and Muslim civilizations alike, and was used to describe and predict motions of celestial bodies by astronomers and astrologists.

Figure: **Left: Ptolemy portrayed on the main door of Duomo in Florence, Italy; Right: The Ptolemaic model of the Solar System.**

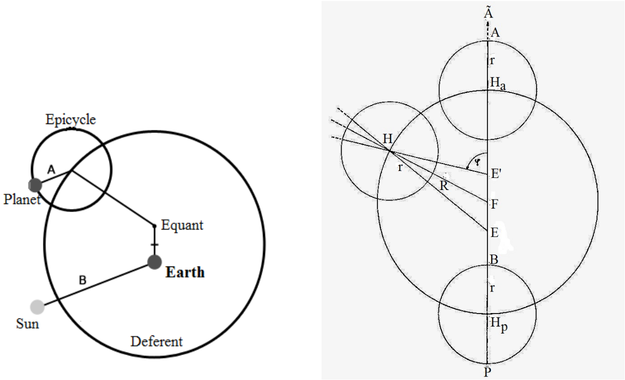


Figure: **Left: The basic elements of Ptolemaic model: Deferent, Epicycle and Equant. Right: The most important features of planetary motion reproduced: eccentricity (EF), retrograde motion (R), and variation of angular velocity between apogeum (A) and perigeum (B). Earth is at (E), equant is at (E')**

At the end of fifth century C.E. the Roman Empire was in shambles. It was divided into the Western and Easter parts already in 395 C.E., and prone to steadily increasing barbarian invasions ever since. The last Roman emperor Romulus Augustulus was disposed of in 476 C.E. by war Germanic chief Odoaker, who proclaimed himself emperor.

Figure: **Roman Empire at the height of its expansion,** 180 **C.E.**

The Eastern part of the Empire with capital in Constantinople gradually transformed into Greek-speaking Byzantine Empire . All these territories, including Egypt and North Africa up to Spain were Christian since the Emperor Constantinus proclaimed Christianity to become state religion.

However, since the fall of the Western Roman Empire , most of these territories were deprived of any organized army and statehood, prone to barbarian invasions, among which the Huns, the Goths and the Vandals were the most important.

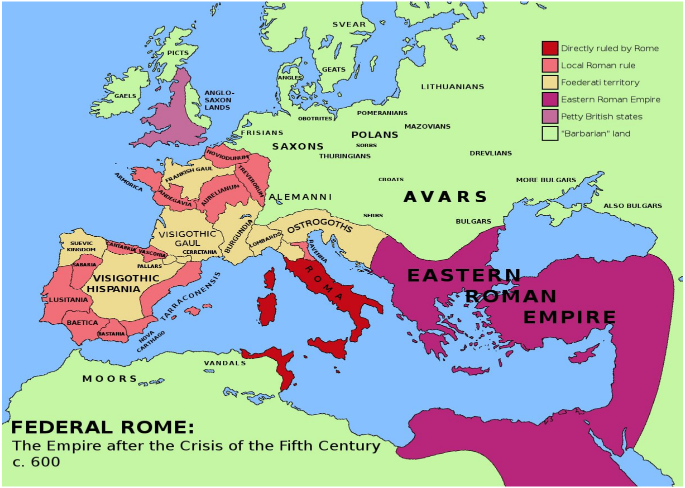


Figure: **Roman Empire after the fall,** 580 **C.E.**

Figure: **Eastern Roman Empire and Persia,** 650 **C.E.**

In the midst of 7^{th} century C.E. a new religion was proclaimed by Muhammad in Arabia. Derived from Jewish and Christian traditions, simplifying them and professing with great conviction the uniqueness of God, This was an important revolution, because it replaced the tribal principle by a more general religious and social unity.

While Europe entered the era of Dark Ages, lasting roughly from 500 C.E. until the 12^{th} century, the Arabs have conquered vast territories creating a buyoant Islamic Civilization, which spread from Moorish Spain in the West, through Western North Africa, through Egypt and Mesopotamia, touching India and even the most western parts of China.

Islam in the 9^{th} century C.E.

