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AURORA IN OMAN: OBSERVATIONS AND IMAGES

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Abstract. The Sun showed extraordinary activity related to sunspot area 3664 on May 8–10, 2024, resulting in solar flares considered the most intense in the current solar cycle. Auroras occurred in several regions around the world. Early on May 12, 2024 near the highest peak in the Sultanate of Oman, a team of Omani astrophotography enthusiasts documented the rare event ever observed in this region. Auroras often occur along the so-called auroral oval zones around the geomagnetic poles, where Earth's magnetic field directs charged particles penetrating from the solar wind. This takes place when a cloud of charged particles is thrown toward Earth by a large explosion on the Sun. Sometimes, these particles can make the aurora visible in places where it is exceedingly rare throughout recorded history. The observation from the mountain Jebel Shams, situated far from the polar regions (23 degrees north of the equator), offers a unique chance to study such an event in a region where auroras are exceptionally rare. We explore the factors contributing to the observed aurora in Oman, including geomagnetic conditions and the role of sunspot region AR3664 in solar activity along with local conditions in Oman that contributed to the visibility of this aurora. Understanding this dynamics can enhance our knowledge of the mechanisms driving auroral visibility at lower latitudes and provide valuable insights into the global impact of solar storms. This study also emphasizes how crucial it is to record auroras in regions like the Arabian Peninsula, where they are rarely documented.

Keywords: aurora, solar activity, solar storms, red aurora glow

INTRODUCTION

Aurora is a colourful light phenomenon caused by a flux of charged particles (solar wind) entering the geomagnetic field thereby inducing a brilliant and beautiful glow at clear-sky night near the north and south poles [Qian, 2023].

The low-latitude aurora appears as a large ring above the geomagnetic North pole, known as the auroral oval. While one might expect this oval to be consistently visible at the same latitudes worldwide, it shifts frequently due to the dynamic nature of the geomagnetic field. The auroral oval is centered around the geomagnetic North pole rather than the geographic one, with its position changing regularly.

Although auroras are rare in low-latitude regions, increased solar activity can expand the auroral zone toward the equator, making it possible to observe auroras in these regions. The Carrington Event (1–2 September 1859), the most intense geomagnetic storm on record, was documented in historical accounts worldwide as a spectacular aurora [Lee et al., 2023]. The catalogue [Vaquero et al., 2003] contains numerous aurora images on the Iberian Peninsula, but it does not address observations that occurred in North Africa.

A search through Islamic texts of Arabian cultural history (mainly from Iraq, Egypt, Syria, Morocco, Spain, and Yemen between 15°–38° N) has revealed 22 auroras between IX and XVI centuries (Table) [Basurah, 2006; Basurah, 2010]. The table lists auroral events in both Mecca and Riyadh located at even lower latitudes than some Oman regions (26°–40° N). The same applies to Yemen located south of Oman, suggesting that auroras might have been visible in parts of Oman as well (particularly during the major event of 1872). However, these sightings were not documented, and they are records we have been unable to access while writing this paper.

In this research, we document the observation of an aurora at Jebel Shams in the Sultanate of Oman (the highest point in the Arabian Peninsula) during the solar activity period between May 9 and 12, 2024. This time period marked the peak solar activity for the current decade.

OBSERVATION AND SITE SELECTION

The May 10, 2024 geomagnetic storm was one of the most extreme over 20 years (https://egusphere.copernicus.org/preprints/2024/egusphere-2024-2174). Usually visible at high latitudes near the poles, auroras can extend further toward the equator during geomagnetic storms. An aurora was caused by the above storm, which was the strongest since the Halloween storms of 2003. During this period, AR3664 produced multiple X-class flares accompanied by halo coronal mass ejections (CMEs). When this CME arrived at Earth, it triggered a geomagnetic storm classified as extreme class G5 on the NOAA

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Auroras as reported in Islamic history [Basurah, 2010]

Event	Periods and Date	Country
1	816, Aug – 817, Jul	Yemen
2	817, Oct 29	Iraq
3	879, Oct 11	Morocco
4	897, May 7 – Jun 4	Egypt
5	931, Nov 9	Iraq
6	939, Oct 17	Syria
7	941, May 6	Spain
8	977, Aug 23	Egypt
9	979, Sept 29	Morocco
10	991, Mar 17 – 992, Mar 7	Egypt
11	1050, Apr 25 – 24 May	Egypt
12	1060, Nov 9 – Dec 7	Egypt
13	1176, Sep 6 – Oct 5	Syria
14	1179, May 7	Syria
15	1203, Oct 9 – Nov 7	Yemen
16	1223, Oct 26	Syria
17	1264, Jul 20 – 30	Syria
18	1321, Jan 30 – 1322, Jan 19	Yemen
19	1370, Nov 27	Syria
20	1422, Dec 14 – 1423, Dec 3	Egypt
21	1449, Aug 26	Yemen
22	1570, Jun 4 – 1571, May 24	Spain

