Synthese (2022) 200:439
https://doi.org/10.1007/s11229-022-03863-z

ORIGINAL RESEARCH

Evidence and analogy in Archaeoastronomy

Francesco Nappo[1] · **Giulio Magli**[1] · **Giovanni Valente**[1]

Received: 4 May 2022 / Accepted: 17 August 2022 / Published online: 25 October 2022

Abstract
This paper addresses the role of analogical reasoning in archaeoastronomy - the discipline which studies the connections between the ancient monuments and the heavens. Archaeoastronomy is a highly interdisciplinary science, placed at the border between the humanities – especially archaeology – and the scientific approach to cultural heritage. As a consequence, its scientific foundations are a delicate matter. We plan to investigate here the question of what constitutes the evidence for analogical inferences in archaeoastronomy and to what extent one can achieve confirmation of archaeoastronomical hypotheses by means of such analogies. Our claim will be that, when deployed in accordance with the methodology articulated in this paper, analogies can be a highly effective epistemic tool for generating and supporting hypotheses about the relation of archaeological sites with astronomical events.

1 Introduction

Analogical reasoning is often employed in the sciences when attempting to investigate systems which we do not have direct empirical access to, and hence the only way to draw inferences about them is to rely on evidence coming from other systems that we regard as similar in some relevant respects. For instance, ethnographic analogy is a method of investigation typically used in archaeology, whereby one tries to interpret the findings in an archaeological site by reconstructing the unobservable behavior of its ancient inhabitants based on the known habits of living groups (Wylie, 1985; Currie, 2016). Likewise, an active research program in cosmology purports to understand the possible behavior of black holes by reasoning with small-scale analogues (Dardashti et al., 2017). Thus, it should come as no surprise that analogical reasoning is also employed as an epistemic tool in the highly interdisciplinary field

✉ Francesco Nappo
francesco.nappo@polimi.it

[1] Department of Mathematics, Politecnico di Milano, Via Bonardi, 9, 20133 Milano, Italy

of archaeoastronomy - "the science of stars and stones" (Magli, 2015) – whose aim is to uncover the hidden connections between ancient sites and monuments and various observable astronomical phenomena.

Notwithstanding the growing debate in the philosophy of science about the reliability of analogical inference, there still lacks a thorough analysis of the matter for archaeoastronomy. We believe that this is an important omission. Since its 19th -century origins, belief regarding the capacity of archaeoastronomical research to contribute to the understanding of the ancient minds and practices has gone through ebbs and flows. As a discipline placed at the border between the hard sciences and the humanities, there has been a prolonged disagreement about what counts as sound methodology in this field (cf. Ruggles, 2001). An important contributor to the aura of skepticism that still surrounds the discipline today is its frequent misuse to support a variety of pseudo-historical accounts. Although such fringes have nothing to do with archaeoastronomy, they dramatically influence its reception among both working researchers and the broader public.

In such circumstances, a systematic appraisal of the scientific foundations of archaeoastronomy is a highly desirable goal. The role of analogical inference deserves particular attention. Given its ubiquitous role in the discipline, a thorough analysis of the conditions under which analogical evidence can best be used to generate archaeoastronomical knowledge is urgent. The natural object of such a methodological study is the knowledge that allows the expert archaeoastronomer to distinguish between shallower and deeper analogies and to draw epistemically responsible inferences about the features of an ancient culture from the orientations of its sites and buildings. By explicating such knowledge, we can not only reassure that the methods employed by contemporary archaeoastronomy are properly scientific, but also shed light on the difference between genuine archaeoastronomy and its many pseudo-scientific forgeries.

By extending the discourse on the scientific foundations of archaeoastronomy developed in Magli (2015), in this paper we plan to answer the related questions of what constitutes the evidence for analogical inferences in archaeoastronomy and to what extent one can expect to achieve confirmation of archaeoastronomical hypotheses by means of such analogies. Even though our treatment will fall short of completeness in some respects, we emphasize that our discussion represents a first attempt at systematizing the varieties of analogical inferences employed in the discipline. Accordingly, our aim will be to offer the starting point for further discussion and debate among both archaeoastronomers and philosophers. On our view, continued engagement with these topics is not only likely to improve archaeoastronomical research, but to also make the philosophy of science more relevant to unsettled methodological issues that have so far been rather neglected, such as those concerning the correct integration of humanistic and hard sciences perspectives.

The discussion below will proceed as follows. In section two, we will review some notable examples of analogical inferences in archaeoastronomical research. An important distinction that we will draw is between *direct* and *indirect* analogies, depending on the relation that the civilization under study bears with that which constitutes the source or model. In section three, we will outline a novel framework for drawing epistemically responsible inferences from archaeoastronomical analogy. We

Fig. 1 Spectacular sun crowning effect on Spring Equinox at Angkor Wat, Cambodia [Source: Wikimedia Commons]

will consider how to assess and refine analogical evidence in archaeoastronomy, both in its function of supporting explanations of astronomical orientations and in that of informing predictions about yet unobserved alignments of archaeological sites. In section four, we will move on to address the problem of justifying the use of analogical reasoning in the discipline, defending a position of cautious optimism. Finally, section five will summarize our arguments and draw connections to the broader philosophical debate regarding the reliability of analogical inference in science, specifically in relation to *globalist* versus *localist* approaches.

2 Orientations

It is a fact about many archaeological sites and buildings around the world that they display astronomical alignments. For instance, we find that the axes of several ancient cities and necropolises are oriented cardinally; this relates to the idea of a cosmic order which is a structural element of any ancient worldview, and – in the case of a flat horizon – also relates to the sun rising in alignment with a city axis at the equinoxes. Several ancient monuments from the most disparate regions of the world – from Egypt to Cambodia to the Americas - have been designed in such a way as to generate spectacular sunlight and 'sun crowning' effects on selected days of the year (Fig. 1). Further examples of such cyclical appointments, which in many cases demonstrate a deep knowledge of the celestial cycles by ancient civilization, include alignments with specific stars (Ruggles, 1999), as well as with Venus (Sprajc, 1993) and the Moon (Malville et al., 1991).

Testing astronomical alignments requires (at least initially) only a moderate amount of instrumentation: a magnetic compass and a clinometer to measure alti-

tudes and azimuths, and a planetarium software to check if the alignments correspond to the position of celestial bodies at the time of the site's construction. In some cases, total station or GPS technology may be necessary if one suspects that the builders achieved a high accuracy (as it happens in the case of many Egyptian buildings; cf. Magli, 2015). Moreover, historical evidence concerning the topological features of the sites and buildings under study (e.g., the presence of a forest or a nearby building) may be useful at this stage. To confirm the robustness of the results, statistical analysis is standardly used to ensure that the accumulations peaks in the data are above some conventionally chosen threshold. (As with other applied science, the correct use of statistics in archaeoastronomy is a hotly debated topic; see, e.g., Aveni, 2006, Silva, 2020 for relevant discussions).

Having established the presence of an alignment by means of an acceptable empirical method, the remaining question concerns its interpretation. Is the alignment merely a coincidence or is it an expression of a purposeful design choice? The main obstacle that archaeoastronomers face in this context is the familiar one of underdetermination: to form a picture of the intentions of ancient designers from the presence of astronomical alignments involves going beyond the scope of what is known or empirically testable. No matter how striking the astronomical alignments might be, then, various streams of converging evidence are necessary to establish robust conclusions about the minds and worldviews of ancient designers. This applies, a fortiori, to aligned sites and buildings of civilizations about whose minds and cultures little is independently known.

