THE POSSIBLE ASTRONOMICAL FUNCTION OF THE EL MOLLE STONE CIRCLE AT THE ESO OBSERVATORY, LA SILLA. II: THE UPDATED MEASUREMENT CAMPAIGN

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Abstract: This paper reviews and updates the accounts of a previous article discussing the possible astronomical significance of a peculiar, man-made circular stone structure, located close to the European Southern Observatory in La Silla, Chile, and attributed to the El Molle culture. Thanks to further, higher-accuracy measurements *in situ*, we can confirm some of the original hypotheses and dismiss others, upholding the main tenets of the original work.

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

1 INTRODUCTION

In a previous paper (Bernardi et al., 2012) we described a peculiar, man-made circular stone structure sited in La Silla, Chile, near the European Southern Observatory, which can be attributed to the El Molle Culture. We proposed that these archaeological relics be read in an astronomical sense. Our interpretation stood on a certain number of facts and measurements, as summarized below.

- Three of these stones looked clearly different from all the others, and could arguably pinpoint the horizontal alignment of three bright stars (Canopus, Miaplacidus, and Rigil Kent or Hadar) close to the horizon, as seen from a specific vantage point inside the structure.
- This astronomical alignment seemed to be most relevant during the El Molle period (i.e. approximately between AD 300 and 800) to which the structure can be attributed, as inferred from the ancient engravings spread all around the place; in particular, this alignment did not occur in earlier epochs due to precessional effects, and is less evident at the present time because the elevation from the horizon of the 3-star alignment is higher than it was in the El Molle period.
- We discovered that it was only during this prehistoric epoch that this astronomical event happened in connection with a significant time of the year; in particular, the stars' alignment was visible at dawn during the end of the austral autumn season, when the warmer months were starting to give way to a colder period.
- We interpreted this temporal coincidence by noticing that: (i) El Molle society was based mainly on farming and herding; (ii) during their epoch this region was less arid than now and therefore probably was able to support pasture grazed by livestock during the summer months. With these hypotheses, the alignment could be important for signalling to the herders that it was time to drive their livestock from high ground down to the plains.

The main weak point of this interpretation was the low accuracy of our measurements, which did not allow us to strengthen our theses, even though a certain number of different independent coincidences seemed to support it. Recently, more accurate measurements at the stone circle site have provided further evidence to this end.

2 THE NEW MEASUREMENTS

During a recent observing run at La Silla we were able to make an additional series of measurements, which we specifically planned in order to achieve better accuracy. Our main goal was to re-measure the principal data on which we based our thesis: (1) the direction of the stones with respect to the south; (2) their relative angular distance; and (3) the height of the horizon.

The best instrument for these kinds of measurements is a theodolite, but we could not bring one with us, so we had to resort to two alternative techniques, using the tools at our disposal: a 20-meter tape, a plumb line, a compass, a goniometer of 20-centimeter radius and a ball of thin string. None of these instruments was particularly sophisticated or expensive but, as will be explained in the text, with the exception of the compass and the determination of the direction of south, the accuracy of the measurements was not limited by the instruments but rather by an intrinsic uncertainty in the definition of the quantities to be measured. The tape had a precision of 1 cm, and that of the goniometer can be conservatively assumed to be 1°. Finally, although the precision of the compass also was nominally 1°, we judged that this could not be actually reached because of the difficulty of making the measurements and the thickness of the needle. An independent calibration provided a more conservative value of 4° for the accuracy of the compass.

If a theodolite had been at our disposal, our measures still would have only been accurate to a few degrees because of the size of the landmarks (i.e. the stones forming the structure). It is also reasonable to assume that the people who constructed the stone structure did not need or wish to obtain better accuracy, given their supposed purpose and, possibly, their skill. However, our previous measurements were in error by about 10° with regard to the direction of south and >5° for angular distances; therefore, we had a reasonable margin for improvement.

Firstly, and most importantly, we wanted to determine the direction of south through the use of the compass. As expected, south is positioned approximately in the middle between stones A and C (see Figure 1), with an uncertainty of about four degrees. Such an error is due to the measurement procedure rather than to the intrinsic accuracy of the instrumentation at hand. In fact, in order to use the goniometer to determine the angular direction of the reference points, it was first necessary to align the former with the direction of south using the compass. The difference in the dimensions of the two devices—the compass was much smaller than the goniometer—and the difficulty of keeping a stable orienttation were actually the main sources of error.

