

Activity 11 - The Aurora: A Critical Look at Phenomenology

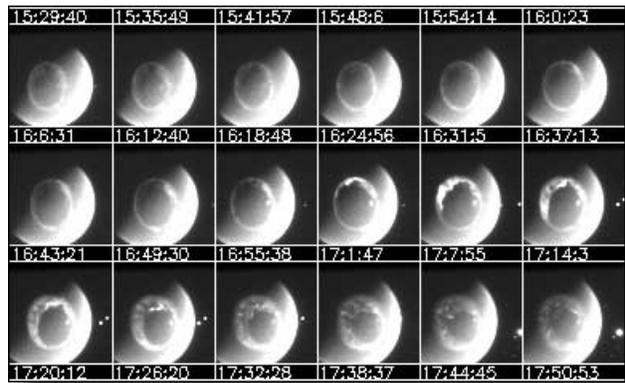
TEACHER'S GUIDE

Auroras have been sighted for thousands of years. Over time, many different terms have been used to describe them. For a glimpse at "aurora terminology," have a look at the newspaper archive at <http://www.solarstorms.org/SRefStorms.html>, which is a chronology of sightings and newspaper accounts since about 1850, each provided in PDF format.

Auroral "forms" do not always change in a random way, but often evolve over time as the display begins, reaches a climax, and fades away. Specific terms have been created to describe these forms. When placed along a timeline of observations, it becomes a much clearer way to identify reoccurring patterns.

GOALS

- 1) Students will learn the names of the basic auroral forms.
- 2) Students will learn that auroral shapes evolve over time and sometimes follow a more-or-less well-organized pattern of changes known as an auroral substorm.
- 3) Students will apply their knowledge of auroral forms and substorms by sorting a collection of images online into a sequence of changes.



Auroras from space make the polar regions of Earth look like they are encircled by a ring of light. The Auroral Oval has been photographed by satellites such as IMAGE and Polar. This photograph, taken by the IMAGE satellite shows an auroral substorm. The substorm starts (onset) around 16:00:23, expands, and the recovery phase begins around 17:14:30.

About 90% of the time, the light from the aurora comes from an altitude of 100-250 km. Electrons from space follow Earth's magnetic field lines down to Earth's upper atmosphere near the magnetic poles. These electrons are sped up by electrical forces and move very fast. When the electrons collide with the gas in the upper atmosphere, mostly N_2 , O_2 , and O , they excite the gas. When the gas relaxes, it gives off light. This is the light of the aurora we can see. This light is found in an oval band around Earth's magnetic poles. Sometimes this oval moves and changes shape in a specific pattern, known as an *auroral substorm*.

PROCEDURE

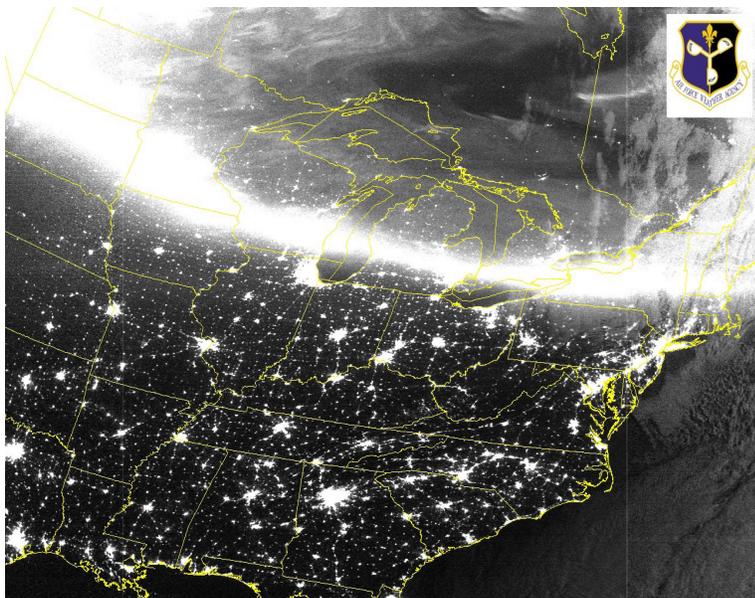
Begin this activity by having students read the following article "A Brief Explanation of the Aurora." It can either be photocopied or students can read it from the on-line web site. Next, students will or-

ganize images, available on a website, of aurora from a magnetic storm in order to become familiar with the different types of aurora and where they are commonly located during a large storm. The students should follow the instructions on the worksheet and turn in a table with their categorization of the auroral images and answers to the worksheet questions. The answer sheet provides a way in which the students can go further with this activity to learn about magnetic latitudes and longitudes. Next the students will read through two descriptions of a single auroral substorm event on the second worksheet and compare the descriptions using UT to organize the timing of events. Students should turn in their responses to the questions on this worksheet.

