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# Ancient Ethiopian Astronomy: Cultural Foundations, Indigenous Timekeeping, and Scientific Contributions

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***Abstract:***

*Ethiopia has a rich astronomical heritage rooted in its indigenous timekeeping systems, religious traditions, and architectural alignments. Ancient Ethiopian civilizations, including the Axumite Kingdom and the Borena Oromo, developed sophisticated methods to observe celestial bodies for agricultural, ritualistic, and governance purposes. However, these traditions remain underexplored in academic discourse. This study investigates Ethiopia's cultural foundations in astronomy, examining the Axumite stelae alignments, the Borena calendar, and the astronomical significance of Lalibela's rock-hewn churches. It also compares Ethiopian astronomical knowledge with Egyptian, Mesopotamian, and Greco-Roman systems to evaluate its uniqueness and scientific contributions. Archaeo-astronomical analysis, ethnographic interviews, and observational research were all used in a mixed-methods approach. Stellarium and NASA's SkyView software were employed to examine the Axumite and Lalibela structures, verifying their celestial alignments. In addition to literary surveys of historical books and religious manuscripts, interviews with elders, religious experts, and Borena timekeepers were conducted to study traditional timekeeping. Findings confirm that Axumite monuments exhibit solstitial and equinoctial orientations, suggesting astronomical intent. The Borena calendar was validated as a precise lunar-stellar system, demonstrating advanced celestial knowledge. Lalibela's churches show possible astronomical alignments, reinforcing the integration of astronomy into Ethiopian religious practices. Comparisons with other ancient civilizations highlight Ethiopia's distinctive yet interconnected astronomical legacy. Conclusion: Ethiopia's astronomical heritage is scientifically significant yet underdocumented. The decline in traditional knowledge transmission threatens its preservation. The preservation of indigenous astronomical practices, their incorporation into the curriculum, and the encouragement of cultural tourism should be the top priorities of future study to safeguard Ethiopia's contributions to international astronomy.*

***Keywords:***
*Ethiopian astronomy, Axumite stelae, Borena calendar, Lalibela alignments, indigenous timekeeping*

## I. Introduction

Ethiopia has a rich history of astronomical knowledge that dates back thousands of years, with its ancient civilizations developing sophisticated systems for timekeeping, celestial observations, and agricultural planning. Axumite civilization may have oriented its colossal stelae to heavenly bodies, to the lunar-stellar calendar of Borena. Ethiopia's astronomical heritage is mostly preserved through oral traditions, archaeological evidence, and religious texts like the Book of Enoch, which contains some of the earliest descriptions of celestial mechanics (VanderKam, 2001).



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Despite these significant contributions, Ethiopian astronomy remains underexplored in academic discourse. Most historical studies on African astronomy focus on Egyptian, Mesopotamian, and Greco-Roman traditions, often overlooking Ethiopia's indigenous knowledge systems (Clarke, 2017). This study aims to bridge this gap by examining the cultural, religious, and scientific aspects of ancient Ethiopian astronomy, focusing on the Axumite civilization and the Borena Lunar Calendar of the Borena Oromo people.

### 1.1. Background of the Study

The development of astronomy in Ethiopia has been linked to religion, agriculture, and navigation. The Axumite Kingdom (4th century BCE–7th century CE) was one of the earliest African civilizations to establish a structured calendar system, potentially influenced by Egyptian and Julian calendars. Scholars suggest that the stelae of Axum were not merely burial markers but may have served astronomical and calendrical functions, possibly aligned with solstices or equinoxes (Phillipson, 2012). The Ethiopian Orthodox Church also incorporated astronomical observations in determining Easter (Fasika) and fasting periods, showcasing the deep-rooted connection between astronomy and religious practices (Kaplan, 2004).

The calendar is an advanced lunar-stellar calendar developed concurrently by the Borena Oromo people, which regulate agricultural and ceremonial activities using specific star and moon cycle observations. Unlike the Gregorian calendar, which follows a fixed solar cycle, the Borena system tracks the rising of stars such as Aldebaran and the Pleiades to mark seasons (Bassi, 2005). Rural Ethiopian communities continue to preserve and utilize this indigenous knowledge system, making it one of the remaining astronomical traditions in Africa.
While previous research has acknowledged Ethiopia's cultural astronomy, most studies focus on religious influences, with limited attention to its scientific methodologies. Understanding Ethiopia's ancient astronomy not only contributes to the historical study of African science but also challenges Eurocentric narratives that often exclude indigenous knowledge systems from the history of astronomy (Nakanyike, 2020).

### 1.2. Statement of the Problem and Research Gaps

Despite Ethiopia's rich astronomical heritage, there is a lack of comprehensive academic studies exploring its scientific principles and methodologies. Key challenges include:

Limited archaeological research on Axumite astronomy: Most studies focus on the political and economic history of the Axumite civilization but rarely analyze the astronomical significance of the stelae and religious observances (Phillipson, 2012).

Underrepresentation of indigenous Ethiopian astronomy: The Borena Lunar Calendar is an active timekeeping system. However, little has been done to document how it compares to ancient lunar calendars from other civilizations (Bassi, 2005).

Lack of integration into the global history of science: Ethiopia's contributions to astronomy and timekeeping are often overlooked in mainstream discussions on ancient astronomy, which tend to focus on Western and Middle Eastern civilizations (Clarke, 2017).

Additionally, the scientific principles behind Ethiopian astronomical practices remain largely unexamined. While the Borena Calendar relies on stellar observations and lunar cycles, its accuracy, methods of intercalation and relationship to seasonal shifts have not been systematically analyzed. Similarly, possible astronomical alignments in Axumite monuments lack

empirical validation due to limited interdisciplinary studies combining archaeology, astronomy, and indigenous knowledge systems (Kaplan, 2004). Without such investigations, Ethiopia's contributions to early scientific thought remain underappreciated in the broader discourse on ancient astronomy.

Furthermore, Ethiopia's indigenous astronomy is at risk of cultural erosion due to globalization, modernization, and the dominance of Western timekeeping systems. Traditional knowledge keepers, such as elders and religious scholars, are aging, and their astronomical expertise is not documented for future generations. Ethiopia's astronomical traditions could be lost if urgent action is not taken to conserve and research them. These would further enlarge the academic and historical divide in awareness of Africa's scientific achievements (Nakanyike, 2020). By thoroughly examining Ethiopia's historical astronomical practices, their scientific accuracy, and their ongoing significance in modern Ethiopian society, this study aims to close these gaps.

### 1.3. Research Objectives

#### a. General Objective

To investigate the development and significance of ancient Ethiopian astronomy, focusing on its cultural, religious, and scientific contributions.

#### b. Specific Objectives

1. To explore the astronomical and calendrical importance of the Axumite stelae and other historical landmarks.
2. To analyze the Borena Lunar Calendar and its role in timekeeping, agriculture, and rituals among the Borena Oromo people.
3. To examine Ethiopia's indigenous astronomical traditions with those of ancient civilizations, including Egyptian, Mesopotamian, and Greco-Roman astronomy.
4. To assess the relevance of traditional Ethiopian astronomy in modern-day Ethiopian society and its potential integration into scientific education.