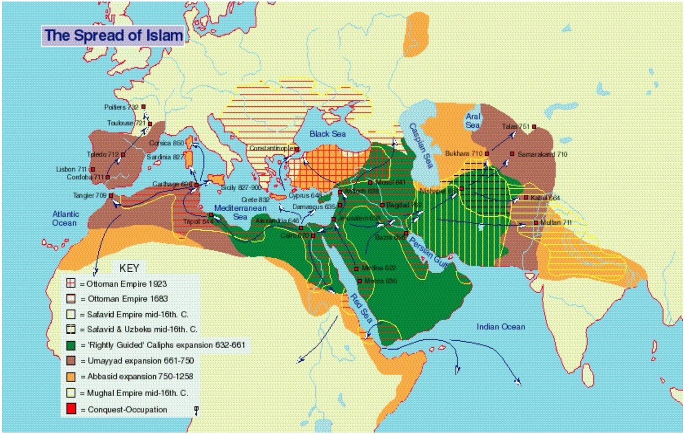


Figure: The spread of Islam from 661 till 1258 C.E.

The only precedent of so rapid expansion was the Hellenistic empire built by Alexander the Great. Like ancient Greek, and Latin in the Roman Empire, Arabic language became universal among Islamic scholars, with Persian and Turkish as subsidiary in the East.

Ancient Greek science has been assimilated and developed further. Aristotle, Euclid and Ptolemy were translated and multiplied in many copies. Medical science of ancient Greeks was also honored, and Hippocrates and Galen translated, too.

The *Golden Age* of Islamic civilization covers the time span from 9^{th} till 13^{th} century C.E. in Baghdad under the *Abassid* dynasty, and in Moorish Spain until the fourteenth century; it lasted a little bit more in Central Asia, falling under the Mongol conquest.

During that time of splendor sciences flourished, especially mathematics, chemistry (called *al-khimiya"*, or alchemy, and astronomy. A number of scientific terms of arabic origin are in use in Western science until today, and known to everybody: it is enough to cite a few, like *algebra*, *algorithm*, *zenith*, *azimuth*, *nadir*, *alcohol*, *alcali*.

Mathematics and astronomy in Islamic world developed in a larger context of cultural, philosophical, religious and scientific development, due to remarkable thinkers, physicians and polymaths, among whom the greatest ones were the following:

- **Al-Farabi, (..? – 950), known in Christian world under the latinized name *Alpharabius*. He spent most of his life in Baghdad. A prolific writer, he authored comments on Platonic and Aristotelian philosophy, and original works on physics, alchemy, psychology, astronomy and music. His authority was so great in Islamic world, that he was often called "The Second Teacher" - meaning second after Aristotle. His comments paved the way to the philosophical synthesis by Ibn Sina (Avicenna) and Ibn Rushd (Averroes). In his late years he moved to Damascus, where he died in 950 C.E.**

- **Avicenna (Ibn Sina), ($.;? - 1037$), renowned physician and philosopher, called "The Third Teacher". His most appreciated work was the *Canon of Medicine*, a manual of medical science in many volumes, which became the authority for European doctors after it was translated into Latin. Among his lasting contributions was the drug testing method and the discovery of the infectiousness of tuberculosis.**

Figure: **Avicenna (Ibn Sina,** ..? – 1037**, often referred to as "the Persian Galen".**

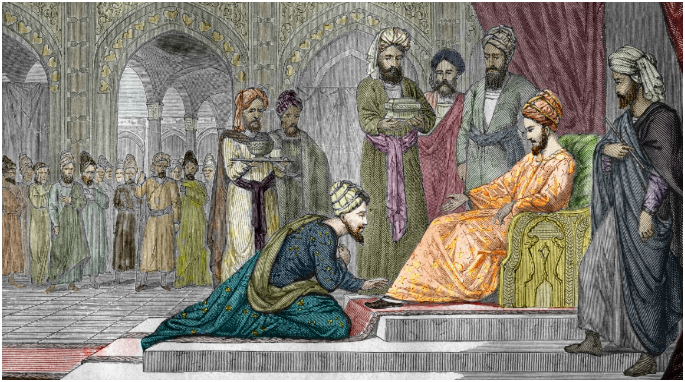


Figure: **Avicenna (Ibn Sina) at the court of the Governor of Isfahan.**

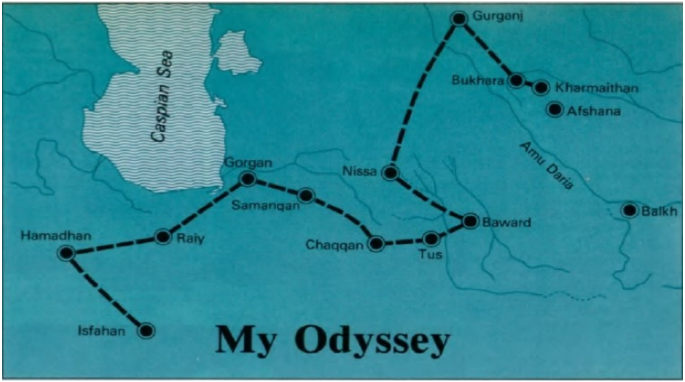


Figure: **Avicenna's (Ibn Sina)** **peregrinations during his life.**

- **Al-Biruni, (..? – 1048), a famous geographer and astronomer, has improved Eratosthenes' estimate of Earth's circumference.**

He also wrote the geographic description of India, a source of new historical, botanical and zoological facts. Unfortunately, never translated into Latin before the modern times.

