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MINOAN STAR SAILORS: LINKING PALACE ORIENTATIONS WITH MARITIME TRADE ROUTES AND CELESTIAL NAVIGATION

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ABSTRACT

This research utilizes *in situ* archaeoastronomical fieldwork to survey the axis orientations of the Neopalatial central courts of Knossos, Kato Zakro, Phaistos, Malia, Galatas, Gournia, and Sisi. The study develops a methodology that analyzes maritime routes, skyscape simulations (accounting for precession and extinction coefficients), archaeological dating, wind patterns, and material evidence of Minoan seaborne exchange cycles. Based on the evidence, the study proposes that Minoan central court axes were oriented toward navigational stars used on sea journeys across the Mediterranean. This is supported by comparative data from Polynesian and Micronesian ethnoastronomy that describes the use of sidereal compasses and "star paths" that represented interisland direct courses. The data indicates that 1) Knossos was oriented toward Sidon via Spica (α Virginis); 2) Kato Zakro toward Pelusium or Avaris via Castor (α Geminorum) and Arcturus (α Bootis); 3) Phaistos toward Cyprus, Qatna and Kadesh via Betelgeuse (α Orionis) and Markab (α Pegasi); 4) Malia toward Megiddo or Tel Kabri via Orion's Belt; 5) Galatas to Byblos via Delphinus; 6) Gournia to Akrotiri via Antares (α Scorpius) or possibly Alalakh via Altair (α Aquilae); and 7) Sisi to Ashkelon via Sirius (α Canis Majoris). It is hypothesized that the orienting of palatial architecture toward star paths and specific sea lanes may have symbolized the special relationships between the palaces and distinct foreign emporia, while also being a source of legitimization of power for the local elite who controlled the ideological and technological frameworks of maritime knowledge.

KEYWORDS: Bronze Age Crete, Minoan, archeoastronomy, star paths, maritime trade routes, Polynesian celestial navigation, loxodromic distances, skyscape, rhumb lines.

1. INTRODUCTION

An academic debate regarding the motivations for the layout and orientation of the Minoan palace central courts has been ongoing for decades. The grand rectangular central courts, oriented generally north-south on the long axis, are considered the defining architectural characteristic of the Minoan Bronze Age palaces in the island of Crete. The significance of the central courts in the design of the palaces cannot be overemphasized as Driessen (2007, 4) argued, "that the Central Court was the '*raison de vivre*' of a Minoan 'Palace'". Although the courts are more extensive in the north-south direction, with a layout ratio of around 2:1, it was the rooms on the west side of the court which served ceremonial functions (Evans, 1928a, 423; Shaw, 2015, 24).

According to Manning (2008, 105), the expansive Minoan trans-oceanic trade network relied on the palace system functioning as redistributive authorities for the encircling territories. The Minoan palaces were multifunctional centres which combined "religious, commercial, manufacturing, social, political, ceremonial" functions as a "microcosm of the Minoan world" (Preziosi and Hitchcock, 1999, 135). However, it might be a misnomer to label them palaces, since "no solid evidence that these were the residences-permanent or temporary-of queens, kings, or priests, or other political or religious functionaries", and their exact function is unclear (Preziosi and Hitchcock, 1999, 135). Nonetheless, the presence of storage rooms along with workshops and manufacturing areas, elucidate the economic importance of these palatial centres (Sherratt and Sherratt, 1991, 359).

The similar architectural layout and harmonic design of the three largest palaces –Knossos, Malia and Phaistos– suggest construction by the same guild of builders and planners (Preziosi and Hitchcock, 1999, 204). The Knossos and Malia palatial centres first appear in Early Minoan (EM) III-Middle Minoan (MM) IA and were given formal structures by the start of MMIB (Manning, 2008, 111). At Phaistos, the first courtyard structures originated from MMIB, while the central court may date to MMIIA to MMIIB, with a possible central space dating to EMI (Manning, 2008, 111). The other four palaces investigated in this paper –Kato Zakro, Gournia, Galatas, and Sisi– date to the Neopalatial period. Although, the discovery of other court-centred buildings, such as Petras and Zominthos, have called into question previous classificatory distinctions between palaces and villas (Preziosi and Hitchcock, 199, 249). Nonetheless, the sites of Petras, Zominthos and Monastiraki will remain outside the scope of this research due to uncertainties about their classification or restrictions to public access. Due to the available archaeological evidence, the research focusses on the Neopalatial period of the central courts.

Given the lack of consensus on the meaning of the various Minoan palace orientations, the goal of this paper will be to propose a new comprehensive way of understanding Minoan archaeoastronomy, which encompasses landscape, seascape, and skyscape. Building on this, the research suggests a novel approach that connects the mapping of sea routes, with astronomical simulations, archaeological chronologies, wind patterns, and material evidence of long-distance contacts. As such, the paper aims to determine if the Minoan central courts were oriented toward foreign emporia, aligned with significant navigational stars, as an embodiment of local elite relationships to specific trade routes.

2. HISTORICAL CONTEXT

The island of Crete, the largest in the Aegean, lies at a safe distance from the coast of three continents while being at the crossroads of sea routes between the Hellespont, Asia Minor, the Levant, and the Nile Delta (Fig. 1) (Chryssoulaki, 2004, 78). Excavations of the Bronze Age civilization centred on Crete, denominated in modern time as the "Minoans" after the legendary King Minos, commenced in the late 19th century, revealing a complex, artistically proficient and literate society. Due to its location, reliance on open sea navigation and international trade cycles were at the heart of Minoan culture. As Chryssoulaki affirmed, "The island's geopolitical location gave it the opportunity to participate in a kaleidoscope of local cultures, a laboratory of civilization" (Chryssoulaki, 2004, 78). The location of its major centres and monumental court-centred complexes, or "palaces" on the coast or along inland routes may have facilitated maritime contact (Manning, 2008, 115).

The adoption of nautical technologies such as the sail, which originated somewhere between the Nile delta and the Levant in the 3rd millennium BCE, enabled the large-scale transportation of crops and cargo, out-competing the previous canoe networks prevalent in the Aegean (Broodbank, 2008, 69-70). Occurring at the beginning of the Middle Bronze Age, the advent of new maritime trade routes toward the Levant and Near East (Fig. 1), perhaps spurred by new wayfinding techniques, facilitated interregional trade and the elite's acquisition of prestige goods. Mediterranean Bronze Age trade was a multicultural and international affair with a "wide variety of people, of varying nationalities" spurred by long-distance voyages made by specialized merchants (Cline, 1994, 91).

According to Parkinson and Galaty (2007, 123-124), the nature of Minoan political authority was ideological and theocratic, based on a "corporate" or "heterarchical" system, where external trade legitimized incipient palatial elites. Accordingly, Protopalatial Crete emerged from "ranked lineages" of large tribal groups, as a "negotiated periphality" with the Near East, Cyprus, Egypt and Anatolia, and was characterized by the absence of iconography of specific rulers and a political authority based on a common Prepalatial ideology (Parkinson and Galaty, 2007, 118). By the Neopalatial period, as architecture and writing were standardized, trade with the Near East increased, in order to acquire social prestige "trinkets" and bulk commodities such as copper oxhide ingots and Canaanite jars (Parkinson and Galaty, 2007, 122; Knappett and Schoep, 2000, 369; Cline, 1994, 10).

In his *History of the Peloponnesian War*, Thucydides famously described a Minoan "thalassocracy," or sea-empire (Thucydides, 1843, 1.4). However, it has been argued that Thucydides claim of a Minoan maritime empire must be contextualized within the naval imperialism of a democratic Athens (Baurain, 1991, 264-265). Wiener (2011, 151), on the other hand, has advocated for the likelihood of a Minoan thalassocracy and a unified state under Knossos control during the Neopalatial period. Nonetheless, the archaeological record provides evidence of a Bronze Age maritime network extending to Mediterranean cities that had direct or down-the-line trade relations with Protopalatial and Neopalatial Minoan Crete. These cities include Byblos, Sidon, Tyre, Ugarit, Alalakh, Tel Kabri, Qatna, and Avaris (along the Pelusiac branch of the Nile), among others (Sørensen, 2009, 19). Suggesting international trade from an early date, some of the earliest known Minoan exports outside of the Aegean are a central Cretan MMIA vase uncovered in Lapithos, Cyprus and a Minoan bronze scraper discovered in Byblos on the Levantine coast (Manning, 2008, 116).

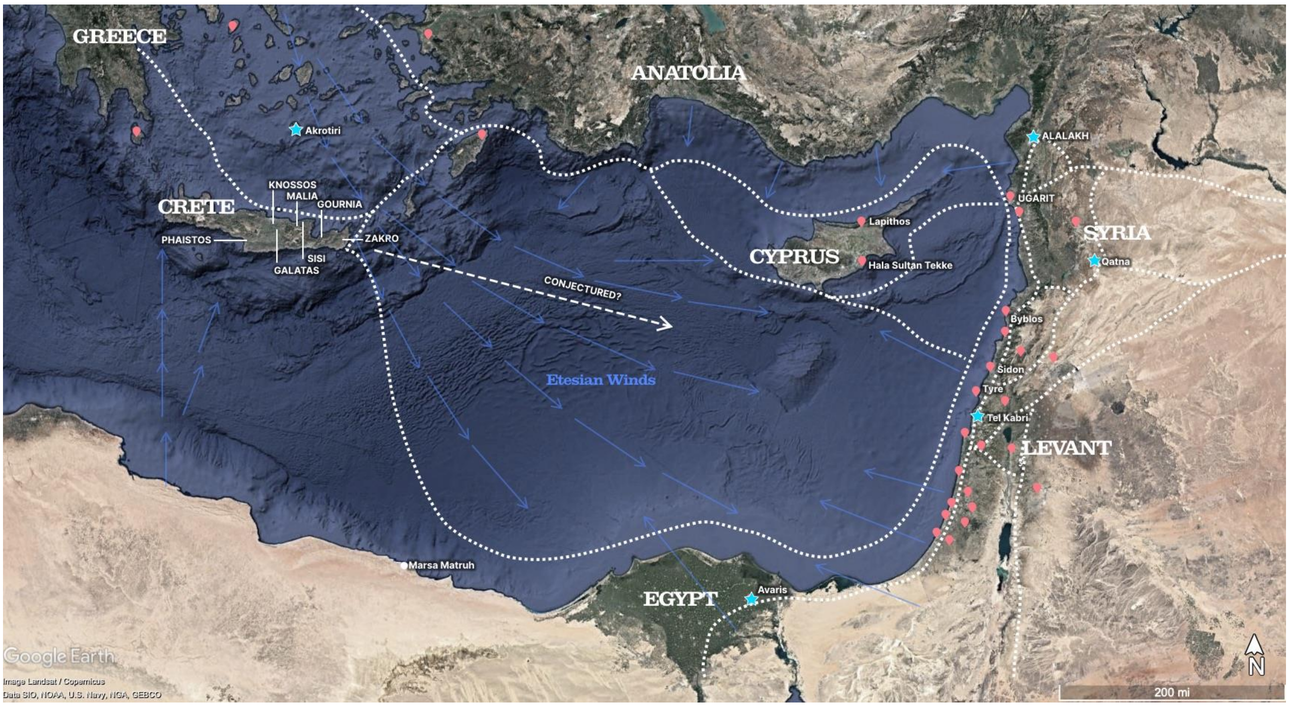

Figure 1. Map of Bronze Age Mediterranean with sites cited in the study. Blue stars indicate localities outside Crete where Minoan frescoes have been discovered. Red markers indicate Minoica found in Eastern Mediterranean (Sørensen, 2009, 19). Bronze Age trade routes around the Mediterranean are based on Hesse (2012, 55). Composite made by author with Google Earth Pro.

In addition, Crete's centrality may have spurred its active participation in the economic and cultural burgeoning of the Bronze Age, while being an impetus for the internal development of the palace system (Chryssoulaki, 2004, 78). As Chryssoulaki (2004, 81) argued, naval dominance presupposes "control, vigilance and defense of trade routes," which included the maintenance of sea routes and the protection of harbours. Protecting sea lanes from piracy would have enabled Minoan merchants to cross the Mediterranean and reach the Euphrates to trade tin at Mari or sail toward the Nile delta, bearing their coveted *objets d'art* (Wachsmann, 2007, 575). Skilful Cretan artisans or those influenced by Minoan artistic vogue adorned palaces around the shores of the Mediterranean with Minoanized vivid frescoes. Archaeologists have uncovered Minoan-style murals painted on the walls of various palaces on the Eastern Mediterranean and Egypt (Fig.1). These appear to embody a "trans-regional elite network" which include discoveries in palaces at Tel Kabri, Alalakh, Qatna, and Avaris in the

Nile Delta (von Rüden, 2013, 1). While it has been argued that the evidence of imported Minoan trade goods may not prove the direct contact with the producer of the artefact (Doumas, 2012, 27), this notion has been questioned by the hypothesis of the "itinerant Minoan craftsmen" (von Rüden, 2015, 355). The Cretan control of sea lanes and long-distance trade networks persisted until the destruction of Minoan polities at the end of Late Minoan (LM) IB period.

3. MINOAN CENTRAL COURTS

According to Marinatos (1932, 198-199), the central court orientations may have imbued religious significance given that in the case of Malia, topographical constraint was not a factor. Some archaeologists believe that the central courts possessed an orientation toward sacred mountains: Ida at Phaistos, Troastolos at Kato Zakro, and Juktas at Knossos (Preziosi and Hitchcock, 1999, 176). However, as discussed by Ridderstad (2009, 19), this notion that the palaces were oriented primarily toward sacred mountains and caves is questionable due to misalignments.

