The discovery of Minoan Astronomy and its debt to Robin Hägg

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Abstract

In 1995, we submitted a proposal to the Swedish Council for Research in the Humanities and Social Sciences, now the Swedish Research Council, for a project the aim of which was to discover as much as possible about Minoan astronomy and its later influence in the Mycenaean and Greek cultures. Such a project had not existed before for primarily two reasons: the lack of Minoan written documents other than a few temporary agricultural records on raw clay tablets accidently burnt to terracotta before being transcribed to the more permanent material used by the Minoans, and the absence until fairly recently of methods to recognize and evaluate evidence of astronomical observations from ancient artefacts. Using these archaeoastronomical methods we found that each of the 19 Minoan buildings in our project had an orientation to sunrise or sunset on days important for maintaining a correct calendar. The Minoans not only discovered simple rules for how to regulate the lunar cycle to keep it synchronized with the solar year, but they also constructed a solar calendar that had a leap year every four years. The expert to judge the applications in our field for the Council was Robin Hägg and he recommended our project. It is thus to him that we owe our discoveries of a third astronomy in the Bronze Age of the eastern Mediterranean, an astronomy as old as that of the Babylonians and the Egyptians.

Introduction

The goal of our project was to show that the Minoans had become so well acquainted with the motions of the celestial bodies that they could construct calendars, use the horizon positions of stars for farmers´ almanacs and the relative positions of the stars to each other to navigate at night. To do this we had to show how the Minoans had achieved this knowledge and how it was used. The absence of Minoan written records of astronomical observations required investigations of other evidence of sky watching, such as the alignments of buildings, columns or other fast structures to suitable positions of celestial objects, for example sunrise at the summer solstice or the heliacal risings and settings of bright stars, in order to mark their yearly appearance. The now fully developed interdisciplinary field of archaeoastronomy is the method of choice for investigations of such phenomena (Blomberg and Henriksson 2001b). We needed to investigate a representative sample of Minoan monuments of different kinds, but we wanted to include all of the peak sanctuaries with remaining walls, as they would have been ideal for studying the stars in the night sky.

Fortunately, it was within the financial scope of our project to make an adequate selection of buildings. We chose 24 buildings at 15 sites: six peak sanctuaries – Juktas, Modi (2), Petsophas, Philioremos, Pyrgos, Traostalos;

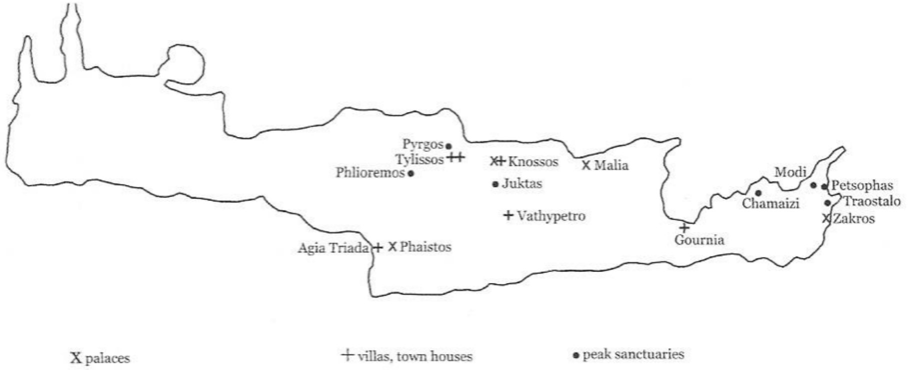


Figure 1. The location of the 15 sites in the project, where 24 buildings were measured.

the four large palaces – Knossos, Malia, Phaistos, Zakros; five villas - Agia Triada, the Southeast House at Knossos, Tylissos A and C, Vathypetro; three attached small houses with cult equipment at Gournia – house Aa, the portico of the palace and the LMIII shrine; the oblique building at Malia; the tripartite shrine at Vathypetro; building H and the large megaron at Agia Triada; and the unique oval house at Chamaizi, which may have been a peak sanctuary (Fig. 1).

We had intended to investigate the peak sanctuary on Vrysinas but could not identify the Bronze Age walls mentioned in Davaras' publication (Davaras 1974). On the basis of their orientations, as well as on their archeological features, it was recognized that the LMIII shrine at Gournia, the oblique building at Malia, the tripartite shrine at Vathypetro, building H and the large megaron at Agia Triada, were built for Mycenaeans. As they are from a later period, they did not contribute to the development of Minoan astronomy and are therefore excluded here.

