

## **Aurora Borealis and Aurora Australis**

The aurora borealis is a natural phenomenon that occurs near the north and south magnetic poles. Planets other than Earth also have aurorae, but many have different types, some of them not in the visible spectrum.

Auroras are visual phenomena created by an interaction between the Earth's magnetic field and solar radiation. They occur year round in high latitudes, called aurora borealis in the north and aurora australis in the south, seen mostly near the magnetic poles. The northern lights were called aurora borealis after the Roman goddess of dawn's name and the Greek word boreas, or northern wind. It is one of the oldest geophysical occurrences recorded, mentioned in many stories, legends, and myths. In 1859 the first recorded attempt to explain the heavenly lights was by physicist Richard C. Carrington who stated that it was linked to the sun. It was only half a century later that anyone believed him.

For those who have not seen it, an aurora appears to be a waving curtain of pulsating color filling the sky. It has many colors such as blue, green, and red, caused by the content of the swirling gases in the sky. The color and waves of the aurora depend on atmospheric conditions.

Optics, the study of what we see, is a branch of physics that studies the way light interacts with different types of matter. Light, the subject of study for optics,

is electromagnetic radiation, which is oscillating waves of energy, a combination of electric and magnetic forces. Their relationship makes stuff happen in odd and curious ways. The way they interact creates attraction between negatively and positively charged particles. An example of this is the adhesion of electrons and protons in atoms. There are multiple types of electromagnetic radiation, but only a small amount can be seen, and the amount that we see consists of the visible light on the electromagnetic spectrum. Because electromagnetic energy travels in waves, it is defined by wavelengths, the distance between the oscillations of the wave. Wavelengths are measured in nanometers, which is one billionth of a meter. Visual light is between 400 and 700 nanometer. This area is called the visual spectrum. Optical phenomena involve light in the visual spectrum.

Earth is a large electromagnet, creating a huge electromagnetic field around it, protecting from space rubble and radiation. The magnetic poles are several kilometers away from the north and south poles, but they shift regularly and move over 15 kilometers a year. Earth's core is mainly solid iron, but the outer core is made of many molten metals, melted by radioactive decay from the core. The radioactive decay creates currents in the outer core, spinning the molten metal around the inner core, creating an electromagnetic generator creating positive and negative energy, thereby making the magnetic poles and magnetic field.

The Sun, a huge nuclear reactor that keeps us alive with just the smallest amount of its nuclear energy, occasionally sends us radiation which we see in the form of auroras. The Sun is made of the fourth state of matter: plasma, which is

similar to gas but with ionized particles. According to scientist 99% of the observable universe is made of plasma. The Sun's superior mass and ulterior motives create pressure that turns gases into plasma, and that plasma is released as energy into the cold dark deep endless depths of space, or just as far as the heliosphere, the area in space which the Sun affects. The radiation that emanates from the sun's corona is called a solar wind, and plays a major part in many happenings. It consists of large sums of charge particles charging at 400km per second, slamming into everything obstructing its way. It just so happens that the Earth is in its way, so when the solar radiation hits the magnetic field it creates the magnetosphere. The magnetosphere is a shield around the Earth protecting us from harmful radiation. It is shaped like a tear, the trailing end facing the anti-solar side. The solar wind hitting the atmosphere forces particles to collide, pushing off of Earth, called bow shock. It pushes the particles around Earth like a stone in a stream, making the trailing end of the magnetosphere called the magnetotail, which reaches millions of kilometers into space. Usually the solar wind is not powerful enough to penetrate the magnetic field, but when the Sun erupts in a solar flare or coronal mass ejection the magnetic field distorts and becomes connected to the solar flare's magnetic field. Subsequently, the solar particles are drawn into the magnetosphere and into the magnetotail, while still connected to the leading edge of the magnetic field. The particle strand stretches until it snaps, the magnetic field returning to its original position, and the front of the particles is pulled into space through the magnetosphere. The particles attached to the leading edge of the

magnetic field are accelerated by the snap, and the magnetic field reconnects selling the magnetosphere while the particles are launched into the atmosphere. The particles join the magnetic field and concentrate on lateral magnetism lines, and when they settle they cause auroras. All of this occurs in the ionosphere, an atmospheric area at lowest 60km and at highest 4,000km above sea level. The light is caused by collision of solar wind electrons and atoms in the ionosphere. When the electrons collide with oxygen, the solar flare electron's energy is transferred to the oxygen, and the oxygen atom releases the energy as light. It will glow greenish or dark red, depending on time between collision and lighting. When the atom is not oxygen, like nitrogen, the lights are different. Nitrogen atoms make a red light, but if an electron from the nitrogen is temporarily dislodged after the collision, when the electron reconnects the light will be blue. The composition of gases in the atmospheric layers differ, so in different layers there are different colours. The top of the auroral curtain is usually red because there is more oxygen in the high atmosphere. The middle of the sheet has equal amounts of oxygen and nitrogen, so light can be green, blue, and red, however it is usually greenish blue. In the lowest layer the molecules are too tight so there is no light, because the excited molecules transfer the energy to other molecules instead of glowing. The lowest part of the curtain is pinkish, because of the blue and red. Occasionally there are rapid shifts in colour and patterns in an aurora, this is usually the result of a substorm. A substorm is a momentary magnetic field disruption, which causes an extra pulse of radiation to move from the magnetotail to the ionosphere. This phenomenon is called an