Once the direction of the south was established and the goniometer was aligned accordingly, we proceeded to determine the angular distances of the stones of the structure from the south. While doing this, we realized that the stone in the middle, the one called B in the previous paper (and see Figure 1 below), is not as significant as originally thought because there are similar ones nearby. This misjudgement was caused by a wrong interpretation of the previous campaign's photographs, which were taken from different vantage points with respect to the central boulder. Consequently, we determined the angular distance of the two principal stones from the south by stretching the string between the center of the goniometer and each pillar.

In this regard, it was immediately evident that the accuracy of the goniometer, which can be estimated to 1°, was higher than the uncertainty due to the dimensions of the stones, which therefore constituted a natural limitation in the definition of the alignment. This was especially true for

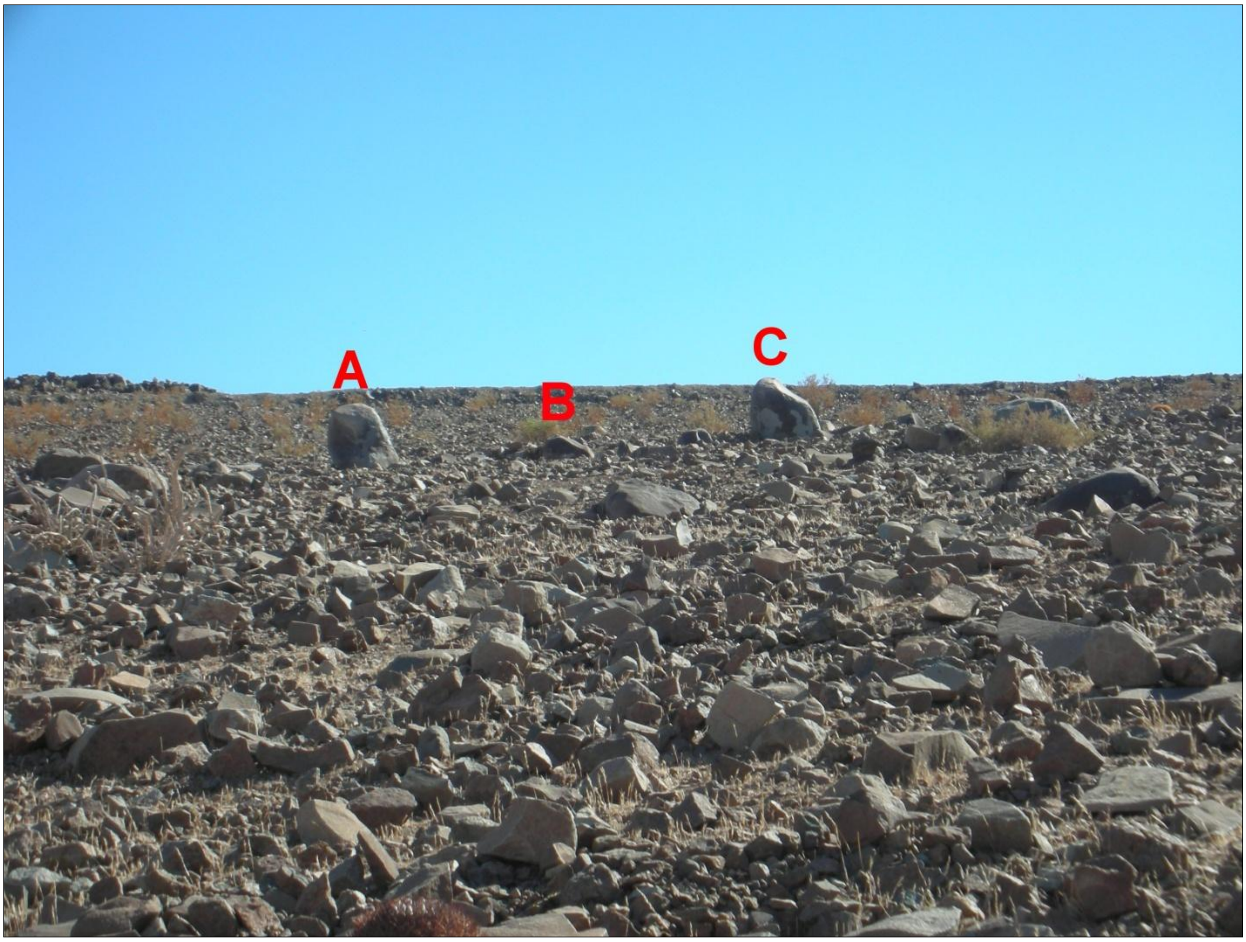

Figure 1: The two pillars (A and C) as seen from inside the circle, and the third lower stone in between (B).

stone A, whose most eastern side (the 'external' one) was 33 ± 1° from the estimated direction of south, while the eastern side (the 'internal' one) was 30 ± 1°.[1] Therefore, the absolute orientation of the pillars encompasses a range of values that account for the physical dimension of the stones plus the instrumental errors.

