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MAN AND SKY:
PROBLEMS AND METHODS OF ARCHAEOASTRONOMY

1. Introduction: the nature of Archaeoastronomy

The term "Archaeoastronomy" is currently used to define the studies concerning «what peoples throughout history and prehistory have made of the phenomena in the sky, how they used these phenomena and what role they played in their cultures» (Sinclair 2006); however these studies were initially defined as "Astro-archaeology", being devoted to the search for evidence of astronomical interest in archaeological finds. This type of research thus pertained mainly to what astronomers held as evident concerning the practices of ancient cultures. When these studies started to include anthropological considerations, the term "Archaeoastronomy" was introduced, in order to distinguish this academic discipline from the study of the influence of celestial phenomena on the present day population folklore, that is instead defined "Ethno-astronomy".

To date, Archaeoastronomy, Ethno-astronomy, Historical Astronomy (the studies dedicated to recovering data of astrophysical interest from historical documents of pre-telescopic epoch, i.e. before the 17th century AD) and History of Astronomy are usually grouped as "Cultural Astronomy", though not every scholar agrees on the appropriateness of grouping all these studies into a single discipline. Furthermore, a different school of thought does not even consider Archaeoastronomy a separate discipline but a sub-discipline of Archaeology. For instance, Bostwick (2006) states that the archaeologist necessarily has the main role in archaeoastronomical studies, since the object of these studies are archaeological finds that hence need to be studied by archaeological methods, taking into account the cultural context of the site. This point of view was already affirmed by Judge (1984), who noticed that the topics of Archaeoastronomy were much more relevant to Archaeology than to Astronomy and this fact implies that Archaeoastronomy has to be developed within Archaeology.

However, many scholars believe that the lack of any archaeological, historical or anthropological information should not be a constraint to an archaeoastronomical analysis, in the case that astronomical considerations make it manifest that an ancient cultural product is in connection with celestial phenomena; on the other hand, it has also been suggested that historical and anthropological data alone should be sufficient to prove the astronomical interest on the part of the makers of a given artifact (Aveni 2006).

It is clear, in any case, that Archaeoastronomy, since the 1980s, has developed as an interdisciplinary science. It must thus be considered "good practice" that an archaeoastronomical working group includes at least one archaeologist, who guarantees that archaeological and anthropological principles are followed, and one astronomer, who ensures the best quality in the observation and interpretation of astronomical phenomena (Bostwick 2006).

Notice that Archaeoastronomy has never been considered a field of Astronomy, since it is not strongly linked with the science presently defined with this name and the only use made of modern astronomical science is limited to the one of Positional Astronomy, in order to find the positions of celestial bodies at a given moment of the past. However, cultural interest for astronomical phenomena had a very important role in the birth of science. The History of Science, and in particular of Astronomy, can thus be greatly helped by Archaeoastronomy. Therefore, the contribution of Archaeoastronomy is double: on one hand, it completes and extends our knowledge of ancient cultures, highlighting the importance and the interpretation they gave to celestial phenomena, and on the other, it completes the framework of the History of Astronomy in those areas where no written texts exist.

2. The evolution of Archaeoastronomy

The first studies, aimed at recognizing the role of celestial phenomena in ancient civilizations and conducted with coherent and at least partially codified methods, can be identified in the United Kingdom between the end of the 19th and the beginning of the 20th century (Ruggles 1999), when a scientific discussion started about the possible astronomical meaning of a number of archaeological sites in the British Islands. Some scholars had actually been speculating for centuries on possible astronomical alignments in Stonehenge; however, the archaeologist Sir W.M. Flinders Petrie (1880) seems to have been the first to quantitatively study this aspect of the famous Surrey megalithic monument, by checking the simplest hypothesis: the presence of an alignment with the summer solstice sunrise.

Fourteen years later the astrophysicist Sir N. Lockyer returned to the idea of astronomical orientations in ancient buildings. His studies (Lockyer 1894, 1906) on the orientation of Egyptian pyramids and of Stonehenge were taken as a model for subsequent archaeoastronomical studies, while his book *Surveying for Archaeologists* (1909) established the basic principles for the part of Archaeoastronomy devoted to the detection of astronomical alignments. Furthermore, Lockyer was the first to suggest the dating of ancient monuments by using the evaluation of the shift in stellar alignments due to the precession of the rotation axis of the Earth (see below). Though this method turned out later to be scarcely productive, Lockyer can still rightly be considered the "father of Archaeoastronomy".

In fact, other scholars obtained significant results by using Lockyer's methods. For instance, Boyle Somerville (1912) noticed how a significant percentage of the megalithic alignments in Callanish (a megalithic Scottish site dated to the end of the 2nd millennium BC), pointed to the directions of the rising of the Moon in particular moments of its cycle, revealing that the local culture had a profound knowledge of the complex apparent motion of the Moon that had not previously been considered compatible with its organizational level.

These early studies gave rise to many similar research projects, concerning other European prehistoric sites as well as important Egyptian, Mesopotamian and pre-Columbian monuments and sites, so that, in the middle of 20th century, it was widely accepted that astronomical orientation was an important component of the architectural solutions chosen by many cultures (Walker 1997).

Archaeoastronomical studies became hugely popular with the general public thanks to the work of the astronomer Gerald Hawkins (1965), who claimed that, due to its position and orientation, Stonehenge was a sort of sophisticated computer used to determine particular positions of the Sun and Moon cycles and many other astronomical phenomena, including eclipses. An unexpected result of his work was the sudden gain in popularity of Stonehenge, which, in people's minds became the symbol of Archaeoastronomy. However, Hawkins' work, though it was published in major journals including even «Nature», was extremely objectionable for the statistical methodology employed as well as for having totally ignored all previous archaeological and paleoethnological knowledge of the social organization of the inhabitants of Surrey in the 3rd millennium BC. The unquestionable incompatibility of Hawkins' conclusions with the archaeological and paleoethnological framework was proven once and for all by Renfrew (1979).

