The Makings of an Aurora

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Lab Section H1

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Encyclopedia Britannica defines an aurora as a “luminous phenomenon of Earth’s upper atmosphere that occurs primarily in high latitudes of both hemispheres” and states that auroras are caused by “the interaction of energetic particles (electrons and protons) of the solar wind with atoms of the upper atmosphere.” (Britannica 2012) Those are some fancy words, but what do they really mean? What is an aurora? How is the aurora that lights up the night skies created?

First, an aurora is not a weather related phenomenon. An aurora forms between 95 kilometers and 1000 kilometers above the earth’s surface while most weather phenomenon occurs within the first 16 kilometers above earth’s surface. (Earth 2007, Geophysical 2003) Neither is an aurora a refraction of sunlight. Unlike a rainbow created when sunlight is put through a prism, which has a continuous transitional spectrum, auroral lights are formed by wavelengths of light specific to the atoms and molecules producing them. (Geophysical 2003) An aurora is actually much closer related to a neon sign it how it is created and works.

The creation of an aurora is actually a fairly complex system made of many parts that, if not performed just right, will fail in their endeavor. To create an aurora pieces as small as atoms and molecules play just as important a role as the big pieces that are the earth’s magnetic field and atmosphere and the sun. With just one piece missing, the whole organization falls apart. So where does the whole process begin? Surprisingly, it does not start on earth. No, the ability to create an aurora all starts 149 million kilometers away on the sun.

The sun is the energy source of an aurora. Because of its active, explosive, gaseous surface, a continuous stream of charged particles is emitted from the sun’s outermost atmosphere, also known as the corona, as seen in reference picture 1 provided at the end of the paper. The high temperatures of the corona, more than one million degrees, caused the hydrogen atoms in the atmosphere to split into protons and electrons, which can be defined as charged particles. Another name for these particles is plasma. They are also commonly referred to as high-energy protons and electrons. Because of the charge of the particles, they are highly conductive. (Geophysical 2003) This will come into play later with Earth's electric field and magnetic field. The intense heat eventually breaks these particles away from the sun's gravitational force and sends them shooting off into space. This phenomenon is called the solar wind, see reference picture 4, and it can travel at speeds from 300 to 1000 km/sec away from the sun. At these speeds, these charged particles can reach Earth's atmosphere in only two or three days. The intensity of the solar wind changes constantly, so the amount of charged particles being carried changes as well. (Earth 2007)

As stated before, the sun is the energy source of an aurora, so the more energy the sun puts out, the stronger and brighter an aurora will form. Thus the more intense the solar wind and more charged particles that make it up, the more intense an aurora will be. (Geophysical 2003, Earth 2007) There are two cycles of the sun that affect the amount of plasma or solar wind released from the sun.

The first is the eleven-year cycle, which correlates to the variation of the sun's solar sunspots. (Omholt 1971) A sunspot is a dark splotch on the sun's surface. The darker coloring comes from the cooler temperature radiating from these spots. The amount and locations of sunspots on the sun's surface change at an almost regular cycle. The cycle peaks every eleven years and during this peak the sun has more sunspots than any other time in the cycle. During this peak, the sun has strong solar wind and some of the strongest auroras are viewed. The reason the amount of sunspots on the sun's surface is important to the making of an aurora is because of a phenomenon known as coronal mass ejection, see reference picture 2. A coronal mass ejection is a massive explosion at the corona of the sun. These explosions then send out large gusts of solar wind. These ejections occur most often around sunspots. Thus the more sunspots there are, the more coronal mass ejections there can be. (Geophysical 2003)

The second cycle that affects solar wind is the 27-day cycle. A solar wind can be developed from a coronal hole as well. A coronal hole, see reference picture 3, is a dark hole on the sun's surface that usually forms after the sunspot cycle peak, mentioned above. These holes can last for more than twelve months. A gust of strong solar wind is emitted from these holes and hits the earth whenever the hole is facing it. Since the sun takes 27 days per one rotation, every 27 days the coronal hole can send a blast of solar wind at the earth. (Geophysical 2003, Earth 2007)