Shaw argued that the Minoans planned the palaces not with the long axis in mind, but for the shorter east-west orientation instead, due to the natural illumination entering the western façades where the sacred structures were located, perhaps in relation to solar dates as well as the southernmost moonrise in the case of Kato Zakro (Shaw, 2015, 23; 1977, 58). Yet, he did not specify to which particular solar dates the palaces may have been aligned and why.

Blomberg and Henriksson surveyed various Minoan sites around Crete archaeoastronomically. Among the various theories, they proposed that the slight variability in the orientation of the west and older side of the Phaistos palace central court, as compared to the New Palace orientation, "is nearly equal to the rate of precession of the equinoxes in 150 years" (Blomberg and Henriksson, 2007, 186). Notwithstanding, they acknowledged the shift is eastwards while precession actually progresses westwards. They also hypothesize that the long axis of the central court of Phaistos was oriented without direct sightline toward the star Canopus (α Car) behind the mountains to the South of the palace (Blomberg and Henriksson, 2007, 190-191).

Goodison (2004, 83) suggested that the Throne Room at Knossos may have been deliberately aligned so that sunlight would stream over the opposing ridge and illuminate the room at specific ceremonial dates. Ridderstad (2009, 1) proposed that the Throne Room of Knossos was oriented toward the heliacal rise of Spica, that Phaistos was oriented toward dates related to the vernal or autumnal equinox, and that Petras was oriented toward the northernmost moonrise. However, neither Goodison, Ridderstad, nor Blomberg and Henriksson proposed a systematic analysis that could explain the orientations of all the palaces, beyond isolated alignments.

In 1973, Belknap proposed that the palaces were oriented toward distant geographical locations, in the now unavailable paper, "A Guide to Cretan Sunrises". As cited by Shaw, Belknap suggested the courtyard axes of Tiryns, Phaistos, Knossos, and Malia aimed at the same location on the coast of Northern Africa, near Tobruk at 32°N latitude (Shaw, 1977, 54). According to this same theory, Gournia directed its courtyard toward Delos (Shaw, 1977, 54). Shaw criticized this hypothesis: "*Such a theory assumes, of course, that the Minoans were so skilled in astronomy and geography that they could make such a calculation, and also that they were quite knowledgeable about and concerned with the exact positions of Cycladic, Mainland, as well as North African sites, aside from certain omissions, archaeological incongruities, and certain errors in the method of estimating direction*" (Shaw, 1977, 55).

According to Shaw (1977, 54-55), Belknap's theory was hampered by faulty methodology due to errors in calculations and chronology. While his methodology was unsound, perhaps Belknap's instinct may have been pointing him in the correct direction. In any case, the lack of academic consensus presents an opportunity to re-analyse the orientation of the central courts.

4. EVIDENCE OF CELESTIAL NAVIGATION

The arrival of the masted plank-built sailing ships (Cherry, 1984, 34), represented in sealstones from EMIII and MMI, was contemporaneous with the development of palace architecture in Crete. Therefore, to better understand the Minoan notions of orientation and direction, it is reasonable to study how Bronze Age sailors may have navigated using celestial navigation techniques. Faced with arduous and dangerous long-distance voyages, it is logical to assume that ancient seafarers would have looked at the skies to determine direction (Liritzis, 2022, 133). However, until recently, some historians disregarded the possibility that ancient navigators could traverse the open seas, much less sail at night. This is a view exemplified by Thomazi's 1947, *Histoire de la Navigation*, as quoted by Davis (2001, 187), "Ancient peoples were mediocre sailors who were so afraid of the sea that they took every possible opportunity to travel by land. They would never sail at night unless they absolutely had to." Chryssoulaki (2004, 79) believed that due to the possible limitations of LMI shipbuilding, long-distance sailing far from shore and overnight sea voyages were unlikely. However, Neolithic sailors were already braving nocturnal sea journeys around the Aegean. During the later Palaeolithic and Mesolithic, paddled boats regularly crossed from the Argolid to Melos on open sea stretches of 10 to 20 nautical miles, which edged the limits of daylight, indicating a familiarity with night-time voyaging (Davis, 2001, 145).

The moderate winds and clear skies of summer nights in the Mediterranean would have facilitated voyaging by the stars (Pryor, 1988, 12; Agouridis, 1997, 17). The earliest historical mention of stellar navigation in the Mediterranean is preserved in Homer's 8th century BCE, *The Odyssey*, when the hero, Odysseus, steered his ship as he, "watched the Pleiades and late-setting Böotes, and the Bear, which is also called the Wain; it circles where it is and keeps an eye on Orion. It alone has no part in the baths of Ocean. The beautiful goddess Calypso advised him to keep this one on his left as he sailed over the sea. (Homer, 1919, 5.269)" Apollonius' epic poem, *The Argonautica*, described how "sailors on the sea looked towards Helice and the stars of Orion from their ships," (Apollonius, 2009, 276-277) which may indicate that navigating by the non-circumpolar constellations, such as Orion, was a technique known by Apollonius' contemporaries. Numerous ancient authors also cite night-time sailing, including Aratus, Silius Italicus, Herodotus, Xenophon, Thucydides, Ovid, and others (Aratus, 1848, 37-44**;** Italicus, 2018, 3.664; Herodotus, 1920, 8.9; Xenophon, 1921, 2.2.3; Thucydides, 1843, 1.48; Ovid, 1922, 2.55-6).

As previously mentioned, the surge of astronautical motifs (i.e., related to celestial navigation) in Minoan material culture coincided with the advent of the sail in the Aegean, spurred by the flourishing of maritime trade during the Bronze Age (Davis, 2001, 154). Motifs, such as stars, spirals, and paddled boats, are carved on the enigmatic frying-pan shaped artefacts from the Early Cycladic II period (Coleman, 1985, 191). Similar imagery of spirals and boats can be found in engravings dating to the Cycladic final Neolithic in Strofilas (Liritzis, 2010, 1369). Cretan hieroglyphic seals also depict what appear to be full moons, lunar crescents, or floating disks, which could potentially be stars, above the sheer of the ships (Fig. 2) (Evans, 1925, 207). The profusion of astronautical iconography in Aegean art suggests that the Bronze Age trade explosion may have been pushed in part by advances in night-time sailing techniques.

Figure 2. Drawing renditions of early Cretan seal stones depicting sailing galleys after Evans (Evans, 1925, 207).

Unfortunately, our incipient understanding of ancient celestial navigation techniques is hampered by the fact that Bronze Age elites monopolized and concealed technological knowledge. As Tartaron (2013, 127-8) wrote, "Maritime knowledge was worth guarding as a potential source of power and independence. In early times, those with access to distant places with their exotic products and esoteric knowledge possessed a special, perhaps even mystical, status as Broodbank suggests for the longboat voyagers of the EBA Cyclades." These maritime "ship societies" may be comparable to the chiefly navigator families of the Pacific that closely guarded the esoteric secrets of navigational astronomy (Adams, 2001, 304; Lewis, 1994, 136). In the Marshall Islands, Winkler (1901, 505) recorded that it was "strongly and religiously forbidden to divulge anything concerning this art [navigation] to the people". Therefore, it is necessary to look at ethnographic parallels that may inform our understanding of ancient seafaring techniques.

5. ETHNOGRAPHIC PARALLELS

It can be argued that direct routes toward distant destinations were more efficient than coastal voyages on circular itineraries around the Mediterranean with the added benefit of avoiding treacherous rocky coastlines or pirate ambushes (Puckett, 2012, 87). This would have necessitated the use of reliable wayfinding techniques, of which there are no written records from the Minoan age. As Soles argues, "In the absence of textual evidence, ethnography is probably the best tool that Aegean archaeologists have at their disposal to reconstruct details of the Minoan past. Ethnography enables archaeologists to identify patterns in prehistory which are meaningful in some larger way (Soles, 1995, 408). Following this reasoning, ethnographic comparison with navigational traditions from the Pacific Islands may illustrate possible navigational techniques used by the Minoans in the Aegean and the Mediterranean. Although the Minoans were literate, as compared to the traditional cultures of the Pacific Island, Tartaron (2013, 126) proposed that, "Ethnographic studies of seafaring in the Pacific are a good point of departure since they offer detailed reconstructions of maritime knowledge and its transmission in a nonliterate society." Davis proposed that ethnographic reports of time-tested celestial navigation techniques from Polynesia and Micronesia can be productive and relevant comparisons that further our understanding of ancient Mediterranean sailing techniques, since Pacific "inter island distances mirror those of the Eastern Mediterranean." (Davis, 2001, 177) Likewise Blomberg and Henriksson (1997, 206) proposed that the Minoans may have had adequate knowledge and boats for star navigation, which has been demonstrated by living traditions of the South Pacific. However, they did not detail specific star paths the Minoans may have employed, beyond a general course toward the Nile by aiming at the stars of the river constellation Eridanus (Bloomberg and Henriksson, 1997, 206-207).

Ethnography has documented that Pacific Islanders instructed sailors on the observance of horizon stars as they rise or set so as to maintain course. By memorizing the stars on the same declinations, "star paths" or linear constellations (Fig. 3) were memorized that represented directions and facilitated recognition during night voyaging (Kursh and Kreps, 1974, 335). When a star had risen too far up in altitude, the next star in a similar bearing took its place, thus creating a linear series of stars, known as *'avei 'a* by the Tahitians (Lewis 1994, 84). Lewis explained: "*The most accurate direction indicators for Pacific Islanders, still used in many parts of the Oceania, are stars low in the sky that have either just risen or are about to set, that is, horizon or guiding stars. You steer toward whichever star rises or sets in the direction of the island you wish to visit. In more technical terms, the direction or bearing of your objective, that is, the course you must follow, is the direction (azimuth or bearing) of its guiding star, at rise if the course be an easterly one, at set if it be westerly*" (Lewis, 1994, 82).

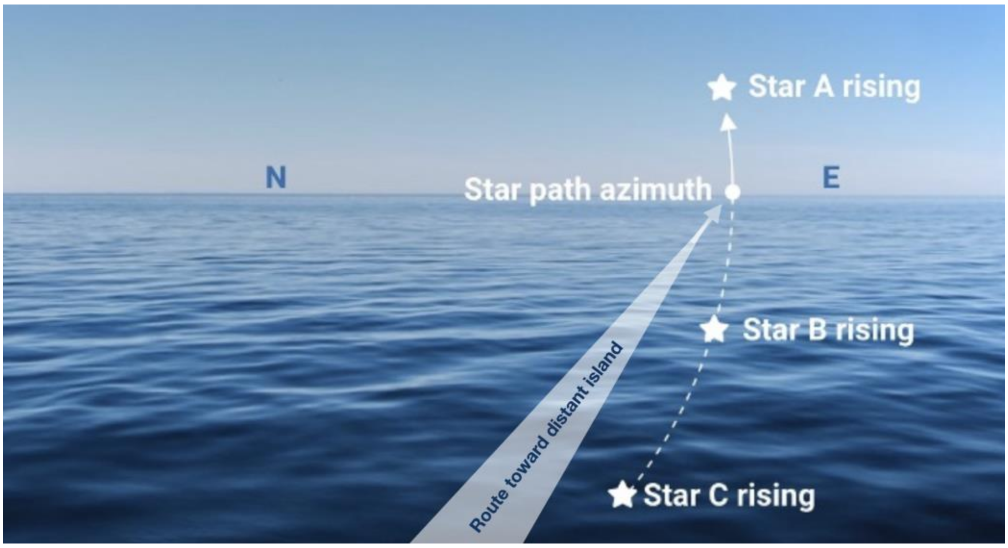

Figure 3. Simulated example of a star path. Image by author.

In the dead reckoning system known as the *Etak,* Micronesian navigators adjusted their traverse by aiming toward a particular star path, checked their leeway angle against swells, aimed at another star path, then corrected back (Silverberg, 2005, 15; Goodenough and Thomas, 1987, 10). This fusion of skyscape and seascape in the Polynesian worldview is encapsulated in the language of the Gilbert Islands, which has no word for "astronomer". As Grimble wrote, "If you would find an expert on stars, you must ask for a *tiaborau* or navigator (Grimble, 1931, 197)."

In the Carolines, the directions took on a more detailed and practical refinement, in the form of a sidereal compass which survived to this day unaltered, and may have been widespread beyond that region (Lewis, 1994, 109; Goodenough, 1953, 7; Halpern, 1985, 27; Pimenta, 2015, 47-48). It was named a "sidereal compass" by contemporary anthropologists, since it is analogous to a mariner's compass (Lewis, 1994, 102). In the Carolinean "star structure" each axis of the sidereal compass corresponded to an outlying island, which was reachable via that azimuth (Fig. 4). Thirty-two unevenly spaced points, drawn with sticks and stones on a square on the floor, so as to define the corners as the cardinal directions, marked the rising and setting of stars used for navigation (Lewis, 1994, 107). Gladwin wrote, "In this way the sky on a clear night becomes a vast compass, the various headings picked out by familiar stars as they move up and down near the horizon." (Gladwin, 2009, 148)

The 15th century Arab navigation treatise, *Fawa 'id,* by Ibn Majid, describe an Arab sidereal compass, with some remarkable similarities to those used in the Pacific Islands (Halpern, 1985, 117), used from at least 840 CE in the Indian Ocean (al-Najdī, 1971, 294-298; Pimenta, 2015, 49). While a sidereal compass is more adequate in equatorial navigation, its presence in Arab countries suggest its applicable use in more northern latitudes. As Halpern (1985, 115) argued, while the sidereal compass satisfies a "universal human need for wayfinding" it cannot be seen as a "necessary product of attempts to elaborate navigational systems". Nonetheless, the possible independent invention of the sidereal compass in different parts of the world along with the well-established effectiveness of star path sailing techniques as demonstrated in the Pacific Islands, suggest that analogous nocturnal wayfinding could have existed in the Bronze Age Mediterranean, as an environmental necessity of seafaring cultures.