Actually, Hawkins' mistake was to believe that it was possible to study the impact of celestial phenomena on ancient cultures without taking into account their context and unfortunately, this error is still common to date. Hawkins' claims and all the more so the plethora of pseudo-scientific publications which followed, sometime supporting clearly absurd hypotheses, provoked a general rejection of all of Archaeoastronomy by the large majority of archaeologists. Consequently, the use of archaeoastronomical methods in Archaeology underwent a decade of stagnation. However, in the same years, a number of significant research projects were conducted, such as the ones by Alexander Thom, a professor of Civil Engineering at Oxford University who dedicated himself entirely to these studies after his retirement. Thom noticed that a statistical analysis of numerous stone circles in the British Islands showed a basic consistency in their structural characteristics and orientations, implying a remarkably detailed knowledge of the lunar motion by their builders, despite the low level of social organization of the corresponding cultures (Thom 1978). However, while many of Thom's results in Archaeoastronomy are widely accepted to date, his claim of a standard unit of measurement (the

"Megalithic Yard") in the Neolithic British Islands and Bretagne has been discarded both by classical (Kendall 1974) and Bayesian (Freeman 1976) statistical reassessment of his data.

An important role in the recovery of archaeoastronomical methods by the archaeological community was played by the Royal Society, which in 1981 promoted the first Oxford International Conference on Archaeoastronomy, where the study of astronomical orientations of archaeological sites was just one of the topics discussed. These Conferences were very important for a reciprocal understanding between humanities scholars, scientists and astronomers, and were later iterated in different localities, though they kept the name of "Oxford Conference". Presently these meetings include various studies on cultural expressions connected with Astronomy in past and present cultures. A similar role was played in Italy by the Accademia Nazionale dei Lincei, that organized a number of important conferences on Archaeoastronomy.

The new interdisciplinary studies on Archaeoastronomy and the recent evolution of Archaeology, which focuses more on the symbolic and religious spheres in the evolution of cultures, has meant that Archaeoastronomy, at least in Anglo-Saxon countries, is often mentioned in tutorial manuals and is a subject commonly taught in basic Archaeology courses (Fisher 2006). Major international and national scientific societies are devoted to these studies and hold periodic conferences on these topics. During the last five years Archaeoastronomy has also seen significant development in Italy (Moscati in press).

Moreover, it is interesting to note that Archaeoastronomy developed also thanks to the interest and the work of people who were neither professional humanities scholars or astronomers, but engineers, artists or simple amateurs, who gave significant contributions to the field. For instance, the well-known painter Anna Sofaer, studying from an artistic point of view the rock art of Chaco Canyon (an Anasazi site, dated 900-1150 AD), was the first to notice that Sun, passing through a fissure in the rocks, illuminates different areas of the paintings, clearly marking the days of solstices.

3. Celestial phenomena of archaeoastronomical interest

In principle, past cultures should have been interested by all astronomical phenomenon visible to the naked eye. However, it is obvious that some of these phenomena are so evident and linked to vital factors that it is difficult to believe they were ignored in any cultural context (Lanciano 2006). These phenomena are thus the first to be considered in an archaeoastronomical study. The most important ones are obviously those connected with the solar cycle, since the Sun has always been recognized by mankind as the source of life.

Because of the rotation of the Earth around its axis, the Sun seems to move in the sky and, rising daily in the East and setting in the West, originates the alternating of day and night. Due to the orbital motion of Earth around Sun and the inclination of the Earth's axis in respect to the orbital plane, the points of the horizon of the rising and the setting of Sun, as well as its maximum height over the horizon, change daily, provoking the variation of the light and darkness period through the year. Solstices are the days when the height of the Sun over the horizon at midday and the length of the day are maximum (summer solstice) or minimum (winter solstice); obviously these days are the ones when the rising point of the Sun reaches its maximum northern or southern position, respectively. Equinoxes are instead the days when the length of daylight and darkness are equal and the Sun rises and sets exactly at the astronomical East and West, respectively. Since climate is mainly determined by the length of the daylight period, solstices and equinoxes usually correspond to the season changes. It is thus not surprising that winter and summer solstices, connected with the start of the coldest and warmest period of the year respectively, have been recognized since the very beginning of civilization and methods allowing the forecast of their arrival can be identified in very ancient monuments and practices.

The Moon has been as important as the Sun: its cycle of 29,53 days ("synodic month") define the month and its division on four parts, correspondent to the four Moon phases. The Moon illuminates some nights, allowing hunting and fishing, regulates tides and many biological cycles, while other ones (like a woman's menstrual cycle) have nearly equal periodicity, perhaps by chance but more probably because of evolutionary reasons. Thus, as the apparent motion of the Sun gives a daily and yearly time reference, the motion of the Moon fixes intermediate periods (month and week). It is thus not by chance that the majority of ancient calendars is based on the lunar month. The Moon follows daily and seasonal paths in the sky that resemble those of the Sun; however the azimuth of the moonrise (or moonset) can oscillate by up to ± 6^{o} 40' (for an observer at 36^{o} latitude) around the Sun rising (or setting) azimuth in the course of a monthly lunar cycle: the extreme points of this cycle are called "lunistices" or "lunar standstills".

In addition, the Sun gravitational perturbation leads to a precession of the Moon orbital axis, with a period of 18,61 years. Thus, every 18,61 years, the rising or setting Moon reaches a northern extreme in rising and setting azimuth respect to the summer solstice, and a southern extreme respect to the winter solstice. These points are called "major lunar standstills". While such standstills can in principle be determined using horizon observations, as is the case of the solstice Sun, the Moon year-to-year angular displacement along the horizon is very small and near to a standstill. However, due to this cycle, four extreme azimuths must be considered for the Moon: the rising and setting points of North and South major standstill (corresponding to the smallest and the greatest azimuth of the Moon rising and setting point, respectively) and the North and South "minor standstill" (the corresponding positions after 9,3 years). The Moon's 18,61 year cycle has been clearly codified in monuments left by a number of cultures (e.g. the Celtic one: Gaspani, Cernuti 1997), though its importance has been at times exaggerated.