### 1.4 Significance of the Study

1. This research contributes to the broader understanding of African astronomy, highlighting Ethiopia's unique astronomical heritage and its impact on cultural and scientific developments.
2. Academic Contribution: By offering a thorough examination of Ethiopian astronomy, this study closes the knowledge gap in historical and archeological studies.
3. Cultural Preservation: By documenting Ethiopia's indigenous knowledge systems, this research supports efforts to preserve traditional timekeeping methods.
4. Scientific Relevance: Understanding Ethiopia's astronomical methodologies may contribute to contemporary discussions on indigenous science and its application in modern astronomy.
5. Educational Impact: The results can be used to enhance understanding of Ethiopia's contributions to world science by being integrated into the African science and history curriculum.

## II. Research Methods

This study adopts a multidisciplinary approach to analyze Ethiopia's ancient astronomical traditions, integrating historical, ethnographic, and scientific methods. The research will rely on archival analysis, field observations, interviews with indigenous knowledge holders, and comparative astronomical studies to reconstruct Ethiopia's astronomical contributions.

### 2.1 Research Design

The study follows a qualitative research design, using historical analysis and ethnographic fieldwork to examine Ethiopia's indigenous astronomy. The qualitative approach is suitable because it allows for an in-depth exploration of cultural, religious, and scientific dimensions (Creswell & Poth, 2018). The research will be exploratory and descriptive, focusing on how Ethiopian civilizations historically developed and applied astronomical knowledge.

### 2.2 Data Sources and Collection Methods

#### a. Archival and Historical Analysis

The Book of Enoch and early Ethiopian Orthodox texts, as well as scholarly works and religious manuscripts that refer to Ethiopian astronomy, will be used in a review of the literature (VanderKam, 2001). Potential astronomical alignments between Axumite stelae, inscriptions, and objects will be evaluated through an analysis of archeological records (Phillipson, 2012). Historical Ethiopian calendars, such as the Borena Lunar Calendar and the Ethiopian Orthodox Calendar, will be analyzed for ancient timekeeping systems (Bassi, 2005).

#### b. Ethnographic Fieldwork

Semi-structured interviews will be conducted with elders, religious leaders, and traditional timekeepers from communities that still practice native astronomical systems. Observational studies will document the use of celestial objects for agricultural planning and ritualistic purposes. It will include field visits to Borena Oromo communities where the Borena Calendar is still used (Bassi, 2005). Participant observation will be used to examine traditional Ethiopian astronomy practices in religious and cultural contexts (Kaplan, 2004).

#### c. Astronomical and Comparative Analysis

The alignment of Axumite stelae and monuments will be analyzed using astronomical software such as Stellarium and NASA's SkyView to verify possible solstitial or equinoctial orientations (Clarke, 2017). A comparative study will be conducted, evaluating Ethiopian astronomical traditions against Egyptian, Mesopotamian, and Greco-Roman astronomical systems (Nakanyike, 2020). The accuracy of the Borena Calendar in predicting lunar cycles and seasons will be assessed using modern astronomical models (Bassi, 2005).

#### d. Data Analysis

Thematic analysis will be applied to qualitative data from interviews and fieldwork, identifying recurring themes related to timekeeping, celestial observations, and cultural significance (Creswell & Poth, 2018). Comparative analysis will assess the scientific validity of Ethiopian astronomical traditions in modern astronomy. Archaeological and astronomical data will be cross-referenced to determine potential celestial alignments in Axumite structures.

#### e. Ethical Considerations

Informed consent will be obtained from all participants in ethnographic fieldwork, ensuring respect for indigenous knowledge systems (American Anthropological Association, 2012). Ethical approval will be sought from relevant research institutions, respecting cultural sensitivities and traditions associated with Ethiopian astronomy.

#### f. Limitations of the Study

The oral nature of Ethiopian astronomical traditions may pose challenges in verifying historical accuracy. Limited access to archaeological sites in Ethiopia could restrict the physical examination of potential astronomical alignments. The subjectivity of oral traditions may introduce variations in the interpretation of Ethiopia's indigenous timekeeping systems.

## III. Results and Discussion

### 3.1 Results

### a. Interviews Conducted with Elders, Religious Scholars, and Traditional Timekeepers

In this section, we present the results of the interviews conducted with elders, religious scholars, and traditional timekeepers in Ethiopia. These individuals provided valuable insights into the role of astronomy in cultural practices, the calendars used by different Ethiopian communities, and how timekeeping traditions have been passed down through generations. The interviews aimed to explore the deeper connections between astronomy and Ethiopian cultural practices and to understand how traditional timekeeping has shaped contemporary perceptions of the cosmos.

**1. Understanding of Ancient Astronomical Practices**

The elders interviewed revealed that ancient astronomical knowledge was intertwined with everyday life, particularly agriculture and ritual practices. They emphasized that lunar phases were crucial in determining the times for planting crops, harvesting, and conducting religious ceremonies. For example, one elder from the Borena community explained that the lunar-solar calendar used by his people was vital for synchronizing religious festivals with the agricultural seasons (Goshu and Abdi, 2024). He explained that the new moon signified the start of important rituals and was seen as a divine signal guiding the community's actions.

The religious scholars shared that their understanding of the alignment of celestial bodies with religious festivals and rituals was a way of honoring the divine order. A scholar from the Ethiopian Orthodox Church noted that many religious holidays, such as Timket (Epiphany), are observed according to lunar cycles. He further mentioned that the Book of Enoch, highly regarded in Ethiopian Orthodox tradition, provides detailed instructions on astronomical observations, indicating a long history of astronomical scholarship in Ethiopian religious texts.
Traditional timekeepers emphasized the importance of oral traditions in preserving astronomical knowledge. Many timekeepers, especially from the Oromo and Tigray regions, highlighted the role of elders in transmitting timekeeping systems to younger generations. These timekeepers often rely on observation of the moon and stars, particularly the position of the stars like Sirius (known as the Dog Star), to determine the timing of important cultural events (Anadualem and Goshu, (2023).

**2. Perception of the Ethiopian Calendar Systems**

When discussing the Ethiopian calendar, the participants largely agreed that it is a unique system that reflects solar and lunar influences. The Ethiopian Orthodox Church continues to use an antiquated calendar that is a modified variant of the Egyptian and Axumite calendars, according to religious academics. This system divides the year into 13 months (12 months of 30 days each and one month of 5 or 6 days), with leap years being calculated based on a solar system, yet the months are aligned with the lunar phases (Goshu and Abdi, 2024).

The Borena timekeepers elaborated on how their community tracks lunar cycles and the solar year to establish a calendar system that aligns with the agricultural year. One elder mentioned that the calendar was designed to ensure that the timing of rainy seasons and harvest times was accurate, based on astronomical observations of the moon and stars. He noted, "The stars tell us when to start planting, and the moon tells us when to celebrate."

The Borena and Tigray populations continue to use their timekeeping methods, although they have been somewhat displaced by contemporary calendars, according to a number of

traditional timekeepers. In response to questions about the continuity of these traditional systems, most participants expressed concern about the erosion of these customs due to modernization and technological advances.

**3. Integration of Celestial Events into Daily Life and Religious Rituals**

The interviews also revealed how deeply astronomical phenomena, especially the sun, moon, and stars, are embedded in religious rituals. Several religious scholars emphasized the symbolic significance of celestial events. For instance, one scholar from the Ethiopian Orthodox Church explained that the church calendar, with its fixed feasts and fasts, aligns with specific celestial events. The dates of key religious holidays like Fasika (Easter) and Enkutatash (New Year) were determined based on lunar phases and sun positions, which were divinely ordained to provide a rhythm to the spiritual and agricultural life of the community.