- **Averroes (Ibn Rushd), (1126 – 1198).** Considered as one of the greatest Muslim scientists, he was born in Andalusia, then ruled by the Almoravid dynasty, later passed under the Almohads. He studied diligently the writings of Aristotle, Al-Farabi and Ibn-Sina (Avicenna). He became the most influential Islamic scientist among the Europeans; his writings were studied in Padova, Salamanca, Oxford and Sorbonne.

In 1189 the Almohad caliph al-Mansour prohibits practicing music, poetry, and overall, philosophy. Averroes is accused of heresy and banished first from Cordoba, then from Andalusia to Morocco; his books are burned and prohibited. Although partly pardoned, he died in Morocco, never being permitted to come back to his hometown Cordoba.

Figure: **Averroes in Cordoba.**

One of the most often repeated claims is that Muslims invented algebra. This is largely true, even if initially they took source in ancient Greek and Indian mathematics. The word "algebra" comes from the arabic *al-jabr* **and means "restoring" or "putting parts together".**

It was coined by Persian mathematician and astronomer al-Khwarizmi (ca. 780 - ca. 850 C.E.) who lived in Baghdad, in his treatise *"Ilm al-jabr wa al-muqabala"*, **which means "Science of putting parts together and balancing".**

In modern algebraical terms, the first word referred to the possibility of replacing terms from one side of an equation to another, and adding or substracting the same quantity from both sides. Al-Kwarizmi's name refers to the city of Khorezm (today in Uzbekistan) and was known in the West in its latinized version *Alkorizm* **or** *Algorithm*, **and became the name of a general prescription in mathematics.**

Figure: **Left: Al-Khorezmi's statue, Right: Postal stamp with Al-Khorezmi, USSR,** During the "Golden Age" of Islam, astronomy was one of the most important sciences. Muslim religion had imposed several requirements which needed important astronomical skills to improve the time-keeping and space orientation. Exact timing of five obligatory prayers a day, beginning and the end of fast during the sacred month of Ramadan, linked to the first and last crescent of the Moon, establishing times of islamic holidays - all that created the need for astronomical observations.

Mosques had to be oriented towards Mecca in the Arabian Peninsula, and so should be positioned a Muslim during his prayer - this alone needed improved geographical and astronomical knowledge, too.

Finally, vast territories of Islam, with flourishing terrestrial and maritime trade, made necessary the emergence of practical astronomy, improving observational devices like sextants and astrolabiums, to be used on land or in the open sea.

The Chief amongst the sciences in which Muslim scholars excelled was astronomy. Success was built upon mastery of mathematics - geometry in particular - as much as the philosophical inheritance of the ancient Greeks and other early civilizations through translation into Arabic.

Observatories founded in the most important centres of learning such as Baghdad and Cairo required specialized instruments for observation and instruction. These included celestial globes, quadrants, and armillary spheres, but the most sophisticated instrument adopted and developed by Muslim astronomers was the astrolabe.

Figure: **Left: Ancient Astrolabe, Toledo** 1067 **C.E.; Right: Armillary sphere from Damascus,** 1120

How great was the impact of the Arabs on European astronomy that took the lead after 16^{th} century can be easily seen in any modern stellar atlas. Here are a few among the best known bright stars whose names are of the Arab origin:

Aldebaran, α Tauri, from arabic *Al-Dabaran*, the "Follower"

Algol, β Persei, from arabic *Al Ghoul*, the "Demon", or "Scary monster".

