NEW ARGUMENTS FOR THE MINOAN ORIGIN OF THE STELLAR POSITIONS IN ARATOS´*PHAINOMENA*

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About 350[1], the Greek astronomer Eudoxos wrote a detailed description of the positions of the stars and constellations relative to the great circles and to each other when close to the horizon. Some 75 years later the poet Aratos set Eudoxos' text to verse. The two works have the same title, *Phainomena*, which means simply the appearances[2]. The *Phainomena* of Aratos has survived, but from Eudoxos we have only the quotations in Hipparchos' commentary and a few other fragments[3]. A puzzling feature of both works is that many of the positions given for the stars are incorrect for the time when the *Phainomena* were written, a fact which has given rise to a number of explanatory theories[4]. Perhaps the best known is that of the Scottish astronomer Michael Ovenden who proposed that the information was correct for Crete in the early bronze age, ca 2500[5]. These theories have not gained general acceptance, primarily because the errors in the two *Phainomena* are not systematic. Some positions are correct, some are only a little off, while others are wide of the mark.

We have found evidence for Minoan systematic astronomical observations and have published our arguments that they navigated according to the stars and had a lunisolar calendar of the same type as the Mycenaeans and later Greeks[6]. On the basis of this evidence it is a reasonable hypothesis that the astronomical data contained in Eudoxos and Aratos stems from a tradition which originated with the Minoans in the Bronze Age. To explain the apparent errors in the *Phainomena* we made the following hypotheses: the two books derive from a didactic tradition created by the Minoans for teaching the positions of the stars. One reason for it was, as Ovenden proposed, stellar navigation. When the Mycenaeans achieved hegemony in Crete around 1450[7], they updated the method, replacing some stars which because of precession had moved away from their circles with others which had moved closer. The Greeks, in their turn, made another revision for the same reason.

To test the hypotheses we calculated the positions through time of the individual stars which according to Aratos and Eudoxos defined the Tropics of Cancer and Capricorn and the Celestial Equator. By this approach there is no need to know the observers' latitude. We do not consider it necessary to assume that the Minoans had developed a system of celestial spheres of the type created by the Greeks, which was the basis for Dicks' criticism of Ovenden's theory[8]. The Minoans could have selected, for example, stars which rose or set close to the six horizon points where the sun rose and set at the solstices and equinoxes. We have found these positions marked by the orientations of several Minoan structures that date to the middle Bronze Age[9].

Aratos and Eudoxos defined the Tropics of Cancer and Capricorn and the Celestial Equator by referring to parts of constellations, as in the quotations below:

> "On it are carried both heads of the Twins"[10]
> "of the Maiden a small part is above".[11]

Using the information from the *Phainomena*, the catalogue of *Ptolemy's Almagest*[12] and a modern stellar atlas, we tried to identify the individual stars which were meant. We could do this with varying degrees of certainty. The "heads of the Twins", for example, are certainly α and β Gemini. It is impossible, however, to be sure which stars Eudoxos meant for the Maiden (Virgo). We ended up with a total of 111 stars (Table 1), which is a conservative number as we tried to select as far as possible those which we could be reasonably confident were meant by the two authors. They are marked in the table with an asterisk.

Next we calculated the distance in degrees of each star from its circle at intervals of 250 years, from 3250 to the year zero, and constructed tables like Table 1 for distance spreads of from ± 1° to ± 5°. The astronomical calculations were performed with our own computer program, based on stringent formulas for precession, the obliquity of the ecliptic, and including the proper motion of the individual stars. We found ± 2½° to be the best interval and also a good working value as it is approximately equal to the width of a man's thumb. Table 1 shows when a star is within this interval and for how long. For example, α Lep came within 2½° of the Tropic of Capricorn between the years 1750 and 1500 and remained there until sometime after 250 but before the year zero. Although a few stars were within ± 2½° for many centuries (o Pup), others are there in the early years and then become more distant (η Cap). Still others are within the interval only later (ζ Peg). Some of the stars which first come within the interval at later dates are those which according to our hypothesis have been added by the Mycenaeans or the Greeks.

