

Aurora What? Where? How?

PHY 482

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The northern lights is one of the most naturally occurring aesthetics that can be experienced residing on Earth. Scientifically known as the Aurora Borealis, this phenomenon happens in various countries around the world at certain times of the year. It is a beautiful sight to see, that I one day I might see for myself. National Geographic names the best places to see the northern lights. A few of those places are Iceland, Alaska, Canada and Norway.¹ There are excursions and vacations centered around the chance to see the beauty of the northern lights. It is most interesting to be able to visualize such a beautiful phenomenon as I imagine this is a small part of the beauty that is seen by an astronaut in space.

It is interesting to note that these phenomena came into its name by way of a simple metaphor being made by Galileo in a second article of the collection, *Discourse on the Comets*.² This article was published under the name of Mario Guiducci, but was immediately recognized to be mostly the work of Galileo. Galileo at the time was under caution from the Catholic church to abandon the Copernican theory of heliocentrism, thus using his pupil as the messenger.

The first appearance of the northern dawn metaphor: ‘And I know Academicians, that many of you will have seen more than once the sky at nighttime illuminated in its northern (settentrione) parts in such a way that its brightness yields nothing to the brightest dawn (aurora) and closely rivals the sun – an effect which in my opinion has no other origin than that part of the vapor-laden air surrounding the Earth is for some reason unusually rarefied, and being extraordinarily sublimated has risen above the cone of the Earth’s shadow so that it’s upper parts are struck by the sun and made able to reflect its splendor to us, thus forming for us questa boreale aurora (this northern dawn)’².



Figure 1: Northern Lights in Iceland
<https://madebyiceland.com/products/northern-lights-tour-jeep>

What is the aurora borealis as we know it now as a phenomenon? As Galileo mentioned in his article very subtly it appears to be an interaction between the sun, vapor-laden air and the Earth’s atmosphere. It is in other words just that. The aurora borealis is a product of interactions that are happening in the Earth’s magnetosphere due to solar energy.

These interactions cause electron precipitation and our atmosphere is bombarded with electrons. These electrons will excite the molecules in our atmosphere, mainly made up of Nitrogen and Oxygen. With the addition of these extra electrons additional atoms are being produced. This production of atoms, for Nitrogen in particular can arise from electron impact dissociation, electron impact dissociative ionization and chemical-ionic reactions.

Electron impact dissociation is a process by which molecules are separated by impact of electrons of a certain dissociative energy, this would be the energy required to break the molecule a part. Electron impact dissociative ionization is an ionization process in which a gaseous molecule decomposes to form products, one of which is an ion. Chemical reactions are pretty self-explanatory. Due to these process Nitrogen atoms are excited but eventually will return to their ground states. When this relaxation happens there is an emission of energy.⁸ Specifically, optical emission, and we get visible

electromagnetic waves. And the colors that we see greenish yellow or red (Oxygen) and blue (Nitrogen) fall under the visible light section of the electromagnetic spectrum.

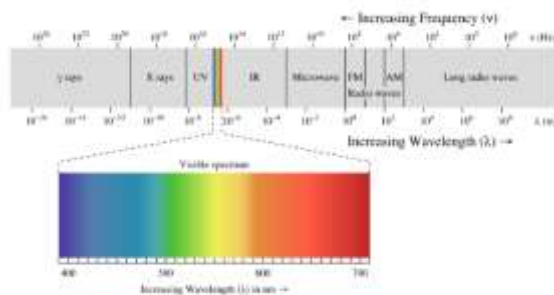


Figure 2 Electromagnetic Spectrum,
[https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Map%3A_Introductory_Chemistry_\(Tro\)/09%3A_Electrons_in_Atoms_and_the_Periodic_Table/9.3%3A_The_Electromagnetic_Spectrum](https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Map%3A_Introductory_Chemistry_(Tro)/09%3A_Electrons_in_Atoms_and_the_Periodic_Table/9.3%3A_The_Electromagnetic_Spectrum)

What is happening in our atmosphere is easier to explain in regards to the contribution of auroral activity. The interactions happening beyond Earth's atmosphere, now that is where things get a bit challenging. I have found so far that in general that most scientist agree on one thing for sure, and that is that the sun contributes to the Earth's auroral activity. Now how specifically do the Sun and Earth come together to create auroral activity. Please note I will not go into great detail, as cosmology and plasma physics are beyond my expertise. In addition, there seems to be ongoing research to lead to some agreement among various science fields of what is exactly happening. My take on things based on Figures 3 and 4 is that Spider Man is the cause of this, but what do I know.