In addition to the Sun and Moon, stars have also certainly always attracted man's attention and the practice of grouping stars into "constellations", that is in figures seen by man in the patterns of stars over the celestial sphere, can be dated to the most ancient times. These figures, as well as the same association in a single figure of a number of stars at a relatively small angular distance, are obviously different from one culture to another, except in a few cases (such as the Pleiades). Because of the Earth's rotation, stars seem to be rigidly rotating throughout the night around a fixed point, the "Celestial Pole". From the geometrical point of view of an observer on the Earth's surface, stars can thus be considered fixed on a rigid sphere rotating around a motionless Earth, as in the Ptolemaic model, and the Celestial Pole can be considered the intersection point of this sphere with the Earth's axis. It is manifest that, because of the orbital motion of our planet, only stars situated in the opposite direction respect to the Sun can be seen at night. The stars visible at sunset in a given day are thus seen to rise later every night, until they are visible only shortly before sunrise, while other stars subsequently take their place, except for the "circumpolar stars", the ones that, because of their angular position near to the Celestial Pole, are over the horizon during the night all the year long.

The *heliacal rising* of a star (or other celestial body such as the Moon or a planet) occurs when it first becomes visible above the eastern horizon at dawn, after a period when it was hidden by the brightness of the Sun. Single bright stars have surely been used in calendric function by many cultures, since their seasonal cycle of visibility was used as an early warning of other important natural phenomena (Walker 1997): the case of the heliacal rise of Sirius, announcing the Nile flooding in ancient Egypt is well known, as well as the one of the agricultural calendar of archaic Greece, based on the appearance and disappearance of stars and constellations, reported by Hesiod in the poem *Works and Days*.

The case of planets needs to be examined with caution. The difference between stars, that were later defined in the Ptolemaic vision of the World (though it has obviously a much more ancient origin) as "fixed stars" and planets, the "wandering stars", that is the ones with an apparent motion different from the one of the celestial sphere, was probably known since a very early epoch: it was, for instance, clearly defined in 3rd millennium BC Mesopotamian astronomy (Pettinato 1998). However, the planets' motion is far less obvious than that of the Sun and Moon. The importance given to planets over the course of time is thus certain (as is proven by the fact that most cultures deified planets, which they considered as objects of veneration and fear) but their actual use for calendric purpose is still far from clear (Iwaniszeswsky 2003), and the only documented case, to date, is the use of the Venus visibility cycle in Mesoamerican pre-Columbian calendars (Aveni 1993).

The above mentioned celestial phenomena are all periodic ones and they are thus functional to the definition of temporal scales allowing a better organization of social activities. However, we have also to consider phenomena that are unexpected, either because they are one-time events or because they have a long, and thus not easily recognizable, periodicity. Some of these events (such as supernovae and comets) had a significant role in the development of the various "World visions" imagined in the course of the history. On the other hand, the contribution of Archaeoastronomy to the study of transient phenomena has been extremely limited up to now because of the scarce likelihood of recovering material finds connected with these events, while Historical Astronomy and Ethno-astronomy have provided a very productive method for exploring this field.

4. Archaeoastronomy measurements and data analysis

Archaeoastronomy employs most of the human science methodologies and technologies, though the data analysis is obviously specific (Moscati in press).

Most common archaeoastronomical studies start from the assumption that the ritual and/or calendric interest of particular artifact builders for a given astronomical phenomenon is shown by alignments with the horizon points where this phenomenon is seen. Because of the reasons explained in the previous paragraph, archaeoastronomical research usually starts with the search for alignments with the average directions of Sun and Moon rise and set during the year and with the local meridian (i.e. with geographical East, West, North and South). Second, the setting and rising directions of Sun and Moon at the extremes of their apparent motions (i.e. the solstices and lunar standstills) are examined. Third, the heliacal rising and setting directions of the most brilliant stars can be considered. Since they are always based on azimuth measurements, field archaeoastronomical measurements are, in these instances, topographic measurements and thus do not differ from the normal survey of an archaeological site, except for the need to refer all measurements to the geographical North and not to the magnetic one, since the difference between the magnetic and geographical North can be strongly influenced by the presence of natural or artificial local magnetic fields (iron mass, electric lines, etc.). However, in the case of topographic surveys addressed to archaeo-astronomical studies, a number of specific problems, analyzed in the following paragraphs, can take on particular relevance.

4.1 *Positional Astronomy codes for archaeoastronomical studies*

The main problem in archaeoastronomical measurements is the determination of the geographical North, to be used as the topographic reference for following measurements of the selected alignments, using any kind of instrumentation. This calibration can be done using various techniques, but the one most used and accurate is the determination of the direction of culmination of any celestial body (usually the Sun, though a star can give a more precise result), that unequivocally identifies the local meridian direction. When it is impossible (e.g. because of clouds) to take the measurements at the exact time of the culmination, the calibration can be done in any moment during the period of visibility of the celestial body over the horizon, if its geographical azimuth at the moment of the measurement is known. The computation of this parameter or of the exact time of the meridian transit of the selected celestial body (the local noon in the case of the Sun) is an easy task which can be performed by using astronomical or nautical ephemeredes. However, the calculation is boring and the possibility of error is significant: it is thus wiser to use a Positional Astronomy computer program. All available commercial programs or freeware are able to give the required result with remarkable precision.

A more complex problem is presented when the measured alignment has to be compared with the appearance of the sky in the epoch when the artefact under study was built and on the day we suppose to be the one of the ancient observations. The change in the position of celestial bodies in the sky, at least due to equinox precession and star proper motion, must be computed for this purpose.

Due to the fact that the orientation of the Earth's axis is slowly changing, tracing out a conical shape, completing one circuit in 25,771.5 years the equinox precession originates an angular movement of the celestial pole position, whose value as a function of time is given by a differential equation taking into account the Earth's angular velocity and angular momentum, the angle between the plane of the Moon orbit and the ecliptic plane and many other parameters, including the Earth's dynamical ellipticity or flattening, which is adjusted to the observed precession because Earth's internal structure is not known in sufficient detail (Williams 1994). This equation can be solved only by numerical integration and the results are given in polynomial form. To date, the best approximation is given by Williams (1994) and Simon *et al.* (1994); however, these solutions are applied only in the best professional computer codes, while the large majority of commercial programs use the older Lieske *et al.* (1977) solution (the so called "IAU formula", since it is based upon the International Astronomical Union IAU/1976/ system of astronomical constants) or its first order approximation or even a simple proportional correction with the average value of -0.024 arcsec per century.