As we considered it probable that the peak sanctuaries had been used as centers for observing the motions of the celestial bodies, it seemed likely that the clay figurines found near them had a relationship to this activity. Peter Blomberg has shown in a number of articles that the figurines do not have features to justify their interpretation as votives in healing or fertility cults (see articles by Peter Blomberg on our website http://minoanastronomy.mikrob.com (2001a). However, they do have similarities to the descriptions of the constellations used by Aratos to give their relative positions to each other during the rotation of the night sky (Kidd 1997), extremely important for navigation, an important aid for Minoan economy. Of the more than

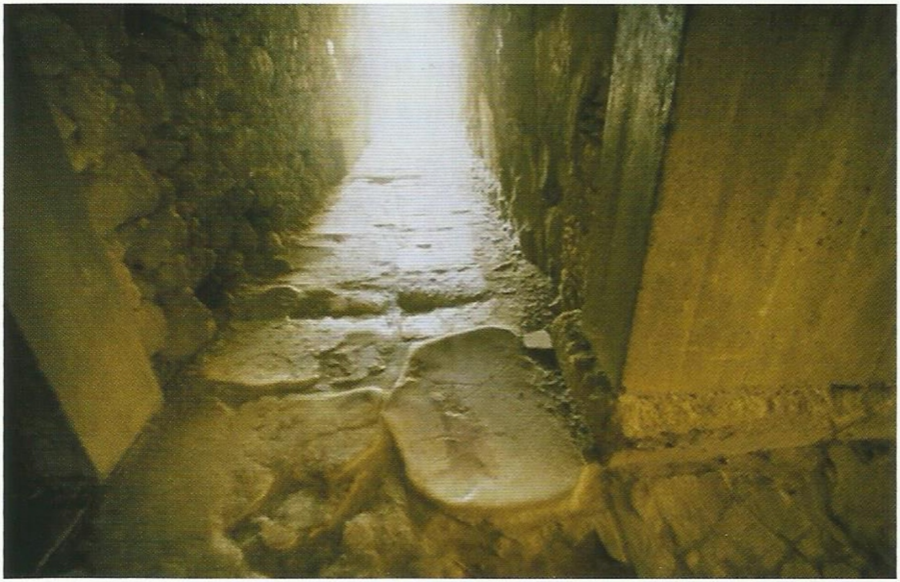


Figure 2. The alabaster bowl in the Central Palace Sanctuary at Knossos.

2 400 small figurines found on Petsophas and Traostalos more than 90% are consistent with such use (P. Blomberg 2000). The figurines could have been used as pedagogical tools in the construction of a model of the horizon showing the shape of a constellation as it rose in the east and that of its opposite as it set in the west. This would explain such bizarre shapes as half a man or the arm of a human, both of which occur in Aratos's poem. There is a tradition that Greek astronomy was indebted to the observations and ideas passed on by much earlier cultures and Aratos uses some positions of stars and constellations that were valid for the latitude of Crete in the Bronze Age instead of the latitude for his own time and place. It is possible that he was influenced by this tradition in his poem. Our indebtedness to Greek astronomy lies farther back in time than the interval separating Aratos from the Minoans. Eighty percent of our constellations owe their origin to the Greeks.

A brief synopsis of the results of the project is given below. A detailed report of the investigation of each site can be assessed on our website.

Methods

Standard archaeoastronomical methods were used in our investigations, as these are uniquely designed to recognize and evaluate the astronomical orientations of buildings

Site	Orientation	Foresight
Agia Triada, villa	sunset equinoxes	
Chamaizi	sunrise winter solstice Arcturus' heliacal setting	artificial artificial
Gournia, MM IA house LM I house	sunrise one month before and after equinoxes sunrise one month before and after equinoxes	
Juktas, peak sanctuary	sunrise equinoxes	natural
Knossos, palace Southeast house	sunrise equinoxes sunrise equinoxes	artificial artificial
Malia, palace	sunrise one month before and after equinoxes	natural
Modi, peak sanctuary (2)	sunrise two months before and after equinoxes	
Petsophas, peak sanctuary	sunrise summer solstice, sunset equinox Arcturus' heliacal rising Arcturus' heliacal setting	natural natural
Phaistos, palace	sunrise equinoxes sunset equinoxes Canopus' heliacal rising and setting	 natural natural
Philioremos, peak sanctuary	sunrise summer solstice	natural
Pyrgos, peak sanctuary	sunrise summer solstice Arcturus' heliacal setting	 natural
Traostalos, peak sanctuary	Arcturus' heliacal rising Arcturus' heliacal setting	 natural
Tylissos, villa A Tylissos, villa C	sunrise summer solstice sunrise one month before and after solstices sunrise one month before and after equinoxes	artificial artificial artificial
Vathypetro, villa	sunrise equinoxes sunrise one month before and after equinoxes sunrise winter solstice	artificial artificial artificial
Zakros, palace	moon southern major standstill	natural

