Research Article

Alignments Along the Main Axes at Mnajdra Temples

Chris Micallef
9, Casa Micallef, Triq il-Bwieraq, Sta Lucija.

Summary: *The Mnajdra temple has been the subject of controversy over the years with regards to the sun alignments with the lower (solar) temple. The aim of this paper is to investigate whether there were in fact any alignments with celestial bodies along the main axes at the Mnajdra complex. An analysis of the use of a megalithic unit for the erection of the Mnajdra temples was also carried out.*

Keywords: equinox, solstice, precession, declinations, azimuth, ellipse – eccentricity.

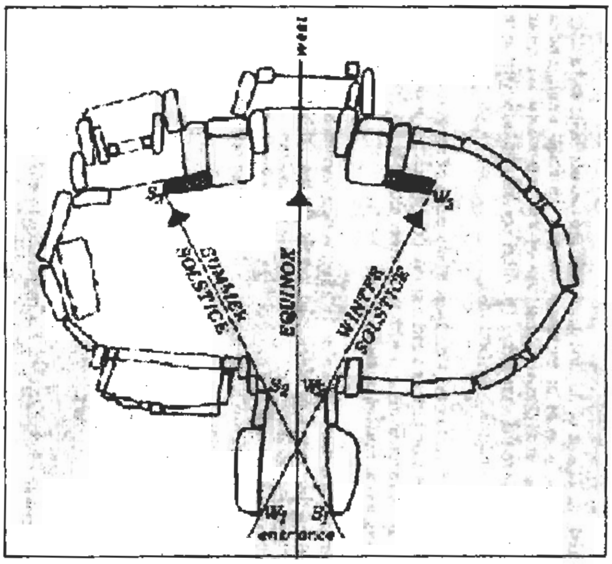
I. Introduction

Did megalithic man possess the fundamentals of field astronomy, or archaeoastronomy as otherwise known today? The conclusions about the Mnajdra complex derived so far certainly show that prehistoric man was indeed a good observer of the movement of the sun. Without any kind of speculation, a prehistoric builder must have noted the position of the rising sun and was intrigued or alarmed by the stationary position of the sun's disc at the summer and winter solstices. Between these two extreme sightings, the sun appears to perform a pendulum movement through one whole year. Even more intriguing is the effect of the movements of other celestial bodies that could have been observed in the lower, high and small trefoil temples at the Mnajdra complex. Distant markers or foresights might have been natural alignment points (cleft or notch), but holes with stakes or stone pillars might have been other possibilities to establish a fixed foresight. The shifting of a distant mark or foresight is not very practical, so the observer must have marked the final position of a required back-sight by a rod or pointed stone. A pointed stone increases the accuracy when sighting a foresight in line with the rising sun. It is important to note that not all pointed stones are phallic symbols as usually accepted in archaeology. Pointed markers may also serve alignment purposes. At the entrance of the south temple at Mnajdra, one finds a small pointed stone on the left-hand side of the main entrance. A similar pointed stone seems to be missing at the right-hand side but there is a space allotted to it. These indicators agree with the procedure of builders who usually fixed markers in the ground to establish the direction of the proposed temple or building. Was the Mnajdra complex used as an astronomical observatory to observe the movement of celestial bodies? Who were the builders of the Mnajdra complex? Were they craftsmen of Maltese origin or did they arrive in Malta to design and build the temple for solar and lunar predictions which were associated with the annual agricultural phases? The objective of this paper is to correlate further and extend the discussion regarding the orientation of the main axes of the Mnajdra temples, to investigate the possibility of any astronomical alignments, and to consider the geometrical properties of their ground plans.

The Mnajdra temple of Qrendi Parish has been surveyed and analysed for many decades since its excavation in 1836. Many archaeologists, excavators and technical missions have written about this temple from the archaeological and historical point of view but nobody had ever attempted to consider the temple's orientation up to the year 1979. Alfred Xuereb and Paul I. Micallef (1990), as well as Frank Ventura and George Agius (1980), initiated a new approach by investigating the orientation of this unique temple in the Mediterranean. The lower Mnajdra temple provided a challenge in fieldwork where linear and angular measurements are concerned. The preliminary task of the investigators was to survey in detail the lower temple and to establish the true geographical north by solar observations.

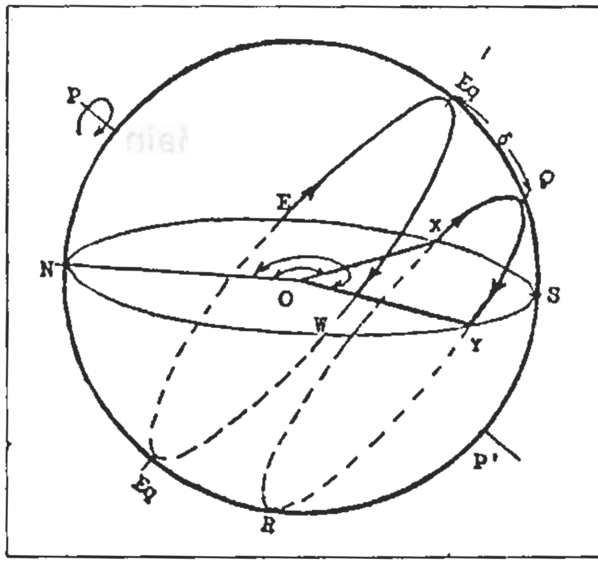
As all the results depended upon the accuracy of the true geographical north, angles were scrupulously measured. The first result that was obtained by Micallef, was that the Mnajdra temple is a device, the use of which allows one to predict the first day of the four seasons of the year, 21st March (Vernal equinox), 21st June (Summer solstice), 23rd September (Autumnal equinox) and 22nd December, (Winter solstice) (Micallef, 1990). Figure 1 shows how the seasons may be predicted at Mnajdra solar temple.

A person standing in the middle of the main passage of the lower temple observes the sun's disc exactly along the bisector of the passage, only at the equinoxes. The appearance of the sun's disc during sunrise along the centre-line of the main passage coincides with two particular dates, namely the vernal and autumnal equinoxes (21st March and 23rd September). At the summer solstice (21st June), the sun's rays are projected upon the left edge of the vertical slab at the left-hand



Source: Micallef (1992).

Figure 1: Prediction of seasons at Mnajdra solar temple.



Source: Adapted from Agius, and Ventura, 1980.

Figure 2: Observer's horizon surrounded by the celestial sphere.

side of the oval space. At the winter solstice (22[nd] December), the sun's rays are projected upon the right edge of a similar slab, which is situated in the same oval space, to the right of the centre line.

The cross-quarter days, that is the days midway between the solstices and the equinoxes, as in the old Celtic calendar system, fall on the 6[th] May, 7[th] August, 6[th] November and 4[th] February. Alignments with these days are currently being studied by Maelee Thomson Foster (1999), of the University of Florida. These were the principal feast days in the old Celtic calendar, which according to Sir Norman Lockyer were believed to have been inherited from the megalithic builders (Micell, 1977).

II. The observational data and method of data analysis.

Azimuth and declination determination

The determination of the azimuth of a building, is a means of measuring its orientation from true north or south. The azimuths quoted below were measured positively from north through east. Since the objective is to correlate the orientation of Mnajdra complex along its main axes with celestial objects, the azimuths and altitudes must also be converted to declinations, that is, to positions on the celestial sphere. Figure 2 shows observation point O, on a plane where ON represents the direction of the true north.