While no unambiguous supporting literary evidence for star path sailing survives from the Bronze Age, Zhitomirsky suggested that knowledge of the celestial circles, analogous to star paths, was present at least far back as Aratus' 3rd century BCE, *Phaenomena* (Zhitomirsky, 1999). According to Brady (2015, 58-62), the poem inferred that ancient observers of the night sky "saw groups of stars on pathways or lines which were defined by the horizon calendar events." If it is possible to assume that Bronze Age sailors plotted routes along star paths to and from destinations on the Mediterranean, then it may be plausible that Minoan conceptions of orientation in architecture may embody the azimuths of navigational star paths.

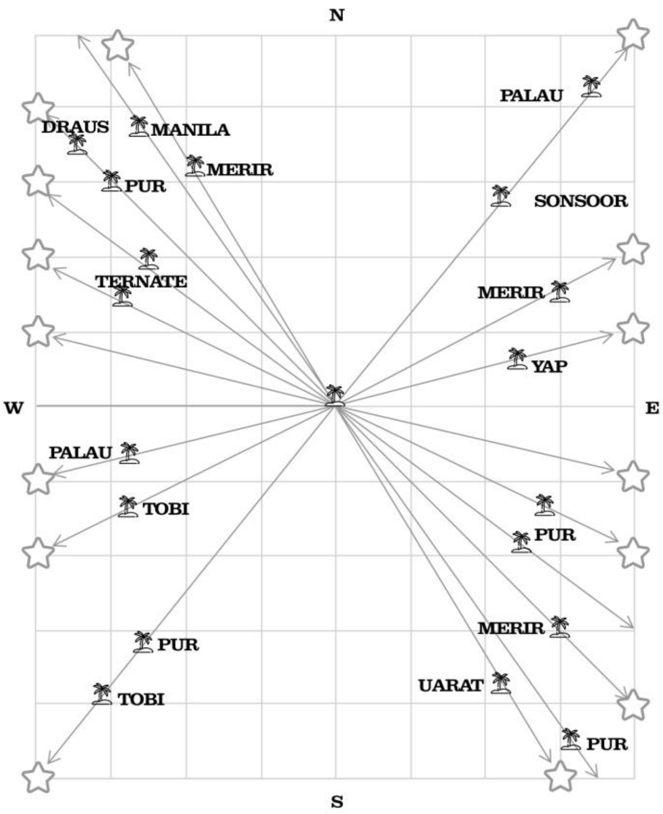

Figure 4. Illustration of a Carolinean sidereal compass with specific star paths as reference points for course angles toward different islands. Image by author after Lewis (1994, 108).

6. ASTRONAUTICAL ORIENTATIONS

In the case of the well-documented Polynesia and Micronesia ethnoastronomy, there is a reliance on azimuths rather than declinations due to the level surface of the ocean's horizon. Kursh and Kreps explained, "In the star path system, on the contrary, the horizon line is of central importance in the determination of space as well as time. It is thus characteristically a sea-level system, since the sea-level horizon can be depended on to remain stable." (Kursh and Kreps, 1974, 336) This fact contrasts with one of the principle tenets of archaeoastronomical research, which is the pursuit of "alignments" established by the declination of celestial bodies along a horizon profile. Prendergast explained: "*The majority of archaeoastronomical surveys are undertaken to initially determine, inter alia, the orientation of a site, monument, or tomb. When combined with location (latitude) and profiles of the local horizon (azimuth and altitude), these data computationally yield astronomical declinations of the indicated positions of prominent celestial bodies of interest – either on the local horizon (rise/set), or of non-horizon events such as a transit phenomenon*" (Prendergast, 2015, 391).

As a consequence, astronautical orientations, which rely on azimuths instead of declinations and encode knowledge of celestial wayfinding, may have remained unrecognized in the archaeological data.

A few known examples of structures around the world embed such orientations and may serve as a template for understanding Minoan court centred complexes. In the southernmost point of the Hawaiian Island of Maui, the "sighting wall" through which the Southern Cross could be seen when it was upright, may have indicated a celestial alignment that memorialized maritime navigation (Kirch, et al., 2013, 57; Ruggles, 2015a, 526-527). According to Kirch and Ruggles, the Hawaiian *heiau* temple system, which is a descendant of the Polynesian *Marae* sacred places, and dates as far back as the 12th century AD, contained stellar alignments to the rising of stars such as the Pleiades and in some instances, was oriented toward topographic targets on other islands, such as enemy territories (Kirch and Ruggles, 2019, 170).

The best example, however, may be in the Arorae Island of southern Kiribati, where the so-called "navigation stones", Te Atibu ni Borau, aim at shores more than 80 miles along and relative star paths (Hilder, 1959, 238) (Fig. 5). Their purpose was solidified in oral traditions for succeeding generations in what can be understood as a "knowledge-based compass" (Brady, 2005, 4). Recently, Akira et al. (2019, 105) confirmed the stones' functions as pedagogical tools for teaching navigation and as an indigenous calendar centred on the constellations.

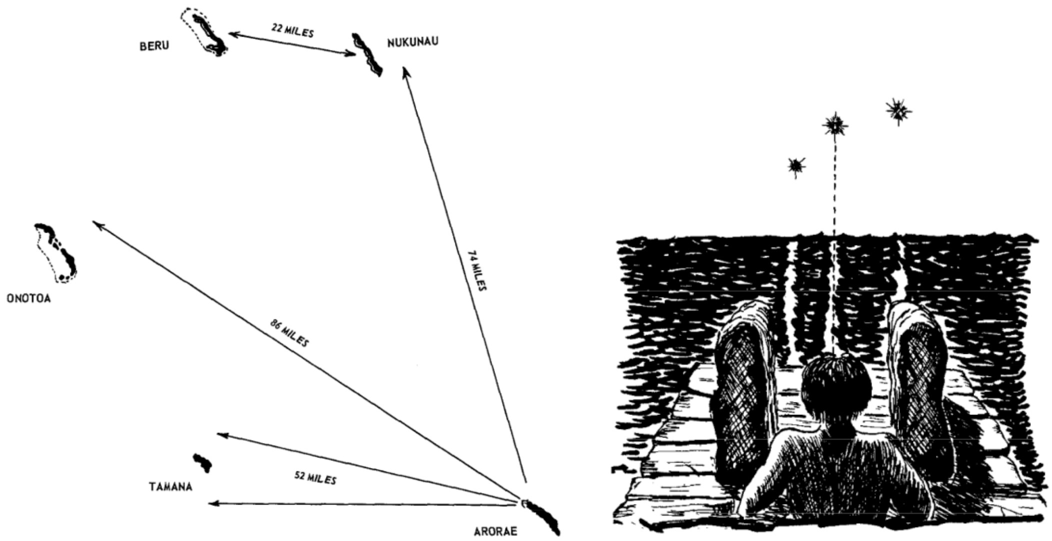

Figure. 5 Aurorae navigation stone orientations with estimated target islands and example of a stellar observation (Hilder, 1959, 236-238).

One must consider that structures that embodied astronautical orientations may not demonstrate visible alignments to celestial bodies. According to Lewis (1994, 97), Gilbertese navigators in the Pacific Ocean were not educated regarding the stars under the open sky, but in roofed meeting-houses called *maneabas*, "As a pupil he had been seated at the base of the central pillar, supporting the ridge pole of the *maneaba*, facing the eastern slope of the roof, which represented the eastern sky. The ridgepole was the meridian, and the central pillar, by which he sat, the star Rigel. Stars and constellations were allotted places on the thatch north and south of the pillar." In such cases, the structural syntax of the site served as a metaphor for the vaulted sky, with the apprentice at the epicentre. The Gilbertese *maneabas* forego the necessity for direct astronomical sightlines, as is traditionally investigated in archeoastronomy, and may suggest that Minoan structural orientations may have embodied star path directions metonymically.

7. MATERIALS AND METHODS

During the survey of Knossos, Malia, Phaistos, Kato Zakro, Gournia, Galatas, and Sisi *in situ* measurements of various walls of the central courts were taken with a professional compass and clinometer, with a stated accuracy of ±(1/3)° (Suunto, accessed 2021). The measurement values were summed, averaged and then adjusted for magnetic declination via the NOAA website (National Geophysical Data Center, accessed 2021). Virtual analysis was also relied upon, since as Ruggles wrote, "In many cases, it may not be necessary to make survey measurements in the field at all, if sufficiently accurate data are retrievable from site plans or maps, although one must beware potential errors…" (Ruggles, 2015, 417) The readings were also compared with virtual measurements from Google Earth and Shaw's theodolite readings (Shaw, 1977, 49). A summed probability density chart (Fig. 6) for the orientation measurements was created using SkyscapeR (Silva, 2020, 9).

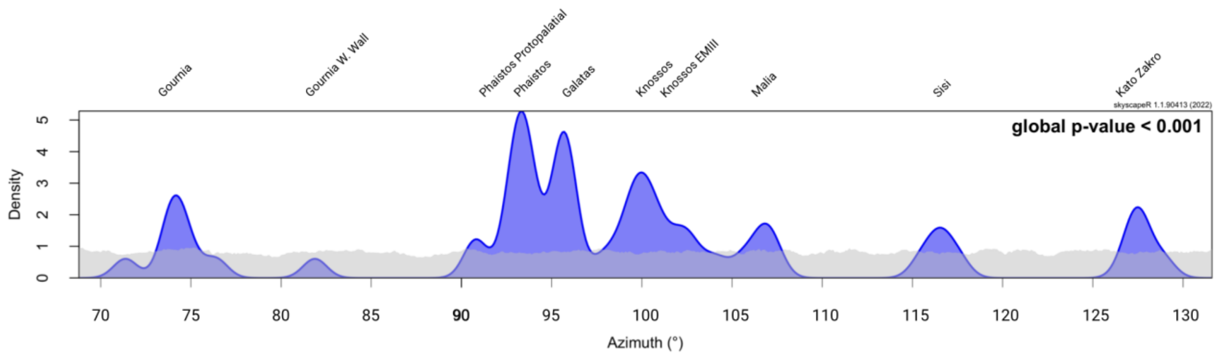

Figure 6. Summed probability densities of the central court orientation measurements taken in situ.

The research utilized the open-source planetarium software Stellarium (v0.20.1), which enables virtual archeoastronomy research. Due to its implementation of a long-time model for the precessional motion of the earth's axis, Stellarium can accurately simulate ancient skyscapes (Zotti et al., 2021). The software allowed for the visualization of the rising and setting of high magnitude stars at their respective azimuths in Bronze Age Crete. The Observability Analysis plugin for Stellarium listed the acronychal and heliacal dates for these stars to determine if they were within the timeframe of the navigation season in the Mediterranean (Stellarium, accessed 2021). The software OpenCPN estimated the rhumb lines between the candidate destinations and wind patterns for the Mediterranean Sea (OpenCPN, accessed 2021).

7.1. *Field Work*

The fieldwork was initiated in October of 2020 and continued subsequently in May of 2022 and August 2022. It was determined that as many "palaces" as possible should be surveyed in order to avoid the pitfall of the dictum "*testis unus, testis nullus*," where "one-off" archeoastronomical alignments can be disproportionately persuasive (Belmonte, 2011, 789). The analysis is based on the principle that only if a consistent pattern emerged, should the results be deemed satisfactory. The methodology employed the open-source software OpenCPN for plotting navigation routes and rhumb lines, or loxodromic distances, between two distant points. Rhumb lines are a constant navigation course, as Silverberg wrote, "If a ship sails on a constant course, cutting each meridian at a constant angle she traverses a rhumb line, and that angle is her course" (Silverberg, 2005, 9). Considering that the palaces may have been originally constructed with the east-west shorter axis in mind (Shaw, 1977, 58), emphasis was given on orientations toward locations in the East.

Due to the lack of written evidence, it is only possible to speculate as to how the Minoans could have determined the course angles from Crete to locations across the sea. This same question surfaces in regards to the Pacific Islands, as Gladwin (2009, 160) wrote, "One can only guess how the stars were originally determined for such distant islands. There are stars too for courses between island pairs so remote that navigators are not even sure which are real and which are mythical." In the case of the Aurorae navigation stones, Hilder (1959, 238) believed they were aligned by trial and error, sailing back and forth, which seems prone to large margins of error when considering the distances of the Mediterranean. Therefore, it must be speculated that the Minoans possessed some currently unknown primitive coordinate system along with a method for computing the course angles between destinations.

To define course angles, it is presupposed that the Minoans may have used coordinates via celestial observation. The determination of latitude by the upper culmination of stars or the sun has been known since antiquity (Klaus and Tupikova, 2017, 61), due to the fact that the declination of a star is equal to the location's latitude. This simple method has been documented in the Pacific navigation traditions, where islands were identified by their "zenith stars", such as Hawai'i by Arcturus and Tahiti by Sirius for example. However, before the invention of mechanical clocks, longitude was more difficult to ascertain. The 2nd century BCE astronomer and mathematician, Hipparchus, discussed a method for determining how far to the east or west were two locations by comparing lunar or solar eclipses simultaneously (Dicks, 1953, 12).

