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POSSIBLE ASTRONOMICAL MEANINGS OF SOME EL MOLLE RELICS NEAR THE ESO OBSERVATORY AT LA SILLA

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Abstact: This paper describes a peculiar, man-made circular stone structure, associated with the ancient rock engravings that are around the site of La Silla in Chile close to the European Southern Observatory, and are attributed to the El Molle Culture. Three stones of the circle, different from all the others, were likely to pinpoint the alignment of three bright stars close to the horizon, as seen from a specific vantage point inside the structure. The El Molle was the only period in which this alignment occurred significantly close to the horizon, moreover it was only in this epoch that it could also be associated with the transition from the warm to the cold season, a period of the year which was quite important for a society that supported itself by herding and farming.

Keywords: prehistoric stone circle, El Molle Culture, La Silla

1 INTRODUCTION

The slopes surrounding the buildings of the European Southern Observatory at La Silla are known to house several hundred rock engravings dating back to the pre-Columbian populations that once inhabited this region. Although precise archaeological studies are missing since none of these sites has been excavated, these petroglyphs are attributed to people of the El Molle Culture (Ballereau and Niemeyer, 1990), who around AD 300 had just abandoned their original lifestyle of hunting and gathering and developed more evolved settlements based on herding and farming. This Culture also produced the first ceramics made in the Norte Chico region. Between AD 700 and 800 the El Molle declined, giving way to a native cultural group called Animas, whose technical skills were presumably more advanced (see Castillo, 1989).

It is difficult to ascertain precisely the meaning of these rock engravings, but (at least) part of their content is clearly related to the daily life of herders. Among the many abstract and geometrical figures, there are several petroglyphs containing the simplified outlines of human figures and animals, the latter often gathered in large herds (e.g. see Figures 1 and 2).

One element of interest is the presence of various spirals scattered among the other figures, which are presumed to be schematic drawings of a snake—the most straightforward interpretation in some cases. Sometimes the spiral includes a straight line drawn outward starting from the centre, ending with a small bulge which could represent the head of the animal (see Figure 3). In other cases, however, where this feature does not clearly appear to be present (see Figure 4 and Niemeyer and Ballereau 1996), the spiral brings to mind the drawings of other ancient cultures widely scattered in space and time and commonly related to astronomical knowledge.[1] Though it was not our purpose to investigate this specific topic, such a characteristic feature made us wonder about possible, as yet undiscovered, astronomical aspects relating to the El Molle people. A circumstance of this kind would not be unusual for a community practising agriculture; nevertheless, we were not able to find any literary reference to this specific topic, even though

> These people had religious beliefs, and their lives were organized by means of ceremonies with the purpose of determining the seasons, or the beginning of the rainy and the dry seasons. (Ballereau and Niemeyer, 1996: 350; our English translation).

To our knowledge, the most recent and comprehensive publication about the El Molle engravings dates


Figure 1: Example of petroglyphs depicting stylized human and animal figures.


Figure 2: A large herd of animals (from http://www.eso.org/sci/facilities/lasilla/site/RockEngravings.html).

Figure 3: Example of spiral, probably representing a snake.

Figure 4: An example of spiral as an abstract shape (courtesy: Monica Rainer).

Figure 5a: The stone circle seen from Cerro las Vizcachas.

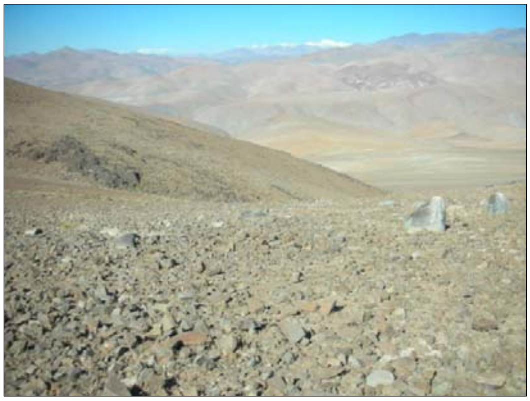


Figure 5b: A closer view of the stone circle. In the centre is the central stone, and to the right of it the two pillars.

to 1996 and is by the same authors of the above quotation, who also state that "Regarding the meaning of the … engravings, it escapes … a detailed study because of the lack of archaeological references." (Ballereau and Niemeyer, 1996: 350; our English translation).

2 THE STONE CIRCLE

One agglomeration of stone engravings is located in the region of Quebrada Los Tambos, a few hundred meters south-east of the dome of the 3.6-m Telescope (latitude –29.74°, longitude –70.67°, approximate elevation 2400m). These engravings can be reached quite easily in about half an hour, by walking along the pathway to Cerro Las Vizcachas. After about one kilometre the path turns right, and then left after another kilometre. After walking a further 200 meters along the pathway, you leave the beaten track and head down the gentle slope to the left, where there are two conspicuous upright stones that are taller than the average and are placed close to each other, like a couple of door jambs.