The additional uncertainty due to the determination of south has to be added to this estimation with the same considerations made in Bernardi et al. (2012), i.e., by keeping in mind that the uncertainties in the absolute orientation of the two pillars are not independent, but are exactly anti-correlated with respect to this error. In other words, if south would be, for example, 2° towards stone A with respect to our estimation, then the absolute direction of A would be 2° smaller, while that of C would be 2° larger.

With these indications in mind, the reader can now understand what is meant by reporting angles in the range [30 ± 1, 33 ± 1] ± 4° east for stone A and [21 ± 1, 22 ± 1] ± 4° west for stone C.

The uncertainty in the absolute direction of south does not affect the estimation of the angular separation between the two stones, which therefore can be given in the range [51 ± 1.4, 55 ± 1.4]°.

The same angular distance is confirmed by another check we carried out which was to use the tape to measure the distance of the two stones from the central one (O) and the distance from A to C. Once again, the largest contribution to the measurement errors came from the difficulty of establishing a single, well-defined, reference endpoint for the connecting segments because of the physical dimensions of the stones. Similarly to the case of the angular measurements, we resorted to determining a 'viability range', by considering two triangles: one with the internal sides of pillars A and C that gave the lowest limit of the range, and the other one with the external sides for the highest limit. All of the distances from O were taken from a single point, the central stone. In other words, we neglected the dimensions of the central stone in our evaluation of the uncertainties of the distances, just like we did for the angular measurements. This was not because this stone is small, but because it is reasonable to assume that the reference point is more or less at the center of this stone and not along one of its sides. In other words, different from the other pillars, in the case of O it was easy to single out a reference point with an uncertainty much smaller than the dimensions of the stone itself.

Regarding the uncertainties of the length measurements, the tape had a nominal accuracy of 1 cm, but this was much better than the accuracy that was actually reasonable to assume. Once again, in fact, we had to face the problem of determining the actual edges of stones A and C, whose shapes are not very regular, and for this reason the accuracy had to be considered ten times larger than the nominal one, that is about 10 cm.

The triangle formed with the external borders had sides AO = 9.40 ± 0.10 m, CO = 9.00 ± 0.10 m and AC = 8.40 ± 0.20 m, and, by means of Carnot's formula for triangles and error propagation, this gives an angular separation of 54.3 ± 1.5°. By comparison, the triangle formed with the internal border had AO = 9.80 ± 0.10 m, CO = 8.50 ± 0.10 m and AC = 7.90 ± 0.20 m, for an angular separation of 50.5 ± 1.5°.

Summarizing, the range we obtained from the length measurements was [50.5 ± 1.5, 54.5 ± 1.5]°, which is perfectly compatible with that obtained from the angular measurements. It should be noted that, while in principle we could get better results with the length measurements because of the potentially higher accuracy of the measurement instrument, in the end the two procedures are at the same level because the real and largest source of uncertainty, as already stated, comes from the dimensions of the stones and from the difficulty of identifying a single, precise reference point, as in the case of the borders.[2]

3 COMPARISON WITH PREVIOUS ESTIMATIONS

Let us see how these results compare with the previous ones and whether they support the hypotheses presented in the earlier paper.

In Bernardi et al. (2012) the angular distance between the two pillars was computed using a rough estimation of the distances, and assuming that they formed an isosceles triangle with the central boulder. The estimation was 47.6 ± 5.3°, which, because of the approximate assumptions we used, is significantly smaller than our current result, although still compatible with it. The most significant comparison, in fact, is with the angular distances between Canopus (the star which should be aligned with stone A) and Hadar or Rigil Kent (stone C), as computed in the same paper.