Space Weather Scales [https://egusphere. copernicus. org/preprints/2024/egusphere-2024-2174]. As a result, auroras were observed across regions where auroras had not been previously recorded, including the Sultanate of Oman located between 16.40° and 26.20° N. We have selected a site entirely free from light pollution at the highest peak in Oman, Jebel Shams, at an elevation of over 2900 meters above sea level. The selected site's geographic coordinates are 23.3030° N, 57.0960° E; altitude-adjusted corrected geomagnetic coordinates [https://sdnet.thayer.dartmouth.edu/aacgm/aacgm_calc.php#AACGM] are 18.48° N, 130.23° E. This setting allowed us to minimize any potential interference from city light noise in capturing the aurora and to make it easier to distinguish (Figure 1).

IMAGING AND ANALYSIS OF THE FIRST DOCUMENTED AURORA OBSERVATION IN OMAN

The unprecedented low-latitude aurora was observed at Jebel Shams, Sultanate of Oman, using a carefully designed imaging facility including two cameras. The first was a full-frame camera Canon EOS 6D Mark I with a Samyang EF 14 mm f/2.8 lens operated in manual mode. The exposure settings are a 25 s shutter speed, f/2.8 aperture, and high ISO sensitivity of 3200, used to capture maximum light under low-light conditions. The camera was mounted on a stable tripod, coupled with a remote shutter to shoot 1062 images over the night to create a time-lapse video and hence to allow a detailed study of the auroral dynamics.

The second camera was Insta360 One RS working in 360-night-lapse mode. It captured the entire space at an exposure time of 23 s, an aperture of f/2.2, and an ISO sensitivity of 2500, with the 360-capability assuring accurate spatial recording that confirmed the aurora formed toward the north.

After capturing the images, post-processing was made in Adobe Photoshop to enhance their quality and ensure they accurately reflected the observed auroras.

We adjusted the contrast and color balance to refine the auroral structures. White balance calibration was carefully carried out to maintain the aurora's natural colors. Advanced noise reduction techniques were also