As you get closer to them, despite the great number of rocks scattered randomly all across the slope, it is easy to recognize the fact that these two stones are part of a larger structure forming a stone circle. This monument is made up of about ten flat stones composing a circle that is less than 20 metres in diameter, with another larger flat stone located in the centre (see Figures 5a, 5b). None of the stones forming the circle is engraved. It is also worth noting that all these stones are quite low, almost at ground level, except for the first two mentioned above, which are completely different in shape and are placed vertically. Finally, another stone is placed along the circumference more or less in the middle between the two 'jambs', but slightly closer to the left one, as seen from inside the circle (see Figure 6).

In the rest of this paper we will speculate on the significance of this distinctive structure and in particular on the interpretation of the three stones. We stress here, anyway, the artificial nature of the whole structure, which resembles a smaller-scale copy of other megalithic constructions found in several sites in Europe and around the world, and whose astronomical functions have been established beyond any doubt. Obviously no direct connection between this and the European structures is suggested; but we deem it interesting to note the alignments with the Sun of the Incan *huacas* discovered by Gullberg (2010) near Cuzco in Peru. It was the Incas who invaded the La Silla region about 400 years after the end of the El Molle Culture.[2]

3 ASTRONOMICAL ANALYSIS

Before giving a tentative astronomical explanation of the La Silla stone circle, we point out that our investigation was not the result of a planned expedition, but originated from a couple of excursions organized during an observing run at La Silla. Given the unexpected character of this discovery, it was not possible to conduct very accurate measurements because of the lack of time and suitable instrumentation. Nonetheless, it is our opinion that a possible astronomical interpretation of this structure can be suggested with a certain degree of accuracy.

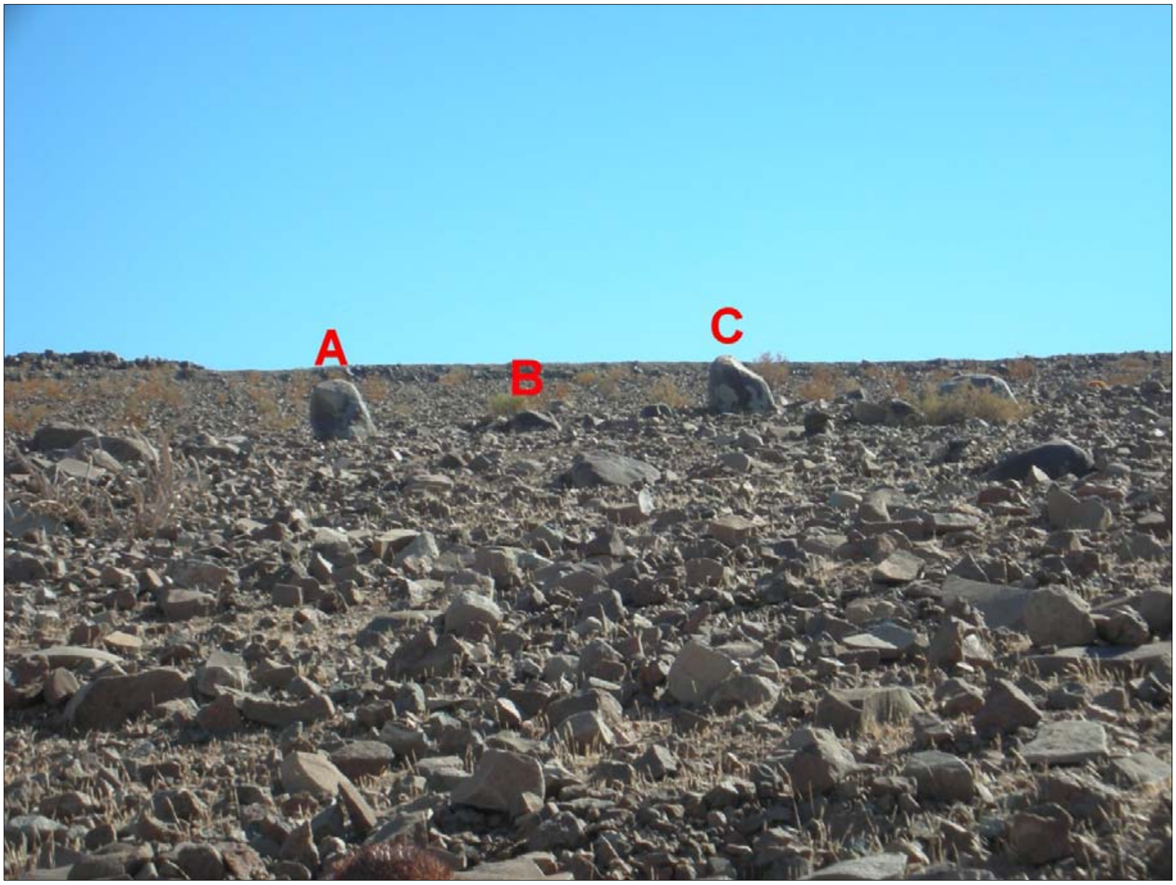


Figure 6: The two pillars (A and C) as seen from inside the circle, and the third lower stone in between (B).