The angular distance between Canopus and Hadar remained stable at 55° 35′ in the years AD 300–800, i.e. that indicated by historians as the most probable period of persistence of the El Molle culture (see Ballereau and Niemeyer, 1990), while that between Canopus and Rigil Kent varied from 57° 9′ in AD 300 to 57° 24′ in AD 800. These angular distances compare quite well with our new estimations. In particular, the former is perfectly compatible with the largest value of the range, while the latter is compatible at the 2σ level. It is of no use to consider the errors of these astronomically-computed quantities since their error is at least at the arcsecond level, which is orders of magnitude smaller than that of the in-field measurements.

Meanwhile, the situation regarding the absolute directions of the two stones appears at first sight to be less favourable. As can be noted from Table 1, where a summary of the values given in Bernardi et al. (2012) is presented, the estimated ranges of [30°, 33°] E and [21°, 22°] W for stones A and C do not compare very well with our expectations. For example, we can see from this table that the absolute orientation of Canopus (i.e. that of stone A) as computed with the SLA LIB software, would range from 27° E to 29° E if stone C is identified with Hadar, and from 28° E to 30.5° E if stone C is identified instead with Rigil Kent, both of which are quite different from the expected values of [30 ± 1°, 33 ± 1° E]. Similar, or even worse, considerations hold when comparing the ranges of Hadar and Rigil Kent with the [21 ± 1°, 22 ± 1°] W range estimated for stone C.

Nevertheless, as in the previous paper, the error in determining south has to be considered. This is quite important in principle as it can shift the reference frame, so a misalignment of south reflects in opposite ways on the directions of the two stones.

In this regard, the error due to the magnetic declination should be taken into account. In the previous paper this was about 15 times smaller than the estimated error of the compass, so it was cited but had no relevance. In this case, however, the ratio is much smaller (i.e. about 4) so it is worth a more detailed examination. The magnetic declination is the angle formed by the direction of north indicated by a magnetic compass and that of the geographical north. The coordinates of the stars refer to the latter, so that the directions of the pillars found with respect to the magnetic south should be corrected by this quantity.

Obviously the magnetic declination can be determined by observations, but since it varies both in space and in time, several geophysical models have been developed, from which an estimation of this angle can be obtained where no explicit measurements are available. There are different websites that provide the outcome of such models for an arbitrary location on the Earth and for a limited time span. We chose to use the service provided by the NOAA National Geophysical Data Center (http://www.ngdc.noaa/geomag-web/#declination) whose WMM 2010 model gives 0° 55′ E for the coordinates of La Silla at the time of our measurements (24 December 2012), while the IGRF model gives 0° 57′ E, both with an estimated accuracy of about 30′. The meaning of these values is that the direction of geographical north is about 1° to the

Table 1: The orientation of the candidate stars at the beginning and end of the historical period of interest (after Bernadi et al., 2012). Since both Hadar and Rigil Kent are good candidates for the alignment with stone C, columns 2 and 3 give the orientations if Canopus is aligned with Hadar, while columns 4 and 5 refer to the case of Canopus and Rigil Kent.

Year	Canopus	Hadar	Canopus	Rigil Kent
AD300	27° E	28.5° W	28° E	29° W
AD800	29° E	26.5° W	30.5° E	27° W

left (i.e. westward) with respect to that shown by the compass. This also means that the direction of the geographical (and astronomical) south is about 1° to the left (i.e. eastward), and therefore that the estimated ranges corrected for the magnetic declination are then [29 ± 1°, 32 ± 1°] E and [22 ± 1°, 23 ± 1°] W.

This literally goes ‘in the right direction’, but still one has to consider the largest source of error, which is the accuracy of the compass. Although this has improved with respect to the 10° of the previous measurements, it is still quite large, i.e. about 4°, as discussed in the previous Section.

Taking into account this error, it is easy to see that if the actual south were some degrees westwards with respect to our estimations, then the absolute directions of the pillars also would be compatible with the computed stellar positions (see the first row in Table 2). Obviously, if the south had been misaligned by the same amount but in the opposite direction, that would probably have been a decisive indication against our hypotheses (see the second row in Table 2).