Table 1. Orientations of Minoan buildings.

and artifacts. Archaeoastronomy is an interdisciplinary science and both authors of this paper are active members of SEAC, the European Society for Astronomy in Culture. Their aim is to promote the study of astronomical practice in its cultural context as a topic of considerable importance within the general study of human societies and their relationship to their environments; UNESCO's World Heritage List includes important archaeoastronomical sites.

To summarize our methods, an exact, radio-controlled clock and a so-called total station were used to measure the orientations of walls and other man-made structures to positions of the sun, the moon and the stars. The measurements were evaluated by appropriate statistical calculations, using the computer programs developed by Göran Henriksson. His computer program was completed in 1985 and has been successfully tested against all well-defined ancient observations back to 3653 BC. The motion of the sun and the moon is based on the theory by Carl Schoch (1930) with all the formulae expressed in Universal Time (UT) used by the ancient observers, and with Henriksson's improvements concerning modern astrophysical parameters. In this method the slowing down of Earth's rotation can be calibrated by direct comparison with ancient observations. The theories used in computer programs available on internet have their formulae expressed in the so called Terrestrial Time (TT). UT (Universal Time) is directly proportional to the earth's decreasing rotation rate and must be known for calculations of ancient celestial events. The theory by Schoch was originally calibrated by solar eclipses back to 600 BCE and Henriksson's latest calibration includes 33 total solar eclipses back to 3653 BCE. The timing error around 3000 BCE is less than 2 minutes. In fact, Henriksson's computer program is the only existing one that can test "the precession of the geodesic" in Einstein´s General Theory of Relativity (Henriksson 2009).

We compared our results with the positions of the celestial bodies as they were in the Bronze Age. The visibility of bright stars close to the horizon at dawn and twilight was calculated using a computer program by Henriksson with parameters from Bemporad (1904), Siedentopf (1940), Ljunghall (1949), and Schmidt (1865). It is important to use Schmidt's visibility calibrations for Athens from ca. 1850 CE, as his observations were made before modern air pollution.

To validate our results, the walls were measured on two occasions, with a one year interval. The structure on Petsophas was measured three times, as this was the first wall examined in our study. We then calculated the margin of error with the least-square method. We also documented by exactly timed video recordings some of the important events, such as sunrise at the autumn equinox in the Central Palace Sanctuary at Knossos and at the summer solstice behind Kali Limni, the highest peak on Karpathos, opposite Petsophas.

These methods can reveal the celestial objects of observation, and since

Site	Months
Petsophas, Phaistos, Knossos (2), Juktas, Vathypetro, Agia Triada	first (autumn equinox)
Malia, Vathypetro	second
Modi	third
Chamaizi, Vathypetro	fourth (winter solstice)
Modi	fifth
Malia, Vathypetro	sixth
Petsophas, Phaistos, Knossos (2), Juktas, Vathypetro, Agia Triada	seventh (spring equinox)
Gournia (2), Tylissos Villas A and C	eighth
Tylissos Villa A	ninth
Philioremos, Petsophas, Pyrgos, Tylissos Villa A	tenth (summer solstice)
Tylissos Villa A	eleventh
Gournia (2), Tylissos Villas A and C	twelfth

Table 2. Orientations of Minoan buildings to the beginning of a solar month.

the positions of the objects change over time due to precession, except in the case of the sun at the equinoxes, which occurs at either of the two points on the celestial equator where it intersects the ecliptic, the study of orientations can also reveal the history of ancient sky watching. The change in the orientation of the Central Court at Phaistos, when the new palace was built (see below) was probably a result of the sensational new appearance of the bright star Canopus in the south, due to precession.