OX represents an axis, whose azimuth and declination are to be determined. The azimuth is defined by angle NOX. Thus the declination can be obtained by considering the celestial sphere, around point O having poles P and P', and an equator Eq, as shown. The declination is zero on any point on the equator ($\delta = 0^{\circ}$). The poles have declinations of $\pm 90^{\circ}$, ($\delta = 90^{\circ}$ at P and $\delta = -90^{\circ}$ at P'). Thus any points in between have declinations between 0° and $\pm 90^{\circ}$ such that points above the equator have positive declinations and points below the equator have negative declinations.

If one considers axis OY, the azimuth angle NOY through east is greater than that of axis OX. The declination in this case has remained the same since XQYR represents the path of the same point as it rotates about the axis PP' of the celestial sphere, the so called "diurnal circle" of the point. OY is directed towards the setting position whereas OX is directed towards the rising position. The conversion of azimuths and declinations involves spherical geometry, which can be found in a number of standard works (Roy and Clarke, 1977).

The azimuth of Mnajdra complex was obtained from published work (Micallef, 1992 a), where a theodolite measuring to an accuracy of one minute of an arc was used, and from other work (Agius and Ventura, 1979) where it was measured with a theodolite. Agius and Ventura (1980) state that several sources of error, excluding instrumental errors, precluded the determination of very precise azimuths. These include the weathering and erosion that has taken place for the main portal entrances of the Mnajdra complex, that is, lower temple, high temple and small trefoil temple, as well as the inexact reconstruction of the temple itself. Other aspects that were taken into consideration prior to the conversion of azimuths to declinations were:

- the latitude of the temple.
- the aspect of the horizon, and
- the refraction at the moment of sunrise.

The latitude of the Mnajdra temple was also taken from

Micallef's work, (1992 b). The latitude makes an appreciable difference on the declination corresponding to a particular azimuth (Roy and Clarke, 1977). Looking from inside the temple along its main axis the horizon opposite the main entrance can be below, at, or above eye level. This plays an important role on the declination and azimuth at which the sun would appear to rise from inside the lower temple.

The motion of the sun.

The sun rises in the east and sets in the west. The sun rises almost exactly in the east and sets in the west around 20th, 21st and 22nd March. This particular date is referred to as Vernal Equinox in the Northern hemisphere since the sun is above the horizon during the day and below the horizon during the night for an equal period of time. After the Vernal Equinox the sun rises and sets from a progressively northern position. The sun rises and sets in its northerly position with this deviation to the north increasing until mid-summer. Around 21st June, known as the day of the June solstice, the sun seems to stop, since during that day, the sun's declination stops increasing and hardly changes.

After the June solstice, the sun progressively rises and sets in a southward position. Around the 23rd September referred to as the autumnal equinox in the Northern hemisphere, the sun rises due east and sets due west. The sun's southerly position continues after 23rd September until around 21st December (winter solstice day in the Northern hemisphere), when the sun rises and sets in its southernmost position. The day is much shorter than the night at our latitude. After 21st December the sun's path turns northward again and the cycle is repeated. The following deductions can be made:

- The declination of the sun is zero at equinox since it follows a path along the celestial equator.
- The declination of the sun is maximum positive at the summer solstice.
- The declination of the sun is minimum negative at the winter solstice.

The declination of the sun at the solstices is actually ± i°, where i is the inclination of the earth to the ecliptic, also called obliquity. Although the value of i is nearly constant, its value has been found to oscillate very slowly between 22°55' and 28°18' with a period of 40,000 years (Weigart and Zimmermann, 1976). This small change in the sun's declination has been taken in consideration using the astronomical computer program Redshift II™. Table 1 shows the sun's declinations for different millennia at the solstices.

Motion of the Moon

The motion of the moon is quite complex. The main features of the moon's path around the Earth can be listed as follows:

Years before present	Declination at solstices (degrees)
4000	± 23.9°
5000	± 24.9°
6000	± 24.1°

Source: Roy and Clarke (1977).

Table 1: Values of sun's declination for different millennia.

- The moon orbits the Earth at an inclination of 5°09' to the ecliptic. The two points where the moon's path intersects the ecliptic are referred to as the "nodes".
- The plane of the moon's orbit precesses slowly such that the position of the nodes appear to slide around the ecliptic in the retrograde direction. The complete rotation of the nodes takes about 18.6 years, when a new cycle starts. This causes different declinations of the moon, caused by the inclination of the lunar to the Earth's orbit, and the same orbital geometry is not repeated except once every 18.6 years.

The most significant declinations occur when either a new or full moon is at the maximum or minimum declination. Table 2 shows declinations the sun and moon respectively, for different millennia.

Summer solstice	Sun's declination	Moon's declination	
		Max.	Min.
4000	23.9	29.1	18.8
5000	24.0	29.2	18.9
6000	24.1	29.3	19.0
Winter solstice		Min	Max
4000	-23.9	-29.1	-18.8
5000	-24.0	-29.2	-18.9
6000	-24.1	-29.3	-19.0
Equinox	0	5.2	-5.2

Motion of the stars.

Source: Roy and Clarke (1977).

Table 2: Sun and moon declinations across the millennia.

The unique engravings found on the broken fan shaped stone excavated at Tal-Qadi, on whose flat surface are carved radiating lines with crescent moon and groups of stars (Ridley, 1971), shows that the megalithic builders might have shown interest in the stars (figure 3). Although the interpretation of the symbols seems acceptable, one can never be sure of its correctness (Ventura and Agius, 1980).

Sir Temi Zammit referred to a pattern of five holes in

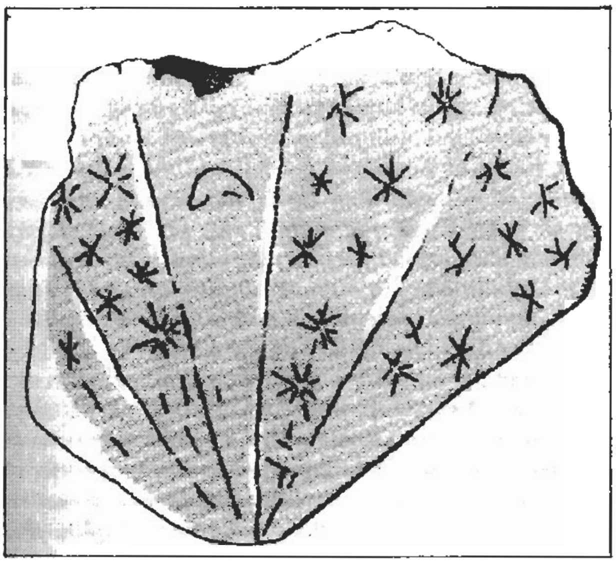
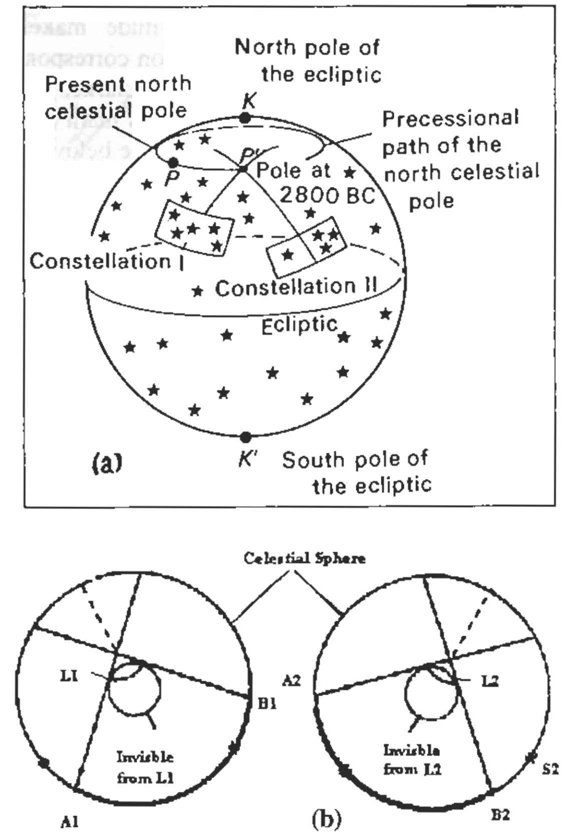


Figure 3: The "tal-Qadi" stone.



