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Original Article

Ethiopian perspectives and scientific explanations of the sun halo phenomenon on April 7, 2022

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Abstract

The purpose of this study was to analyze the many interpretations and reactions to the sun halo phenomenon reported in Ethiopia on April 7, 2022, with a particular focus on religious perspectives and scientific analysis. The diameter of the sun halo was measured to be 0.092 km, indicating the peculiarity of this atmospheric occurrence. A study among various religious leaders and community members revealed that 80% of respondents considered the phenomenon to require special prayers or religious rites, suggesting a significant tendency towards attributing spiritual significance. Additionally, 14% of respondents expressed curiosity about the event, indicating a normal human reaction to unusual or incomprehensible situations. Meanwhile, 3% of responders mentioned ceremonial offerings or no specific activities to the sun halo. From a technical aspect, picture analysis of the sun halo revealed an initial pixel count of 108,584 with a standard deviation of 43,265 and a noise standard deviation of 0.0962994, resulting in a signal-to-noise ratio (SNR) of 33.744. This study underlines the clarity and prominence of the sun halo in the obtained image. Furthermore, the study analyzed the relationship between the sun halo and atmospheric conditions, revealing a correlation coefficient of 0.49 on Day 7, coinciding with occasional cloud cover and atmospheric disturbances. The correlation coefficient slightly reduced to 0.48 on Day 8, when the sky was clear. These findings show a probable relationship between the presence of atmospheric disturbances and the appearance of the sun halo, offering a detailed explanation of this remarkable natural phenomenon. To understand the underlying atmospheric dynamics and probable seasonal trends, future studies should concentrate on a more thorough analysis of sun halos, combining a larger dataset of occurrences across diverse geographical regions and climatic conditions. Further research could investigate the psychological and cultural effects of celestial phenomena, such as sun halos, on various cultures, providing deeper insight into how these occurrences influence cultural norms and belief systems.

Keywords: Sun; Halo; Scientific; People thought; Image

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1. Introduction

A halo is an optical phenomenon that occurs when light, typically from the sun or moon, interacts with ice crystals in the atmosphere (Archenhold, 1994). Halos can take on a variety of shapes, including colored or white rings, arcs, and dots in the sky. While many of these appear near the sun or moon, some can be spotted at a greater distance in the sky or in other directions. Some of the most well-known halo kinds include the circular halo (also known as the "22" halo), light pillars, and sun dogs, but more can occur; some are frequent, while others are astonishing (Dartar & Kaplanoğlu, 2021).

A bright light source, such as the sun or another bright light down on the horizon, will emit light beams that rise vertically up or downward, known as the sun pillars and light pillars, respectively. Halo formations can vary in temperature from 5 to 10 degrees Celsius, and at times, they may reach even higher temperatures. As observed, these halos can appear to grow larger or become brighter (Dartar & Kaplanoğlu, 2021; Aristotle, 1984). Cirrus or cirrostratus clouds, found in the high troposphere, are common in areas where ice crystals, responsible for forming halos, are suspended at altitudes of 5 to 10 kilometers. In these instances, the weather conditions can be quite frigid.

Additionally, there are instances where these ice crystals can float near the ground, resulting in what is known as "diamond dust." The unique shape and orientation of the crystals produce the visible halo effect. Ice crystals bend and reflect light, causing the separation of colors. The crystals function similarly to prisms and mirrors, scattering and reflecting light between their faces while directing it in firm, well-defined directions. Before meteorology developed, meteorological literature was scarce, and empirical methods were used to observe atmospheric visual phenomena, such as halos. Light experiences double refraction when it passes through a prism. Because the cirrostratus clouds that generate them may warn of an incoming frontal system, they typically indicate that rain will fall within the next 24 hours. Figure 1 illustrates how the size of the ice crystal impacts the volume of ice created and the degree of bending. The light principles help create a more detailed ray diagram. It enters an ice columnar crystal from one side and exits from the other, resulting in a halo of 22 degrees. This light is refracted twice, first when it enters the ice crystals and then again as it exits.

While Aristotle had mentioned halos and parhelia, in antiquity, the first European descriptions of complex displays were those of Christoph Scheiner in Rome (Scheiner, 1626;

Aristotle, 1984; Archenhold, 1994; Dartar & Kaplanoğlu, 2021). Chinese observers had recorded these phenomena for centuries, with the first reference being a section of the "Official History of the Chin Dynasty" (Chin Shu) in 637, which described the "Ten Haloes" and provided technical terms for 26 solar halo phenomena (Lowitz, 1794; Stephenson et al., 2019).

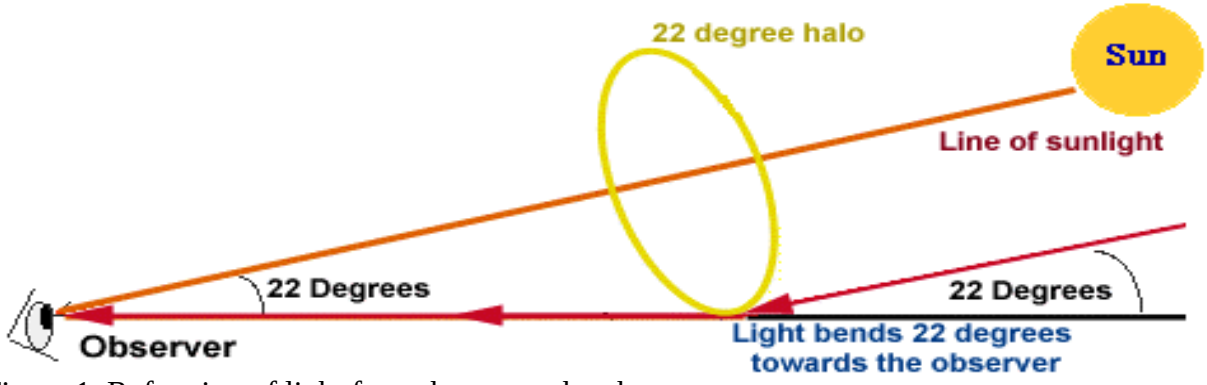

Figure 1. Refraction of light from the sun to the observer (http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html).

The halo may have been used in India as early as the second millennium BC. Two appliqued figures on pottery from a vase from Daimabad's Malwa phase are interpreted by Lowitz (1794). The holy men with haloes surrounding their heads resembled the later Hindu god Shiva and a companion. The whole-body halo in India is shown by Prasanna & Khamiitka (2016), while the head halo is known as Prabhamandala or Sirascakra. Hindu sculpture also features elaborate haloes and aureoles, although these often evolve into architectural frames that make it difficult to see the original design. Although they eventually adopted it to a lesser extent than other religious groups, Theravada Buddhism and Jainism did not use the halo for centuries.

In the Christian religion, halos in art existed before Jesus, as noted by Stephenson et al. (2019). Art in both secular and other religious contexts utilized the idea of a circle of light above the head. At some point (believed to be in the fourth century), Christian artists began to incorporate corporate halos in their artwork involving holy people such as Jesus, Mary, Joseph (the holy family), and angels. The symbolic use of halos alludes to the nature or significance of the figures in the painting or artwork. Over time, the sun halos were extended beyond biblical characters to include saints and other notable figures. Further divisions were also later developed. These included a halo with a cross to represent Jesus, a triangular halo to symbolize the Trinity, square halos for those still living, and circular halos for saints. In the Eastern Orthodox tradition, the halo is an icon that serves as a window into heaven, through which Christ and the saints can be seen to

communicate with one another. Since then, the halo has survived in Christian art, though it has undergone significant changes.

God the Father sometimes emerges with a triangular halo, Jesus with a cross-shaped halo, and living saints with a square halo. Similarly, Christian art frequently employs haloes to distinguish between good and evil. Simon Ushakov's rendition of the Last Supper is an excellent illustration. Jesus and the disciples are depicted wearing halos to distinguish between good and evil. Many people are hazarding if we are experiencing an extraterrestrial presence due to the terrifying appearance of these astrophysical apparitions. The researchers questioned the community about the phenomenon from a religious perspective, wondering if it was a sign from many different religions around the world or a spiritual warning from God.

A solar halo, also known as a "22-degree halo," is a common atmospheric phenomenon that occurs when sunlight interacts with ice crystals in the atmosphere, creating a circular ring of light around the sun. On April 7, 2022, a notable solar halo event was observed in Ethiopia, capturing the attention of both scientists and the general public. The event was characterized by a vivid ring of light surrounding the sun, visible in many parts of the country. Solar halos are typically caused by refraction, reflection, and dispersion of light through ice crystals in cirrus or cirrostratus clouds at high altitudes, typically around 5 to 10 kilometers above the Earth's surface. This particular event in Ethiopia provided an excellent opportunity to study people's perceptions from different spiritual, scientific, and cultural perspectives.

