# 1

# Astronomy before history

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Most historians of astronomy spend their days reading documents and books in libraries and archives. A few devote themselves to the study of the hardware – astrolabes, telescopes, and so forth – to be found in museums and the older observatories. But long before the invention of writing or the construction of observing instruments, the sky was a cultural resource among peoples throughout the world. Seafarers navigated by the stars; agricultural communities used the stars to help determine when to plant their crops; ideological systems linked the celestial bodies to objects, events and cycles of activity in both the terrestrial and the divine worlds; and we cannot exclude the possibility that some prehistoric and protohistoric peoples possessed a genuinely predictive science of astronomy that might have allowed them, for example, to forecast eclipses.

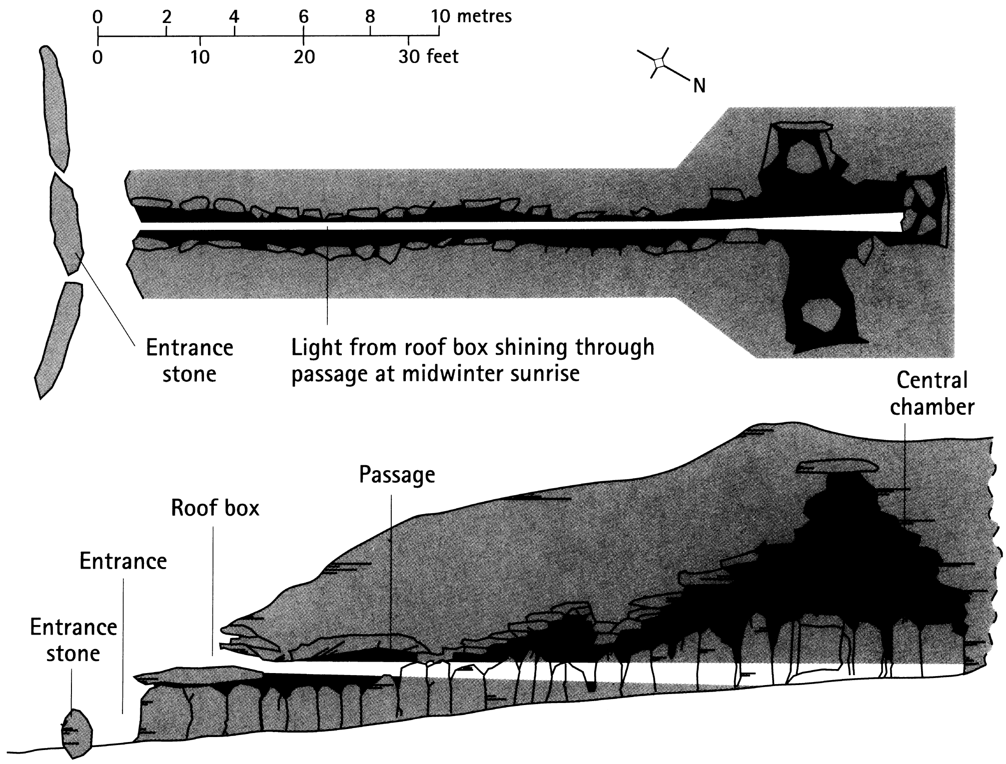
This *History* will concentrate on the emergence of the science of astronomy as we know it today. The historical record shows this development to have taken place in the Near East and, more particularly, in Europe. We therefore begin by asking if anything is known of how prehistoric Europeans viewed the sky, and whether there is any evidence of predictive astronomy. Because it is all too easy for us to fall into the trap of imposing our Western thought-patterns and preconceptions onto the archaeological remains, we also look, by way of comparison, at members of two other groups who viewed or view the sky with minds untouched by Western ideas: the peoples who lived in America before the Spanish conquest, and peoples living today who pursue their traditional ways of life in relative isolation from the rest of mankind.

The celestial phenomena in the two regions most intensively investigated by students of prehistoric and protohistoric astronomy – northwest Europe and the American tropics – are very different. In the tropics the Sun and the other celestial bodies rise and set almost vertically, and for people living there the two times in the year when the Sun passes directly overhead often have special significance. At the higher European latitudes the celestial bodies rise and set along a slanting path and culminate in the south. Around midsummer the days are long, but thereafter the Sun's rising and setting points move steadily further south and the days get shorter and colder: a pattern that threatened disaster, unless the Sun could be persuaded to turn back. Although modern 'Druids' gather at Stonehenge at the midsummer sunrise, the monument's orientation in the opposite direction, towards the midwinter sunset, may well have held powerful symbolism for its builders.