Source: (a) Adapted from Roy and Clarke (1977)
(b) Agius and Ventura (1980)

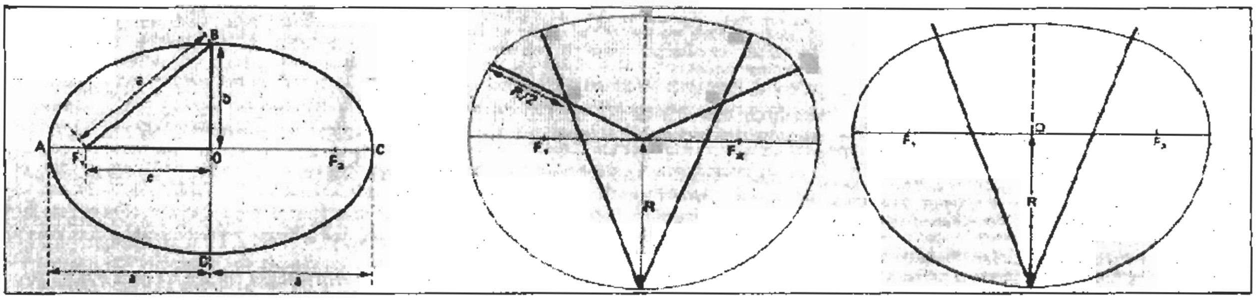
Figure 4: The effect of precession on stars during the night sky.

the forecourt of Tarxien temple, as an image of a constellation, that of the Southern Cross. This constellation was easily seen in the Maltese hemisphere during the time of the building of the Maltese temples (Zammit, 1929).

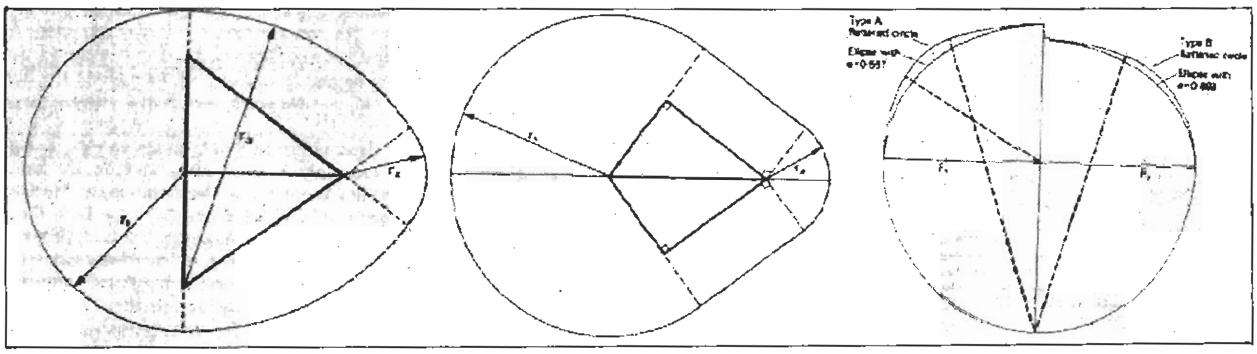
The apparent interest in the stars by megalithic man may not mean much. However this gives us an objective to investigate whether in fact any alignments did take place along the main axes of the lower, high and small trefoil temples at Mnajdra. One should not overlook the fact that during the rising and setting of stars, they appear much fainter due to atmospheric extinction. Another point worth mentioning is that certain stars can easily be missed due to hazy conditions as well as moonlight, although one must mention that the hill profile in front of Mnajdra lower temple helps to minimize such effects (Hawkins, 1974). Although the stars seem to be fixed year after year, on closer observation, one will notice that some are rising to higher declinations whilst others are going to lower declinations in the sky. Over thousands of years such movements become evident. The term that describes this movement is referred to as precession. Every 25,800 years the Earth's axis precesses at a slow rate. The Earth's poles revolve with reference to the celestial sphere of fixed stars. Thus stars that are presently visible from a particular latitude may be invisible in a few hundred years and vice-versa (Figure 4).

In Figure 4b (i), stars between A_1 and B_1 are invisible from the latitude L_1. In Figure 4b (ii), stars between A_2 and B_2 are now invisible from L_2. Thus stars that were invisible between B_1 and B_2 are now visible and vice-versa between A_1 and A_2.
The rate of precession is well known and considering the motion of the stars proper motion, the exact position could be calculated relative to the direction in space of the Earth's polar axis and to the equinox positions for any age. The relative longitude and latitude of the Mnajdra temples were fed to the computer astronomical program, Redshift II ™, together with the respective azimuth and declination of the main axes of the lower, high and small trefoil temples of the site. The base years that were investigated were 2876-2875 BC for the lower temple, 2751-2750 BC for the high temple and 3451-3450 BC for the small trefoil temple, pertaining to archaeological dating accepted by archaeologists.

The elliptical forms at Mnajdra complex.
Let us consider some of the most essential features necessary in understanding the geometric principles of megalithic mathematics before looking at the geometric forms at the Mnajdra complex. The Pythagorean 3, 4, 5 triangle which is the simplest right-angled triangle was certainly familiar to Early Bronze Age men, (Thom 1971), as this triangle or other similar ratios pertaining to the 3, 4, 5 ratio occurs over and over again in stone constructions of this period. John Edwin Wood claims that at some sites, megalithic man used triangles that are not quite Pythagorean (Wood, 1978 d). However on



Elliptical megalithic structure | Type A flattened circle | Type B flattened circle



Type I egg-shape structure | Type II egg shape structure | Flat circles approx. by ellipses

Source: Wood (1978)

Figure 5: Identified Megalithic structures.

calculation, the angle between the two shorter sides is 89.6° instead of 90°. This shows that early megalithic man was not aware of this mathematical relationship in order to arrive at drawing a right angle on the ground. Therefore it seems that the concept of certain triangles giving right angles was discovered by accident. These triangles were used in the construction of stone circles, megalithic structures in the shape of an ellipse, type A and type B flattened megalithic circles, type I and type II egg-shape megalithic structures, and flattened circles approximated by ellipses megalithic structures (Wood, 1978 a), (Figure 5). Thom suggests that these megalithic builders had devised their own unit of length. Their aim was to make their structures with perimeters equal to 2½ times a whole number of these units (Wood, 1978 b). Thom calls the unit the Megalithic Yard, abbreviated MY, and claims that 1 MY = 0.829 m. Therefore 2 ½ MY, the Megalithic Rod = 2.073 m.

One of the properties of an ellipse is that the distance between the focus to the top of the ellipse on the minor axis, (extreme point A) is equal to half the length of the major axis, (Figure 6). The proof comes directly in how the ellipse is drawn. When the stake is at C, the loop goes from F_2 to C and back again; its length is therefore 2a+2c. When the stake is at A, the loop of rope goes round F_1, F_2, and B; its length is $2AF_1 + 2c$. By subtraction, $AF_1 = a$. The triangle AOF_1 is right-angled, and it would not come as a surprise to find Pythagorean numbers incorporated in megalithic ellipses.

