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Archeoastronomy in Sardinia: Evidence for 3000 years of advanced astronomy in monumentality

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Abstract

This work presents the culmination of a 15-year archeoastronomic investigation conducted across Sardinia, the second largest island in the Mediterranean. Our ojective was to determine the celestial orientations of 85 monumental structures dating from the Neolithic to the late Bronze Age. These include hypogea (*Domus de Janas* - DdJ), megalithic graves (*Tombe di Giganti* - TdG), Megaron-style temples, *Pozzi sacri/ Fonti sacre*, and the iconic megalithic cone-shaped structures called Nuraghes. This study aimed to establish a detailed overview of Sardinia's architectural continuum and its correlation with celestial alignments, independent of the monuments' construction periods. We calculated each monument's azimuth with the utmost accuracy, utilizing compasses, theodolites, and local topography skylines, along with magnetic declination adjustments and laser planimetry of the interior of the monuments. Ultimately, all the sites were visited in person to document the events for the site's with the most promising orientations. Our findings reveal compelling evidence of intricate alignments with solstices, lunar standstills, and other celestial events across diverse structures. The precision of these alignments suggests an advanced grasp of celestial mechanics, showcasing a high level of technical skill across various cultural phases for over 3000 years. As a broad conclusion it stands out that an inter-generational legacy was at play in Sardinia, where advanced celestial wisdom was preserved across generations - a phenomenon seldom documented in other ancient civilizations.

1 Introduction

The archaeological tapestry of Sardinia, extending from the Paleolithic to the end of the Bronze Age, is marked by the presence of various ancient cultures[3],[10],[5]. As custodians of a remarkable megalithic heritage, Sardinians left an indelible mark on the landscape, either excavating thousands of complex and intricate hypogea or erecting thousands of unique

Figure 1: Sardinia hosts thousands of ancient megalithic monuments. In the upper panel, from left to right, we show the interior of a *DdJ* (Mesolithic), an aerial view of a *TdG* (Neolithic to the Bronze Age), and a *Nuraghe* (Bronze Age). The lower panel features a *Fonte sacra* (Bronze Age), a cromlech (Mesolithic), and a late Megaron-type temple.

tombs and conic-shaped towers ([9], [1]) that transcended mere functionalism to embrace a sophisticated understanding of the physical sciences, such as engineering, geometry, or the cosmic mechanics. This legacy started to be built around the end of the neolithic era and endured till the end of the bronze age, spanning more than 3000 years in time [5](see Fig. 1).

2 Methodological strategy

In our approach, we adopt the equatorial coordinate system for celestial measurements, relying on precise determinations of altitude and azimuth to characterize the movement of celestial objects (Fig. 2). The latitude of a site assumes paramount importance in this context, as it significantly influences the azimuthal angle at which objects rise or fall along the line of the horizon ([4], [6], and [8]). In this study, we outline a systematic approach to measuring the orientations of doors and entrances of various archaeological monuments in relation to celestial bodies. Our methodology was structured as follows:

- Identify archaeological sites with intact doorways or entrances,
- Determine the state of conservation of the monument and address limiting factors to realistic accuracy,
- Calibrate the compass to account for local magnetic declination,
- Stabilize theodolite setups against fixed reference points in the horizon to uphold measurement accuracy,

- Use GPS to accurately determine the geographical coordinates of the site,
- Determine the range of azimuths or skyline covered by the monument's entrance,
- Align lasers with the corridor's axis to define its precise orientation,
- Use lasers to map the interior of the monument and drawing of the planimetries,
- Combine measurements from all the instrumentation,
- Calculate the azimuth and altitude angles of the entrance corridor,
- Cross-reference astronomical data with archaeological record,
- Use of astronomical software databases such as *Stellarium* (see *e.g.* [7] or [2] to identify celestial bodies rising or setting along the calculated azimuth for different epochs, especially solstices equinoxes and lunar standstills,
- Go to the site, register the celestial key event in real time.

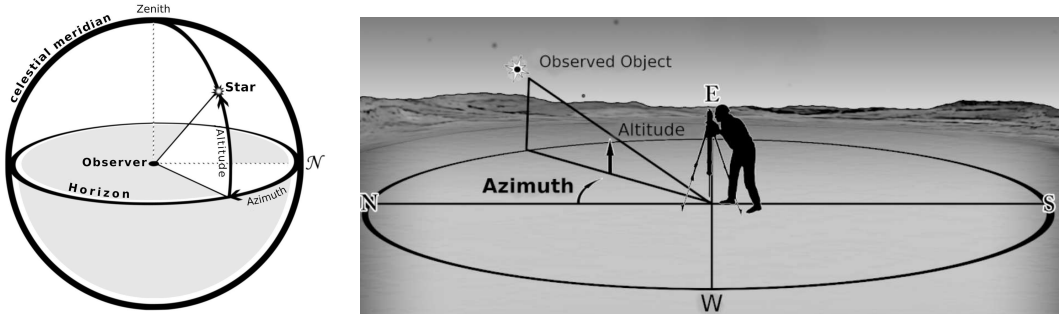

Figure 2: In the left panel, the horizontal coordinate reference system. In the right panel we show the use of the theodolite to compute the azimuth of the rising or waning celestial objects along the line of the horizon at each site's location.