TABLE 1. *Stars within ±2½° of the Tropic of Cancer, Capricorn or the Celestial Equator at 250-year intervals from 3250 BCE to the year 0.*

Cancer	3250	3000	2750	2500	2250	2000	1750	1500	1250	1000	750	500	250	0
α Gem*	X	X	X											
β Gem*	X	X	X	X	X									
χ Aur								X	X	X	X			
θ Per*	X	X	X	X										
ξ Per*									X	X	X	X		
ι And*				X	X	X	X	X						
κ And*		X	X	X	X	X	X							
λ And*	X	X	X	X										
χ And					X	X	X	X						
ρ And*										X	X	X	X	X
π Peg*											X	X	X	X
κ Peg*														
ϕ Cyg*														
η Cyg*														
ε Cyg*	X	X	X	X	X	X	X	X	X	X				
β Oph*														
γ Oph*														
ι Oph*				X	X	X	X							
κ Oph*			X	X	X	X								
α Oph*				X	X	X	X							
ω Her									X	X	X	X		
β Ser*												X	X	X
δ Ser'								X	X	X	X			
λ Ser*						X	X	X						
α Ser*					X	X	X	X						
ε Ser*			X	X	X	X								
η Leo*													X	X
α Leo*	X	X	X	X	X	X	X	X	X	X	X	X		
31 Leo*	X	X	X	X	X	X	X	X	X					

ν Leo*	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ρ Leo*	X	X	X	X	X	X	X	X	X	X				
53 Leo*					X	X	X	X	X	X	X	X		
ι Leo*									X	X	X	X	X	
η Cnc*			X	X	X	X	X	X	X	X	X	X	X	X
θ Cnc*						X	X	X	X	X	X	X	X	X
γ Cnc*	X	X	X	X	X	X	X							
δ Cnc*			X	X	X	X	X	X	X	X	X	X	X	X
C. Equator	3250	3000	2750	2500	2250	2000	1750	1500	1250	1000	750	500	250	0
α Ari*			X	X	X	X								
β Ari*					X	X	X	X						
η Ari*					X	X	X							
θ Ari*						X	X	X						
ν Ari*				X	X	X								
ε Ari*				X	X	X	X							
μ Tau*													X	X
90 Tau*							X	X	X	X	X	X		
δ Ori*														
ε Ori*														
ζ Ori*														
ι Hya*														
β Crt*	X													
α Crt*	X	X	X	X	X	X	X							
γ Crt*				X	X	X	X	X	X					
δ Crt*							X	X	X	X	X	X		
α Crv*	X	X	X											
ε Crv*	X	X	X	X	X									
ζ Crv*		X	X	X	X	X								
β Crv*	X	X	X	X	X									
ι Lib’					X	X	X							
γ Lib*								X	X	X				
η Oph*			X	X	X	X								
ζ Oph*								X	X	X	X			
γ Aql														
ν Peg*														
θ Peg*														X
ζ Peg*										X	X	X	X	X
ξ Peg*								X	X	X	X	X	X	
γ Peg*									X	X	X	X		
τ Psc*														
ψ1 Psc*				X	X	X	X							
ψ2 Psc*					X	X	X	X						
χ Psc*					X	X	X	X						
υ Psc*	X	X	X											
φ Psc*	X	X	X	X	X									
ψ3 Psc*						X	X	X	X					
Capricorn	3250	3000	2750	2500	2250	2000	1750	1500	1250	1000	750	500	250	0
φ Cap*	X	X												
η Cap*	X	X	X	X	X	X								
ε Cap*														
κ Cap*														

δ Aqr*														X
68 Aqr*														
ι Cet*									X	X	X	X		
β Cet*														
τ1 Eri														
α Lep'								X	X	X	X	X	X	
β Lep*											X	X	X	X
β CMa			X	X	X	X	X	X						
ξ1 CMa*									X	X	X	X	X	X
η CMa*														
ρ Pup*	X													
ξ Pup*	X	X	X	X	X	X	X	X					X	X
ο Pup*	X	X	X	X	X	X	X	X	X	X	X	X	X	X
α Pyx*	X	X	X	X	X	X	X	X	X	X	X			
β Pyx*														
ν Cen							X	X	X	X				
φ Cen							X	X	X	X				
ζ Cen			X	X	X	X								
γ Cen	X	X	X	X										
τ Cen	X	X	X	X	X									
λ Sco*				X	X	X	X							
υ Sco*				X	X	X	X							
δ Sgr*							X	X	X	X	X			
ε Sgr*			X	X	X	X								
λ Sgr*													X	X
μ Sgr*														
ψ Sgr							X	X	X	X	X	X	X	X
τ Sgr					X	X	X	X	X	X				
ζ Sgr					X	X	X	X						
ω Sgr		X	X	X	X	X								
ε Lup				X	X	X	X							
λ Lup				X	X	X	X							
π Lup			X	X	X									
TOTAL:	25	26	35	43	50	48	44	37	32	31	27	23	19	18

We see that there are more than twice as many stars within 2½° of their respective great circles in the years around 2000, when the Minoan culture was reaching its height, than there are in the interval between 500 and 250, the time closest to when Eudoxos and Aratos were writing their *Phainomena*. This seems unlikely to be a random result. Still we decided to compare it with how the 1028 stars in the catalogue of *Ptolemy's Almagest* relate to the same circles for the same years (Table 2)[13]. We see that the percentage of stars in the catalogue which lie within ± 2½° of the circles is lower for both years and considerably lower for the year 2000. We interpret this to mean that a selection was made and more likely around the year 2000 than 500.