It is in this context that analogy plays a role in archaeoastronomy. A military metaphor is especially fitting here (Pickering, 1997; cf. Weil, 1979). Starting from the available evidence, the research strategy is to identify a "bridgehead" (as Pickering, 1997:48 puts it) that links some observed feature of the civilization under study with those of a more familiar culture. Such link may be provided by similarities in the respective material artefacts or buildings, by evidence of common religious forms and cultural practices, or by considerations of historical and geographical contiguity. Once an adequate bridgehead is available, the remaining work consists in a "transfer" (49) of the system of meanings of the familiar culture into the description of the target civilization, revising and filling those aspects of the source culture that are either inapplicable or missing. In this way, an analogy with a more familiar civilization can become a source of new insights and hypotheses about people whose intentions and worldview would otherwise entirely escape us.

Clearly, the possibility of the analogizing strategy depends on the existence of a suitable bridgehead. Although nothing strictly speaking guarantees it, in practice the problem is less acute than it might seem. Key to understanding the linkage between architecture and the sky that we find across so many past civilizations is the role of astronomy in human affairs. As Eliade (1959) has first stressed, from the regulation of space (typically arising from the cardinal directions) and that of time (through a calendar), the celestial cycles give order to the human existence. In most ancient cultures, religious and secular powers present themselves as the keepers of that cosmic order – as expressions of a divine will. An important link thus emerges between architecture, power and the sky: astronomically aligned sites and buildings symbol-

ize that communion of earthly things with the heavens that religious and secular power helps preserve through the centuries.

This initial characterization of the rationale behind the analogizing strategy in archaeo-astronomy is still rough in some respects and will require sharpening. An important distinction that we should stress here concerns the culture that serves as the source or 'model' (cf. Wylie, 1985; Currie, 2016). In *direct* analogies, the source is a civilization that has a direct historical and geographical relation with the target civilization. In *indirect* analogies, instead, the source is a civilization with no historical or geographical link with the target. To illustrate this difference, a few examples of analogical inferences in current archaeoastronomical research are in order.

2.1 The urban plan of Aosta

The Italian town today called 'Aosta' was founded around 20 BC by the Roman legions to control the way to Gauls (France) with the name Augusta Praetoria Salassorum. It is clear that the city was devoted to Augustus – who is celebrated by a triumphal arc – but we do not have written sources of any kind about its foundation. The town has the standard, orthogonal Roman plan. Archaeoastronomical research shows that one axis was carefully oriented to the Sun rising at the winter solstice, which at the time was occurring in Capricorn (due to the phenomenon of precession, today it is not so, so much for modern believers in astrology). Is this alignment (see Fig.2) intentional? Some hints towards resolving this question come from the evidence of other Roman cities and monuments where the existence of astronomical references is supported by textual sources or direct measurements (cf. Magli, 2008, Rodriguez-Anton et al., 2018). This comparison suggests, by *direct analogy*, that Aosta's specific orientation was a purposeful design choice (as we shall see in section three, the cultural context also plays a role in this analogy).

2.2 The funerary project of Amenemhet III

In the so-called Middle Kingdom (approx. 2055 – 1790 BC), during the Twelfth Dynasty, the Egyptian king Amenemhet III constructed two pyramids, one in Hawara (Fayoum) and the other in Dashur. The interior apartments of the latter – known as the 'Black pyramid' - show clear signs of structural damage, but it is very doubtful that they appeared at the time of construction (instead of being due to later earthquakes). Hence, the question arises as to why a single king constructed two pyramids. By considering the topographical aspects of the Hawara site and the astronomical alignments of the pyramid, however, a striking resemblance emerges with the two double building complexes completed more than six centuries earlier by Egyptian king Snefru at Dashur and Meidum-Seila (cf. Magli, 2012, Belmonte & Magli, 2015). The resemblance between the respective complexes supports the hypothesis, by *direct analogy*, that the two pyramids built by Amememhet III formed a large two-fold complex, a double tomb meant as a replica of Snefru's. Although direct, this analogy is based on the impressive cultural continuity that characterizes the Egyptian civilization: in other words, while Aosta belongs to the same cultural environment

Fig. 2 Center of Aosta on winter solstice. [Source: Regione Autonoma Valle d'Aosta Official Website]

from which we extract the interpretation, in this case more than six hundred years have passed.

2.3 Gobekli Tepe

The megalithic enclosures at Gobekli Tepe (Urfa, Turkey) are the most ancient monuments in stone known so far – dating around the 10th millennium BC. Their function is clearly religious, but their antiquity is so astonishing (they were built before the "Neolithic revolution" and therefore before sedentarism) that interpreting them is very difficult. In fact, their discovery brings the construction of "temples" back in time of many millennia (Schmidt, 2001). A typical enclosure at Gobekli is formed by an oval wall in which several T-shaped megaliths are partly embedded, and two further central, free-standing T-shaped megaliths. The latter are parallel and define an orientation for the structure. All megaliths are decorated by animal and/or abstract bas-reliefs. These structures have a marked similarity with megalithic sanctuaries which were built some 8500 years later on the island of Menorca, Spain (Fig.3). Of course, the two cultures are unrelated but the analogy is striking. The sanctuaries of Menorca, built during the Bronze Age, are indeed oval stone walls enclosing a huge, T-shaped megalith (so-called 'taula') whose face in the direction of the entrance pro-

vides an orientation for the structures (Hoskin, 2001). The taula sanctuaries have been shown to be oriented towards the brilliant stars of the Cross-Centaurus group – which were, at those times, still visible in the Mediterranean area (today precession has brought them below the horizon). The similarities in form and orientation suggest (by indirect analogy) that the enclosures at Gobekli Tepe might have been similarly oriented to stars which were visible at the southern horizon – and, indeed, their alignments might be related to Sirius, which was in those remote times just becoming visible again after completing a precessional cycle (cf. Magli, 2016).

The distinction between direct and indirect analogies is relevant because the resulting analogical inferences work in different ways (cf. Sect. 3.1 below). In direct analogies, the inference to the target's predicted property is mainly fueled by the common lineage with the source: for instance, the obvious connection between different cities built under the Roman empire. Such connections are typically sufficient to make it plausible that a similar meaning as the one associated with an astronomical or topographical alignment in the monuments of the source culture will also be found in the derivative culture. Direct analogies in archaeoastronomy can therefore be considered the equivalent of *homologies* in evolutionary biology, whereby two species related by close common ancestry are expected to possess similar heritable traits (cf. Currie, 2016).

In indirect analogies, conversely, no such appeal to common lineages is possible. There is, for instance, no plausible direction of influence from inhabitants of Gobekli Tepe in the 10th millennium BC to the civilization flourishing in Menorca more than 8000 years later. It is in this case that the discourse about the linkage between architecture, power and the sky that we have mentioned earlier becomes most relevant. For, in the absence of direct inheritance, the analogical inference must rest on some broader uniformity in human experience and behavior. Indirect analogies are thus like *homoplasies* in biology, whereby two not closely related species are predicted to possess functionally similar traits as the result of similar environmental pressures.

It must be stressed that, although the bridgehead in the indirect case is often less secure than its direct counterpart, the distinction between direct and indirect analogies in archaeoastronomy does not coincide with that between stronger and weaker analogical inferences. (The same is arguably true in biology, despite the common injunction against homeoplastic inferences; cf. Lorenz, 1974:233). The following is another example of a strong indirect analogical argument:

2.4 Stonehenge

According to some archaeologists (e.g., Parker Pearson and Ramilisonina, 1998a) the British complex of Stonehenge was intended to be a place for the dead, whereas the nearby Woodhenge – made in wood, a perishable material – was a place for the living. Archaeoastronomy comes into play in a quite intriguing way in this context. Indeed, it is well known that Stonehenge is oriented to summer solstice sunrise. However, the symmetry axis of the internal horseshoe structure – the external being a circle – is oriented to summer solstice sunrise from inside looking out, but the horizon is flat in both directions, so it is also oriented to winter solstice sunset from outside looking in, along the direction of approach to the monument marked by a processional avenue

(Allen et al., 2016). Due to the association of the winter solstice with a moment of 'rebirth', alignments of this kind are common in tomb's architecture across many ancient civilizations – the most familiar example being Ireland's Newgrange, roughly contemporary to the first phase of Stonehenge. In this case, an *indirect* archaeoastronomical analogy (with the orientations of tombs in other, mostly unrelated civilizations) supports the interpretation of Stonehenge as a place devoted to the dead.