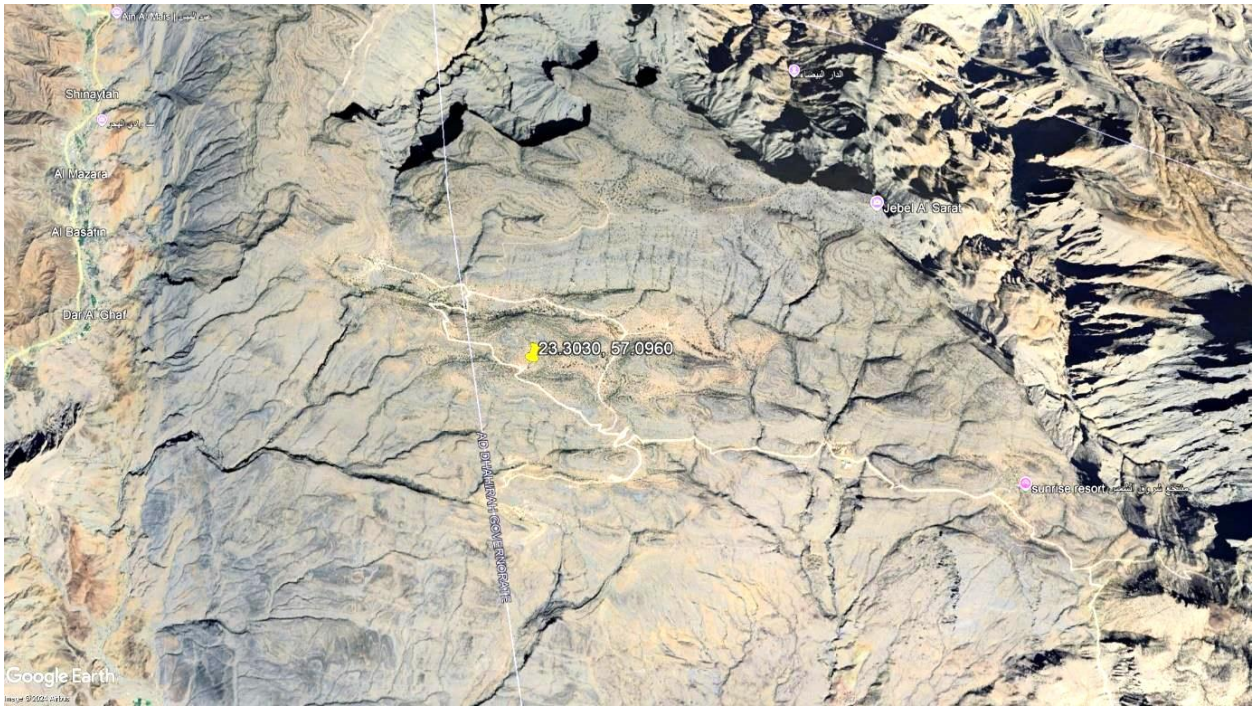

Figure 1. Location and coordinates where the aurora was observed and photographed in the Sultanate of Oman

employed to address the problems of low-light imaging, resulting in sharper and more detailed visuals. The star Vega (α Lyrae) was observed from a site with coordinates RA/Dec 18h37m46s / +38°48'29" with an apparent magnitude of 0.00. The final processed images captured with Camera No. 01 (Canon 6D, Samyang 14 mm f/2.8 lens, 25 s exposure, ISO 3200) on May 11, 2024 at 23:45 UTC are presented in Figure 2.

Figure 3 shows the most prominent feature that is emission at 630.0 nm characteristic of mid-latitude auroras (this rare red hue was observed in the northern sky from Jebel Shams, Oman, indicating its southernmost extent. The image was taken with Camera No. 02 (Insta360 One RS) at a 30 s exposure, ISO 2500, and an f/2.2 aperture. The image was captured on May 11, 2024 at 23:16 UTC with coordinates 23.3030° N, 57.0966° E.

High-altitude 630.0 nm (red) atomic oxygen emissions occurring above 200 km are typically associated with red auroras during powerful geomagnetic storms. Observing this red color at ~26° N is very rare, thereby indicating exceptional atmospheric and geomagnetic conditions. These conditions might have allowed charged particles to penetrate deeper into Earth's upper atmosphere than usually, reaching altitudes where they could lose energy through collisions with atmospheric molecules.

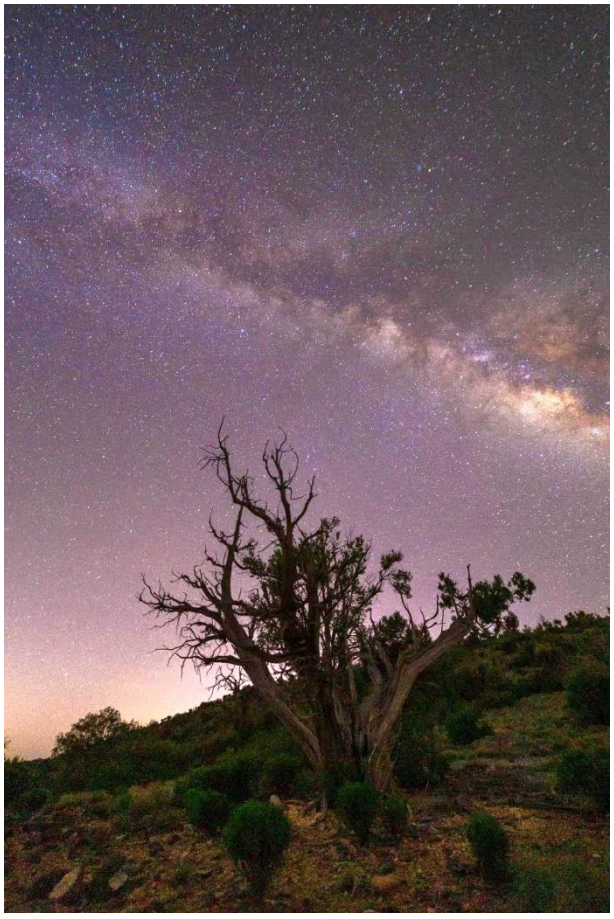

Figure 2. Low-latitude aurora as observed from Jebel Shams. The image was captured with Camera No. 01 (Canon 6D, Samyang 14mm f/2.8 lens, 25-second exposure, ISO 3200) on May 11, 2024 at 23:45 UTC. The image is part of a time-lapse video recording.