3 Light Phenomena observed

The light phenomena identified in this work *via* precise laser planimetries and direct observation of the events can be divided into 4 main categories:

a. Solstitial and Equinoctial Alignments. Observations of the Sun's azimuth (along each site's skyline) at its rising and setting points during the solstices and equinoxes (Fig. 3).

b. Major and Minor lunar Standstills occurring approximately every 18.6 years.

c. Ephemeral light projections in Nuraghes. The strategic placement of a small window on top of the doorway architrave allows for the ingress of sunlight or moonlight during the solstices, equinoxes, and lunar standstills, which produces ephemeral projections on the monument's interior walls (Fig. 4).

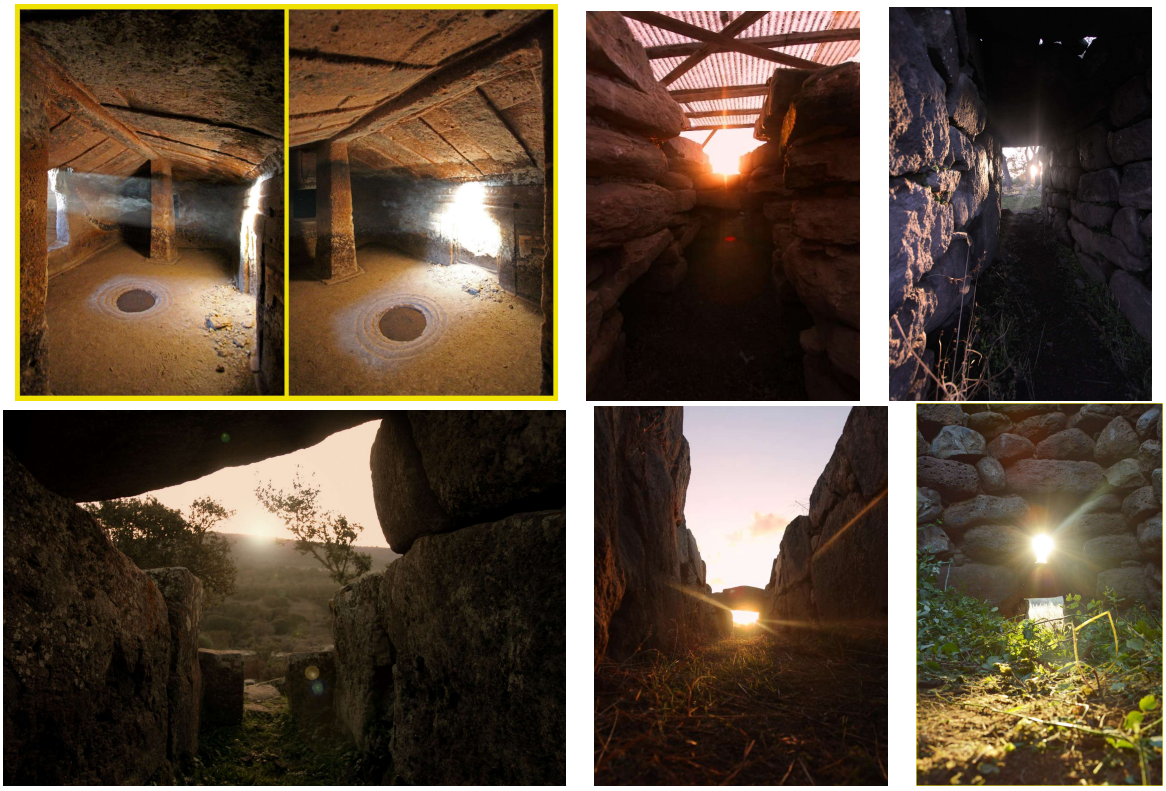

Figure 3: In the upper panel, from left to right, the winter solstice sunrise within the DdJ S'Incantu (Neolithic), the sunset at winter solstice at the megalithic tomb Pranu Siara (Mesolithic), and the equinox sunrise at Sa Mandra Wall (Copper age). The lower panel features the sunrises at winter solstice at TdG of Laccaneddu (early Bronze Age), of Su Picante (Bronze age), and at Nuraghe Lobos (Bronze Age).