## The sky as a cultural resource in prehistoric Europe

Europeans living today enjoy at best the flimsiest of links with the prehistoric peoples who occupied the region. Some links may nevertheless exist. It has been maintained that in Bronze Age Britain a calendar was in use whereby the year was divided into four by the solstices and equinoxes, and each of these four into two and then into two again, giving in all sixteen 'months' of from twenty-two to twenty-four days each; and it may be that vestiges of an eight-fold division of the year survived into Celtic times and hence into the Middle Ages, where they were represented by the feasts of Martinmas, Candlemas, May Day and Lammas in addition to the four Christianized solstices and equinoxes.

Again, legends associated with the huge passage tomb at Newgrange in County Meath, Ireland, built around 3000 BC, make the omniscient god Dagda (or his son) dwell in the monument. Dagda's cauldron was the vault of the sky, and a connection with much earlier practices may be indicated by the modern discovery that the winter sunrise penetrated the furthest recesses of the tomb. From an entrance on the southeastern side, a 62-foot passage leads to a central chamber 20 feet high, from which three side chambers open out. Some time after construction, when the bones of many bodies had been placed in the tomb, the entrance was blocked by a large stone. Yet although the living were excluded, the light of the midwinter Sun continued to enter via an otherwise-inexplicable 'roof-box', a slit constructed above the entrance. For some two weeks either side of the winter solstice, the Sun, on rising, shone down the length of the entrance passage and illuminated the central chamber – as it still does. That this should happen by chance, and that the 'roof-box' has some other explanation, is so unlikely that there is little doubt that Newgrange was




Newgrange, diagrammed from above (top) and in cross-section (below), showing the path of the Sun's rays at midwinter sunrise. The tumulus covering the tomb is some 250 feet across and over 30 feet high.

deliberately constructed to face sunrise at the winter solstice. But we must note that the sunlight was intended to fall upon the bones of the dead, not be seen by the living, and that even a living occupant of the central chamber would have learned only a very approximate date for the solstice.

Even when no such direct links with the past exist, it may be possible to identify with some confidence examples of prehistoric monuments whose construction reflected a concern for the heavens. In the Alentejo region of Portugal, for example, to the east of Lisbon, there are numerous neolithic tombs. Each tomb has an axis of symmetry and an entrance lying on this axis, and so there is a well-defined direction in which the tomb may be said to 'face'. There are scores of these tombs, scattered over a very wide area, yet the directions in which they face all fall within the narrow range of an octant or so – a uniformity that cannot have occurred by chance.

How could the uniformity have been achieved? The terrain is flat, and there is no mountain (for example) that the builders could have used to determine the alignment of the axis as they laid out a new tomb. Nor did these neolithic peoples possess the compass. It seems, therefore, that the custom they were following must have involved the heavens, for only the heavens would have appeared the same from all places throughout this large region.

The orientation of such a tomb is something we can measure, and it is a matter of fact; the high degree of uniformity among the orientations of these tombs is likewise a matter of fact; and the involvement of the heavens in their layout is at least highly likely. On the other hand, we cannot interrogate the builders and they left us no written records, so we have to speculate on the meaning that the orientation of a tomb might have conveyed to its constructors and their contemporaries. Can the range of orientations shed any light on this?

It so happens that each tomb faced sunrise at some time of the year. The south-easterly limit of the tomb orientations coincided with the south-easterly limit of sunrise, at the winter solstice, but most tombs faced sunrise in the late autumn and early spring. The autumn is indeed a likely time of year for beginning the construction of a tomb, for then there would have been less work to be done in the fields and with the animals but the weather was still favourable. We know from historical records that many churches in England were laid out to face sunrise on the day construction began, and that one can calculate possible calendar dates for the beginning of construction from measurement of the orientation of the axis. It seems we can do the same for the Alentejo tombs, and so gain new insights into the annual rhythm of life in neolithic times.

