Aurora

. . . fabled glowing lights
of the Sun-Earth connection

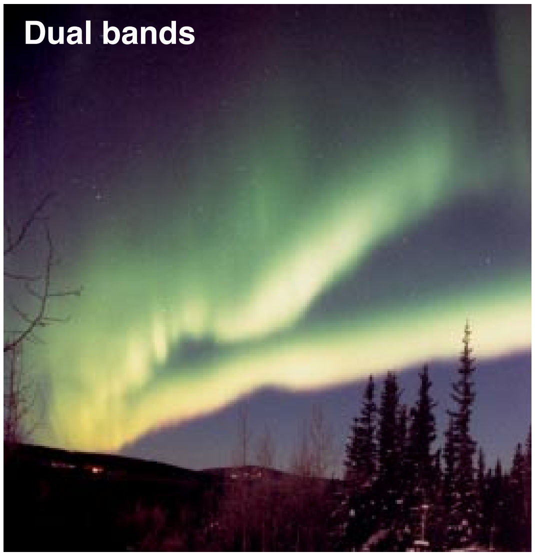
Photo credits: Jan Curtis

What is the aurora?

Named for the Roman goddess of dawn, the aurora is a mysterious and unpredictable display of light in the night sky. The **aurora borealis** and **aurora australis** – often called the northern lights and southern lights – are common occurrences at high northern and southern latitudes, less frequent at mid-latitudes, and seldom seen near the equator. While usually a milky greenish color, auroras can also show red, blue, violet, pink, and white. These colors appear in a variety of continuously changing shapes. Sometimes the aurora is so dim and scattered as to be mistaken for clouds or the Milky Way; sometimes it is bright enough to read by.

Jan Curtis

Auroras are a spectacular sign that our planet is electrically connected to the Sun. These light shows are provoked by energy from the Sun and fueled by electrically charged particles trapped in Earth's magnetic field. While beautiful to behold, they can be a nuisance to those who depend on modern technology.



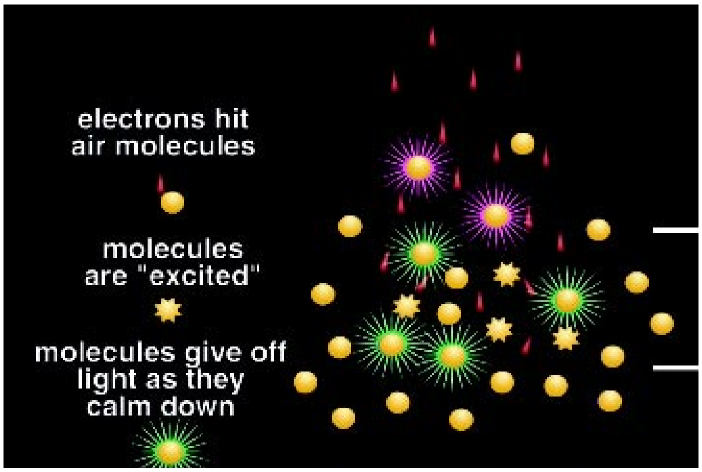
Jan Curtis

What does an aurora look like?

Auroras can appear as long, narrow **arcs** of light, often extending east to west from horizon to horizon. At other times they stretch across the night sky in **bands** that kink, fold, and swirl, or even ruffle like curtains. They can spread out in multi-colored **rays**, like vertical shafts of light that stretch far up into space. And sometimes they engulf the sky in a thin cloud or veil. As aurora expert Robert Eather once wrote: "Like snowflakes, no two are ever quite the same."

Dramatically different auroras can appear in the course of a single night, and all of the forms can vary in intensity. The late evening auroras are usually long diffuse arcs, which slowly evolve into rayed arcs or bands that show increasing activity. As the night progresses, the bands and arcs become rippled and folded, eventually breaking into rays and -- if the viewer is lucky -- a **corona**. The corona is considered the most spectacular form of a rayed aurora, appearing overhead with all shafts converging to a center point. **Patches**–fluffy clouds of light–and flickering auroras are generally seen later in the night.

Jan Curtis



What causes the aurora?

The typical aurora is caused by collisions between fast-moving electrons from space with the oxygen and nitrogen in Earth's upper atmosphere. The electrons—which come from the Earth's **magnetosphere**, the region of space controlled by Earth's magnetic field —transfer their energy to the oxygen and nitrogen atoms and molecules, making them "excited". As the gases return to their normal state, they emit photons, small bursts of energy in the form of light. When a large number of electrons come from the magnetosphere to bombard the atmosphere, the oxygen and nitrogen can emit enough light for the eye to detect, giving us beautiful auroral displays. This ghostly light originates at altitudes of 100 to more than 400 km (60 to more than 250 miles).