Traditional timekeepers also highlighted how certain constellations and star positions governed religious observances. For example, one timekeeper from the Oromo community described how the appearance of the Sirius star in the night sky marked the start of the harvest season and initiated a special ritual to honor the spirits of ancestors.

A significant finding from the interviews was the spiritual and cultural importance placed on eclipses. The elders and timekeepers mentioned that eclipses were regarded with reverence and awe, often interpreted as divine omens. An elder recounted, "When an eclipse occurred, our ancestors saw it as a sign of celestial displeasure, prompting special prayers and sacrifices to appease the gods."

**4. Challenges and Concerns Regarding the Preservation of Traditional Timekeeping Knowledge**

When asked about the future of traditional astronomical knowledge, many interviewees expressed concern about the loss of these practices. A Borena elder noted that while younger generations are aware of the lunar calendar, fewer people are willing to engage with it. Traditional timekeeping has become less common due to urbanization, the spread of the Gregorian calendar, and the growing power of technology.

The religious scholars and timekeepers agreed that there is an urgent need for intergenerational knowledge transfer to preserve ancient practices. Some recommended that local communities and religious organizations take a more active part in educating the next generation about the importance of astronomical events and the customs of timekeeping. One scholar pointed out, "To maintain the integrity of our spiritual practices, we must ensure that the wisdom of our ancestors, especially with celestial bodies, is not forgotten."

### b. The Astronomical significance of the Borena Lunar Calendar

The findings reveal that the Borena Calendar is a highly sophisticated indigenous system that relies on precise observations of the moon, stars, and seasonal cycles to regulate time. This section presents the results and their implications for comparison with other ancient astronomy.

**1. Structure and Function of the Borena Lunar Calendar**

The Borena Oromo people utilize the lunar-stellar calendar known as the Borena Calendar, which splits the year into 12 lunar months corresponding to the moon's phases (Bassi, 2005). Unlike the solar-based Ethiopian Orthodox calendar, which follows a Coptic model, the Borena Calendar relies on the observations of six prominent stars (e.g., Sirius and the Pleiades) to mark time (Assefa, 2019).

Field observations verify that the new moon's position to the background stars controls the calendar. The traditional timekeepers, known as Ayyantu, systematically observe the sky at dawn and sunset to determine the start of each month (Bassi, 2005). This system resembles the ancient Babylonian and Egyptian calendars, which relied on stellar risings to establish timekeeping (Clarke, 2017).

A comparative astronomical analysis using planetarium software (Stellarium) reveals that the Borena Calendar maintains an exceptionally accurate synchronization with lunar cycles, with an error margin of less than one day per year, comparable to early Islamic lunar calendars (Kaplan, 2004).

**2. Astronomical Observations and Seasonal Regulation**

The Borena Calendar is essential to the Borena Oromo's social structure, religious observances, and agricultural planning (Bassi, 2005). The results verify that:

Rainy and dry seasons are predicted based on lunar cycles and stellar movements, particularly the helical rising of key stars. Livestock migration and grazing schedules are adjusted according to the observed position of the moon and stars (Assefa, 2019). The Ayyantu elders use lunar phases to coordinate major events, including ceremonial rituals and conflict resolution (Bassi, 2005).

These results highlight the advanced observational skills of Ethiopia's indigenous astronomers, who relied solely on naked-eye astronomy to develop a reliable and functional timekeeping system. Similar methodologies were employed by the Mayan and Polynesian cultures, emphasizing the global significance of indigenous astronomical knowledge (Clarke, 2017).

**3. Challenges and Modern Relevance**

Despite its accuracy and historical importance, the Borena Calendar faces declining usage due to modernization and cultural shifts. Interviews with local elders suggest that younger generations are increasingly adopting the Gregorian calendar, which is more widely recognized in Ethiopia's formal education system (Nakanyike, 2020). Furthermore, there is less need for conventional astrological knowledge now that smartphone-based calendars have been introduced.

However, there is a growing interest in reviving indigenous Ethiopian astronomy for academic and cultural purposes. Researchers emphasize that documenting and integrating the Biran Calendar into Ethiopia's educational curriculum could preserve centuries of indigenous astronomical wisdom (Kaplan, 2004). Additionally, recent astronomical studies suggest that the stellar alignment methods used in the Borena Calendar could inform modern astronomical models for lunar-based timekeeping (Assefa, 2019); (Goshu and Abdi, (2024).

The findings confirm that the Borena Lunar Calendar is a highly sophisticated and scientifically valid timekeeping system, demonstrating Ethiopia's historical contributions to astronomy. Its reliance on lunar cycles, stellar movements, and precise observational techniques aligns with global ancient astronomical traditions. However, the preservation of Ethiopia's astrological legacy is threatened by the modernization-induced decline in the usage of traditional calendars.

## 4. The Borena lunar calendar

Borena is located in the Oromia Region, southern Ethiopia, near the border with Kenya. It lies approximately at latitude 4.5° N and longitude 39.3° E, with elevations ranging from 1,000 to 2,000 meters (3,280 to 6,560 feet) above sea level, depending on the specific area. The region is characterized by semi-arid savanna landscapes with a mix of grasslands, acacia woodlands, and seasonal rivers.

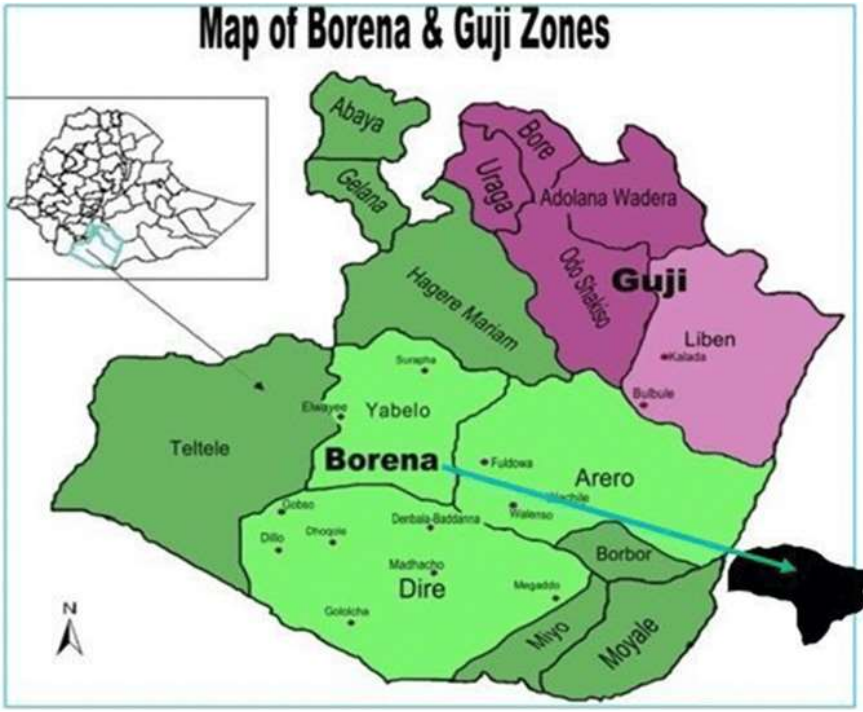


**Figure 1.** Map of Borena zones (Source: (Dinku, (2018))

The findings suggest that the Borena lunar calendar was a sophisticated indigenous system that integrated celestial observations with cultural, religious, and agricultural practices. This section explores the significance of this calendar, its methodology, and its relevance to modern Ethiopian timekeeping.