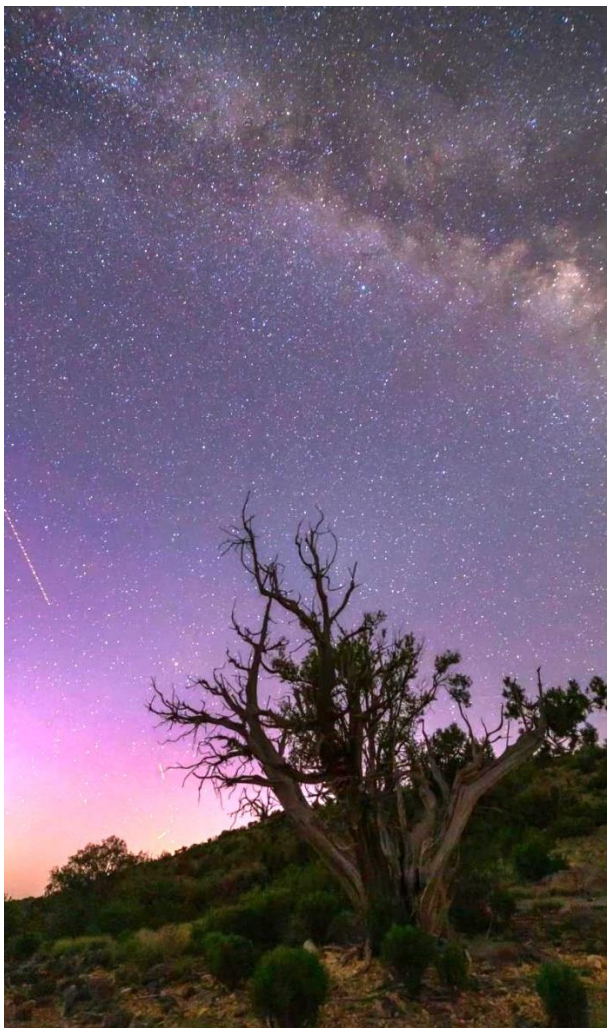

Figure 3: Low-latitude aurora observed from Jebel Shams, Oman, featuring a rare red hue in the northern sky, marking its southernmost extent. The image was taken on 11 May 2024 at 23:16 UTC at 23.3030° N, 57.0966° E.

Figure 4. Faint red auroral glow observed near the horizon from Jebel Shams.

Since red emissions at 630.0 nm are far less common at lower latitudes compared to the more frequently observed green emissions at 557.7 nm at higher latitudes, the distinctive red hue played a crucial role in identifying the phenomenon as a low-latitude aurora [http://arxiv.org/abs/ 2405.08821] (Figure 4**)**.

This observation marks the first documented occurrence of the low-latitude aurora in Oman, highlighting the unique conditions of the event and contributing significantly to the understanding of auroral phenomena at low latitudes. The combination of advanced imaging techniques and the distinct red aurora recorded during this event underscores the scientific, cultural, and historical value of this discovery.

RESULTS AND CONCLUSION

Our analysis has revealed a rare observation of subvisual aurora captured from Jebel Shams in the Sultanate of Oman on May 11, 2024. Study of this event was validated through collaboration with the Aurorasaurus Project and further supported by astrometric analysis that identified the observed red glow as the southernmost extent of the low-latitude aurora over Europe during the period of observation. This finding highlights the potential for detecting auroral phenomena at low latitudes under exceptional geomagnetic conditions.

The low-latitude aurora observed from Jebel Shams in Oman is an extraordinary and rare phenomenon at low latitudes. The faint red glow recorded during the event serves as strong evidence of how geomagnetic activity can affect Earth's upper atmosphere, even in regions far from the poles. This finding supports current models that suggest auroras can be visible during intense solar flares and highlights the possibility of witnessing such events in surprising locations.

From a scientific perspective, this event underscores the importance of expanding aurora research beyond traditional polar and subpolar latitudes. The effective recording in Oman enhances the use of remote dark-sky sites for follow-up studies and highlights the need to establish international observing networks.

Moreover, this observation and its analysis make a valuable contribution to the broader understanding of space weather impacts and auroral dynamics. It also underlines the importance of citizen science and collaboration in detecting, reporting, and validating rare atmospheric phenomena. This research opens up new possibilities for more comprehensive global studies of auroras by increasing awareness and documenting events in rare places, providing new perspectives on their occurrence and variability concerning solar activity and geomagnetic conditions.

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