To this aim, the first thing to do is to find the orientation of the circle, specifically of the 'entrance' formed by the two stones. Thanks to a simple magnetic compass, it could be established that the direction connecting the central stone with the middle of the entrance was South within ±10°.[3] Another noticeable thing is that the circle is placed in such a way that the entrance can look towards a direction where the slope is rising, but the horizon is relatively free from obstacles and quite horizontal. It seems plausible that such a position and orientation were chosen on purpose, since from here the profile rises both on the right and on the left.

Moreover, looking from the centre of the circle, the top of the two vertical pillars are quite accurately aligned with the horizon, as can be seen in Figure 6. This observing condition is obviously allowed because the structure is placed in such a way that the chosen direction is pointing toward the rising slope, and in our opinion it can hardly be considered accidental. At this point it is worth noting that it is plausible to assume that the horizon did not change very much because of human activities, since the pathway to Cerro Las Vizcachas follows the ridge line.

Given these premises, are there any possible astronomical interpretations of this configuration? First of all it should be noted that, though approximate, the estimated orientation is accurate enough to exclude any possible solar-related events, like sunrise during the solstices or at the equinoxes, simply because, in the Southern Hemisphere and at these latitudes, the Sun always crosses the horizon too far from these points. For similar reasons, one can very likely exclude any relation with the planets or the Moon, given the orientation of the Ecliptic. Therefore, it seems that the only plausible hypothesis could be the existence of a particular alignment of one or more stars with the stones of the circle, and most probably with the two vertical pillars. Moreover, if we accept that the stone circle relates to the El Molle Culture, then this hypothetical alignment would have occurred during the period spanning approximately from AD 100 to 800.

A couple of such alignments can be found for bright stars visible from the Southern Hemisphere: one is between α Carinae (visual magnitude –0.55, at present) and α Centauri (0.14), also known as Canopus and Rigil Kent, and the other one is between α Carinae and β Centauri (Hadar, magnitude 0.54). Before starting to explain the details of how we determined these alignments, it is worth noting that Antares, being a comparable bright star, could also be a good candidate, but it has to be excluded because of the configuration of the ridge. As indicated at the beginning of this Section, in fact the profile of the terrain rises on both sides of the pillars, so that Antares sets behind the mountain well before the dawn. In the following discussion we will get back to the importance of this particular point in the context of our interpretation.

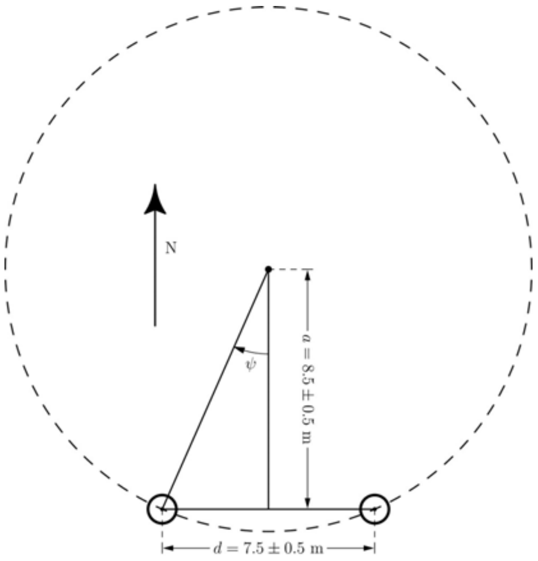


Figure 7: Schematic representation of the circle dimensions.

3.1 Tools Used in our Analysis

In order to predict the stellar positions in the past we implemented a FORTRAN code which invokes some routines of the SLALIB astronomical library (Wallace, 1994).[4] This provides an accuracy of better than 1 arcsecond for the calculation of precession throughout the time span of interest.[5]

For the computation of solar coordinates and the prediction of the sunrise time, we used the MDIC Solar Position Calculator.[6] The data resulting from these algorithms have been processed with Asymptote,[7] a powerful descriptive vector graphics language that provides a mathematical coordinate-based framework for technical drawings, which not only provided the tools for drawing the graphs, but also the algorithms to fit the ephemerides and find the data listed in the tables.

3.2 Orientation and Alignments

We measured the distance a from the centre of the circle (i.e. the central stone in Figure 7) to the mid-point between the two pillars, which we estimated to be 8.5 ± 0.5 meters, while the measured distance d between the two pillars was 7.5 ± 0.5 meters. For the geometry of Figure 7, this gives an angular distance, 2ψ, of 47.6° ± 5.3°, using the formula

$$\psi = \arctan\,(d/2a) \qquad (1)$$

The angular separations between the two pairs of stars during the historical period associated with the El Molle Culture was about 57.25° for Canopus and Rigil Kent and 55.5° for Canopus and Hadar (the precision is sufficient given the accuracy of our measurements). These two quantities are compatible with 2ψ at the 2σ level, but more stringent constraints can be fixed by other kinds of estimations, somewhat reducing the problems arising from the low precision of our measurements.