The results from our measurements are placed as far as possible in their larger cultural context and interpreted in connection with available sources of other kinds. We use the chronology argued for by Manning (1999).The variation in the conflicting chronologies is about 100 years and our results do not help to confirm their correctness, as the change in the positions of the celestial bodies is due to precession, the slow rotation of the earth's axis that completes one revolution in about 26,000 years. The monuments we have measured have walls that are not so well-preserved to give orientations close enough to be of help in this respect. More discoveries of phenomena like the reorientation of the Central Court at Phaistos could be of help.

The nature of Minoan astronomy

Beginning with our investigations of the peak sanctuaries, we recognized a number of features as characteristic for Minoan astronomy:

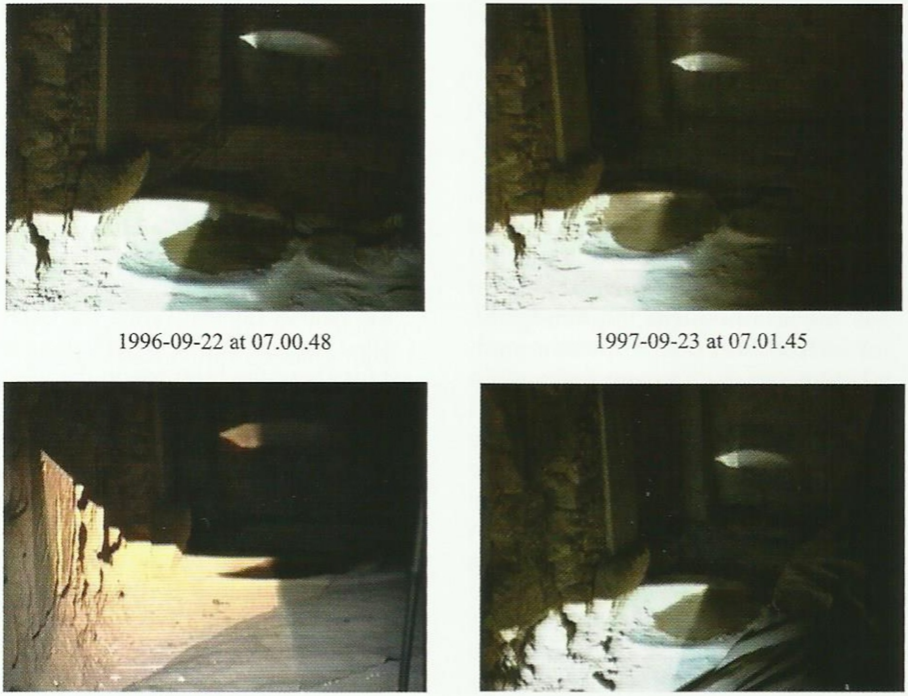
- Eighteen of the 19 Minoan buildings had a wall or a point in a room considered to be being significance aligned to a position of the sun or moon that is important in a solar or lunar calendar. Examples of relevant points are the approximate middle of the alabaster bowl in the Central Palace Sanctuary at Knossos and the middle of the throne in columnar hall at Vathypetro at approximately eye level of someone sitting on the throne. Our measurements of the direction of walls were adjusted by calculating the margin of error with the least-square method. Seven buildings have alignments to sunrise or sunset at the equinoxes, three have alignments to sunrise at the summer solstice, one to sunrise at the winter solstice, one to moonrise at the southern major standstill, five to the first day of the eight months of the solar year not signified by sunrise and sunset at the equinoxes and the solstices. Four buildings have alignments to more than one major calendar horizon position and five have, in addition, alignments to the heliacal rising or setting of Arcturus or Canopus. The 19th building, Traostalos, has alignments to the heliacal rising and setting of Arcturus (Tables 1 and 2). On the dates relatively to sunrise at the equinoxes and the solstices the sun rose in the same direction and therefore the beginning of the months could be determined. We have argued that the day of the autumn equinox was especially important for the Minoans as it was the first day in the solar year. The New Year started when the new crescent moon appeared in the evening sky after the autumn equinox (see below point 4). The beginning of the month before the autumn equinox was important for the regulation of the lunar calendar because from the day in this month when the new crescent moon was sighted, the Minoans could decide if it was necessary to insert a leap lunar month.
- The buildings were closely aligned to the positions of the celestial bodies intentionally and not to a geographical feature. For example, at Petsophas the sun rose at the summer solstice directly behind the highest peak on Karpathos in the Early Bronze Age, in the years around 3600 BCE, but when the present building was built in the Middle Bronze Age (ca. 2000 BCE), the orientation of the axis of symmetry of the room was to sunrise at the summer solstice at that time, somewhat south of the peak.
- Orientations were usually marked by a natural or an artificial foresight – to use the archaeoastronomical term, a prominent natural feature such as a mountain peak or a man-made structure such as a column (Table 1 above). This indicates that the alignment of buildings to the celestial bodies was of vital importance in Minoan cosmology, as it

served to established relationships between their world and the celestial sphere.

