Int. Res. J. of Science & Engineering, 2020 Volume 8 (1) :24-34
ISSN: 2322-0015
SJIF Impact Factor 6.68
REVIEW ARTICLE
OPEN ACCESS

Review of terrestrial auroras (*Aurora australis*) and non-terrestrial auroras.

Dr (Ms) Swaroopa Rani N. Gupta

Department of Chemistry, Brijlal Biyani Science College Amravati, Maharashtra, India
Email: swargupta@yahoo.com

Manuscript Details
Available online on http://www.irjse.in
ISSN: 2322-0015

Editor: Dr. Arvind Chavhan

Cite this article as:
Gupta Swaroopa Rani N. Review of terrestrial auroras (*Aurora australis*) and non-terrestrial auroras, *Int. Res. Journal of Science & Engineering, 2020,* Volume 8 *Issue 1*: 24-34..

ABSTRACT

An aurora sometimes referred to as polar lights, northern lights (aurora borealis) or southern lights (aurora australis), is a natural light display in the Earth's sky, predominantly seen in the high-latitude regions around the Arctic and Antarctic. Auroras are perhaps the most spectacular manifestations of the complex interaction of the solar wind with the uter atmosphere. The energetic electrons and protons responsible for n aurora are directed by the solar wind along magnetic fields into Earth's magnetosphere.

The Earth's atmosphere, which is primarily made up of oxygen and nitrogen atoms, absorbs the heat from the solar wind when the particles collide with the oxygen and nitrogen atoms. This impact and the heat put the atoms in an excited state. When these atoms come back to their normal state, they release the excessive energy in the form of visible photons. These photons are what we see and name as the Northern Lights and Southern Lights. The Aurora phenomenon is not exclusive to Earth. The lights can be seen on any and all planets that have magnetic poles.

The portion of Earth that traverses the midnight portion of the auroral oval is known as the auroral zone. In the Northern Hemisphere this zone lies along a curve extending from the northern regions of Scandinavia through Iceland, the southern tip of Greenland, the southern region of Hudson Bay, central Alaska, and on to the coast of Siberia. This is the prime region from which to view an aurora in the Northern Hemisphere. The Aurora Australis is visible from high southern latitudes in Antarctica, Chile, Argentina, New Zealand, and Australia.

The most common type of aurora is associated with bombardment of the atmosphere by electrons with energies of up to 10,000 electron volts. Auroral displays are also produced by bombardment of the atmosphere by energetic protons. Protons with energies of up to 200,000 electron volts are responsible for auroral activity in a diffuse belt that is equatorward of the main auroral zone. The magnetosphere includes two doughnut-shaped radiation belts, or zones, centred on the Equator that are occupied by appreciable numbers of energetic protons and electrons trapped in the outermost reaches of the atmosphere called Van Allen radiation belts. This paper deals with review of terrestrial auroras which includes aurora, auroral zones, causes of auroral displays, Van Allen radiation belts, various images of terrestrial auroras - aurora australis. It also includes non-terrestrial auroras and some auroral events of historical significance.

Keywords: Aurora, Auroral zones, Van Allen radiation belts, Aurora Australis, Jupiter aurora, Saturn's aurora

INTRODUCTION

An aurora (plural: auroras or aurorae), [1] sometimes referred to as polar lights, northern lights (aurora borealis) or southern lights (aurora australis), is a natural light display in the Earth's sky, predominantly seen in the high-latitude regions (around the Arctic and Antarctic).

The name Aurora is the name of the Roman goddess of dawn. As the lights look like approaching dawn, they were named after the goddess of dawn. The name Borealis is the Greek name for the north wind, hence denoting that it occurs in the north, while the name Australis is the Latin word meaning ‘of the South’ or ‘Southern’.

Auroras are perhaps the most spectacular manifestations of the complex interaction of the solar wind with the outer atmosphere. The energetic electrons and protons responsible for an aurora are directed by the solar wind along magnetic fields into Earth’s magnetosphere.

The Earth’s atmosphere, which is primarily made up of oxygen and nitrogen atoms, absorbs the heat from the solar wind when the particles collide with the oxygen and nitrogen atoms. This impact and the heat put the atoms in an excited state. When these atoms come back to their normal state, they release the excessive energy in the form of visible photons. These photons are what we see and name as the Northern Lights and Southern Lights.

Auroras occur in both hemispheres, confined for the most part to high latitudes in oval-shaped regions that maintain a more or less fixed orientation with respect to the Sun. The centre of the auroral oval is displaced a few degrees to the nightside with respect to the geomagnetic pole. The midnight portion of the oval is, on average, at a geomagnetic latitude of 67°; the midday portion is at about 76°. An observer between 67° and 74° magnetic latitudes generally encounters auroras twice a day once in evening and once in morning.

The Aurora phenomenon is not exclusive to Earth. The lights can be seen on any and all planets that have magnetic poles. Similar to Earth, these auroras come in a large number of different colors, such as but not limited to red, green, yellow, pink, purple, blue, as well as ultraviolet and infrared, which are not visible to the naked eye. These colors occur depending on the atoms that are releasing the photons. The most common is the green aurora, which is due to the participation of the oxygen atom.