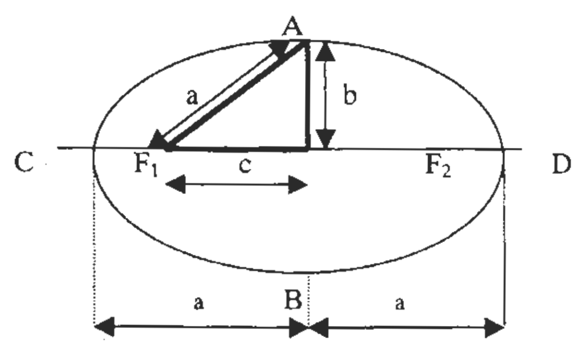


Figure 6: Geometry of an ellipse.

III. Results

Correlation with planets, stars, sun and moon along lower temple axis.

At this stage it was important to correlate the temple's declinations with those of significant celestial bodies alignments. I have chosen to date the lower temple according to standard archaeological dating (Ventura and Agius, 1980), that is, early Tarxien 3000-2500 BC. Thus, I have taken my investigative base year as 2875 BC, pertaining to the early Tarxien phase. The azimuth of the lower temple was fixed on 92°30'11" with a declination of 00°00'00" together with latitude of 35°49'40" and longitude of 14°26'15". Redshift II™ was used to correct the declinations for the sun and moon for parallax and for the positions of sun and moon approximately 5000 years ago. Table 3 shows the alignments that occurred at 2876-2875 BC (and are still occurring) at Mnajdra lower temple. One should note

Date	Time	Celestial Body	Declination (Degrees, minutes, seconds)	Azimuth (Degrees, minutes, seconds)
5.12.2876 BC	01:34	Mars	-00.05.37	92.32.30
14.12.2876 BC	**13:26**	First quarter moon – Age 9 days	**-00.37.34**	**92.32.29**
28.12.2876 BC	00:37	Last quarter moon – Age 22 days	-00.21.19	92.32.45
29.12.2876 BC	11:52	Jupiter	-00.01.35	92.25.39
4.01.2875 BC	23:40	Saturn	00.53.17	92.29.18
31.01.2875 BC	07:45	Venus	00.00.07	92.34.26
7.02.2875 BC	**08:06**	Crescent Moon – Age 2 days	**-00.09.15**	**92.33.40**
21.03.2875 BC	06:20	Sun	-00.04.45	92.32.14
13.05.2875 BC	15:33	Gibbous moon – Age 12 days	00.15.15	92.29.37
21.07.2875 BC	23:00	Gibbous moon – Age 20 days	-00.32.03	92.26.21
29.07.2875 BC	09:11	Venus	00.07.31	92.30.45
3.08.2875 BC	**10:09**	Crescent moon – Age 4 days	**00.11.43**	**92.34.54**
26.08.2875 BC	19:29	Mercury	00.06.19	92.35.08
19.09.2875 BC	06:20	Sun	00.57.11	92.29.48
19.09.2875 BC	06:45	Saturn	-00.01.24	92.31.06
27.09.2875 BC	**06:30**	New moon – Age 0 days	**00.06.30**	**92.29.40**
7.10.2875 BC	04:58	Venus	00.01.53	92.30.16
11.10.2875 BC	17:39	Full moon – Age 14 days	-00.15.09	92.33.13
16.10.2875 BC	04:55	Mercury	00.12.58	92.30.29
12.11.2875 BC	03:27	Venus	-00.03.21	92.34.46
21.11.2875 BC	02:57	Crescent moon-Age 26 days	-00.54.36	92.30.31
5.12.2875 BC	**14:10**	Gibbous moon – Age 9 days	**00.18.50**	**92.26.28**

Table 3: Alignments for Mnajdra lower temple.

that the celestial bodies shown in bold could not be seen or are very difficult to observe due to the brighter sky background.

Another investigation was then conducted to check whether there were any star alignments that took place at Mnajdra lower temple at 2875 BC. All stars which were difficult to see were excluded, i.e. those with magnitude 4.00 or higher. To analyse all possible star alignments that could have taken place for the lower temple, two dates separated by 6 months were chosen, that is 8th December 2876 BC and 8th May 2875 BC. In fact possible rising star alignments on an azimuth of 92°30'11" and declination of 00°00'00" together with the temple's longitude and latitude were found for constellations of Aquila, Pegasus, Taurus and Hydra (table 4).

The same investigation was also held for any star alignments that took place at Mnajdra middle temple. Since the middle temple is dated as Tarxien phase (3000-2500 BC), then the year of analysis of 2750 BC was used. To analyse all possible star alignments that could have taken place for the middle temple, two dates separated by 6 months were chosen, that is 8th December 2751 BC and 8th May 2750 BC. In fact possible rising star alignments on an azimuth of 138°30'00" and declination of -38°06'00" were found for constellations of Puppis, Canis Major, Vela, Ara and Aquarius (Table 4). No alignments with planets, sun or moon were found for Mnajdra middle temple and small trefoil temple.

Setting star alignments that took place at Mnajdra small trefoil temple (Ggantija phase) at 3450 BC were also investigated. To analyse all possible star alignments that could have taken place for the small trefoil temple, two dates separated by 6 months were chosen, that is 8th December 3451 BC and 8th May 3450 BC. In fact possible star alignments on an azimuth of 204°00'00" and declination of -46°06'00" were found for Columba, and Pavo (Table 4).

Significance and determination of ellipse equations for Mnajdra complex.

Neolithic and early bronze age man did not possess any of our modern ideas about mathematics. However there is no doubt whatsoever that megalithic man was fascinated with geometry. At Mnajdra the identified geometric shapes resemble closely the ellipse for the small trefoil temple and the solar temple. The high temple ellipses are rather flattened at the top and bottom ends. In order to study the ellipse forms at Mnajdra, primary data was retrieved on site. A measuring tape was used to determine the lengths of the major and minor axes of all the temples at Mnajdra. The ellipse

Lower Temple star alignments.

SAO	Bayer Name Flamsteed Name	Magnitude	Declination (Deg, min, sec)	Right Ascension (Deg, min, sec)
Date: 8th December 2876 BC				
76155	Maia - 20 Tauri	4.00	00.28.38	23.25.33
76140	Taygeta – 19 Tauri	4.40	00.32.53	23.24.56
76172 PLEIADES	Merope – 23 Tauri	4.30	00.05.04	23.26.18
76199	Alcoyne – 25 Tauri	3.00	00.17.28	23.27.15
76228	Atlas – 27 Tauri	3.80	00.18.42	23.28.48
182244	Hydrae – 49 Hydrae	3.50	(-)00.24.55	09.55.21
Date: 8th May 2875 BC				
76199	Alcoyne - η Tauri	3.00	00.17.20	23.27.13
127029	Enif - ε Pegasi	2.50	(-)00.21.49	20.44.24
76131	Electra – 17 Tauri	3.80	00.11.03	23.24.53
76155	Maia – 20 Tauri	4.00	00.28.30	23.25.32
76228	Atlas – 27 Tauri	3.80	00.18.34	23.28.46
135896		4.00	(-)01.19.55	04.20.04
144150	θ Aquilae	3.40	(-)01.15.41	15.58.25

High Temple star alignments.