Taking into account the negligible effect of the equinox precession on the solstice sunrise and sunset azimuth of the Sun and the intrinsic uncertainties in the evaluation of this value by ancient cultures (see below), once again most commercial codes and freeware can be used to check if an ancient artifact has this kind of alignments; actually, in most cases, the solstice alignments are still working to date, with minor differences respect to the time when they were built, even when the related structures are 6000 years old. However, the use of approximate solution can give significant differences with respect to the results obtained by Williams (1994) in case of lunar standstills and position (including heliacal rising and setting) of stars. On the other hand, the differential equation of the equinox precession itself contains a number of coefficients that are not exactly known, and the value of which is obtained by adjusting the solution on historical eclipse data. These events have been described with adequate precision only since the 8th century BC and the values obtained on these data are then extrapolated back for previous epochs. No computer code, including the professional ones, can thus guarantee the reconstruction of the exact sky appearance before the middle of the 2nd millennium BC and the uncertainties increase going back in time.

The position of stars is affected by a further problem. Obviously, stars are not fixed on a celestial sphere as in the Ptolemaic model, but are orbiting around the Galactic Centre with complex trajectories. The composition of this motion with that of the Sun would make their relative position as seen from Earth variable in time even in the case that the Earth's axis is not affected by its precession; the change in star position on the celestial sphere due to this effect is called "proper motion". Though most of the stars are so far from Earth that this effect is negligible, some stars are close enough to have significant proper motions and thus past positions significantly different from the one computed taking into account the equinox precession only. Some of these stars, such as those in the Big Dipper and the Centaurus, are very luminous and were surely important for ancient peoples. All commercial Positional Astronomy codes use very approximate values for proper motion correction; when more reliable values are used, results can be quite different (Antonello 2008, for the case of the Big Dipper).

Concerning lunar standstills, an evaluation of the precision of the lunar motion reconstruction by a specific Positional Astronomy code can be obtained by comparing its result on past Moon eclipses with the one recorded on the NASA-JPL database[1], by far the most precise available to date. The matching of these reconstructions clearly proves an accurate computation of

[1] http://planets.gsfc.nasa.gov/eclipses/eclipses.htm.

the Moon position. To the author's knowledge, best results in this sense are obtained by two freewares: Planetario V2.0, by Massimino (2002) and Solex V10.02, by Vitagliano (2008).

4.2 *Measurement precision*

An enduring discussion among Archaeoastronomy scholars concerns the required measurement precision.

Very refined techniques, based on GPS and able to reach a precision of 0.01 deg, have been proposed and employed to determine the direction of the meridian (Gaspani 2006). Other scholars claim the need to use total station or, at least, repeated theodolite measurements (Esteban, Cabrera 2005), while others simply use a good bearing compass or a *laser-compass* (Hoskin 2004; Polcaro, Polcaro 2006).

This discussion actually no longer has a *raison d'être* since the angular precision necessary for an archaeoastronomical study critically depends on the nature of the artifact under consideration (Hoskin 2004). In fact, it is evident that a measurement precision of the supposed alignment higher than the one of the building technique is useless. Although the use of the theodolite in order to measure the alignments of a refined Greek or pre-Columbian temple is at least reasonable, this instrument becomes completely useless if the artifact under study is a Bronze age dolmen. In this case, a series of measurements made by means of a bearing compass, giving a precision of ±1 deg on the single measurement and of at least ±30 arcmin with a series of repeated measurements, is surely preferable; it is, in fact, illogical to suppose a mastery of higher precision technologies from the builders and furthermore, the greater ease of transport and use of the bearing compass allows one to attain a higher number of measurements, *ceteris paribus* a major element of success for a survey. We just wish to point out that a hundredth degree precision is, in any case, useless, since even the present day building techniques do not reach this degree of precision.

On the other hand, there are a number of reasons suggesting that, even in the case of developed building techniques, a measurement precision much higher than ±1 deg can be useful only in a few cases. For instance, if we want to verify the alignment of a given artifact with the rising azimuth of the Sun at solstice, we have to bear in mind that the Sun is an extended object, with an angular diameter of 32'35". The direction to be considered thus depends on what the builders' culture considered as the "sunrise direction": it could be the point where the first direct light appears, the center of the Sun when its disk is fully visible, the direction of a gnomon shadow when it first becomes observable or others. This direction can significantly differ from the others; lacking further information, it thus seems useless to refine the measurement precision under the angular diameter of the Sun. A similar situation is present also in the case of lunar alignments. In conclusion, it is worth noticing that the actual azimuth of the horizon points where Sun or Moon are seen to rise or set critically depends on the observer's horizon profile and that it can be considered equal to the theoretical one only in the case of a completely flat and free horizon, as on the sea or a broad plain.

It is actually evident that the presence of a mountain (or even of a small hill) to the East allows the observer to see the celestial body only when it is at an angular height higher than the angle covered by the obstacle. This datum can easily be computed when a detailed topographical map of the site is available; however, significant factors, such as the exact position of the observer, the eventual presence of forest trees and the same geological effects altering the obstacle profile over the centuries, are hardly ever evaluated. The resulting uncertainties can easily overcome the instrumental precision of the same bearing compass.

When the hypothesis being tested is an alignment with the heliacal rising or setting of a star, the problem is even more complex. From the Positional Astronomy point of view, given the date and the geographical coordinates, computation of the day when a star is exactly on the astronomical horizon of the observer at sunrise or sunset and the related azimuth is a relatively easy task. However, this does not imply that on that day and at that time the star was actually visible. In fact, we have to take into account not only the horizon profile, as discussed before in the case of the Sun and Moon, but also a number of atmospheric effects that can be very relevant in the case of a point-like object, such as a star. In particular, the atmospheric refraction, due to the variability of the Earth's atmospheric density as a function of height, has the effect of increasing the apparent angular height over the horizon. This effect can be computed by using an atmosphere model[2], when atmospheric conditions at the time of the observation are known.