Auroral zones

The portion of Earth that traverses the midnight portion of the auroral oval is known as the auroral zone. In the Northern Hemisphere this zone lies along a curve extending from the northern regions of Scandinavia through Iceland, the southern tip of Greenland, the southern region of Hudson Bay, central Alaska, and on to the coast of Siberia. This is the prime region from which to view an aurora in the Northern Hemisphere. The Aurora Australis is visible from high southern latitudes in Antarctica, Chile, Argentina, New Zealand, and Australia.

The phenomenon is by no means static, however. The auroral zone shifts poleward at times of low solar activity, while during periods of high solar activity it has been known to move as far south as 40° (geographic latitude). At low latitudes, an aurora assumes a characteristic red colour. In ancient times this colour was often interpreted as evidence of impending disaster. More recently it has been taken as a sign of approaching fires. Auroras assume a variety of forms, depending on the vantage point from which they are observed. The luminosity of an aurora is generally aligned with the magnetic field. Field lines are close to vertical in polar regions, and so an aurora occurring there appears to stand on end, hanging from the sky in great luminous drapes. It is a spectacular sight indeed, especially if viewed from a distance either from the north or south. At lower latitudes, the magnetic field lines are inclined with respect to the vertical. There an aurora appears as streamers radiating from the zenith. Such is the majesty of the aurora that no two displays are totally alike. Light can move rapidly across the sky on some occasions, and at other times it can appear to stand in place, flickering on and off.

Causes of auroral displays

The most common type of aurora is associated with bombardment of the atmosphere by electrons with energies of up to 10,000 electron volts. The energy source for these electrons originates ultimately from the Sun. It is propagated through space by the solar wind along bundled, rope like magnetic fields that form temporarily between the Sun and Earth's magnetosphere, most probably to the plasma sheet. Energetic electrons enter the atmosphere along magnetic field lines. They produce a shower of secondary and tertiary electrons, approximately one for every 35 electron volts of energy in the primary stream. Primaries can propagate to altitudes as low as 100 km (60 miles). Most of the luminosity is produced, however, by low-energy secondary and tertiary electrons. Prominent emissions in the spectrum of this luminosity are associated with the red line of atomic oxygen at 633 nm, the green line of atomic oxygen at 558 nm, the first negative bands of ionized molecular nitrogen at 391 nm and 428 nm, and a host of emissions from atomic oxygen, molecular oxygen, ionized molecular oxygen, and molecular nitrogen. Many of these features are present also in the day and night airglow. They are most notable in auroras because of their intensity and the rapidity with which they switch on and off in response to changes in the flux and energy of incoming primaries. An aurora has a characteristic red colour if the energy of primaries is relatively low. Emission in this case is dominated by atomic oxygen and is confined for the most part to altitudes above 250 km (150 miles). If the energy of the primaries is high, an aurora has a greenish blue colour and extends downward to altitudes as low as 90 km (55 miles).

Auroral displays are also produced by bombardment of the atmosphere by energetic protons. Protons with energies of up to 200,000 electron volts are responsible for auroral activity in a diffuse belt that is equatorward of the main auroral zone. These protons can be detected from the ground by observation of Doppler-shifted radiation emitted by fast hydrogen atoms formed by charge transfer from atmospheric atoms and molecules. Protons also play a role at higher latitudes, especially at times following major solar flares. It is thought that the protons responsible for auroras at the polar caps are solar in origin. Associated energies may reach as high as one million electron volts, and particles may penetrate as deep as 80 km (50 miles). Polar cap auroras can provide a significant transient source of mesospheric and stratospheric nitric oxide (NO). They can be responsible for small but detectable short-term fluctuations in the abundance of stratospheric ozone.

Van Allen radiation belts

The magnetosphere includes two doughnut-shaped radiation belts, or zones, centred on the Equator that are occupied by appreciable numbers of energetic protons and electrons trapped in the outermost reaches of the atmosphere. No real gap exists between the two zones; they actually merge gradually, with the flux of charged particles showing two regions of maximum density. The inner belt extends from roughly 1,000 to 5,000 km (600 to 3,000 miles) above the terrestrial surface and the outer belt from some 15,000 to 25,000 km (9,300 to 15,500 miles). The belts were named in honour of James A. Van Allen, the American physicist who discovered them in 1958. His was a triumph of serendipity—he detected the presence of the trapped particles with a Geiger counter designed to measure the flux of cosmic rays in space. It was the first great discovery of the space age and was achieved by combining data obtained with instruments carried by three of the earliest United States scientific satellites - Explorer 1, Explorer 4, and Pioneer 3.

The flux of protons crossing a square centimetre of surface in the inner Van Allen belt can be as large as 20,000 per second, higher than the flux of cosmic radiation in space by a factor of 10,000. Protons in the inner belt have energies in excess of 7×10^8 electron volts, enough to enable them to penetrate about 10 cm (4 inches) of lead. Spacecraft flying through the belts must be protected; otherwise, their electronic components would be subjected to irreparable damages.