SAO	Bayer Name Flamsteed Name	Magnitude	Declination (Deg, min, sec)	Right Ascension (Deg, min, sec)
Date: 8th December 2876 BC				
196698	Furud – ξ Canis Majoris	3.10	(-)37.51.36	03.22.54
Date: 8th May 2875 BC				
196698	Furud - ξ Canis Majoris	3.10	(-)37.52.01	03.22.53
197258	κ Canis Majoris	3.80	(-)36.48.46	03.56.37
197795	π Puppis	2.70	(-)37.48.16	04.32.41
219082		3.80	(-)37.04.08	05.11.08
237522	φ Velorum	3.70	(-)38.06.04	07.17.32
238813		4.00	(-)37.49.53	08.11.58
244168	η Arae	3.70	(-)37.28.11	11.40.59
191683	δ 8 Aquarii	3.80	(-)38.07.50	18.20.19

Small Trefoil Temple star alignments.

SAO	Bayer Name Flamsteed Name	Magnitude	Declination (Deg, min, sec)	Right Ascension (Deg, min, sec)
Date: 8th December 2876 BC				
246574	Pavonis	2.1	(-)47.22.15	17.59.35
Date: 8th May 2875 BC				
246574	α Pavonis	2.10	(-)47.22.18	13.18.10
196059	Phaet - α Columbae	2.80	(-)48.36.14	02.29.23
250374		4.00	(-)46.52.29	06.40.24

Table 4: Star alignments at Mnajdra solar, high and small trefoil temples.

Mnajdra complex	Small Trefoil temple	High temple (Larger ellipse)	High temple (Smaller ellipse)	Lower temple
Measurements	Units: metres/ megalithic yards	Units: metres/ megalithic yards	Units: metres/ megalithic yards	Units: metres/ megalithic yards
Length of major axis	9.2 11.1	16.5 19.9	13.8 16.6	13.8 16.6
Length of minor axis	4.7 5.7	7.3 8.8	6.0 7.2	7.0 8.4
Extreme point A	(0,2.35) (0,2.83)	(0,3.65) (0,4.4)	(0, 3) (0, 3.6)	(0, 3.5) (0, 4.2)
Extreme point B	(0,-2.35) (0,-2.83)	(0,-3.65) (0,-4.4)	(0, -3) (0, -3.6)	(0, -3.5) (0, -4.2)
Extreme point C	(-4.6,0) (-5.55,0)	(-8.25, 0) (-9.95, 0)	(-6.9, 0) (-8.3, 0)	(-6.9, 0) (-8.3, 0)
Extreme point D	(4.6, 0) (5.5, 0)	(8.25, 0) (9.95, 0)	(6.9, 0) (8.3, 0)	(6.9, 0) (8.3, 0)
Eccentricity (e) ($e^2 = 1 - b^2/a^2$)	0.86 0.86	0.89 0.89	0.9 0.9	0.86 0.86
Determination of focus 1 (ae, 0)	(3.95, 0) (4.77, 0)	(7.4, 0) (8.9, 0)	(6.2, 0) (7.5, 0)	(5.946, 0) (7.2, 0)
Determination of focus 2 (-ae, 0)	(-3.95, 0) (-4.77,0)	(-7.4, 0) (-8.9, 0)	(-6.2, 0) (-7.5, 0)	(-5.9, 0) (-7.2, 0)
Determination of directrix 1 (x=a/e)	5.4 6.5	9.2 11.1	7.6 9.2	8.0 9.6
Determination of directrix 2 (x=-a/e)	-5.4 -6.5	-9.2 -11.1	-7.6 -9.2	-8.0 -9.6
Latus Rectum ($2b^2/a$)	2.4 2.9	3.2 3.9	2.6 3.1	3.5 4.3

Table 5: Data for the determination of ellipse for small trefoil, high and lower temples at Mnajdra.

equation can be found from this data using the theory of ellipse equation. Table 5 shows the calculations of the ellipse geometry both in standard metric system as well as in megalithic yards identified by Thom (1971). If the megalithic yard of 2.72 feet or 0.829 metres is used the results as shown in Table 5 are achieved.

IV. Discussion of results

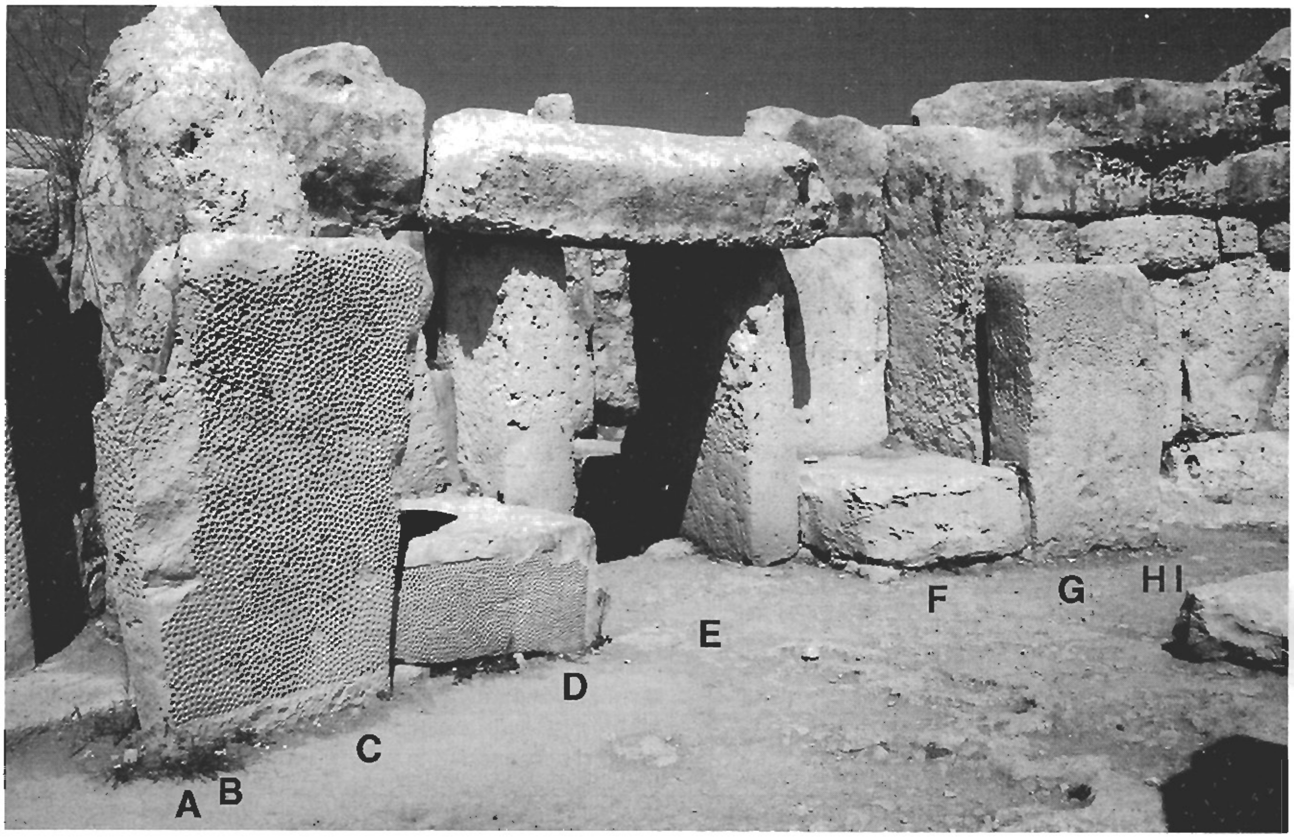
At Mnajdra lower temple the alignment at both equinoxes, that is, the vernal equinox and the autumnal equinox, the sun's disc appears to stand on a point on the slope exactly opposite the main passage when viewed from the interior. The calculations for the year 2875 BC show that the sun faced exactly the main passage of the temple which is in fact the vernal and autumnal equinoxes. This is still true and is still occurring.