We meet another example of the likely involvement of astronomy in the orientations of prehistoric monuments, in the *taula* sanctuaries on the Spanish Mediterranean island of Menorca, where a Bronze Age culture was at its height around 1000 BC. Such a sanctuary consisted of a walled precinct in the centre of which was the taula, a flat vertical slab of stone set into the ground, with a horizontal stone on top. The front face of the taula looked out through the entrance, nearly always in a southerly direction. Significantly, taulas were invariably located so that worshippers within had a perfect view of the horizon. Why was this important, when today there is nothing of interest to be seen away to the south?

We can find the probable answer by calculating backwards the effect of the wobble ('precession') of the Earth's axis caused by the pull of the Sun and Moon on the non-spherical Earth, which over the centuries alters the stars to be seen from any given location. We find that in Menorca in

1000 BC the Southern Cross was visible: it rose well to the south, being followed shortly by the bright star Beta Centauri, and then by Alpha Centauri, the second brightest star to be seen from the island. This prominent star grouping has been (and is) of great importance in many cultures, and not only in navigation. If, as seems probable, it was associated with the rituals in the taula sanctuaries, we learn something of the religion of the prehistoric people of Menorca; and it may well be that they had links with Egypt, where constellations were routinely identified with deities.

The involvement of the heavens in prehistoric ritual in Europe therefore seems well established. But was there also a quasi-scientific astronomy of precise observation, perhaps even leading to the prediction of astronomical events? In Britain the suggestion that megalithic monuments, now known to have been built in the third and early second millennia BC, incorporated alignments chosen for astronomical reasons goes back to the eighteenth century, while at the beginning of the twentieth century an astronomer of the calibre of Sir Norman Lockyer could write: 'For my own part I consider that the view that our ancient monuments were built to observe and to mark the rising and setting places of the heavenly bodies is now fully established.'

The subject came to popular attention in the 1960s with the publication of a book on Stonehenge in which the author – himself an astronomer – claimed that in addition to the well-known phenomenon of the midsummer Sun rising over the Heel Stone, a great many other astronomical alignments were built into the configuration of the monument. He showed that, given regular observations extending over many years, it was technically possible to use elements of Stonehenge to keep track of the solar calendar, to study the more complex cycles of the Moon, and even to predict eclipses. And this, the author insisted, had indeed been one of its purposes.

If Stonehenge had been one among many similar monuments, these other monuments could have been examined to see if they displayed the same features. Unfortunately Stonehenge is without parallel anywhere in the world – it was an object of wonder even in Antiquity. Its explanation is further complicated by the fact that it was constructed, modified, and reconstructed, over a period of some two millennia. Moreover, the stones we see today may not be exactly in the position they occupied when first erected; and when erected, they may not have been exactly in the position the builders intended. As we cannot interrogate the builders, and as they left no written records of their intentions, we are forced to fall back on probability: we must ask ourselves how likely it is that an arrangement of the stones, that to our eyes is of astronomical significance, has occurred by design rather than by chance. That is, the study of Stonehenge involves us in statistics – and for statistical investigation a unique monument is unsatisfactory.

The least contentious statement that can be made about Stonehenge is that the general orientation of the axis of the monument at various stages in its development was towards sunrise at the summer solstice in one direction, and towards sunset at the winter solstice in the other, and that this may well have been deliberate. A precision equivalent to, at best, two or three solar diameters is involved: the popular notion that the Heel Stone defined the direction of solstitial sunrise more precisely is quite unsupportable, because the supposed observing position (the centre of the monument) cannot be defined precisely enough, while the Heel Stone is too near to provide an accurate foresight and the horizon behind it is featureless.

Most students of Stonehenge have identified certain features at the site and tried to invent a theory to 'explain' them. Even when this is done impartially there are grave dangers in imposing astronomical (and geometrical) frameworks onto what is a very limited sample of the features at this much-altered site – those that today are superficially obvious, those that happen to have been excavated (while large areas of the site are still unexplored), and so on. For example, the Heel Stone is now known to have had a companion, long since destroyed, whose existence was discovered during rescue operations in 1979.