As to the second part of our hypothesis, that the system was modified as stars became more distant to their circles, we should keep in mind that such a system, based as it was on knowledge of the motions of the heavenly bodies, would almost certainly have had a religious dimension and this would have counteracted any modifications. If the choice of stars were made with

TABLE 2. *Percentage of stars within ±2½° of the Tropics and Celestial Equator according to Ptolemy (n=1028) and Aratus and Euxodos (n=111) for the years 2000 and 500 BCE.*

	2000 BCE	500 BCE
PTOLEMY	16.5%	15.8%
ARATOS AND EUDOXOS	42.0%	20.5%

the rising or setting of the sun at the solstices and equinoxes as the guiding principle, then this suggests an original religious conception of a procession of figures, represented by the constellations, following the sun as it rose and set at the significant dates in the calendar. When the feasibility was recognised of using the figures to teach the positions of the stars for navigation, the parts which served this purpose best would have been selected. However the choice would not have been limited to the parts of the nearest constellations, but those of important nearby figures would have been included. Rules of thumb would have been devised so that such parts would have functioned in the system. This would explain the inclusion of Orion for example, which may have represented the sacred double axe (as described by $\alpha, \gamma, \delta, \varepsilon, \zeta, \kappa$ and β Ori).

Another factor which would have worked against any modification of the system is that the constellations, because they were regarded as divine and because of the imperceptibly slow rate of precession, were believed to be perfectly regular in their motions. In Aratos' words: "These you can see as the years pass returning in succession; for these figures of the passing night are all well fixed in the sky just as they are".[14] When the discrepancies due to precession became apparent, the likely explanation would have been that the observers of earlier times had been mistaken. However, because of the religious dimension to the system, we consider it unlikely that the Minoans would have altered it at all, but would instead have developed techniques to compensate for the changes due to precession.

Members of another culture with a different religion taking up the system would have been much freer to go in and make changes. If the take-over entailed translation to a different language, revision would have been more opportune. This calls to mind, of course, the Mycenaeans who most likely adapted the system for their uses just as they adapted the Minoan Linear A script for writing their language. Yet even in such a case, the choice of omissions and inclusions would probably not have been solely practical. A star would not have been removed from the list only because it moved to a distance greater than ± 2½° from its circle. In any case, a precise measurement such as *2½* would certainly not have been used by the Minoans, the Mycenaeans or the Greeks. This is a requirement imposed by the computer. These different factors explain why the number of stars within ± 2½° of their horizon points did not remain constant between the years 2000 and 250.

Our hypotheses make a lot of sense historically. If the system had been developed by the Minoans, the most likely time would have been early in the middle Bronze Age when their culture was developing rapidly in many areas. According to literary sources, they controlled the islands of the Aegean,[15] and we have much archaeological evidence from the same period for foreign trade between Crete, Mainland Greece, Egypt and the Near East.[16] We also know from the archaeological remains that the Mycenaeans gained hegemony in Crete and throughout the Aegean by the 14th century.[17] They would have needed the navigational skills of the Minoans and they had the opportunity to acquire them. However, by their time, some 600 years or more after the system had been developed by the Minoans, precession would have led them to replace of some stars which had become distant to their respective horizon points with others which had moved nearer. The Greeks, in their turn, would have repeated the process and for the same reasons.

We had a statistician at Uppsala University evaluating our data. He used the sign test and made the following assumptions[18]: 1) the stars were selected at a single point in time; 2) the selection can be approximated as an independent selection with replacement and 3) the year a star was closest to its circle could lie with equal probability in the future as in the past. The following stars were excluded as not helpful in determining when the initial selection was made: those never within 2½° (e.g., κ Peg) and those whose change in declination at approximately the year 500 was less than 2½° in a 1000 years (e.g., ρ And). The 17 less certainly identified stars were weighed as half and the stars which could be assumed to belong to the same selection were placed in one group (e.g., ι, κ, λ And). The number of such groups is 33. To weight the result negatively, the calculations were made using only the star in each group which appears latest (e.g., ι And). The year 600 was chosen for the null hypothesis, where the assumption that the initial selection was made after 600 could be rejected at the significance level of *0.05*. The result showed a systematic shift earlier in time from the year 350, and with 95% certainty either the initial selection of stars occurred before the year 600 or there must be another explanation for the shift. Due to the negative weighting of the data it is reasonable to assume a date considerably earlier than 600 for the original selection of the stars.