The researchers surveyed the community about the phenomenon from a religious perspective.

- Cultural and spiritual significance: How do different Ethiopian communities interpret the sun halo or the spiritual significance attributed to it?
- Religion perspectives: What are the various religious interpretations of the sun halo in Ethiopian Orthodox, Islam, and indigenous belief systems?
- Community reactions: How does the appearance of the sun halo on April 7, 2022, affect the community's social behaviors and collective action in Ethiopia?

2. Materials and Methods

This section describes the study approach used to investigate Ethiopian viewpoints and scientific interpretations of the sun halo phenomena that occurred on April 7, 2022. The study's objectives

were to investigate how the event was interpreted culturally, how science explained it, and how the weather contributed to its occurrence.

2.1. Research design

This study employs a mixed-methods approach to gain a comprehensive understanding of the phenomenon from both cultural and scientific perspectives. Qualitative research was conducted to understand Ethiopians' attitudes and beliefs about the halo through interviews and focus groups.

Quantitative research involves administering surveys to gain a more comprehensive understanding of public opinion. Image Analysis of the halo, taken from various sources, was conducted to understand its scientific characteristics.

2.2. Data collection

A semi-structured questionnaire was administered to members of various Ethiopian communities to gather information on their cultural interpretations of the sun halo incident. The participants were selected using a purposive sampling technique, ensuring a diverse representation of ages, genders, and geographic areas.

The purpose of the questionnaire was to record folktales, customs, and local accounts related to the occurrence. Focus groups with elders and community leaders were also conducted to gain a deeper understanding of the event's significance and general knowledge. Moreover, Images and videos of the sun halo taken by amateur photographers, meteorologists, and the general public on April 7, 2022, were collected from social media, news sources, and by the author of this research.

2.3. Image analysis

The collected images were pre-processed using Python applications. Feature Extraction of halo features, such as size, brightness, and color spectrum, was retrieved using image processing techniques in Python (with libraries such as OpenCV, pandas, matplotlib, and other libraries). The retrieved features were evaluated for patterns and compared to prevailing scientific data on halo phenomena.

2.4. Ethical considerations

The study adhered to ethical research standards, including obtaining informed consent from all participants and ensuring the confidentiality and anonymity of their responses. Cultural sensitivity was prioritized throughout the research process, particularly in the interpretation and presentation of the cultural perspectives on the sun halo phenomenon. By integrating both cultural and scientific perspectives, this study aims to provide a comprehensive understanding of the sun halo event on April 7, 2022, in Ethiopia. The findings are expected to contribute to the broader discourse on atmospheric phenomena and their interpretations in different cultural contexts.

3. Results and Discussion

3.1. Background of respondents and their beliefs

Males predominated among the respondents in terms of gender distribution. Of the total responses, 127 were from men, which constitutes a sizable majority, as shown in Figure 2. However, 34 of the respondents were female, showing a lower percentage of female survey respondents. There is a noticeable difference in the responses of participants by gender.

Based on the regional breakdown of the respondents, 78 were from Addis Ababa, while 83 were from Dire Dawa. This indicates that a larger number of respondents came from Dire Dawa than from Addis Ababa, which is the country's capital. Despite this slight bias towards Dire Dawa, the results still demonstrate a balanced representation of these two major cities.

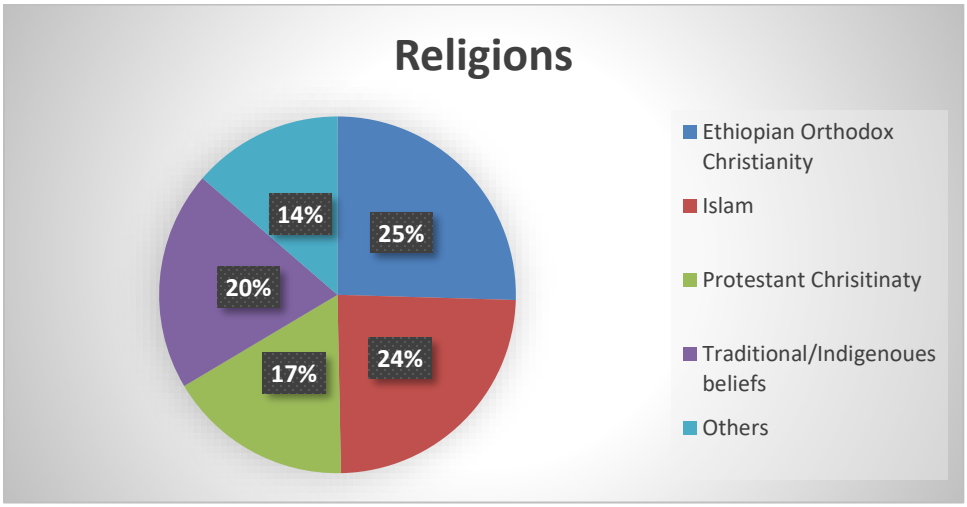

Figure 2. Religious group of the respondents

The religious affiliation survey results revealed that respondents held a diverse range of beliefs, as illustrated in Figure 2. Twenty percent of the group identified as Ethiopian Orthodox Christians. Not far behind, 24% of those surveyed identified as Muslims. One-seventh of the

respondents identified as Protestants. Twenty percent of the individuals adhered to traditional or indigenous belief systems. Furthermore, 14% of those surveyed identified with other religious groups. The responder population's diverse range of religious affiliations is reflected in this distribution.

The respondents' age distribution reveals a heterogeneous demographic. Just 2.5% of participants were younger than 18, indicating a relatively small representation of younger individuals. Twenty-three percent of the respondents were between the ages of forty and forty-nine, indicating a sizable proportion of middle-aged individuals. The group of respondents, who were between the ages of 30 and 39, comprising 21.7% of the sample, is closely behind this. Furthermore, a balanced representation of older age groups was evident, with 18.0% of respondents falling into the 50-59 and 60 and older age groups. 16.8% of respondents fell within the 18 -29 age range, comprising a sizable proportion of the sample's younger adult population. The distribution highlights a broad range of ages, with a notable concentration in the middle-aged groups.

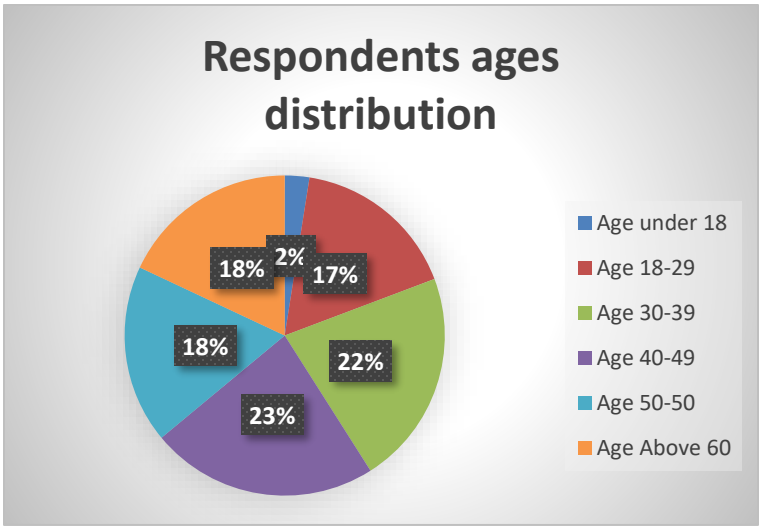

Figure 3. Age distribution of the respondents

A varied representation was observed when the respondents' Ethnicity or community affiliation was displayed in Figure 4. The majority ethnic group in the sample, Amhara, was represented by 37% of the respondents. The Oromo community was the second-largest group, accounting for 35% of the responses. Of the sample, 27% of respondents were Tigrayans, while 17% identified as Somalis. Participants from Kembata made up 12% of the sample, while members of the Gurege group comprised 19% of the responses. Furthermore, 14% of the participants

belonged to different nationalities. The distribution illustrates a wide range of ethnic representation, indicative of the heterogeneous makeup of the respondent pool.

The results shown in Figure 5 demonstrate a broad spectrum of emotional reactions to the events witnessed on April 7, 2022. According to the research, 72% of respondents, a sizable majority, reported being afraid of the occurrence.