The high-energy protons in the inner Van Allen belt are thought to originate from the decay of neutrons that are produced by the interaction of the atmosphere with energetic cosmic rays of galactic origin. Some of these short-lived neutrons—they have a lifetime of 12 minutes—are ejected upward. A fraction of them decay into energetic protons and electrons as they pass through the region occupied by the Van Allen belts. These protons and electrons become trapped and travel in spiral paths along the flux lines of Earth's magnetic field. The particles reverse their direction at intermediate altitudes (about 500 km [300 miles]) and low latitudes because, as the particles approach either of the magnetic poles, the increase in the strength of the field causes them to be reflected back toward the other pole. Collisions with atoms in the thin atmosphere eventually remove the particles from the belts, but they generally survive for about 10 years. This relatively long lifetime allows particles to accumulate in the radiation belts, providing high fluxes despite the small magnitude of the intrinsic source.

The inner belt merges gradually with the outer belt, which extends from about two to eight Earth radii. A portion of the ionization in the outer belt is derived from the solar wind, as demonstrated by the presence of helium ions in addition to protons. Unlike the outer zone, the inner belt contains no helium ions, while it has been established that helium ions account for about 10 percent of solar wind. The flux of electrons in the outer belt can vary by orders of magnitude over intervals as short as a few days. These changes appear to correlate with times of strong magnetic disturbances. They are not, however, as yet well understood.

IMAGES OF TERRESTRIAL AURORAS - AURORA AUSTRALIS

Figure 1 shows a display of aurora australis, or southern lights, manifesting itself as a glowing loop, in an image of part of Earth's Southern Hemisphere taken from space by astronauts aboard the U.S. space shuttle orbiter Discovery on May 6, 1991. The mostly greenish blue emission is from ionized oxygen atoms at an altitude of 100–250 km (60–150 miles). The red-tinged spikes at the top of the loop are produced by ionized oxygen atoms at higher altitudes, up to 500 km (300 miles). [2]

Figure 3 Aurora Australis Observed from the International Space Station Among the views of Earth afforded astronauts aboard the International Space Station (ISS), surely one of the most spectacular is of the aurora. These ever-shifting displays of colored ribbons, curtains, rays, and spots are most visible near the North (aurora borealis) and South (aurora australis) Poles as charged particles (ions) streaming from the Sun (the solar wind) interact with Earth's magnetic field. While aurora are generally only visible close to the poles, severe magnetic storms impacting the Earth's magnetic field can shift them towards the equator. This striking aurora image was taken during a geomagnetic storm that was most likely caused by a coronal mass ejection from the Sun on May 24, 2010. The ISS was located over the Southern Indian Ocean at an altitude of 350 kilometers (220 miles), with the astronaut observer most likely looking towards Antarctica (not visible) and the South Pole. The aurora has a sinuous ribbon shape that separates into discrete spots near the lower right corner of the image. While the dominant coloration of the aurora is green, there are faint suggestions of red left of image center. Dense cloud cover is dimly visible below the aurora. The curvature of the Earth's horizon (the limb) is clearly visible, as is the faint blue line of the upper atmosphere directly above it (at image top center). Several stars appear as bright pinpoints against the blackness of space at image top right. Auroras happen when ions in the solar wind collide with atoms of oxygen and nitrogen in the upper atmosphere. The atoms are excited by these collisions, and they typically emit light as they return to their original energy level. The light creates the aurora that we see. The most commonly observed color of aurora is green, caused by light emitted by excited oxygen atoms at wavelengths centered at 0.558 micrometers, or millionths of a meter. (Visible light is reflected from healthy (green) plant leaves at approximately the same wavelength.) Red aurora are generated by light emitted at a longer wavelength (0.630 micrometers), and other colors such as blue and purple are also sometimes observed.

Figure 7 At the time, the International Space Station was moving over the southern Indian Ocean towards the Great Australian Bight and Melbourne, Australia. Auroras are created in the upper atmosphere when the solar wind (a stream of charged particles emitted by the Sun) interacts with the Earth's protective magnetic field. Charged particles within the magnetosphere are accelerated down field lines toward the ionosphere, where they collide with different gases (particularly oxygen and nitrogen) and emit light as a reaction. Auroras often appear as neon green, purple, yellow, or red, depending on the gas molecules being excited. Green, for example, indicates collisions with oxygen. [8]

NON-TERRESTRIAL AURORAS

Figure 8 Jupiter aurora; the far left bright spot connects magnetically to Io; the spots at the bottom of the image lead to Ganymede and Europa. (image of Jupiter aurora in UV, taken with the Space Telescope Imaging Spectrograph (STIS) of NASA's Hubble Space Telescope • STScI-PRC00-38 Bright streaks and dots are caused by magnetic flux tubes connecting Jupiter to its largest moons: Io: bright streak on the far left Ganymede: bright dot below center Europa: dot right of Ganymede dot) [9]
Figure 9 An aurora high above the northern part of Saturn; image taken by the Cassini spacecraft. A movie shows images from 81 hours of observations of Saturn's aurora (A false-colour still image of visible light of the aurora above Saturn's North pole taken by the Cassini spacecraft.) [10]