To sum up, archaeoastronomical research makes frequent use of the analogizing strategy to advance and support hypotheses about past civilizations. In this section, we have distinguished two sorts of bridgeheads in the application of the strategy, namely direct and indirect analogies, depending on the civilization that constitutes the source of the analogical inference. In the next section, we will address the issue of how to assess and improve the reliability of the analogical transfer of a source civilization's properties to make inferences about an unfamiliar target.

3 Responsible inferences

Given the frequency with which analogies are invoked in archaeoastronomy, an important question is the following: what makes for a *strong* application of the analogizing strategy? This question has received relatively marginal attention in methodological discussions by archaeoastronomers, who concentrated on rather specific instances – such as the pitfalls one runs into when exporting Western notions and mind-frames to the study of non-Western civilizations (e.g., Aveni, 2003).

To address the general question, three clarifications are in order. First, in what follows we are concerned with the evaluation of analogical inferences in what philosophers call the *material* mode (cf. Hesse, 1963), i.e., in their purported use in support of empirical hypotheses. This contrasts with their use in the *formal* mode, in which the analogy is used simply as a means of raising new questions or clarifying some concepts (cf. Parker Pearson and Ramilisonina, 1998b).[1] In the latter case, any credibility claimed for a hypothesis must come solely from its capacity to fit the evidence collected about the target system – just as the myriad of alternative hypotheses that may fit the evidence equally well. On the contrary, when an analogy is used in the material mode, the study of the source domain serves not merely to generate or illustrate a given hypothesis, but also as a defeasible basis for supporting an inference to an unobserved feature of the target civilization.

Second, we will consider evaluative criteria that apply to *both* analogical arguments that draw from similarities in astronomical orientations between sites and buildings to infer a similar cognitive explanation – as in the cases of Aosta (2.1), double pyramid (2.2), and Stonehenge (2.4) – *and* those moving in the opposite direction, drawing from similarities in cultures and practices of different people to inform predictions about the likelihood of astronomical alignments in some given archaeological site or building, as in the case of Gobekli Tepe (2.3). To adopt the terminology

[1] Nyrup (2020) distinguishes the formal use in two further uses: 'generative' and 'pursuit-worthiness'. While agreeing that all such uses are important to historical research, below we will zero in on the evidential use.

introduced in Bartha (2009), our criteria are intended to apply to both archaeoastronomical analogies of the *abductive* (viz., from similar alignments to similar intentions) and of the *predictive* kind (viz., from similar intentions to similar alignments).

Third, in the following discussion we are solely concerned with the *internal* (or *descriptive*) question of what, by the lights of the expert archaeoastronomer, makes for better or worse attempts at drawing analogical inferences from the comparison with a more familiar culture. Such a question is one that the expert archaeoastronomer should be (at least in principle) in a position to answer, as it concerns the implicit norms governing strong analogical inference in the discipline. The question is importantly different from the *external* (or *normative*) issue regarding what, if anything, makes it rational for working archaeoastronomers (given their cognitive setup, environment, and aims of inquiry) to reason analogically in broad accordance with those implicit norms.[2] The latter is a distinctly philosophical question; it will be considered in more detail in the next section.

Of course, given the complexity of problem situations in which the analogizing strategy is used in the discipline, there is no reason to expect that the answer to the internal problem will be any easier in archaeoastronomy than it is in other sciences. As with military strategies, a skillful use of the analogizing strategy in archaeoastronomy remains something more akin to the application of an artistic technique than to the implementation of an algorithmic procedure. Even so, it seems possible to advance (again, just as it happens with military strategy) guidelines concerning what tends to make for a sound application of the analogical method. Instructive discussions of this kind already exist for archaeology (e.g., Wylie, 1985; Wylie & Chapman, 2016), ethnography (Currie, 2016), and other historical sciences. Below we will attempt to provide a list of field-specific criteria tailored for archaeoastronomy.[3] Specifically, we will discuss criteria regarding the relevance of the similarities (3.1), their quality (3.2), and the availability of contextual information (3.3).

3.1 Relevance

A central criterion of evaluation for analogical inferences in archaeoastronomy is the *relevance* of the known similarities. The main concern is to ensure that the relation that one must posit between the known and the merely predicted similarities – in short, the relation between observed alignments and associated worldviews - is not affected by differences in geographical or temporal location between source and target. Only in this way one can argue with some plausibility that what appear to be the 'same' alignments across source and target are related to similar worldviews, or vice versa.[4] Even in a case such as Aosta (2.1), for instance, we must be careful to consider whether there may be other reasons for the city's orientation – e.g., reasons due to the

[2] For the distinction between descriptive and normative issues about inductive reasoning, see Lipton (1991).

[3] Our criteria aim to integrate discussions of 'best practices' for archaeastronomy, as in Ruggles (2015, ch. 25).

[4] For the idea that the relation between the known and the predicted similarities is a central dimension of evaluation of an analogical argument in science, see also Hesse (1963), Wylie (1985), and Bartha (2009).

landscape or the wind's direction, rather than symbolic ones. Of course, the issue is all the more pressing when considering analogical inferences of the indirect kind, as in the case of Stonehenge (2.4). In what follows, we will discuss criteria of relevance for direct and indirect analogies separately.

A useful example for direct analogies is the double pyramid case (2.2). To provide some background, we know that the necropolis of Dashur in Egypt started to be used as a royal pyramid field by king Snefru (the father of Khufu) around 2600 BC. Snefru completed as much as two complexes, each one composed by two pyramids and their respective annexes. The first double project is in Dashur and comprises the so-called 'Red' and 'Bent' pyramids; the second is further south and includes the pyramid of Meidum and that of Seila, which overlooks the Fayoum oasis (Lehner, 1999). The reasons for such a phrenetic activity are mostly symbolic, as archaeoastronomy (in the broader sense of a discipline investigating the symbolic meaning of topographical relations) convincingly shows. In particular, the double tomb projects relate to the idea that the Pharaoh was the holder of both Upper and Lower Egypt, as symbolized by the 'coupled' crown of the two lands. As a result, Snefru needed two tombs (one of which we would call 'cenotaph' in modern terms), as also visible in the (chronologically precedent) Step Pyramid complex by king Djoser.

Is king Amenemhet III's decision to build a second pyramid at Dashur after his Black pyramid at Hawara an attempt to mimic Snefru's architectonic project 600 years earlier? Although the resemblances between the two projects are striking (see also Sect. 3.2), the intentions behind the two double complex projects might have been radically different. As a matter of fact, an important element in favor of the hypothesis of an intended continuity in design comes from an Egyptian text known as the 'Prophecy of Neferti' (dating around 2000 BC) – a text with a propagandist aim, having the specific objective of identifying the kings of the 12th Dynasty (which include Amenemhet III) as the legitimate heirs and keepers of Snefru's legacy. This written source turns out to play a crucial role in establishing the relevance of the resemblances in topographical and astronomical respects of the two double complex projects. In effect, it provides us with independent evidence of an intended connection between the two temporally distant kingdoms.

Here we have an illustration of one of the hallmarks of a strong archaeoastronomical analogy of the direct kind, which we can express in terms of the following criterion of plausibility:

R1 *There is evidence in support of the robustness of the hypothesized property across the known temporal and geographical distance.* Such would be, for instance, the evidence of the 12th Dynasty's attempt at claiming king Snefru's legacy, strengthening the hypothesis of continuity.

As we stressed, meeting this requirement is important even when the temporal or geographical distance between source and target culture is relatively small – as in the example of Aosta (2.1).

