Chapter 9: The Classical World

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What we identify here as the ‘classical world’ is better defined culturally than geographically. Chronologically, it spans the Greek and Italic societies of the Iron Age (8th to 4th century BC) and the Hellenistic and Roman civilizations, finishing with the end of the Roman empire. In geographical extent it comprises today’s Greece and Italy, together with the Greek colonies and Roman settlements extending through almost all the other Mediterranean countries.

The origins of astronomy and astronomical thought in this area can certainly be traced back to the Bronze Age. This is evident, for instance, from astronomical references in Homer’s and Hesiod’s works, and from the analysis of the archaic Roman (so-called Numan) calendar dating from at least the mid 6th century BC. Influences from the Middle East and Egypt probably occurred in very ancient times, but the true merging of the cultures eventually occurred in the Hellenistic era.

Ancient Greek astronomy: an overview

The extraordinary development of mathematical astronomy in ancient Greece resulted from the efforts of the Classical philosophers to demonstrate the regularity of the motions of the heavenly bodies, which, in Hellenistic times (after 323 BC, following the conquests of Alexander the Great), fused with a Babylonian prepossession with predicting those motions as accurately as possible. The Classical Greek philosophers regarded their astronomy as the ‘scientific’ pursuit of truth, to be distinguished absolutely from the ‘common’ use of astronomy, for example by farmers and administrators in keeping calendars.

Ancient Greek mathematical astronomy *by Efthymios Nicolaidis*

Ancient Greek mathematical astronomy can be defined as the astronomy of epicycles. This system of describing celestial movements, which survived until the 17th century, is an invention of the 3rd century BC. The Greek astronomers of that time who arrived at this explanation of the planetary movements already had the benefit of three centuries of observations and mathematical theories.

Little is known about the mathematical astronomy of the Presocratics. Thales of Miletus (7th–6th century BC) is considered to be the first Greek astronomer. He predicted solar eclipses by studying their periodic recurrences, but with significant errors. Anaximander (6th century BC) identified what we now know as the obliquity of the ecliptic. Pythagoras (6th–5th century BC) established the correct order of the planets within the geocentric system (Earth, Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn), while Aristotle later placed the Sun between the Moon and Mercury. A little more is known about Meton, a contemporary of Socrates, who defined the 19-year solar-lunar cycle by observing from the hill of the Pnyx in about 432 BC.

The observational data (especially those concerning retrograde planetary motions and Sun and Moon anomalies) were important enough in Plato's time for him to pose the problem of 'saving the phenomena' (how to explain the observations while interpreting the celestial bodies' motions in terms of circular orbits with uniform speed). According to Simplicius (6th century AD), it was Eudoxus (4th century BC) who managed this, producing a system composed of concentric spheres. The combination of two spheres rotating with constant velocity can effectively represent the retrograde planetary motions. For the motion of the Sun, Eudoxus employed three spheres (one to account for an observation now known to have been mistaken), and another three for the Moon.

In fact, Eudoxus' system only partially saved the phenomena: in particular it did not take into account the variations in the distance of the heavenly bodies (the variation in the apparent diameter of the Sun or in the brilliance of the planets). This problem was recognised during the 3rd century BC. The heliocentric system proposed by Aristarchus of Samos (4th–3rd century BC) was an adequate response to that problem but, probably for philosophical reasons, was not pursued by the main Greek astronomers. According to a later source, Theon of Smyrna (2nd century AD), a system was proposed during the 3rd century BC similar to that envisaged nineteen centuries later by Tycho Brahe. In this system the two inner planets, Mercury and Venus, orbit the Sun, while the latter orbits the earth, the centre of the universe. This system explained the motions of Mercury and Venus far better than that of Eudoxus, and it is highly probable that it was the origin of the astronomy of epicycles. Indeed, if the orbit of the Sun is replaced by the deferent cycle of Mercury and Venus, one reaches the solution attributed to Apollonius of Perge (born c. 244 BC).