Mysteries of the Aurora

Note: Because it's important to see these pictures in color, this article can also be found online at http://ds9.ssl.berkeley.edu/themis/mission_auroraexplain.html.

As you read the following description of the aurora, consider the general question of what causes an aurora. What might cause the shape to change? What might affect the timing of changes? Why might the aurora glow in different colors? Write down your ideas about the answers to these questions in your lab book. Don't worry about being wrong — science is about first coming up with hypotheses after gathering initial data. Scientists revise their ideas later, after they gather more information from experiments. You will gather more data later that you will incorporate into your hypothesis, which eventually becomes a scientific model of what causes the aurora.



Aurora and city lights were photographed by the US Air Force DMSP satellite on November 6, 2003, with a map drawn over the image in yellow. Auroras are found in an oval band around Earth's magnetic pole. Note the sharp southern edge in this image, defining the equatorward edge of the auroral oval as it passes over Montana, the Great Lakes, and New England. Observers as far south as Georgia saw a spectacular display looking north to the aurora, located at an elevation of 100 km.



The space shuttle crew photographed aurora from above Earth. The height of the aurora reaching above 100 km in altitude is plainly seen in this oblique view with the stars shining above Earth's surface. Also note the color changes from green at lower altitudes, to reddish at highest altitudes. Sometimes the auroral oval moves and changes shape in a specific pattern known as an *auroral substorm*.



Arches and *arcs* are long ribbons of light extending from horizon to horizon without structure, often from the east to west. Sometimes these arcs turn in forms called folds. Arcs are often green, sometimes with red above the green and sometimes with purple below the green. Arcs mostly remain motionless in the sky and are always present, usually at very high latitudes (such as far north). This is the type of aurora one can usually see during the quiet phase of the aurora. During the growth phase of an auroral substorm, this arc slowly drifts sideways in the direction of the equator. For an observer in the north, this would mean the arc drifts slowly towards the south. From an image, it is hard to tell if aurora is in a quiet phase of the aurora, or a growth phase of a substorm. If it is very bright, it is more likely to be in the growth phase.



Bands are arcs with structure. When seen on the horizon, bands often have rays and are called curtains or drapes. An auroral arc curling in its length-wise direction from horizon to horizon causes these curtains. These curls can be seen from below. Sometimes shooting rays will quickly flow down the curtain to lower altitudes, and “trains” of these rays may flow eastwards or westwards along the curtain. Other times, bands will rapidly move across the sky. Bands are often green, sometimes with red above the green and sometimes with purple below the green. These forms make their appearance during the *substorm expansion phase*, also known as the substorm break-up phase. The transition from a slowly moving arc in the growth phase to quickly moving aurora in the form of curtains and rays is known as *substorm onset*.



Auroras appear as *coronas* during the *expansion phase* of a substorm whenever an active, rayed curtain passes over the observer’s zenith. Geometric perspective effects make it look as though the auroral rays are coming from a “vanishing point” and flowing to the horizon in all directions. The top of an auroral curtain may be over 250 km above the ground, and the rays are only a few kilometers wide, giving a spectacular visual effect.





Diffuse glows are the most common at the end of an auroral display, during the substorm recovery phase. At high latitudes, the displays are usually greenish. At lower latitudes during intense storms, red diffuse aurora are common. Diffuse auroras are often hard to observe with one's eyes because they are very faint.