Why do auroras come in different colors and shapes?

The color of the aurora depends on which gas — oxygen or nitrogen — is being excited by the electrons, and on how excited it becomes. The color also depends upon how fast the electrons are moving, or how much energy they have at the time of their collisions. High energy electrons cause oxygen to emit green light (the most familiar color of the aurora), while low energy electrons cause a red light. Nitrogen generally gives off a blue light. The blending of these colors can also lead to purples, pinks, and whites. The oxygen and nitrogen also emit ultraviolet light, which can be detected by special cameras on satellites.

The different shapes of auroras are a mystery that scientists are still trying to unravel. The shape seems to depend on where in the magnetosphere the electrons originate, what causes them to gain their energy, and why they dive into the atmosphere.

Jan Curtis

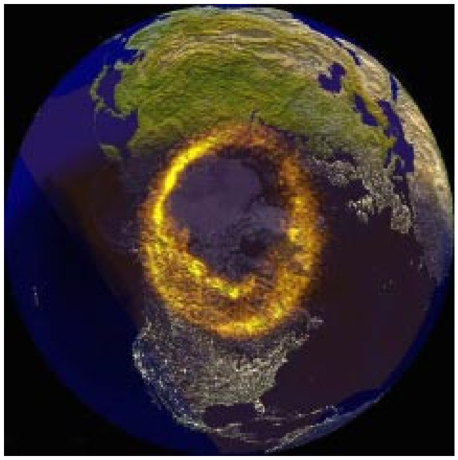
Jan Curtis

Where can you see an aurora?

Auroras usually occur in ring-shaped areas about 4,000 km (2,500 miles) in diameter around the magnetic poles of the Earth. These rings are known as **auroral ovals**. The northern oval traces a path across central Alaska and Canada, Greenland, and northern Scandinavia and Russia. In the southern hemisphere, the auroral oval hovers mostly over the oceans circling Antarctica, but it can occasionally reach the far edges of New Zealand, Chile, and Australia. There is a common misconception that auroras can only be seen near the poles of the Earth, but auroras are actually quite rare at the geographic and geomagnetic poles. In fact, if you made an expedition to the north coast of Alaska, you would usually have to look south to see an aurora.

The auroral ovals expand and contract with the level of auroral activity, sometimes extending to lower latitudes to cover much of North America or Europe when the space around Earth is most disturbed.

The complete auroral ovals in the north and south are nearly mirror reflections of each other, or **conjugate**. But it wasn't until the Space Age, when satellites could gather images of the entire Earth, that scientists were able to see the large-scale auroras around both poles at the same time.

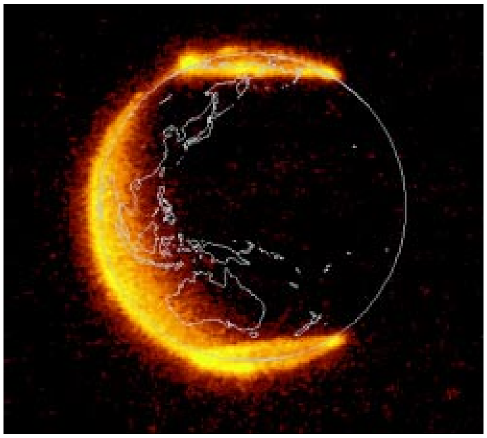


UV image of auroral oval superimposed on a figure of partly sunlit Earth

When can you see an aurora?

Low levels of auroral activity occur day and night, every day, in the northern and southern **auroral ovals**. Since the aurora is much dimmer than sunlight (a million times), it cannot be seen from the ground in the daytime. The best displays tend to occur in the few hours before midnight.

Light pollution caused by city lights makes it difficult to see auroras except in dark rural areas. Perhaps the best chance to see an aurora is during a high-latitude airplane flight at night. But when a really bright aurora occurs, you can see it from the city and even through thin clouds.



Polar spacecraft

Auroral ovals in UV light from far above the equator. The arc of light (left) is sunlight.

In Alaska and central Canada, the aurora can be a nightly occurrence. Go a little further south and you might see an aurora ten times a year. Auroras are much more likely to occur during periods of high sunspot numbers, at the peak of the Sun's eleven-year **sunspot cycle**. Then you might see an aurora once or twice a year in regions as far south as Texas or Florida. In the rarest events, auroras are observed near the equator, as when in 1909 the most potent geomagnetic storm on record brought an aurora to Singapore.