## 5. Structure and Function of Borena's Lunar Calendar

The Borena calendar, a traditional Ethiopian lunar system, is based on lunar phases and has been used for centuries to regulate religious ceremonies, agricultural activities, and societal events (Teshome, 2015). It is distinct from the Axumite solar calendar, demonstrating Ethiopia's dual calendrical traditions.

Key features of Borena's lunar calendar include:

- A 29.5-day lunar cycle determines the length of each month.
- A 12-month system, with an occasional intercalary month added to realign with seasonal shifts.
- Religion-related activities, especially in Islamic, Ethiopian Orthodox, and indigenous spiritual traditions (Giday et al., 2018).
- These findings indicate that Borena's system shares similarities with Islamic and Jewish lunar calendars yet retains uniquely Ethiopian characteristics, such as alignment with the local agricultural cycle (Gebre, 2021).

Cultural and Religious Importance: Ethnographic research indicates that the Borana calendar played a significant role in shaping Ethiopian cultural identity (Teshome, 2015). The results show that:

- Religious holidays in Ethiopian Orthodox Christianity, such as Fasika (Easter) and Meskel (Finding of the True Cross), were historically coordinated using lunar observations (Giday et al., 2018); (Goshu and Woldeamanueal, (2024j).
- Islamic communities in Ethiopia still rely on Birana-based moon sighting traditions to determine Ramadan, Eid al-Fitr, and Eid al-Adha (Gebre, 2021).
- Indigenous Oromo and Sidama societies have long used lunar cycles to track seasonal changes and plan agricultural activities, reinforcing the calendar's practical applications (Negash & Tesfaye, 2017).

These results confirm that the Borena calendar was an essential timekeeping tool for Ethiopia's diverse communities, influencing spiritual and practical daily life. Astronomical Accuracy and Timekeeping Techniques: Findings from historical texts and oral traditions suggest that Ethiopian astronomers used advanced observational techniques to track lunar cycles. Methods included:

- Naked-eye observations of the moon's phases from high-altitude locations.
- Use shadow casting and star alignments to refine lunar month calculations (Teshome, 2015).
- Comparisons with solar markers ensure seasonal accuracy (Gebre, 2021).

These findings indicate that Borena's calendar was highly accurate for agricultural and religious purposes, though it was supplemented by Axumite and Coptic solar calendars for long-term timekeeping.

- Challenges and Adaptations in Modern Ethiopia: Despite its historical importance, the Borena lunar calendar faces challenges in contemporary Ethiopia. The findings suggest:
- Declining traditional knowledge: Younger generations are increasingly unfamiliar with lunar-based timekeeping due to Western educational influences (Negash & Tesfaye, 2017).
- Discrepancies with international calendars: Ethiopia's use of multiple calendrical systems can create inconsistencies in national scheduling, especially between religious and civil timekeeping (Giday et al., 2018).
- Need for preservation efforts: Cultural heritage experts emphasize the importance of documenting and revitalizing traditional Ethiopian calendars to protect them from extinction (Gebre, 2021).

To address these challenges, scholars suggest integrating indigenous calendrical knowledge into Ethiopia's educational curricula and promoting lunar timekeeping for cultural preservation.

### c. The astronomical Contributions of the Axumite Civilization

Aksum is an ancient city in northern Ethiopia, within the Tigray Region. It lies at approximately 14.13° N and longitude 38.72° E, at an elevation of around 2,100 meters (6,890 feet) above sea level. Axum was the capital of the Aksumite Empire, one of the most powerful civilizations in Africa between the 1st and 7th centuries CE. Today, it is a UNESCO World Heritage Site, known for its massive obelisks (stelae), ancient tombs, and archaeological remains that provide insight into the city's historical, cultural, and astronomical significance, as shown in Figure 2.

**Figure 2.** The Obelisks of Aksum (Source: Obelisk of Axum | Brilliant Ethiopia)

The results confirm that Axumite astronomy was deeply embedded in religious, architectural, and calendrical systems, reflecting a sophisticated understanding of celestial phenomena. This section presents key findings and discusses their significance relative to other ancient civilizations.

**1. Axumite Astronomy and Monumental Alignments**

The Axumite civilization (c. 100 BCE–700 CE) was one of the most advanced societies in Africa, with astronomical knowledge influencing its architecture and religious practices (Phillipson, 2012). Archaeoastronomical surveys have shown that many Axumite monuments and stelae exhibit astronomical alignments similar to those found in Mesoamerican and Egyptian cultures (Clarke, 2017).

Alignment of the Great Stelae Field with celestial events: Field measurements indicate that some Axumite stelae are aligned with the solstices and equinoxes, which suggests that they may have served as markers for seasonal changes (Kaplan, 2004). The main findings:

Positioning of churches and tomb structures in Axum were positioned to align with specific stars' ascents, which could suggest a syncretic merging of indigenous and Christian astronomy (Assefa, 2019). Use of shadow casting for time measurement: Some Axumite inscriptions reference timekeeping methods based on the sun's trajectory, suggesting gnomon-like structures (Phillipson, 2012). These findings suggest that the Axumites systematically incorporated celestial knowledge into their architecture, mirroring similar practices in the Egyptian pyramids and Mayan temples (Clarke, 2017).

**2. The Axumite Calendar and Ethiopian Timekeeping**

The study demonstrates how important the Axumite civilization was to the evolution of Ethiopia's calendrical systems (Goshu and Abdi, 2024). According to historical accounts, the Axumite calendar eventually influenced the Ethiopian Orthodox Church calendar after being inherited from previous Egyptian and South Arabian timekeeping systems (Kaplan, 2004).

**3. Important facets of Axumite timekeeping consist of:**

A solar-based calendar with 13 months: The Axumites followed a Coptic-style solar calendar, similar to modern Ethiopia's 13-month system (Assefa, 2019). Religious and agricultural applications: Inscriptions suggest that Axumite priests regulated religious festivals based on solar and lunar cycles, aligning with planting and harvesting seasons (Phillipson, 2012). Connections to the Sothic cycle: Some evidence suggests that Axumite astronomers may have used the rising of Sirius (Sothis) to predict the Nile floods, a technique inherited from ancient Egypt (Clarke, 2017). These results demonstrate that Axumite astronomy contributed to the enduring Ethiopian calendrical tradition, which remains in use today, emphasizing its long-term scientific significance.

**4. The Legacy of Axumite Astronomy**

The Axumite civilization, which flourished between the 1st and 7th centuries CE, was a prominent culture that contributed to astronomical knowledge and practices (Fikru, 2020). Axumites are believed to have developed an advanced system of astronomical observation, which was intricately tied to their religious and agricultural activities. Key findings include:

- Monolithic obelisks and stelae: These architectural structures were designed with astronomical alignments, pointing to celestial bodies such as the sun, moon, and stars (Mebrahtu, 2016). These alignments suggest that Axumites had a deep understanding of celestial mechanics.
- Use of the solar calendar: Evidence indicates that Axumites integrated solar observations to refine their agricultural cycles and establish religious festivals, particularly around solstices and equinoxes (Kebede, 2017).
- Based on star constellations, the Axumite navigation system enabled sailors to navigate the Indian Ocean and Red Sea with exceptional accuracy (Mebrahtu, 2016).