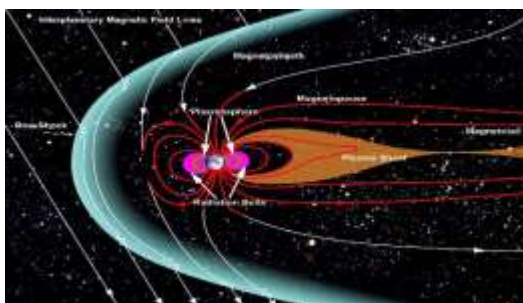


Figure 4 Earth's Magnetosphere & Plasma Sheet,
<http://www.planetary.org/multimedia/space-images/earth/earths-magnetosphere-and-plasmasheet.html>

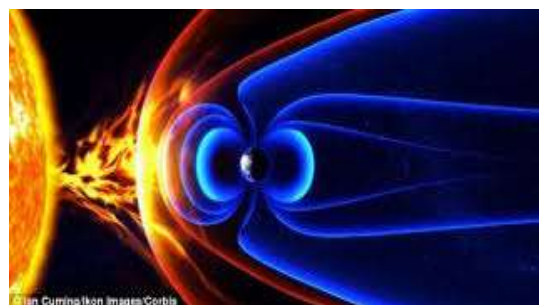


Figure 3 Solar Wind & Earth's Magnetosphere

The sun produces a solar wind which is made of magnetized plasma.⁹ This magnetized plasma hits the Earth's magnetosphere (magnetic cavity around the Earth). The magnetosphere becomes distorted due to the projection of the solar wind and the magnetotail is formed (See Figure 3 & 4). The magnetotail is basically the Earth's magnetic field, being stretched out, extending from the Earth into interplanetary space. The magnetotail is believed by most to be the origin of the processes/interactions that will ultimately contribute to the release of electrons in our atmosphere.

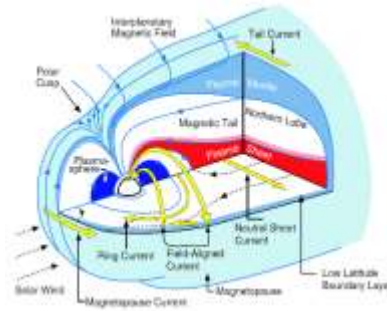


Figure 5 Detailed diagram of Earth's magnetosphere,
<http://esp.igpp.ucla.edu/research.html>

The magnetotail consists of adjacent halves called lobes, which have opposing magnetization. In the upper lobe the magnetic field points sunward and the field lines connect to the north polar region of the Earth. In the lower lobe, the field lines connect to the Earth's south polar region. The two lobes are separated by a sheet of electric current that flows across the midplane of the tail and then loops around to the north and south lobes. These loops of current create the magnetic fields in the lobes. Some solar-wind plasma will penetrate the magnetosphere's sunward region and will populate on the surface regions of the tail. The plasma then flows through the lobes toward the midplane of the tail, where it forms a concentration of plasma called the plasma sheet. The plasma sheet is the site of current separation. The interactions of charged particles, electric currents, electric fields and magnetic fields all sustain the magnetotail. You have solar wind pushing on the Earth's magnetosphere which is 'pushing' the field lines giving way to the shape. We have two opposing magnetic fields in each lobe and a plasma sheet which also is a source of current.³ The charged particles are acted on through the Lorentz Force.