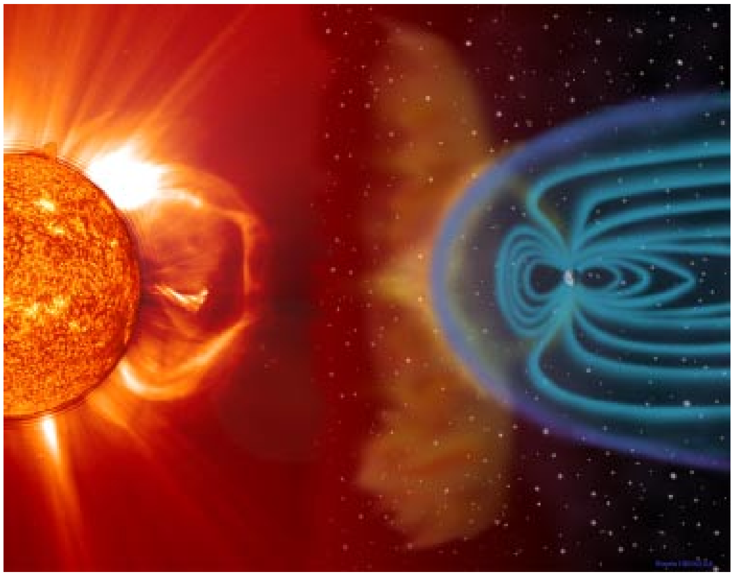
Auroras are easier to see in the wintertime because it is dark for longer periods of the day. And clear winter nights tend to be better for observing the sky due to less haze and water vapor in the air.

How is the aurora related to the Sun?

Auroras are a sign that Sun and Earth are connected by more than sunlight. They indicate that something electric is happening in space.

The Sun provides the energy for the aurora, but particles in the aurora come from Earth's own neighborhood in space. The Sun's energy is carried toward the Earth in the **solar wind**, a stream of electrically charged particles (mostly protons and electrons) flowing out from the Sun in all directions. As these particles approach Earth, they interact with our planet's magnetic field. This field deflects most of the particles, creating a huge cavity in the solar wind–the magnetosphere. This region stretches about 60,000 km (40,000 miles) toward the Sun and several hundred thousand kilometers in a long tail on the night side, away from the Sun.

Variations in the properties of the solar wind control the amount of energy that can leak into the magnetosphere. Here the energy is converted into electric currents and electromagnetic energy and temporarily stored in the magnetosphere, especially in its tail. When this influx of energy is relatively large, the magnetosphere loses its equilibrium, or balance. To become stable again, the excess energy is released suddenly, with much of the energy going into the acceleration of electrons.

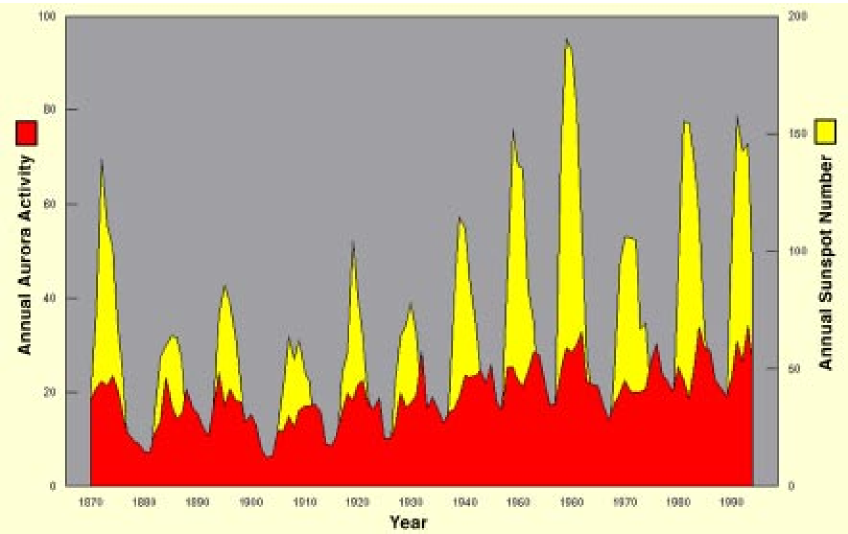


Steele Hill, NASA

A solar storm blasts out from the Sun and heads towards Earth's protective shield, the magnetosphere (sizes not to scale)

The aurora primarily occurs where the magnetic field guides the electrons from the tail of the magnetosphere into the atmosphere where they produce the aurora. Because the tail is on the night side of the Earth (away from the Sun), the more intense, dynamic and beautiful auroras occur near midnight.