Figure 4: Light projections at sunrise of the winter solstice against the inner walls of the main chambers of Nuraghe Zuras (left) and Nuraghe Santa Barbara (right).

d. Apical holes in Nuraghi during summer solstices. Some Nuraghi lack capstones on their ogival domes. During summer solstices sunlight at its zenith penetrates through this hole,

illuminating the floor in front of the central niche with remarkable precision (Fig. 5).

The survey of over 85 monuments of different types distributed across the Sardinian

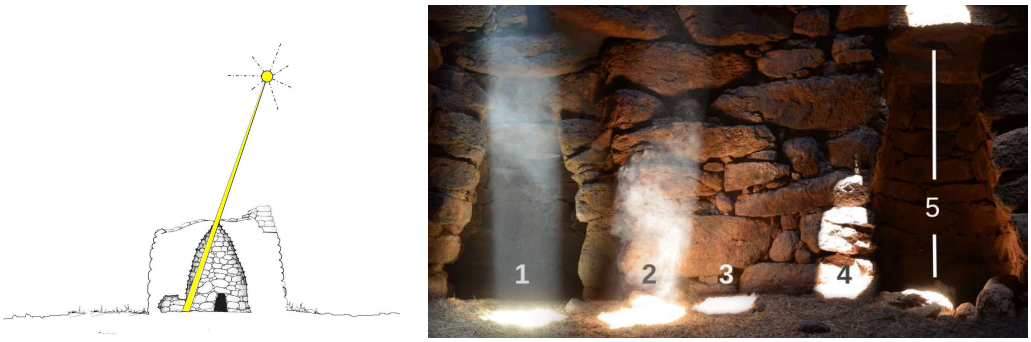

Figure 5: (Left panel) Illustration of the sunlight path at summer's solstice at a Nuraghe and time lapse of the sunlight of the summer solstice at noon traveling overtime from one inner niche to another (starting from 1 to 5) at Nuraghe Tettinosa.

landscape uncovered an impressive accuracy of less than one degree in the orientation of the entrance or doorway in monuments from different time periods, from the Neolithic to the Bronze age. In Table 1 we show the correlations of the central axis of the monument with the rise and set of the sun and the moon in key celestial events. The final sample consisted on 8 DdJ, 2 dolmens, 2 cromlechs, 2 copper age enclosure walls, 2 Megarons, 6 TdG, 62 Nuraghes, 2 *Pozzo sacro/ Fonte sacre* in a adequate state of conservation.

It stands out from our results that although cultures rose and fell, the same celestial wisdom seemed to be applied over and over onto the monuments, no matter the typology or final purpose of the building. The possibility that such a great number of structures, with a complex architecture and infinitesimal details, that demanded the carving of 40 cubic meters of bedrock and the cutting and transportation of tens of tons of rock, were incidentally oriented to celestial key special events seems all the more unlikely. Some of the most intricate phenomena are especially difficult to explain if purposefulness is not included in the equation.

4 Conclusions

While the initial goal of the project was to document and analyze, with the highest precision, the interaction of solar or lunar light within these monuments, this investigation has expanded to highlight the careful design of these structures, many of which are aligned with solstices, equinoxes, and lunar standstills. These spatial orientations, often with sub-degree accuracy, reflect an advanced knowledge of celestial events and the physical sciences such as advanced calculus or even geometry. Most importantly, while there are gaps in the archaeological record of Sardinian cultures, the consistent alignment of these various monuments throughout the different historical periods suggests a continued tradition of celestial observation and architectural sophistication. Though we cannot conclusively prove a cultural continuum,

Table 1: Number of confirmed monument alignments with solstices, equinoxes, and lunar standstills, categorized by type. SR and SS stand for Sunrise and Sunset and Northern and Southern for Northern and Southern Hemisphere standstills.

Monument	Solstices				Equinoxes		Lunar standstills	
	Winter		Summer				Northern	Southern
	SR	SS	SR	SS	SR	SS		
DdJ	3	1	2		1	1	1	
Dolmens	1	1						
Temple Walls	1				1			
Cromlechs	1	1		1		1		
TdG	5		2					
Nuraghi	31	3	4		5	1	1	5
Megaron-type		1		1				
Fonte/ Pozzi Sacri		1	1					

the recurring construction features across different time periods hint at the persistence of knowledge transmission over millennia.
As astronomy is concerned, it seems evident that to capture a celestial event within a 10-100 tons building, meticulous preparation and planning is demanded, often at least with a year in advance for solar events and 18.6 years for lunar standstills. This conclusion suggests the persistence of a millennia-old knowledge on celestial mechanics that is rarely documented in ancient civilizations worldwide, except for a handful of notorious ancient cultures.

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