

# *theHoustonMuseumofnaturalscience*

Dear Science Educator:

Because of its relationship to the Sun, Solar Physics, and Earth Science, the *Experience the Aurora* planetarium show provides rich curriculum connections. This Teacher's Resource packet is designed to bring these resources into your classroom. Enclosed are 3 disks: Space Weather CD, Experience the Aurora DVD, and Space Weather Connections CD. They are all connected. The Space Weather CD is very rich in the Space Weather software plus activities and games. I describe these in the pdf called **Pre or Post Visit Activities**. The Space Weather software has an incredible amount of material (like being on the Internet without any risk). You can run the program from the CD or you can install it in as many computers as you like. Once installed, you can update some of the images from the Internet. A curriculum pdf called **Space Weather Activities** can be used with the Space Weather program. You can select those activities that are most relevant for your students or they can be a set of independent discoveries students can make on the computer. A copy in black and white is provided for copying. The Space Weather CD also has over 100 different activities arranged in folders by topic. Rough grade levels are provided but I recommend your opening any activity with an interesting topic and consider how you might adapt it for your students if the grade level is too advanced or too elementary.

The *Experience the Aurora* DVD allows you to play the show for students as part of a post-visit discussion. I recommend that it not be used before students see *Experience the Aurora* in full-dome so the effect of the full-dome aurora is not diminished in any way. Two files support the DVD: **Experience the Aurora illustrated color.pdf** and a black and white version for copying purposes. This document has the complete script as students heard it with discussion questions in bold ahead of the paragraph that answers each question. You can play the movie and stop when the topic changes to pose a question. Students can discuss the question and then discover the answer from the Experience the Aurora show.

The Space Weather Connections CD contains all of the support files described above plus four more traditional documents. **Aurora Show Glossary.pdf** defines every science word that students hear in the show. The **Auroral Dictionary.pdf** provides the associated physics concepts for older students studying the Sun-Earth System. **Aurora Curriculum Color .pdf** (and the black and white version) provide three types of post-visit assessment: Essay or Discussion Questions, Multiple Choice Questions, and Fill-in-the Blank Questions. Answers for these come directly from the Experience the Aurora show. An answer key is also provided (**auroranswers.pdf**).

Experience the Aurora is so valuable for students because most of them will never see the real aurora and certainly not the different kinds of auroras on display in this program. Also the Sun-Earth connection is most important in understanding how the sun affects our changing planet. The aurora provides a topic to spark student interest in changes on the Sun and how they cause changes on Earth.

I hope you will enjoy using these activities as much as I enjoyed writing them. And I must thank Dr. Patricia Reiff of Rice University for her help in organizing this product and in providing the Space Weather CD through NASA's Magnetospheric Multiscale Mission.

Sincerely,



Dr. Carolyn Summers  
Vice President for Astronomy and the Physical Sciences  
Houston Museum of Natural Science

## EXPERIENCE THE AURORA

Script with discussion questions in bold.

### What is a Big Sky Experience?

An incredible big sky experience is something few of us can enjoy in the 21<sup>st</sup> century.

Like a storm in the desert;

...the Milky Way crossing the July sky;

...the electrical fireworks of a massive thunderstorm;

...the rare and exotic majesty of a total solar eclipse;

...or most desirous of all: the Aurora, the Northern Lights. For most of us it's an experience glimpsed on a television or movie screen.



### What is special about the video in the Experience the Aurora show?

This box shows the area of the sky typically photographed. Now, for the first time ever, we can enjoy one of nature's marvels as it is meant to be seen and experienced in its immersive beauty.



*Capturing the Aurora like this was something I had wanted to do for tens of years. I had to wait until camera technology developed sufficiently to allow the capture of the whole sky, in color, in detail and movement. The Sun also needed to co-operate, to be active enough to stimulate vibrant Auroras: bright enough to be photographed. Eventually all these came together, and I planned a seven-month campaign to bring the Aurora to the domes of digital theatres.*

### Where do you see the aurora?

From the most populated parts of the world, auroras often are seen low on the horizon. To be immersed in the Aurora, you need see it from regions close to, but not at, the Poles of the planet.

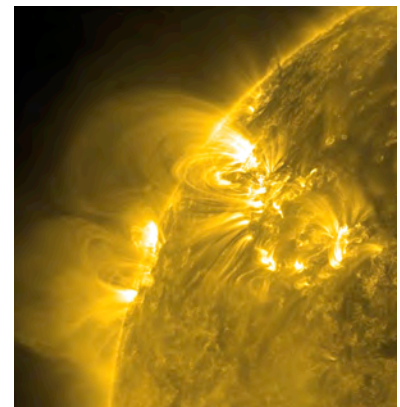
### What did people long ago think the aurora was?