In an effort to respond to the solar anomaly, while respecting the principle of circular uniform motion, 3rd-century Greek astronomers proposed the 'eccentric' solution: the Sun travels on an eccentric circle (centred on a point that does not correspond to the earth's centre). This system presented two difficulties: it was not symmetrical and it was contradictory to Aristotelian physics, which could not accept a motion around an imaginary point. It was probably Apollonius who resolved the problem of symmetry, by demonstrating that an eccentric circle was equivalent to an epicycle travelling around a concentric (deferent) circle. (The 'Aristotelian' problem was never resolved.) This epicycle-plus-deferent solution came to characterise all astronomical systems up until the beginning of the 17th century, when Kepler formulated his first planetary law, that of elliptical orbits.

Between them, Apollonius and Hipparchus (who was observing at Rhodes in c. 128 BC) developed a complete epicycle-plus-deferent astronomical theory. By suitably combining the radii and the motions (clockwise or anticlockwise), they could reproduce the retrograde motion of the planets (but not the fact that the 'loops' produced by this motion were asymmetrical) and represent to a reasonable approximation the motions of the Sun and Moon.

By reversing the 'methodological' approach of astronomy, Hipparchus played a decisive role in the development of Greek astronomy. According to the available information, which comes mainly from Ptolemy, Hipparchus was the first to prioritise the collection of observations in order to determine the empirical laws governing the motions of the celestial bodies. Having done so, he modelled these in terms of circular uniform movements, determining the radii of the deferents and the planetary epicycles accordingly.

Hipparchus also produced a successful theory for the motion of the Sun, determining its eccentricity and thus resolving the principal anomaly, that of the inequality of the length of the seasons. It was probably while working on the theory of the Sun that he made his main discovery, that of the precession of the equinoxes. By comparing historical observations, Hipparchus noticed that, in its annual movement, it took the Sun a little more time to reach the same zodiacal point than it did to reach the celestial equator: the sidereal year was therefore different from the solar year. This phenomenon, actually due to the slow rotation of the axis of the earth, was interpreted by Hipparchus as a very slow shift in the sphere of the stars, from west to east, of about 1 degree per century (the true value is 1° 23′ 30″).

The apex of Greek astronomy was the magisterial work of Claudius Ptolemy. His *Great Mathematical Syntaxis of Astronomy*, also known as the *Almagest*, completed between AD 142 and 146, included all the astronomical phenomena known at that time. This book constituted a unique advance in the history of science: it was to be the main reference for all astronomers until the work of Tycho Brahe and Kepler, almost 1500 years later. Indeed, all Greek, Islamic, or Roman planetary astronomy up until the time of Kepler can be characterized as Ptolemaic.

Ptolemy continued and concluded Hipparchus' work. His method was similar: to collect as many observations as possible; to highlight the anomalies in the planetary motions; to find the empirical laws governing these anomalies; to combine various circular uniform movements in order to 'save the phenomena'; to choose the best of the different solutions, determining the radii and the positions of the circles and the angular speeds; and to compute the planetary tables. If subsequent observations accorded with the computed predictions, then this would confirm the theory.

According to Ptolemy, the main celestial movements were (a) the diurnal motion of the sky from east to west and (b) all other motions, which mainly took place from west to east and close to the ecliptic. Whenever Ptolemy could choose from several possible solutions, he preferred the simplest. Thus he adopted Hipparchus' model for the Sun, but favoured the eccentric rather than the deferent-plus-epicycle. For all the other heavenly bodies he presented his own solution, which in the case of Venus, Mars, Jupiter, and Saturn involved the famous 'equant' (a name that was assigned during the Middle Ages). His idea was that the centre of the epicycle does not move with a uniform motion but instead the circular uniform motion is 'transferred' to a point of another circle (the equant). As a consequence, the phenomena were saved (the planets travel faster at their perigee and more slowly at their apogee), but this represented a serious departure from Aristotelian physics and from the principle of uniform circular motion posed by Ptolemy himself. The system was also extremely complicated: Ptolemy even added circles to move the level of the epicycle from that of the deferent!