Once these charged particles have traveled from the sun and reached earth, they crash into the earth's magnetic field and are then deflected away from the surface. This collision does not stop their movement thought. It only changes the particles' course. The particles travel along earth's magnetic field and, as they travel, the particles actually move the field outward, stretching it into what most call the tail of the magnetosphere, see reference picture 4. At a distance of more than six million kilometers, this tail is long. It even reaches past the moon. (Geophysical 2003, Earth 2007)

Note that both the earth and the sun are magnetic and thus have magnetic fields. The Earth's magnetic field is created from the Earth's rotation, which causes the molten metal core of the earth to rotate. This rotation generates a moving electrical force. Since there are moving electrical charges, the earth has a magnetic field. (Stewart 2011, Geophysical 2003) The particles that make up the surface of the sun are in constant motion, which is how the magnetic field is developed in the first place. (Savage 1994) A magnetic field is created when the particles of an electric field are in motion. (Stewart 2011) When the charged particles break loose from the sun's atmosphere, the magnetic field is still with them. Therefore, the particles go hurtling through space with an electric field from their charge and a magnetic field as well. Therefore, the two magnetic fields of the particle and earth interact together. They eventually fuse together in the outer parts of the magneto-tail, which is a common name from the tail of the magnetosphere mentioned above. As the charged particles move along this fused magnetic field, electrical power is generated. This happens because electricity is produced when a conductor, like the high-energy particles, experiences a change in its magnetic force. This force can come from moving the charged particles across a magnetic field. This will send a flood of the charged particles, both protons and electrons, down along the magnetic field lines. (Savage 1994) The magnetic field lines eventually lead back to the earth's magnetic poles just like in a magnetic dipole where the magnetic field lines run from the north oriented side to the south oriented side of the magnet. The field lines are always closed in a magnetic dipole. (Stewart 2012) Thus, all of earth's magnetic field lines lead to the magnetic poles.

The charged particles travel down the magnetic field lines and through the semi-vacuum that is the magnetosphere until they reach the upper edge of the ionosphere. The ionosphere, unlike the magnetosphere, has a thin collection of gas particles making it up. Earth's atmosphere is made up of 78% nitrogen, 21% oxygen, and 1% of miscellaneous gases. The amount and thickness of the collection of gases thins with increasing altitude. With the ionosphere being the upper most atmospheric layer, besides the magnetosphere, which is practically void of these gases, it has the thinnest amount of gases making it up. (Geophysical 2003, Savage 1994) In the ionosphere is where the effects of all these interactions begin to take shape into an aurora.

The gases that make up the layers of the atmosphere have a unique reaction when interacting with the plasma from the sun. This reaction is what causes the formation of an aurora. As the charged particles travel through the ionosphere, they collide with the oxygen atoms and nitrogen molecules that make up the ionosphere. During this collision, the energy from the charged electron particles is transferred to atmospheric gases. This transfer of energy puts the atoms and molecules in what is called an “excited” state. (Omholt 1971)

During this excited state, the atom or molecule attempts to regain balance in its charges by removing the extra energy. This is done in two ways. The first is not very exciting and does not result in an aurora. If an excited atom or molecule collides with another atom or molecule, the energy is lost in the collision and the atom or molecule returns to its original state. The second is the basis for an aurora. If an atom or molecule does not collide with another right away, after a split second the atom or molecule will release the extra energy that was transferred to it by releasing a burst of light thus expending the extra energy. The transfer of energy and burst of light takes only microseconds to occur. Just one tiny atom releasing a bit of light does not sound very exciting, but when thousands of atoms release this light all at once, an aurora is formed. (Geophysical 2003, Savage 1994)