auroral eruption, and happens all the time but is best seen in the far north and south. The best sites to see auroras shift with the magnetic poles. Because the Sun goes through a 11 year cycle, the auroras are stronger every 11 years. Sept 1 1895 during the Carrington event telegraphs caused paper to catch fire, the strongest solar wind event ever recorded.

Mars is one of the planets known to have auroras, however they are not of the type that occur on Earth. In 2014 auroras were seen in ultraviolet light, during the day, in Mar's north hemisphere. This was initially a surprise because Mars has no magnetic field, so naturally scientists were eager to find the cause of these light shows. Later they figured out Mars had a different type of aurora, called a proton aurora. During the summer on Mars there are large dust storms, which force water vapour up into the atmosphere, where the water molecules are hit by extreme ultraviolet light which breaks the molecules down into their basic compounds, hydrogen and oxygen. Because the hydrogen is so light, Mars's gravity holds it in a loose gas cloud around the planet. Like all other known auroras, solar wind is involved. When solar wind hits the atmosphere, the protons in the solar wind become neutral atoms by taking electrons from the hydrogen in the gas cloud. When the atoms hit the atmosphere, the excess energy becomes ultraviolet light. This theory has been proven true, because when more water escapes the auroras become stronger and more frequent.

Jupiter, the largest planet in the galaxy, has some of the most powerful auroras ever seen-but in ultraviolet and x-ray light. Thin auroras were first seen on

Jupiter in 1979 in visible light. In the 1990s it was found that Jupiter's ultraviolet and x-ray auroras were much stronger and much more frequent, and in 2007 NASA even said Jupiter had constant auroras. Jupiter spins once every 10, generating volts by itself, which can create auroras even in low solar activity. Charged particles also come from one of the gas planet's moons, the volcanic satellite Io, which has a torus of charged particles. This is yet another example of the diversity of auroras.

Jupiter, the far off gas giant that is the largest planet in our solar system, also has the largest and strongest auroral displays. In the southern hemisphere x-ray auroras are constant, occurring every nine to twelve minutes. In the northern hemisphere the auroras are erratic, and not affected by the south, like on Earth. The reason behind this is still unknown, but scientists think it involves solar wind, oxygen, and sulfur ions from Io. Another curious thing is that what causes the stronger auroras on Earth makes weaker auroras on Jupiter.

Saturn's mysterious warmth could be explained by auroras. Nearly one billion miles from the sun, Saturn should be frigid, and mostly is. The exception is the upper atmosphere, with temperatures of 125–325° Celsius or 257–617° Fahrenheit. The high temperatures were first found by the VOYAGER missions in the 1980s, and had scientists confused until now. They are looking at the problem in a whole new **light** now that they think it may be connected to **auroras**. The temperatures are highest at latitudes 60°N and 60°S, overlapping Saturn's auroral areas. Saturn's auroras, which are stronger in the ultraviolet spectrum, were first seen in 1979 by Pioneer 11 and later by the Voyager missions. Much later in 2014 the

Cassini spacecraft, equipped with cutting edge technology for its launch date October 15, 1997, reached Saturn and collected masses of data. Solar winds hit the planet causing an electrical current, which releases heat and light causing the aurora. Because Saturn has hydrogen in its atmosphere, the auroras are in the ultraviolet spectrum. This could explain why Jupiter, Uranus, and Neptune also have unusually hot atmospheres.

Venus, a swirling planet of storms and sulfur—mostly sulfur, had flashes of light presumed to be auroras. Venus has no magnetic field to speak of, but by now that means nothing in consideration to auroras. In 2012 Journal Science announced the discovery of magnetotails, something that planets with magnetic fields had when barraged with solar winds, making a magnetosphere. On Venus a magnetotail is created by solar wind directly hitting the atmosphere. What causes auroras on Earth creates magnetic bubbles around Venus. This could explain the flashes of light on Venus and comet tails. Usually magnetic reconnection, when in auroras the strand of solar flare particles snaps back, only occurs on planets with magnetic fields. Since Venus has a magnetotail without a magnetosphere, it also has magnetic reconnection. This magnetic reconnection creates a plasma bubble that lasts for 94 seconds. The plasma dynamics on Venus are very similar to Earth. With magnetic reconnection, the flashes could be auroras.

In 2012, NASA released images of auroras on the cold, distant planet of Uranus. The auroras were caused by charged particles hitting the atmosphere,

exciting molecules and encouraging them to glow, creating the same effect as on Earth.