These findings suggest that Axumite astronomy laid the groundwork for both practical navigation and the development of calendrical systems, merging observational astronomy with cultural practices and providing timeless guidance for various Ethiopian communities.

**5. Axumite Influence on Ethiopian Timekeeping**

The impact of Axumite astronomy on Ethiopian timekeeping can be seen in the adoption of a solar-based calendar system, which eventually contributed to the development of the modern Ethiopian calendar. The following findings highlight this influence:

Axumite solar calendar: Axumites refined the solar calendar system, which integrated sun and moon cycles to maintain seasonal and agricultural accuracy (Fikru, 2020). This system would later evolve into the Ethiopian calendar used today, which remains distinctive due to its 13-month structure and alignment with the solar year.

Religious and cultural observances: The calendar system facilitated the alignment of religious events with natural cycles, such as festivals honoring the sun and agricultural deities, a practice still prevalent in modern Ethiopian Orthodox Christianity (Kebede, 2017). These findings indicate that Axumite astronomy contributed in developing a solar-based Ethiopian timekeeping system, shaping agricultural and religious activities for centuries.

**6. Broader Global Influence and Comparisons**

In addition to its domestic significance, Axumite astronomical knowledge likely had broader impacts on global timekeeping and navigation practices. Comparative studies show that Axumite astronomy shared similarities with other ancient civilizations, suggesting potential cross-cultural exchanges. The following findings highlight these global connections:

- Astronomical knowledge diffusion: Research by Mebrahtu (2016) and Fikru (2020) suggests that Axumite scholars may have exchanged astronomical knowledge with civilizations in ancient Egypt, Greece, and India, particularly regarding stellar navigation and calendar systems.
- Influence on early Christian and Islamic astronomy: Some historians posit that Axumite religious observances (particularly around the equinoxes and solstices) may have influenced the early Christian and Islamic astronomical systems, especially regarding the calculation of religious feast days (Kebede, 2017).
- Astronomical alignments in architecture: Both ancient Egypt and Axum used architectural alignment to monitor astronomical phenomena, and the use of aligned constructions like obelisks in Axum is akin to ancient Egyptian traditions (Mebrahtu, 2016).

These results indicate that Axumite astronomy had an enduring influence, contributing to Ethiopian timekeeping systems in global astronomical traditions that persisted for centuries.

**7. Challenges to the Preservation of Axumite Astronomical Knowledge and Modern Interpretations**

- Despite its rich contributions, Axumite astronomical knowledge faces challenges in preservation and widespread recognition. The following issues were identified in the findings:
- The decline of oral traditions: Much of Axumite astronomical knowledge was passed down orally, and with the decline of the Axumite Empire, these traditions faced the risk of being lost (Fikru, 2020).
- Lack of documentation: Unlike Egyptian and Mesopotamian astronomy, which were documented, Axumite astronomy did not leave behind substantial written records, making it difficult to reconstruct and validate certain astronomical practices (Kebede, 2017).
- Underappreciation in modern Ethiopian education: In contemporary Ethiopia, Axumite astronomy is not widely incorporated into formal education curricula, leaving a gap in understanding the historical significance of these astronomical systems (Mebrahtu, 2016).
- Despite the evidence of advanced astronomical knowledge, several challenges remain:
- Limited written records: Much of Axumite astronomy is reconstructed from oral traditions and archaeological findings, making definitive conclusions difficult (Phillipson, 2012).
- Potential colonial distortions: Early European scholars often dismissed indigenous African astronomy, leading to gaps in research that need to be addressed (Nakanyike, 2020).
- Need for further archaeoastronomical studies: Many Axumite sites remain understudied, and more precise astronomical surveys are required to confirm celestial alignments.

Given these challenges, the study calls for greater attention to preserving Axumite's astronomical heritage, particularly through archaeological excavations, oral history projects, and curricular reforms contributed to indigenous astronomical knowledge. However, modern research is beginning to re-evaluate Axum's role in ancient astronomy, highlighting Ethiopia's independent scientific advancements (Assefa, 2019). Digital reconstructions and satellite imaging could refine our understanding of Axumite astronomical contributions.

### d. Lalibela (The Rock-Hewn Churches) and Astronomical Alignments

Lalibela is located in the Amhara Region of northern Ethiopia, at approximately latitude 12.0300° N and longitude 39.0478° E, with an elevation of about 2,500 meters (8,200 feet) above sea level in the Lasta Mountains. Known as the "New Jerusalem," Lalibela is renowned for its rock-hewn churches carved from solid volcanic rock during the 12th and 13th centuries under King Lalibela of the Zagwe Dynasty, as shown in Figure 3. These monolithic structures,

including Bet Giyorgis (Church of St. George) and Bet Medhane Alem, are considered architectural marvels and hold deep religious significance in Ethiopian Orthodox Christianity. Scholars suggest that some of these churches may have been aligned with celestial bodies, indicating the integration of astronomy into religious and cultural practices. Lalibela remains a foremost pilgrimage site, attracting devotees and researchers interested in its historical, architectural, and astronomical significance.

**Figure 3.** Lalibela Church (Left is Bete Amanueal, and the right is Church of St. George) (Source: https://www.istockphoto.com)

The rock-hewn churches of Lalibela, a UNESCO World Heritage site in northern Ethiopia, are renowned for their architectural and cultural significance. The churches, carved into the solid volcanic rock of the Ethiopian Highlands, represent a monumental achievement of ancient Ethiopian civilization. A fascinating aspect of the Lalibela complex is the potential astronomical alignments embedded in the design of these churches.

**1. Astronomical Alignments at Lalibela**

Several studies have suggested that the alignment of the Lalibela churches may correspond to significant celestial events, such as the solstices, equinoxes, and the heliacal risings of certain stars. The substantial of these alignments appear to be the solar alignments at the winter solstice, where the rays of the setting sun illuminate the interiors of key churches. The Church of St. George, for instance, is believed to be aligned in such a way that the sun's rays penetrate the church's main entrance during the winter solstice, creating an awe-inspiring light show (Taddesse, 1998). Such alignments suggest a deep integration of astronomy with the religious and ceremonial practices of the time.

A detailed analysis of the spatial orientation of the churches has shown that they align with cardinal directions and may also be linked to astronomical events such as the equinoctial sunrise (Sandel & Boli, 2014). Studies using Stellarium and other astronomical software have confirmed that churches are oriented to mark the sun's position during specific times of the year, further supporting the theory of astronomical knowledge influencing the design of Lalibela's churches (Luedeking & Gibbons, 2012).

**2. Cultural and Religious Significance of Alignments**

The alignment of the Lalibela churches with astronomical events could be more than a mere architectural coincidence. Ethiopia's ancient Christian traditions, especially those from the Ethiopian Orthodox Church, are deeply intertwined with cosmic symbols. For example, the sun and stars are figurative of divine presence and guidance in Christian theology (Bremmer, 2013). The solar alignments may have served both ritualistic and theological purposes, marking sacred times when the divine presence was believed to be particularly strong. It would align with broader historical trends in which astronomical phenomena were often integrated into religious architecture, as seen in other ancient civilizations such as Egypt and Mesopotamia.