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

Another interaction happening here on the charged particle is called the E-cross-B drift.³ The Lorentz force gives us the trajectory of the charged particles of plasma from the solar wind, drift adds extra motion. When an electric field is imposed perpendicular to a magnetic field the spiraling particles tied to magnetic field lines experience a drift perpendicular to both the electric field, \vec{E} , and the magnetic field, \vec{B} .

$$\vec{v}_d = \frac{c\vec{E}_0 \times \vec{B}_0}{B_0^2}$$

In some literature you will find that changes in magnetic field, specifically from a process called magnetic reconnection or breaking is the reason for the energy released from the magnetotail. It is said that the field lines break and/or reconnect at the neutral line, where the magnetic field is zero. There is argument that reconnection does not happen and/or that it can not happen since no energy release can occur from any point at which no energy is stored. If we go with the belief that reconnection happens, when it does along with the solar wind interacting with the magnetosphere, magnetohydrodynamic, (MHD), generator behavior is created.

The magnetohydrodynamic process generates electricity and this electricity is injected into the Earth's magnetic field resulting in electric current that stretches the Earth's field lines.⁵ The stretching results from an electromagnetic phenomenon called the J-cross-B force. During the increase of energy and stretching a new neutral line is formed and disrupts the current that normally crosses the plasma sheet. The current is suddenly reduced, and the magnetic field lines in that particular region suddenly "collapse" toward the Earth. This collapse rains electrons into the upper atmosphere, producing auroral

lights.⁵ Here we are! All this stuff that happens to produce the aurora borealis does not stop happening. The Sun never stops behaving as it does so therefore, we are always going to get these interactions happening and therefore the auroral activity.

This is the less detailed version of what is going on with these beautiful lights in the sky. Through my readings I found some contradictions of what others might believe is actually happening out there in space, but they all agree whatever is happening the Sun is where it starts. There are other planets that experience this magnetotail effect. These magnetotails are formed wherever a planetary body has an intrinsic magnetic field (Earth, Jupiter, Mercury and Saturn) or a body that has an electrically conductive atmosphere (Venus) embedded in a flowing magnetized plasma. I would like to say that there are some electrostatic and electromagnetic happenings going on fostering this cycle. These things are continuously being studied and are very interesting to say the least. I will leave this particular phenomenon to the astrophysicists, cosmologist, plasma physicists and any one else who wants a go at it. I will stick the hopes of being just an observer of this beauty one day.

Bibliography

¹<https://www.nationalgeographic.com/travel/top-10/7-aurora-destinations/>

²Siscoe, G. L. (1978), An historical footnote on the origin of “Aurora Borealis”, *Eos Trans. AGU*, 59(12), 994–997, doi:[10.1029/EO059i012p00994](https://doi.org/10.1029/EO059i012p00994).

³Hones, E. (1986), The Earth’s Magnetotail. *Scientific American*, 254(3), 40-47, <http://www.jstor.org/stable/24975910>

⁴Dungey, J.W. (1961), Interplanetary Magnetic Field and the Auroral Zones. *Physical Review Letters*, 6(2), 47-48, doi:10.1103/PhysRevLett.6.47.

⁵Hones, E. (1985), Magnetic Reconnection in the Earth’s Magnetotail. *Australian Journal of Physics*, 38, 981-997

⁶ Ajith, K. R. (2013), Magnetohydrodynamic Power Generation. *International Journal of Scientific Research and Publications*, 3(6), 1-11

⁷ Scott, D. (2007), Real Properties of Electromagnetic Fields and Plasma in the Cosmos. *IEEE Transactions on Plasma Science*, 35(4), 822-827

⁸ Rees, M. H. (1985), Atomic Nitrogen in Aurora: Production, Chemistry and Optical Emissions. *Journal of Geophysical Research*, 90(A10), 9871-9879

⁹ Borovsky, J. (2018), The Earth’s Magnetosphere: A Systems Science Overview and Assessment. *Surveys in Geophysics*, 39, 817-859

¹⁰ Hones, E. (1963), Motions of Charged Particles Trapped in the Earth Magnetosphere. *Journal of Geophysical Research*, 68(5), 1209-1219

¹¹ Chamberlain, J. (1953), Atomic and Molecular Transitions in Auroral Spectra. *Journal of Geophysical Research*, 58(4), 457-472

¹² Block, L. P. (1990), The Role of Magnetic-Field-Aligned Electric Fields in Auroral Acceleration. *Journal of Geophysical Research*, 95(A5), 5877-5888

¹³ Eastwood, J.P. (2015), What Controls the Structure and Dynamics of Earth’s Magnetosphere?. *Space Science Review*, 188, 251-286