Ptolemy presented his cosmological speculations (the mechanisms responsible for all the motions of the heavenly bodies) in his book *Planetary Hypotheses*. This work was the precursor of Islamic astronomical theories on the mechanisms of the celestial spheres (see Chapter 10). Another of Ptolemy's astronomical works, the *Handy Tables*, a revised version of the *Almagest*, remained in use throughout the Middle Ages.

The main Greek commentator on Ptolemy was Theon of Alexandria (4th century AD). His commentary on the *Almagest* and two commentaries on the *Handy Tables* were the last important works of ancient Greek astronomy. In the 6th century, John Philoponus wrote the first known Treatise on the Astrolabe (c. 520–550), based on an unknown source. The first Byzantine astronomer of any note is considered to be Stephanus of Alexandria. He wrote a Commentary on the *Handy Tables* (c. 610–620) inspired by the Small Commentary of Theon, a work designed for students unable to do multiplication and division.

Heritage relating to Greek mathematical astronomy *by Clive Ruggles*

While the development of Greek mathematical astronomy forms a crucial part of the history of modern scientific astronomy, there is very little immovable heritage directly relating to it. No direct evidence remains of the observations carried out by these astronomers: even in the case of Ptolemy, nothing is known about his 'observatory'. On the other hand, some observational places are known, such as Pnyx, the place where Meton observed (see Case Study 9.1).

An exceptional portable item relating to the heritage of Greek mathematical astronomy does exist, however. This is the Antikythera mechanism, discovered in a Roman shipwreck in 1901. It is a bronze mechanical device containing at least 30 gearwheels, probably hand-driven, that calculated and displayed a range of astronomical cycles. These included the phase cycle of the moon, the passage of the sun and moon through the zodiac, the 19-year (235-lunation) Metonic Cycle, the 223-lunation Saros eclipse cycle, and also, probably, a number of planetary cycles. The gears that determined the position of the moon included a remarkable pin-and-slot device that modelled, according to Hipparchus' theory, the irregularities of the moon's motion across the sky due to the ellipticity of its orbit around the earth. Special symbols helped to predict lunar and solar eclipses. There was even a dial that modelled the four-year cycle of the Olympiad. The Antikythera mechanism is thought to have been constructed in the later 2nd century BC. It was originally housed in a wood-framed case, and its two doors appear to have been inscribed with instructions for its use, implying that it was probably intended for personal use by a non-expert traveller. It is unlikely to have been unique.

Fig. 9.0.1. The front of the main surviving fragment of the Antikythera Mechanism. This contains 27 gears: the large gear with four spokes at the front is the Mean Sun Wheel. Photograph © Antikythera Mechanism Research Project (http://www.antikythera-mechanism.gr)

Other forms of astronomy in ancient Greece *by Clive Ruggles*

The use of stars as seasonal indicators had been known to Greek farmers since at least the 8th century BC, as is evident from the writings of Hesiod. A farmer and poet, his *Works and Days* (recorded three centuries later) contains a series of astronomical signs, such as the first pre-dawn appearance (heliacal rise) of various stars, and activities to be triggered by them. It is both an accumulation of folk knowledge and a kind of farmers' almanac. By the 5th century BC, the development of peg-hole star calendars known as *parapegmata* had begun to play a critical role in regulating the various civic lunar calendars operating, until then largely or completely independently, in different cities.

Astronomy also played a crucial role in Greek religion and cult practices. Watching the sky for signs of divine intervention was common in Greece, an example being the 4th-century-BC custom of the Pythais sacred pilgrimage from Athens to Delphi, which only proceeded if the Pythaistai group saw the correct omens (in this case, lightning flashes) during prescribed days and nights beforehand. Many Greek religious festivals were performed in open spaces, and at night. Various historical sources attest to the importance of the sky as an integral part of the cult experience, as well as to its importance in determining the correct timing of various rites (both the date and the time of day/night).

The practice of constructing large stone temples dates from the 7th century BC, and the ancient Greeks clearly derived both inspiration and technological expertise from ancient Egypt (see Chapter 8). It is not surprising, therefore, to find some evidence of apparently deliberate cardinal and solstitial orientation. However, claims that the predominantly easterly orientation of Greek temples has to do almost exclusively with the sunrise have been thoroughly refuted.