Some of the most famous astronomical theories regarding Stonehenge depend upon statistical arguments that the number of astronomical alignments between pairs of points selected are of possible significance. These arguments fall down on many different grounds: lack of prior justification for the points chosen, and archaeological doubts about some of those that were chosen; numerical flaws in the probability calculation; and, perhaps most importantly, the non-independence of data (for example, except in hilly regions, a line that roughly points towards midsummer sunrise in one direction will automatically point towards midwinter sunset in the other). When these errors are taken into account, no evidence whatsoever remains for preferred astronomical orientations of this sort.

One writer has pointed out that the 56 Aubrey Holes (named after their seventeenth-century discoverer, John

Aubrey) could have been used as an eclipse predictor, if markers were moved around from hole to hole. The problem here is that while this undoubtedly represents a way in which a modern astronomer could use a structure at Stonehenge to predict eclipses, there is ample archaeological evidence to suggest that the prehistoric users of Stonehenge did no such thing. There are in fact dozens of circular enclosures and so-called henge monuments (monuments that resemble the first phases of Stonehenge, before it acquired its distinctive structures of Bluestones and Sarsens) where rings of postholes or ritual pits inside a ditch have been found, and in these the holes vary in number from under twenty to over 100.

On the other hand, in the region around Stonehenge there appears to have been a shift from lunar to solar symbolism as development progressed from the Neolithic into the Bronze Age. This is reflected in the directions in which the burial cairns from each period are aligned, and also in the apparent shift in the axis of Stonehenge from lunar alignment in the earlier phases to solar alignment in the later. A group of post-holes situated in the northeastern 'entrance' – a gap in the ditch between the Aubrey circle and the Heel Stone – may represent evidence that the original construction of the axis was oriented on an extreme rising position of the Moon, though this interpretation remains controversial.

In short, there is good reason to think that the construction of Stonehenge and related monuments embodied astronomical symbolism, but we have as yet no convincing evidence that what we might think of as scientific astronomy was practised there.

While Stonehenge was attracting popular attention (and controversy) in the 1960s, Alexander Thom (1894–1985), a retired Oxford professor of engineering, was quietly continuing the mammoth task he had set himself, of surveying to professional standards the many hundreds of stone rings and other megalithic monuments that survive in Britain, Ireland and northern France. Thom was a collector of facts, and most collectors of facts shy away from speculation. Not so Thom. He maintained, not only that these megalithic monuments were constructed according to complex geometrical designs and laid out using carefully-determined units of measurement (one of which he termed 'the megalithic yard'), but that the prehistoric builders had anticipated an idea later proposed by Galileo and had precisely located their monuments in order to facilitate astronomical observations of great accuracy.

In 1632, in his *Dialogue on the Two Great World Systems*, Galileo has one of his characters relate how he found himself making an accurate determination of the summer solstice, with an instrument provided by Nature free of charge:

> From a country home of mine near Florence I plainly observed the Sun's arrival at, and departure from, the summer solstice, while one evening at the time of its setting it vanished behind the top of a rock on the mountains of Pietrapana, about 60 miles away, leaving uncovered a small streak of filament of itself towards the north, whose breadth was not the hundredth part of its diameter. And the following evening, at the similar setting, it showed another such part of it, but noticeably smaller, a necessary argument that it had begun to recede from the tropic.

Thom believed that the constructors of the megalithic monuments he was studying had anticipated Galileo by three millennia or more. Some standing stones, he maintained, were astronomical backsights; their locations had been carefully selected so that, for example, the Sun at a solstice, or the Moon at one of its extremes, might be glimpsed setting behind a distant mountain, very much as Galileo describes. Priests with knowledge of the dates of these significant solar and lunar events, Thom suggested, might even have been able to predict eclipses and thus reinforce their privileged status in the community.

Not surprisingly, Thom became the centre of controversy: such prehistoric sophistication, especially among the inhabitants of regions remote from the supposed cradle of civilization in the eastern Mediterranean, appeared incredible to many archaeologists. To assess the plausibility of Thom's claims it was necessary to decide whether Thom had focused attention on a particular feature of the skyline as seen from the given site because he already knew it lay in a direction of astronomical interest. Objectors argued that if the skyline contained numerous mountain peaks, one of which was in the direction of (say) the winter solstice, then the alignment of this particular peak with the solstice may well have been accidental.