Above images courtesy Jan Curtis
(<http://climate.gi.alaska.edu/Curtis/aurora/aurora.html>)

EVOLUTION

For Northern Hemisphere observers, an auroral substorm display begins with the appearance of an auroral arc above the northern horizon or in the zenith. Over the course of 30 minutes during *substorm growth phase*, this arc will grow in brightness exceeding that of the full moon, with a white or pale green color. It will also drift across the sky towards the zenith or towards the equator. The auroral arc often will resolve itself into folds of light extending from the eastern horizon to the western horizon in the northern sky. From the ground, the *substorm onset* begins suddenly within seconds.

This is followed by the *substorm expansion phase* (also known as the *break-up phase*). In the expansion phase, the auroral arcs or bands break into many moving bands, which dance wildly across the sky both to the north and south. Within minutes, rays of light will start streaming down the developing curtains, which often surge westwards. From space, the expansion or break-up phase is seen as a thickening of the auroral oval along its north-south extent. The auroral oval's substorm brightening region begins to expand westward, dissolving into numerous individual structures, which we see from the ground as individual curtains. As a curtain passes directly overhead, the rays flowing down the curtain create an auroral corona, which from a central point look like a meteor shower raining down the sky – an effect of perspective.

Within 30 minutes, the activity begins to slow and fade, and retreat northwards during the recovery phase. From space, the recovery phase is seen as a thick oval, often with two bright regions to the north and south. From the ground, pulsating aurora will be visible, which are large patches of diffuse aurora that brighten and fade with periods of seconds. The aurora slowly becomes a diffuse glow. An uninterrupted recovery phase lasts several hours. At any time during this sequence, the aurora may erupt into another auroral display if a new magnetic substorm event is triggered by disturbances in Earth's magnetotail region.

SOUNDS

Observers from many countries claim, rather steadfastly, that they sometimes hear sounds from aurora, such as crackling or swooshing. This subject is an interesting one for students to explore. Are people simply imagining the sound because auroras LOOK so much like fires in the sky? For decades, scientists have looked into this subject, but have not been able to capture any sound on tape.

One thing we do know is that direct observations show that auroras never occur closer than about 70 km above the ground, where the air is nearly a vacuum. There is no gas to carry pressure waves that could make our ears sense sound. This has caused some scientists to look into indirect “sympathetic” causes. Some of these are psychological. Others may involve powerful electrical currents flowing in the ground that cause electric “crackling” discharges on sharp objects near the observer (pine needles, etc). These currents are well-known to exist at the latitudes where sounds are reported.

Student Name _____ *Date* _____

The Aurora: October 29-30th, 2003

In this exercise, you will examine a number of aurora photographs taken around the world by amateur photographers on October 29th and 30th, 2003. These observers were located at a number of different locations and latitudes. We will use photographs assembled from the photographs at the October, 2003 spaceweather.com aurora gallery and located at: http://ds9.ssl.berkeley.edu/themis/gallery_auroras.html

We will be studying the major “Great Aurora” that was viewed on October 29-30, 2003.

1. Create a table with 15 rows, and four columns.
2. Label the columns as follows: location, latitude, description, substorm phase.
3. Visit the above website and fill in the information in Columns 1 (location) and 3 (description) from the information provided in each picture’s caption. For example, in Row 1, use the aurora photographed by Lionel Bernardi. In Column 1, enter “Tromsø, Norway.” In Column 3 enter a description of the aurora, including color. Use the standard terms described in the photo gallery provided by your teacher. For example, this first row aurora could be described as “purple, white, and yellow corona.”
4. From your descriptions in Column 3, assume the aurora was part of an auroral substorm and estimate the phase of the auroral substorm. Write this in Column 4 (substorm phase) using the descriptions provided by your teacher (quiet, growth, expansion, recovery phases). For example, Row 1 would be an expansion phase aurora.
5. When you are finished with the web gallery for pictures taken on October 29 and October 30, in Column 2 enter the latitudes of the locations given in Column 1 by using a map. Or, use a web page that gives the latitudes for a given location. Latitude degrees need only be integers, not decimals. For example, instead of writing “35.47 degrees” just round it to “35 degrees.” For this first aurora in Row 1, you would write 69 degrees since Tromsø, Norway is located at 69 degrees.
6. When complete, answer the following questions:

Question 1 – Geographically, for which latitudes were the most diffuse aurora seen by observers?

Question 2 – What was the lowest latitude from which observers reported aurora?