We also made statistical tests which included all of the 111 identified stars. The standard and average deviations of the distances from the three great circles and also the kurtosis and skewness were calculated for every 250 years within the time interval 4000 BCE-500 CE. The minima for the distributions of standard and average deviations gives the corresponding optimum year assuming that all stars were included in that year. The distribution of the standard deviation for each time interval is quite symmetrical and can be approximated by a parabola (Fig. 1). To get an estimation of the uncertainty in the determination of the year for the minimum standard deviation, three samples were chosen simply by taking every third star in the list of 111 stars. This gave three sets of 37 stars each and the fit to a parabola was made for each of the corresponding sets of standard deviations. The resultant years were 1642, 1608 and 1807, with mean value 1682 ± 62 years and standard deviation 106 years. If we compute the year for the minimum standard deviation for all the stars we get 1686 ± 62 years. The standard deviation is more sensitive to a few large errors than the average deviation. This can explain the different shapes of the curves for the minima in Figure 1. The year of smallest average deviation can be estimated to 1950, which means that not all the 111 identified stars were selected at the same time.

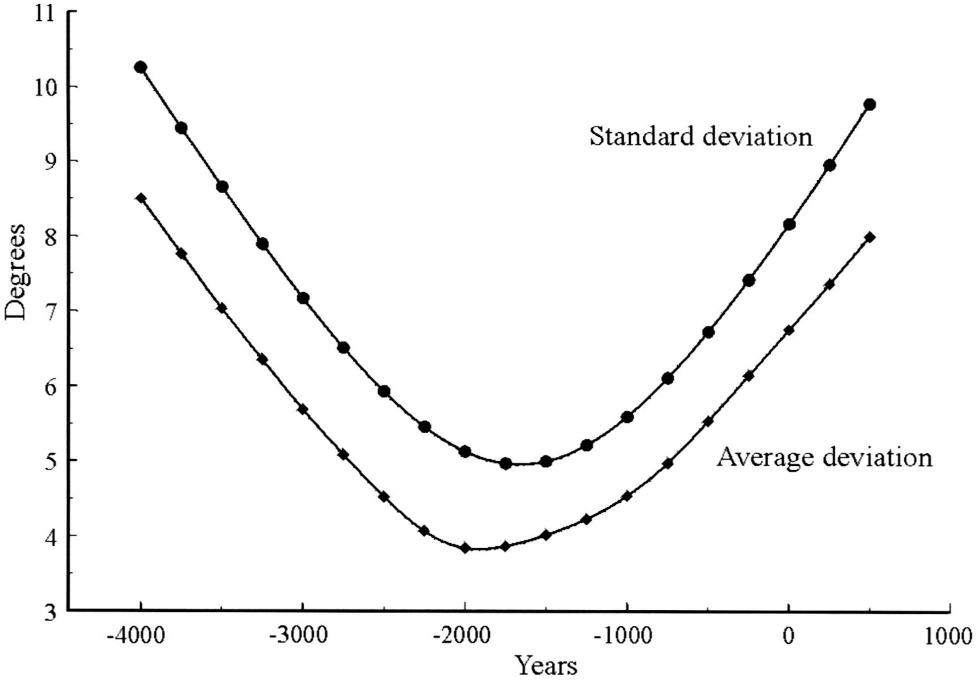

Figure 1. Standard and average deviations from the Tropics of Cancer and Capricorn and the Celestial Equator of the 111 stars identified as having been used by Aratos and Eudoxos to define those circles.

To estimate the year when the majority of the stars were chosen, we determined the variation in skewness and the so-called kurtosis, which gives a measure of the deviation of a distribution from a normal distribution (Fig. 2). These are important quantities in the theory of the Gram-Charlier Series.[19] The kurtosis is a measure of the peakedness or flatness of a distribution. Where it is positive there are more small errors in the observed distribution than in a normal distribution; where it is negative there are more large errors than in a normal distribution. In Figure 2 we can see a single positive peak at 2250. If we fit a parabola to estimate the optimum years we get 2282, 2430 and 2190 for the three sets of stars and the mean value 2300 ± 70 years with standard deviation 121 years. If we fit a parabola to the values of the kurtosis nearest to the peak for all 111 stars we get 2273 ± 70 years as the optimum year for the initial selection of stars. The distribution of the skewness has its lowest negative value around 2250 and its highest positive value around 300. This can be interpreted to indicate that stars were added or deleted several times during this interval of time.