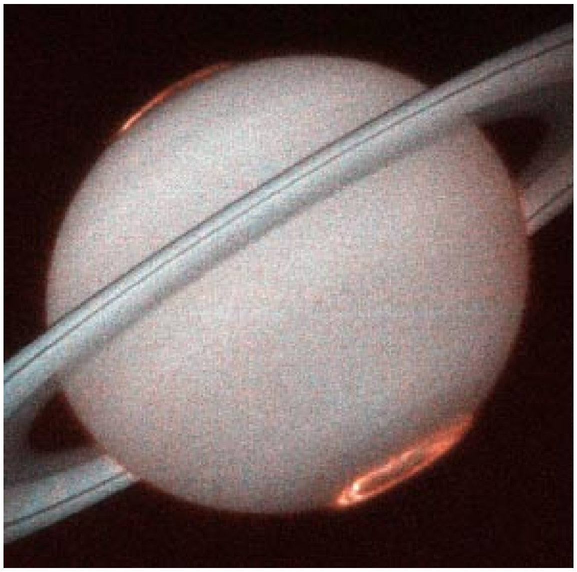
For many years, it was thought that the particles in the aurora came directly from the Sun because great auroral displays often occurred a few days after large eruptions on the Sun. But particles coming directly from the Sun would lose their energy at much higher altitudes than where we find the aurora. And due to the deflection of solar wind particles by the magnetosphere, particles straight from the Sun can gain access to the atmosphere only near the Poles, so they would not form the auroral ovals that we see lying a couple of thousand kilometers out from the Poles.



Historical record of linkage between sunspots and auroral activity

Do other planets have auroras?

Auroras have been observed on Jupiter, Saturn, and Uranus, but not on Mars, Venus, or Mercury. Any planet with a magnetic field and an atmosphere should likely have auroras (Mars and Venus have no global magnetosphere; Mercury has almost no atmosphere). Since an aurora indicates the presence of an atmosphere, we might be able use the presence of auroras to find planets beyond our solar system that could support life.



J.T. Trauger/JPL and NASA

Conjugate auroras on Saturn

Does the aurora make a sound?

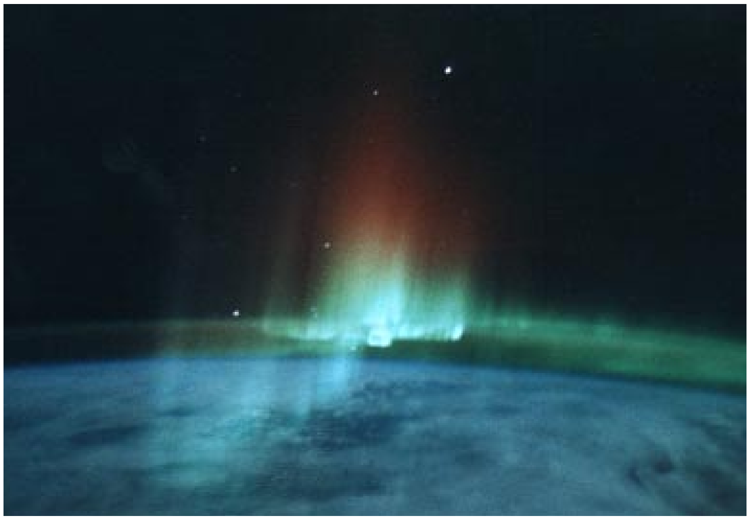
Observers have speculated about this for hundreds of years, noting that they have heard crackling, swishing, and hissing sounds while they watched the aurora dance in the sky. But scientific experimenters have been unable to detect any audible sound from the northern lights, and most scientists cannot find a reason why the lights should make a sound. The air in the upper part of the atmosphere where auroras are formed is too thin to conduct audible sound any distance. So if sounds are heard, they must come from some other phenomenon occurring at the same time.

Photo: Dick Hutchinson

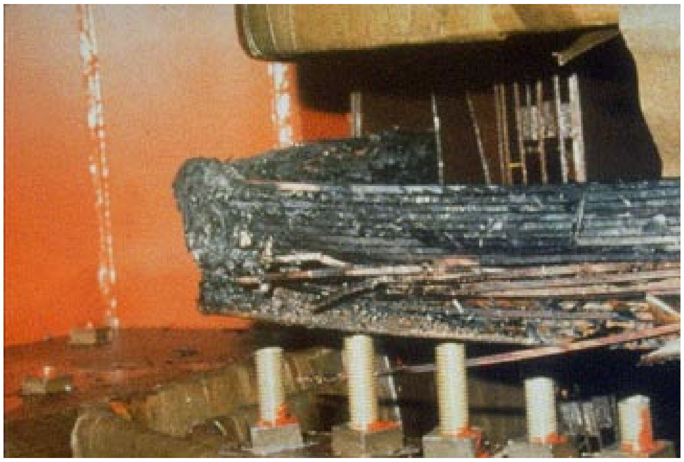
Why do we care about auroras?