Question 3 – What was the lowest latitude from which expansion-phase aurora were seen?

Question 4 – What were the most common expansion phase features that were seen?

Question 5 – Where would you have to live in the USA to see expansion phase features?

TEACHER ANSWER KEY

Question 1: Geographically, for which latitudes were the most diffuse aurora seen by observers?

Answer: Missouri, Ohio, West Virginia, Indiana, and Colorado all saw diffuse aurora. The latitudes vary from 39 to 41 degrees north.

Question 2: What was the lowest latitude from which observers reported aurora?

Answer: Elkins, West Virginia, at a latitude of 39 degrees north.

Question 3: What was the lowest latitude from which expansion phase aurora were seen?

Answer: For this storm, the lowest latitude where discrete auroral features were observed were from La Otto, Indiana at 41 degrees north. Expansion-phase auroras were seen from 41 degrees north to 69 degrees north.

Question 4: What were the most common expansion phase features that were seen?

Answer: Bands with rays.

Question 5: Where would you have to live in the USA to see expansion phase features?

Answer: From this activity, it seems it would be necessary to live above about 41 degrees north. However, since the magnetic pole is not located at the geographic pole, it would be more accurate to find the magnetic latitudes of all of these types of aurora and answer the questions.

GOING FURTHER

Have your students find the geographic longitude of all the locations, as well as the geographic latitudes. Then have them use a converter to obtain the magnetic latitudes for all of these locations using the geographic latitude, longitude to magnetic latitude, longitude converter on the webpage:

<http://swdcwww.kugi.kyoto-u.ac.jp/igrf/gggm/>

Have them then answer the same questions using magnetic latitude instead of geographic latitude and discuss any differences they find.

Student Name _____ *Date* _____

Aurora of 1859

On August 28, 1859, people all over Earth saw spectacular aurora (Northern and Southern Lights.) It was reported in all the major newspapers, poems were written about it, and famous artists painted its shapes and forms. It also caused severe problems with telegraph networks at the time, which lasted for many hours worldwide. Although scientists gave detailed reports of the changing forms of this vivid display, many ordinary citizens offered their own impressions of this event too. Two of these descriptions, as seen from two different locations, are written below. Read these descriptions and respond to the following questions and instructions.

Galveston, Texas:

“August 28 as early as twilight closed, the northern sky was reddish, and at times lighter than other portions of the heavens. At 7:30 PM a few streamers showed themselves. Soon the whole sky from Ursa Major to the zodiac in the east was occupied by the streams or spiral columns that rose from the horizon. Spread over the same extent was an exquisite roseate tint which faded and returned. Stately columns of light reaching up about 45 degrees above the horizon moved westward. There were frequent flashes of lightning along the whole extent of the aurora. At 9:00 PM the whole of the streaking had faded leaving only a sort of twilight over the northern sky.”

London, England.

“At 0:15 AM on August 28th the auroral light in the north assumed the form of a luminous arch, similar to daybreak, and in the southwest there was an intense glare of red covering a very large extent of the sky. At 00:20 AM streamers appeared; at 00:25 AM the streamers rose to the zenith and were tinged with crimson at their summits. At 00:45 AM frequent coruscations appeared in the aurora. At 01:20 AM the arch which had partially faded began to reform and the body of the light was very strong but not bright enough to read newspaper print. At 1:30 AM the light had begun to fade. By 2:00 AM the aurora was very indistinct.”

When organizing observations from different places around the world, a common problem scientists face is that observers tend to note when things happened by their local time. Scientists simplify these accounts by converting them into Universal Time, which is the local time in Greenwich, England, also called Greenwich Mean Time (GMT). To make time calculations easier, UT is expressed in the 24-hour clock format —so that 11:00 AM is written as 11:00 UT— but times after noon such as 1:00 PM are written as 13:00 UT. 10:00 PM is written as 22:00 UT. Since London is very close to Greenwich, the times mentioned in the London account above are already in Universal Time and only need to be converted to the 24-hour format. For Galveston, Texas, the time is 5 hours behind UT so to get the equivalent UT for Galveston, first convert the Galveston times to the 24-hour format, then add 5 hours. See Activity 11 for more details.