Indirect analogies in archaeoastronomy require a separate discussion. When source and target are unrelated civilizations, making the case that similar astronomical alignments trace back to similar intentions (or vice versa) is often a significant inductive leap. Although, as we said, general patterns of behavior or universals of human experience can be used in support of the inferences, they must be considered

carefully. For example, it may be argued that an aligned monument is an effective solution to a problem that is common across cultures, such as the building of a shared memory. However, one must be cautious in drawing conclusions from considerations of this type. Among other things, geographical and historical differences often lead to different problems – or at least different priorities. Moreover, even when one can safely assume that there is a common problem between source and target culture, there may still be multiple valid solutions for it.

As a matter of fact, the strongest inferences of the indirect kind are those in which the causal link between the observed and the predicted respects of similarity is very tight – as can be evidenced by the emergence of the same alignment-worldview pattern in several unrelated civilizations. An example would be the association between winter solstice orientations and beliefs about regeneration and the afterlife that fuels the inference in the Stonehenge case (2.4). Archaeoastronomy shows that this is a relatively common (though not exceptionless) association that is present across a variety of unrelated civilizations. The stability of this association in so many unrelated contexts is evidence that the causal link between worldview and alignment is less likely to be affected by differences in geographical and historical respects between source and target. Conversely, indirect analogical inferences in which the alignment-worldview link is not tight, in requiring a concomitance of many independent factors for its obtaining, are inevitably less secure.

From the considerations above, we can extrapolate the following criterion of plausibility for analogical inferences of the indirect kind in archaeoastronomical research:

R2 *There is evidence that the relation that the argument posits between observed and predicted similarities is robust across a significant range of geographical, temporal, and cultural variations, so as to exemplify a very common (possibly universal) human pattern.* For instance, the observation that tombs in unrelated civilizations are often aligned to winter solstice provides independent support to the hypothesis that the latter is associated with beliefs about the afterlife.

Criteria R1 and R2 are displayed in the attached Table 1, which also includes a synopsis of the discussion regarding quality of similarities and contextual information which is to follow.

3.2 Quality of the similarities

Another central element in the evaluation of an analogical inference in archaeoastronomy is the qualitative assessment of the similarities between source and target system. The main concern is to ensure that, in addition to being relevant, the observed similarities are important enough to do the requisite lifting work in the analogical inference. To this effect, one requirement that we believe plays an important role in archaeoastronomy is that the respects of similarity can be articulated in a *precise* way. For instance, a similarity with respect to the cardinal orientation of the pyramids in Snefru's and Amenemhet III's respective double complexes makes little room for doubts about the genuineness of the analogy, since it can be expressed in precise quantitative terms. On the contrary, vague resemblances, resonances, and feelings of 'relatedness', however useful to the individual archaeoastronomer, are typically

Table 1 Some criteria of strong analogical reasoning in archaeoastronomical practice

Relevance	Direct: R1 *There is evidence for the robustness of the hypothesized property across the known temporal and geographical distance.*	Indirect: R2 *There is evidence that the relation that the argument posits between observed and predicted similarities exemplifies a common (possibly universal) human pattern.*
Quality of the Similarities	All types: Q1 *The respects of similarity are expressible in a precise (possibly quantitative) manner*	
	S-type: Q2 *There are several independent respects of similarity.* Q3 *At least some of the respects of similarity are rare.*	C-type: Q4 *The known respects of similarity are part of a recurrent cluster*
Contextual Information	All types: C1 *Contextual information supports, or at least permits, the analogical inference.*	

insufficient to support a strong analogical argument. Hence, we take the following to be a plausible evaluative criterion for all archaeoastronomical analogies:

Q1 *The respects of similarity are expressible in a precise (possibly quantitative) manner.* This could be, for instance, noting that two sites share the same orientation (with negligible error).

Of course, precision is not all that matters. To specify the remaining criteria, we would like to draw a further distinction among archaeoastronomical analogies – orthogonal to the one between direct and indirect analogies. It is based on what one might call the *leverage* of an analogical inference.[5] To illustrate, let's return to the double pyramid case (2.2). The analogy here relies on a series of rather striking similarities. First, each pyramid in the two double complexes have their axes oriented cardinally. Second, Snefru's pyramids Meidum and Seila were designed to be distant yet visible to one another – so as to be perceived as "sentinels of power" (Magli, 2012:69); the same is true for the Hawara and Dashur pyramids later built by Amenemhet III. Third, the slope of the pyramidion (the monolithic stone in pyramidal form which was used to cap the king's pyramid's summit) is the same (7/5 or 54° 30' in modern terms) as that of the lower section of the Bent pyramid – the only two known examples of the use of such a slope in pyramid construction.

The double pyramid case illustrates one type of analogical inferences in archaeoastronomy: those which make leverage on the *independence* and *rarity* of the observed similarities. We will call these *S-type* inferences (for 'sparseness'). The following criteria apply to them:

Q2 *There are several independent respects of similarity.* For instance, position and slope in the two double pyramid complexes are features unrelated to one another, which arguably support the hypothesis of an intended continuity in projects more than each similarity separately does.

Q3 *At least some of the respects of similarity are rare*. For instance, the above-mentioned resemblance in slope of the Black pyramidion and the Bent pyramid's lower section is an extremely rare fact in light of available archaeoastronomical knowledge about ancient Egypt.

We highlight that these criteria extend naturally to the case of Stonehenge (2.4), an indirect analogical inference. In this case, source and target in the analogy feature stone-made enclosures aligned to both summer and winter solstice. These are independent and relatively rare respects of similarity, indicating that Stonehenge's apparent orientation is unlikely to be merely coincidental.

The case of Gobekli Tepe (2.3) illustrates *C-type* (for 'clustering') analogical inferences. To recall, here we have the remains of a remarkably ancient sacred site, the likely destination of pilgrims much before the shift from nomadism to sedentarism and from hunting to agriculture. The hypothesis of a connection with the stars is made plausible by the analogy with similar megalithic structures, such as those in

[5] In this sense, our descriptive approach is different from the one Currie (2016) suggests for ethnographic analogies, insofar as the latter distinguishes the relevant evaluative criteria solely on the basis of the *source* of the analogical inference and not, as we will suggest below, also partly on the basis of the inference's *leverage*.

Fig. 3 Megalithic structures in Gobekli Tepe, Turkey (left) and Menorca, Spain (right) [Sources: Berthold Steinhilber/ Laif/Redux; Ben Salter)

Menorca (Fig.3), which are astronomically aligned.[6] In this case, the idea is that there exists a relatively stable interest of megalithic civilizations for the celestial cycles; from this association, and the fact that megalithic enclosures in other civilizations were astronomically aligned, one infers that the megaliths at Gobekli Tepe are also likely aligned.

When considering what makes for strong analogical inferences of the C-type, one difference with S-type analogical inferences strikes us as most important. C-type analogical inferences put less emphasis on the exceptionality of the observed similarities and more on their forming a relatively stable *cluster* common to source and target. For instance, the most compelling aspect of the similarities between the megalithic sites of Gobekli Tepe and the later ones in other parts of Europe is not their rarity, but their conjuring up to form a common architectonical kind that we can identify across pre-historic sites. The reiteration of this cluster of features is what makes it plausible to conjecture that the Gobekli Tepe site is astronomically aligned. Conversely, S-type analogical inferences are stronger when more idiosyncratic similarities are involved: the fact that two pyramid constructions have the same slope is strong evidence precisely because it is rare.

We can express this difference by noting that the following is a plausible evaluative criterion for archaeoastronomical analogies of the C-type (replacing criteria Q2 and Q3 above):

Q4 *The known respects of similarity are part of a recurrent cluster.* For instance, the hypothesis of an astronomical alignment for Gobekli Tepe is strengthened by the recurring appearance of the cluster: heavy stone building, sacred area, presence of engravings.