Before telegraphs and telephones, rockets and radio, people were not affected by auroras. Solar activity and the resulting auroral light shows were curiosities of nature. But then humans started to harness the power of electromagnetism, developing networks of electrical power and communications systems. It was soon learned that the aurora could affect those systems.

The electrons spiraling down the Earth's magnetic field to produce the aurora are themselves an intense electric current. The rapidly changing current can cause unwanted electrical currents to flow through long communication lines, power lines and pipelines, producing disruptions in communication, electrical outages, brownouts, and fuel leaks. At the same time, the upper atmosphere, or **ionosphere**, becomes rippled like a piece of corrugated cardboard. Radio signals are refracted (bent) differently than expected or even absorbed, making it difficult to communicate at certain frequencies. Electrons accelerated to high energies in the tail of the magnetosphere can raise havoc with satellites, damaging electronics and creating false commands.

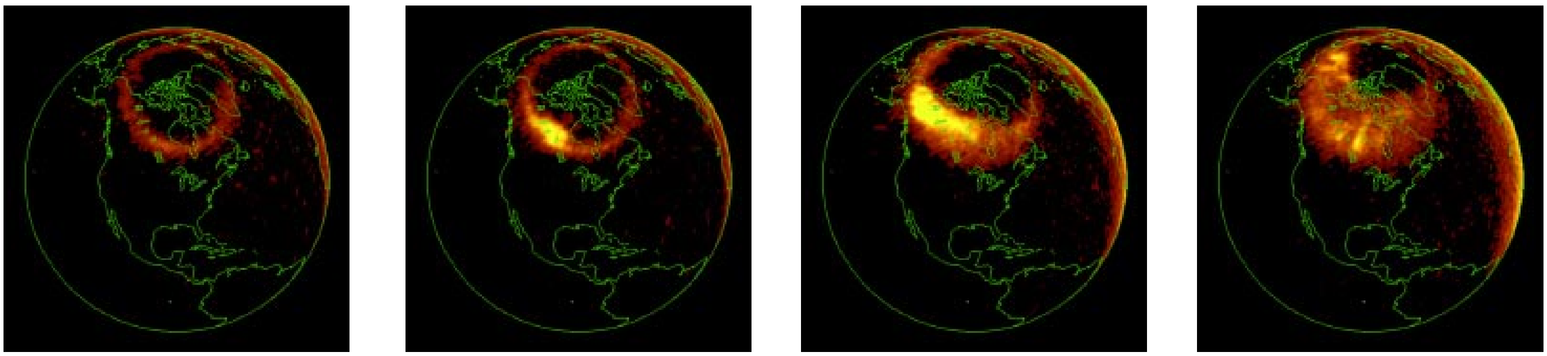


Aurora australis (Southern Lights) from a space shuttle



Courtesy: John Kappenman

Large transformer damaged by 1989 geomagnetic storm at NJ power plant



Polar spacecraft

An auroral oval seen from space as it increases in intensity and area over several hours (seen in UV light)

Who has helped us understand the aurora?

Some of the brightest minds in history have puzzled over the aurora. In the **4th century B.C.** Aristotle made one of the first truly scientific accounts of the aurora borealis, describing "glowing clouds" and a light that resembled flames of burning gas.

Courtesy: Danish Meteorological Institute

A Finnish oil painting of the aurora

The real advances in auroral science began when scientists started connecting auroras to magnetism. In the **late 16th century**, William Gilbert conducted experiments that led him to propose that the Earth itself was a giant magnet, with a North and South Pole as if a great bar magnet had been buried inside.

In the **17th century** Anders Celsius proposed that the lights were caused by moonlight reflected by ice and water in the air. Rene Descartes (France) and other scientists asserted that the refraction of moonlight and the reflection of colored rays by ice crystals in the atmosphere somehow caused the aurora. Some of these misconceptions survive even today.

In **1739,** a London watchmaker, George Graham, noticed that on some days, a compass needle made irregular motions from true north that he could not explain. That same year in Sweden, Anders Celsius detected the same phenomenon and noted that it seemed to occur when auroras danced in the sky.

Benjamin Franklin wrongly attributed the lights to a sort of lightning or electric discharge from clouds above the polar regions.