Altair, α Aquilae, from arabic *an-Nisr ut-Ta'ir*, the "Flying Eagle",

Betelgeuse, α Orionis, from arabic *Yad al Jawza*, the "Hand of Al-Jawza", a mythical character

Deneb, α Cygni, from arabic *Dhaneb ud-Djadjab*, "Tail of the Hen"

Dubhe, α Ursae Majoris, from arabic *Dubb*, "Bear"

Fomalhaut, α Piscis Austrini, from arabic *Fum al-Hul*, the "Mouth of the Whale"

Figure: **Muslim Astronomers working around Taqi-ad-Din at the Istanbul Observatory, from and old Turkish book.**

Arab astronomers continued observations using the techniques inherited from Greeks and incorporating other ancient traditions, e.g. from Persia and India. They were often able to improve and enrich the data collected by Ptolemy in his *Almagest*. To take an example:

Following Hipparchus, Ptolemy estimated precession of the equinoxes to be of 1^o per 100 years, which would correspond to completing the full cycle in 36000 years. Egyptian astronomer Ibn Yunus ($850 - 1009$ C.E.) has corrected this estimate, reducing it down to 1^o in 70 years, which corresponds to the full cycle of 25200 years, very close to the modern value.

The most eminent Muslim astronomers include Al-Battani, Al-Sufi, Al-Biruni, Al-Bitruji, Ibn Yunus, al Tusi and al Shatir.

- **Al-Khwarizmi** (ca. 786 – 850 C.E.),

of Persian origin, was appointed by al-Mamoun, the son of Harun-al-Rashid of the Abbasid dynasty, as the chief astronomer and head of the library in the "House of Wisdom" in Baghdad. Al-Khwarizmi's important strides in astronomy and geography include the measurement of the length of a degree of a meridian in the plain of Sinjar, improving Erastothenes' evaluation of Earth's circumference, the creation of a world map based on the geography of Ptolemy, providing more accurate coordinates of approximately 2 400 **sites in the known world. These results were contained in his book "***Kitab surat al-ard* **("The Image of the Earth")**

Another al-Khwarizmi's treaty that made it into the Western canon of mathematical studies was a compilation of astronomical tables including a table of sines, and was translated into Latin. He also produced two treatises on the sundial, on the astrolabe, and one on the Jewish calendar.

Around 1110 the Englishman Robert of Chester, who was then in Spain, translated into Latin Al-Khwarizmi's al-Jabr (Algebra) and introduced into Europe Arabic numerals, including the figure zero, which the Arabs themselves had borrowed from the Indians.

- **Al-Battani (died in 929)** **known to Europe as Albategni or Albatenius was the author of the** ***Sabian tables*** **(al-Zij al-Sabi), a work which had great impact on his Muslim and Christian successors. His improved tables of the orbits of the sun and the moon comprise his discovery that the direction of the sun's eccentric as recorded by Ptolemy was changing. This, in modern astronomy, means the Earth's line of apsides is slowly moving. He also worked on the timing of the new moons, the length of the solar and sideral year, the prediction of eclipses, and the phenomenon of parallax.**

Figure: **Al-Battani, called by the contemporaries “The Second Ptolemy”**

Al-Battani was also a pioneer in the field of trigonometry. He was among the first, if not the first to use trigonometric ratios as we know them today. During the same period, Yahya Ibn Abi Mansour had completely revised the Zij of Almagest after meticulous observations and tests producing the famous Al-Zij al Mumtahan (the validated Zij).

In al-Zij al-Sabi (known as the Sabian Tables), Al-Battani plotted the Sun's orbit more accurately than Ptolemy. In his De Revolutionibus, Copernicus was to refer to Al-Battani's calculations no fewer than 23 times.

- Belonging to the same era, **Abd-al Rahman al-Sufi** (903 – 986) made several observations on the obliquity of the ecliptic and the motion of the sun (or the length of the solar year). He became renowned for his observations and descriptions of the stars, their positions, their brightness and their colour, setting out his results constellation by constellation.

For each constellation, he provided two drawings, one from the outside of a celestial globe, and the other from the inside (as seen from the sky). Al-Sufi also wrote on the astrolabe, finding numerous additional uses for it (including one's location, measuring distances and heights, etc.)

- **Ibn Yunus** (d 1009), **in his observation endeavours included, amongst others more than 10, 000 entries of the Sun's position throughout the years using a large astrolabe of nearly 1.4 m in diameter. His work, in French edition, was centuries later an inspiration for Laplace in his determination of the "Obliquity of the Ecliptic" and the "Inequalities of Jupiter and Saturn".**

Ibn Yunus made observations for nearly thirty years ($977 - 1003$**) using amongst others a large astrolabe of nearly 1.4 m in diameter, determining more than 10,000 entries of the sun's position throughout the years. The famous european astronomer Newcomb also used his observations of eclipses in the motions of the moon.**

Figure: **Left: Ibn Yunus al Masri, Right: A page from Ibn Yunus book al-Zij**

- **Al-Biruni** (973 – 1050) **claimed that the Earth rotated around its own axis. He calculated the earth circumference, and fixed scientifically the direction of Mecca from any point of the globe. Al-Biruni wrote in total 150 works, including 35 treatises on pure astronomy, of which only six have survived.**

In addition, in the late 10^{th} century Abu-al-Wafa and the prince Abu Nasr Mansur stated and proved theorems of plane and spherical geometry that could be applied by astronomers and geographers, including the laws of sines and tangents. Al-Biruni was Abu Nasr's pupil; he produced a vast amount of high-quality work, and was one of the masters in applying these theorems to astronomy and to such problems in mathematical geography as the determination of latitudes and longitudes, the distances between cities, and the direction from one city to another.