It must be stressed that the distinction of S-type and C-type inferences is not always sharp. For instance, we may interpret the inference to Aosta's (2.1) intentional orientation as of the S-type, based on rare similarities with other cities having their axes oriented cardinally. However, by collecting further information about Roman urban planning, we may be led to regarding Aosta's case as an instance of a recurrent pattern of astronomically aligned cities – making the analogical inference C-type. Incidentally, this example also shows that the distinction between S-type and C-type does not coincide with Bartha's (2009) distinction regarding the *direction*

[6] Another piece of relevant evidence is the decreasing 'azimuths' (i.e., the angle between the north and a given point in the sky) of the more recent enclosures at Gobekli Tepe, reinforcing the hypothesis of a stellar target.

of the analogical inference.[7] Although inferences from similar alignments to similar worldviews – 'abductive' analogies in Bartha's terms - often make leverage on idiosyncratic and striking similarities and inferences from similar worldviews to alignments – 'predictive' analogies - often rely on recurrent clusters of properties, there is at most a defeasible association between the respective classes. For instance, the inference to Aosta's intentional orientation is abductive and yet (arguably) C-type.

3.3 Contextual information

A third important element in the assessment of an analogical inference in archaeoastronomy concerns the availability, or lack thereof, of converging evidence in the background information. A prime example in which contextual factors play a crucial role is the case of Aosta's orientation (2.1). Despite the lack of written documents, we do have a clear picture of the cultural context of its foundation, the so-called "Augustean age" (Zanker, 1990). Augustus credited himself as the harbinger of a new Golden Age of peace and prosperity, and the idea of renewal – traditionally linked to the winter solstice – was associated with the astrological sign that Augustus chose for himself: the Capricorn (although he was not born in Capricorn). This piece of contextual information offers strong backing to the hypothesis that Aosta's urban plan was intentionally designed so as to have one of its main axes oriented to winter solstice for symbolic reasons (cf. Bertarione and Magli 2015).

In some cases, supporting evidence can take the form of an aesthetic consideration. For instance, in the two pyramids case (2.2) additional evidence is provided by the topographical clues indicating Amenemhet III's intention to harmonize his double complex with existing ones – not only with Snefru's older pyramids, but also with the monuments built under Amenemhet II and Senwosret III, who immediately preceded Amenemhet III. As Magli (2012) writes: "Visitors sailing on the Dashur lake perceived a spectacular effect of perspective, with the two imposing monuments of Snefru in the background and their respective companions, those of Amenemhet II and III, in the foreground. Aligned with these, further north, the imposing pyramid-cenotaph of Senwosret III towered above the whole area" (67). These considerations arguably strengthen the case for the hypothesis of a double complex project intended in deep continuity with Snefru's.

Stonehenge (2.4) is another interesting case in this regard. One piece of evidence for the hypothesis that the megalithic constructions were devoted to the care of the ancestors consists in an ethnographic analogy. As Parker Pearson & Ramilisonina (1998a) have discussed, inhabitants of Madagascar until recently drew a symbolic difference between wood and stone. The former—a perishable material - was used for the houses and was associated with life, whereas the latter – a symbol of indestructibility - was used to honor the dead and was associated with the afterlife. The similarities between tombs in Madagascar and those in paleolithic Britain suggest that the wood versus stone distinction may be at play in the Stonehenge complex as well. Thus, an ethnographic analogy integrates and strengthens an archaeological and archaeoastronomical hypothesis.

[7] We are very grateful to an anonymous referee for pointing out that some 'abductive' analogies are C-type.

Contextual information can also weaken an analogical inference – sometimes in a decisive way. For instance, archaeologists have recently identified another sacred site in the vicinity of Gobekli Tepe, called 'Kaharan Tepe'. This new site – 46km to the east of Gobekli Tepe –features T-shaped engravings similar to those of its sister site, as well as obelisks depicting animal figures, which may be older than those found at Gobekli Tepe. Because of the assumed connection between the two sites, evidence of unaligned engravings at Kaharan Tepe might tell heavily against the hypothesis of a connection of Gobekli Tepe's monuments with the sky. Of course, as the Kaharan Tepe site is for the most part unexcavated, we do not yet have this form of direct counter to the hypothesis of Gobekli Tepe's being intentionally oriented to a stellar target.

Altogether, the case-studies above illustrate the following final evaluative criterion, which we regard as valid for all kinds of analogical inferences (i.e., S-type, C-type, direct, indirect):

C1 *Contextual information supports, or at least permits (i.e., does not disallow) the analogical inference.* For instance, information about the Augustean age and Augustus' political and ideological projects strengthen the case for Aosta's intentional orientation to winter solstice.

To summarize, in this section we have presented a set of criteria (Table 1) that arguably govern the practice of analogical inference in archaeoastronomy. Although such criteria are (like all norms) vague in some respects, they impose non-trivial constraints on epistemically responsible analogical inferences in the discipline, illustrating how different streams of converging evidence are needed to strengthen them. Further methodological investigations into the several branches of archaeoastronomy may be able to uncover additional field-specific norms that escape the depth of field of our discussion. We encourage such future endeavors by both archaeoastronomers and philosophers of science.[8] For the sake of comprehensiveness, in the next section we will abandon descriptive issues to address the hard epistemological problems related to justification.

4 The problem of circularity

The question that has remained unaddressed is whether there can be a genuine *epistemic* use of analogy in archaeoastronomy – in other words, whether an analogy with the artefacts of a more familiar culture can be a source of confirmation for hypotheses about the relation of some unfamiliar sites or buildings with the celestial cycles. The central epistemological predicament is arguably what Wylie (1985) calls the "problem of circularity" (98): the use of analogy may end up obscuring rather than illuminating a problem situation, setting ourselves up to interpret the evidence in the way that we find most convenient. Precisely because they are the easiest to reach, then,

[8] Another important theme, which we are unable to cover in this paper, is the use of archaeoastronomical tools to apply in landscape archaeology: see, e.g., Magli's (2020) work on the intricate connections between Feng Shui geomancy, astrology and astronomy as embodied in sacred sites and landscapes in Imperial China.

familiar contexts may mislead us into assuming uniformity of cultural expressions when there is diversity. The inevitable result of turning analogical reasoning into a methodology seems to be a version of the historical facts that is suspiciously 'user-friendly' - as if neglecting that cultural practices across human groups are highly heterogenous and disunified. However, our aim in this section is to show that these concerns about the epistemic use of analogy can be overcome.

It is important for these purposes to distinguish various ways of articulating the circularity problem. One argument takes the form of an 'in principle' consideration, stemming from the very nature of archaeoastronomical research. Thus, it may be argued that, insofar as one of the aims of archaeoastronomy is to unearth past attempts at answering "existential questions such as who we are, how we came into being, and how we seek to participate in the cosmologies we create" (Aveni, 2003:173), its methodology should be designed so as to be open to the broadest variety of possible answers. The more properly scientific attitude for working archaeoastronomers to take might accordingly appear to be a form of skepticism, whereby even the seemingly strongest resemblances should not be relied upon to form expectations about unfamiliar cultures. After all, as Bednarik (2012) writes (addressing the general issue of analogy in the historical sciences), "it is not the role of true science to create, reinforce and perpetuate mythologies about the way the world is" (224).

The 'in principle' version of the circularity worry is arguably overstated: as a matter of fact, a responsible use of analogy is just as likely to *question* existing mythologies about the ancient world than to corroborate them. We need to look no further than the previous case-studies to find telling illustrations. For instance, studying the topographical and astronomical similarities between Amenemhet III's funerary project and the much earlier one by Pharaoh Snefru helps question comfortable historical narratives about the reasons behind Amenemhet III's double pyramid complex – such as the hypothesis that an earthquake occurred just around the time of completion of the so-called 'Black' pyramid. Moreover, and most importantly, identifying a significant bridgehead with such a distant ancestor culture contributes to a re-examination of previously unexpected links between Egyptian kingdoms. In this case, the result of the use of analogies is a much *less* 'user-friendly' version of the historical facts – contrary to what the skeptic alleges.