The last measurement to be performed was the height of the sensible horizon. Once again we used the goniometer and the rope to determine the visible horizon from the observation point. We then used a plumb line in order to align the goniometer to the vertical of the place and find the astronomical horizon, thus allowing us to use it as a rudimentary clinometer, again by ‘pointing’ at the visible horizon with a piece of string stretched from the center of the instrument. With this technique, the height of the sensible horizon was 5 ± 3°. The measurement accuracy was mainly limited by the difficulties of aligning the goniometer with a plumb line and establishing visually the horizon. In this case, once again a theodolite would have provided a more accurate measure; nevertheless, our re-

Table 2: Estimated absolute directions of the two stones, A and C. The values in Section 2 have been first corrected for the magnetic declination. We then consider that the uncertainty on the determination of the South was about 4° (see again Section 2). The two lines then represent the resulting values when this error is applied in the two extreme and opposite cases.

South (°E)	A (°E)	C (°E)
−4	[25 ± 1, 28 ± 1]	[26 ± 1, 27 ± 1]
+4	[33 ± 1, 36 ± 1]	[18 ± 1, 19 ± 1]

sults confirm those already presented in the previous paper, but now with greater accuracy.

4 CONCLUSIONS

In this paper we present further measurements made at La Silla on the stone structure mentioned in Bernardi et al. (2012). With respect to the conclusions drawn in that paper, after this latest campaign some statements have to be rejected, but the main result regarding the possible astronomical significance of the stone structure is confirmed with a much higher level of confidence.

In particular, what is likely to be rejected is the alignment with three stars, because the relevance of the central stone (which pinpointed Miaplacidus) was probably misjudged on the basis of the pictures taken at the time when the first measurements were made.

On the other hand, the new measurements confirmed, with an accuracy of 1–2°, that the angular separation of stones A and C as seen from the center of the stone circle coincided with that of Canopus and Hadar during the historical period of interest. Meanwhile, the angular separation of Canopus and Rigil Kent is somewhat disfavoured, but is still compatible at the 2σ level of confidence.

It is more difficult to give a final answer about the absolute directions of the stones because of the accuracy of our magnetic compass. We can confirm the absolute alignment of the stones with Canopus and Hadar, but with an accuracy of ~4°, a factor of two improvement with respect to our previous estimation. An accuracy level similar to the one reached for the angular separation might be obtained only with the help of a theodolite. In our opinion, such a precise measurement could provide the final word in favor of or against our astronomical hypothesis, and therefore it should be the main purpose of any additional verification. However, it is worth remarking that even with a theodolite the accuracy of the angular measurements probably will not be improved, for reasons that have nothing to do with the instruments used but rather relate mainly to the physical dimensions of the stones. It is also worth noting that if the purpose of the stone circle was indeed to observe the stars we have identified then the ancient observers did not need—and therefore did not seek—a higher level of accuracy.

The height of the sensible horizon was found to be 5 ± 3°, which is compatible with the requirement that the alignment occurred just above the horizon, which was obviously needed for our hypothesis to hold. Once again, a theodolite would have allowed us to reach a higher level of accuracy.

As a final consideration, aside from the measurement errors, we would like to restate the aspect that struck our minds from the very beginning of this research: countless rocks are spread all around the site, which extends for several hundreds of meters in all directions; these rocks are of varied dimensions and shapes; amongst all of them, two stand out because of their distinctive shapes and placement in a vertical position, making it hard to believe that they ended up practically side-by-side just by chance; they not only lie close to each other, and their tops are close to the visible horizon represented by the uphill mountain ridge. The formulation of our thesis stemmed from two additional observations: 1) a third stone seemed to indicate a significant vantage point, and when the two vertical ones were looked at from this place at least two bright stars (one of which was indeed the brightest in the Southern sky) were seen in the direction of the vertical stones; and 2) the heliacal rising and setting of these two stars happened during a seasonal change which can be reasonably considered of some importance for a population living there during the relevant historical period. Our suggested explanation makes all these 'coincidences' fall consistently into place, and although not demonstrable to an accuracy of better than 1–2°, it is certainly more convincing than a mere 'by-chance interpretation', and at the same time it provides an intriguing speculative argument.

5 NOTES

1. Such uncertainty cannot be regarded as a normal Gaussian error, because the problem of making an estimate in this case is not caused by the difficulty of associating a precise value with a well-defined direction because of the accuracy of the instrument, but rather by the difficulty of defining the direction itself.
2. This kind of uncertainty cannot be further improved, and the results support our previous statement that having a more precise instrument, such as a theodolite, would not have been of much help, with the exception of determining the absolute directions from south, as we pointed out above, or that of the height of the sensible horizon (see Section 3).

6 REFERENCES

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