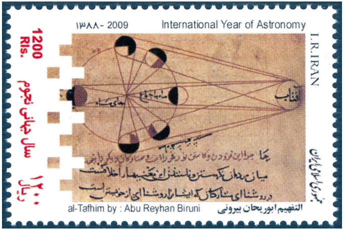


Figure: **Left: Al-Biruni; Right: Al-Biruni's commemorative stamp, Iran.**

- **Al-Farghani** was one of Caliph Al-Mamun's astronomers. He wrote on the astrolabe, explaining the mathematical theory behind the instrument and correcting faulty geometrical constructions of the central disc, that were current then. His most famous book *Kitab fi Harakat Al-Samawiyah wa Jaamai Ilm al-Nujum* on cosmography contains thirty chapters including a description of the inhabited part of the Earth, its size, the distances of the heavenly bodies from the Earth and their sizes, as well as other phenomena.

- **Al-Zarqali (Arzachel) (**1029 – 1087**)** **prepared the Toledan Tables and was also a renowned instrument maker who constructed a more sophisticated astrolabe: a** *safiha*, **accompanied by a treatise explaining how to use it.**
- **Jabir Ibn Aflah** (d. 1145) **was the first to design a portable celestial sphere to measure and explain the movements of celestial objects. Jabir is specially noted for his work on spherical trigonometry. Al-Bitruji's work "***Kitab-al-Hay'ah***" was translated by the Sicilian based Michael Scot, and bore considerable influence thereafter.**

- **Nur ad-Din al-Bitruji (ca. 1150 – 1200 C.E.), known in Europe as *Alpetragius* is the author of *Kitab fi al-haya*, "A Book on Cosmology". He lived in Moorish Spain, in Andalusia, at the end of the Islamic Golden Age. He was probably a disciple of astronomer Ibn Tufayl.**

The problem faced by al-Bitruji was that faced by all Aristotelians who read Ptolemy's Almagest. Aristotle clearly stated that the planets must move with circular motions and implied that the center of these motions must be identical with the center of the Earth; he further desired a mechanism to transfer the motion of the prime mover to the planetary spheres.

Ptolemy, on the other hand, while preserving the principle of circular motions (on eccentrics and epicycles), placed the centers of these motions elsewhere than at the center of the Earth; for **Saturn**, **Jupiter**, **Mars**, **Venus**, and **Mercury** he placed the centers of their uniform motions not at the centers of their respective eccentric deferents but at points called equants.

Eudoxus of Cnidus had already shown that it is theoretically possible to explain the two most obvious anomalies in planetary motion: retrogression and latitude by means of homocentric spheres. Aristotle, by adding more spheres, converted this system to a mechanical model of the universe (though technical details make it impossible for such a model to yield correct predictions of the retrogressions and latitudes of Mars and Venus).

Al-Bitruji followed the suggestion of Ibn Tufayl, as did the latter's other pupil Averroes, and attempted to adjust the Aristotelian solution in such a way that it would correspond to observed reality. The attempt failed owing to the inherent inadequacy of the homocentric system to describe the phenomena.

- **Al-Tusi (1201 – 1274), was the last great astronomer of Islamic Golden Age, and without exaggeration can be given the title of "Hipparchus of Islamic Astronomy".**

Of Persian origin, he studied in his native town Tus, then the nearby town Nishapur, educated in philosophy, medicine and mathematics. Already in Nishapur al-Tusi acquired a reputation as an oustanding scholar, and became a member of Ismaili Court invited by the shi'ite ruler Abd ar-Rahman.