However, in the case of archaeoastronomical applications, these conditions have to be evaluated as average climatologic values, with a high level of uncertainty. A further and more complex problem emerges from the fact that the instant of the actual visibility of a star is a function of its contrast with respect to the background light of the sky, which depends not only on the star luminosity and the observer's eyesight but also on the sky view and transparency, on the possible presence of fog or haze and other local and time-variable phenomena. A new research branch, named "Celestial Visibility" (Schaefer 1993) is now developing precise formulas for determining the visibility limits of astronomical objects. Other scholars (Cernuti, Ga-

[2] Positional astronomy codes usually employ the ICAO standard atmosphere model (Doc 7488-CD, Third Edition 1993) or occasionally the IOS (ISO 2533:1975) one for the atmospheric refraction computation.

spani 2006) are presently applying the "Fuzzy Logic" methods to this topic. However, from a practical point of view we are forced to admit the possibility of a delay in the order of a number of days in the actual observation of the phenomenon, respect to the theoretical date of heliacal rising or setting of a celestial object, depending on the local and unpredictable behavior of the atmosphere. The related direction over the horizon must thus be considered intrinsically variable by a number of degrees from year to year.

4.3 *Proofs of intentionality of an astronomical alignment*

The power of Archaeoastronomy lies in the fact that its hypotheses are based on a few very evident events, of undoubted universal interest. Its weakness, on the other hand, is the risk of a quasi-automatic search for solar and lunar alignments in any archaeological site worldwide, scanning the horizon looking for any peculiar feature that could be useful for calendric purposes, taking their presence for granted in all cultures and in all epochs. It is thus unfortunately common that some scholars claim the presence of solar or lunar alignments, on the basis of the astronomical evidence alone, regardless of the archaeological context, usually in cases where the builders' culture is poorly known. However, as stressed by Iwaniszeswsky (2003), «It is very easy today, with PCs and astronomical software at hand, to investigate astronomical elements in different cultures. Nevertheless, the danger of reaching premature and culturally biased conclusions is great, since computations can be easily performed while historical and anthropological investigations are more challenging. Setting a problem in its proper cultural milieu is much more difficult than performing the calculations».

In fact, the existence alone of astronomical alignments in a monument does not prove the actual intention of the builders to purposely search for these effects, since they can be the result of chance or coincidence.

Thus, many astronomical alignments, even those claimed by famous scholars, have been objected to on the grounds that they were not thought of by their builders but exist only in the minds of present day scientists (Renfrew 1979; Schaefer 2006). This concern has been proven true on many occasions and has generated, as we saw in the case of Stonehenge (but this is certainly not the only one), a diffused mistrust of Archaeoastronomy among professional archaeologists.

For this reason, Schaefer (2006) suggested that, in order to claim the intentionality of an astronomical alignment, two and possibly three conditions must be satisfied: it must be statistically significant at a level of at least 3 σ, its intentionality must be confirmed by archaeological evidence and, where possible, it should be supported by ethnographic or anthropological attestations of the symbolic value of the claimed astronomical alignments. Actually, following Schaefer (2006), the probability, respect to the "null hypothesis" of chance coincidence, to find within 1 deg a single alignment corresponding to the eight astronomically relevant directions known to most cultures (the four cardinal directions and the ones of the sunrise and sunset at the winter and summer solstices) in a given architectural structure is equal to 1/22, i.e. 2.08 σ: it is thus quite a significant probability. Furthermore, we must take into account other non astronomical reasons of a given orientation, such as the slope of the ground or the choice of a south-eastern orientation of the building in order to take advantage of the sunlight and heat (Castellani 2003).

The situation is much worst if we want to check the alignment with the heliacal rising or setting of a bright star. There are 21 stars brighter than 2nd visual magnitude. The corresponding heliacal rising and setting azimuths are thus 42, covering, because of what was said before, 84° of the horizon. This corresponds to a probability of chance coincidence respect to the null hypothesis greater than 1/5: it is obvious that it is meaningless to claim the intentionality of an alignment solely on the basis of such low statistical evidence.

It is thus wise to avoid any excess of enthusiasm and flights of fancy in Archaeoastronomy (as already stressed, e.g. by Romano 1994 and Iwaniszeswsky 2003, Schaefer 2006 and many others) and rely only on well documented archaeological, anthropological and statistical facts.

However, the statistical procedures to be followed in an archaeoastronomical analysis of a single monument are considerably different from those employed in a survey of the alignments of a series of monuments built by the same culture.

Below, we will illustrate these differences by using two specific cases studied by the authors.

4.3.1 The case of single monument: the "Preta 'ru Mulacchio" on Monte della Stella

The Monte della Stella is a 1131 m high mountain, belonging to the range separating the Alento Valley from the Tyrrhenian Sea, south of the city of Agropoli in Italy. At 1030 m above sea-level, a large, isolated outcrop of bedrock is present. This rock (Fig. 1) is well known to local people and called the "Preta 'ru Mulacchio", the expression meaning in the local dialect "The Bastard Child Rock". The "Preta" is basically composed of three rocks that originated for natural reasons from a single block of arenite in its upper part and from a rough conglomerate in the lower one; between the three rocks, two tunnels (thereafter F and G) were thus formed. However, it is easy to see that the "Preta" was profoundly modified by human intervention: large stones were wedged into exact positions between the three original blocks or positioned as a cover (Ienna 2005; Polcaro, Ienna 2009).

We found that F gallery has an astronomical azimuth of 359 deg and G gallery of 240 deg. Inside the measurement precision (±1 deg), the galleries