One is the determination of the alt-azimuthal coordinates of these stars when they become aligned with the horizon. Table 1 provides a list of these coordinates at the time of the alignment for the eight centuries between AD 100 and 800, where it can be seen that the alignment of Canopus with Rigil Kent finds Canopus 28-31° eastward from the south, and Rigil Kent 27-30° to the west, depending on the chosen year, while for the alignment with Hadar we have the former at 26-29° eastward from south and the latter at 27-30° westward.[8] Meanwhile, the orientations of the left (more eastward) and right pillars are +23.8°+/–10° ± 2.65° and –23.8°+/–10° ± 2.65° (to the west), respectively (+/–10° accounts for compass error). These constraints have more or less the same significance as the previous computations of the angular separations, with the additional information that the directions of the stars are approximately compatible with those of the stones; but a more interesting constraint comes from their altitude.

Table 1: Alignment data of the two pairs of stars.*

Year	Canopus		Hadar			Canopus		Rigil Kent		
AD	*A*	*h*	*A*	*h*	Δ	*A*	*h*	*A*	*h*	Δ
100	+153°56'	+3°12'	+209°33'	+3°12'	55°35'	+152° 51'	+4° 06'	+209°58'	+4° 06'	57°03'
200	+153°28'	+3°32'	+209°05'	+3°32'	55°35'	+152° 20'	+4° 30'	+209°31'	+4° 30'	57°06'
300	+153° 00'	+3°52'	+208°38'	+3°52'	55°35'	+151° 50'	+4° 54'	+209°05'	+4° 54'	57°09'
400	+152° 32'	+4°14'	+208°11'	+4°14'	55°35'	+151° 20'	+5° 19'	+208°41'	+5° 19'	57°12'
500	+152° 05'	+4°36'	+207°45'	+4°36'	55°35'	+150° 51'	+5° 44'	+208°17'	+5° 44'	57°15'
600	+151° 39'	+4°58'	+207°20'	+4°58'	55°35'	+150° 23'	+6° 10'	+207°54'	+6° 10'	57°18'
700	+151° 13'	+5°21'	+206°56'	+5°21'	55°35'	+149° 56'	+6° 36'	+207°32'	+6° 36'	57°21'
800	+150° 48'	+5°44'	+206°33'	+5°44'	55°35'	+149° 29'	+7° 03'	+207°10'	+7° 03'	57°24'

*Alt-azimuthal positions and angular separations (Δ) of the two couples of stars at the alignment at different years, from 100 to 800 AD. The left and right data refer to the alignment of Canopus with Hadar and with Rigil Kent, respectively. The altitude *h* is referred to the sensible horizon, which takes into account the elevation of the observing place (ca. 2400 m) and adds approximately 2° to the value of *h* referring to the geometrical horizon. This is done consistently with the sunrise data. However, the listed values do not consider the slope of the terrain, whose effect is to raise the horizon, and therefore to decrease the apparent altitude, as discussed in the article.

Table 2: Estimation of the distances between the three stones and their ratios based on pixel measurements of three different kinds of fiducial points: extremes at the base, extremes at the top and the single highest point of each stone. In the first two cases we have computed the distances (in pixels) using the average values $<x>$ of the two extremes x_{left} and x_{right}. The δ_x columns are the estimated uncertainties, in pixels, of the measured pixel position of the left column. The σ_x columns are the estimated uncertainties on $<x>$ obtained by standard error propagation. The ratio and its estimated error are shown in the last row.

	Base points						Top points						Highest point	
	x_{left}	δ_x	x_{right}	δ_x	$<x>$	σ_x	x_{left}	δ_x	x_{right}	δ_x	$<x>$	σ_x	x	δ_x
A	761	5	898	1	829.5	2.5	748	3	838	10	793.0	5.2	815	5
B	1224	2	1340	3	1282.0	1.8	1233	5	1278	30	1255.5	15.2	1255	5
C	1714	10	1860	3	1787.0	5.2	1708	5	1768	40	1738.0	20.2	1744	4
d_{AB}/d_{AC}	0.473 ± 0.003						0.489 ± 0.019						0.474 ± 0.006	
$<d_{AB}/d_{AC}>$ (weighted)	0.473 ± 0.003													