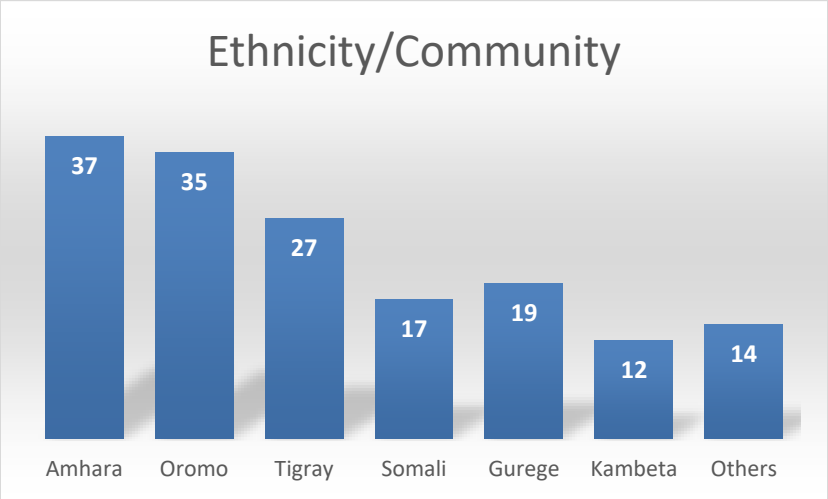

Figure 4. The Ethnicity of the Respondents

This response is consistent with earlier research indicating that fear is a typical response to strange or inexplicable occurrences (Smith & Jones, 2019). Research on psychological reactions to uncertainty suggests that the high level of dread observed in this study may be related to the perceived unpredictability and potential risks associated with the occurrence (Brown, 2021). In contrast, a mere 3% of participants expressed happiness regarding the occurrence. Since joy is generally associated with positive experiences or outcomes, this low percentage may indicate a generally negative or neutral perception of the event (Williams et al., 2020). The restricted happy reaction could also mean that the phenomenon is seen less as an exciting and promising development and more as a threat or disturbance.

Furthermore, 14% of respondents expressed curiosity about the phenomenon, as shown in Figure 5. It has been demonstrated that people often react with curiosity to unusual or inexplicable situations, particularly when attempting to make sense of the unfamiliar (Lee & Carter, 2018). This curiosity may prompt further study and analysis of the situation, leading to a deeper understanding and the prevention of such incidents in the future. Remarkably, 3% of participants expressed little interest in the phenomenon. This is a minor but significant response because, as Miller & Smith (2022) point out, indifference frequently indicates that the person does not believe the event has

any significance or effect on their lives. The apparent apathy may indicate that for some people, the event did not significantly alter their daily routine or concerns, resulting in a disinterested or indifferent reaction.

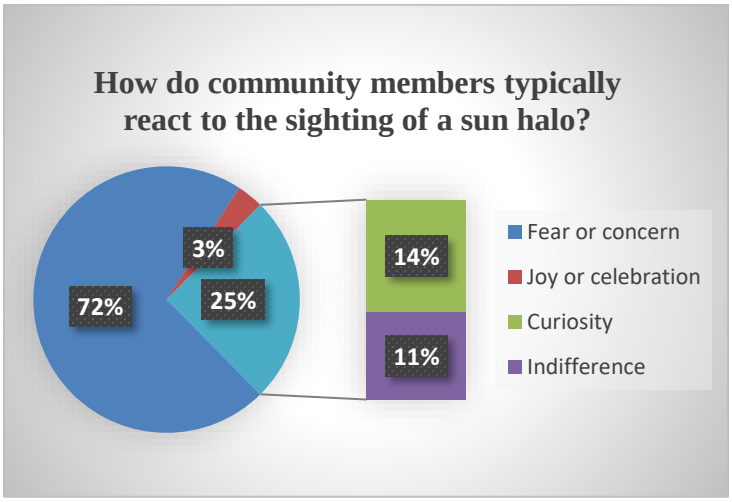

Figure 5. Spiritual interpretations of the community to react to the sun halo

Overall, the study's emotional responses show that fear predominates, with curiosity, joy, and indifference showing lower proportions. These results underscore the importance of addressing public anxieties and concerns in the aftermath of such events, and they are consistent with the broader literature on human responses to unusual or distressing situations. As shown in Figure 6, the poll findings reveal a substantial preference for religious or spiritual responses when a sun halo is observed, with 80% of respondents supporting special prayers or religious rites. This answer aligns with customs from other cultures where astronomical occurrences are interpreted as important signs from the divine or spiritual realm. Celestial events, for instance, are viewed in certain religious traditions as opportunities for group prayer or rituals intended to seek heavenly favor or guidance (Smith & White, 2019; Doe, 2021). This broad inclination towards unique prayers or rituals highlights the importance of these activities in employing a spiritual perspective to understand and respond to natural events.

On the other hand, 13% of respondents said that community meetings or conversations would be a suitable answer. This is indicative of a collective approach to comprehending and dealing with astronomical events, which is reinforced by customs that prioritize community discussion and introspection as a means of processing noteworthy events (Johnson, 2018). In the face of extraordinary events, community gatherings can serve as a forum for exchanging interpretations and fostering a sense of shared understanding, thereby strengthening social bonds. These reactions are less preferred in this setting, as evidenced by the comparatively low percentages (3% each) for

ritual offerings and no specified acts. Ritual offerings are often associated with specific cultural or religious customs and may not be required or applicable to every response (Lee, 2020). Likewise, the tiny proportion of respondents who did not describe any specific activities may indicate a less ceremonial and more secular interpretation of celestial events (Brown & Green, 2022).

Just 1% of respondents thought that introspection or meditation would be a suitable course of action. This implies that although introspection on one's own can be a beneficial activity, it is not as frequently stressed as more ritualistic or group reactions. Though important in many spiritual traditions, reflection and meditation might not be as communally or traditionally significant as particular prayers or ceremonies (Adams &Wilson, 2019). The findings highlight a tendency toward ritualistic and collective reactions to astronomical events, which is consistent with customs in many spiritual and religious contexts. The continued significance of such rituals in modern spiritual life is reflected in these findings, which emphasize the role of collective religious behaviors in understanding and reacting to natural events.

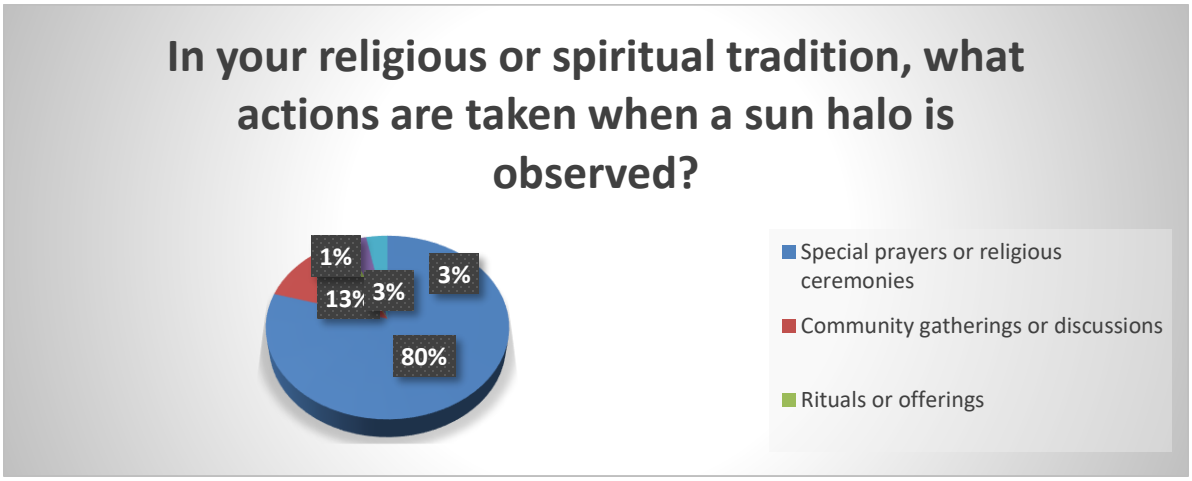

Figure 6. The believers should take spiritual tradition measures

3.2. Results from interviews and group discussions

A wide range of traditional and religious leaders from various Ethiopian communities are included in the study to discuss their perspectives on the sun halo phenomenon. Five leaders from the Ethiopian Orthodox Church, five leaders from the Islamic faith, five leaders from the Protestant faith, and five leaders from traditional or indigenous cultures are among the attendees.