The colors of the lights in an aurora are determined by the gases emitting the light. See reference picture 10 for an example. The main gases that emit these colored lights are of course the two most abundant in the atmosphere: oxygen and nitrogen. The oxygen atom emits the most common light color, green-yellow, found in an aurora. Oxygen atoms can also emit less frequently a deep red light. (Earth 2007) The green-yellow light is emitted from the normal oxygen atom’s collision with a solar electron. After a second, the green-yellow light is emitted. While this is the norm for oxygen atoms, they can also hold the energy transferred from the high-energy electrons for up to two minutes. If an oxygen atoms manages to keep the energy for anywhere near that length, the light emitted is a deep red. The length an oxygen atom has to go without colliding into another atom to produce a red light explains why it is the less frequent of the two colors emitted from oxygen atoms. (Geophysical 2003) Nitrogen emits either a blue light or a pinkish-red light. The bluish light from a nitrogen molecule happens when a nitrogen molecule becomes ionized after it is struck by the high-energy electrons from the solar wind. (Earth 2007) The solar electrons knock some of the nitrogen’s electrons loose causing the nitrogen to regain its lost electrons before returning to the excited state. Once back in the excited stated, it released a bluish light to expend the energy. The pinkish-red light is the light emitted through the normal transfer of energy from the solar wind electrons to the nitrogen molecule. (Geophysical 2003)

The location where these colors appear is also fairly routine. The deep red of oxygen atoms is found in the upper most atmospheres. The most common green-yellow is found ranging from the upper to the middle to the lower atmosphere. It is the most abundant color usually seen in an aurora, so it obviously takes up the most area. At the bottom atmosphere is the bluish light from the nitrogen molecules and below even that is that pinkish light also from the nitrogen. (Geophysical 2003)

Of course, there are distinct things that come into play to put these lights in their specific arrangements. One of these is the atmosphere itself. Auroras usual become visible anywhere between 400 and 1000 kilometers above the earth’s surface. The highest an aurora can appear, or the highest the top most part of an aurora will materialize, is about 1000 kilometers above the earth’s surface. This is in the ionosphere mentioned earlier. In the part of the atmosphere the amount of oxygen atoms is very thin, so when they are hit with the solar electrons, the oxygen atoms can hold the energy for longer than usual without colliding with any other atoms. (Earth 2007) Thus, this leads to the deep red being the uppermost layer of an aurora. As the lights form closer to earth, the oxygen atoms have less time to hold on to the energy, so the green-yellow light starts emitting more and more. About 100 kilometers above the earth’s surface, there are too many oxygen atoms in the atmosphere for them to be able to hold onto the energy long enough to emit light. They just start colliding with one another. This is when the nitrogen molecules come in to play. A nitrogen molecule emits light at a much faster rate than an oxygen atom, so in the lower atmosphere where oxygen can no longer emit light, nitrogen keeps going. Therefore, between 100 kilometers and 70 kilometers above the earth's surface, the nitrogen atoms release their common colored light of pinkish-red. Below 70 kilometers the atmosphere is too thick even for nitrogen to have time to emit light before colliding, thus the auroral lights stop. Also by this time, the velocity that has carried the high-energy solar electrons through the earth's atmosphere has lost most, if not all, of their momentum and cannot penetrate any further into the atmosphere. (Geophysical 2003, Earth 2007)

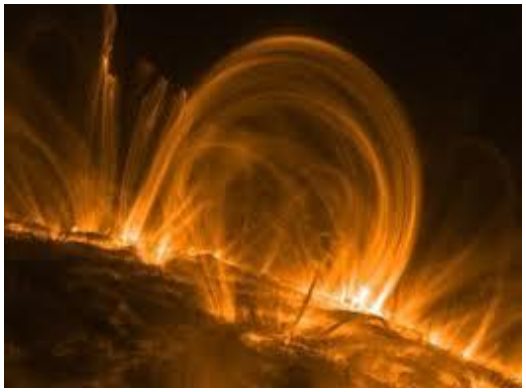
Because the charged particles flow down the magnetic field lines to the earth's magnetic poles, an aurora can only be seen at the magnetic poles. From outer space, high above the earth's atmosphere, the aurora appears as distinct oval rings encompassing the magnetic poles in both the north and the south hemispheres, see reference picture 5. These two rings are symmetrical to one other and their auroras happen at nearly the same time. (Savage 1994, Omholt 1971) The center of the ring is the magnetic north and south poles not the geographic north and south poles. There is a difference! The geographic poles are fixed positions that can be found on any world map, while the magnetic poles tend to shift over time due to the fact that the earth is not a permanent magnet and thus its magnetic field is not centralized. Because an aurora is not geographically bases, the auroral oval does not fall on the line of latitude equally, so people at the same latitude on opposite ends of the world do not have an equal chance of seeing an aurora. Although that only works if they are both in the area that an aurora can normally be seen from, also known as the auroral zone. (Earth 2007)