- The 11-day difference between the 12-month lunar year and the yearly cycle of the sun was known and used (orientations at three sites: *Petsophas, Knossos and Juktas*). For example, if the new moon occurred in the 11 days following the heliacal rising of Arcturus at Petsophas, which occurred one moon month before the autumn equinox, then a moon month should have been added that year in order to keep the cycles of the sun and the moon commensurate within the larger cycles of eight or nineteen years (Henriksson and Blomberg 1996: 113). This 11-day difference was well marked in the calendar regulator found at Knossos (see below). The circumstances of the orientation to the autumn equinox at Knossos, Juktas and Petsophas make it probable that it determined the beginning of the Minoan New Year.

The orientations to important calendar points that existed for all Minoan buildings that we investigated reveal that the construction of calendars was a primary goal of Minoan astronomy. This presupposes a longstanding tradition of sky watching and recording with respect to the sun, the moon and the bright stars that must have begun very early. By the end of the third millennium, the Minoan astronomers had acquired a deep understanding of the motions of the sun and the moon and were able to construct both a lunar and a solar calendar that could be kept accurate through time by simple methods. There are the archaeological remnants of a calendar regulator that had once functioned — and still functions — in the most sacred part of the old palace at Knossos. It consisted of an alabaster bowl embedded in the floor in the darkest part of the original Central Palace Sanctuary (Fig. 2), which is now known as the Corridor of the House Tablets. When the bowl is filled with a liquid, a reflection is cast for about ten minutes on the west wall of the Sanctuary on the equinoxes when the sun first strikes the bowl at sunrise on its journey towards the solar standstills. The reflection becomes lenticular in shape as the sun rises higher and it reaches its largest size after about four to five minutes. There is a somewhat worn lenticular depression of similar size in the wall exactly at the site of the reflection. It was probably incised to indicate the place for the reflection after future refurbishing of the stucco, which was the usual covering of Minoan walls. The stone is in its original position but is now much worn, as the Sanctuary in which it was placed was altered by the Mycenaeans when they took over the palace ca 1450 BCE, and a corridor was built in the area of the stone leading through a newly-cut door into the storage magazines to the west (Hallager 1987).

The reflection at sunrise on the morning of the equinoxes is larger when the sun is closer to the true equinox, the point or node where the ecliptic crosses the celestial equator. The sun rises within an interval around this point in the 24-hour equinoctial day.



1996-09-22 at 07.00.48

1997-09-23 at 07.01.45

1998-09-23 at 07.01.13

1999-09-23 at 07.01.07

Figure 3. The reflection has a different size on the morning of the equinoxes due to the distance of the rising sun from the node of the ecliptic and the celestial equator in that year.

On that day the reflection appears in the lenticular depression after a cycle of 365 days for three consecutive years, but in the fourth year the reflection will not appear there after 365 days but will appear on the day after, on the 366th day. The Minoans must have realized that an extra day should be added every fourth year at this time to maintain a correct yearly calendar. We have documented this with photos on the actual equinoctial day of four consecutive years (Fig. 3).

The sun casts a reflection from the bowl for 11 days after the autumn equinox and before the spring equinox, due to the width of the door. If the new crescent moon, for example, appeared in one of these 11-day intervals, then a moon month should be added to the lunar calendar. This is a calendar regulator for both a lunar and a solar calendar and was located in what was probably the most sacred room in Minoan Crete, as indicated by its age, the pillar crypts inscribed with

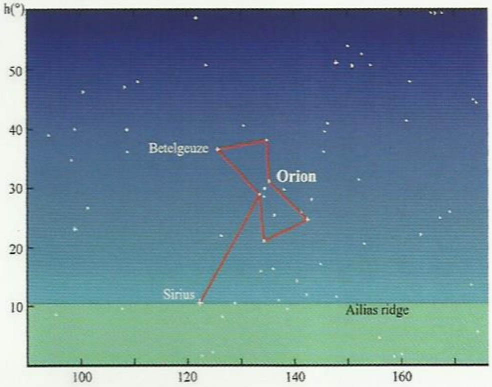


Figure 4. The hypothesized Minoan constellation of the double axe.

multiple double axes and the temple treasures in the vestibule (Panagiotaki 1999). There are the natural foresight of the Ailias Ridge and the artificial foresights of the north and south part of the door frame.