Ganymede, Jupiter's moon, enjoys its own auroral lights. So far it is the only moon in the solar system to have a magnetic field. The magnetic field was found in 2002 by NASA's Galileo spacecraft. In 2015 by watching the auroras they think that there may be an ocean under the surface. Ganymede is also in Jupiter's magnetic field and therefore affected by the gas planet's field shifts.

In the 1990s Voyager 2 sailed the skies dark blue, reporting auroras on Neptune. Hmm, this is getting repetitive, about every planet except for Pluto is known to have auroras now. Anyhow, the auroras on Neptune are not concentrated in one area, which may be due to Neptune's high tilt, which causes a more complex magnetic field. The auroras are scattered around the planet but at weaker levels.

Planets and moons are not alone in having planets. Comets, rocky outposts floating through space in a lonely orbit, have auroral light shows that keep them company. ESA's Rosetta mission to Comet 67P/Churyumov-Gerasimenko proved to be very successful in many ways. While researching the comet Rosetta found that it had auroral displays. This was the first time that auroras were seen on a comet, and scientists were eager to find out more. No one thought that comets could have auroras due to their lack of any magnetic field, but here was Comet 67P/Churyumov-Gerasimenko with its unmistakable ultraviolet auroras. The Rosetta mission was equipped with state of the art technology, for the time it was launched. It had an IES (Ion and Electron Sensor) and ALICE FUV spectrograph. The



IES sensed the aurora and ALICE saw the ultraviolet glow. The scientists were surprised when they found it was an aurora because originally they thought it was dayglow. Like on Earth, the aurora is caused by solar wind interacting with the gas around the comet. However, it is not the photons that make the light but the electrons in the solar wind. The ambipolar electric field makes an electron pressure gradient by making a well that draws electrons to the comet's nucleus. The electrons are then moved along the oblong magnetic field lines into the well. The ambipolar field is created by cometary plasma and the electron pressure gradient. The solar wind and cometary plasma make localised acceleration of solar wind particles which creates the aurora. This shows that there are many ways to make auroras, and this one doesn't even need solar flares. The Rosetta mission was a great one, the first spacecraft to orbit a comet, the first spacecraft to travel with a comet, the first spacecraft to land on a comet, and the mission that discovered cometary auroras. Even though after 12.5 years on September 30th 2016 it was intentionally smashed against the comet, Rosetta shall always live on in our hearts. (And science books)

Many tales mention the unearthly sounds, such as what resembled radio static, faint crackling, light rustling, hissing and clapping, made by powerful auroras, and scientists thought the sounds were just that-tales. But Finnish scientists have proven that these sounds are actual happenings. There is a layer in the atmosphere that forms on cold nights filled with charged particles. The particles rapidly discharge when solar radiation hits, creating noises. When solar flares cause

geomagnetic storms, there are massive auroras. Before their enlightenment, they thought pine needles or cones could be the cause. Geomagnetic storms make high charge between the air and the ground, and pointy things help electricity discharge, making sounds. But in 2002 researcher Unto K. Laine proved that the sounds were coming from 70 meters above the ground. His team did a follow up study, which showed in the inversion layer in the air temperature increased with altitude, contrary to usual. This happens after calm sunny days, when warm air rises and the surface cools. The hot and cold don't mix because of the calm. The layer is basically a lid that blocks negatively charged particles below, and positively charged particles above. The geomagnetic storm crashes through the layer, and the charge is released, making a sound.

However, not all aurorae are auroras. First seen in Alberta, Canada in the year 2016 STEVE is a long purple streak across the sky. It was obvious it was different from usual auroras due to its colour and visibility at lower latitudes, even though it also occurred in the ionosphere. The citizen scientist who first observed STEVE called it Steve as a reference to the 2006 animated comedy Over the Hedge. Elizabeth MacDonald, a space physicist at NASA, liked the name so made the backronym STEVE (Strong Thermal Emission Velocity Enhancement). In 2008 it was called a new type of aurora, but later in 2019 they classified it not as an aurora but a different type of sky glow. Recently STEVE has been found by itself, and there were most certainly not enough charged particles for a typical aurora. The latest study was in May 2019, where probes and satellites were sent to STEVEs to study

further. It certified that it was in the ionosphere, and definitely not an aurora. It was found to be low energy streams of excited particles bouncing off neutral particles, creating friction. The friction is transferred into heat, which comes off as a purple glow, like a lightbulb filament. Auroras have been seen before next to what is called a 'green picket fence'. This is a type of aurora, caused by a magnetic bubble releasing waves of particles. When the wave hits the ionosphere, the electrons are slammed into the upper atmosphere, hitting particles and transferring energy, making dramatic pause, light. However, this study only researched three STEVEs, so more proof is needed to be certiant, but we can know for sure that scientists will stop at nothing to reveal STEVE's secrets.

*If another Carrington event occurs, at least we can be assured that there will be simply fabulous auroras to watch as the human civilization collapses around us.*

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