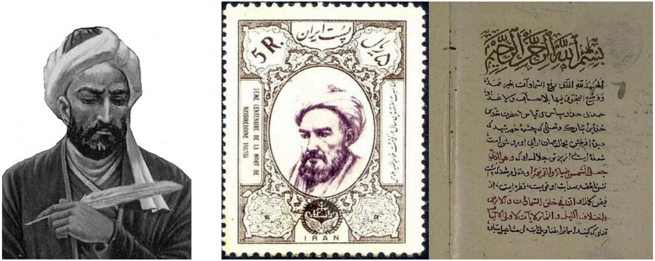
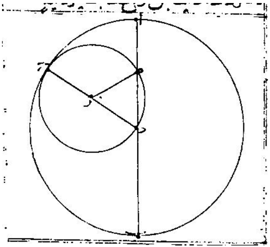


Figure: **Left: the Al-Tusi, a portrait, Right: al-Tusi commemorative stamp, IRAN.**

Al-Tusi stayed and worked in the Alamut castle until it fell to the troops of Dzhengis Khan's grandson Hulagu. Al-Tusi's reputation was so great that Hulagu named him his own advisor, and took him along to Baghdad, which was conquered by the Mongols in 1258.

Hulagu made Maragheh (in northwestern Iran) his capital, and the Observatory of the same name was built there. Under al-Tusi's direction, it has become a renowned center for mathematical and astronomical studies in the Islamic World. Al-Tusi designed many unique astronomical instruments, including a giant *azimuth quadrant* **with radius of** 4 **meters, and an improved astrolabe.**

Al-Tusi is mostly known for his geometric decomposition of linear motion into a sum of two circular motions, called **"the Tusi couple"**, shattering the established Aristotelean view on exclusivity of circular motions in heaven. The same construction was used by **Copernicus** 250 years later, probably re-invented independently.



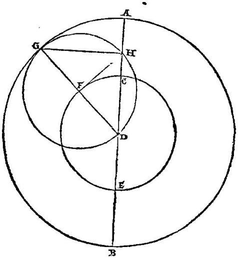


Figure: **Left: the Tusi couple, from his** *Memoir on Astronomy*, **Right: the same construction from Copernicus'** *De Revolutionibus* 250 **years later.**

Al-Tusi published the *Ilkhanic Tables*, relating his atsronomical observations made during 12 years. Using his geometrical findings, he improved substantially the model of lunar motion.

He also determined the almost exact value of precession of the equinoxes, establishing it at $51'$ per century. Al-Tusi's *Commentary on the Almagest* contained excellent trigonometric tables with values of chords calculated to three sexagesimal places for each half degree of argument.

- **Ibn al-Shatir** ($1394 - 1375$) **was a prominent astronomer and mathematician in Damascus, during his life under the rule of the Ummayad dynasty. After completing studies in Cairo and Alexandria, he was appointed the** *muwaqqit* **at the great Ummayad mosque.**

His most important book was an astronomical treatise entitled *"The Final Quest concerning the Rectification of Principles"* **contains new lunar, solar and planetary models, seriously departing from the Ptolemaic scheme, although firmly geocentric in principle.**

Figure: **Left: Ibn al-Shatir, Right: A page from al-Shatir's book, with his lunar model.**

Ibn al-Shatir was not concerned with adhering to the theoretical principles of natural philosophy or Aristotelian cosmology, but rather to produce a model that was consistent with empirical observations.

Ibn al-Shatir's concern for observational accuracy led him to eliminate the epicycles in the Ptolemaic solar model and all the eccentrics, epicycles and equant in the Ptolemaic lunar model.

Shatir's new planetary model consisted of new secondary epicycles instead of equant, which improved on the Ptolemaic model.

The Maragha Observatory

At the time of decline of science in medieval Islam, when Baghdad ceased to be the flourishing cultural center after the Mongols sacked it in 1258 thereby ending the reign of the Abbasides, a new influential institution called the Maragha Observatory, was created in northern Persia under the patronage of Hulagu, Gengis Khan's grandson.

Hulagu appointed Nasir al-Din Tusi (1201-1274), an eminent Persian mathematician and astronomer, to be Observatory's director as well as his personal advisor.

The Maragha was much more than just an astronomical observatory: it became a unique center of scientific research, endowed with a library containing more than 100 000 volumes, the main building surrounded by auxiliary ones, including accomodation quarters for visitors.

Astronomers and mathematicians from all parts of the vast Islamic world participated in the design and construction of astronomical instruments, many of which were genuinely new inventions. Al Tusi appointed Mu'ayyad al-Din al-Urdi (died in 1266) as chief astronomer and instrument designer.

Figure: **One of the rare traces found on the site of ancient Maragha observatory. The huge concrete circle served as foundation of one of huge astronomical instruments.**

An anonymous treatise in Persian named *al-Risala al-Ghazaniyya fi 'l-alat al-ra-adiyya*, Ghazan's (or Ghazanid) treatise on the observational instruments, describes the structure, construction, and functions of twelve "new" observational instruments in the medieval period that appear to have been proposed and invented during the reign of Ghazan Khan, the seventh Ilkhan of the Ilkhanid dynasty of Iran (1295 – 1304).