There is no evidence that the Minoans or their contemporaries in the Near East understood spherical trigonometry. However, the Plimptom 322 tablet, which was contemporary with the Protopalatial period, demonstrates that the Babylonians possessed ratio-based trigonometric tables with Pythagorean triplets (Mansfield and Wildberger, 2017, 395). The 16th century BCE Egyptian Rhind Mathematical papyrus includes mathematical questions involving the concept of *seked*, a primitive cotangent function used with the royal cubit for calculating the slopes of pyramids

(Robins and Shute, 1985, 108). If any of this knowledge was known or shared with the Minoans it is currently unknown.

Due to the lack of textual evidence, course angles between the palaces and the distant locations were determined via spherical trigonometry and also with a simple plane trigonometric function analogous to the Babylonian system. To calculate the course angle using plane geometry, the difference between the latitude and longitude between both locations was used as the altitude and base of a right triangle. For the calculations of a course angle between two points on a loxodrome (rhumb line), the website PlanetCalc was utilized (Anton, accessed 2022). The palace central court azimuths were extended virtually both as loxodromic curves and with the alternate plane trigonometry method (Fig. 7). To determine the probable celestial navigation routes, it was noted, whether the palace axis virtually extended on a direct route toward a relevant Minoan trading partner along the azimuth of a prominent star path.

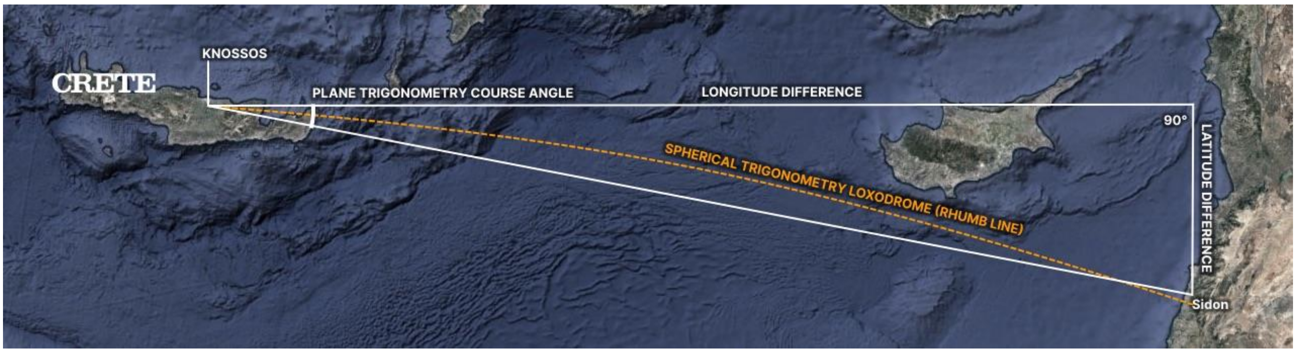

Figure 7. Approximate course angle difference between a loxodrome (rhumb line) and a plane trigonometry calculation from Knossos to the Sidon. Image by author using Google Earth Pro.

In practice, a single navigational star would not have been used to reach such distant localities; however, as found with the Pacific Islanders, they elected a main guiding star for labelling each star path route (Lewis, 1994, 98). Polynesian and Micronesian sailors did not have to maintain the exact degree of the azimuth of a course angle when sailing toward an island. The use of sea marks, water coloration, currents, and especially the presence of birds, indicated the general vicinity of an island to an acceptable margin of error. Kursh suggested star paths were actually bands that involved several degrees of declination (Kursh and Krepps, 1994). Thus, a level of uncertainty of ±2.0° in the azimuth orientations was deemed acceptable. The precession of the relevant star paths was taken into account and will be dealt with later.

To determine the correct altitude at which a star was visible on the horizon, the extinction co-efficient of 0.25 was configured in Stellarium, which according to Schaefer is the average for a night at sea level (Schaefer, 2002, 349), along with limiting visibility to stars of magnitude 6 to mimic naked eye observations. As with Polynesian navigation, named stars of medium and bright magnitude were also considered. Both setting and rising star paths were taken into account, since Polynesian and Micronesian sailors used stars and their reciprocals for navigation (Goodenough and Thomas, 1987, 4). Also, reciprocal stars at 90° angles were included, based on ethnoastronomy reports of relevant techniques.

To determine the window of possible dates in which a rising star may have guided sailors, it was hypothesized that this would occur from the time the star had its heliacal rise, until its apparent acronychal rise, which Ruggles defines as when the star "is seen to rise just as the sky gets sufficiently dark in the evening following sunset" (Kirch et al., 2013, p. 141). Likewise, for the azimuth of a setting star, the timeframe calculated was from its heliacal set (sometimes confusingly termed acronychal set) to its acronychal set. Wind patterns were also taken into account, based on 30-year historical wind data collected by NOAA and made available in the OpenCPN Climatology plugin. A similar attempt at correlating ancient stellar navigation with wind patterns was made by Liritzis, et al. (2018, 665-667) when analysing Plutarch's *DeFacie*. Studies indicate that seasonal wind patterns have not changed considerably since antiquity (Murray, 1970, 159).

8. DISCUSSION

8.1. The Orientation of Central Courts Toward Foreign Emporia

If, as suggested by Shaw (2015, 23), natural illumination of the cultic rooms on the western side of the central courts were one of the determining architectural considerations of the builders, one would suspect that the palaces would have been oriented consistently within the solar range to maximize this light phenomenon. The central court of the Kato Zakro palace, unlike the other palaces, lies outside the solar range of the equinoctial midpoint and the winter solstice (Fig. 8), which could indicate that the solar light phenomena was not a systematic consideration for the orientations. Also Shaw's claim that Kato Zakro orientation could be an outlier due to a possible alignment to the Major Lunar Standstill presupposes a Minoan interest in such an alignment for reasons which are not evident. Therefore, the large variation of orientations is not properly accounted for by their relation to the solar range.

It seems that the orientations of central courts to peak sanctuaries or sacred caves may have been secondary motivations, if present at all. At Knossos, the oft-mentioned orientation toward the peak sanctuary of Mt. Juktas is divergent by 5° ±.66° from the central court axis, a considerable divergence. Blomberg and Henriksson (2007, 190) suggested that the orientation of the Neopalatial Phaistos palace aimed toward the Kamares cave and coincided with a setting of Canopus at 5.33° circa 1700 BCE, or 2° away from the central court orientation. It is doubtful the Minoans would have made this orientation this imprecise given the visual sightline to the cave. The situation is similar in Galatas, where the east-west axis could have been aligned to the largest visible nearby peak, Aféndis, however it diverges by 3.63°. As such, a satisfactory theory for the orientation of the central courts should systematically account for their variability in directions.

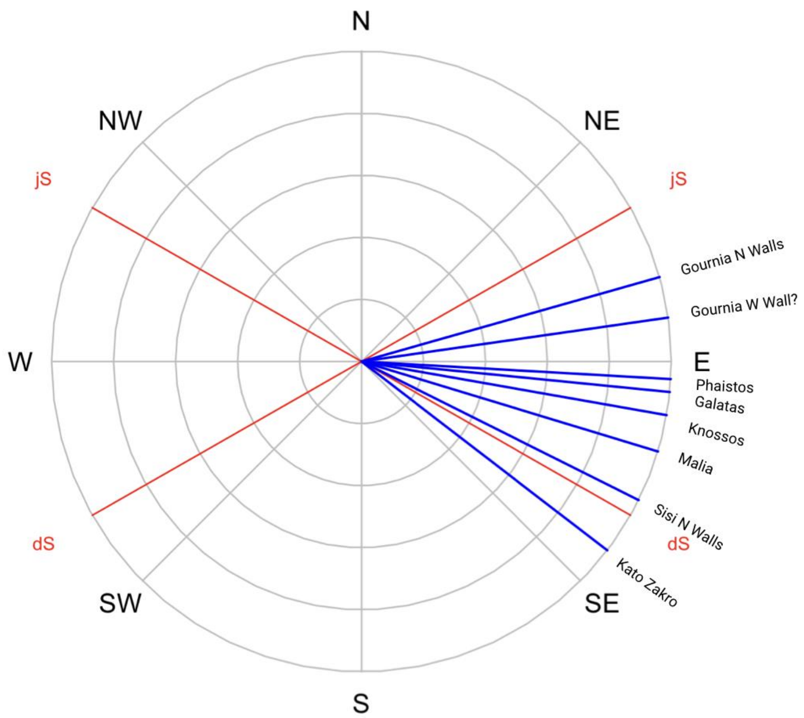

Figure 8. Polar plot of Minoan Neopalatial central court orientations.

The data shows that the central court azimuths coincide with course angles toward major trading hubs on the Eastern Mediterranean and Egypt, many of which have traces of Minoan artefacts including: Qatna, Kadesh, Sidon, Avaris, Byblos, Alalakh, Megiddo, and Tel Kabri, the north-south axis was also considered, as is the case with Gournia's potential alignment toward Akrotiri. In this sense, most of the orientations fall within the solar range due to the fact that these trade centres were on the eastern Mediterranean. Kato Zakro, on the far east side of the island, is the outlier since it orients toward the Nile Delta where it would have been a logical outpost for navigators heading to Egypt. As expected, the results also appear to indicate that despite its real-world errors, the plane trigonometry angles match closer with the probable intention of the palace orientation than calculations using modern spherical trigonometry. This is the case with Knossos to Sidon, Malia to Megiddo, Galatas to Byblos, and Gournia to Akrotiri all which are closer in value to the plane trigonometry angle than their respective rhumb lines.

Table 1. Comparison of palace central court axes, trade route destinations, course angles, and matching star paths.

Central Court	~Year BCE	Court Axis (±.66°)	Destination	Plane Trig.°	Δ	Loxo-dromic°	Δ	Star Path	Star Path Azimuth°	Δ
Knossos	1700	99.96	Sidon	99.61	-0.35	101.60	1.64	Spica	280.15 (100.15)	0.19
Phaistos	1700	93.26	Kadesh	92.42	-0.84	92.92	-0.34	Markab	93.25	-0.01
Phaistos (Proto.)	1900	90.76	Qatna	91.08	0.32	91.25	0.49	Sheratan	92.37	1.61
Malia	1700	106.86	Megiddo	105.49	-1.37	108.53	1.67	Orion's Belt	105.7 - 106.87	-0.01
		106.86	Akko	103.78	-3.08	106.57	-0.29	Orion's Belt	105.7 - 106.87	-0.01
		106.86	Tel Kabri	103.23	-3.63	105.90	-0.96	Orion's Belt	105.7 - 106.87	-0.01
		106.86	Jaffa?	109.1	2.24	112.72	5.86	Mirach S	287.43 (107.43)	0.57
Kato Zakro	1600	127.49	Avaris	126.06	-1.43	132.61	5.12	Arcturus (+90°) Castor S Mirfak S	38.42 (128.42) 306.13 (126.13) 308.3	0.93 1.36 0.81
		127.49	Pelusium	122.82	-4.67	127.43	-0.06	Arcturus (+90°) Castor S Mirfak S	38.42 (128.42) 306.13 (126.13) 308.3 (128.3)	0.93 1.36 0.81
Galatas	1700	95.65	Byblos	95.76	0.11	96.97	1.32	Delphinus S (α, γ^2)	276.4 (96.4) – 277.4 (97.4)	0.75
Gournia	1600	344.22 (NS)	Akrotiri	342.55	-1.67	346.27	2.05	Antares S	254.47 (344.47)	0.25
		-	Kato Zakro – Marsa Matruh	165.46	-	167.66	-	Antares S	254.47 (164.47)	-
		74.22 (EW)	Tarsus?	78.81	4.59	76.28	2.06	Antares S	254.47 (164.47)	
West wall?		81.87 (EW)	Alalakh?	83.92	2.051	82.56	0.69	Altair	82.67	0.8
Sisi	1600	116.53	Ashkelon	111.94	4.59	115.69	0.84	Sirius Rigel	117°, 5.75° alt. 112.5°, 0° alt. 117.75°, 5.75° alt. 113.9°, 0° alt.	0.47 1.22

Some of the orientations also appear to conform to the vertex angle of Pythagorean triplet triangles when calculated from due east. The Kato Zakro to Avaris/Pelusium course angle matches the famous 3-4-5 triplet, which in antiquity was linked to Egypt (Plutarch, 1936, 205–8 and 509). Sisi to Ashkelon (adjusted for the azimuth of Sirius rising on the horizon) corresponds to the angle of a 5-12-13 triplet. Meanwhile Malia to Megiddo and Gournia to Akrotiri is in agreement with a 7-24-25 triplet. A 11-60-61 triplet may have been used for the orientation of Knossos to Sidon. Due to acuteness of their angle, the orientations of Galatas and Phaistos would require less common triplets.

The proposed nautical orientations were then analysed in relation to any viable star paths on the horizon at the time of the palaces. Since stars do not maintain a single rising or setting azimuth with the passing centuries due to the effects of axial precession, a chart (Fig. 9) was plotted that could accommodate three azimuths: 1) rhumb line or plane trigonometry course angle, 2) central court orientation, and 3) high magnitude stars with precessional drift. The axes and the course angles were compared to the star paths to find probable time range periods when they coincide. The data demonstrates that most of the sites surveyed appear to be oriented toward the brightest stars of known classical constellations during their phase of construction 1) Knossos was oriented via Spica (α Virginis) toward Sidon; 2) Phaistos via Markab (α Pegasi) toward Kadesh; 3) Malia via Orion's Belt toward Megiddo; 4) Kato Zakro via Mirfak (α Perseii) and Arcturus (α Bootis) toward Pelusium or Avaris; 5) Galatas via Delphinus to Byblos; 6) Gournia via Antares (α Scorpius) to Akrotiri or possibly Altair (α Aquilae) to Alalakh; 7) Sisi via Sirius (α Canis Majoris) to Ashkelon.