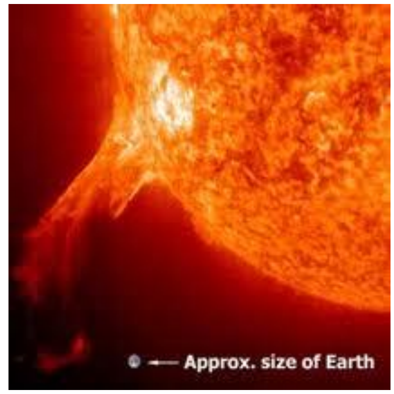
The width of the oval of an aurora can range from ten kilometers to 1000 kilometers and the oval has a radius, centered at the magnetic pole, of approximately 3000 kilometers during the quieter solar periods. The circumference of the oval can and will expand during the cycles mentioned before when the aurora becomes brighter and more intense. During some of the stronger auroras, the deep red light emitted in the upper most atmosphere could be seen as far south as Mexico, Japan, and Italy. These sighting are very rare and many happen only once every few decades. (Savage 1994, Geophysical 2003)

From the earth's surface, the aurora looks like a waving, distorted curtain. It is never one solid shape. During any auroral display, the curtain-like formation can and usually does consist of different shapes and forms. These smaller forms will partly overlap and embed themselves in each other. They have been studied and classified into several main forms and structures. First is the homogeneous arc or band, see reference picture 6, which takes the shape of a straight or curvy line across the sky. It has a very elongated shape with reports of one arc being more than 1000 kilometers long. It is a more tightly packed formation. Second is the auroral ray, see reference picture 7, which are often embedded in homogenous arcs but can occur in isolation as well. The rays have a distinct pattern that has their lights following the magnetic field lines, making them look like vertical brushstrokes bunched together. Next are the diffuse and irregular auroral patches, see reference picture 8. These usually cover an area of about 100 square kilometers and occur simultaneously with other patches. (Omholt 1971) Another is the rising vapor column, which appears to be touching the earth because of its vertical descent. Although, it is very similar in shape and form to the homogenous band and is sometimes categorized with it. The last is the corona, see reference picture 9. They have the appearance of an explosion with debris shooting out in every direction from one centralized point in the middle. Perspective is a key part in the formation of the last two because the aurora is neither touching earth, as discussed earlier it stops many kilometers above the surface, nor is it exploding from one point, since it is an oval surrounding the poles. (Geophysical 2003) Much of how these formations are viewed depends on the location of the viewer in regards to the auroral oval. From one side, the aurora might appear broad and curtain-like while from another point across the continent it has a thin snake-like appearance. (Omholt 1971)

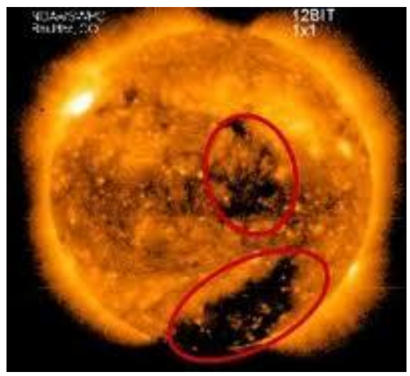
While still beautiful to behold, the aurora is not as simple more completely mysterious as it once appeared. The creation of an aurora is a process steeped in science, but the basics are quite easy to grasp for the average aurora watcher. Savage states it best when she says “modern auroral science is less deadening…instead of reducing our vision, it enlarges it. Instead of sapping our spirit, it reminds us of cosmic power.” (Savage 1994) The aurora is a scientific phenomenon that has been combed over with a fine-toothed comb and still throws mysteries in the face of science whenever it feels like it.