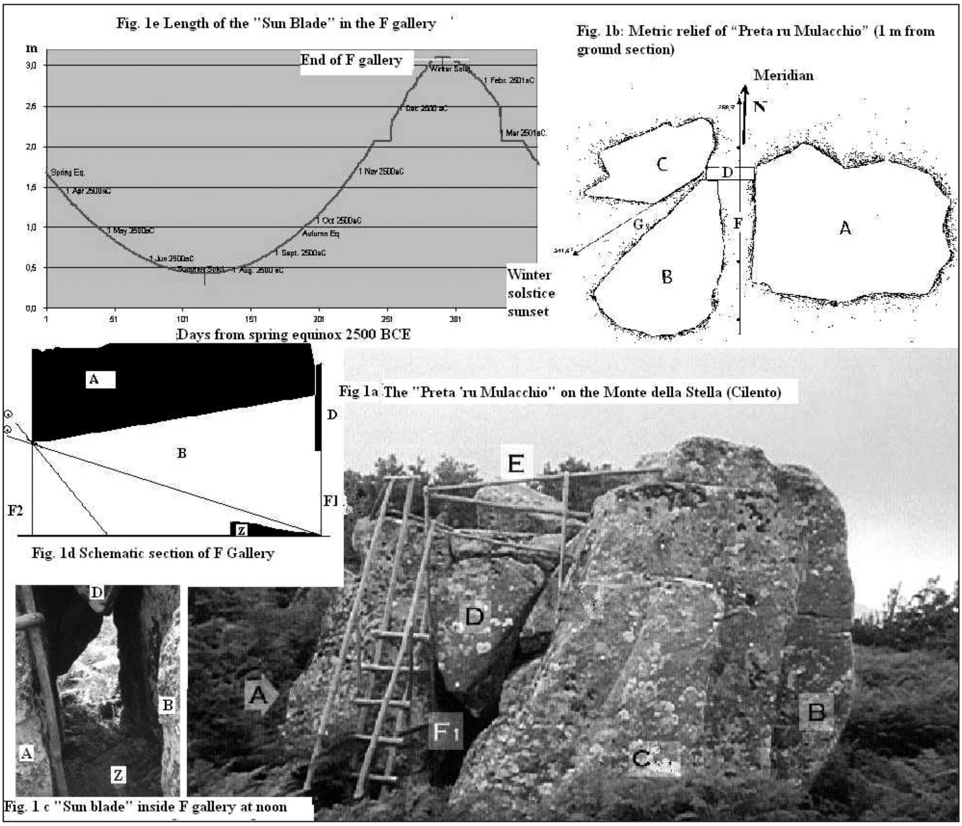

Fig. 1 – The "Preta 'ru Mulacchio": N-W side view, section at 1.5 m from ground, alignments and light effects.

are thus respectively oriented to the meridian and to the sunset of the winter solstice. The meridian alignment of F gallery let a "Sun blade" penetrate inside at noon (Fig. 1c). The length of this beam of light obviously varies during the year from a minimum at the summer solstice to a maximum at the winter solstice, when it reaches exactly the end of the F gallery (Fig. 1d).

We must first evaluate the probability of the "Sun blade" length at the winter solstice being equal to the length of the gallery due to chance coincidence. Since, from a statistical point of view, the "Sun blade" could have a length equal to the one of the gallery on each day of the year, or even never reach this value, we can infer that the probability of having the length of the light beam at noon and the one of the gallery on a given day is $\leq 1/365$, corresponding to 3.25 σ. Furthermore, following Schaefer (2006), the probability, respect to the "null hypothesis" of chance or coincidence, to find within 1 deg a single solar alignment in a given architectural structure is equal to 1/22, i.e. 2.08 σ. The composed probability of having, in the case of the winter solstice, at the same time two coexisting solar alignments within 1 deg (as in our case the meridian and the sunset) and the length of the "Sun blade" equal to the one of the gallery is thus ≥4.38 σ, corresponding to about 1 over 180000. We can thus conclude that the "Preta 'ru Mulacchio" withstands the statistical test of intentionality in the alignments.

Furthermore, there is also clear archaeological evidence of the intentionality of these alignments: for instance, the triangular stone D, making the length of the gallery equal to the one of the "Sun blade" exactly at noon of the winter solstice has actually been purposely wedged into its position. Lastly, modern folklore associated with the rock seems to recall very ancient fertility rites (La Greca 1997), often connected with the winter solstice, the day of the "rebirth" of Sun. We can thus claim that the "Preta 'ru Mulacchio" is most probably a monument, dated to an epoch presently unknown but possibly preceding the Greek colonization of Cilento, built in order to determine with a high degree of precision the winter solstice for ceremonial reasons.

4.3.2 The case of surveys: the dolmens of the Wadi Zarqa valley

Statistic analysis alone can indicate the intentionality of an astronomical alignment when this orientation is found in a statistical significant sample of structures typologically similar and having reference to the same cultural context (see, e.g. the study by Aveni, Romano 1994, of the "mutare", small artificial mounds of soil and stones found in Veneto between the Piave and Tagliamento rivers attributed to the Villanovan culture). The statistic tools used in this case are exactly the same as those used in other kinds of archaeological surveys (Fletcher, Lock 2005). However, again in this case, archaeological and anthropological considerations are needed if we want to interpret these alignments or consider other monuments of the same culture.

For instance, dolmens and other megalithic structures, dated to the Early Bronze age, are very common in the whole Palestinian area (Prag 1995). These monuments are precious evidence of the symbolism used by the populations living in this area at the time, who did not leave us written records of their world vision. On the other hand, it has been clearly demonstrated in many other archaeological contexts that megalithic structures are often astronomically oriented and that these orientations could supply useful information about the religion of their builder. In the specific case of the Early Bronze age Palestinian sites, the archaeo-topographic and archaeoastronomical studies of the megalithic monuments are scanty and only Belmonte (1997) performed a detailed archaeoastronomical survey of two dolmen fields (Ala Safat and Al-Matabi).

During a survey of dolmen fields dated to the Early Bronze I in Jordan (i.e. to the end of the 4th millennium BC), started in October of 2004 and still in progress, we measured the alignment of a statistically significant sample of dolmens in the upper Wadi Zarqa valley (Polcaro, Polcaro 2006). The number of dolmens aligned in angular bins of 8° was then computed in order to increase the statistics. The results were first checked versus the hypothesis of isotropic distribution in azimuth and, when a statistically significant peak was found, it was best-fitted by using Gaussians, in order to evaluate the hypothesis of a random distribution around a fixed direction.

In this way we measured and analyzed the alignments of a random sample of 44 dolmens (6.7% of the total and thus statistically significant) in the dolmen field of Jebel Mutawwaq, an Early Bronze Ia site, excavated and described by Fernández-Tresguerres (1998), and a total of 29 other dolmens from four minor dolmen fields in the upper Wadi Zarqa valley (where we measured all the surviving dolmens).