A solar calendar at Mnajdra lower temple.

The cross quarter and eighth days at Mnajdra lower temple bring sunlight image projections that hit the megalithic stones inside the solar calendar, at other important dates. The cross-quarter days are midway between the solstices and equinoxes whilst the eighths days are mid-way between the cross-quarter days and equinoxes and between the summer and winter solstices and the cross-quarter days. The dates of the 'eighths' are 14th April, 1st June, 12th July, 31st August, 16th October, 30th November, 10th January and 25th February. The edge of the shaft of light from the rising sun hits the inside of the temple at important positions inside the temple as shown in Figure 7.

In fact the declinations of the sun during the summer and winter solstices, the autumnal and vernal equinoxes and cross quarter and eighth days at Mnajdra solar temple, fit Thom's hypothesis (Table 6). Thom statistically studied more than three hundred sites, and came up with the most important sun declinations (Wood, 1978 c). Thom's calendar is distributed in eleven months of 23 days, four months of 22 days and one month of 24 days. If Thom's hypothesis is correct, then the people of Early Bronze Age had indeed accomplished a very important system.

In a different study on the investigation of prehistoric solar calendars, MacKie, (1988 a), concludes, that by using the sequence of solar 'months' deduced by Thom, and by using the 'megalithic' rather than the true equinoxes, one could obtain the following 16 'month' dates with the cross-quarter days, the solstice dates and the equinox dates being shown in italic: *22 March*, 14 April, *7 May*, 31 May, *23 June*, 16 July, *8 August*, 30 August, *21 September*, 13 October, *4 November*, 27 November, *20 December*, 11 January, *4 February*, 27 February and *22 March* (Micallef, 1990). One should



A	B	C	D	E	F	G	H	I
21st Jun	1st June	5th May	14th April	21st March	25th Feb	5th Feb	10th Jan	22nd Dec
	12th July	8th Aug	31st Aug	23rd Sep	16th Oct	8th Nov	30th Nov	

Figure 7: The Mnajdra solar calendar (Photo: *Maurice Micallef*)

note that the dates which Thom proposed, and subsequently MacKie, agree with our Mnajdra temple calendar.

On a separate investigation that I performed using Redshift II ™ astronomical program, the following dates were deduced, with the eighths being shown in italics: 21 March, *14 April*, 5 May, *1 June*, 21 June, *12 July*, 8 August, *31 August*, 23 September, *16 October*, 8 November, *30 November*, 22 December, *10 January*, 5 February and *25 February*. These dates were arrived at after scrutinising different sun declinations which Thom used as his basis to arrive at these important dates, and comparing them with those derived for Mnajdra lower temple. Again one should notice the similarity in dates between those proposed by Thom and MacKie and the ones derived for the Mnajdra solar temple.

The moon path facing the lower temple.

The realization of the observer's position (known as the back-sight) was in itself adjusted in relation to a specific peak or point on the horizon. The aim was to create a long alignment giving fine measurements of the sun's position, moon or stars. The high precision involved is by far greater than that required in a simple agricultural calendar and must surely have involved full-time professional observers.

According to MacKie (1988 a), it would have been necessary to spend many years first searching for suitable sites and then patiently observing to establish the exact position of the required back-sights. These back-sights are usually marked by a standing stone, (Hoskin et al, 1992). This points to the existence of a more developed Neolithic society rather than the rural primitive societies, that archaeologists believe in. The main question here is, what is happening to the moon at the most important dates during autumnal and vernal equinoxes as well as the summer and winter solstices rising sun and other celestial bodies?

The motion of the moon is quite complex, so for reasons of simplicity it will be assumed that the moon's orbit is in the same plane as the Sun. The aim is to have the moon's orbit in the same plane as the ecliptic. At the spring equinox (21st March), the sun sets very close to due west or due west. This means that the northern half of the ecliptic is therefore above the horizon at sunset at this time. Thus the first quarter moon is on the meridian in the same place as the sun at summer solstice. When full moon is attained it rises due east at sunset, and its position is at the autumnal equinox. The last quarter moon is at the winter solstice.

During the summer solstice (21st June), the sun sets in the north-west, and the first quarter moon, is now at the autumnal equinox position and follows the celestial equator. The full moon, now at the winter solstice, rises

Month No.	Number of days	Number of days from the spring equinox to the beginning of the month	Declination of the sun at the beginning of the month at 1800 BC (degrees). Thom's analysis.	Corresponding date in our calendar (Thom's analysis).	Number of days	Declination of the sun at the beginning of the month. Author's analysis for Mnajdra solar temple for 2875 BC. (Degrees, minutes, seconds).	Corresponding date in our calendar for 2875 BC (Author's analysis).	Number of days	Declination of the sun at the beginning of the month. Author's analysis for Mnajdra solar temple for 1999 AD. (Degrees, minutes, seconds)	Corresponding date in our calendar for 1999 AD. (Author's analysis)
1	23	0	0.44	20-Mar	0	(-)00.04.06	21-Mar	0	00.05.12	21-Mar
2	23	23	9.16	12-Apr	24	9.01.01	14-Apr	24	09.15.47	14-Apr
3	24	46	16.67	05-May	21	15.59.46	05-May	21	16.07.58	05-May
4	23	70	22.06	29-May	26	22.04.56	31-May	27	21.59.34	1-June
5	23	93	23.91	21-Jun	22	24.00.13	22-Jun	20	23.26.06	21-Jun
6	23	116	22.06	14-Jul	24	22.06.47	16-Jul	21	22.01.21	12-Jul
7	23	139	16.97	06-Aug	25	16.03.47	10-Aug	27	16.15.03	08-Aug
8	22	161	9.17	28-Aug	21	09.00.53	31-Aug	23	08.46.51	31-Aug
9	22	183	0.44	19-Sep	21	00.06.41	21-Sep	23	00.04.27	23-Sep
10	22	205	-8.46	11-Oct	20	(-)08.03.54	11-Oct	23	(-)08.44.58	16-Oct
11	23	227	-16.26	02-Nov	22	(-)16.00.15	02-Nov	23	(-)16.27.56	08-Nov
12	23	250	-21.86	25-Nov	28	(-)22.38.24	30-Nov	22	(-)21.35.08	30 Nov
13	23	273	-23.91	18-Dec	20	(-)24.00.15	20-Dec	22	(-)23.26.21	22-Dec
14	23	296	-21.86	10-Jan	23	(-)21.57.51	11-Jan	19	(-)22.00.13	10-Jan
15	23	319	-16.26	02-Feb	24	(-)16.13.25	04-Feb	26	(-)16.01.23	05-Feb
16	23	342	-8.46	25-Feb	21	(-)9.11.13	25-Feb	20	(-)09.13.13	25-Feb

Source: Wood (1978)
after analysing declinations at Mnajdra solar temple.

Table 6: Bronze Age calendar proposed by Thom compared to Mnajdra lower (solar) temple.

well south of east. The last quarter moon is at the spring equinox and appears higher in the sky than in spring when it crosses the meridian.

On 23rd September (autumnal equinox), the sun's setting point shifts back due west and at sunset the whole of the south part of the ecliptic is above the horizon. The first quarter moon, occupies the full moon's position at the winter solstice. The full moon, whose position is now at the vernal equinox is higher when on the meridian than when in summer. The last quarter moon, is now at the summer solstice position.