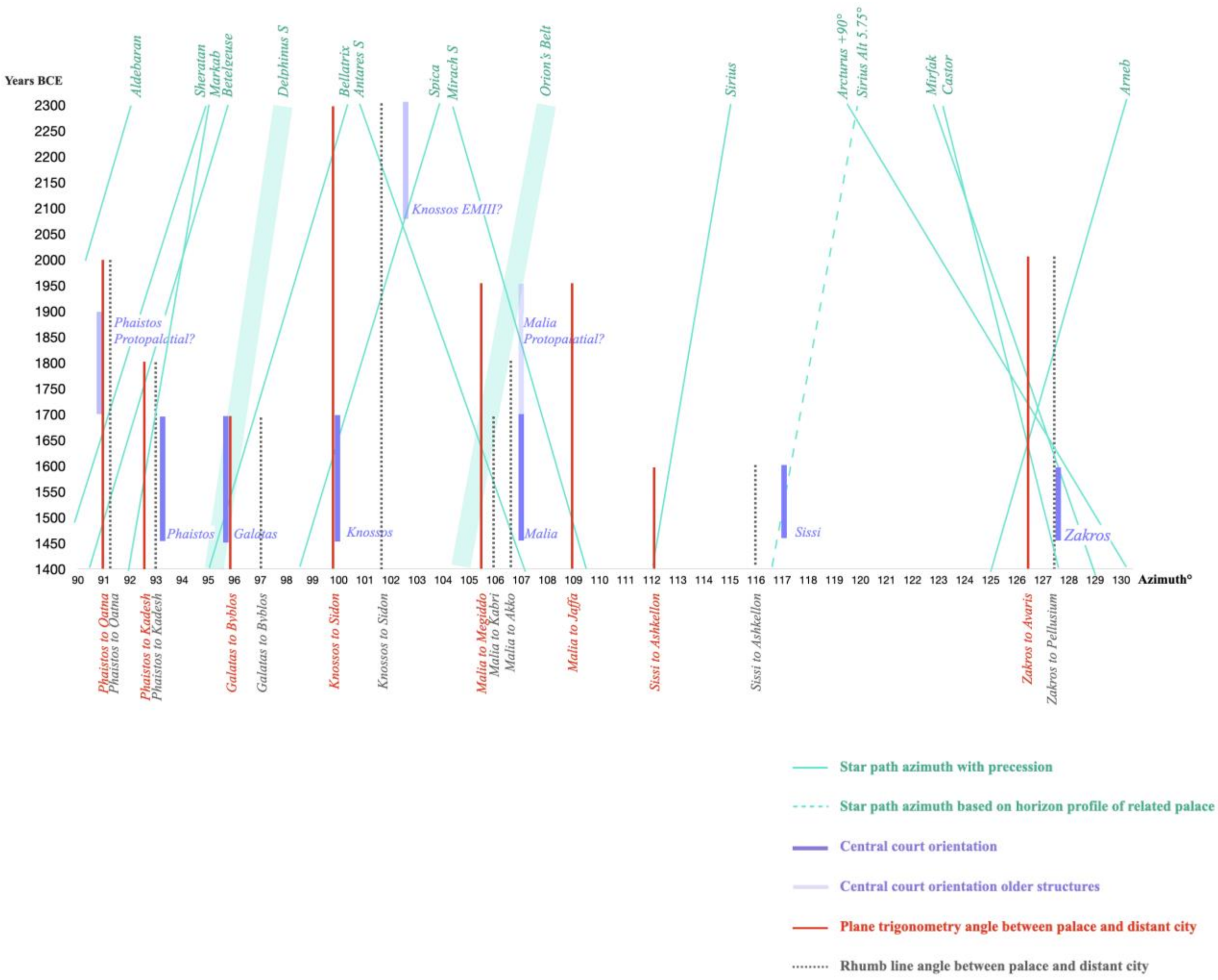

Fig 9. Plane trigonometry and rhumb line azimuths between selected palaces and maritime destinations compared with central court orientations and star paths. The star azimuths drift during the centuries due to the effects of precession. The purple lines indicate the central court orientations relative to the dates the palace existed.

8.2. Legitimization of Power Through Long-Distance Trade

The cultural context of orientations are essential to understanding their underlying significance. This is the basis of Malville's application of Geertz' "thick descriptions" whereby "astronomical events contained in the archaeological record [act] as signifiers of deeper meaning and purpose within the culture" (Malville, 2015, 112). Chryssolouaki (2005, 88) proposed that Minoan centres may have had unique agreements with different markets and emporia in distant lands, ensuring exclusivity of particular goods. According to Schoep (2006, 52-53), the exchange of exotic goods and technological knowledge via long distance trade were essential for Minoan elites who sought to obtain, consolidate and legitimize power. The partnerships between palaces and distant markets would have relied on innovations in celestial wayfinding along with new shipbuilding techniques which influenced the dramatic increase in long distance trade in Protopalatial and Neopalatial Crete. Similar to the Pacific Islanders, Minoan knowledge of sea lanes and star paths would have comprised a tome of arcane seafaring knowledge, akin to "state secrets". Thus, the embedding of navigational knowledge along specific sea route into the orientations of the palaces may have symbolized the source of the local elite power who may have exerted influence over specific trade contacts.

The builders appear to have concealed the orientations toward star paths into their architecture often without visible sightlines, somewhat analogous to the Polynesian *maneabas*. At Phaistos and Kato Zakro the architects could have oriented the constructions toward their respective stars with visible sightlines as they rose on the horizon to the east. On the other hand, Knossos, Malia, Galatas and Gournia did not have direct sight lines to the stars due to the local horizon profile. In these cases, it is supposed that they used an alternate reference point, perhaps cardinal north via a gnomon, and then measured the orientation accordingly with a Pythagorean triplet triangle. Sisi appears to be an outlier, since it seems to have been oriented toward Sirius and Rigel as they rose above the mountains, with the architects opting for a direct sightline rather than a sea-level alignment.

To compensate for the lack of sight lines at most of the palatial centres, apprentice seafarers may have been taught the sidereal directions atop the local peak sanctuaries, whose religious and remote nature may suggest initiatory practices, while their high altitude would mimic the flat horizon visible at sea. It can also be proposed that the concealment and education of these star path orientations may have been part of the ideological and theocratic basis for the political authority of the Minoan polities. Each palace may have functioned as specialized training centres for the particular sea route embedded in their orientation. The central courts may have also embued religious symbolism beyond just economic interests, as can be seen with the Quibla and the orientation of Muslim mosques to Mecca. Thus, the variability in orientations between the palaces may not have been due to the solar range, or reverence toward sacred mountains, but as an embodiment of special relationships with foreign trade contacts, be they commercial, cultural, or ancestral. What follows is a case by case analysis of each palace orientation.

8.3. Knossos to Sidon

The central court of the palace of Knossos is a monumental open quadrangle of almost 54 by 28 m (Driessen, 2007, 5). Knossos is speculated to have reached a population of 50,000-70,000 inhabitants and was inhabited since at least the Early Neolithic c. 6000 BCE (Preziosi and Hitchcock, 1999, 27). The mean average of the compass measurements taken on the western façade of the Knossos palace's central court (Fig. 10, walls A-D) indicate the east-west axis was oriented toward the azimuth of 99.96° ±0.66° (Table 1). Thus, the Neopalatial east-west axis of the central court of Knossos was oriented, within the margin of error, to the azimuth of the star Spica (α Virginis) (Table 1). A measurement of the few structural remains dating to EMIII (Fig. 10, walls E, F) tentatively suggest an orientation toward Spica at that early date as well. The central court orientation, faces the Ailias hill, where a Minoan cemetery from the Middle Minoan period has been found (Hood, 2010, 161).

Figure 10. Knossos' in situ measured walls. A-D: Neopalatial, E-F: Prepalatial

From the Protopalatial period to the Neopalatial period, a Minoan navigator could have sailed along the route toward the important Levantine harbour of Sidon by observing Spica (α Vir) set astern using techniques comparable with the Pacific Islanders (Fig. 3). According to Goodenough and Thomas (1987, 4), the Polynesians and Micronesians memorized reciprocal star paths so as to navigate by stars astern, also known as fore-and-aft sailing. Lewis (1994, 96) adds that navigators used "stars abeam, behind, or at any angle to the actual track, either in default of a suitable star in front or because clouds obscure part of the sky." While sailing in the open sea for 500 nautical miles often without land in sight would be long and arduous, this route is less than one-quarter of the distance from Tahiti and Hawaii, which the Hōkūleʻa experiment demonstrated to be navigable by traditional Polynesian star sailing and shipbuilding techniques (Finney, 1975, 1).

A Minoan cup excavated in Sidon suggests a direct or at minimum down-the-line trade between Crete and Sidon from at least the Protopalatial period (MacGillivray, 2003, 20). The rhumb line from Knossos reaches Sidon with the constant azimuth of 101.56°, a variation of about a 1.5° from the Neopalatial axis measurement (Table 1). However, a plane trigonometry calculation between the coordinates of both locations yields a value of 99.61°, identical to the orientation of the palace, which could be evidence that such a method was used for calculating the course angle between both cities. Since Knossos is on the north of the island, the journey to cross the Mediterranean would have begun from Crete's eastern shore, probably from Kato Zakro, by maintaining the same rhumb toward Sidon.

To calculate the latitudinal difference between Knossos and Sidon, navigators may have observed zenith stars overhead. By 2000 BCE and into the Protopalatial period, the "breast" of Queen Cassiopeia, the star Shedar (α Cassiopeiae) would culminate exactly at the zenith at the latitude of Knossos and other palaces on Crete. By the Neopalatial period the star Kornephoros (β Herculis) was the closest zenith star for Knossos. During the Neopalatial period from its achronycal rise in early June to its achronycal set in late august, the star Sadr (γ Cygni), would have been a precise zenith star for navigators to find the latitude of Sidon.

A classical text from Knossos, which mentions *a-ne-mo i-je-re-ja* or priestesses in service of wind deities, underscores the importance of meteorological knowledge for navigating the seas (Blakolmer, 2010, 26). While a circular itinerary around the Mediterranean is documented in antiquity (Pryor, 1988, 7), with the appropriate navigational methods, the summer Etesian winds may have been used to propel sailors from Crete directly toward the Levant and Sidon (Fig. 1). During the Neopalatial period, Spica's navigational window is within the timeframe of the Etesian winds from its acronychal set around mid-March to its heliacal set around mid-August. June and July would have been ideal months for sailing to Sidon from the eastern shores of Crete. According to NOAA's historical wind data, the second half of the journey had an average wind direction of 280.87°, precisely along the rhumb line aiming toward Sidon. Therefore, palace orientation, star path visibility, and wind direction aligned on this hypothetical direct route toward Sidon.

The rhumb line along the star path of Spica connecting Knossos to Sidon may have had etymological and mythological significance. Spica's classical name originates from the Latin "spike, ear of wheat", which Virgo held in her hand in Graeco-Roman zodiacs. While there is no evidence Virgo was a known Minoan constellation, the earliest mention of Spica is found in the Babylonian Mul.Apin star tables, perhaps dating to 1000 BCE, which equate Virgo "The Furrow", with the goddess "*Šala*, the ear of grain" (Mul-Apin, Tablet I line 52). The Linear A word KU-NI-SU followed by the ideogram GRANUM (for grain) has been speculated to mean "a type of grain or wheat" and was compared to the Babylonian *kunasu* meaning "emmer" (Best, 1988, 17). Younger and Rehak (2008, 152) have suggested that it might indicate a personal name, and most probably the toponym of Knossos itself. Therefore, it is conceivable that the etymology for Knossos bears relation to a Linear A word meaning "emmer wheat", which would be consistent with the central court orientation toward Spica, later named as the "spike, ear of wheat".

Searching for historical evidence in mythology is fraught with risk as Doumas argued (2012, 25), therefore, mythology should be used cautiously in archaeoastronomical inquiries. With this consideration, it may be noted that the myth of Zeus's theriomorphic transformation into a bull and subsequent abduction of the Tyrian princess Europa, occurs on the beaches of Sidon (Lucian, 1905, 24; Dictys Cretensis, 1966, 26; Ovid, 1922, 2.839). The pair crossed the Mediterranean to Crete, where according to legend, she gave birth to King Minos who heralded the beginning of the Minoan civilization. The myth has been interpreted as representing early mariners steering westward (Apollodorus, 1921, 3.1.1: footnote 2) and is a common motif in ancient coins from the city. Given the probability that the Minoans practiced some form of ancestor worshipped (Wilson, 2008, 93), it can be suspected whether the Knossos orientation toward Sidon may been memorialized by the later myth of Europa and King Minos, the mythical ruler of the city.