The earliest records of Aurora come from China in the 6<sup>th</sup> century B.C. Red Auroras were considered bad omens. In our own time, Auroras have made rare appearances as far south as Athens and Miami. The name Aurora originates from the Roman goddess of dawn, which distant auroras emulate. In Arctic regions, where Auroras are common, they were said to be flickering torches lighting the way to heaven for the spirits of the dead.



### How does the Sun cause the aurora?

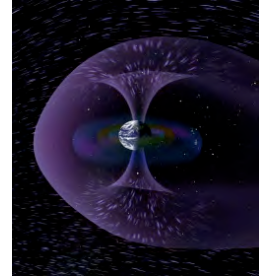
Today we know that the Aurora is the most spectacular demonstration of the way the Sun and Earth are invisibly linked through the **solar wind**. The frequency and intensity of the Aurora have long been known to follow the rhythmic cycle of cool spots on the sun over an eleven-year period. The more spots, the more Auroras. The **Sun's magnetic field** drives all forms of solar activity in ways that we don't fully understand. Associated with **sunspots** are **solar flares**, massive explosions shooting



streams of energetic particles far into space. Immense compared to our tiny Earth, **prominences** can last for days or months, and when erupting can spew vast amounts of hot gas into space. Greater still are **coronal mass ejections**. They can expel up to ten billion tons of gas.

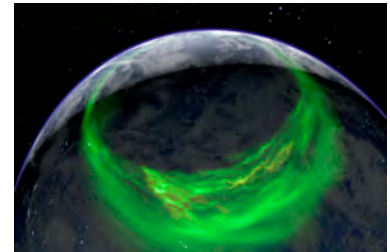
### What happens when the solar wind reaches the Earth?

Fortunately our own **magnetic field** protects us from this very harmful radiation. The field gets severely distorted and as it rearranges itself, particles from distant parts of the field are accelerated to the **Earth's magnetic poles**. Even Saturn, eight times further away from the Sun than us, develops spectacular Auroras at its poles. High above our planet the currents of particles pick up even more energy as they flow toward the Poles and then collide with the upper atmosphere. This is the result: an explosion of light and color as particles flow along the magnetic field into the Polar Regions and interact with **nitrogen** and **oxygen** atoms in the atmosphere. The interaction can be bright enough to be seen in a city...compete with brilliant urban lighting as here in Kiruna, Sweden and even can add a dynamic celestial backdrop to the evening commute.



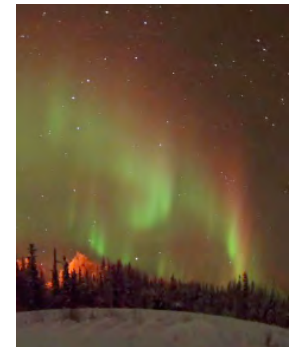
### Where do auroras occur?

Centered on the **North and South Magnetic Poles** and starting at a height of 100 kilometers, the **auroral oval** is a permanent region of interaction. The Earth turns under it. The oval contracts and expands with the changing flux of particles. Amazingly the northern and southern auroras are mirror images of each other: proven when two aircraft recorded Aurora simultaneously from the **Arctic** and **Antarctic**. The particles create auroral twins as they bounce from one hemisphere to the other. From space the oval is like a cylinder beginning at a height of 100 kilometers and extending almost 1000 kilometers upward. From the Earth's surface this cylinder looks like great arcs attached to the horizon. Of course, it's not. It's high above the planet.



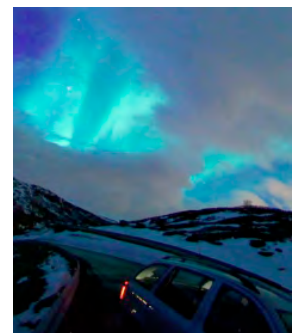
### Fairbanks Aurora

*For my winter shooting campaign I chose a series of sites in and around the **Arctic Circle**. I was hoping that the changing geometry with respect to the auroral oval would enable me to capture the different forms and colors of the Aurora. From Fairbanks in December my target was high altitude red Aurora. The Sun obliged and I was ready. Evening fell and the temperature dropped to forty below freezing. Would the cameras survive? After eight hours of a pale green arc, the sky came alive and there, at over 300 kilometers high at the top of the shimmering curtains, was the brilliant red I was hoping to capture.*



### What causes Auroral Light?

Auroral light is generated when the energetic particles hit the air molecules or atoms and cause them to briefly store energy. This energy is then released as green and red auroral light from atomic oxygen. In the denser lower regions of the atmosphere the stored energy can be passed on in another collision and no light will be emitted. Higher up, above 300 kilometers or so the atoms are very far apart and so have time to emit their striking red light. That's why red is normally seen at the top of the Aurora. Our eyes are not very sensitive to this light, so we mostly see the Aurora as green.