On 22nd December (winter solstice), the first quarter moon at sunset, climbs higher in the sky, as it is now located in the vernal equinox position. The full moon is now at the summer solstice position. The last quarter moon is at the vernal equinox position and rises due east. Table 7 shows the position of the moon during the most important seasonal dates.
Different phases of the moon could have also been observed along the main axis of Mnajdra lower temple, as Table 3 shows. It is interesting to note that alignment along the main axis of the lower temple with the full moon occurred four times throughout the year on 19th March, 17th August, 15th September and 10th October 2875 BC. No alignments were found for the moon for the high and small trefoil temples. This is not surprising given the declinations of the temple.

Summer solstice positioning slab	Equinox main altar	Winter solstice positioning slab
21st MARCH EQUINOX		
First quarter moon	Full moon	Last quarter moon
21st JUNE SUMMER SOLSTICE		
	First quarter moon	Full moon
	Last quarter moon	
23rd SEPTEMBER EQUINOX		
Last quarter moon	Full moon	First quarter moon
22nd DECEMBER WINTER SOLSTICE		
Full moon	First quarter moon	
	Last quarter moon	

Source: Observations at the Mnajdra lower temple.

Table 7: The moon's position during important seasonal dates at the Mnajdra lower temple.

Alignments with planets

It was also interesting to find that Mnajdra lower temple is aligned towards the planets. Again this is not surprising, and at this point one should ask, whether these alignments were intentional or not? Towards the end of the year 2876 BC, Mars was aligned (and still is), towards the main axis of the lower temple (Table 3). This was followed by Saturn, Venus, Mercury and Venus. No alignments with planets were found for the high and small trefoil temples at Mnajdra. This is not surprising given the declinations of the high and small trefoil temples.

Interpretation of sun, moon and planets alignments at Mnajdra temple.

Interesting enough is MacKie's hypothesis for megalithic sites in England and Scotland, used for Mnajdra lower temple. It seems that the beginning of each 'megalithic' month could have been marked by the rising of celestial bodies along the temple's main passageway (axis), which indicates their use by megalithic man to mark their own calendar. The fact that the cross quarter days are still important today, and until recently they marked important seasonal and other festivities, suggests that they might have been inherited from a very old solar calendar with well established feast days and religious ceremonies on the eight major subdivisions of the year (MacKie, 1988 b). MacKie also states that the intermediate eighths were useful seasonal indicators. MacKie believes that the eighths marked the beginning of spring, hence the time for sowing, the beginning of summer, the beginning of autumn, hence harvest time and the beginning of winter. This could be the same case for a latitude which is different from Malta's.

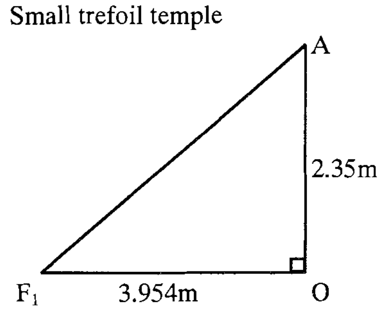
The rising of the sun on the first day of the four seasons, the cross-quarter days and the eighth days as seen by an observer in the temple, as well as the positioning of planets, and moon, leaves nothing to the imagination or speculation. Thus it seems that megalithic man could have constructed the Mnajdra lower temple to predict the solar and lunar motion during the year, although one must mention that the situation could be sheer coincidence as to date there is no evidence of intent. It was due to this connection of the sun's rising at different positions with the lower temple that Micallef (1992) had re-named the lower temple as the solar temple. The high temple and small trefoil temple also predict the rising and setting of certain stars. The rising of celestial bodies, as seen by an observer in the small trefoil temple, high temple and lower temple makes us more aware of the capacity and knowledge that these sky watchers possessed in ancient times.

The ellipse forms at Mnajdra complex

It is interesting to note the eccentricity of the ellipses at Mnajdra. The eccentricity is 0.86 for the small trefoil temple and 0.9 for the inner ellipse of the high temple. The other ellipse of the high temple bears an eccentricity of 0.9 also, whilst the solar temple's eccentricity is again 0.86. The same cannot be said when one compares the Mnajdra site with other megalithic structures. Wood claims that the eccentricities of megalithic ellipses are generally between 0.3 and 0.7 (Wood, 1978 d). The stone settings at Postbridge, Devon is the least elliptical with an eccentricity of 0.29, at Penmaenmawr, Gwynedd the megalithic ellipse has an eccentricity of 0.31, whilst at Machrie Moor on the Isle of Arran the megalithic stone ellipse has an eccentricity of 0.5.

During the construction of these stone ellipses, it is supposed that two posts were hammered into the ground. The posts represent the foci of the ellipse. A loop of rope was made to go round both simultaneously. A stake in the loop will eventually mark out an ellipse. As the posts are marked further away from each other, this produced an elongated type of ellipse, as in the case of the Mnajdra temples. An investigation was carried out on other measurements pertaining to the small trefoil temple, the high temple and the lower temple (Table 8).

Small trefoil temple



From Pythagoras Theorem

$AF_1^2 = AO^2 + OF_1^2$

$AF_1^2 = 2.35^2 + 3.954^2$

$AF_1^2 = 21.16$

$AF_1 = 4.5996 \text{ m} \approx 4.6 \text{ m}$

Hence the length of AF_1 is equal to the length of half the major axis as the theorem suggests. This makes the above triangle incorporated in the small trefoil temple a right-angled triangle. Let us investigate the angles of the above triangle AOF_1 using trigonometric principles.

Tan AF_1O = opposite/adjacent = AO / OF_1 = 2.35 / 3.654 = 32.7°.
Tan F_1AO = opposite/adjacent = OF_1 / AO = 3.654 / 2.35 = 57.3°.

To an accuracy of 1 decimal place the angle F_1OA is exactly 90°.

If one is willing to believe the reason why the megalithic builders set out these temples in special geometric shape, then one might ask, why did they do it in the first place? Why did they have to go through such complications when a stone circle would have sufficed? Thom (1971) suggests that these structures have perimeters equal to 2½ times a whole number of these units (Wood, 1978 e). An interesting item inscribed on the right upon the threshold of the Mnajdra's high temple is interpreted as the universal numerical building

Mnajdra Temple	AF_1	Angle AF_1O	Angle F_1AO
Small Trefoil	4.6m	32.7°	57.3°
High (larger ellipse)	8.25m	26.3°	63.7°
High (smaller ellipse)	6.9m	25.8°	64.2°
Lower	6.9m	30.5°	59.5°

Table 8: Measurements at Mnajdra megalithic ellipses.

Criteria	Small trefoil temple	High temple (larger ellipse)	High temple (smaller ellipse)	Lower temple
Triangle based dimensions (metres)	2.35 3.95 4.60	3.65 7.40 8.25	3.00 6.21 6.90	3.50 5.95 6.90
Triangle based dimensions (megalithic yards)	2.84 4.77 5.55	4.40 8.93 9.95	3.62 7.49 8.32	4.22 7.17 8.32
» Perimeter of ellipse (metres)	9.57	16.33	13.56	14.34
» Perimeter of ellipse (megalithic yards)	11.55 » 11½	19.69 » 19½	16.36 » 16¼	17.29 » 17¼
Perimeter of ellipse as a multiple of 2.5 MY	11.5/2.5 = 4.6	19.5/2.5 = 7.8	16.25/2.5 = 6.5	17.25/2.5 = 6.9
Perimeter of ellipse (megalithic rod)	» 4 ½	» 8	» 6 ½	» 7
Major axis of ellipse (m)	9.2	16.5	13.8	13.8
Major axis of ellipse (megalithic yards)	11.098 » 11	19.903 » 20	16.647 » 16 ½	16.647 » 16 ½
Major axis of ellipse (megalithic rod)	4.438 » 4	7.959 » 8	6.66 » 6½	6.66 » 6½
Distance between foci of ellipse (metres)	7.908	14.798	12.428	11.892
Distance between foci (megalithic yard)	9.539 » 9½	17.85 » 18	14.99 » 15	14.345 » 14¼
Distance between foci (megalithic rod)	3.815 » 4	7.138 » 7	5.995 » 6	5.738 » 6

Table 9: Investigation of primary data of ellipse characteristics for Mnajdra complex.

unit. According to Formosa (1975), it looks like a large L inscribed on the stone that acts as a threshold. Maelee Thomson Foster (1999) measured the incised unit which fits Thom's megalithic building unit.