8.4. Kato Zakro to Pelusium and Avaris

Similar to Knossos, Kato Zakro's central court orientation aligns toward a major Minoan trade contact along traditional navigational stars, while being exactly oriented with the Etesian winds. By the Neopalatial period as Minoan Crete's economy flourished and became more complex, Kato Zakro, a coastal city on the far east coast of the island, became a loci for international trade (Preziosi and Hitchock, 1999, 173). Within walking distance from a protective bay, Kato Zakro lies on the flood plain of the Gorge of Zakro, where Minoan tombs have been found inside its many caverns. Cargo and raw materials arriving from the Near East by boat may have been paraded ceremoniously to the Neopalatial court centre, where they could have been converted into artworks or shipped elsewhere along the Minoan trade network (Preziosi and Hitchcock, 1999, 174). Given the difficult terrestrial access to the site and the six oxhide copper ingots and elephant tusks which were found on the west wing of the palace, it is highly probable that Kato

Zakro may have acted as a significant hub of sea traffic with the Near East and Egypt (Preziosi and Hitchcock, 1999, 173).

The plan of the site appears to be canonical with a central court embraced by a colonnade on the north and east sides (Preziosi and Hitchcock, 1999, 218). *In situ* measurements taken at the western and northern walls of the central court (fig. 17, walls A, B) were calculated to be 127.58° ±.66°, while the eastern and southern walls were deemed unreliable for measurement. The short axis measurement is only slightly askew from Shaw's theodolite reading of 127.55°. When calculated from due east, the orientations is 37.58° ±.66°, which is approximate to the angle, 38.53°, of the 3-4-5 triangle, the most famous Pythagorean triplet.

When compared to the Knossos, Malia or Phaistos palaces, the oblique axes of Kato Zakro and Gournia, appear to be outliers. Shaw (1977, 53) hypothesized that the Minoans may have shifted the axis of the Kato Zakro palace by 20° to shelter the court from the forceful Etesian summer winds or to aim at the southern moonrise extreme. If in fact this was an issue for the builders, one could imagine more efficient ways of protecting the palace from the wind, such as using the local topography. If on the other hand, the hypothesis that the central courts were oriented toward distant trading emporia on the Levantine and Egyptian coasts proves correct, then given the proximity to Egypt it would be reasonable to assume that Kato Zakro should be facing the Nile river, which appears to be the case. Evidence of contact between Bronze Age Aegean and Egypt are extensive. Depicted on the tombs of nobles from Thebes, dating to the reigns of Hatshepsut and Thutmose III, are a procession of inhabitants from *kftyw* (Crete) and from the "The Isles in the Midst of the Sea" bearing ornate tributes and royal gifts (Wachsmann, 2007, 575; Wachsmann, 2009, 85). There is also textual evidence of contact between the later Mycenaeans and ancient Egypt, in the so-called Aegean List inscribed on five statue bases on the mortuary temple complex of Amenhotep III (circa 1390–1352 BCE) (Tartaron, 2013, 28; Cline, 2007, 194).

A rhumb line toward Pelusium (Tel Farama), at the mouth of the Pellusiac branch of the River Nile, was at the constant azimuth of 127.43°, precisely aligned with the central court orientation (Table 1) (Fig. 11). Pelusium, the easternmost major city of Lower Egypt, functioned as the regional centre for terrestrial and maritime trade with the Levant (Stanley, et al., 2008, 451). Though its chronology is unclear, the historical and archaeological record suggests Pelusium was founded between the Middle Kingdom in the early 2nd millennium BCE and the Saite to Persian eras in the 8th to 6th centuries BCE (Stanley et al., 2008, 451-452). It may have served as a navigational hub from at least the 18th and 19th dynasties of the New Kingdom (Stanley et al., 2008, 451-452). Pelusium was a bustling oriental-Egyptian city, which functioned as a "link between Egypt and the rest of the ancient world with a special allowance towards the cities of the Near East" and was teaming with Carian and Ionian settlers alongside the presence of exotic gods and cults (Jakubiak, 2012, 572). Foreign merchants reaching Pelusium would have cruised upriver to the military outpost of Tjaru or to Avaris, the Hyksos capital.

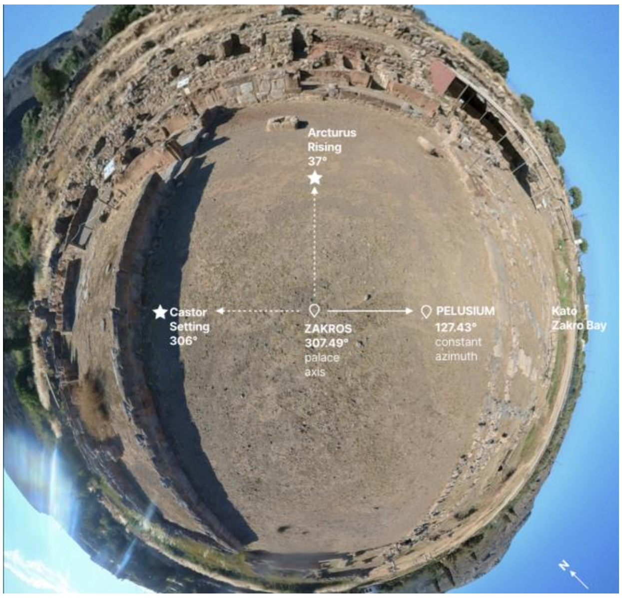

Figure 11. 360° photograph of Kato Zakro central court and measured orientations. Photograph by author.

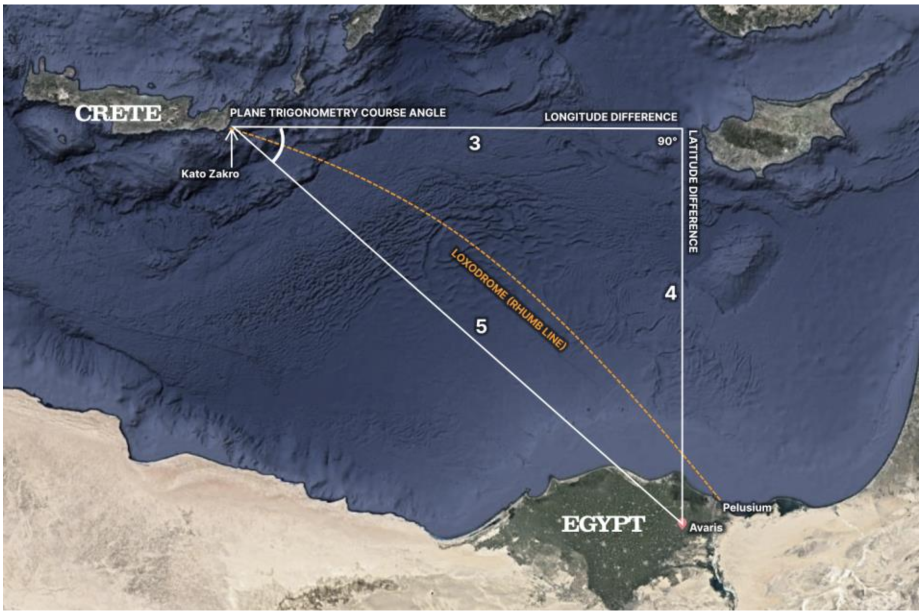

Figure 12. Comparison of rhumb line and plane trigonometry course angles from Kato Zakro to Pelusium and Avaris. The orientation conforms to the cotangent angle of the Pythagorean triplet 3-4-5. Image by Author with Google Earth.

The plane trigonometry calculation between the coordinates of Kato Zakro and Pelusium deviates by 5° from the palace orientation (Fig. 12). This suggests that the builder's intention for the orientation may have been to align toward Avaris instead of Pelusium, where a plane trigonometry angle deviates by only 1.4° from the central court orientation. Therefore, sailors following that course angle hoping to reach Avaris would have reached Pelusium instead due to inaccuracies of using plane trigonometry on a spherical route. Minoans who sailed up the Pelusiac branch of the Nile would have eventually reached Avaris, where evidence of Minoanized frescoes have been found. According to Manfred Bietak, the regional pharaonic naval base of *prw nfr,* where Cretan *keftiu* ships disembarked, received large influxes of non-Egyptian immigrants or tradesmen selling their imported wares (Bietak, 2010, 11). In fact, there is evidence the Minoans received royal gifts from the Hyksos pharaohs of Avaris such as an alabaster vase lid inscribed with the cartouche of Khyan (Niemeier and Niemeier, 1997, 94).

Polynesian and Micronesian wayfinding may help elucidate how the Minoans may have sailed from Kato Zakro to the Nile. The north-south axis of the central court was oriented toward the rising of Arcturus (α Boötis), a known navigational star in Pacific Island traditions. According to Goodenough and Thomas (1987, 4), students of Polynesian and Micronesian navigation would memorize star paths, which were at right angles of each other. This may have been the case with sailors leaving Kato Zakro for the Nile. Minoan navigators could have kept Arcturus port side (Fig. 13), while they navigated toward the shores of the Pelusiac branch of the Nile river. The east-west axis was oriented toward Mirfak (α Persei) and Castor (α Geminorum) setting, guiding sailors who kept the star astern as they journeyed toward Pelusium (Fig. 14). Known as the Dioscuri twins, Castor and Pollux, are remembered in Greek mythology as saviours of shipwrecked sailors, receiving prayers and offerings for favourable sailing conditions (Diodorus Siculus, 1933, 4.43.1).

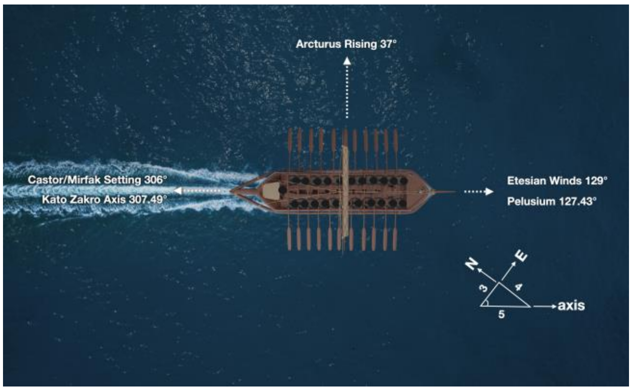

Figure 13. Simulation of perpendicular star path of Arcturus on rhumb line between Kato Zakro and Pelusium. The central court orientation of Kato Zakro is consistent with the angle of a Pythagorean 3-4-5 triplet toward Avaris. Image by author.

Although somewhat faint, the heliacal rising of the star Arneb (α Leporum), in the hare constellation, at the beginning of Summer would have been the best-timed aid for navigators to set their course angle toward the Pelusiac branch of the Nile wanting to take advantage of the Etesian winds (Fig. 15). Castor may have been a useful navigational star from its acronychal set in mid-December to its heliacal set on at the end of May, before the summer sailing season. Arcturus may have served as a useful navigational star during the Neopalatial period roughly from its helical rise in mid-September to its acronychal rise around the end of February. This, however, would have entailed sailing during the Autumn and the perilous Winter months, which may account for the star's association with stormy weather in ancient texts (Aratus, 1848, 744-747). The star signalled the limits of the sailing season in Hesiod's (1983, 663-665) Greece and Vegetius' (1767, 4.39) Rome.

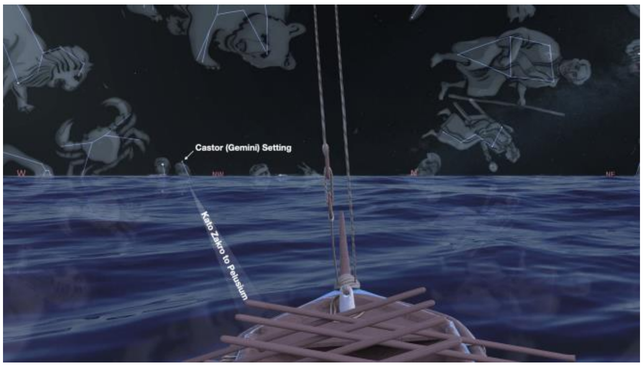

Figure 14. Recreation of a Minoan stern aiming at Castor setting while following the rhumb line from Kato Zakro to Pelusium. The actual Minoan constellations are unknown. Image by author.

Figure 15. Comparison of star path visibility patterns for Kato Zakro during the Neopalatial period.

According to the 30 years of NOAA climatology data, at mid-Spring, the average wind direction from Kato Zakro flows toward Pelusium. Thus, a Minoan sailor leaving at the end of April, would benefit from favourable winds. During the 390 nautical mile journey, the first two thirds of the trip had an average wind direction of 309.52° (129.25°). This wind astern would propel the ship less than three degrees on average away from Pelusium and the setting azimuth of Castor. On the last leg of the trip, as Egypt came into view on the horizon, the wind direction would alter to around 307°, precisely the westerly orientation of the central court. In late July, after the first third of the voyage, a Minoan sailor leaving Kato Zakro for the Nile, utilising Arneb as a star path, would find that the wind would have kept a mean direction of 306.5° (126.5°), aiming the boat precisely toward Pelusium.

Coincidentally, during the beginning of the Neopalatial period, the star Mirfak would have been the exact zenith star by which to determine latitude for Pelusium and Avaris. By 1600 BCE, when Kato Zakro was rebuilt, it would have still served as a zenith star, moving away by less than a degree. By then, Castor, could have determined the latitude of both locations. Therefore, both Castor and Mirfak served the double function of setting a rhumb line from Kato Zakro and determining latitude for Pelusium and Avaris. Kato Zakro combines an easy to calculate course angle, via the most basic Pythagorean triplet, with a route toward a known foreign trade hub in the Nile Delta, aligned with favourable Etesian wind directions and star paths.