An even starker illustration of how analogies contribute to problematize existing narratives is given by the hypothesis of an astronomical orientation of the megaliths of Gobekli Tepe based on their similarities with stone enclosures in other parts of Europe. The site's dating before what is standardly regarded as the shift from nomadism to sedentarism challenges deep-rooted ideas about human development. A standard 'progressive' narrative has it that the birth of monumental architecture was one of the results of the shift to sedentarism and agriculture. The hypothesis of an astronomical orientation of the megaliths at Gobekli Tepe might turn this picture on its head: the shift to sedentarism may have been partly *produced* by the development of monumental architecture and the emergence of pilgrimage sites related to the sky and the care for the ancestors. The fact that domesticated grain may have its origin from the slopes of the nearby volcano Karaga Dag (Heun et al., 1997) may, if confirmed, provide further evidence for this surprising claim.

A different version of the circularity problem takes the form of a *de facto* consideration: very frequently, adopting the analogizing strategy in archaeoastronomy leads to false conclusions. Examples of such failures, dictated by a preference for what is near and familiar, are easy to come by. In a paper which effectively revived the attention for archaeoastronomy in the twentieth century, Hawkins (1963) defended the striking claim that Stonehenge had been built to be used as an elaborate astronomical computer – similar in function, though different in design, to modern computers. On Hawkins's account, the stone enclosures at the Stonehenge site allowed their visitors to not only describe the motion of the Sun and the Moon, but also to accurately predict eclipses and other astronomical events. Archeologists were, for the most part, skeptical. Reacting to what she considered as a weak and modish comparison, Hawkes (1967) sentenced that "Every age has the Stonehenge it deserves – or desires" (174). As a matter of fact, much of the interpretation and its material basis later collapsed under systematic criticism (Ruggles 2015:378).

While failure stories necessarily urge caution, we do not think that they are decisive against the epistemic use of analogy. A first consideration is that, as Wylie (1985) notes in the context of archaeology, the picture of a historical discipline that entirely refuses the analogizing strategy is hard to conceive. Unless supported by an unusual amount of target-specific evidence, establishing a cultural basis for observed alignments requires assuming some degree of similarity with people whose worldviews are well-understood. Without some such connection, the possibilities of interpretation are practically endless; the observation of a site's alignment ceases to be much evidence for any hypothesis. Plausibly, then, attempts at establishing archaeoastronomical conclusions about civilizations remote from ours must, on pain of declaring its object unintelligible, exploit some similarity with more familiar cultures as part of their justification.

Additionally, one must consider that, as discussed in the previous section, a relatively stable set of criteria for the assessment and responsible use of newly proposed analogical inferences in archaeoastronomy can be identified, whose role is to constrain the practice of analogical inference in those points where error is most likely to emerge. For instance, the criteria aim to ensure that the similarities that are exploited for the purpose of the analogical argument are important and relevant to the conclusion; moreover, that there exists a robust connection between the known and the merely predicted similarities in the argument. Arguably, then, the practice of analogical inference in archaeoastronomy includes the means for its own self-correction. This suggests a position of cautious optimism (cf. Wylie, 1985; Currie, 2018): although analogical reasoning is fallible, there are reasons to expect that, as our knowledge of ancient cultures grows, so our capacity to draw sound inferences about the relation of their architecture to the sky will improve.

Finally, it must be stressed that, even though analogies that satisfy the criteria above do not fail to lead astray quite often, they should be seen as serving a confirmatory function in archaeoastronomy only as part of a larger portfolio of historical, anthropological, and archaeological evidence. Wylie (2011) has stressed for archaeology, "evidential reasoning depends on multiple strands of arguments" (386). Specifically, she adopts the notion of *horizontal independence* to convey how converging evidence from independent sources is often necessary to support hypotheses about unfa-

miliar people. On our view, sound research in archaeoastronomy should be no less sensitive to such considerations. Hence, viewing archaeoastronomical analogies as potential sources of confirmation does not mean that they may replace other streams of evidence, but that they represent a possibly modest yet non-negligible addition to research, in the way of achieving an increasing degree of horizontal independence.

Although so far our response to the circularity problem has piggybacked on existing arguments in the philosophy of archaeology, we believe that a more forceful and original claim can be defended here: in fact, archaeoastronomy is better placed than most other historical disciplines to overcome concerns of circularity and make analogy a highly effective confirmatory tool. In the broadest possible terms, this has to do with the fact that, as Aveni (2003) puts it, "most ancient civilizations paid some attention to what goes on in the sky" (149). As we will discuss below, this fact constrains the space of conceptual possibilities for research in important ways, paving the way for an epistemic use of analogy. What follows from our comparative argument is, minimally, that localized skepticism about the epistemic use of analogy in archaeoastronomy is untenable. If one admits that analogy can be used effectively in a historical discipline such as archaeology, one should *a fortiori* concede that an effective use is possible in archaeoastronomy. Conversely, if one rejects an epistemic use in archaeoastronomy, a more generalized skepticism must follow.

The productive constraints that we have in mind concern both the side of the material evidence and that of the interpretation. On the former side, possible references to the celestial cycles in ancient sites and monuments are both precisely measurable and limited in number – since they concern the motion and position of the Sun, the Moon, the brightest stars, and sometimes Venus. This fact makes it relatively easier to establish that claimed similarities in alignments are genuine when compared to analogies based on less quantifiable similarities, such as vague resonances between the artistic products of otherwise unrelated cultures (see also criterion Q1 above). In many circumstances, the existence of an identical or similar alignment in monumental sites and buildings is something as close as anything can be to an empirically ascertainable fact. Indeed, coherent groups of monuments – such as tombs in geographically contiguous areas – are often fruitfully studied by means of precise measurements of orientations (Hoskin, 2001).

On the side of the interpretation, the analogical transfer of beliefs from source to target in archaeoastronomy is facilitated by the centrality of the sky's role in most ancient civilizations. This fact helps ensure, first, that the cultural practices that accompany the study of celestial cycles are likely to be an important aspect of cultural inheritance, insofar as knowledge of those cycles constituted a crucial source of information. Secondly, the sky's importance to most ancient civilizations makes it a relevant possibility that similar beliefs and practices regarding the main celestial events (e.g., solstices, equinoxes, etc.) are likely to emerge even in unrelated civilizations, simply as the result of similar beliefs and interests related to the knowledge of those cycles. Hence, the sky's centrality to the ancient mind represents a critical form of support for analogical inferences of both the direct (via inheritance) and the indirect kind (via accidental convergence), contributing to ensure that the relevance criteria (respectively, R1 and R2 above) are satisfied.

To bring out the significance of these constraints to the epistemological credentials of analogical reasoning in archaeoastronomy, we wish to highlight their application to what may be regarded as a strengthening of the *de facto* objection for analogy in the historical sciences: what Currie (2018) calls the problem of "contingency" (213). In the context of archaeoastronomy, the opponent concedes that, when one population is related ancestrally to another, the monumental architecture of the former and its relation to the sky can sometimes shed light on that of the latter – in other words, at least some archaeoastronomical analogies of the direct kind are justified. What the opponent denies is that, when the historical relation between cultures is too loose or non-existent, there can be any reasonable hope of successfully discovering facts about the less familiar culture from the more familiar one. Because of the diversity of initial conditions and the chanciness involved at each stage, historical processes are overwhelmingly likely to produce artefacts – in our case, sites and monuments – that are 'unique' in their historical origin, design and functions.