An important discovery of the link between solar activity and the aurora occurred in England in **1859** when astronomer Richard Carrington and amateur sun-watcher Richard Hodgson independently noticed bright patches of white light coming from around some sunspots. These were the first reported observations of a solar flare. About 18 hours after the flare, the magnetic instruments at the Kew Observatory in London measured large variations in the Earth's magnetic field. Across the Atlantic, Elias Loomis, a Yale professor, noted a day later that the auroral light show was "one of the most remarkable ever recorded in the United States."

It wasn't until the **late 1800s and early 1900s** that spectroscopic measurements of auroral light identified oxygen and nitrogen as the color sources for the aurora.

Around the **turn of the 20th century,** Norwegian physicist Kristian Birkeland revived Gilbert's experiments. He placed a spherical magnet inside a vacuum chamber and shot an electron beam at it. He found that the beam was guided by the magnetic field to hit the sphere near the poles. He reasoned that the Sun must shoot beams of corpuscles (now called electrons) toward Earth, where the planet's magnetic field guides them in near the Poles. His view of the aurora was close to the truth, except that the corpuscles originate in our magnetosphere, not from the Sun.

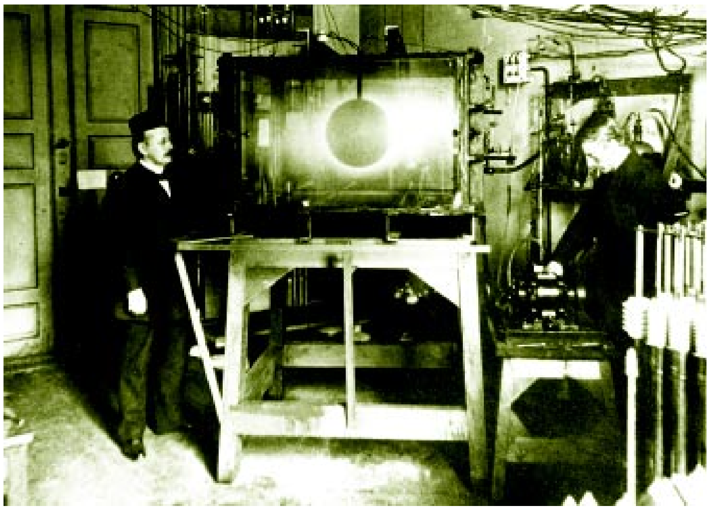


Photo: Fra Birkeland

Birkeland in his lab testing his theories on what causes aurora

In the **1930s**, Sydney Chapman and Vincent Ferraro proposed that clouds of electrically charged particles ejected from the Sun fly across empty space and envelope the Earth to cause auroras; we now call this mixture of electrons and protons plasma, the fourth state of matter. Since these clouds would be excellent conductors of electricity, they would generate currents and distort Earth's magnetic field.

Following the launch of the Sputnik satellites by the Soviet Union and the Explorer satellites by the United States, centuries of scientific theories, remote observations and wild speculations were put to the test by first-hand observations. Scientists such as James Van Allen and Sergei Vernov discovered that the space around Earth was filled with high-energy particles, trapped by the Earth's magnetic field into doughnut shaped rings around the Earth, called the **radiation belts**. Russian and American space probes proved the existence of the solar wind and a series of US satellites mapped out the shape of the magnetosphere. Satellites in the tail of the magnetosphere found it unstable, and low altitude polar satellites measured the electrons producing the aurora.

Today scientists understand much about the transfer of energy from the Sun, its temporary storage in the magnetosphere, and its release into electrons that crash into the atoms and molecules of the atmosphere to produce the awesome auroral light shows. But the aurora still keeps hidden a number of mysteries about why and how it appears as such wondrous displays.

How do different cultures react to the aurora?

"These northern lights have this peculiar nature, that the darker the night is, the brighter they seem, and they always appear at night but never by day…. In appearance, they resemble a vast flame of fire viewed from a great distance. It also looks as if sharp points were shot from this flame up into the sky." -- Written in A.D. 1230 by an anonymous Norwegian author

Photo: Michel Tournay

Dancing aurora taken near Quebec, Canada

To the dispassionate, objective viewer, auroras can appear as colorful, wispy curtains of light ruffling in the night sky. But legend and lore across the ages and around the world tell of more in the heavens than just a brilliant, ghostly light show.

Ancient folklore from China and Europe describes auroras as great dragons or serpents in the skies. In Scandinavia, Iceland, and Greenland, an aurora was often seen as the great bridge Bifrost, the burning archway by which the gods traveled from heaven to Earth.