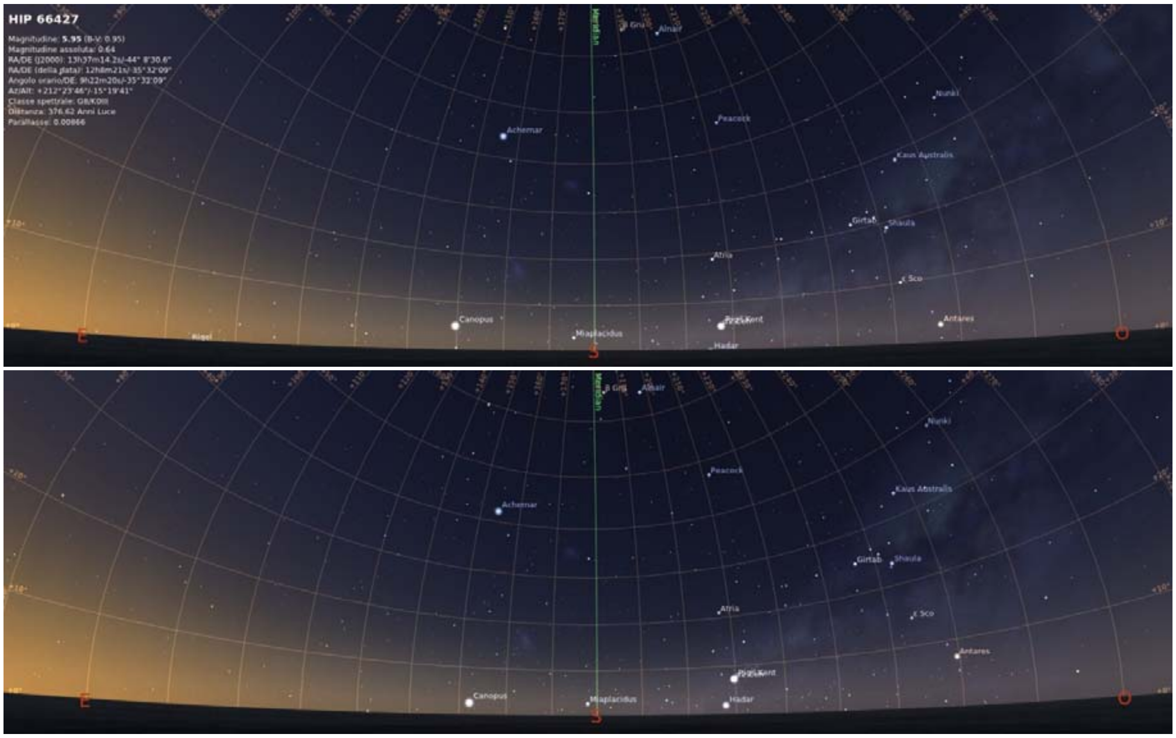
Table 3: Alt-azimuthal positions of Miaplacidus at the alignment with Hadar (left) and Rigil Kent (right) in different years from 100 to 800 AD. The last two columns give the angular separation between Canopus and Miaplacidus, and the ratio between this separation and that between Canopus and the farthest star. The same consideration of Table 1 about the altitude *h* applies here.

	Miaplacidus				*Miaplacidus*			
Year	*A*	*h*	Δ_{AB}	Δ_{AB}/Δ_{AX}	*A*	*h*	Δ_{AB}	Δ_{AB}/Δ_{AX}
100	+179°30'	+3°30'	25°33'	0.46	+178°25'	+3°33'	25°33'	0.45
200	+179°02'	+3°53'	25°33'	0.46	+177°55'	+3°57'	25°33'	0.45
300	+178°35'	+4°17'	25°33'	0.46	+177°26'	+4°21'	25°33'	0.45
400	+178°08'	+4°41'	25°34'	0.46	+176°57'	+4°47'	25°34'	0.45
500	+177°42'	+5°06'	25°34'	0.46	+176°29'	+5°13'	25°34'	0.45
600	+177°17'	+5°31'	25°34'	0.46	+176°02'	+5°39'	25°34'	0.45
700	+176°52'	+5°57'	25°35'	0.46	+175°36'	+6°07'	25°35'	0.45
800	+176°28'	+6°23'	25°35'	0.46	+175°10'	+6°35'	25°35'	0.45
	Alignment with Hadar				Alignment with Rigil Kent			

When referred to the alignment of Canopus and Rigil Kent, their altitude over the *sensible horizon*, which takes into account the elevation of the observing place, is about +4° 06′ to +7° 03′ (again depending on which year we are considering), while for the alignment between Canopus and Hadar they lie in the range 3° 12′ to 5° 44′. It is interesting to compare these altitudes with the actual altitude of the horizon, given by the mountain ridge, as seen from the stone circle. One can estimate that the distance of the structure from the ridge is between 100 and 200 meters, while the rise is around 10 meters, which implies an altitude of the horizon between 2.8° and 5.7°. In other words, the pairs of stars were close to the visible horizon at the time of their alignment. It should be noted that the precession makes these conditions disappear in years preceding the period examined (the stars were too low) and at the present day (the altitude is >10°).