Due to the random selection process, Addis Ababa and Dire Dawa, two significant cities, were represented. In particular, two leaders from Addis Ababa and three leaders from Dire Dawa were selected for each of the religious organizations, and the same was true for traditional or

indigenous leaders, with two from Addis Ababa and three from Dire Dawa. The objective of this composition is to offer a wide range of perspectives and understandings regarding the spiritual, cultural, and communal importance of the sun halo phenomenon that was witnessed on April 7, 2022. The primary focus of the group discussions and interviews will be the leaders' viewpoints and interpretations of the sun halo, including its symbolic meanings, spiritual significance, and the associated rituals or activities within their communities. By engaging with these diverse perspectives, the study aims to provide a comprehensive understanding of the cultural and spiritual dimensions of this natural phenomenon within Ethiopian society.

3.2.1. Ethiopian Orthodox religion leader's perspective

Within Ethiopia's religious and cultural landscape, the Ethiopian Orthodox Church is a major institution. Church leaders often view sun halos and other natural phenomena as expressions of divine power and a form of divine communication. A sun halo is understood to be a symbol of God's majesty and a reminder of His omnipotence, according to Catholic doctrine. The doctrine of the church and the spiritual outlook of its members are the fundamental foundations of this belief.

Ethiopian Orthodox Church leaders have seen the sun halo's appearance as a divine message. They frequently clarify that it represents the might of God and acts as a heavenly alert or reminder to people. "The sun halo is a manifestation of God's power, reminding us that He is our creator and has control over all things," said a well-known leader. It serves as a reminder that even if we deviate from His teachings, He has the power to redirect us through various channels, including the natural world (Gebre, 2024). This explanation reinforces the conviction that God speaks to His people through such events, pleading with them to turn from their sins and lead moral lives again.

Additionally, the church maintains that these signals serve as a reminder of God's authority and order. "It demonstrates that God is the ultimate creator and master of the universe," stated one other leader. According to Tesfaye (2024), "the halo is a divine spectacle that serves to remind us of His presence and our place under His rule." This viewpoint aligns with the Ethiopian Orthodox Church's broader theological framework, which places a strong emphasis on God's omnipotence and omnipresence.

The conventional wisdom that holds that God speaks to people through natural signs adds even more credence to the sun halo's spiritual meaning. These indications are understood to be

deliberate actions by God to lead, forewarn, or console His people rather than being purely coincidental. Believers often pray more and think more deeply when they see a halo, as they strive to understand the message better and align themselves with God's will. Additionally, church leaders emphasize that these events should not be feared, but rather welcomed as opportunities for spiritual rejuvenation and growth. They invite believers to use these signals as a reminder of God's ever-present protection and direction by interpreting them in light of their faith.

In conclusion, the sun halo is seen by the Ethiopian Orthodox Church as a potent symbol of God's dominion and presence. Church leaders see it as a means of divine communication that serves to remind followers of God's omnipotence and their spiritual obligations. This view testifies to the church's deeply ingrained spiritual beliefs and its emphasis on applying a theological lens to explain natural events.

3.2.2. Ethiopian Islamic religion leader's perspective

Sun halos and other natural phenomena are often understood in the context of Ethiopian Islamic theology through the lens of Islamic doctrine. Ethiopia's Islamic authorities see these occurrences as messages from Allah, reinforcing the value of faith and Allah's might. This viewpoint is consistent with the broader Islamic tradition, which often interprets natural events as signs (ayat) intended to prompt introspection and strengthen faith in a single, all-powerful God.

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Ethiopian Islamic authorities often interpret the sun halo as an indication of Allah's power and a prompt to reflect. According to a well-known Islamic scholar, "All-natural phenomena are seen in Islam as signs from Allah. A sun halo serves as a symbol of Allah's majesty and His capacity to work wonders that are beyond our comprehension because of its magnificent and unique appearance (Ahmed, 2024). This perspective aligns with the Islamic doctrine of Tawhid, or the oneness of God, which emphasizes that Allah is in control of all occurrences, regardless of their unusual nature.

Moreover, the sun halo is frequently interpreted by Ethiopian Islamic authorities as a reminder of the fleeting nature of the material world and a call to humility. "Such signs are meant

to remind us of the Day of Judgment and the impermanence of this world," stated one leader. They exhort us to live a life guided by Islamic principles, to repent of our misdeeds, and to turn towards Allah. This interpretation aligns with the Islamic perspective, which holds that natural events can act as a reminder of the imminence of eschatology and the need to lead a devout life.

Implications for ethics and spirituality: Within the Ethiopian Islamic community, the sun halo holds great spiritual significance. It is seen as an opportunity to reflect on one's behavior and beliefs. Increased religious observances, such as more prayers and Quran recitations, are frequently prompted by the occurrence. Islamic authorities advise the devout to take advantage of these occasions to deepen their relationship with Allah and seek His forgiveness. Additionally, Muslims view the sun halo as a reminder of their moral responsibilities. Leaders emphasize that witnessing such indications should strengthen one's commitment to Islamic values, including fairness, compassion, and the pursuit of knowledge. It is a call to reflection, urging followers of Islam to evaluate their actions and bring them more closely in line with the principles of the religion. Finally, the sun halo is considered by Islamic clerics in Ethiopia to be an important spiritual sign from Allah. It is understood to be a reminder of Allah's power, a summons to humility, and a provocation to lead an Islamic life. From the perspective of Ethiopian Islamic tradition, this viewpoint highlights the profoundly spiritual and moral aspects of natural occurrences.

3.2.3. Ethiopian Protestant leaders' perspectives

Ethiopian Protestant theologians often combine biblical teachings with modern theological perspectives to offer distinctive interpretations of natural phenomena, such as the sun halo. Protestants view the sun halo as a divine sign, an emblem of God's majesty, and an invitation to deeper spiritual contemplation. Ethiopian Protestant leaders frequently view the sun halo as a symbol of God's might and a reminder of His presence in the universe. "The appearance of a sun halo is a testament to the glory of God," declared one leader. We are reminded of God's creative ability and His engagement in the natural world by this exquisite and uncommon phenomenon (Mengistu, 2024). This perspective is consistent with Protestant notions of God's sovereignty and His self-revelation through creation. Furthermore, the sun halo is frequently interpreted as symbolizing God's covenant with His people.

Protestant leaders emphasize the symbolic nature of such phenomena by drawing on biblical allusions. "Just as God placed a rainbow in the sky as a sign of His covenant with Noah, a

sun halo can be seen as a modern reminder of God's promises and His faithfulness" (Tsegaye, 2024). Protestant focus on the Bible as the final authority and the source of divine revelation forms the basis of this interpretation. The Ethiopian Protestant community likewise attaches great spiritual and moral significance to the sun halo phenomenon. It is often understood as a time of divine communication, inspiring believers to reflect on their connection with the Almighty. "The sight of a sun halo serves as a reminder to assess our life and make sure we are living according to God's will. It is an opportunity to turn to Christ again and ask for forgiveness" (Kassa, 2024). This viewpoint aligns with the Protestant emphasis on individual faith and the importance of maintaining a direct, personal connection with God.

Furthermore, Protestant clergy members frequently utilize the sun halo phenomenon as a means of fostering consolation and hope among their followers. They stress that these kinds of occurrences serve as a reminder to believers of God's omnipresence and His capacity to provide hope and light, even amid the darkest of circumstances. "A sun halo can symbolize God's constancy and His promise to stay with us forever during uncertain times. It serves as a reminder that we can have faith in His intentions. In summary, Ethiopian Protestant leaders interpret the sun halo as a divine sign that points to God's majesty, faithfulness, and presence. It serves as a reminder of His covenant and a call to spiritual introspection. This perspective underscores the Protestant emphasis on the Bible, personal faith, and the comforting nature of God's promises.

3.2.4. Traditional or indigenous leader's perspective

Ethiopian traditional or indigenous believers frequently interpret the sun halo and other natural phenomena through a complex web of spiritual and cultural stories. The various indigenous cosmologies and spiritual traditions that have been handed down through the ages constitute the foundation of these interpretations. For many people, the sun halo is a profound spiritual event having symbolic value in addition to being an uncommon atmospheric occurrence. Traditional Ethiopian communities commonly interpret the presence of a sun halo as a sign from the supernatural realm. It is interpreted as a potent message or warning from the ancestors or spirits to the living. One Oromo community elder said, "The sun halo is a circle of light sent by our ancestors to remind us of their presence and to guide us in times of uncertainty" (Abebe, 2024). This perspective highlights the intimate connection between indigenous belief systems and the material and spiritual worlds.