As an approximation the circumference of an ellipse can be expressed as $\pi\sqrt{(ab)}$ where a stands for the semi-major axis and b stands for the semi-minor axis. Therefore it is quite possible to get the major axis of an ellipse and its circumference to be simultaneously whole numbers in any unit. According to Thom (1971), the megalithic builders set themselves the difficult task to make all the three sides of the right-angled triangle incorporated in the stone ellipse, whole numbers of megalithic yards all at once. It is impossible to do this exactly, and very difficult even to do it approximately. Thom (1971) states that it was not always possible to be as close as this to whole numbers. In general, the ellipse was based on a Pythagorean triangle and the perimeter was allowed to depart from a multiple of 2 ½ MY, or the length of the perimeter was kept 2 ½ times a whole number of megalithic yards and modified the triangle (Wood, 1978 f). In the latter case megalithic man let the minor axis with an awkward length, but made the major axis and the distance between the foci equal to a whole number of yards. The objective was to ensure that the length of the rope used for laying out the ellipse integral in megalithic yards. Table 9 shows the above mentioned criteria for the small trefoil temple ellipse, the high temple ellipses and the lower temple ellipse.

Several interesting facts arise from the calculations derived from Table 9. The triangles within the ellipses derived for the Mnajdra temples are not Pythagorean numbers. Therefore it seems that these megalithic builders adjusted the eccentricity of the ellipse by moving the foci of the ellipse on the major axis with the objective of getting whole unit numbers for the perimeter and major axis of the ellipse.

The perimeter of the ellipses, in terms of whole number of units, was achieved for the high temple (larger ellipse) and the lower (solar temple) in terms of the megalithic yard. For the small trefoil, and the high temple (smaller ellipse), half a megalithic unit (Table 9). For the major axis of the ellipse in terms of megalithic yards, accurate results, in whole unit numbers, were achieved for the small trefoil temple and the larger ellipse of the high temple. The same cannot be said for the smaller ellipse of the high temple and the solar temple and probably half a megalithic unit was used. Quite accurate results were attained for the small trefoil, high and lower temple when measurement in terms of the megalithic rod is considered for the major axis of the ellipses. Another discrepancy is the distance between foci for the lower temple ellipse. The error involved is 2.4% unless the megalithic builders used a quarter of a megalithic rod in their construction. Quite accurate results in terms of whole number units were achieved for the ellipses of the high temple. The results derived for the Mnajdra complex positively show that the distances between the foci and the major axis and the perimeters of the elliptical temples were achieved by means of some megalithic unit (Table 9).

The question still remains: did megalithic man possess mathematical knowledge in the construction of these elliptical figures. Further investigations on other megalithic temples with this elliptical shape in the

Maltese Islands may eventually shed more light and knowledge in relation to Maltese megalithic temples building unit.

Conclusion

The daily slit images produced at the Mnajdra solar temple and alignments with celestial bodies may qualify this megalithic monument to be seriously considered as an astronomical observatory since the images hit important stones inside the solar temple throughout the year. The alignments at Mnajdra's lower temple with planets, especially the red planet Mars, is an intriguing fact . It seems that after all it was not only the Mayans or the Egyptians who either made reference or aligned some of their temples with either Venus or Mars respectively. The yearly alignment of Mars along the main passageway of the lower temple could have served as a means to indicate the beginning of a new-year. The other alignments of Venus, Mercury, the Moon and the Sun could have served as seasonal indicators or for festive religious ceremonies. The conversion of the measurements of the lengths of the temple apses into integral or near integral values taken at the Mnajdra temples, is more indicative of an ancient Maltese unit used during the construction of the temple, as shown by the calculations and results obtained.

Acknowledgements

I would like to extend my gratitude to Professor Frank Ventura from the University of Malta for his continuous interest in the astronomical part of this paper as well as being an excellent problem identifier during the preliminary drafts of this paper. Special thanks also to Professor Emeritus Maelee Thomson Foster of the University of Florida, for providing me with the necessary literature. Last but certainly not least a word of thanks to all at home especially my parents Agnes and Maurice without whose interest and support the purpose of this paper would not have been reached.

References

Agius George and Ventura Frank, "Investigation into the possible astronomical alignments of the Copper Age temples in Malta", University Press, 1980.

Formosa G., "The megalithic monuments of Malta", Skorba Publishing, Vancouver, Canada, 1975.

Hawkins G.S., "Astronomical alignments in Britain, Egypt and Peru", Philosophical Transactions of the Royal Society of London, A 276, (1974), page 160, as quoted in [2].

MacKie Euan, "Investigating the prehistoric solar calendar", Records in Stone-Papers in memory of Alexander Thom, University of Cambridge, 1988a, page 212-228.

MacKie Euan, "Investigating the prehistoric solar calendar", Records in Stone-Papers in memory of Alexander Thom, University of Cambridge, 1988b, page 226.

Micallef Paul I., "Mnajdra Prehistoric Temple – A Calendar in stone", Union Print Co. Ltd, 1990, page 10.

Micallef Paul I., "Mnajdra Prehistoric Temple – A Calendar in stone", Union Print Co. Ltd, 1992a, page 16.

Micallef Paul I., "Mnajdra Prehistoric Temple – A Calendar in stone", Union Print Co. Ltd, 1992b, pages 48-49.

Micell John, "A little history of astro-archaeology", Thames and Hudson, London, 1977.

Ridley Michael, "The Megalithic Art of the Maltese Islands", Poole, 1971, page 67.

Roy A.E., and Clarke D., "Astronomy: Principles and Practices", Bristol, Adam Hilger Ltd., 1977, pages 36-67.

Thom Alexander, "Megalithic Lunar Observatories,", Oxford, 1971.

Thomson Foster Maelee, "Orientation – A design determinant utilized as a means to explore", unpublished paper, 1999, page 7.

Wood John Edwin, "Sun, moon and standing stones", Oxford University Press, 1978a, page 30-50.

Wood John Edwin, "Sun, moon and standing stones", Oxford University Press, 1978b, page 40.

Wood John Edwin, "Sun, moon and standing stones", Oxford University Press, 1978c, page 50.

Wood John Edwin, "Sun, moon and standing stones", Oxford University Press, 1978d, page 51.

Wood John Edwin, "Sun, moon and standing stones", Oxford University Press, 1978e, page 94.

Wood John Edwin, "Sun, moon and standing stones", Oxford University Press, 1978f, pages 40-51.

Zammit Temistocles, "The Neolithic Temples of Hal-Tarxien", Malta Empire Press, 1929, page 17.

Weigart A., and Zimmermann H., "Concise Enclyopedia of Astronomy", Adam Hilger Ltd., 1976.

Hoskin Michael, Serio Fodera Giorgia, Ventura Frank, "The orientation of the temples of Malta", Journal of the History of Astronomy, 1992, vol xxiii, pp. 107-119.