Let us now consider a further element of interest concerning another stone positioned in a particular way, which we mentioned earlier. This is a stone that is higher than those forming the circle, but is lower than the two pillars, and is placed between them but a little closer to the left pillar (Figure 6). We tried to understand if this shift could be regarded as significant, so using our pictures we measured the distances (in pixels) between the three stones in three different ways: by considering the positions of their a) bases, b) tops, and c) highest points. The results of such estimations are reported in Table 2, and if we call the left and right pillars A and C respectively, and the middle stone B, the weighted mean of the three ratios d_{AB}/d_{AC} is 0.473 ± 0.003. It seems, therefore, that the third stone was placed on purpose a little to the left of centre. Quite surprisingly, it seems that the star Miaplacidus (β Carinae) can take the place in the sky that B has in the stone circle. It is still quite bright—at visual magnitude 1.67 it is the brightest star in between the two stars of the pair—but at the same time is significantly fainter than the other two, regardless of whether C is associated with Rigil Kent or Hadar, and the ratio between the corresponding angular distances in the sky is about 0.45 for the former and 0.46 for the latter (see Table 3).

We want to stress here the different nature of this kind of coincidence. This is, in fact, a relative measurement that holds irrespectively of the uncertainties of the previous estimations on the precise absolute orientation of the two pillars. Obviously this correspondence would be significant only if the middle star were conveniently aligned with the others. In fact, if we consider the time of alignment of the main pair with the horizon, we can see that the altitude of Miaplacidus is quite similar: it goes from 3° 30′ to 6° 23′ if we identify Hadar as the second star, and from 3° 33′ to 6° 35′ in the case of Rigil Kent. In the first case, Miaplacidus is a little lower than the two brighter stars, while in the latter case the three stars are almost perfectly aligned. In add-



Figures 8a and 8b: From Stellarium (http://www.stellarium.org) the alignments among the three stars in 400 AD in the case of Rigil Kent (a) and of Hadar (b). These renderings should only be viewed as graphical aids to aid the interpretation. Actual computations have been made with the software reported in Section 3.1, and these, and the plots given in Figures 9a and 9b, should be considered for a more precise evaluation.

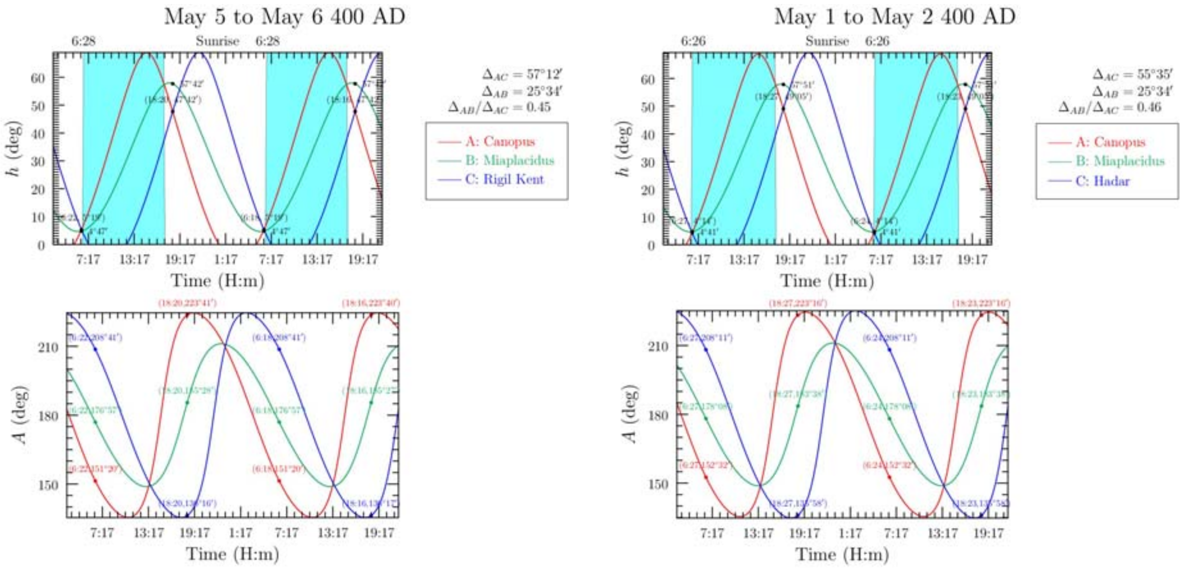


Figure 9a (left) and 9b (right): Two examples of how the graphical tools have been used to find the coordinates and time of the alignments in the case of Rigil Kent and of Hadar. In each figure, the top panel plots the altitude relative to the sensible horizon (see Table 1) of the three stars vs. time (approximately two days, negative altitudes are not shown). A fit of each curve provides the intersection points between stars A and C, which give the times and the altitude at the alignment for each day. A similar fit is used to find the altitude of B at the time of alignment. The filled areas represent the daylight. These data have been obtained by the MDIC Solar Position Calculator with the following input: starting date, March 01, end date August 01 (same year), time interval between two points, 10 minutes, site location: latitude –29.74°, longitude –70.67°, elevation 2400 m, time zone, –4.711333. The bottom panel, instead, shows the azimuths, and their values at the time of alignment are obtained with similar fits. At the top, to the right of each plot, the angular distances between A and B and A and C, and their ratios, are reported.

ition to this, it has to be noticed that Miaplacidus is a circumpolar star now and was in the past until the El Molle period, but this characteristic did not apply in earlier times: two thousand years ago its lowest altitude was <3° (i.e. still circumpolar, but it probably was below the horizon as seen from the stone circle), while some centuries before this it was no longer a circumpolar star.[9]

Table 4: Summary of the astrometric data for the four stars (J2000.0) from the Hipparcos catalogue (Perryman et al. 1997; van Leeuwen 2007) (New Reduction, Vizier code: I/311/hip2). Spectroscopic and photometric data (radial velocities and magnitudes) from Anderson and Francis (2012). Extended Hipparcos Compilation, Vizier code: V/137/XHIP.