8.5. *Phaistos to Cyprus, Qatna and Kadesh*

Phaistos (or "PA-I-TO" in Linear B tablets) was one of the principal palaces of Bronze Age Crete, second only to Knossos. Built on a large promontory point, it overlooks the Mesara plain in Southern Crete. The site's chronology comprises of two principal building phases: 1) the Protopalatial, and 2) the Neopalatial periods. The grand central court measures about 27m wide by 63m long. It is believed that the two phases of construction were aligned to the twin peaks of Mount Ida, where the cave sanctuary of Kamares is visible from Phaistos (Preziosi and Hitchcock, 1999, 136; Myers et al., 1985, 234). As previously stated, the possible orientation toward the Kamares Cave is inconclusive since it has a 2° difference from the north-south axis, despite the fact that its directly visible from the palace.

During the Protopalatial period, the Phaistos central court EW orientation of 90.76° ±.66° may have pointed to the setting of Aldebaran (α Tauri) and the rising of Sheratan (β Ari). However, only one Protopalatial central court wall is identifiable with this orientation, therefore this could be a "one-off" alignment (Fig. 17). Nonetheless, following a rhumb line along this star path, or using latitude stars, sailors would have voyaged due east and traversed Crete, making landfall at the island of Cyprus. In the case of Phaistos, both the rhumb line and plane trigonometry angles are nearly identical. This route would have circled the island passing by Hala Sultan Tekke, where numerous examples of Minoan pottery from the Late

Minoan periods have been found (Zeman-Wiśniewska 2020, 17-18; Fischer and Bürge, 2017, 174). Minoan merchants based at Phaistos may have set sail from Kommos, the main harbour of Southern Crete, where significant evidence of trade between Crete and Cyprus exists, then circled the island eastward. According to Zeman-Wiśniewska (2020, 26-27), Kommos contains the "most visible trace of contacts between [Crete and Cyprus]" in the Middle Minoan period, which suggests intense trade relations between the region of Phaistos and Cyprus. Hala Sultan Tekke later became the Phoenician city of Kition, while Kommos itself flourished as a Phoenician trading post (Negbi, 1992, 608-609).

By continuing on this star path, Minoan sea merchants could have reached the Levantine coast and then journeyed terrestrially to the inland kingdom of Qatna at 91.25° azimuth. The rhumb and plane trigonometry course angle from Phaistos to Qatna are within the margin of error of the Protopalatial central court wall orientation (Table 1). The orientation is almost exactly due east-west along the equinoctial sunrise or sunset, which would have facilitated daytime navigation. Evidence of Minoan contact with Qatna originated in the Neopalatial period, with the Bronze Age palace of Qatna which contains Minoan frescoes rarely found outside the Aegean. Dating to circa 1650-1550 BCE; they depict typical Minoan motifs such as palm trees, rivers, spirals, and a dolphin (Pfälzner, 2012, 795). Furthermore, Text 30 of the Zimri-Lim texts mentions Cretan officials alongside the kings of Qatna and Hazor (Sørensen, 2009, 17), suggesting that the Minoans may have partaken of elite gift exchange cycles with these Levantine polities.

A century prior to the Protopalatial period, circa 2000 BCE, Qatna had already risen to become the regional capital. Qatna was a major Syrian kingdom and commercial centre, positioned at the crossroads of the north-south route between Anatolia to Egypt (from Aleppo via Hama to Damascus), and the east-west roads connecting to Mesopotamia (from Mari across the Syrian desert to the Mediterranean) (Fig. 1) (Novák, 2004, 299; Sørensen, 2009, 12). About a century before the end of the Protopalatial period, Qatna's King Ishi-Addu took up residence in Kadesh, one of the principal cities of the kingdom, to quell a local rebellion (Ziegler, 2007, 314).

According to the data (Table 1), the Neopalatial central court orientation of Phaistos has a mean average azimuth of 93.26° ±.66°, which orients toward a rising Markab (α Peg) at 93.26°, Betelgeuse (α Ori) at 92.33° and the setting of Hamal (α Ari) at 272.59°. Along these star paths, the Neopalatial central court aimed toward the Syrian city of Kadesh at the headwaters of the river Orontes, where the king of Qatna had taken up residence a century prior. Navigators could have set course angle toward Kadesh by the Markab star path from its heliacal rise in early February to its acronychal rise in late July. Betelgeuse could have been used for the rest of the year, from its heliacal rise in mid-June to its acronychal rise in mid-December. Circa 1700 BCE, Menkalinan (β Aurigae) would have been a precise zenith star to determine the latitude of Kadesh. Given the fact that both Qatna and Kadesh were inland cities, it is possible that the intended star path navigation route from Phaistos was primarily towards Cyprus.

Figure 16. Phaistos Neopalatial measurments (A, B, C) and Protopalatial measurement (D).

8.6. Malia to Megiddo or Tel Kabri

Located about 37km to the east of Knossos, Malia was one of the principle palatial centres of Minoan Crete. The Malia and Knossos palatial centres first appear in EMIII-MMIA and were given formal structures by the start of MMIB (Manning, 2008, 111). According to Driessen, the central and west courts of Malia may have existed from EMIIB (Driessen, 2010, 564, 558). An archaeological excavation at the courtyard penetrated as far down as a red earth floor at the MM IA stratigraphy (Driessen, 2007, 7). As Marinatos (1932, 198) and Shaw (1977, 52) discussed, the palace of Malia was constructed over an open area, unhindered by geography, suggesting that the orientation was not fortuitous. The fieldwork recorded the palace central court orientation at 106.86° ±0.66°, which encompassed a mean average of the measurements for the eastern, southern, and western walls of the court and is largely consistent with virtual measurements and Shaw's theodolite reading of 107.03°. This orientation intersects with the star path azimuths of Orion's Belt rising and Mirach (β And) setting during the Neopalatial period (Fig. 9).

The navigational route intended by the orientation of the Malia central court is not easily ascertained due to the agglomeration of candidate destinations. The plane trigonometry angle of 105.49° between Malia and Megiddo diverges by only 1.37° from the central court orientation. Circa 1700 BCE during the Middle Bronze Age II, when Megiddo reached its apogee as a Canaanite city-state, the plane trigonometry angle from Malia to the city, aligned to the rising of the Belt of Orion when the star Alnitak became visible on the horizon (Fig. 9). In Polynesia and Micronesia, Orion's Belt was one of the group of stars commonly used for navigation. LMIB Minoan pottery has been found in the site of Ta'Anach neighbouring Megiddo (Sørensen, 2009, 44). Also, sailors on a course angle toward Megiddo from Crete may have made landfall at the beaches of Tel Nami, where four Aegean storage jars dating no later than 1750 BCE have been found (Sørensen, 2009, 43). The "lion tail" star, Denebola (β Leonis), was precisely the zenith star for Megiddo during the Neopalatial period. Orion's belt was an ideal navigational asterism to reach Megiddo since it's heliacal rise occurred during the beginning of Summer, when the Etesian winds blew, and could have been used until its acronychal rise in mid-December.

If a Minoan was able to journey on a perfect rhumb from Malia along the central court orientation, they would miss Megiddo by circa 1.67°, and instead reach the shores of Akko and the nearby Tel Kabri with less than a degree of precision. The site of Tel Kabri, where rare fragments of Minoan frescoes have been found, was one of the major South Levantine sites during the Middle Bronze Age II period (Niemeier and Niemeier, 1997, 77). Sørensen explained: "*According to the present excavators of Kabri, the city thrived from the MB I period until its destruction around 1600 BCE. During its heyday, a port at the small fortified site of Nahariya could have been in use by the rulers and traders of Kabri to conduct seaborne trade. Hazor lay 40 km east of Kabri, almost in a straight line, with no great mountains to cross*" (Sørensen, 2009, 13).
Meanwhile, Akko was the region's largest port and international maritime hub situated in Galilee, modern-day Israel, and was urbanized by at least the early 2nd millennium BCE (Artzy, 2018, 88; Bryce, 2009, 18-19). Ancient Egyptian execration texts from circa 1800 BCE and the Thutmose III list both record the toponym for Akko (Artzy, 2018, 90). The evidence of Minoan presence in the neighbouring Tel Kabri (19km away) suggests that the Minoans or their emissaries were in the vicinity of Akko.

A fourth candidate city is Jaffa, given that Mirach (β Andromedae) and the central court orientation aim at the Levantine harbor to within 2° of accuracy when using the plane trigonometry method (Table 1). That a star in Andromeda pointed at this city may have some cultural significance. The myth of Andromeda was depicted on coins from the city of Jaffa (Iope) (Kaizer, 2011, 332). Moreover, the city's own name may be etymologically related to Cassiopeia, Andromeda's mother, through its Hebrew meaning of "beauty". The star path from Zakros to Jaffa may have been preserved in a local legend that survives to this day in the modern Israeli town. On the harbor of Jaffa, a rock memorializes where Andromeda was chained, ready to be devoured by the sea monster Cetus before being saved by the hero Perseus. The earliest archaeological evidence of a settlement on the site dates to around Middle Bronze Age IIA (c. 2000 BCE) (Burke, 2011, 66). According to Shaick (2020, 153), based on Numismatic evidence, Perseus was likely a major hero at Akko. According to her analysis, the origin of Andromeda/Cepheus/Cassiopeia myth may have been at the river Belus in Akko, which may have been confounded with Belus the father of king Cepheus (Shaick, 2020, 155). It is possible to contemplate a relationship between the star path navigation route, as codified by Malia's central court orientation toward Akko or Jaffa, with Mirach and local mythologies regarding Andromeda.

8.7. Galatas to Byblos

Discovered in 1992, the Minoan palace of Galatas dates to the MMIIIB period (Christakis, 2011, 178). Various *in situ* measurements taken at the palace indicate a consistent mean average azimuth orientation of 95.65°. The rhumb line from Galatas to Byblos, one of the major trade harbours of the Levantine coast, was at 96.97°, or +1.32° degree from the central court short axis. However, the plane trigonometry angle between both coordinates is 95.76°, a difference within the margin of error. Considering that Galatas is not a port city, the Minoans could have used the same rhumb line by leaving from the Eastern coast of Crete, near Kato Zakro, to set course for Byblos.

Byblos has been continually inhabited since the Neolithic and it was the chief exporter of cedar and other woods to ancient Egypt, as such it was a powerful trading centre in the Bronze Age. The earliest imports in Crete originated from Byblos and dated to the end of the 3rd millennium BCE during the EM III period (Branigan, 1967, 12). During the second dynasty of Egypt, a trade route from Egypt to Byblos was established to acquire precious timber used to manufacture boats and coffins. As Sørensen confirmed, "A tentative conclusion to be drawn from the material presented would be that Byblos was chosen as a favourite port of call at least from EM II–MM II(A?)" (Sørensen, 2009, 19). A survey of the Minoica collected in the Levant reveals that more than half were excavated in Byblos, Ugarit, and Alalakh, all which functioned as persistent trade centres during the Bronze Age (Sørensen, 2009, 19).

Bellatrix (γ Orionis) rose at 96.80° azimuth during the Neopalatial period of Crete. With its heliacal rise in late June to its acronychal rise in late November, it was an effective star path since it coincided with the Etesian winds. The small constellation of Delphinus would have been ideal for setting course toward Byblos from Crete, since it set astern around 275-276° during the Neopalatial period. From its achronycal set in late July, at the beginning of Summer, to its heliacal set in early January, the setting of the constellation also coincided with the Etesian winds. This constellation was associated with various navigation myths in ancient Greece including the tale of Arion the Citharist (Hyginus, 1960, 194), considered one of the greatest harpists of his time. In the myth, he was saved from pirates by dolphins which were later placed in the heavens as the constellation. Another myth linked the constellation to the god of music himself, who transformed himself into a dolphin to save sailors (Homeric Hymn to Apollo, 1914, 399-401 and 440-443). According to Boutsikas, the Temple of Apollo at Delphi was ostensibly aligned to Delphinus, a constellation associated with stellar navigation in Greek mythology (Boutsikas, 2015, 1577; Homeric Hymn to Apollo, 1920, 399-401, 440-443). Liritzis and Castro (2013, 202) proposed that the Temple of Apollo in Delphi was used for observing the constellations of the Lyre and Cygnus as well, both linked mythologically to the god.

Beginning around 1800 BCE, the zenith star for the latitude of Byblos was precisely Sulafat (γ Lyrae), the tip of the Lyre, Apollo's harp constellation. While there is currently no orientation data confirming this star path, during the Neopalatial period from Pelusium or Avaris in the Nile Delta, a sailor could follow the rising of Vega (α Lyrae), the brightest star of the harp of Apollo, on a direct route to Byblos. Therefore, during this era, Byblos was reached from the Nile via Vega and the Lyre, while the same constellation also indicated its latitude. The lyre was a symbol connected to Byblos via the Cyprian culture hero and harpist, Cynaris (Franklin, 2009, 4), who, according to Strabo, ruled in Byblos (Strabo, 1932, 16.2.18). Cynaris may have been equivalent to the minor Ugaritic deity, Kinnâru, the deification of the lyre (Brown, 1981, 391-393; Franklin, 2009, 23; Franklin, 2015, 447). Franklin (2009, 23) also suggested that the Canaanite Shift of *Kinnâru* to Hebrew *kinnôr* and Greco-Phoenician *kinyra* indicate the 18th century BCE as the *terminus ante quem* for when the lyre was deified (Franklin, 2009, 23). Therefore, it is enticing to connect the contemporaneous deification of the lyre in the Levant to the celestial navigation routes based on Delphinus and the Lyre toward Byblos, where Cynaris, the harpist, was said to have ruled.