Fig. 9.0.2. The Erechtheion, Athens. Photograph © D.S. Levine, Creative Commons Licence.

Greek religious practices were highly localised, with many different deities and cults: prior to the development of temples these were performed in the open air, and it is likely that the placement and design (including the orientation) of any given temple was strongly influenced by the cult practices with which it was associated.

Evidence is gradually accumulating of temple orientations that deliberately reflected the celestial associations of the gods to whom they were dedicated, so that these associations could be displayed and reinforced during the cult performances held there. Example include the oracle of Apollo in Delphi (connected with the constellation Delphinus), the sanctuary of Artemis Orthia in Sparta (connected with the Pleiades), and the Erechtheion on the north side of the Acropolis in Athens (connected with the constellation Draco). In all three cases, there appears to have been a connection between the timing of certain rites and a stellar event visible above the horizon in the direction towards which the relevant temple was oriented. In each case, the connection between the deity and the star or constellation concerned is confirmed by several strands of evidence: mythology, and in particular the foundation myth of the cult concerned; historical accounts of the timing of the festival; the archaeoastronomical evidence of the temple orientations; and associated archaeological artefacts.

Astronomy in the Italic and Roman world *by Giulio Magli*

The Italic world in the Iron Age comprised a variety of peoples and cultures, with an active network of cultural and trading exchange operating within the Mediterranean area. The Romans were simply one of these Italic peoples. Their expansion and conquest began in the early 4th century BC.

By this time a religion had already developed of which several aspects were intimately connected with the sky. On the basis of the archaeological records and the few available written sources (such as the *Tavole Eugubine)* it is reasonable to conclude that, despite the cultural differences, the main features of this religion were common to all the Italic peoples, although Roman historians only directly refer them to the Etruscans. In this religion, a fundamental connection between humans and gods was provided by the *aruspexes,* priests learned in the so-called *Disciplina*, who exerted the art of reading the will of the gods in the flight of the birds and in the liver of sacrificed sheep, for instance at the foundation of new towns. The sacred workplace of these priests was the *auguraculum,* a square (or rectangular) structure usually deprived of walls and disposed in a prominent position with respect to the landscape and the town. The *Disciplina* is known to us essentially through the writings of Roman authors such as Cicero, but the tradition of *auguracula* is very old, since this kind of building is already documented in the 6th century BC. A fundamental duty of the aruspexes was to reaffirm the cosmic order, and consisted of the individuation of a terrestrial image of the heavens (*templum*) in which the gods were 'ordered' and 'oriented' in 8 (or 16) radial directions starting from due north. As a consequence, these buildings tend to be oriented in the cardinal or inter-cardinal directions.

Other vestiges of Italic religious beliefs relating to the sky can be found in the spectacular *acropoli* of several towns, especially within an area centred upon the *Latium Vetus* (essentially today's Lazio, with its regional capital Rome) and extending through the whole western side of central Italy from Umbria to Campania. Here, impressive polygonal stonework was used to construct imposing buildings aligned upon the cardinal or intercardinal points (e.g. Alatri [see Case Study 9.2] and Ferentino) and/or to the summer solstice sunrise or sunset (such as again Alatri and Norba). An interest in the rising and setting of bright stars, especially those of Gemini, is also well attested.

Almost all Etruscan towns were redeveloped by the Romans, but traces of the foundation rituals and the corresponding division of the 'cosmos' can still be seen in Misa (today's Marzabotto), which was destroyed by Celts before the arrival of the Romans, as well as in the spectacular 'funerary towns' (necropoleis) such as Cerveteri, where the tumuli are mostly oriented towards the north-west.