Student Name _____ *Date* _____

Aurora of 1859

QUESTIONS AND INSTRUCTIONS:

Write your responses to each of these questions and instructions in your lab book.

- 1) From the two descriptions, extract the time and description of specific events in each narrative. Write these down, including the given times converted to Universal Time. Note the stories' similarities.
- 2) From the sequences of events in each description, create a storyline for the aurora display that fits the most details. Draw pictures to help illustrate the storyline.
- 3) Rewrite the timeline using the auroral substorm phases. Would you call this an auroral substorm?
- 4) Describe your ideas for why the aurora was observed to reach closer to zenith (directly overhead) in London than in Galveston?
- 5) Telegraphs work in general by using long wires and electromagnetic devices at each end. At one end, the telegraph operator sends an electrical current through wires that causes a magnetic needle to move at the receiving end and then a device measuring the change in the magnetic field (magnetometer) indicates how much current was sent from the sender. Based on the fact that telegraph networks were disturbed during this time of spectacular auroras, describe how your hypothesis about what causes aurora is validated or needs to be changed.
- 6) If you have not done so already, also think and write about where the energy to make such unusually brilliant and far-reaching auroras might come from.

TEACHER ANSWER KEY

- 1) From these two descriptions, extract the specific points of each narrative. Change the times to Universal time while doing this. What are the stories' similarities? **Answer:** Here are the main points in each story with the similarities highlighted.

Story 1:

1. Display began at end of twilight with faint **reddish light in north**.
2. 7:30 PM (00:30 UT) **streamers began to appear**
3. Streamers of spiral columns filled eastern sky
4. Faint rose-colored light covered same eastern sky, fading and returning
5. Columns of light reached **45 degrees to zenith**, and moved westwards
6. Frequent flashes of light along the whole aurora
7. 9:00 PM (02:00 UT), the **aurora faded** and left a twilight glow in north.

Story 2:

1. 00:15 AM (00:15 UT) - Luminous arch **appeared in northern** sky
2. 00:16 AM (00:16 UT) - Intense glare of red in southwest
3. 00:20 AM (00:20 UT) - **Streamers appeared**
4. 00:25 AM (00:25 UT) - Streamers **reached zenith** and were crimson at highest points
5. 00:45 AM (00:45 UT) - Frequent **coruscations appeared in aurora**
6. 01:20 AM (01:20 UT) - Arch begins to fade and reform
7. 01:30 AM (01:30 UT) - Aurora **begins to fade**.
8. 02:00 AM (02:00 UT) - Aurora very indistinct.

Similarities: Auroral light appeared in northern sky. Streamers appeared soon afterwards. The streamers expanded in the sky until they were nearly overhead from Galveston, and overhead in London. The aurora shapes showed activity in the form of flashes and movement (coruscations). Soon after this active phase, the aurora faded. The auroral display started and ended at about the same Universal Time at each location.

- 2) From the sequences of events in each description, create a storyline for the aurora display that fits the most details. **Answer:** Each student might group the events differently because the eye-witness accounts are not detailed enough. Because this aurora is seen in the Northern Hemisphere, it is properly called the Aurora Borealis. Here is one way to organize the timeline:

“The aurora borealis started with a faint wash of reddish light in the north. A brilliant arch of light formed. Five minutes later, streamers began to appear which were crimson at their highest points above the horizon. Then, coruscations (waves) began to appear in the brightening red glow of the aurora with the streamers filling the entire eastern sky. The columns of light and streamers began to move westwards, and frequent flashes of light were seen along the aurora as the luminous arch of began to fade and reform. After an hour and fifteen minutes, the aurora began to fade away, leaving behind a twilight glow that persisted for another half-hour.”

- 3) Rewrite the timeline using the auroral substorm phases. Would you call this an auroral substorm? **Answer:** Yes, this could be called a substorm.
The growth phase began with a brilliant arch of light. Substorm onset occurred at 00:20 UT with streamers and active aurora as the expansion phase started. Recovery phase started with the arch fading and reforming.
- 4) Why was the aurora observed to reach closer to zenith in London than in Galveston? **Answer:** because the aurora is a polar phenomenon and London is at a higher latitude than Galveston. That means that the aurora will be seen higher in the northern sky from London than from Galveston.