8.8. Gournia to Akrotiri or Alalakh

Due to its miniaturized architectonic similarities with the three large palaces of Knossos, Malia, and Phaistos, Gournia has been considered a palatial compound and probable residence of a ruling elite family (Preziosi and Hitchcock, 1999, 204). The fieldwork measurements for Gournia included the northern steps leading to the central court, a western section of the central court wall, plus the southern, eastern and northern walls of the central hall, adjacent to the court (Fig. 17, walls A-F). Some central court sections were not measured due to their uneven orientation. The mean average of the measurements amounted to 74.22° ±.67. Considering a Late Minoan date of 1600 BCE (Soles, 1991, 17), this orientation would correspond to Antares (α Sco) setting at 254.77° (74.77°+180°), within the margin of error (Table 1). An easterly rhumb line along this azimuth would aim toward Tarsus in the Anatolian coast by about 2°, however the plane trigonometry angle is off by 5° (fig. 17). Tarsus was at the centre of several trade routes connecting Anatolia and Syria, functioning as an important stop *en route* from the Eastern Mediterranean to the Aegean. Antares' rising azimuth was visible from early April to mid-November. However, the 5° difference from the plane trigonometry angle to the orientations of parts of the central court puts into question whether this was the intended course angle or not.

Figure 17. Gournia in situ measurerments. Walls A-F are oriented toward Akrotiri on the NS axis, and wall G toward Alalakh.

The orientation along the north-south axis is within 2° of both a plane trigonometry angle and rhumb line toward Akrotiri on the island of Thera, where Minoan style frescoes have been discovered. This means that Gournia could be an outlier, whose main primary orientation was on the north-south direction unlike the other palaces. Another tempting piece of evidence, is the fact that the star path of Antares setting, if navigated from Kato Zakro during the Neopalatial and Postpalatial periods, could have been used on a rhumb line toward Marsa Matruh. This port lies 240km west of Alexandria, Egypt and has been inhabited since the Late Bronze Age. Two Minoan and three Mycenean sherds have been found on the site, including a Cretan stirrup jar belonging perhaps to the LMIIIA (White, 1986, 77).

Another possibility can be found with a western wall of the central court (Fig. 17, Wall G), which has the unique orientation of 81.87° ±.67, corresponding to Altair (α Aquilae) rising (Fig. 18). This star path could have set course for the city of Alalakh, where fragments of Minoanized frescoes have also been discovered (von Rüden, 2013, 1). This azimuth is less than 2° away from either the rhumb line or the plane trigonometry course angle between Gournia and Alalakh. Altair, a known navigational star path in the Pacific Islands, could have served Minoans from its acronychal rise early June as the summer Etesian winds grew in strength to mid-December after they died down. Coincidentally, both Akrotiri and Alalakh had almost the exact same latitude, therefore they had the same zenith stars at this time: Zosma (δ Leonis) and Deneb (α Cygni). Given that Wall G is the only surviving wall on the central court with such an orientation it is inconclusive whether this course angle was intentional. It is nonetheless tempting to speculate that this orientation was intended given that Alalakh has evidence of Minoan contact.

8.9. *Sisi to Ashkelon*

The orientation of Sisi's central court appears to be an outlier when compared to the other sites (Table 1). The court is unevenly shaped and probably consists of several different building phases. Measurements were taken at the north-eastern, northern and north-western segments of the central court and date probably to circa 1600 BCE (Driessen, personal communication). The central court azimuth of 116.53° is aligned toward the declination of Sirius and Rigel rising over the mountains to the east. This would appear to diverge from the pattern of alignments toward stars azimuths on a sea-level horizon. However, the azimuth for Sirius rising on the sea-level horizon, 112.5°, coincides with a route toward the powerful coastal city of Ashkelon, in the southern Levant, when calculated with plane trigonometry (Table 1).

According to Sørensen, "The largest and most powerful coastal site in the southern Levant seems to have been Ashkelon." (Sørensen, 2008, 11). While Sirius and Rigel were the only bright star paths near that azimuth and Ashkelon was the major trading hub in Southern Levant at that time, it seems reasonable to assume Sisi's central court referenced this sea route. It is also a noteworthy and anachronistic coincidence that Sirius, known as the "Dog Star" in antiquity, pointed toward Ashkelon during the Bronze Age, where over one thousand canine burials, the largest dog cemetery of ancient Levant, dating to the 5th Century BCE, was found (Edrey, 2008, 267).

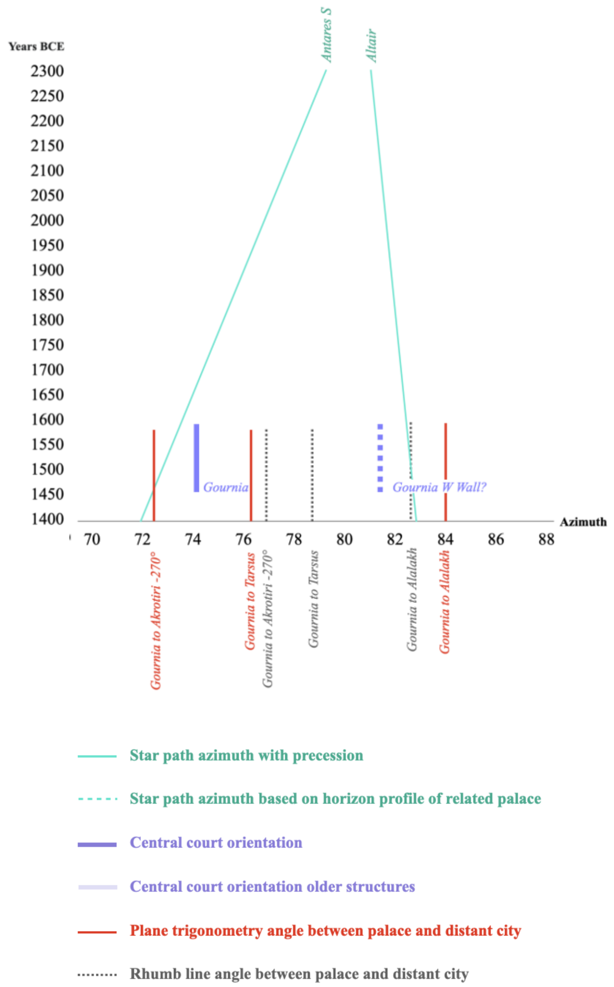

Fig. 18. Plane trigonometry and rhumb line azimuths between of Gournia and maritime destinations compared with central court orientations and star paths. The star azimuths are drift during the centuries due to the precession effect. The purple lines indicate the central court orientations relative to the dates the palace existed.

One conclusion to be taken from Sisi, is that the builders broke with tradition, for unknown reasons, and opted to orient their palace toward the Sirius/Rigel star path when the stars were visible over the mountains, unlike the other palaces which aligned to the stars as they would have risen on a sea-level horizon. Given Sirius's status as the brightest fixed star, the architects may have opted to engender special ritualistic or calendrical respect to the star's appearance. The rising of Sirius coincided with the Summer Etesian winds, from its heliacal rise in late June to its acronychal rise in early January. Ashkelon possessed the easily identifiable zenith stars Algieba (γ Leonis), with its meridional pair Regulus (α Leonis); and Mirfak (α Persei) with its meridional pair Algol (β Persei).

9. CONCLUSION

The aim of this research was to investigate if the axes of Minoan palace central courts were oriented toward star paths aimed at distant coastal emporia in the Levant, Egypt, and the Aegean, important historical and commercial Bronze Age destinations. The evidence suggests that the Minoans may have used wayfinding methods analogous to those documented in Polynesia and Micronesia, which relied on celestial navigation traditions for the memorization, practical use, and oral transmission of gift exchange routes. A new methodology was elaborated that synthesized traditional skyscape archaeology fieldwork with virtual analysis centred on astronautical orientations along rhumb lines. The research concludes that the Minoans may have used star paths and zenith stars to reach the busiest ports on the Eastern Mediterranean and Egypt (Fig. 19). The data also disagrees with the often cited proposition that the central court palaces were primarily aligned toward sacred mountains or caves.

The fact that the orientations correspond to the simple Pythagorean triplets of 3-4-5, 5-12-13, 7-24-25, and 11-60-61 hint at a currently unknown mathematical method for calculating the course angles between locations. However, questions still linger regarding how the Minoans may have measured the "coordinates" of each location based on celestial observations. Also, while the material record may support a special relationship between Phaistos and Kommos with a maritime route due east to Cyprus, and between Kato Zakro to Egypt, further archaeological and historical research is needed to substantiate the proposed link between specific palaces and partner cities.

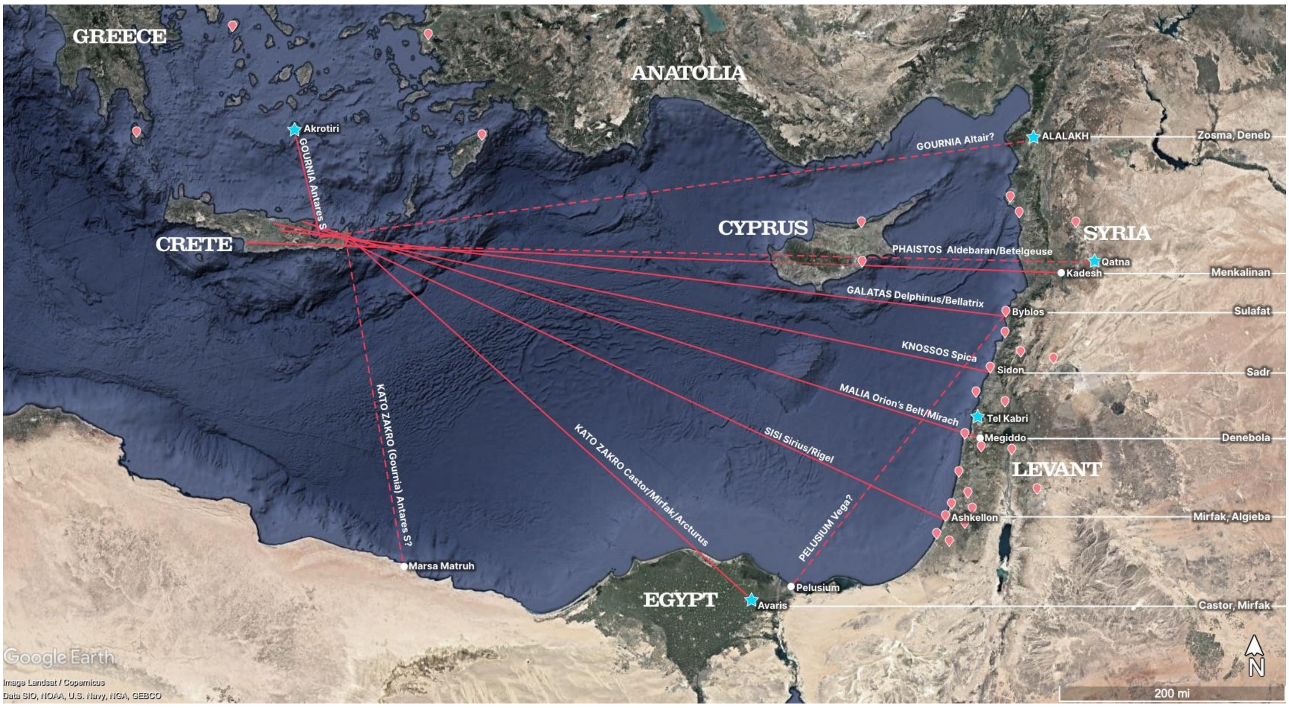

Figure 19. Map of proposed Minoan star path direct routes to the Levant and Egypt. Red lines illustrate the approximate course angles intended from central court orientations using the simplistic plane trigonometry method. The corresponding zenith stars of each city are aligned to the right. Image by author using Google Earth Pro.

The routes from Knossos to Sidon and Kato Zakro to Avaris/Pelusium are convincing examples of star path routes that align with the Etesian wind directions and palace orientations. The notion that Knossos was oriented toward Spica, the "ear of wheat", finds tempting evidence in the Linear A word KU-NI-SU GRANUM, perhaps meaning "emmer wheat", which has been speculated to represent the toponym itself. While not definitive evidence, mythology suggests the existence of these direct maritime routes: from Knossos to Sidon via the legend of Europa; from Malia to Akko and Jaffa via Mirach and the myth of Andromeda; and from Galatas to Byblos via Delphinus, Arion the harpist and the deified harpist Cynaris.

Mediterranean celestial navigation, like in Polynesian and Micronesia, must have involved initiatory knowledge of star paths, wind patterns, favourable dates, and trade contacts. In some cases, the palace architecture may have encoded this discretely by not exposing the explicit sight lines to the rising or setting star paths. Like the navigation stones of Aurorae Islands, the orientations of the central courts could have served mnemonic or educational purposes. Would-be Minoan navigators could have been taught the star paths within palace structures, similar to the metonymic representations of the sky in Polynesian maneabas. Furthermore, unlike the religious significance behind the homogenous orientation of the Muslim Quibla toward Mecca, the varied azimuths of Minoan palaces may have reflected the economic and cultural interests of the local ruling families. The embedding of long-distance navigational knowledge within the palace axis, must have symbolized the association of specific sea lanes with entrepreneurial palatial elites who sought to consolidate and legitimize power. In this manner, the central courts were the economic and astronautical heart of Minoan culture, combining landscape, seascape, and skyscape into one.

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