Aurora Borealis

By: Alicia England
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Aurora Borealis, also known as the northern lights, are commonly known especially due to the many legends and folklores that originate from the mysterious lighting. Ancient Eskimos looked at the northern lights as a lighted pathway that lead spirits to the afterlife. Still others looked at the lights as a living entity, protecting themselves with knives out of fear that the lights would carry them off[1]. Mort recently and more accurately, the aurora have been described as “a shifting pattern of images displayed on the fluorescent screen provided by the atmosphere[2].” It was not until the 1950’s that realistic answers began to be formulated for the appearance of these seemingly supernatural light shows.

Briefly, Aurora Borealis refers to the natural light show that occurs occasionally in the northern hemisphere. This occurrence results from charged particles called solar wind, which is a continually emittance of electrons and proton from the sun, entering the Earth’s atmosphere guided by Earth’s magnetic field[2]. Once captured by the Earth’s atmosphere, the particles interact with molecules contained within the atmosphere. The collisions occurring between the electronically charged particles and atmospheric molecules result in fluorescent luminosity which is known as Auroras.

The name Aurora Borealis, given by Pierre Gassende in 1632[3], originates from the Greek goddess of dawn, Aurora, and the Greek term for “wind,” “Boreas”. A similar occurrence known as Aurora Australis, named using the Latin word for “southerly”, occurs in the southern hemisphere. In actuality, these two occurances, Aurora Borealis and Aurora Australis, are the same phenomena and will occur at the same time with the same intensity during peak solar activity[4].

The luminosity that can be observed on a clear night is explained by collisions occurring between charged particles emitted from the sun that have entered Earth's atmosphere and atmospheric molecules[2]. The atmosphere is composed of mainly nitrogen and oxygen atoms; therefore, these molecules are most commonly involved in these collisions. When the charged particles collide with a molecule at high velocities, the molecule is either stripped of one or two electrons (ionized) or raised to a higher energy state while the charged particle continues into the atmosphere at a slower rate[2]. Both events put the molecule into an extremely unstable energy state. When the molecule is able to return to stable state, energy is released in the form of a characteristic wavelength which correlates to the molecule that the energy originated from[1]. Since the atmosphere is more densely compact molecularly near the surface of the Earth when compared to the upper most regions of the atmosphere, the farther into the atmosphere the charged particles are able to travel, the more frequent collisions occur and the brighter and larger the aurora will be. Aurora phenomena occur when a plethora of these collisions occur and a large amount of energy is being released by several molecules.

The colors of the aurora are determined by the molecules that the charged particles collide with and at what altitude the collisions occur. The colors of the auroras most commonly range from green to blue-green and pink to red. When an excited oxygen atom releases energy, it produces either a green or red light at 5,577angstroms or 6,300 angstroms respectively. An ionized nitrogen molecule produces violet and blue light which ranges from 3,914 to 4,700 angstroms. In addition an excited nitrogen molecule emits a deep red light at 6,500-6,800 angstroms[2]. However, aurora displays are predominately green and blue. This is because the altitude of the collisions contributes to color as well. At 100 kilometers, oxygen radiation of 5,577 angstroms and nitrogen radiation at 3,900 angstroms dominate whereas 6,300 angstrom emission of oxygen molecules mainly occurs between 200 and 400 kilometers[2].

At lower altitudes (100 kilometers) oxygen molecules are not likely to emit radiation in the 6,300 angstrom range. However, this is not because there is a lack of oxygen molecules available to become excited to this state. If an oxygen molecule were to become exited to the stage of being able to emit 6,300 angstroms, the spontaneous emission of energy would occur only after about 200 seconds[2]. At this low altitude with such a high density of molecules, there is a high probability that the excited molecule will collide with another atmospheric molecule and dispel the majority if not all of the energy. However, at these low altitudes, an excited oxygen molecule will spontaneously discharge at 5,577 angstroms in only 0.7 seconds[2]. In this limited amount of time, the molecule is unlikely to be bombarded by other molecules and lose energy. Therefore, because of the difference in spontaneous energy emission time, green light will dominate over red light in auroras occurring at lower altitudes.