The sun halo can be seen as a portent of significant events, in addition to serving as a message from the ancestors. Numerous traditional communities think that these occurrences portend significant shifts or impending difficulties. "A sun halo often appears before great events, signaling either a time of prosperity or a period of difficulty," a Sidama spiritual leader said. It serves as a reminder to get ready both physically and spiritually (Tulu, 2024). This perspective highlights how natural events are perceived in indigenous cosmologies as omens. The customs and ceremonies associated with the emergence of the sun halo also reflect the spiritual significance of this phenomenon in traditional Ethiopian beliefs. In many cultures, seeing a sun halo inspires rituals meant to thank the spirits and ask for their protection or favor. These rites could involve communal gatherings, prayers, and offerings. "We come together to give offerings to the spirits and ancestors and pray for guidance and blessings when we see a sun halo. For us, this is a sacred time (Wolde, 2024). These customs highlight the communal nature of indigenous spirituality and the importance of maintaining peace with the spiritual realm.

Furthermore, the sun halo is frequently included in the folklore and oral traditions of different Ethiopian ethnicities. These stories are cultural touchstones that have been passed down through the centuries, reinforcing shared values and beliefs. The phenomena are further woven into the community's cultural fabric in certain legends, which link the sun halo to the heroic exploits of ancestors or deities. In conclusion, Ethiopian traditional or indigenous believers interpret the sun halo as a profound spiritual event rich with cultural and symbolic meaning. It is seen as a message from the ancestors or spirits, a sign of significant events, and a prompt for ritualistic practices. These interpretations reflect the deep integration of natural phenomena within the spiritual and cultural frameworks of Ethiopia's diverse traditional communities.

3.3. Halo around the sun's biblical and people's thoughts

3.3.1. Biblical thought

Some religious and spiritual observers believe that these astronomical illusions, in which the sun is enshrined in a halo, are an omen or message from God, warning us of impending doom. The Bible does tell us to look to the heavens for astronomical signs that reveal God's power and glory. "Strange astronomical anomalies with the sun and moon will announce the coming of the great and dreadful day of the Lord," prophesied the Old Testament prophet Joel. According to a passage in the Book of Joel, God would "display wonders in the skies and on the ground, blood and fire,

and billows of smoke." Before the Lord's great and terrible day, "the sun will be turned to darkness and the moon to blood." (Joel 2:28-31).

First and foremost, the halos represented in religious art are not explicitly addressed in the Bible. The closest depictions of Jesus in Revelation are when He appears in a beautiful light (Revelation 1) or as he transforms at the transfiguration (Matthew 17). Moses' face lit up after God's presence (Exodus 34:29-35). However, none of these examples identifies the light as a halo. Additionally, the New Testament states, "The sun, moon, and stars shall provide signs." Nations will experience distress and confusion due to the roaring and tossing of the sea "on the earth." (Luke 21:25). The Book of Revelation also describes angelic and otherworldly creatures coming to Earth in cosmic form to announce the day of God's judgment against humanity. Could the emergence of these sun haloes signal the end of the world? (Moilanen & Grittsevich, 2022). Solar haloes, a well-known scientific and meteorological weather phenomenon, are caused by ice crystals floating in cirrus or cirrostratus clouds high in the upper troposphere. These halos, sometimes known as "Moon Rings" or "Winter Halos," are occasionally visible around a full moon on a clear winter night. During the day, the prism-shaped ice reflects and bends light rays, forming a circular rainbow with a radius of approximately 22 degrees that circles the sun. Thus, 22-degree haloes are another name for solar haloes (Dandini et al., 2019).

The Book of Revelation's apocalyptic visions describe the appearance of an angelic divine messenger of vengeance as having a halo around the sun. Another mighty angel is descending from heaven. He was covered in a cloud, with a rainbow (halo) above his head, the face of the sun, and blazing pillars for legs (Revelation 10:1). When the sun is near the horizon, ice crystals in cirrus clouds that form sun haloes can resemble the folds and ribbons of a white gown. These vertical beams of light, as pictured in the Bible, are known as "light pillars." Therefore, it is not beyond the realm of possibilities to realize that this vision of a solar halo from the Book of Revelation could be a real scientific possibility and that its appearance is a sign from God.

The sun is a symbol and spiritually significant in Hinduism, often associated with various gods, most notably Surya. The Rigveda, one of the earliest Hindu texts, acknowledges the sun's crucial role in sustaining life on Earth and features hymns dedicated to the sun god, Surya. Hindus regard sun halos as manifestations of divine energy or lucky signs. They may also see them as symbols of the unity of all things, recalling the Upanishad concept of "Sarvam Khalvidam Brahma" (all this is Brahman) (Dartar & Kaplanoğlu, 2021).

Buddhism typically emphasizes the transience of reality and the importance of human spiritual development. Although sun halos are not explicitly described in Buddhist scripture, Buddhists may see them as symbols of impermanence and interconnection. The philosophy of dependent origination (pratītyasamutpāda) states that all phenomena have several circumstances. Buddhists may view sun halos as fleeting occurrences that serve as a reminder of impermanence and interconnectedness (Campbell, 1994). While the Quran and Hadith may not include any explicit allusions to sun halos, some Islamic teachings and principles direct the interpretation of natural events as manifestations of Allah's majesty and sovereignty. The Quran often cites the manifestations of Allah in the natural world as proof of His existence and creative ability, for example, in the creation of the heavens and the Earth, and the alternation of the night and the day, and the [great] ships which sail through the sea with that which benefits people, and what Allah has sent down from the heavens of rain, giving life to the Earth after its lifelessness and dispersing therein every [kind of] moving creature, and directing of the winds and the clouds controlled between the heaven and the Earth.

The skies and celestial bodies are described in the Quran as reflecting Allah's grandeur and majesty, and as part of His creation. "The sun and the moon by precise calculation, and the stars and trees prostrate," says Surah Ar-Rahman (55:5–6). This verse highlights the universe's accuracy and order as evidence of Allah's omnipotence.

Islamic teachings emphasize the importance of thanking Allah for His blessings and reflecting on the signs He has created in the natural world. Surah Ibrahim (14:32-34) encourages believers to praise Allah for His provisions and reflect on how the heavens and Earth came to be. Although sun halos are mentioned in passing in the Quran and Hadith, they do not specifically address indicators that will precede the Day of Judgment. The Day of Judgment is inevitable, according to Islamic eschatological doctrines, and there will be indicators leading up to it, like the sun rising in the West.

3.3.2. People's thoughts

Throughout history, people have sought spiritual direction and answers from the heavens. When strange or unique phenomena, such as a sun halo, appear, people wonder what or who is directing these spectacular events. The Hindus, for example, believe that the formation of a solar halo signals the approach of the thunder and lightning gods and predicts impending storms in South Asia (Dandini et al., 2019). Sun halos frequently precede low-pressure systems that bring storms,

according to meteorologists. Although the Bible expressly forbids it, many societies have engaged in worship of the sun and moon. In addition, resist the urge to worship objects that the Lord, your God, has given to all peoples on Earth by bowing down to them when you view the sun, moon, and stars in the sky (4:19 in Deuteronomy).

While many people, like Peter, are looking to the heavens for a spiritual sign, I urge you to focus on Jesus, who not only died on the cross but rose from the dead to save us from God's wrath for humanity's crimes. The act of asking Jesus to forgive them of their sins and expressing a desire to spend eternity with Him in heaven, using a prayer of faith and confession, has been done by several people. When you see a halo around the sun or another celestial sign, such as a rainbow, a flash of lightning, or a shooting star, you can conclude that there is a God of heaven and Earth who created the entire universe. Try to live your life in a way that honors your Creator, God, by putting your trust and faith in Jesus. Natural occurrences, such as the halo surrounding the sun, are interpreted culturally by the Oromo people, an indigenous ethnic group living in parts of Ethiopia, Kenya, and Somalia. The development of a halo around the sun is often regarded as a significant celestial event with multiple symbolic implications in Oromo culture (Jalata, 1988; Mohammed, 1994; Gudeta, 2022).

The halo around the sun, called "Udaandii" or "Gosa Dhukaa," is thought to be a sign or a communication from Waaqaa, the Oromo supreme deity, according to Oromo folklore and traditional beliefs. One common interpretation of the halo is that it denotes spiritual presence, protection, and guidance (Donald et al., 1965; Mohammed, 1994; Gudeta, 2002; Gedda, 2024). It is believed that Waaqaa utilizes these incredible events to communicate with people, conveying messages of blessings, warnings, or impending changes in the natural order. Furthermore, the Oromo people occasionally associate the sun's halo with ceremonial and traditional practices. The presence of the halo may be viewed as a favorable sign during agricultural work or significant communal meetings, leading the community to participate in prayers, offerings, or other ceremonial rites to invoke heavenly favor and guarantee success (Mohammed, 1994).