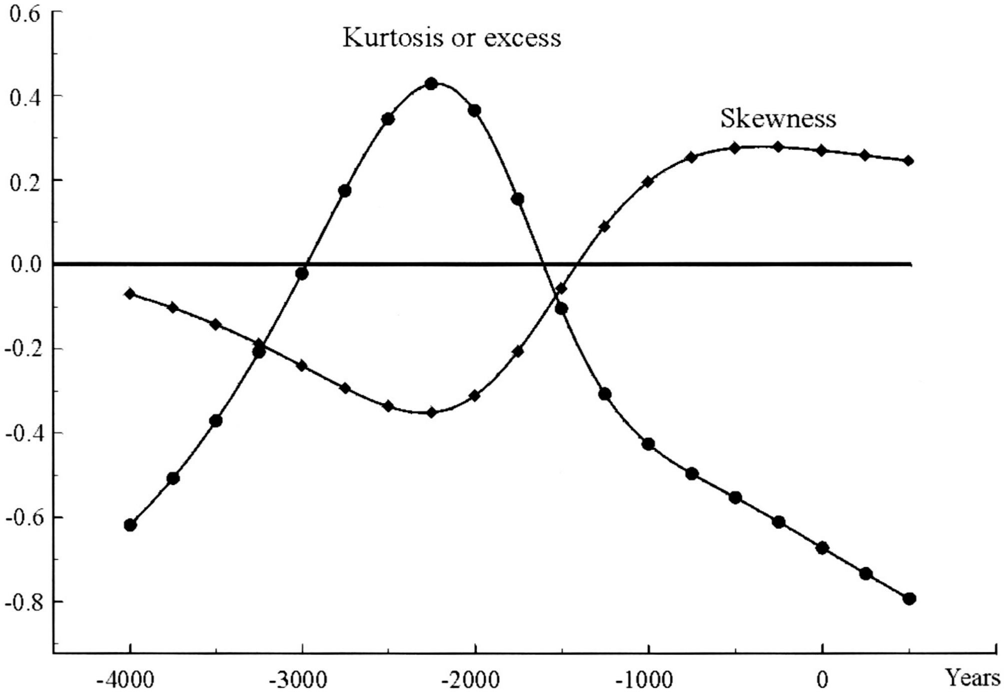

Figure 2. Corresponding kurtosis and skewness for the same data.

The origin on Crete of the system for learning the positions of the stars implies that the forms of the constellations and their distribution in the sky were largely Minoan creations, and what we know of the Greek constellations supports this. There are many indications that we are dealing with a very conservative tradition. Of the 48 constellations in Ptolemy's catalogue, all but two—Equuleus and Corona Australis—were used by Aratos and also by Eudoxos. For all but five the name was the same or was a Latin equivalent. Aratos used other names for Hercules, Cygnus, Pegasus, Libra, and Lupus. The origins of many of the names were so ancient that the Greeks knew little about them. The name of one—Corona Borealis or the Crown of Ariadne—came from Cretan mythology and there were Cretan-derived alternatives for the Bears—Helice and Cynosura, the nurses of Zeus. We still use all 48 of Ptolemy's constellations.

When the Mycenaeans took over Minoan astronomy, along with the calendar and stellar navigation, they probably changed some of the names of the constellations to those from their own mythology, and introduced new stars into the didactic system devised by the Minoans with others that were more timely. The Greeks in all probability made their additions and changes.

NOTES AND REFERENCES

1. All dates are BCE unless otherwise given.

2. We use the original spelling for Greek authors and titles except when citing works by modern authors.

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7. J. DRIESSEN and C. MacDONALD, *The Troubled Island. Minoan Crete before and after the Santorini eruption* (Liege 1997).

8. *op. cit.* (note 3), 161.

9. HENRIKSSON and BLOMBERG, *op cit.* (note 5).

10. *Aratus* (note 2), line 481.

11. *Hipparchi in Arati et Eudoxi Phainomena commentariorum libri tres* (note 2), 1.2.18.

12. *Ptolemy's Almagest,* trans. and annotated by G. J. Toomer (London 1984)

13. *Ibid.* 341-399.

14. *Aratus:* Phaenomena (note 2), lines 451-3.

15. *Thucydides: History of the Peloponnesian War*, ed. and trans. by C. F. Smith (London 1928), 1.4.

16. *Bronze Age trade in the Mediterranean*, ed. by N. H. Gale (Jonsered 1991), passim.

17. Driessen and Macdonald, op. cit. (note 6).

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