Thom's sites have since been re-examined under procedures carefully designed to ensure objectivity. The controversy continues, but the re-examination has greatly reduced the plausibility of his claims to have demonstrated the existence in prehistoric Britain of a science of predictive astronomy.

How does the debate now stand? A particularly interesting example of Thom's sites is Ballochroy in the Kintyre peninsula in Scotland. Here there is a row of three standing stones, two of which are thin slabs oriented across the alignment of the row. A few yards away is a rectangular burial cist; this is aligned with the stones, and its longer sides are oriented in the same direction.

Around the solstices, the Sun's rising and setting positions are changing almost imperceptibly: thus in the week before or the week after a solstice, the Sun's rising and setting positions at this latitude alter by only one-third of its diameter. This makes determination of the actual solstices difficult, and the solstices are basic to a knowledge of the annual cycle of the Sun. Thom, however, believed that at Ballochroy the prehistoric erectors of the stones had overcome this problem by the location they had contrived for the stones – one from which the Sun was to be seen at the winter solstice setting behind Cara Island which is on the horizon 7 miles away, and at the summer behind Corra Bheinn, a mountain more than 19 miles distant. Even though the Sun is then altering its setting position from one night to the next by only a few arc minutes, this change becomes apparent to the observer within a very few days of the actual solstice, because of the sensitivity of the vast measuring instrument that Nature has provided. According to Thom, the direction of midwinter sunset was indicated by the alignment of the stones, and that of midsummer sunset by the flat faces of the central stone.

One problem with testing such a theory arises from our ignorance of when, to within several centuries, the stones were erected. Although the directions of solstitial sunrise and sunset at a given location alter only slightly from one millennium to the next, this is enough to make an important difference when we are observing with instruments tens of miles in length. At a site with distant mountains in roughly the right direction, it may well be possible to find a date for the site when it would have had the exceptional characteristics that Thom's theory requires. As to the 'indications' supposedly built into the stones themselves, these are of the kind that tend to be identified by the investigator after he has already convinced himself of the astronomical purpose of the site. It is then that he is likely (in this example) to focus attention on the middle slab (which points roughly in the 'right' direction) rather than on the northernmost (which does not), and to specify the 'intended' alignment of the stones themselves, to a precision quite unjustified for a despoiled (and originally longer) row of three closely-placed, large and irregular stones, two of which are slabs set across the axis. At Ballochroy there is the additional difficulty that the cist would have been covered by a cairn in prehistoric times, and this cairn would have obscured the view towards the midwinter sunset; indeed, the cairn is still to be seen in a seventeenth-century sketch of the site. All in all, then, while there is no doubt that what we may term Thom's Galilean method was feasible in prehistoric Europe (as elsewhere), the claims of this Scottish engineer to have discovered a prehistoric science of predictive astronomy at present merit the peculiarly Scottish verdict of *not proven*.

In conclusion we note that we must avoid a false dichotomy between ritual or folk practice on the one hand and high-level predictive astronomy on the other. Hesiod's description of an early Greek farmer's use of a constellation's heliacal rising (its reappearance at dawn after some weeks of absence lost in the glare of the Sun) to tell the season favourable to planting, is an example of prediction at a low level, and similar predictions are used by farmers in parts of Europe to this day. And since Galileian-type precision observations could have been recorded adequately by backsights consisting simply of poles inserted in the ground, then if stone monuments were indeed erected as backsights, they must also have served another and presumably ritualistic purpose.

## Early astronomy in the Americas

The student of prehistoric Europe has virtually no written or oral evidence to guide him, and the monuments he studies are usually modest structures. The complex societies that developed in the American tropics have left a much richer legacy. Many of the buildings that have survived are of great sophistication; investigators have the opportunity to question living descendants; and we possess written records of various kinds – stone inscriptions and other meaningful carvings, documents such as the handful of Mayan bark books known as codices, and detailed accounts from the first Spaniards to come into contact with these cultures.

A strange aspect of Inca society that flourished in Peru at the time of the conquest (in the middle decades of the sixteenth century) has been revealed largely through the study of accounts written by Spanish settlers shortly thereafter. This is the system of *ceques*, conceptual straight lines radiating out from the Coricancha or Temple of the Sun, the central religious monument in the Inca capital of Cuzco. There were 41 ceque lines, along which sacred monuments