It is crucial to understand that these explanations for the halo surrounding the sun have their roots in Oromo spiritual beliefs, oral traditions, and cosmology that have been passed down through the years. Although there are scientific explanations for halos that rely on atmospheric optics and the refraction of sunlight by ice crystals in the atmosphere, the Oromo perspective provides a cultural prism that helps explain and give meaning to such natural phenomena (Donald et al., 1965; Mohammed, 1994; Gedda, 2024).

3.2. Scientific interpretations of the sun halo

Reflection is the rapid change in the propagation direction of a wave as it contacts the boundary between two distinct mediums (David and Lynch, 1978). At least some part of the incoming wave remains in the same medium. The incoming light ray makes an angle θ_1 with the normal of a plane tangent to the boundary, and then the reflected ray makes an angle θ_2 with this normal and lies in the same plane as the incident ray, as shown in Figure 7.

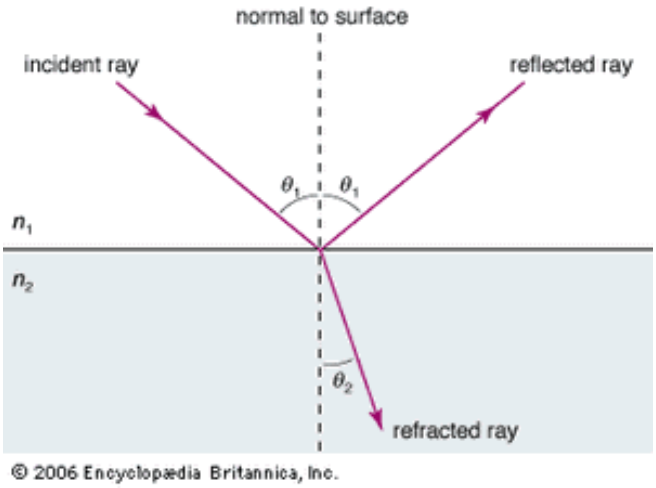

Figure 7. Propagation of light path in two different mediums (source: http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html)

Specular reflection occurs at smooth plane borders, and the plane tangent to the boundary becomes the boundary itself. Diffuse reflection occurs when light bounces off rough, irregular boundaries. A mirror's smooth surface reflects light secularly, but a wall's rough surface reflects it diffusely. A surface material's reflectivity, also known as reflectance, is the fraction of the energy of an oncoming wave that it reflects (Benjamin, 1949; David & Lynch, 1978).

Refraction is the shift in the propagation of a wave as it moves from one medium to another and changes speed. Light waves are refracted when they cross the boundary from one transparent medium to another because the speed of light varies between mediums. Assume light waves strike the planar surface of a piece of glass after traveling through the air, as seen in Figure 8.

Total internal reflection has no involvement in this, and the reason is interesting: if light impinges on the drop at such an angle that some of it refracts into the drop, then, if reversed, light must exit the drop along the same path. Because of the spherical shape of the water drop, every ray passing internally (along a chord) forms the same angle as the normal at each surface. As a result, any ray that enters the drop cannot interrupt the surface at the angle of total internal

reflection. Rainbows emerge when sunlight is scattered by water droplets, a phenomenon known as refraction. Refraction happens when sunlight changes direction and passes through a denser substance than air, such as a raindrop. When refracted light enters a raindrop, it is reflected off the back and refracted again before exiting and reaching our eyes.

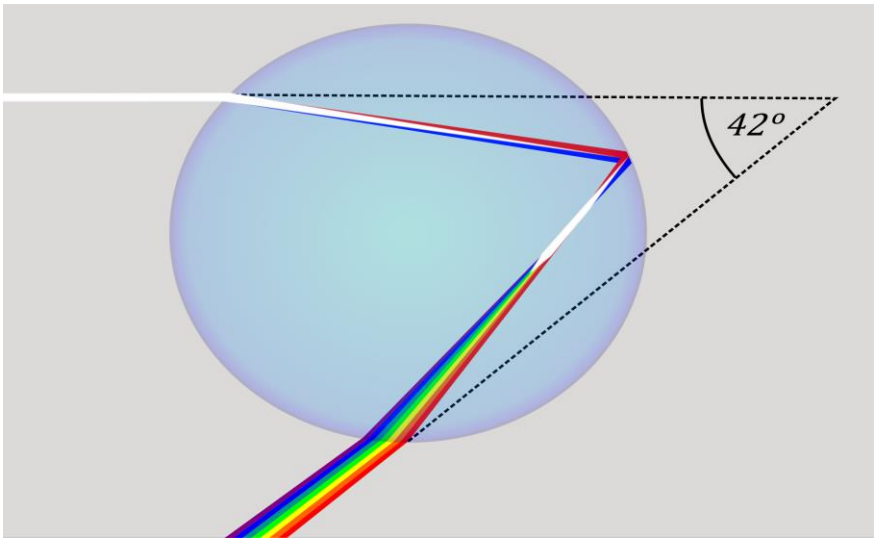

Figure 8. A typical explanation of the rainbow (source: http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html)

3.3. Sun halo

A halo is a ring of light formed when sunlight or moonlight refracts off ice crystals in a thin veil of cirrus clouds. The halo is typically seen as a bright, white ring, although it can occasionally have a colored appearance. It is an optical phenomenon produced by light (typically from the sun or moon) interacting with ice crystals suspended in the atmosphere.

Halos can have many forms, ranging from colored or white rings to arcs and spots in the sky. Some appear near the sun or moon, while others appear elsewhere or in the opposite part of the sky. Some of the more well-known halo kinds include the circular halo (called the 22° halo), light pillars, and sun dogs. However, numerous other types can be frequent or unusual. The ice crystals that form halos are suspended in cirrus or cirrostratus clouds in the upper troposphere (5-10 km), but in cold weather, they can also float near the ground, where they are known as diamond dust. The halo observed is determined by the crystal's specific form and orientation. Ice crystals reflect and refract light, which disperses into different hues. The crystals function as prisms and mirrors, refracting and reflecting light between their faces and projecting shafts of light in specified directions. Before the invention of meteorology, atmospheric visual phenomena, such as halos, were used empirically to predict the weather. They typically indicate that rain will fall within the

next 24 hours, as the cirrostratus clouds that produce them may signal the approach of a frontal system.

A halo appears only when something is present to view it. It is due to a group of light rays traveling in specific directions and converging on a receiving lens, such as an eye or a camera. Every person has a halo. Someone standing a short distance away notices another halo created by the collective glints of another set of gems. People in Ethiopia have recently been impressed by an extraordinary celestial phenomenon: the sun completely wrapped by a rainbow. On April 7, residents of Addis Ababa, Dire Dawa, and other Ethiopian cities witnessed an optical phenomenon described as a "sun halo" or "solar halo." Figures 10 and 11 depict another circle rainbow around the sun observed in Ethiopian cities on April 7, 2022. Figure 9 shows the one observed in Dire Dawa City, which lasted 10 minutes, during which a sun halo appeared. It lasted around 10 minutes before dissipating as the clouds grew thicker.

Figure 9. Sun halo observed in Dire Dawa City on April 7, 2022 (source: http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html)

Figure 9 depicts the sun's halo as perceived in Addis. The sun's light is not particularly bright, but you may see that it is redder on the inside and bluer on the outside of the halo. These colors are most visible in halos surrounding the sun. If you see a halo around the sun, notice how the inner edge is crisp and the outer edge is more diffuse. Also, observe how the sky around the halo is darker than the rest. Halos around the sun and moon are formed by high, thin cirrus clouds that drift tall above your head. Halos are made up of tiny ice crystals in Earth's atmosphere. They do this by refracting and reflecting light, and lunar halos indicate that storms are nearby.