Star	α	δ	μ_α (mas/yr)	μ_δ (mas/yr)	π (mas)	v_r (km/s)	V
Canopus (α Car) HIP 30438	6h 23m 57.1s	–52° 41' 44.4”	19.93 ± 0.52	23.24 ± 0.69	10.55 ± 0.56	20.3	–0.55
Rigil Kent (α Cen) HIP 71683 A	14h 39m 36.5s	–60° 50' 02.4”	–3679.3 ± 3.89	473.67 ± 3.24	754.8 ± 4.11	–21.4	0.14
Hadar (β Cen) HIP 68702 A	14h 03m 49.4s	–60° 22' 22.9”	–33.27 ± 0.50	–23.16 ± 0.41	8.32 ± 0.50	5.9	0.54
Miaplacidus (β Car) HIP 45238	9h 13m 12.0s	–69° 43' 01.9”	–156.47 ± 0.14	108.95 ± 0.11	28.82 ± 0.11	–5.1	1.66

In summary, it seems that during the El Molle period, a triple alignment existed of three bright stars, but with a possible uncertainty as to whether α or *β* Centauri should be considered part of the group. Whatever the choice, this group of stars was visible just above the horizon at the time of day when they were parallel to it, and Figures 8a and 8b give an artistic impression of this event. This triple alignment is reproduced and can be identified with significant accuracy for an observer standing at the centre of the stone structure, by using the three stones of the circle, whose dimensions, moreover, might be connected to the stars' relative magnitudes. This astronomical event was not visible before the period of interest, because it occurred below the observed horizon, and it is much less significant at the present day, because of the relative distances of the three stars and because of the increased altitude at which this event occurs. Table 4 summarizes the data for the four stars taken from the Hipparcos Catalogue, while Figures 9a and 9b give an example of how to interpret the plots used to exploit the data coming from the software listed in Section 3.1.

4 POSSIBLE FUNCTION OF THE STONE CIRCLE

Having found a noticeable connection of the stone circle with an astronomical event, though with a certain degree of approximation, it is logical to explore the existence of a practical function for such a structure and how it was used by the people who built it. Moreover, since the relatively low accuracy of the measurements makes our deductions less compelling, the discovery of a possible role for this structure could also provide further evidence supporting our astronomical interpretation.

It has to be stressed that the orientation of the line connecting the three stars is, in a certain sense, mainly ruled by the Earth's rotation around its axis, and therefore this particular alignment with the horizon does indeed occur every day. The two other motions of the Earth affecting this astronomical event are precession and the orbital motion of the Earth around the Sun. The former, as we pointed out in the previous Section, influences the altitude of the alignment with respect to the horizon, while the latter determines the time of day when this event is visible, so that in some parts of the year it may be impossible to see it because it happens during daylight, while on other dates it will happen during the night.

The case of the heliacal rise of Sirius can give us some useful hints for our investigation. It is well known in fact that for the Egyptians this event signalled the period of the year when flooding by the Nile River occurred, which was a fundamental date in their calendar because of several activities connected with the farming needs of their society. Following this suggestion, we searched for the periods of the year when the alignment occurred at dawn or at twilight.

It was easy to discover that over the period of interest during the El Molle Culture the alignment coincided with the dawn between the end of April and the first half of May (see Table 5 and Figure 9a and 9b for a more detailed explanation on how these data have been obtained), which is quite an interesting coincidence since during this period of the year the winter was approaching. According to Niemeyer and Ballereau (1996) in the past the climate was different to the present one: rain was more abundant, feeding non-permanent water courses, and this region was much less arid than it is today. The surviving traces of human occupation scattered all around Cerro La Silla support this hypothesis. It is therefore possible that the farmers of the El Molle Culture herded their livestock (whose existence is testified by the rock engravings, as shown in Figure 2) here and on other high ground pastures during the warm season, and only descended to the plains when the winter was approaching. In this scenario, the occurrence of the stellar alignment at dawn would have indicated the right moment for this annual migration. The stone circle therefore would have helped the farmers to pinpoint this event easily and without any doubt, and could well pertain to a culture which—as with many other prehistoric populations around the world—probably held ceremonies to acknowledge the changing of the seasons (Ballereau and Niemeyer 1996). If this interpretation is correct, then the time at which the alignment occurs at dusk is much less significant because it happens in the second half of October, when the cattle might have just started populating the pastures. In this case, an astronomical event heralding the right time for the migration to higher ground should have been determined beforehand from the plains.