Both Jupiter and Saturn have magnetic fields that are stronger than Earth's (Jupiter's equatorial field strength is 4.3 gauss, compared to 0.3 gauss for Earth), and both have extensive radiation belts. Auroras have been observed on both gas planets, most clearly using the Hubble Space Telescope, as well as on Uranus and Neptune. [11]

The auroras on the gas giants seem, like Earth's, to be powered by the solar wind. In addition, however, Jupiter's moons, especially Io, are powerful sources of auroras on Jupiter. These arise from electric currents along field lines ("field aligned currents"), generated by a dynamo mechanism due to the relative motion between the rotating planet and the moving moon. Io, which has active volcanism and an ionosphere, is a particularly strong source, and its currents also generate radio emissions, which have been studied since 1955. Using the Hubble Space Telescope, auroras over Io, Europa and Ganymede have all been observed.

Auroras have also been observed on Venus and Mars. Venus has no magnetic field and so Venusian auroras appear as bright and diffuse patches of varying shape and intensity, sometimes distributed over the full disc of the planet. A Venusian aurora originates when electrons from the solar wind collide with the night-side atmosphere.

An aurora was detected on Mars, on 14 August 2004, by the SPICAM instrument aboard Mars Express. The aurora was located at Terra Cimmeria, in the region of 177° East, 52° South. The total size of the emission region was about 30 km across, and possibly about 8 km high. By analyzing a map of crustal magnetic anomalies compiled with data from Mars Global Surveyor, scientists observed that the region of the emissions corresponded to an area where the strongest magnetic field is localized. This correlation indicated that the origin of the light emission was a flux of electrons moving along the crust magnetic lines and exciting the upper atmosphere of Mars. [11, 12]

The first ever extra-solar auroras were discovered in July 2015 over the brown dwarf star LSR J1835+3259. [13] The mainly red aurora was found to be a million times brighter than the Northern Lights, a result of the charged particles interacting with hydrogen in the atmosphere. It has been speculated that stellar winds may be stripping off material from the surface of the brown dwarf to produce its own electrons. Another possible explanation for the auroras is that an as-yet-undetected body around the dwarf star is throwing off material, as is the case with Jupiter and its moon Io. [14]

AURORAL EVENTS OF HISTORICAL SIGNIFICANCE

The auroras that resulted from the "great geomagnetic storm" on both 28 August and 2 September 1859, however, are thought to be the most spectacular in recent recorded history. In a paper to the Royal Society on 21 November 1861, Balfour Stewart described both auroral events as documented by a self-recording magnetograph at the Kew Observatory and established the connection between the 2 September 1859 auroral storm and the Carrington-Hodgson flare event when he observed that, "It is not impossible to suppose that in this case our luminary was taken in the act." [15] The second auroral event, which occurred on 2 September 1859 as a result of the exceptionally intense Carrington-Hodgson white light solar flare on 1 September 1859, produced auroras, so widespread and extraordinarily bright, that they were seen and reported in published scientific measurements, ship logs, and newspapers throughout the United States, Europe, Japan, and Australia. It was reported by The New York Times that in Boston on Friday 2 September 1859 the aurora was "so brilliant that at about one o'clock ordinary print could be read by the light". [16] One o'clock EST time on Friday 2 September would have been 6:00 GMT and the self-recording magnetograph at the Kew Observatory was recording the geomagnetic storm, which was then one hour old, at its full intensity. Between 1859 and 1862, Elias Loomis published a series of nine papers on the Great Auroral Exhibition of 1859 in the American Journal of Science where he collected worldwide reports of the auroral event.

That aurora is thought to have been produced by one of the most intense coronal mass ejections in history. It is also notable for the fact that it is the first time where the phenomena of auroral activity and electricity were unambiguously linked. This insight was made possible not only due to scientific magnetometer measurements of the era, but also as a result of a significant portion of the 125,000 miles (201,000 km) of telegraph lines then in service being significantly disrupted for many hours throughout the storm. Some telegraph lines, however, seem to have been of the appropriate length and orientation to produce a sufficient geomagnetically induced current from the electromagnetic field to allow for continued communication with the telegraph operator power supplies switched off. The conversation occurred between two operators of the American Telegraph Line between Boston and Portland, Maine, on the night of 2 September 1859. The conversation was carried on for around two hours using no battery power at all and working solely with the current induced by the aurora, and it was said that this was the first time on record that more than a word or two was transmitted in such manner. [16]

Such events led to the general conclusion that the effect of the aurorae on the electric telegraph is generally to increase or diminish the electric current generated in working the wires. Sometimes it entirely neutralizes them, so that, in effect, no fluid is discoverable in them. The aurora borealis seems to be composed of a mass of electric matter, resembling in every respect, that generated by the electric galvanic battery. The currents from it change coming on the wires, and then disappear: the mass of the aurora rolls from the horizon to the zenith. [17]