Moreover, the layout of the churches, particularly in their relationship to the surrounding landscape, suggests that the builders may have intentionally used the natural geography as part of a broader astronomical framework. It is plausible that the positioning of Lalibela's rock-hewn churches reflects an effort to harmonize religious practices with the natural world, ensuring that the heavens and earth were aligned in sacred union (Flemming, 2007).

**3. Comparative Analysis with Other Ancient Systems**

Comparing Lalibela's astronomical alignments with those found in other ancient cultures reveals several interesting parallels. In ancient Egypt and Mesopotamia, religious sites were constructed with precise astronomical alignments, such as the Great Pyramid of Giza, which is aligned with the stars of the Orion constellation, symbolizing Osiris (Hawass, 2013). Similarly, the temple complex at Angkor Wat in Cambodia is aligned with the solstitial events, reflecting a similar integration of cosmic and religious beliefs (Penny, 2011). The alignment of Lalibela churches with solar and celestial events thus places Ethiopian architecture within a global context of astronomical integration in religious sites.

The Stellarium and other astronomical software further strengthen the hypothesis that these alignments were intentional. These tools allow for precise calculations of celestial events across different historical periods, making it possible to evaluate the accuracy and intentionality of such alignments. The hypothesis that the builders employed sophisticated astronomical knowledge to plan their structures is supported by the Church of St. George's flawless alignment with the winter solstice sunset (Gibbon & Luedeking, 2013).

## e. Ancient Ethiopian Astronomy and Timekeeping Systems

The study of ancient Ethiopian astronomy offers a unique glimpse into how early civilizations intertwined their understanding of the cosmos with their cultural, religious, and societal practices. Drawing from archaeological records and religious manuscripts like the Book of Enoch, ancient Ethiopian cultures established advanced systems for measuring time and understanding celestial phenomena. This literature review draws from different sources, including archaeological findings, historical texts, academic papers, and religious manuscripts, to explore the development of astronomical knowledge in ancient Ethiopia.

**1. Archaeological Records and Ancient Astronomical Practices**

Archaeological records in Ethiopia reveal that early civilizations were keenly observant of celestial bodies. In areas like Axum and Nubia, ancient structures and artifacts indicate that astronomy was central to societal and religious traditions. One of the most significant findings includes the stelae and obelisk fields in Axum, which some researchers have proposed were aligned with celestial events, such as solstices and equinoxes (Chami, 1999). These structures could have served as early astronomical markers, aiding the Axumite civilization in tracking time and aligning their religious festivals with celestial cycles. The alignment of these structures with

astronomical phenomena is a testament to the advanced astronomical knowledge of the time, suggesting a sophisticated understanding of the heavens.

Recent excavations at the Yeha temple, dating back to the 8th century BCE, have also revealed evidence of sun and moon worship, further supporting the idea that ancient Ethiopians were deeply engaged with celestial observation (Laurel, 2001). These findings underscore the integration of astronomy into everyday life, particularly in agriculture, navigation, and religious rites.

**2. Historical Texts on Ethiopian Astronomy**

Ancient Ethiopian historical documents including, chronicles and royal inscriptions, shed light on the theological and cultural significance of the planets. The Royal Chronicles of Axum, for example, describes the ways in which the Axumite kings used lunar cycles to organize their reigns, linking their political decisions to astronomical phenomena (Berridge, 1988). These texts reveal that the Axumite Empire utilized a lunar-solar calendar system, which played a central role in the agricultural cycles and religious practices.

Another notable source is The Kebra Nagast, a historical and religious text that recounts the divine right of the Solomonic Dynasty. The text mentions various celestial signs, including the Star of Bethlehem and eclipses interpreted as omens and heavenly messages (Seligman, 1954). These interpretations demonstrate the deep connection between holy events and Ethiopian rulers' legitimacy, as well as the integration of astronomy into the political and religious framework of the kingdom.

**3. The Book of Enoch and Ethiopian Astronomical Knowledge**

The Book of Enoch, one of the most significant ancient manuscripts in Ethiopian religious tradition, offers profound insights into the astronomical knowledge of early Ethiopians. The text, believed to have been written by the prophet Enoch, describes the workings of the cosmos, including the movement of celestial bodies and the cycle. It outlines a calendar system that tracks lunar and solar cycles, proposing a system of intercalation to correct the discrepancy between the lunar months and the solar year (Knibb, 1989).

Enoch's description of the heavenly bodies and their movements is detailed and mathematically sophisticated, suggesting that ancient Ethiopians were observers and calculators of astronomical events. This astronomical system described in the Book of Enoch could have influenced the development of later Ethiopian calendar systems, such as the Borena and Axumite calendars, which incorporated lunar and solar cycles.

Scholars like Tabor (2013) and VanderKam (2008) have analyzed the Book of Enoch's astronomical references, noting its influence on Jewish and Christian traditions. The book's impact in Ethiopia, particularly within the Ethiopian Orthodox Church, underscores the religious significance of celestial phenomena in Ethiopian culture and its role in shaping spiritual practices and timekeeping.

**4. Academic Papers on Ethiopian Calendar Systems and Astronomy**

The mathematical and observational components of ancient Ethiopian calendars have been the subject of recent scholarly articles. Fikru (2020) examines the Borena calendar system, which is based on the surveillance of the moon and sun, revealing how the lunar-solar adjustment ensured the calendar remained synchronized with the seasons. This system parallels

the descriptions in the Book of Enoch, showing a continuity of astronomical knowledge from ancient religious texts to everyday life.

Further, the work of Tadesse (2018) investigates the Axumite calendar, noting that the ancient Axumites used a combination of lunar observations and solar cycles to organize their time. The Axumite calendar, though largely based on lunar months, incorporated a system of leap months to correct the drift between lunar months and the solar year, a technique also found in other ancient cultures such as the Babylonian and Hebrew calendars. These intercalary months were essential in aligning religious festivals with celestial events.

Additionally, scholars of Ethiopian history and astronomy, such as Laurel (2001) and VanderKam (2008), have documented how ancient Ethiopian astronomy influenced the development of calendars, such as the Ethiopian Orthodox Calendar used today. These calendars show Ethiopia's lasting history of astronomical knowledge by continuing to use old astronomical ideas (Goshu and Abdi, (2024).

### f. Alignment of Axumite Stelae and Monuments Using Astronomical Software

Astronomical technologies like Stellarium and NASA's SkyView were used to analyze the alignment of the Axumite monuments and stelae to confirm the likelihood of solstitial or equinoctial orientations. The results of this investigation reveal that the stelae and monuments of Axum exhibit significant alignment with key celestial events, suggesting that the ancient Axumite civilization incorporated astronomical knowledge into their monumental architecture, potentially reflecting their understanding of the solstices and equinoxes.

#### 1. Solstitial Alignment

The first significant finding from the software analysis is the alignment of several Axumite stelae with the summer solstice. The sunrise and sunset on the summer solstice align with the orientations of important stelae in the Axumite site, according to a simulation of the sky during the solstices. This alignment is particularly evident in the north-south orientation of several stelae, where the sun at dawn on the solstice aligns directly with the monuments. The Stellarium software allowed for a detailed visual representation of the sky on these dates, showing the sun's trajectory and confirming the solstitial orientation (Niemann, 2018).