Our survey shows, with a very high statistical significance, that dolmens from the Jebel Mutawwaq field are predominantly oriented in the meridian direction: 24 of them (54,5%) are oriented between 168° and 192°. A smaller, but still significant number (6) seems to cluster around the alignment of 152° (Fig. 2); this excess is best fitted by the sum of two Gaussian, one centered on South and the second to 152°. This model has a statistical probability, evaluated by means of the reduced χ^2 test, equal to 94%. The standard deviation of both Gaussian is of 6,5°, corresponding to a random error of the alignment of ±3,25°, most probably due to the precision achieved during the building of the dolmens. The distribution of the whole sample of dolmens we measured in the fields of the Zarqa valley can be fitted by the same model (with a statistical significance of 5,4 σ respect to the isotropic distribution) and its statistical probability, evaluated by means of the reduced χ^2 test is equal to 99%. A comparison with the results of the Belmonte (1997) survey of the dolmens of the Ala Safat field, used as comparison sample, confirmed the model.

Archaeological considerations lead us to conclude that these orientations were linked to the complex funerary customs of the local semi-nomadic people, who inhabited Palestine between the end of the 4th millennium and the beginning of the 3rd millennium BC. The related rituals were most probably performed during festivals dedicated to the god Dumuzi, identified with the Orion constellation, which coincide with the winter solstice. Actually, the 152° azimuth corresponds to the direction of the Orion constellation when the shape of the man seen in it appears to "stand up", i.e. he is in a vertical position (Fig. 3). The Mesopotamian god Dumuzi is considered by ancient Near East scholars to be a "western" god, i.e. the myth came to Sumeria from the West (Botero, Lavander Flagan 2004). It is thus probable that he was venerated by the shepherds of the Jordan valley and of the nearby regions.

This conclusion, reached mainly on the basis of statistical considerations, could be considered only speculative. On the other hand, it is supported

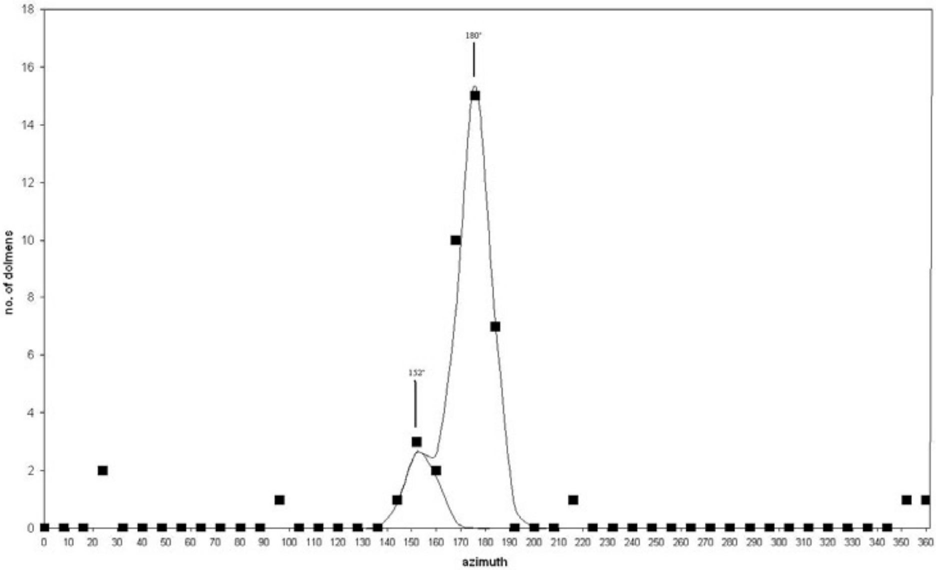

Fig. 2 – Orientations distribution of a statistically significant sample of dolmens from the Jebel Mutawwaq site.

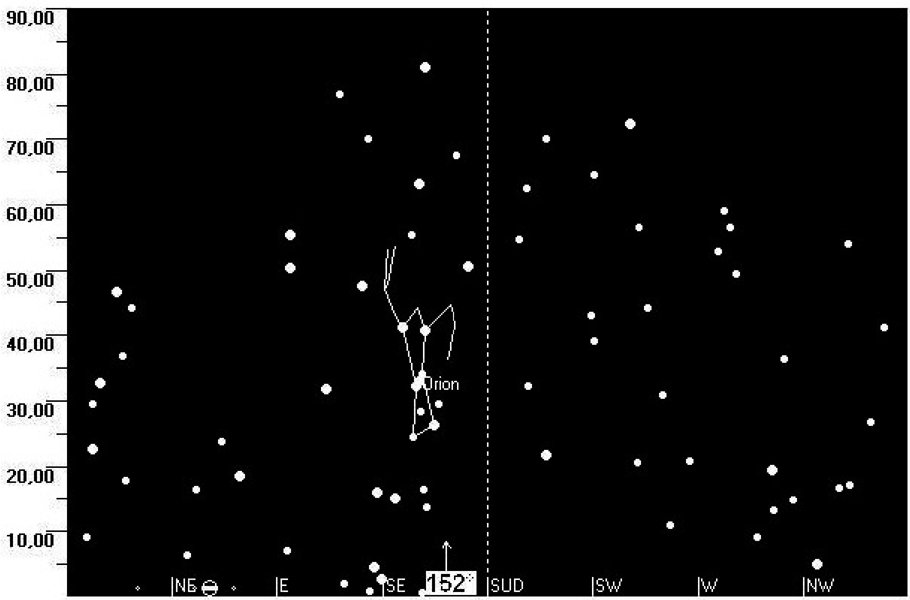

Fig. 3 – Reconstruction of the sky over the Wadi Zarqa at the winter solstice of 3000 BC (by using *PlanetarioV2.0*).

by the analysis of other archaeological sites belonging to the same cultural context.

For instance, archaeological excavations conducted in 1988-1991 (Aveni, Mizrachi 1998) provided information on the geometry of Rujm el-Hiri, a well-known megalithic monument on the central lower Golan, and on alignment associations between the architecture of this complex and astronomical events. These studies clearly demonstrated that its north-eastern entryway is aligned, with a remarkable precision, to the direction of the summer solstice sunrise in the middle of the 4th millennium BC, while the two boulders, located on the eastern section of the outermost circular stone wall of the complex, form a sight line from the geometric centre of the complex, identifying the direction of the equinoctial sun with an accuracy of less than 1,5°, corresponding to a precision in time of 3-4 days. On the basis of these measurements and of the analysis of the local environment, these authors suggest that the north-eastern entryway was used for ritual processions on the occasion of the festivals dedicated to the god Dumuzi during the summer solstice; these rituals are well known in the Mesopotamian context (Cohen 1993). On the other hand, the orientation of the Rujm el-Hiri south-eastern entryway turns out to be equal to 151°51', thus more than 20° away from the direction of the winter solstice. Aveni and Mizrachi (1998) evaluated many other astronomical and topographical hypotheses, but none of them fits with the experimental data. They thus conclude that: «The SE gate may be oriented to a place in which some historically significant episode for these people took place».