Higher in the atmosphere, the molecular density of the atmosphere is considerably less, and therefore, the probability of an excited molecule colliding with another and dispelling energy in the 200 seconds that it takes for spontaneous release is reduced greatly. For this reason, the likelihood of an oxygen molecule releasing 6,300 angstroms is greater at higher altitudes. However, there is so few oxygen molecules located in altitudes higher than 100 kilometers that in order to produce a red emission with a forceful presents, incoming particles from solar with must be dense enough to excite a large majority of oxygen molecules in the upper atmosphere[2]. Since different molecules release different amounts of energy at different altitudes, valuable information regarding the molecular composition of the upper atmosphere at different altitudes can be determined using the colors of aurora flares.

The general shape of auroras is often compared to a ribbon or an arch. Many accounts of aurora sightings show that in addition to this ribbon-like structure, the illuminations also seem to consist of parallel rays that run the width of the projection[5]. On average, the illuminations have vertical dimensions of a few hundred kilometers, lateral dimensions of a few thousand kilometers, and are only a few hundred meters thick[2]. These dimensions obviously will fluctuate as the flux of incoming solar particles changes; however, from the dimensions, one can conclude that a sheet like beam of electrons is the culprit that creates the eerie atmospheric projections[2]. Another important aspect to recognize is that the parallel rays running through the ribbon projections and in fact the ribbon structures themselves, both closely follow that path of Earth's magnetic field. The parallel rays that run laterally through the projection trace a component of the Earth's magnetic field that is largely ignored. Contrary to the deception of a traditional magnetic compass, the Earth's magnetic field not only runs north and south from pole to pole, but also laterally running into the Earth in a downward direction[5]. These parallel rays are a result of this component of Earth's magnetic field. The ribbons structure of the aurora typically span in the east-west direction, which indeed lines up with Earth's magnetic field. The electrons traveling along these field lines in fact spiral around the magnetic field as they travel towards Earth. The different appearance of the projections are due to prospective and the intensity of the incoming plasma. At time the projections are calm and referred to as "quiet aurora" while at other times the projections are erratic, "active aurora[5]." This difference is due to the different intensity of incoming plasma. When observed from afar at more southerly latitudes, the aurora will appear on the northern horizon and will have more of a ribbon-like appearance than if the observer is located directly below the aurora. In the latter case, the aurora will look more like a cloud with no predictable pathway[5]. These two differences are due only to a difference in perspective.

Solar wind contributes greatly to the occurance of aurora; therefore the concept of solar wind will be explored in greater detail. In 1943, observations of comet tails lead to the theory of the existence of a "solar corpuscular radiation," a steady emission of particles from the sun; however, at the time the reason why such emission existed was unknown. In 1958, while trying to derive the equilibrium structure of a corona, Eugene Parker from the University of Chicago proposed a theory that explains the existence of solar wind[5]. The particles incorporated in the sun are held together by the sun's gravitational similar to the way Earth's atmosphere contains matter at Earth's surface; however, the velocity of all particles is determined by the temperatures at which they exist. The gravitational field of the sun is considerably greater than that of the Earth, but the temperatures on the sun far surpass that of the Earth as well. In fact, the temperatures are so great that the gravitational field of the sun is not adequate enough to contain all particles that compose the sun. Some of the particles are traveling fast enough, due to high temperatures, to break free from the gravitational field of the sun[5]. For this reason, the sun continually emits particles, known as solar wind, into space at a velocity of 400 kilometers/second.

The occurance of solar flares on the surface of the sun can intensify the flux of sun particles that reach Earth. The term solar flare refers a violent release of energy near a sun spot[6]. As one can imagine, as the flux of particles that are able to reach Earth increases, so does the frequency of aurora illuminations. A sun spot is a darken spot on the surface of the sun that is an area of intense magnetic density. Sun spots are thought to be caused by an uneven rotation within the sun[5]. The equator region of the sun rotates faster than regions near the poles. This uneven rotation and the fact that the sun's outer most layer are consistently churning is thought to induce the areas of intense magnification known as sun spots. This area on the sun appears to be darker that the rest of the run because the magnetic field induced in the area is much cooler than the rest of the sun. Sun spots form continuously on the surface of the sun; however, they follow an 11-year cycle[2]. According to this cycle, the frequency of sun spots and therefore also the frequency of solar flares can be predicted. The last maximum of solar flare activity occurred in 2001[5], and therefore, the last maximum in aurora activity occurred around this same time. Aurora activity seems to peak along with the 11-year cycle, but the increased aurora activity continues for up to three years after the peak season.