Discussing the problem of contingency as it arises for paleobiology, Currie (2018) argues that scientists often successfully circumvent the uniqueness of contingency's products by a careful use of several imperfect analogues. More specifically, the strategy consists in representing the unfamiliar target system as what Currie calls an 'exquisite corpse' (from the name of a French game developed by surreal artists in the 1920s): a combination of features drawn from different analogues, each of which resembles the target in certain specific respects while diverging in others. In Currie's example, the saber-toothed metatherian *Thylacosmilus atrox*, a rather unique species which lived through much of the Cenozoic in South America, is compared to *Smilidon fatalis* in its bite mechanisms, in that both favor the use of neck over jaw strength to bite preys, as well as to current-day bears in killing style, in that both aim to first secure the prey by immobilizing it. In this way, a picture of *T. atrox*'s bite and killing style is inferred from two imperfect analogues.

Although we find Currie's point about the exquisite corpse strategy in paleobiology persuasive, we highlight that more direct and solid routes are frequently available to address archaeoastronomical uniqueness, even in its starkest forms. The spectacular light effects of the Kukulkan temple at Chichen Itza and of the Pantheon in Rome are both prime examples of historical products that are unique in their kind. In the former, the shadow cast by one edge of the temple over the main staircase creates, on Spring equinox, the illusion of a snake descending from the top to a nearby cenotes. In the latter, the sunlight coming from a circular opening in the vaulted roof hits the north entrance exactly at noon on April 21st (alleged foundation of Rome). Importantly, in neither case do we have any analogue of each monument's specific light-shadow effect in the same culture, nor any written sources documenting the buildings' actual functions and symbolisms.

Their uniqueness notwithstanding, there is little doubt among archaeoastronomers that the respective builders intentionally designed and oriented the monuments with a symbolic function in mind. More specifically, the two monuments reciprocally illustrate Eliade's (1959) notion of the construction of a *sacred space* – a place in which "the sacred manifests itself" (21). The respective light-shadow effects have been conceived as a *hierophany* – a manifestation of the sacred in the material world, capable of "annul[ing] the homogeneity of space and reveal[ing] a fixed point" (28). In each

case, the most plausible function of carefully oriented monumental architecture is to make the appointment with the sacred recurrent. Conversely, it would be surprising if such idiosyncratic occurrences of light effects in the monuments turned out the be coincidental. Here, then, 'contingency' is a weak argument vis-à-vis the evidence of such specific light effects and of a common schematism surrounding the construction of a sacred space.

What we aim to illustrate through this example is that, precisely as the result of the favorable conditions discussed above, archaeoastronomers are often in a better epistemic position than other historical scientists to draw reliable inferences from archeological remains. On the side of the evidence, the extreme precision with which the light effects at Chichen Itza and Rome obtain on significant days of the year makes the explanation that they occur by chance unlikely. On the side of the interpretation, the two monuments function as reciprocal illustrations of the symbolic meanings associated with light-shadow effects in ancient architecture. Here, no 'exquisite corpse' strategy is necessary to overcome the problem of contingency: there is no need to introduce further imperfect analogues that, as Currie (2018:206) puts it, "compensat[e] for each other's failings".[9] The nature of the observations and the palpable occurrence of a light symbolism, as we also find in a single and highly imperfect analogue, suffice for drawing a relatively strong inference.

A more general point can be extracted from the above examples, regarding the scientific practice of inferring features of the ancient mind from archaeological remains. Recent work in the philosophy of archaeology (e.g., Currie & Killin 2019; Sterelny forthcoming) emphasizes the insufficient constraints provided by psychology to infer (possibly idiosyncratic) beliefs of ancient people from material remains. While recognizing the epistemological quandary, Currie & Killin (2019) resist pessimism by insisting that, in many cases, "the inferences cognitive archaeologists make are compatible with multiple general theories of cognition" (273). Our analysis adds a further angle: sometimes, as it happens in many archaeoastronomical contexts, the record can be so high-quality as to significantly mitigate doubt. Besides assuming that people at Chichen Itza, Dashur, or Gobekli Tepe conceived of the idea of a sacred space, significant progress in some hard cases can be achieved simply by letting the idiosyncratic features (e.g., orientations) of the material remains – when we can capture them in precise quantitative terms – speak for themselves.

To summarize, in this section we have considered the normative problem of justifying the use of analogical reasoning in archaeoastronomy. While sharing the concerns about the pitfalls that one may run into by reasoning from analogy, we have argued that they are best addressed by means of a careful interpretation and observance of the field-specific norms that govern the use of analogical inference in the discipline, accompanied by the recognition that analogies are only part of a larger portfolio of evidential sources to be used in support of archaeoastronomical hypotheses. A responsible use of analogical inference does not, of course, safeguard from error entirely, but can at least assuage concerns about circularity. As we briefly illus-

[9] The exquisite corpse strategy may still prove useful in other cases: e.g., in determining whether a 'dagger-of-light' effect in the inside of Is Paras' *nuraghe* (in Sardinia) had been intentionally planned by its builders.

trated through cases of seemingly 'unique' monuments, archaeoastronomy can often take advantage from the study of analogue sites and buildings - even highly imperfect ones in geographically and temporally remote civilizations. In the next concluding section, we will provide a final overview of our arguments and link our discussion to the existing philosophical literature on analogical reasoning in science.

5 Conclusion

This paper has offered a first systematic discussion of the use of analogy in archaeoastronomy – the "science of stars and stones" (Magli, 2015). To account for the variety of analogical inferences that we observe in the discipline, we have proposed a four-fold taxonomy, based on the *source* and *leverage* of the inferences. By reference to case-studies, we have argued that a relatively stable set of norms describes the practice of epistemically responsible analogical reasoning in archaeo-astronomy. On the question of what justifies their epistemic use, in providing inductive support to archaeoastronomical hypotheses, in section four we have tentatively outlined a response: the justification is in the details. What makes a given analogical inference capable of evidential support depends on how it manages to make use of the contextually available information in accordance with the field-specific norms. Although still partial in many respects, our discussion aims to be starting point for further methodological investigations by both philosophers and practitioners.

We may further clarify our epistemological stance by reference to the broader philosophical debate about analogical reasoning in science. A useful distinction is between *globalist* and *localist* approaches (cf. Norton, 2020). The former view purports to identify some general pattern that all analogical arguments share, in virtue of which they may be either capable or incapable of justifying yet untested empirical hypotheses. Skepticism about analogical reasoning in science is a form of globalism insofar as it takes it that *no* analogical argument is capable of yielding justification (even that of the highly defeasible kind). Non-skeptical versions of globalism have also been defended. One approach, which traces back to J. M. Keynes' (1927) work, consists in the defense of a principle of 'limited variety' as a postulate of inductive rationality, which has as its consequence that observed similarities with a source increase the probability of a hypothesis about a target.

Alongside Wylie (2011), Currie (2016, 2018), and Norton (2020), among others, we favor a localist approach to the epistemology of analogical reasoning. Specifically, on our view, the question of whether an analogical argument in archaeoastronomy can confirm a historical conclusion is unlike determining whether a given set of sentences in premise-conclusion form is deductively valid. Rather, virtuous exercises of the analogizing strategy depend on the ensemble of knowledge and inferences that constitute their necessary background. Justification attaches to those attempts that best exemplify the responsible use of the contextually relevant facts in accordance with the norms governing responsible analogical inference in archaeoastronomy. For example, the inference to the purposeful nature of Amenemhet III's double complex project (2.2) can be regarded as justified only insofar as several contextually relevant facts converge towards it (so as to meet to the field-specific criteria of respon-

sible analogical inference) and not insofar as it may happen to instantiate a universal schema that all confirmatory analogical arguments share.