It is obvious that this kind of a conclusion is not satisfactory. In fact, the orientation of the Southeast Gate of Rujm el-Hiri is just the same as the one found in our survey of the Wadi Zarqa valley dolmens (Polcaro, Polcaro in press). We can thus argue that this orientation in the Southeast Gate of Rujm el-Hiri had a role in ceremonies dedicated to Dumuzi in occasion of the winter solstice, similar to the one of the north-eastern Gate used for rituals connected with the same god on the summer solstice. This finding allows us to interpret all the main orientation of the Rujm el-Hiri complex in a single conceptual framework, strongly supporting the Aveni and Mizrachi (1998) conclusions concerning the cultural role of this monument.

The study of the "Temple of Snakes" in Jebel Mutawwaq (Polcaro in press) further confirms the association of the 152° alignment with Orion constellation and the cult of Dumuzi; this point will be explained in detail below.

5. Conclusion: an Archaeology based on a synthesis of human and physical science?

The examples that we have summarized show how the use of Archaeoastronomy can be extremely useful not only in studies of historical cultures, where written sources can help to outline the astronomical knowledge and religious customs of people, but mainly in research on prehistoric cultures. From the first known Neolithic cultures it is clear that the observation of the starry sky was a central point in the formation of cults, rituals and mythologies of mankind. Studies on ritual and funerary practices are based mainly on translations of religious texts and interpretations made by philologists, correlated with the analysis of data obtained from archaeological excavations.

The synthesis of these two sciences allows us to obtain a more or less precise reconstruction of what ancient peoples thought about religion. Actually, archaeological investigation on temples and religious buildings supplies information about cult objects and the dynamics of rites performed in the sacred buildings: these results, when put in relation to the text interpretations, clarify the modalities, times and ideological meanings of the ceremonies. In funerary contexts, archaeological investigation makes it possible to analyze the funerary gifts and rituals; consequently, these elements, together with a philological analysis, put us in a position to attempt a reconstruction of the eschatology and the ideology of death. However, in the absence of textual references, the excavation alone enables us to reconstruct the actions performed during the ritual, but it does not assure the identification of the innermost meaning of the rite; in a purely "archaeological" investigation, the understanding of the underlying mythological framework is also lost. The use of sciences such as Geology, Paleobotany, Physical Anthropology and many others is, to date, central to an archaeological investigation and to the subsequent analysis of data obtained from the excavation.

On the other hand, only rarely can a physical science help us understand the "ideology" underlying a ritual act; it can better clarify the modality and the times of the act, however, it can never reveal to the modern scholar its surrounding superstructure. This is the great value and potential of Archaeoastronomy, as long as it is strongly linked and continuously compared with excavation data. A practical example can be given by the excavations of a well defined environment, such as a sanctuary, where the archaeological investigation, correlated with the use of physical sciences, analyzes all the findings inside the sacred structure, including equipment left, traces of rites such as accumulations of ashes or long-lasting depositions of objects in a given area; the analysis of the architectural typology can clarify cultural influences and correlations of the structure under investigation with the coeval context where it was designed and built.

However, these results cannot always answer one of the first questions that an archaeologist asks himself about a sacred building: to whom was it dedicated? Who was the god or the complex of divine entities worshipped here in the rituals reconstructed through the excavations and the subsequent interpretation of the material findings? Sometime, even when textual data are lacking, the answer can be given by the same cult equipment present *in situ*;

however, often many doubts remain and can be solved only by the chance discovery of a symbol specifically connected with a single divinity. On the contrary, if, during these investigations, the measurement of the orientation of the sacred building reveals that it was aligned with a precise point of the sky such as a particular position of a celestial body on a given day of the year, we can gather information which is totally absent from the data collected during the analysis previously described, but strongly indicative of the actual purposes of the buildings.

We previously mentioned the case of Jebel Mutawwaq "Temple of the Snakes". A recent analysis performed by one of the authors (Polcaro in press) on this complex, dated to the 4th millennium BC, identified the orientation of the entryways of this temple to the particular azimuth where the hero, represented in most of cultures by the Orion constellation, "stands up". This discovery was the key point for the identification of the deity venerated in this structure. This god has been identified in the typology of the god "dying and resurrecting", well known in the cultural contexts of the Near East (Dumuzi/Tammuz; Xella 2001), and also documented in later sources (Polcaro in press). The relationship of a god similar to Dumuzi/Tammuz with applications representing snakes and trees on cult vessels found in the temple cell on one hand and the alignment of the temple entryways to the particular position of the Orion constellation seasonally appearing and disappearing in the Sky and representing the god passing from the House of Gods to the Netherworld, found by the previously described analysis of the Wadi Zarqa valley dolmens, on the other, is an example of the capacity of Archaeoastronomy to support Archaeology in various cultural contexts, providing valuable assistance in the interpretation of material data.

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ABSTRACT

Archaeoastronomy is a discipline devoted to the study of the astronomical observations preceding the invention of the telescope. It is an interdisciplinary science, requiring the knowledge of astronomers, archaeologists, linguists, anthropologists and architects. It has highlighted the great importance that ancient civilizations attributed to celestial phenomena and demonstrated how the analysis of the testimonies of this interest can greatly help us in the understanding the past history of mankind. However, we must avoid the mistake of believing that it is possible to study the impact of celestial phenomena on ancient cultures without taking into account their context: unfortunately, this error is still common to date. This paper illustrates the evolution of Archaeoastronomy since the beginning of the 20th century, its basic principles and the modern methodologies for Archaeoastronomy measurements and data analysis. Moreover, the proofs needed to claim the actual intentionality of an astronomical alignment are discussed, showing the potential of Archaeoastronomy, as long as it is strongly linked to, and continuously compared with, excavation data, and combined with Archaeology in various cultural contexts, thus providing valuable assistance in the interpretation of material data.