Looking at the composition of solar wind, it is comprised of the same material, in the same proportions as the sun itself because, in essence, the wind is a decaying portion of the sun. Particles leave the sun in the form of a plasmid, an neutrally charged composition of charged particles; therefore, solar wind has some distinct characteristics of plasmids. Namely, plasmids are able to capture and carry magnetic fields far beyond the normal reach of the field lines. Hence, the sun's magnetic field is spread to the other planets of the galaxy by solar wind. The interplanetary magnetic field, IMF, solely referrers to the sun's magnetic field that is carried to other planets by the solar wind[5]. This field had a distinct role in the creation of aurora illuminations.

Auroras are initiated by interactions between solar wind and the Earth's magnetosphere. As discussed earlier, solar wind is a plasmid, or a neutral composition of both positive and negatively charged particles[6]. A is characteristic of a plasma, the plasma from the sun is highly electrically conductive; therefore it is able to carry particles to the Earth and it is also able to trap and carry the sun's magnetic field to Earth[7]. The magnetosphere, also known as Earth's magnetic field, is a magnetic shield that surrounds the Earth. The field, like all magnetic fields, is created by the movement of electrical charges. In the case of the Earth, the origin of the magnetic field is thought to be "associated with electrical currents produced by the coupling of convective effects and rotation in the spinning liquid metallic outer core of iron and nickel.[8]"

Contrary to the name, the magnetosphere is distinctly non-spherical. The shape of the magnetosphere is determined by the shape and intensity of the Earth's magnetic field, the intensity of the solar wind, and the forces caused by the interplanetary magnetic field, commonly referred to as IMF. The shape of the magnetic field close to the surface of the Earth is similar to that of a bar magnet in the sense that is a dipole with poles that are located at the northern and southern ends of the earth. Further from the surface, when solar wind, traveling at 400 kilometers per second comes in close contact with the Earth, the magnetic field of the sun, carried by the plasma, and the magnetic field of Earth interact causing violent distortions of Earth's magnetic field[7]. The side of the magnetic field facing the sun, and therefore being bombarded by solar wind is pushed inward and condensed. This interaction slows the plasma greatly; however, the magnetic field of the sun still remains large and continues to distort Earth's field. The solar wind is deflect around the field of the earth upon impact, but the magnetic field carried by the wind causes the portion of Earth's magnetic field that does not face the sun to stretch into a tail that extends more the 1,000,000 kilometers into space[7]. This causes the distinctive shape of the magnetosphere which is illustrated in Figure 1[11].

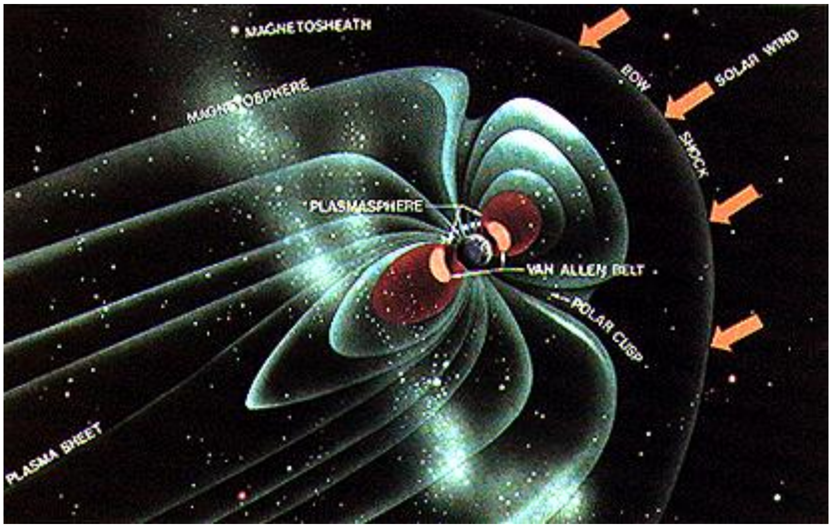

Figure 1: Shape of the Earth's magnetosphere[11]