5 CONCLUSIONS

In this paper we proposed that archaeological relics close to the La Silla Observatory can be interpreted in an astronomical sense. In particular, the most intriguing find was a circle of stones, three of which are clearly distinct from all the others. The site is

Table 5: Dates at which the triple alignment occurred at dawn, and the hour of the dawn for the corresponding year. The dates listed here are expressed in the Proleptic Gregorian calendar, which is closer to the actual season of the year. During the range of interest for this table, the differences with the (historical) Julian calendar went from –2 days to 4 days. In order to choose the day, we adopted the criterion that the alignment should occur at least 2 minutes before dawn. Different criteria, however, cannot change the date by more than one or two days.

	Alignment at dawn with					
	Hadar			*Rigil Kent*		
Year	Day	Hour	Dawn	Day	Hour	Dawn
100	29 Apr	06:19 AM	06:24 AM	01 May	06:20 AM	06:25 AM
200	30 Apr	06:22 AM	06:24 AM	03 May	06:20 AM	06:26 AM
300	02 May	06:21 AM	06:26 AM	04 May	06:23 AM	06:27 AM
400	02 May	06:23 AM	06:26 AM	05 May	06:28AM	06:28 AM
500	04 May	06:22 AM	06:27 AM	06 May	06:26 AM	06:29 AM
600	05 May	06:25 AM	06:28 AM	08 May	06:25 AM	06:30 AM
700	07 May	06:24 AM	06:29 AM	09 May	06:28 AM	06:30 AM
800	07 May	06:27 AM	06:30 AM	10 May	06:28 AM	06:32 AM

attributed to the El Molle Culture which dominated the region from the first centuries of our era to about AD 800, and we showed that during this period the three stones seem to reproduce, or indicate, the positions of three bright stars (Canopus, Miaplacidus, and Rigil Kent or Hadar) which from the centre of the circle could be observed almost perfectly aligned with the horizon. The accuracy of our measurements does not allow a confirmation of this interpretation beyond any doubt, but different independent coincidences seem to support it. For example, this alignment does not concern a single star, but three, and the alignment was visible only during the historical period of the El Molle Culture because in earlier epochs the stars in question were below the horizon whereas today they are in a much less significant position well above it. Moreover, during the El Molle epoch this region was less arid than now, and probably supported pasture that was grazed by livestock during the summer months. We discovered that during this prehistoric period this astronomical alignment happened at dawn when the warmer months were starting to give way to a colder period, signalling to the farmers that it was time to drive their livestock from the high grounds down to the plains. Future, more accurate, measurements at the stone circle site could provide further evidence for this interpretation.

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7 NOTES

1. The astronomical interpretation of the spiral, and its presence in stone carvings attributed to many prehistoric cultures, is well known. For example, carved spirals with a well-established astronomical meaning are found in Malta and at Newgrange during the fourth millennium BC, but also in New Mexican sites almost five thousand years younger (see Sofaer et al., 1979 and the references in http://www.solsticeproject.org/research.html, for papers about the New Mexican sites).
2. *Huacas* were a kind of sacred shrine of the Incas, and were represented by a particular location or object, and regarded to "… manifest the superhuman." (Gullberg, 2010). Where *huacas* were represented by alignments of carved stones or pillars on a mountain ridge these were often associated with significant positions of the Sun, as during the solstices. But some stones were classified as "… non-astronomical rocks …" by Gulberg, because no alignment with the Sun could be found for them. It should be noted, however, that the title of Gullberg's paper clearly indicates that any kind of astronomical alignments differing from those with the Sun were considered beyond the scope of his research.
3. The measurement was made in 17 April 2011, when the magnetic declination at the place was approximately 38′ (NOAA: http://www.ngdc.noaa.gov/ geomagmodels /struts/calcDeclination), i.e. much less than the accuracy of the compass.
4. The SLALIB code can be found at the Starlink project URL http://starlink.jach.hawaii.edu/starlink.
5. Given the accuracy of the measurements, nutation effects have not been included.
6. Measurement and Instrumentation Data Center, of the National Renewable Energy Laboratory (NREL). See http://rredc.nrel.gov/solar/codes and algorithms/solpos/ for the C source and http://www.nrel.gov/midc/solpos/solpos.html for the web interface to the binaries.
7. http://asymptote.sourceforge.net/
8. About the possibility that Antares could also be considered by the ancients, one should notice from Figure 8a that this star is more or less aligned with Canopus and Rigil Kent, but its azimuth is >65°. Because of the profile of the ridge (which is not reproduced in our figure) this star would not have been visible during the alignment. This is further indirect evidence in support of our thesis.

9. Also the alignment condition has changed with time because of the different proper motions of these stars. While in the past Miaplacidus was aligned with Canopus and Hadar, at present the alignment with Rigil Kent is better.

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