Precisely in the spirit of a localist approach, we have suggested that sweeping forms of skepticism about the epistemological status of analogical reasoning in archaeoastronomy are untenable: while it is true that such reasoning requires caution, it does not follow that, regardless of the circumstances, analogical inferences are incapable of backing up archaeoastronomical hypotheses. On the contrary, as previously discussed, archaeoastronomy is one historical science in which responsible appeals to analogy may be the most legitimate and scientifically fruitful.

Acknowledgements The authors would like to thank two anonymous referees for their helpful feedback.

Funding PRIN Project 'From Models to Decisions' (G. Valente et al., 201743F9YE), Ministero dell'Istruzione, dell'Università e della Ricerca, Governo Italiano.
Open access funding provided by Politecnico di Milano within the CRUI-CARE Agreement.

Declarations

Conflict of interest none.

Informed consent not applicable.

Ethical approval not applicable.

References

Allen, M. J., Chan, B., Cleal, R., French, C., Marshall, P., Pollard, J., Pullen, R., Richards, C., Ruggles, C., Robinson, D., Rylatt, J., Thomas, J., Welham, K., & Pearson, P. (2016). M., "Stonehenge's avenue and 'Bluestonehenge'". *Antiquity*, 90 (352): 991–1008

Aveni, A. (2003). Archaeoastronomy in the ancient Americas. *Journal of Archaeological Research*, *11*(2), 149–191

Aveni, A. (2006). "Evidence and intentionality: on method in archaoeastronomy". In T. Bostick, & B. Bates (Eds.), *Viewing the Sky through Past and Present Cultures* (15 vol., pp. 57–70). Phoenix: City of Phoenix. Pueblo Grande Museum Archaeological Papers no

Bartha, P. (2009). *By Parallel Reasoning*. New York: Oxford University Press

Bednarik, R. G. (2012). Ethnographic analogy in rock art interpretation. *Man in India*, *91*(2), 223–234

Belmonte, J. A., & Magli, G. (2015). Astronomy, architecture and symbolism: the global project of Snefru at Dahshur. *Journal for the History of Astronomy*, *46*(3), 173–205

Bertarione, S., and Magli G (2015). Augustus' power from the stars and the foundation of Augusta Praetoria Salassorum. *Cambridge Archaeological Journal*, *25*, 1–15

Currie, A. (2016). Ethnographic analogy, the comparative method, and archaeological special pleading. *Studies in History and Philosophy of Science Part A*, *55*, 84–94
Currie, A. (2018). *Rock, Bone, and Ruin*. Cambridge, MA: MIT Press
Currie, A., & Killin, A. (2019). From things to thinking: cognitive archaeology. *Mind and Language*, *34*, 263–279
Dardashti, R., Thébault, K., & Winsberg, E. (2017). Confirmation via analogue simulation: what dumb holes could tell us about gravity. *The British Journal for the Philosophy of Science*, *68*(1), 55–89
Eliade, M. (1959). *The Sacred and the Profane: The Nature of Religion*. London: Harcourt
Hawkes, J. (1967). God in the machine. *Antiquity*, *41*(163), 174–180
Hawkins, G. S. (1963). Stonehenge decoded. *Nature*, *200*, 306–308
Hesse, M. (1963). *Models and Analogies in Science*. Notre Dame, IN: University of Notre Dame Press
Heun, M., Schaefer-Pregl, R., Klawan, D., Castagna, R., Accerbi, M., Borghi, B., & Salamini, F. (1997). Site of einkorn wheat domestication identified by DNA fingerprinting. *Science*, *278*, 1312–1314
Hoskin, M. (2001). *Tombs, Temples and their Orientations. A New Perspective on Mediterranean Prehistory*. Ocarina Books
Keynes, J. M. (1927). *A Treatise on Probability*. London: Dover Publications
Lehner, M. (1999). *The Complete Pyramids*. London: Thames and Hudson
Lipton, P. (1991). *Inference to the Best Explanation*. New York: Routledge
Lorenz, K. (1974). Analogy as a source of knowledge. *Science*, *185*, 229–234
Magli, G. (2008). On the orientations of Roman towns in Italy. *Oxford Journal of Archaeology*, *27*(1), 63–71
Magli, G. (2012). The Snefru projects and the topography of funerary landscapes during the 12th Egyptian Dynasty. *Time and Mind*, *5*(1), 53–72
Magli, G. (2015). *Archaeoastronomy: Introduction to the Science of Stars and Stones*. New York: Springer-Verlag
Magli, G. (2016). Sirius and the project of the megalithic enclosures of Gobekli Tepe. *Nexus Network Journal*, *17*, 1–11
Magli, G. (2020). *Sacred Landscapes of Imperial China*. New York: Springer-Verlag
Malville, J., Eddy, F., & Ambruster, C. (1991). Lunar standstills at Chimney Rock. *Journal for the History of Astronomy*, *22*(16), S43–S50
Norton, J. (2020). *The Material Theory of Induction*. BSPS Online Press
Nyrup, R. (2020). "Three uses of analogy: A philosophical view of the archaeologist's toolbox". In M. Marila, M. Ahola, K. Mammerman, & M. Lavento (Eds.), *Interarchaeologia 6: Archaeology and Analogy*. Helsinki: Department of Cultures, Helsinki University
Parker Pearson, M., & Ramilisonina (1998a). Stonehenge for the ancestors: the stones pass on the message. *Antiquity*, *72*(276), 308–326
Parker Pearson, M. and Ramilisonina (1998b). Stonehenge for the ancestors: part two. *Antiquity*, *72*(278), 855–856
Pickering, A. (1997). "Concepts and the mangle of practice: constructing quaternions". In Herrnstein Smith and Plotnitsky (eds.), *Mathematics, Science and Postclassical Theory*. Durham, NC: Duke University Press, 40–82
Rodriguez-Antón, A., González-Garcia, A. C., & Belmonte, J. A. (2018). An astronomical approach to Roman urbanism. Orientations of Roman settlements across the empire. *Mediterranean Archaeology and Archaeometry*, *18*(4), 89–95
Ruggles, C. L. N. (1999). *Astronomy in Prehistoric Britain and Ireland*. New Haven & London: Yale University Press
Ruggles, C. L. N. (2001). "Pushing back the frontiers or still running around the same circles? 'Interpretative archaeoastronomy' thirty years on". In his (ed.) *Archaeoastronomy and Ethnoastronomy: Building Bridges between Cultures*. Cambridge: Cambridge University Press
Ruggles, C. L. N. (Ed.). (2005 (ed.)). *Handbook of Archaeoastronomy and Ethnoastronomy*. New York: Springer-Verlag
Silva, F. (2020). A probabilistic framework and significance test for the analysis of structural orientations in skyscape archaeology. *Journal of Archaeological Science*, *118*, 105138
Schmidt, K. (2001). "Göbekli Tepe, Southeastern Turkey. A preliminary report on the 1995–1999 excavations". *Paléorient*, 26(1): 45–54
Sprajc, I. (1993). "Venus orientations in ancient Mesoamerican architecture". In C. Ruggles (Ed.), *Archaeoastronomy in the 1990s*. Loughborough: Group D Publications

Sterelny, K. (forthcoming) "Ethnography (Ed.). archaeology and the late Pleistocene". *Philosophy of Science*: 1–39

Weil, A. (1979). "Une lettre et un extrait de lettre à Simone Weil". In his *Collected Papers, I*, New York: Springer-Verlag, 244–255

Wylie, A. (1985). The reaction against analogy. *Advances in Archaeological Method and Theory*, *8*, 63–111

Wylie, A. (2011). "Critical distance: stabilizing evidential claims in archaeology". In P. Dawid, W. Twining, & M. Vasilaki (Eds.), *Evidence, Inference, and Enquiry*. New York: Oxford University Press

Wylie, A., & Chapman, R. (2016). *Evidential Reasoning in Archaeology*. New York: Bloomsbury Academic

Zanker, P. (1990). *The Power of Images in the Age of Augustus*. Ann Arbor, MI: The University of Michigan Press