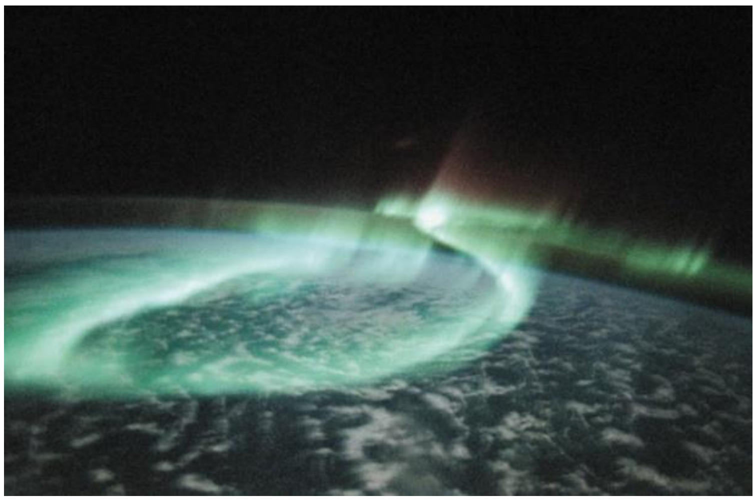

Figure 1. Aurora australis U.S. space shuttle orbiter Discovery

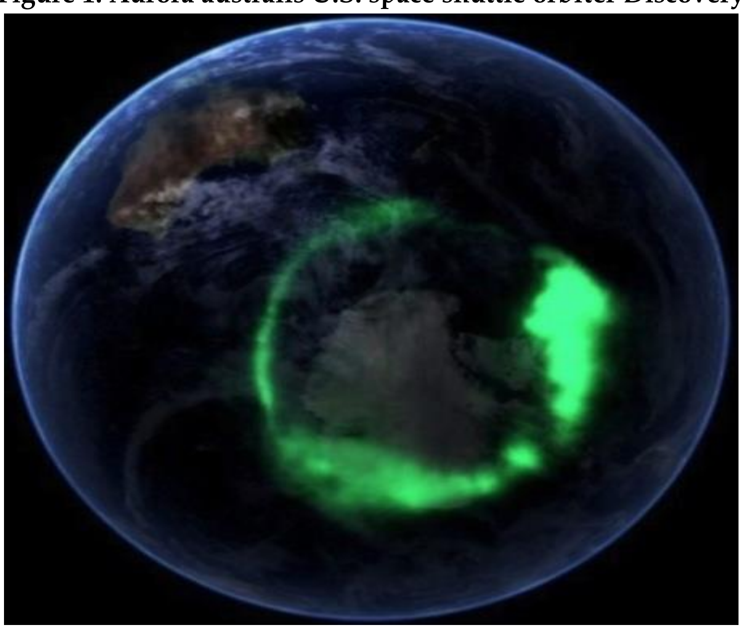

Figure 2. Aurora australis (11 September 2005) as captured by NASA's IMAGE satellite, digitally overlaid onto The Blue Marble composite image. [3]

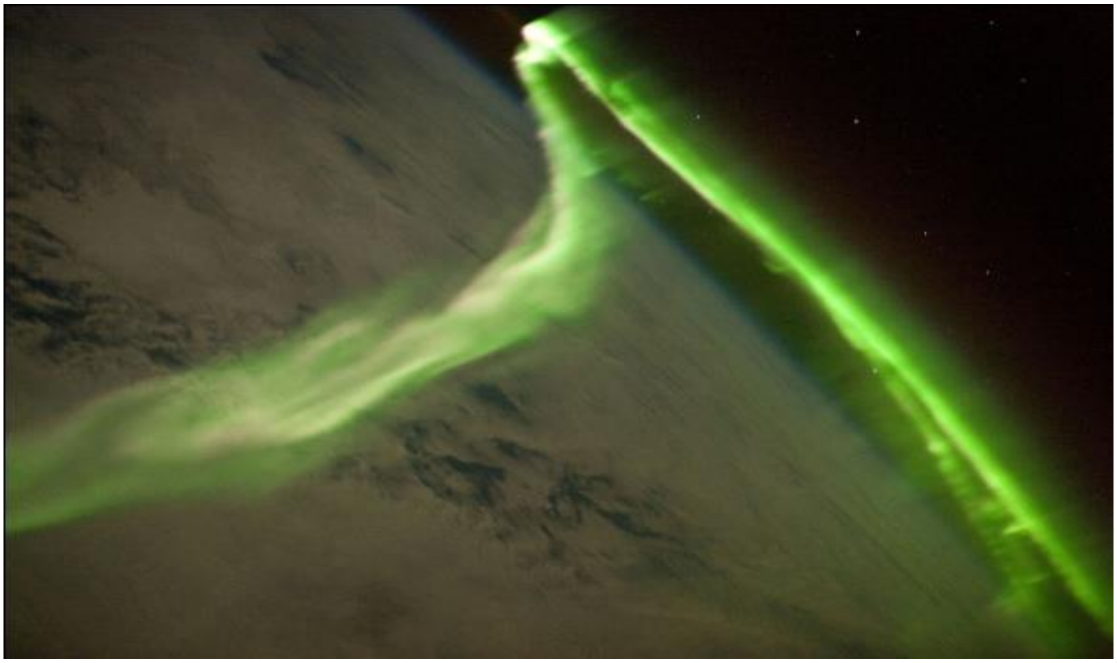

Figure 3. Aurora Australis on 24 May 2010, taken from the International Space Station [4]