When looking back at the main cause of aurora illuminations, the bombardment of atmospheric molecules with particles contained in solar wind, there is more that needs to be explained. If the sun particles just merely passed through the magnetosphere and into Earth's atmosphere, they would not posses enough energy or be traveling fast enough to transfer the proper amount of energy to create a visible aurora. In early 2007, NASA set out to explore the source of acceleration and energy. They launched a fleet of five satellites called THEMIS, Time History of Events and Macroscale Interactions during Substorms, in order to view the cause of substorms from Earth's atmosphere[9]. Simultaneously, NASA set up watch stations in order to observe aurora activity on Earth's surface, to see between substorms and aurora activity. "Substorms are global reconfigurations of the magnetosphere involving storage of solar wind energy in Earth's magnetotail and its abrupt conversion to particle heating and kinetic energy[10]." The fact that auroras are caused by substorms is a widely known fact; however, what was not known at the time was the cause of a substorm. This was NASA's goal, to find what caused substorms. Scientists set out to determine which of two phenomenons was the cause of magnetic substorms. Substorms were either triggered by a disconnection in the electrical current which flowed across the tail of the magnetosphere which occurs close to the Earth, or triggered by a process called magnetic reconnection which occurs considerably further from the Earth[10]. Both events were known to occur during a substorm and therefore during aurora illuminations; however, the direct cause of the substorms was unknown.

The satellites were launched so that they would align around the equator once every four days and take images that correlated to surface imagery. During one of these line ups in early 2008, the satellites observed the onset of a substorm occur in space while the watch stations located at the surface recorded an increase of aurora activity and space current in the northern latitudes[9]. From this observation and others collected from the THEMIS fleet, NASA was able to determine confidently for the first time that magnetic reconnection was the cause of magnetic substorms.

Magnetic reconnection is the rearrangement of two magnetic field lines from dominating sources into one magnetic field line[6]. Magnetic reconnection, in regards to substorm activity, occurs when a southern facing magnetic field originating from the sun, is carried by the solar wind toward the earth's magnetic field[10]. The northern facing magnetic field of the earth and the southern magnetic field of the sun, which is trapped in the plasma, strongly interact. If these interactions are strong enough, for example the intensity of the sun's magnetic field is intensified by a solar flare, the two magnetic fields will break, rearrange and connect into a magnetic field that is at a lower energy state[6]. This event is the first of two reconnections that aid in the acceleration of the sun particles. This reconnection leaves a hole in the magnetosphere which freely allows solar wind to pass through. At this point, even though the two magnetic fields have combined, the field is still captured by the solar wind plasma. The plasma carries the combined sun and earth magnetic field backward into the tail of the magnetosphere. In the tail, the magnetic field is stretched to the far edges of the tail which in roughly 1,000,000 kilometers away from the Earth's surface[6]. This stretched magnetic field is extremely unstable. In order to return to a more stable energy state, the magnetic field breaks and recombines again, this time into two regions. One of the regions while be completely dominated by the Earth's magnetic field, while the other region returns to the form of solar wind. The region that now consists of Earth's magnetic field is forcefully pulled back toward the surface of the earth at accelerated speeds bringing with it the plasma particles that were trapped in the field after the first reconnection[6]. The forceful pull of the field back toward Earth gives the particles the acceleration and the energy required to create aurora projections.

The particles that have been trapped by the field then travel back to Earth following the earth's magnetic field lines. The particles rapidly spiral around the field lines as they approach the surface. Since there is no selectivity of the northern pole over the southern pole, the particles are free to travel to either. Due to the lack of selectivity, the particles will actually flow to each, the north and the south poles of the earth in equal proportions. Therefore, as mentioned earlier, the aurora borealis and aurora australis will occur simultaneously and will actually be mirror images of one another[7].

In short, the auroras are caused by solar particles, solar wind, bombarding atmospheric particles and transferring energy. When the atmospheric particles spontaneously release this energy, it appears as a luminous glow. The aurora comes in different colors according to the molecules being bombarded and the altitudes at which the collisions occur. The shape and intensity of the aurora is determined by the flux of the incoming solar particles, which can be altered by solar flare which are prominent at a peak or an 11-year cycle, and by the placement and perspective of an observer. The magnetosphere provides the foundation for the initiation of a substorm which correlates to the onset of aurora projections. NASA was able to determine that substorms are caused by the combination of magnetic fields into a more stable field, magnetic recombination. The magnetic recombination of the sun's field, carried by the solar wind plasma, and the earth's field provided the necessary energy and acceleration for an aurora to be visible. After the recombination, the particles are able to freely traverse along the earth's magnetic field lines to the poles where the aurora borealis and aurora australis phenomenon occur as simultaneous mirror images of one another. The aurora, initially not understood, not only provides a fascinating display of nature's supremacy, but it also provided puzzle to be solved. Through years of observation and experimentation, scientists have slowly begun to unravel the mysteries behind the great aurora borealis.

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