Such primary historical sources may contain interesting notes and claims concerning Ghazan Khan's astronomical activities and especially the new observatory that he founded in Tabriz. The fact is that at present there are hardly any sound and historically reliable accounts of the activities of the Maragha Observatory from around 1280 onwards.

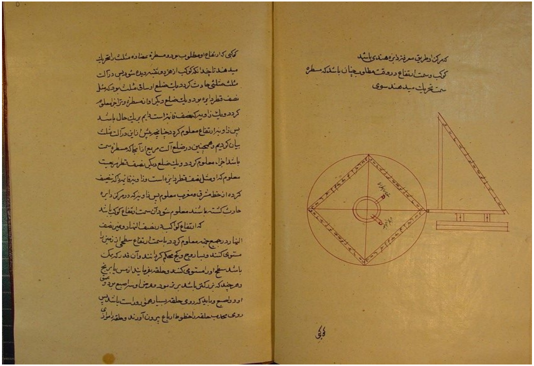


Figure: **A page of anonymous manuscript describing the instruments present in the Maragha observatory.**

The astronomical equipment of Maragha included a mural quadrant with a 40-meter large radius, a solstitial armilla, an azimuth ring, a parallactic ruler (called *triquetrum*, (parallactic ruler) in Latin), and an armillary sphere with a radius of about 160 cm.

The Maragha Observatory represented a new period of scientific activities in the Islamic world in the mid 13th century, A number of sophisticated pre-Copernican, but non-Ptolemaic systems were elaborated there, explaining the planetary motions with greater accuracy than ancient Greek astronomers were able to produce. Several observatories in Persia, Asia Minor and Central Asia were built with Maragha serving as a model.

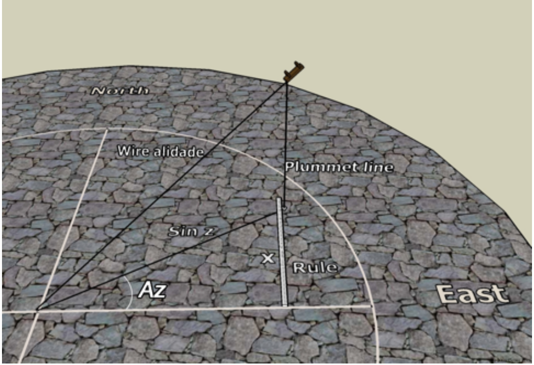


Figure: **One of the simplest instruments at the Maragha observatory (virtual reconstruction). Measuring the azimuth and the altitude simultaneously.**

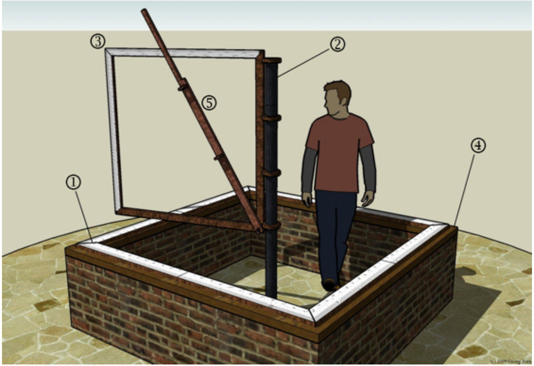


Figure: **The quadrant used in the Maragha observatory (virtual reconstruction). Measuring the the altitude at the meridian. (1) First Square (2) Iron Shaft (3) Second square (4) Wooden Framework (5) Alidade.**

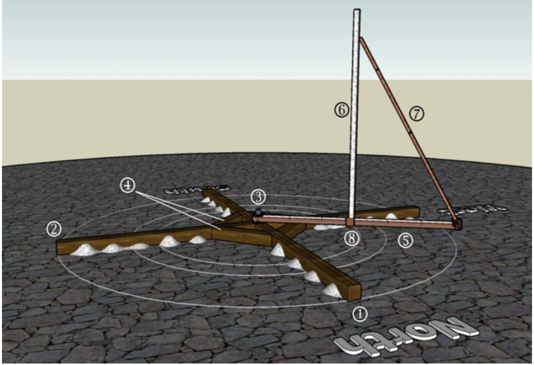


Figure: One of the most sophisticated instruments at the Maragha observatory (virtual reconstruction). (1) Meridian Rule (2) East-West Rule (3) Iron Shaft (4) Supportive Rules (5) Versine Rule (6) Sine Rule (7) Alidade (8) Pipe. To measure the altitude, the Sine Rule was shifted to touch the alidade .