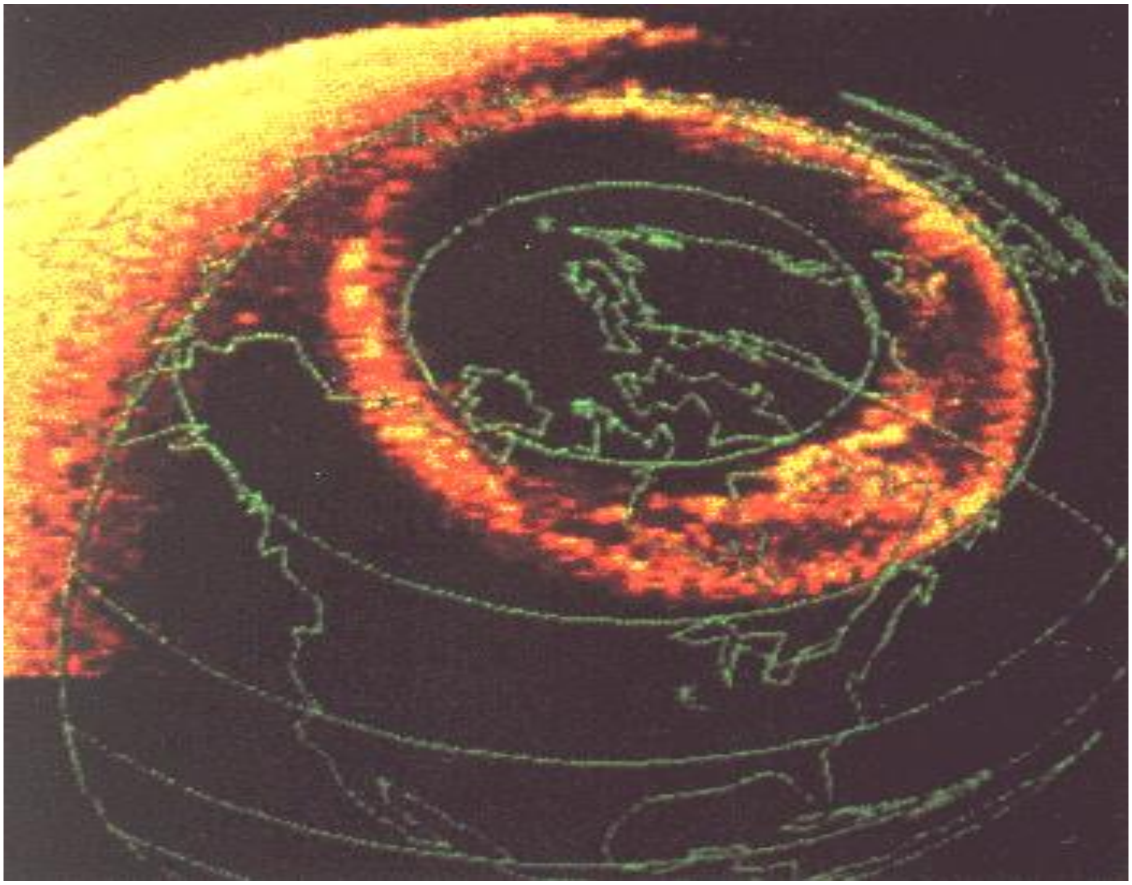

Figure 4. Diffuse aurora observed by DE-1 satellite from high Earth orbit [5]

Figure 5. Aurora australis in Antarctica [6]

Figure 6. Images of auroras from around the world, including those with rarer red and blue lights (Aurora australis panorama) [7]