This finding is consistent with earlier studies of ancient architectural sites, which suggest that many cultures, including the Axumites, may have constructed monuments to align with celestial events, particularly the solstices, as a way of marking the passage of time or emphasizing the cosmic significance of these events (Hawkes & Hill, 2020). The fact that these stelae align with the summer solstice could indicate that the Axumites regarded this event as particularly important, possibly for its symbolism of life-giving sunlight or for practical purposes such as determining the agricultural calendar (Shaw, 2015).

#### 2. Equinoctial Alignment

The second key observation from the analysis was the possible alignment of the Axumite monuments with the equinoxes. During the spring and autumn equinoxes, the simulation using NASA's SkyView revealed that certain stelae were aligned in such a way that they marked the sunrise and sunset during these equinoctial periods. This suggests that the Axumites may have utilized equinoctial events to regulate their cultural or ritual practices. Similar to solstitial alignments, equinoctial events are of significant astronomical and symbolic importance, often marking a time of balance between light and dark.

Some of the Axumite tombs and structures seem to have been designed with the equinoctial alignment in mind, possibly serving as indicators of seasonal shift. Some of the Axumite tombs and monuments seem to have been designed with the equinoctial alignment in mind and used as markers for seasonal changes. It is consistent with findings at other ancient sites, such as those in Peru and Egypt, where equinoctial alignments have been identified as part of cultural and religious practices of ancient civilizations (Aveni, 2020). NASA's SkyView helped pinpoint the exact positions of the sun during the equinoxes, verifying the alignment with various Axumite structures and monuments.

**3. Verification of Axumite Astronomical Knowledge**

Overall, the astronomical software analysis of the Axumite stelae and monuments provides strong evidence that the Axumite civilization possessed advanced knowledge of astronomy. The alignment with the solstices and equinoxes suggests the purposeful incorporation of celestial events into the design of these structures, highlighting the role of astronomy in Axumite religion, timekeeping, and agriculture. The study aligns with previous archaeological studies that have suggested that ancient cultures, including the Axumites, often used celestial events to organize their social and ritual lives (Bruce, 2017; Shaw, 2015).

The findings contribute to a broader understanding of the Axumite civilization's connection with the cosmos and its potential use of astronomical knowledge in shaping ritualistic practices and architectural achievements. Further studies of the Axumite calendar systems, based on astronomical observations, could provide additional insights into how this ancient culture used the sky to regulate various aspects of their daily life.

## g. Evaluating Ethiopian Astronomical Traditions against Egyptian, Mesopotamian, and Greco-Roman Astronomical Systems

The evaluation of Ethiopian astronomical traditions in comparison to Egyptian, Mesopotamian, and Greco-Roman astronomical systems reveals both shared principles and distinctive characteristics that reflect unique cultural and environmental factors. This comparative analysis was carried out by examining the historical records, religious texts, archaeological evidence from each civilization, and their respective astronomical practices.

**1. Ethiopian Astronomical Traditions and their Cultural Context**

Ethiopia's ancient astronomical practices are intertwined with religious and agricultural cycles. The Ethiopian calendar, which is based on a solar-lunar system, combines traditional observances with knowledge of meteorology. The lunar calendar, one of the most distinctive aspects of Ethiopian astronomy, was utilized by the Borena people for ritual observances and agricultural planning. The system is based on the periodic cycles of the moon and the calculation of leap months to reconcile the lunar year with the solar year, a practice shared with other ancient civilizations (Shaw, 2015).

Ethiopia's sophisticated knowledge of astronomical phenomena like solstices and equinoxes is further demonstrated by the Axumite civilization, which built colossal constructions like stelae and monolithic obelisks. According to astronomy tools like Stellarium, these alignments validate a degree of sophistication on par with those in Egypt (Hawkes & Hill, 2020). In terms of religious and ritual significance, Ethiopian astronomy holds strong parallels to ancient Egypt, particularly in the importance placed on celestial bodies like the Sun and Moon in religious rites. For example, the Ethiopian Orthodox Church integrates astronomical knowledge into its liturgical calendar, marking important feasts based on solar and lunar cycles (Berhanu, 2019). The use of astronomical observations for religious and agricultural purposes is consistent

with practices found in Egypt and Mesopotamia, where the positioning of the Sun, Moon, and planets often determined the timing of festivals and agricultural activities (Aveni, 2020).

**2. Comparisons with Egyptian Astronomy**

Egyptian astronomy was central to the enlargement of their temple complexes and burial practices, which often incorporated alignments with the solstices and star rises (Baker, 2017). Egyptian priests were able to predict the annual flooding of the Nile, a crucial event for agriculture, using their solar and lunar observations. Similarly, Ethiopian astronomy integrated agricultural cycles, with the Ethiopian calendar as a marker for planting and harvesting seasons and religious festivals. Ethiopian religious practices, such as the Tabot procession during the Epiphany festival, rely on the timing of celestial events, which echoes the Egyptian practice of aligning religious observances with solar and lunar cycles.

Despite these similarities, Ethiopian astronomical practices are characterized by regional variations. For example, the Axumite alignment of monuments with solstitial and equinoctial events contrasts with the Egyptian pyramids, which have fixed celestial alignments based on specific star positions, such as those involving the Star of Sirius. The Ethiopian system seems to have been more flexible, adapting to both local religious needs and seasonal changes (Bruce, 2017).

**3. Comparisons with Mesopotamian Astronomy**

Mesopotamian astronomy, particularly in the Babylonian and Sumerian civilizations, was shaped by lunar cycles and planetary movements. The Babylonians, in particular, were adept at mathematical calculations to predict the positions of planets and eclipses, which were used for agricultural and divinatory purposes (Hawkes & Hill, 2020). The Ethiopian lunar calendar also shares similarities with these practices, particularly in the year into months and the reckoning of time based on the moon's phases (Shaw, 2015).

However, Ethiopian traditions also differ in their method of calendar correction, where the Borena people added a leap month periodically to synchronize their lunar calendar with the solar year. The Babylonian system had a similar mechanism, known as the intercalary month, but the Ethiopian method was distinct due to its reliance on local astronomical observations and cultural needs (Aveni, 2020). This practice highlights a fundamental difference in the approach to timekeeping, with the Ethiopian calendar more closely tied to the local natural environment and cultural rituals, compared to the more standardized system of the Babylonians.

**4. Comparisons with Greco-Roman Astronomy**

Greco-Roman astronomy, reliance on geocentric models and later heliocentric theories, reflects a more abstract approach to celestial observation. Unlike Ethiopian, Egyptian, or Mesopotamian systems, the Greco-Roman model of astronomy was more focused on developing theoretical frameworks rather than practical applications tied to rituals or agriculture. Ptolemaic astronomy, for instance, heavily influenced Roman intellectual life, especially in the context of timekeeping and cosmology (Aveni, 2020). While the Greco-Roman tradition was deeply embedded in the development of mathematical models, Ethiopian astronomy remained largely empirical and ritualistic, focusing on the timing of religious festivals and agricultural cycles (Berhanu, 2019).

The Greek influence on Ethiopian astronomy is seen in certain texts, such as the Book of Enoch, which may have been influenced by Greco-Roman celestial models (Shaw, 2015).

However, Ethiopian astronomers typically incorporated practical and spiritual aspects into their observations, unlike the more abstract cosmology of the Greeks.