1893 Fridtjof Nansen woodcut of aurora

Some Native American tribes pictured spirits carrying lanterns as they sought the souls of dead hunters, while Eskimos saw souls at play, using a walrus head as a ball. One legend from the Inuit describes the aurora this way: "The sky is a huge dome of hard material arched over the flat Earth. On the outside there is light. In the dome, there are a large number of small holes, and through these holes you can see the light from the outside when it is dark. And through these holes the spirits of the dead can pass into the heavenly regions. The way to heaven leads over a narrow bridge that spans an enormous abyss. The spirits that were already in heaven light torches to guide the feet of the new arrivals."

In Norway, the aurora is to be viewed with awe. There is to be no waving, whistling, staring, or any other form of "defiance". If you wave at the aurora, according to myth, it will increase in activity and reach down and touch you, with apparently unwelcome results.

Those who did not see supernatural beings often interpreted the aurora as a predictor of the weather. Snow and bitter cold were often thought to follow bright auroral displays in Scandinavia, while the Eskimos saw just the opposite: the spirits were bringing favorable weather.

"And the skies of night were alive with light, with a throbbing, thrilling flame;
Amber and rose and violet, opal and gold it came.
It swept the sky like a giant scythe, it quivered back to a wedge;
Argently bright, it cleft the night with a wavy golden edge.
Pennants of silver waved and streamed, lazy banners unfurled;
Sudden splendors of sabres gleamed, lightning javelins were hurled.
There in awe we crouched and saw with our wild, uplifted eyes
Charge and retire the hosts of fire in the battlefield of the skies."

— Robert Service, from "The Ballad of the Northern Lights," published in 1908

For more information on the web

The Exploration of the Earth's Magnetosphere
http://www.phy6.org/Education/Intro.html

The Aurora Explained
http://www.alaskascience.com/aurora.html

Windows to the Universe
http://www.windows.ucar .edu/spaceweather/

Sun-Earth Day 2003
http://sunearth.gsfc.nasa.gov/sunearthday/2003/

LESSON: Planning a trip to see the aurora

Objectives: The student will identify the range of latitude with the highest probability of seeing an aurora and choose a location to visit to view them.

List of Materials: 1 cm x 1 cm graph paper, colored pencils (4 different colors)

Background: The location of aurora sightings around the world is not random. There is a pattern to the number of sightings found in different locations around the Earth. What do you think it is?

Directions:

1. Looking at an atlas, a world map, or a web site (http://www.getty.edu/research/tools/vocabulary/tgn/ is a good one), research and record the latitude and longitude for each location in the chart that is blank.

Location	*Geographic Latitude*	*Geographic Longitude*	*Number of days per year with auroral sightings**
San Diego, California, USA			0
Tokyo, Japan (*Tokyo, Nihon*)			0
Athens, Greece (*Athínai, Ellás*)			0
Rome, Italy (*Roma, Italia*)			1
Paris, France			2
London, England			3
Moscow, Russia (*Moskva, Rossiya*)			5
Toronto, Ontario, Canada			10
Calgary, Alberta, Canada			20
Thule, Greenland (*Thule, Grønland*)			50
Peary Land, Greenland			60
North Pole	90º 0' N	---	65
Alert, Nunavut, Canada	82º 30' N	62º 18' E	70
Ny-Alesund, Svalbard	78º 55' N	11º 56' E	75
Anchorage, Alaska, USA			90
Reykjavik, Iceland			280
Murmansk, Russia (*Murmansk, Rossiya*)			280
Barrow, Alaska, USA			300

**Auroras can't be seen well in the summertime in the northern hemisphere, but they still occur. These numbers include summer auroras.*

2. Using the geographic data and sightings from the table, place a small "x" of the proper color on each of the locations on the world map.

Number of auroral sightings	**Mark on the map**
0-49	blue
50-99	green
100-149	yellow
150 or more	red

3. Create a graph large enough to fill most of a sheet of graph paper following these directions:
   a. Label the x-axis "Latitude in degrees". The range of that axis should be the same as the latitude range in the table in 1.: approximately 30-90 degrees.
   b. Label the y-axis "Number of sightings". The range for this axis is in the table in 2.: 0 - 300.
   c. From the table in 1., average the number of auroral sightings per year for each 10 degrees of latitude (30-39 degrees, 40-49 degrees, etc.). Plot the points on your graph to compare the average number at different latitudes. Use the colors from 2. Give your graph a title.

Data analysis: Looking at both the map and the graph, answer the following questions:

a. Which latitudes have the most sightings?
b. Does the number of sightings change as you get closer to the North Pole?
c. What can you conclude about where the aurora is most likely to be seen?
d. Read the "Where can you see an aurora?" section on this poster. Do your results agree with the scientific research? Explain.