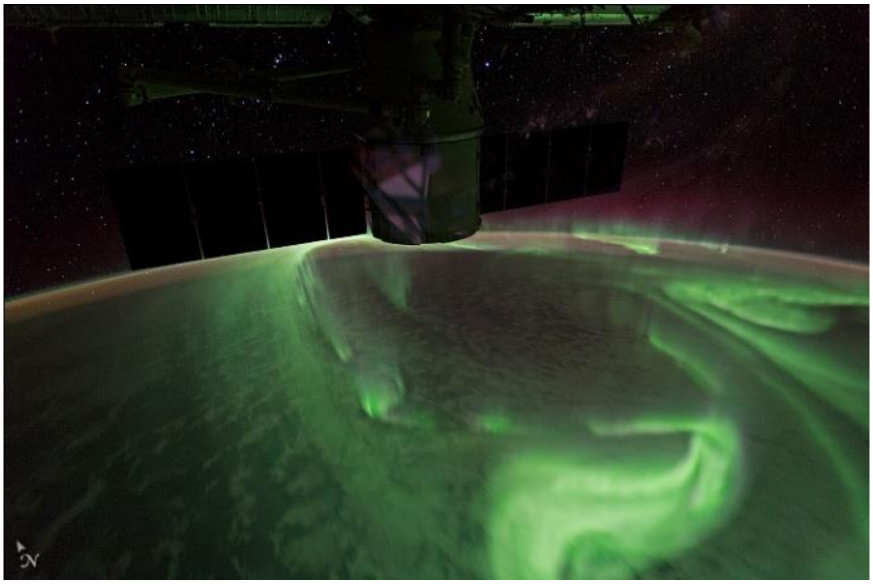

Figure 7. Aurora australis in 19 August 2017 from the ISS

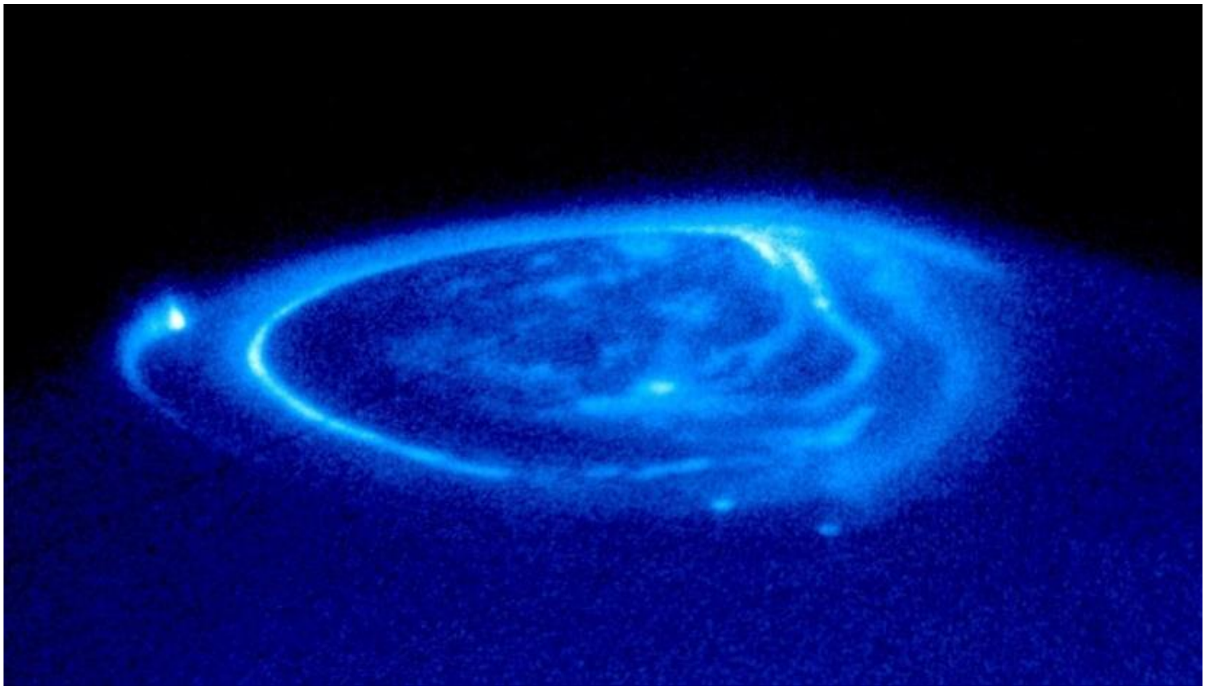

Figure 8. Jupiter aurora in UV [9]