Our constellation of Orion dominated the eastern sky opposite the Sanctuary on the evening of the autumn equinox in the Middle Bronze Age, and it is probable that its brightest stars together with the brightest of all stars, Sirius, formed the constellation of the double axe, the most important Minoan symbol (Fig. 4, calculated for 21 Sept 2000 BCE, at 23:38 local mean solar time). When the sun at sunrise at the equinoxes first illuminated the Sanctuary it cast a shadow on the southern wall that just touched the engraving of a double axe on the wall, which has the same degree of inclination as the double axe in the sky (Fig. 5).

A richly furnished pillar crypt on the lower level of the Southeast house at Knossos shows some similarities to the arrangement at the Palace. There are relationships to the sun at the equinoxes that are the same as those in the Central Palace Sanctuary, but the crypt is not so well preserved. The upper limb of the sun at sunrise appears at the intersection of the top of the Ailias ridge and the northern door frames of the two doors of the pillar crypt and illuminates a hole in the southwest corner and the southern corner of the niche in the center of the crypt. We think that the hole was originally the site of a similar kind of marker as the bowl in the Central Palace Sanctuary for recording the sun's rays on equinox mornings, but that it may have been destroyed by the later Mycenaean inhabitants of the building. The position of the house on the slope in relation to the Ailias ridge op-

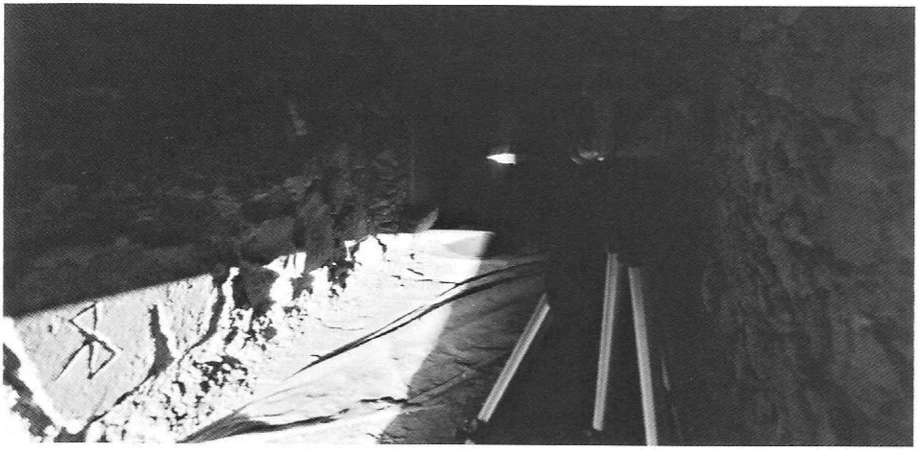


Figure 5. Sunrise on the day of the equinoxes touches the tip of the double axe on the southern wall of the Central Palace Sanctuary.

posite is responsible for the relationship of sunrise on the equinoxes to the pillar crypt, just as the alignment of the Central Palace Sanctuary to the ridge is responsible for the phenomena to be observed there. The sun appears at the intersection of the Ailias ridge and the northern door frame of the southern door, just as it did at the Central Palace Sanctuary (Henriksson and Blomberg 2016).

Striking celestial events in the eastern sky at the autumn equinox allow us to assume that the Minoan year always started in connection with that time. One is the heliacal rising of Arcturus one lunar month before the autumn equinox opposite the peak sanctuary on Petsophas where the orientation of the wall AB is to that event. A similar relationship is true in the case of the peak sanctuary on Juktas: the upper limb of the sun at the equinoxes could be seen from the altar to rise in a saddle of the mountain Selena, and 11 days after the autumn equinox it rose where two mountains intersect. Sunrise 11 days after the spring equinox did not occur at a well-marked place (Henriksson and Blomberg 2016). The new heliacal rising of the bright star Canopus in the south was three days before the autumn equinox and its appearance would have been an excellent harbinger of the autumn equinox and the New Year. Its appearance must have been sensational. The year probably began with the appearance of the new crescent moon after the autumn equinox. It was usual at that time that the new year began at a specific phase of the moon relative to an equinox or a solstice in the eastern Mediterranean and, later, in the Aegean. In the Hellenistic Period, the year still began at the same time in Knossos. (Guarducci 1945).