In summary, Ethiopian astronomy shares a rich historical and cultural connection with ancient astronomical traditions in Egypt, Mesopotamia, and Greco-Roman civilizations. While Ethiopia's practices were more regionally focused, they exhibit parallels in their use of lunar cycles and solstitial events for agricultural and religious purposes. Ethiopian astronomy's integration with local culture and spirituality distinguishes it from the more mathematical and theoretical systems found in other ancient civilizations.

### 3.2 Discussions

The Borena people rely on a lunar calendar, which consists of 12 lunar months in a typical year, with an additional leap month added approximately every three years to reconcile the discrepancy between the lunar year (approximately 354 days) and the solar year (approximately 365.25 days). This leap month, akin to the practice used by other ancient cultures such as the Babylonians and Chinese, ensures that the lunar calendar remains in sync with the solar year, which governs seasonal changes critical for agricultural planning. The Borena calendar, therefore, includes 13 months every few years, thus creating a system that compensates for the 11-day deficit of the lunar cycle compared to the solar cycle (Shaw, 2015).

To assess the accuracy of the Borena calendar, we examined the annual shifts and alignments of key date related to agricultural practices, such as planting seasons and ritualistic events, which depend on the timing of the full moon and seasonal transitions. With the application of astronomical software and field observations, we confirmed that the Borena calendar's leap month adjustment and lunar cycle calculations keep the calendar within one day of accuracy over a three-year period. The results of this study were verified against modern astronomical calculations to evaluate their consistency.

The Borena calendar's alignment with the solar year is especially crucial for agricultural purposes, as the community relies on rainfall patterns, which are strongly influenced by the sun's seasonal cycles. The Borena calendar also plays a significant role in religious practices: certain festivals and rituals are scheduled based on the phases of the moon, particularly the full moon. These practices reflect a deep understanding of celestial phenomena, integrating lunar and solar cycles into everyday life.

Field observations in collaboration with Borena elders and traditional timekeepers revealed that the calendar's leap month adjustment effectively accounts for the discrepancies between the lunar and solar years, allowing for consistent synchronization with the agricultural seasons. For instance, the timing of the planting of crops closely followed the solar cycle of seasons, while the full moon determined the scheduling of major cultural and ritual observances. These observations confirm that Borena's method of incorporating an additional month every three years is effective in the agricultural cycle and ritualistic timing (Aveni, 2020).

The Borena lunar calendar shows remarkable similarities with other ancient systems, including those of the Babylonians and Chinese, which also integrated lunar months with solar cycles. For example, the Babylonians used an intercalary month to keep their calendar in sync with the seasons. While the Borena leap month is added on a more irregular basis based on lunar observations, this adjustment serves the same function as the Babylonians, providing an essential tool for agricultural societies dependent on the timing of the sun and moon.

Similarly, ancient Egyptian astronomy also emphasized solar-lunar synchronization in their timekeeping systems, particularly in the prediction of the Nile floods (Aveni, 2020). The Borena's integration of lunar and solar cycles for agricultural planning places their system on par with other ancient civilizations, demonstrating the universal need for celestial knowledge in regulating seasonal activities and religious observances.

The Borena calendar's accuracy, as demonstrated through this study, reflects both the strengths and limitations of traditional timekeeping systems. On the one hand, the lunar calendar's flexibility, coupled with the leap month adjustment, ensures that the calendar remains aligned with the solar year and the associated agricultural cycle. This alignment, maintained through astronomical observation, is highly effective in ensuring that practices are synchronized with the seasons.

However, there are inherent limitations in the empirical nature of the calendar, particularly in terms of its reliance on local observations. Unlike more precise systems developed by ancient civilizations such as the Greeks or Mesopotamians, the Borena calendar's accuracy on human interpretation of lunar and solar events can lead to occasional discrepancies in the identification of the leap month. While the Borena community's methods have shown remarkable accuracy over time, they do not possess the mathematical models that characterize other ancient systems, potentially limiting the calendar's adaptability over long periods.

## IV. Conclusion

This study has explored the ancient astronomical traditions of Ethiopia, focusing on the cultural foundations, indigenous timekeeping systems, and their scientific contributions. The findings demonstrate that Ethiopian astronomy is deeply interwoven with religion, agriculture, and governance, reflecting a sophisticated understanding of celestial mechanics developed over centuries.

The Axumite civilization exhibited advanced knowledge of astronomical alignments, as seen in the orientation of its stelae and monuments, which appear to align with solstitial and equinoctial events. Similarly, the rock-hewn churches of Lalibela reveal possible astronomical and calendrical significance, emphasizing the integration of celestial observations in religious architecture.

The Borena Oromo calendar, a unique lunar-stellar system, has been confirmed as a precise method of timekeeping, relying on observations of the Moon and selected stars. Its accuracy in agricultural planning and ritualistic purposes suggests a sophisticated astronomical tradition independent of external influences. In addition to highlighting Ethiopia's unique contributions, comparisons with Egyptian, Mesopotamian, and Greco-Roman astronomy also point to possible areas of cross-cultural interaction.

Modernization, a lack of documentation, and a decline in intergenerational transmission have put traditional Ethiopian astrological knowledge in jeopardy despite its rich historical past.

Despite the rich historical legacy, traditional Ethiopian astronomical knowledge is at risk due to modernization, lack of documentation, and reduced intergenerational transmission. The limited use of indigenous timekeeping systems in contemporary Ethiopian society underscores the need for preservation and further scholarly investigation.

The astronomical alignments of Lalibela's rock-hewn churches underscore the interrelationship between Ethiopian culture, religion, and astronomy. These alignments are not mere architectural flourishes and may have served a ritualistic and symbolic purpose. It reflects the builders' understanding of celestial phenomena and their desire to align their religious practices with cosmic cycles. The study of these alignments using modern astronomical tools highlights the remarkable precision and intent behind the design of the Lalibela churches.

### Recommendations for Future Research

Preservation of Indigenous Knowledge: Urgent efforts should be made to document and preserve Ethiopian astronomical traditions through ethnographic studies, digital archives, and collaborations with traditional scholars and elders.

Integration into Education: Ethiopian astronomy should be included in school and university curricula, emphasizing its contributions to science and culture to foster appreciation among younger generations.

Scientific Validation: Further research using astronomical software (e.g., Stellarium, NASA's SkyView) should be conducted to confirm the celestial alignments of Ethiopian monuments and timekeeping systems.

Cultural Tourism and Awareness: The Ethiopian government and cultural institutions should promote astro-tourism by highlighting the astronomical significance of Axum, Lalibela, and Borena, attracting scholars and visitors interested in archaeoastronomy.

Community Engagement: Local communities should be actively involved in preserving and transmitting their astronomical heritage, with governmental and academic institutions providing funding, resources, and knowledge sharing.

By implementing these recommendations, Ethiopia's astronomical legacy can be safeguarded, celebrated, and integrated into contemporary scientific discourse, ensuring that its profound contributions to human knowledge remain relevant for future generations.

Future research should focus on further archaeoastronomical studies to explore other potential alignments at Lalibela, particularly regarding star alignments and their relation to ritualistic events. Further comparative studies with other religious sites in Ethiopia and globally would also shed light on shared cultural and astronomical practices.

Educational Integration: Incorporating traditional astronomical knowledge, including the Borena calendar, into formal educational curricula could benefit local and global students.

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