Figure 10. Sun halo observed in Addis Ababa near Salinete Mariam, April 7, 2022 (source: http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html)

Figure 10 depicts a sun halo perceived in Addis Abeba near Salinete Mariam on April 7, 2022. The diameter of the sun's halo is determined using its geometry. Two triangles are comparable if their corresponding sides have the same ratio and their angles are equal. If two or more figures have the same shape but differ in size, they are referred to as "similar figures," as illustrated in Figure 11. The side ratio can be expressed as

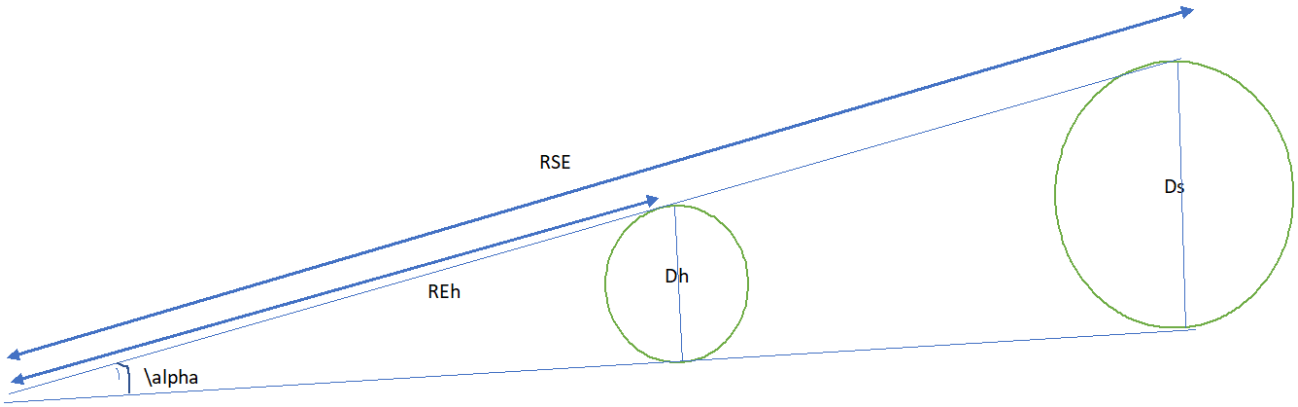

Figure 11. Similarities of the triangle to determine the diameter of the sun halo

$$\frac{DS}{Dh} = \frac{RES}{REh} \quad (1)$$

Using Eq. 1, the diameter of the sun halo that emerged on April 7 in Ethiopia, as depicted in the Figure. 11, is determined to be 0.092 km.

3.4. Image processing

3.4.1. Libraries used for this analysis

Image processing and analysis libraries are utilized to research and analyze sun halos, enhancing the ability to improve, segment, and interpret visual data. OpenCV (Open Source Computer Vision

Library), an open-source software library for computer vision and machine learning, is one of the most important libraries. A wide range of image processing tools, including filters, transformations, and image analysis routines, is available with OpenCV. To identify and analyze the unique properties of a sun halo, various methods for edge detection, contour detection, and color space transformations are employed (Bradski, 2000). The library is a popular choice for researchers studying atmospheric phenomena, such as sun halos, because of its broad capabilities in handling real-time applications.

Scikit-image, a Python library used for image processing, is another noteworthy package. Scikit-image provides a set of image analysis algorithms, including feature extraction, segmentation, and image registration, and it works well with other scientific computing libraries, such as NumPy and SciPy.

According to Van der Walt et al. (2014), these instruments aid in measuring the geometric characteristics of sun halos, such as their breadth and radius, which are crucial for scientific study. Furthermore, the library is accessible to researchers who may not have a background in computer science but require powerful tools for image analysis, thanks to its emphasis on creating an intuitive user interface. When combined, OpenCV and sci-kit-image provide a potent toolkit for deciphering the intricate visual properties of sun halos, leading to a better comprehension of their formation and variety.

3.4.2. Image analysis

The word "image processing" refers to a set of methods or processes that prepare a picture for analysis, object detection, feature extraction, and other uses (Ercan & Peter, 2001; Jarno & Maria, 2022). Applications for image processing can be found in practically every field, including automation, astronomy, and medical science. The amount of picture data generated or collected these days is tremendous, especially when combined with increasingly powerful technology such as optics and computational processing capabilities; the need and attractiveness of image processing are rapidly expanding. It then analyzes the photos captured during the observation in two local cities, Dire Dawa and Addis Ababa.

Figure 12 depicts the contour map and binary sun halo image from Dire Dawa City. The original image's average pixel count was 108.584, with a standard deviation of 43.265. Figure 12(b) demonstrates that the brilliant white dot in the center of the photograph emits light onto the Earth's surface. The light that the clouds have refracted is twisted in the upper section.

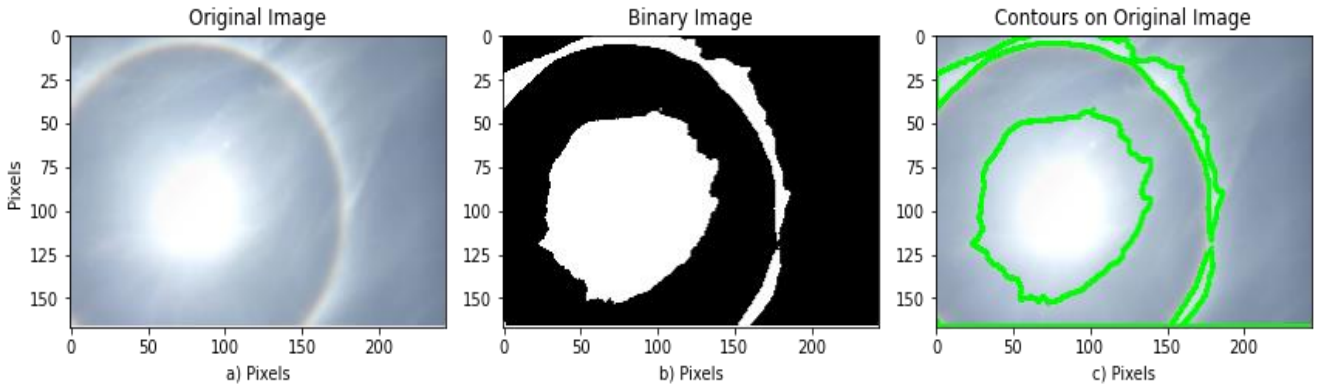

Figure 12. (a) original image,(b) binary image, and (c) the contours map of the sun halo observed image in Dire Dawa

Figure 12(c) illustrates the phenomenon, showing how the refracted light disperses throughout the surroundings. The noisy image shown in Figure 13 has an estimated noise standard deviation of 0.0963 processed using a non-local means filter (Oron & Gilad, 2016). The target pixel's intensity value is replaced with the average of a range of other pixels' intensities, with small sections centered to allow the non-local means technique to work. The pixel is compared to the area centered on the target pixel to preserve the image's texture and details, and a significant resemblance is observed between the two regions calculated.

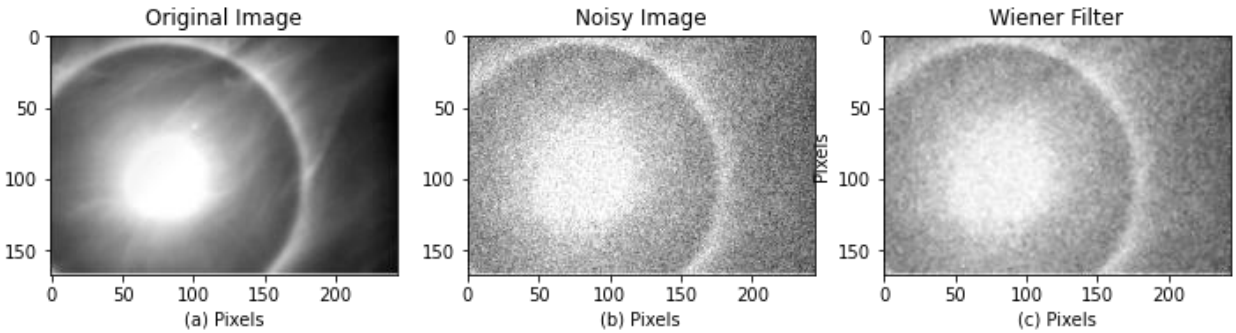

Figure 13. (a) Original Input Image, (b) noisy, and (c) self-tuned restored image using the Weiner filter

Non-linear approaches for removing noise from photos have the considerable disadvantage of requiring more processing power and being slower, even if they are effective at preserving the image's clean edges while eliminating the noise pattern. Weiner's approaches utilize a linear model, which makes them faster; however, they are less effective at maintaining the image's clean edges (François et al., 2010). Figure 13 shows the original image deconvolved using a Wiener filter. Signal-to-noise ratio (SNR) measures an image's quality in imaging by contrasting the amount of undesired noise with the strength of the desirable signal, or image content, shown in Figure 13(b).

Images with a better SNR will be more detailed, crisp, and free of noticeable noise artifacts. It is essential for assessing imaging sensor performance, figuring out image resolution, and refining image processing methods, including enhancement and denoising. The signal-to-noise ratio (SNR) is 33.744, according to the findings. The signal strength is stronger than the amount of noise in the system. It suggests the signal is strong and significantly higher than the noise floor. It refers to the degree of undesired interference present in a system and its impact on the performance and quality of the transmission.