The Romanisation of the Italic peoples was a gradual process, and it is likely that the orientation of Roman towns inherited beliefs and practices from the existing tradition. However, the role of astronomy in imperial Roman monuments and temples is still far from clear. A key example is the problem of the role of astronomy in the Campus Martius project, the huge flat field near a bend of the Tiber that was conceived by Agrippa as a 'sacred place' devoted to the glorification of the emperor Augustus. The Augustus mausoleum towards the north, a sundial using an Egyptian obelisk (found today in the nearby Piazza Montecitorio) as a gnomon in the 'centre', the Ara Pacis towards the east and the Pantheon towards the south were all fundamental elements in the organization of this space. The complex appears to have embodied a deliberate hierophany, in that the shadow of the obelisk pointed towards the entrance of the Ara Pacis at the equinoxes. However, whether this was specifically planned to highlight Augustus's birthday (implying that the huge sundial played a fundamental role in representing Augustus' central place in the new 'cosmic order'), or just reflected a simpler seasonal relationship, or indeed whether it was intentional at all, is much debated and remains unresolved. On the other hand, there is no doubt that the most representative of the Campus Martius monuments, the Pantheon, which we see today as it was reconstructed by Hadrian around AD 120, is a monument that is strongly connected with the annual and daily cycles of the sun (see Case Study 9.3).

Astronomical heritage within Italy

The sites of interest, or at least those that have been sufficiently well studied, are concentrated in Central Italy. In alphabetical order, the principal Italic/early Roman sites are Alatri, Circei, Ferentino, Norba, and Sant'Erasmo di Cesi, and the principal Etruscan sites are Banditaccia Necropolis (Cerveteri) and Misa. Research on astronomy in Imperial Rome is mainly focused on the Pantheon (together with the whole area of Augustus' Campus Martius) and the Domus Aurea. All of these sites are well preserved, enclosed in protected areas or in living towns, and open to the public.

There is also movable heritage with a strong astronomical interest. A good example is the statue called the Farnese Atlas. Residing today in the National Museum in Naples, it is a masterpiece of early Imperial times representing the god Atlas carrying the celestial sphere. This sphere contains the most complete representation of the constellations coming from the Roman period that is known. Attempts have even been made to reconstruct the original data for this sky map back as far as Hipparcus' 'lost map'.

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Case Study 9.1: The Pnyx, Athens, Greece

Michael Wright

Presentation and analysis of the site

Geographical position: Roughly 300m west of the Acropolis, Athens, Greece.

Location: Latitude 37° 58′ 18″ N, longitude 23° 43′ 10″ E. Elevation 97m above mean sea level.

General description: The Pnyx is an elevated area within ancient (Classical) Athens. Until late in the Classical period it was the usual place of assembly for political meetings, and for this reason its principal significance is usually held to be its association with the development of democracy. Its significance to the history of astronomy is due to the erection there by the astronomer Meton of an instrument named the *heliotropion*, whose name suggests that it was connected with observations of the solstice. It is likely that the observations themselves made use of a natural horizon foresight on nearby Mount Lykabettos. These observations helped Meton identify his famous calendrical cycle, based on the fact that 19 solar (tropical) years are very close indeed to (i.e. within about 2 hours of) 235 lunar (synodic) months.

*Inventory of the remains***:** The place where Meton observed is an almost flat area that was enhanced and enlarged artificially, and occasionally remodelled, explicitly for this purpose.

There is no trace of the *heliotropion* and we do not know what form it took. However, identifying when the solstice occurs using only a self-contained instrument would have been very difficult, because the sun's declination changes extremely slowly close to the solstice. It is likely, therefore, that such observations made use of distant markers, effectively magnifying the scale of the 'instrument'. The view from the observing site on the Pnyx does in fact contain a natural marker in the form of Mount Lykabettos, a hill some 3km away rising to an elevation of about 300m. This northern flank of this hill presents an angular profile interrupting the skyline at the point where the midsummer sunrise occurred. One portion of this profile is steeper than the path of the rising Sun, raising the possibility that there was a particular spot from which the very edge of the sun was seen to 'flash' only on, or very close to, the day of the solstice. Ongoing investigations are ongoing to see if such a spot exists within the area now regarded as the Pnyx. In that case it is possible that the *heliotropion* was simply a marker post or column, forming a backsight and marking the observing spot.