Ulugh Beg

Ulugh Beg was born in northern Iran in 1394, as the oldest son of Shahrukh, one of Tamerlan's sons. As a young prince, he was designed to rule over the vast province of Transoxania (today in Uzbekistan). He assumed his full responsibilities in 1411, although he continued to be subordinate to his father, who ruled the empire from Herat (today in Afghanistan).

After his father's death in 1447, Ulugh Beg succeeded him, but survived only two years as an independent ruler before being overthrown and beheaded by his own son in 1449.

Figure: **Left: A portrait of Ulugh Beg, Right: The Samarkand Madrasa.**

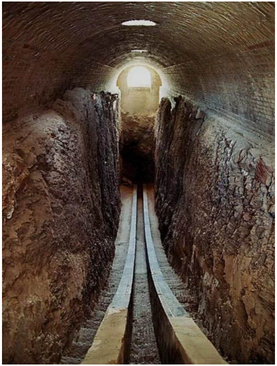


Figure: **Left: A monument dedicated to Ulugh-Beg in Samarkand; Right: The gigantic quadrant remains.**

He is remembered mostly for his extraordinary achievements in astronomy, and the construction of the greatest and the most modern astronomical observatory and *madrasa*, a high school, a library and a reaserch center combined.

The first director of Ulugh Beg's observatory was Qazizadeh Rumi, a native of Anatolia, who was also one of Ulugh Beg teachers. After his master's death he left Samarkand for Istanbul, followed by other astronomers employed in the madrasa.

Ulugh-Beg's observatory was built from 1420 till 1430 on a hill to the north of Samarkand, and was in use until his death in 1447. Its exact location is unknown, because it was almost completely destroyed a few generations after his death.

Ulugh Beg constructed the largest mural sextant (or it might have been rather a quadrant) in the 15^{th} century, which had a radius of 40.4 meters. He took inspiration from the first known mural sextant constructed in Ray, Iran, by Abu-Mahmud al-Khujandi in 994, to measure the obliquity of the ecliptic.

Housed in the main building, it had a finely constructed arc with a staircase on either side to provide access for the astronomers who performed the measurements. It would have been used to measure the angle of elevation of major heavenly bodies, especially at the time of the winter and summer solstices.

Light from the given body, passing through a controlled opening, would have shone on the curved track, which was marked very precisely with degrees and minutes. Fainter objects were observed directly and the elevation angle reported to the sextant.

Travelers and scientists who visited Samarkand and the observatory have described many astronomical instruments which were lost afterwards. There were several armillary spheres of various sizes and huge astrolabes, among others.

Ulugh Beg was certainly the most important observational astronomer of the 15^{th} century. The obliquity of the ecliptic measured by his astronomers was almost perfect, within half a minute discrepancy with what we know at present.

His permanently mounted astronomical instruments were first of their kind in the world, and it was their firm position that ensured greater precision of observation. Among his great achievements was the star catalogue containing more than thousand stars (1018 precisely), with exact coordinates attributed to each of them.

Ulugh-Beg's masterpiece *"Chronology"* was translated into Latin and edited in Europe in 1650, and the publication of his star tables followed in 1675.

The determination of the obliquity of the ecliptic was much better than those of Hipparchus and Ptolemy. His observations of planets remained unsurpassed until Tycho Brahe's more than a century later.

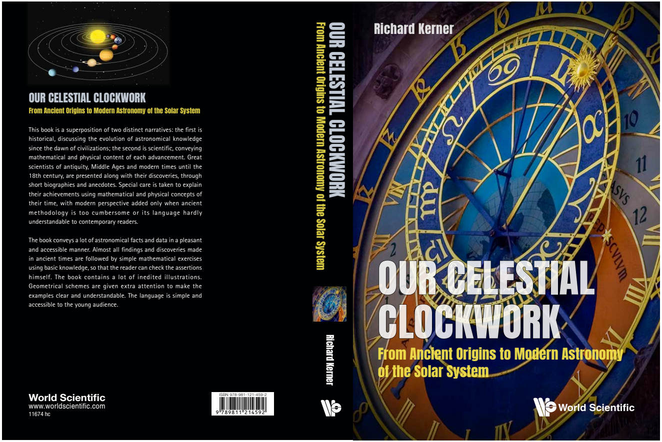


Figure: "Our Celestial Clockwork", World Scientific Ed., 2021.