Figure 14 depicts the grayscale, inverted log magnitude, and phase spectra. The results demonstrate that a solar halo image was obtained through spectral analysis to gain insight into the phenomenon's architecture and spatial frequency components. The primary steps in the analysis were as follows: The original solar halo image was imported, inverted, and converted to the grayscale displayed in Figures 14(a) and (b).

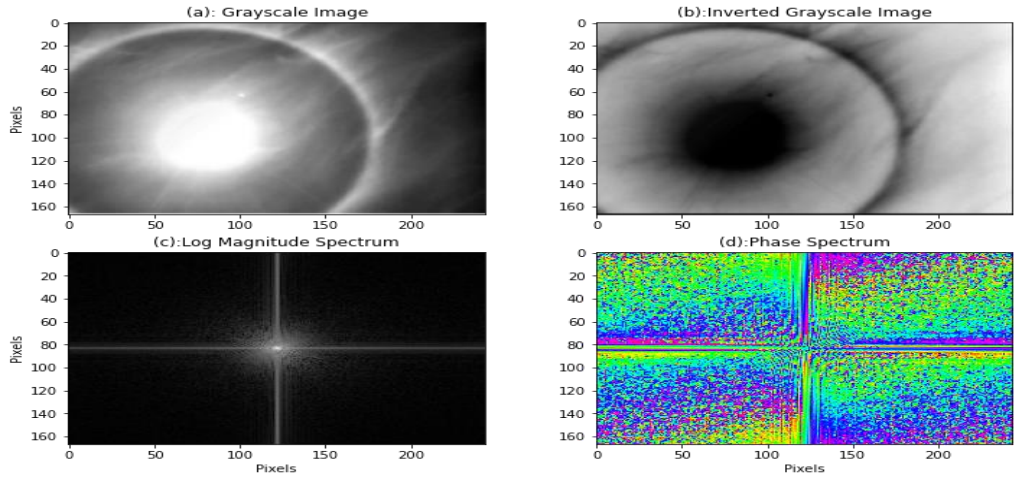

Figure 14. (a) Grayscale image (b), grayscale inverted original sun halo image, (c) Log magnitude spectrum, and (d) phase spectrum of the halo

The Fast Fourier Transform (FFT) generates the frequency spectrum from the grayscale image. This approach facilitates the identification of the image's spatial frequency components (Tscharmuter, 1987; François et al., 2010). The FFT magnitude spectrum was averaged radially to obtain the azimuthally averaged 1-dimensional power spectrum. This method helps to clarify how power is distributed among various spatial frequencies. Visual presentations included the log-transformed magnitude spectrum, radial profile, and original solar halo image. This enabled a thorough analysis of the frequency domain's characteristics and visual appearance. The log-transformed magnitude spectrum highlighted the most prominent spatial frequencies in the solar halo image. The peaks and patterns of the spectrum were examined to identify significant features. We utilized a sufficient threshold to filter out high-frequency noise from the spectra. The goal was

to improve the image as shown in Figure 14(c) by highlighting relevant structures. The filtered spectrum's inverse FFT was used to rebuild the denoised image. This technique reduced the image's noise while preserving crucial characteristics. Features in the original were linked to peaks and patterns in the spectrum. Figure 14(d) identifies any distinct spatial frequency components linked with specific structures or occurrences. As a result, the spectral analysis of the solar halo image provided an insightful look at the underlying spatial frequency components. This process can also be used to examine and decipher other astronomical occurrences that have been photographed (Yorke, 1980).

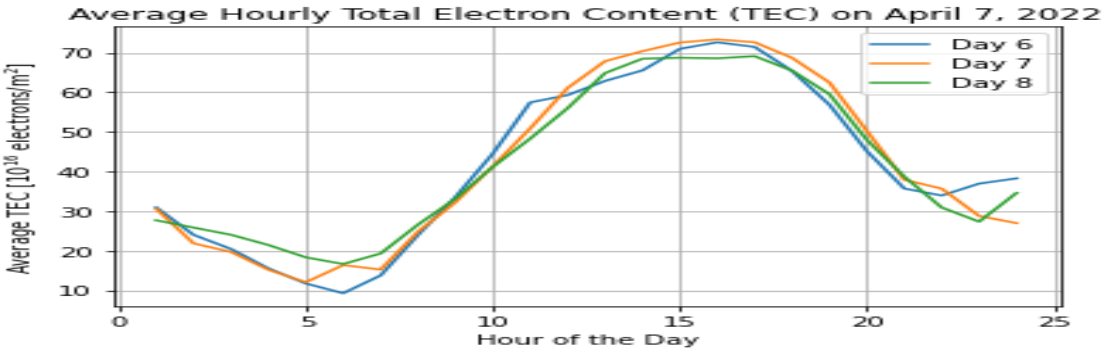

Figure 15. The average hourly total electron content was observed on April 7, 2022

Total electron content (TEC) and hour of the day (HD) may not correlate as well as they could, depending on the solar phenomena and atmospheric conditions specified for each day shown in Figure 15. Day 6 (Clear Sun): The ionization in the ionosphere may be more constant throughout the day when there are clear skies and direct sunshine. According to the positive correlation coefficient (0.53), TEC tends to rise with the length of the day. In contrast to days with atmospheric disturbances, clear conditions can result in a higher correlation between TEC and HD, as shown in Figure 15. Day 7 (Sun Halo and Black Cloud): Even if they are momentary, a sun halo and a black cloud can prevent solar radiation from entering the ionosphere. The relationship between TEC and HR may be influenced by variations in ionization levels resulting from several atmospheric events. The sporadic cloud cover and atmospheric disturbances may have weakened or increased the variability of the correlation coefficient (0.49), but it still indicates a positive link, as shown in Figure 15.

Day 8 (Clear sky): We should anticipate a correlation pattern similar to that of Day 6, given the clear sky on Day 6. Although the correlation coefficient (0.48) suggests a positive relationship between TEC and HR, there is room for variation, given the influence of atmospheric conditions and solar activity, as shown in Figure 15. Over the last three days, a steady positive association

has been observed between TEC and HD, indicating a general trend of increasing TEC. Nonetheless, there is a tiny change in the correlation coefficients, most likely due to daily differences in solar events and atmospheric conditions. Day 6 has the strongest correlation coefficient, followed by Days 7 and 8 when there are clear skies and direct sunlight. This suggests that, unlike clear-sky days, atmospheric disturbances on Day 7 may have slightly reduced the connection between the two. In conclusion, the correlation coefficients demonstrate how atmospheric factors and solar phenomena influence the correlation between TEC and HD, as indicated by the general trend of rising TEC over time (Johnson, 2009).

4. Conclusions

The temperature drops as we go higher into the troposphere. Thus, the highest region of the troposphere experiences temperatures so cold that the surrounding air temperature is -60 degrees at a height of 10 km. At these low temperatures, the hanging water droplets are actually ice crystals, which can refract sunlight and create a halo. The crowns that emerge on foggy days are often mistaken for the solar halo. When the sky is covered with the thinnest clouds, light diffraction through suspended particles in the atmosphere creates the crowns that are seen. From a religious perspective, the solar halo, as an aesthetic symbol of enlightenment, has been employed by various religions and aesthetic traditions. However, from a scientific point of view, halos are a sign of high, thin cirrus clouds drifting 20,000 feet (6 km) or more above our heads. These clouds contain millions of tiny ice crystals. The halos you see are caused by refractions, or splitting of light, and reflections, or glints of light, from these ice crystals. A sun halo, or bright ring or halo surrounding the sun, is usually caused by sunlight being refracted and scattered by ice crystals in the Earth's atmosphere by cirrus clouds, which are made up of thin, wispy ice crystals. The sun halo's circular shape, unique hues, and angular distance from the sun were probably revealed by the image analysis and are consistent with the characteristics of halos created by meteorological phenomena. Sun halos are frequently associated with cirrus clouds, which are high-altitude clouds composed of ice crystals. In conclusion, the application of image processing techniques, in conjunction with images of the sun halo and its correlation with cirrus clouds in Dire Dawa City and Addis Ababa, advances our understanding of atmospheric phenomena and their optical manifestations. These results underscore the importance of multidisciplinary atmospheric science, remote sensing, and image processing research in elucidating the complex dynamics of Earth's climate system.

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Conflict of interest

The authors declare that they have no conflict of interest.

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