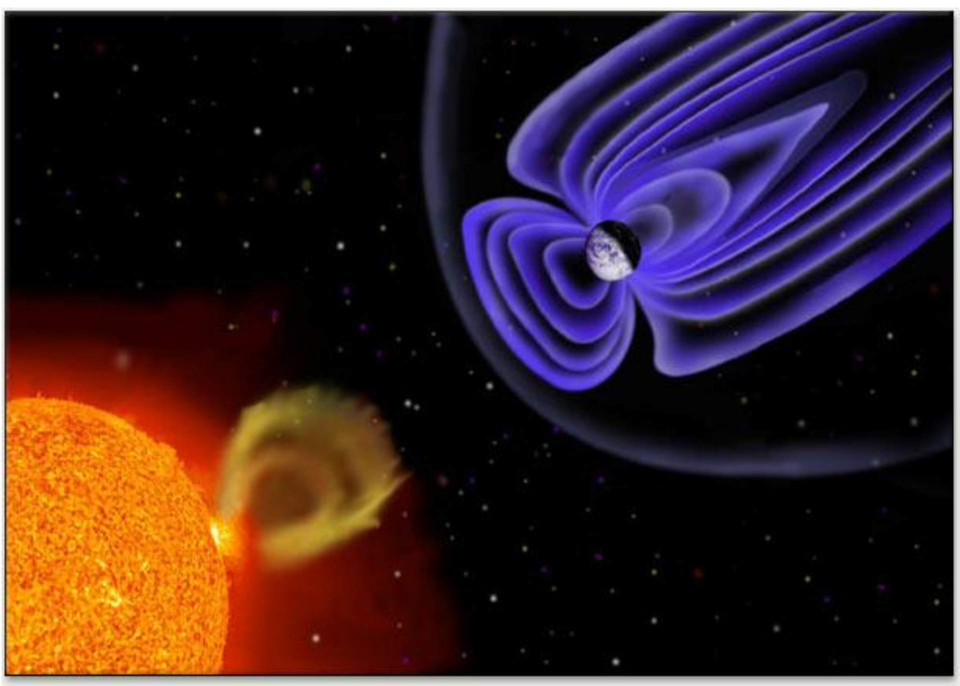
Reference Pictures

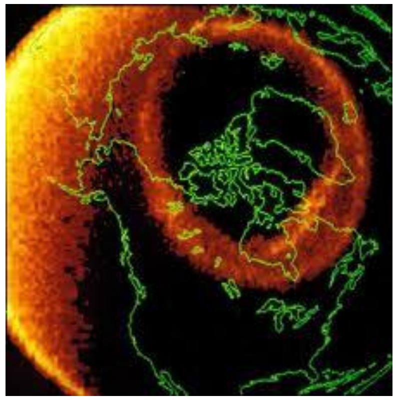

Picture 1: Corona of the Sun



Picture 2: Coronal Mass Ejection


Picture 3: Coronal Holes


Picture 4: Solar Wind (Yellow), Magnetosphere and Magneto-tail (Blue)



Picture 5: Northern Auroral Oval

Picture 6: Homogeneous Band

Picture 7: Auroral Ray

Picture 8: Diffuse and Irregular Patches

Picture 9: Corona

Picture 10: Auroral Colors (from space)

References

Omholt, A. *The Optical Aurora.* New York: Springer-Verlag, 1971.

Savage, Candace. *Aurora: The Mysterious Northern Lights.* San Francisco: Sierra Club Books, 1994.

Stewart, John. *Course Guide for University Physics II.* Arkansas: University of Arkansas, 2011.

Geophysical Institute. "Geophysical Aurora Classroom." Last modified August, 2003. Accessed April 26, 2010. http://www2.gi.alaska.edu/Geophysical/index.htm

Encyclopedia of Earth. "Aurora Borealis." Last modified April 17, 2007; Accessed April 26, 2012. http://www.Encyclopediaarth.org/article/Aurora_Borealis

Encyclopedia Britannica Online. "Aurora." Accessed April 26, 2012. http://www.britannica.com/EBchecked/topic/43410/aurora.