The influence of bright stars on Minoan architecture is clearly demonstrated by the change in orientation of the west side of the central court at Phaistos when the old palace was replaced by the new palace ca 1750 BCE. The new orientation was to the highest peak of the mountain in the south behind which the second brightest star Canopus rose and first became visible from the slopes of Mt Ida as a result of precession. The orientations to Arcturus at four sites, Petsophas, Traostalos, Chamaizi and Pyrgos, is another instance of Minoan alignments to bright stars, in this instance as a calendar star for the agricultural year, as it was later used by the Greeks (Hesiod 45, 49). The stars and constellations were not only regarded as mechanical regulators for calendars but, like the double axe constellation, were also important symbols in Minoan religion.

It must be stressed that no later than the end of the third millennium BCE the relationships of buildings to the celestial bodies that we have discovered in Crete and the progress achieved in the creation of accurate lunar and solar calendars, farmers' stellar almanacs, as well as a method for charting the motions of the stars during the night sky, presuppose a longstanding tradition before that time of sky watching and recording of the motions of the sun, the moon and the bright stars. The retention at Knossos of the orientation of the earlier EM III "palace" for the Old Palace when it was built in MM IB (Catling 1974: 34) shows recognition of the importance of alignments to the equinoxes in the construction in calendars, as they do not change because of precession.[1] The yearly motions must become readily retrievable by an imbedded oral tradition and probably also by a formal system of written records. This also implies the early establishment of a school or schools for teaching this information. The relationships of the stars to each other throughout the night, for example, must be made completely familiar for navigators. Recognition of the eight and nineteen year cycles of the moon would also require a long tradition of systematic observations. These and other regularities that repeat themselves only after long periods of time are very important to the development of astronomy.

So far we have not found any evidence of interest in the planets.

Summary

The important recovery of Minoan economic clay documents shows that the Minoans kept detailed accounts of farm produce (Godart and Olivier 1976-1985), and thus it is probable that their astronomers kept careful records of their observations of the motions of the celestial bodies. Our lack of such texts deprives us of specific knowledge, but we can infer their scope from comparisons with contemporary neighboring societies and from customs in the later history of the island that are echoed in Mycenaean and Greek myths and rituals. Minoan astronomers had constructed both a lunar and a solar calendar that could be regulated precisely before the end of the third millennium, as the earlier orientation of the Knossos structure (EM III) that preceded the first palace seems to indicate. They probably also had a stellar calendar that could be used for agriculture and navigation. These are major achievements in astronomy, and the level reached by the Minoans seems equally advanced as that of the Egyptians and the Babylonians.

The precise orientation of Minoan buildings to positions of the sun marking the beginning of each solar month (Table 2) implies that the celestial sphere had important symbolic meaning in Minoan traditions and religion. Each place may have had its responsibility in celebrating some of the significant festivals at the right time, for example celebrations for a god or goddess, rituals to be performed by the rulers or priests, times for sowing, harvesting and sailing, and other local and island-wide religious celebrations. Each settlement could have had its part to play in the wider context of Minoan cosmology by being a link in the chain of months recording terrestrial time and its dependence on the motions of the celestial sphere.

The influence of astronomy on the development of a culture is incalculable. The motions of celestial bodies are ruled by exact mathematical laws and it is natural that this challenged the intellect of humans at an early stage. It seems that systematic observations of the sky became an essential part of human activity no later than the Neolithic period. Astronomical observations were the first steps towards the scientific conquest of nature. Our insights into Minoan astronomy may open the door to that culture in a way that was not available before. The knowledge of navigation increased security on the seas and fostered foreign contacts that had long lasting Minoan influence in many eastern Mediterranean cultures. The discovery of lunar and solar calendars created order in the timing of recurrent events. Calendars were not only temporal markers of these events, but had the important religious function of connecting the earthly with the heavenly and incorporating the two in Minoan cosmology.

Our archaeoastronomical studies have begun to influence Minoan archaeologists in measuring the orientations of buildings to important calendric, agricultural and similar positions of the celestial bodies, and thus the future looks bright for the deepening of our knowledge of Minoan, as well as Mycenaean, astronomy. This is a great debt that we owe to Robin Hägg.

Notes

1. We are grateful to Sinclair Hood for showing us a wall from this building.

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