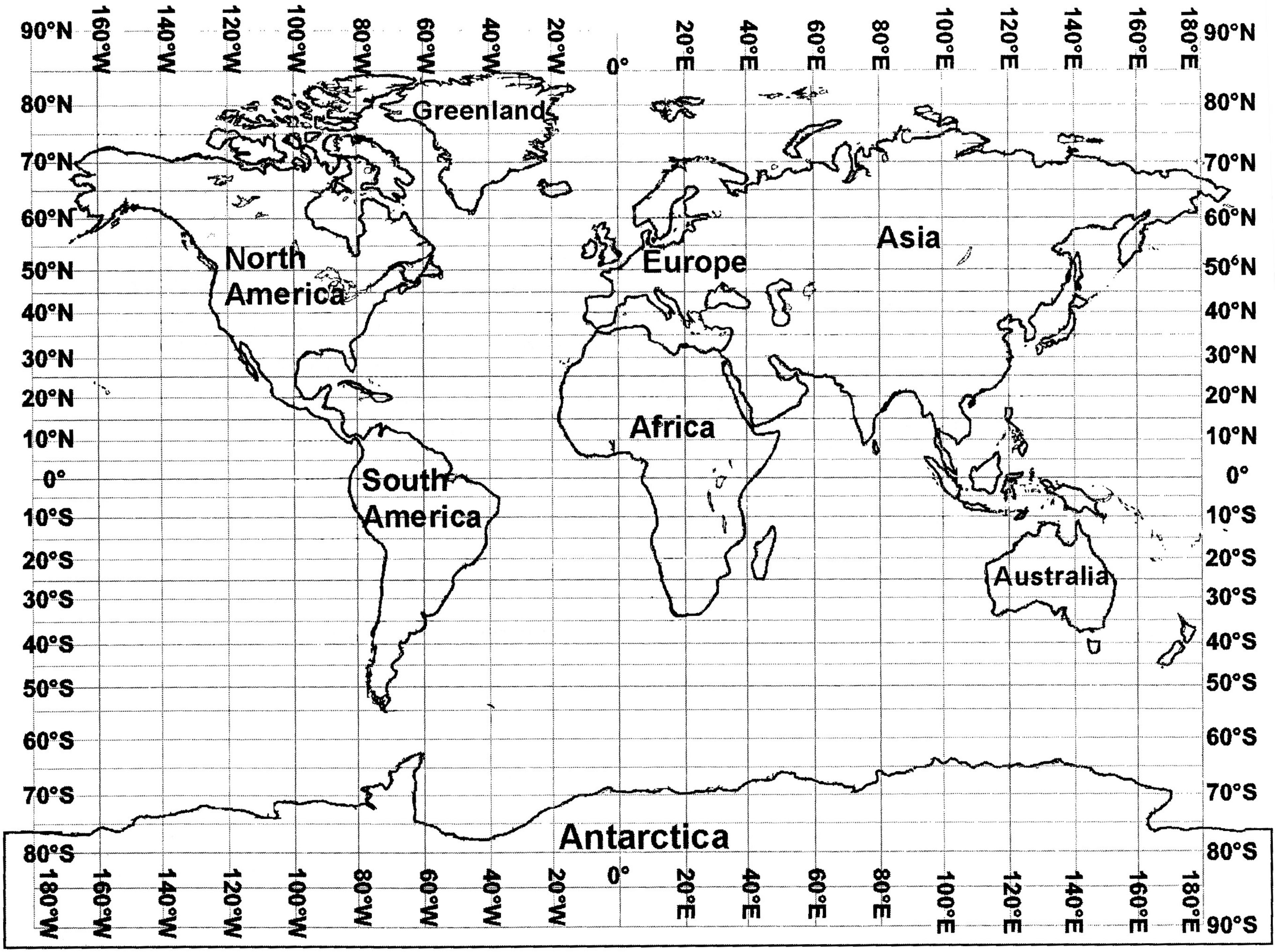
Science journal: Write in your journal:

a. What can you predict about the probability of seeing an aurora in your town?
b. Discuss the advantages and disadvantages of visiting the locations with high probabilities. What other conditions should you consider in selecting a location?
c. Why can't you see a summertime aurora well in the northern hemisphere?

Extension: The Earth's magnetic poles do not line up with its geographic poles and in fact have changed location over time (see http://www.geolab.nrcan.gc.ca/geomag/e_nmpole.html). Do you think the location of the magnetic poles affects the location of auroral sightings?

(Answer key is at http://sunearth.gsfc.nasa.gov/sunearthday/2003/poster.html)

Education Standards–*Poster: NSES Science Content Standards B, D, F (Grades 5-8). Lesson: NCTM Math Standards Data Analysis and Probability, Connections, Representation (Grades 6-8); NCGE Geography Standards 1,4*



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