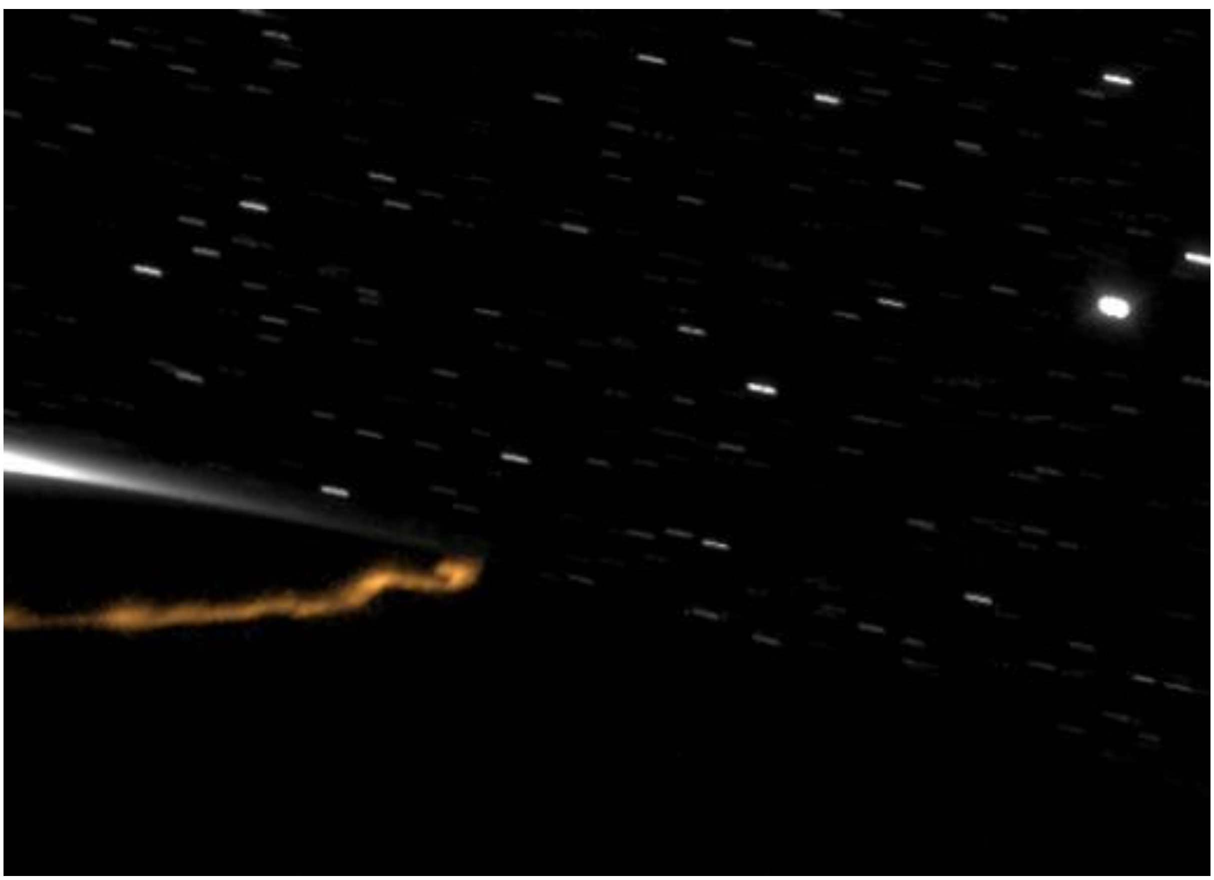

Figure 9. Saturn's aurora [10]

The discovery of a 1770 Japanese diary in 2017 depicting auroras above the ancient Japanese capital of Kyoto suggested that that storm may have been 7% larger than the Carrington event, which affected telegraph networks. [18, 19]

Conflicts of interest: The authors stated that no conflicts of interest.

REFERENCES

1. "University of Minnesota Style Manual". .umn.edu. 18 July 2007. Archived from the original on 22 July 2010. Retrieved 5 August 2010.
2. NASA/Johnson Space Center/Earth Sciences and Image Analysis Laboratory https://www.britannica.com/science/ionosphere-and-magnetosphere?oasmId=75797
3. https://en.wikipedia.org/wiki/Aurora#/media/File:Aurora_australis_20050911.jpg
4. https://en.wikipedia.org/wiki/Aurora#/media/File:Aurora_Australis_From_ISS.JPG
5. https://en.wikipedia.org/wiki/Aurora#/media/File:DEaurora.gif
6. https://upload.wikimedia.org/wikipedia/commons/0/07/Aurore_australe_-_Aurora_australis.jpg
7. https://en.wikipedia.org/wiki/Aurora#/media/File:Aurora_australis_panorama.jpg
8. https://en.wikipedia.org/wiki/Aurora#/media/File:Aurora_australis_ISS.jpg
9. https://en.wikipedia.org/wiki/Aurora#/media/File:Jupiter.Aurora.HST.UV.jpg
10. https://en.wikipedia.org/wiki/Aurora#/media/File:Saturns_Northern_Aurora_still.jpg
11. ESA Portal – Mars Express discovers auroras on Mars". Esa.int. 11 August 2004. Retrieved 5 August 2010.
12. Mars Express Finds Auroras on Mars". Universe Today. 18 February 2006. Retrieved 5 August 2010.
13. O'Neill, Ian (29 July 2015). "Monstrous Aurora Detected Beyond our Solar System". news.discovery.com. Discovery. Retrieved 29 July 2015.
14. Q. Choi, Charles (29 July 2015). "First Alien Auroras Found, Are 1 Million Times Brighter Than Any On Earth". space.com. Retrieved 29 July 2015.
15. Stewart, Balfour (1860–1862). "On the Great Magnetic Disturbance of 28 August to 7 September 1859, as Recorded by Photography at the Kew Observatory". Proceedings of the Royal Society of London. 11: 407–10. doi:10.1098/rspl.1860.0086. JSTOR 111936.
16. Green, J; Boardsen, S; Odenwald, S; Humble, J; Pazamickas, K (2006). "Eyewitness reports of the great auroral storm of 1859". Advances in Space Research. 38 (2): 145–54. Bibcode:2006AdSpR..38..145G. doi:10.1016/j.asr.2005.12.021.
17. The British Colonist, Vol. 2 No. 56, 19 October 1859, p. 1, accessed online at British Colonist. Ca Archived 31 August 2009 at the Wayback Machine., on 19 February 2009.
18. Frost, Natasha (2017-10-04). "1770 Kyoto Diary". Atlas Obscura. Retrieved 2017-10-13.
19. Inclined zenith aurora over Kyoto on 17 September 1770: Graphical evidence of extreme magnetic storm". AGU Publications. 2017-09-17. Retrieved 2017-10-13.