### Can you see the aurora on a cloudy night?

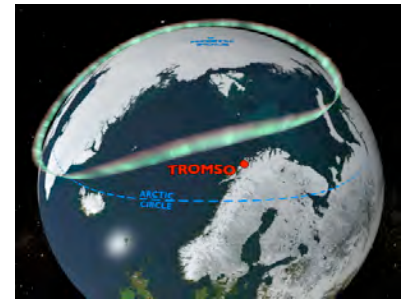
*At the beginning I was concerned about clouds during a night's shoot until I realized that they can provide a rather beautiful foreground for the heavenly dancers beyond. You can see me here at work taking photographs with an ordinary camera through gaps in the clouds. Naturally I looked forward to nights when it was almost clear, like this scene in late October when some light from the hidden Moon adds a touch of blue to the sky. The display begins with a series of arcs. Over time they get more active and move across the sky in a southerly direction.*



*As activity increases, this indicates that an **auroral substorm** is about to occur. This is what aurora watchers love to see. Substorms can last from minutes to hours and are a wonder to behold.*

### Where were most of the aurora photographed and why?

The bulk of the photography for this show was done around Tromso in northern Norway. It's the easiest city to reach north of the Arctic Circle, and moves under the auroral oval quite often. With a population of 50,000, it has good winter infrastructure, which makes travel and photography much easier. It's also home to the world's most northerly planetarium, where some of the first time-lapse movies of the Aurora were made and presented.



### How do you predict an aurora?

*Predicting an aurora is difficult. Solar disturbances are not predictable, and the effects take time, 1-3 days, to reach Earth, and might only last for 24 hours. I used coronal holes to plan photographic trips. These dark areas are places where the solar wind travels directly into space. As the sun rotates, jets spiral outward like water from a sprinkler. Through the open magnetic field at a coronal hole, the solar wind can shoot at up to 900 kilometers per second - twice its normal speed. Coronal Holes can last for months, so as the sun turns they can blast the Earth again and again every 27 days.*

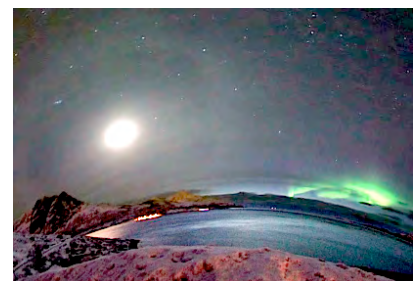
*January, and the Earth is traveling inside a solar wind stream from a coronal hole. It lasted for several days. As the solar wind fires up the generator in our magnetosphere, the magnetic field lines stretch out then suddenly snap back like rubber bands, flinging particles toward the poles. The result - many days of auroral activity and numerous substorms. In the next scene, look for the purple fringes at the bottom on the brightest aurora. This*



*was auroral light from Nitrogen. Its red and blue light is always there, but our eyes are not very sensitive to it. However when a very energetic particle stream gets really low, in this case about 80 kilometers high, the intense aurora gets a purple edge at the bottom, a mixture of the red and blue emissions. Toward the end of a display large areas of the sky can flicker off and on, sometimes many times a second: 27 days later another coronal hole and another immersion.*

### How did the cameraman react to seeing his first aurora?

*I'd seen a distant Aurora before from the United States, but when the sky exploded with color and light, I was awestruck. The speed that the aurora forms shot across the sky was unbelievable. A number of solar explosions occurred during*

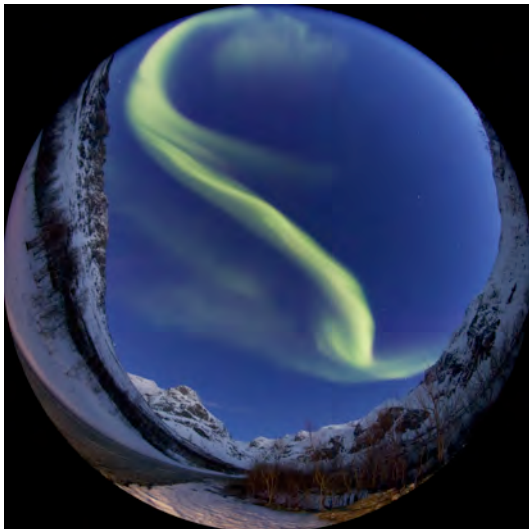


*the shoot in addition to a stream from the coronal hole, so each evening was filled with expectations of things to come. Here we are setting up the equipment, and already just after sunset there's a faint Aurora in the sky. It was dang cold out, about minus 20 Celsius. This is what the cameras recorded. The bright object is the Moon. Look for the halo of ice crystals around it. During March the Sun was very active...but so was the weather with heavy snow, cold temperatures and strong winds. Auroras barely peeked through breaks in snow showers. Snowdrifts and ice made driving difficult, but there was always one eye on the sky. Tantalizing breaks revealed lots of activity...but the snow clouds won out in the end. A month later, with no clouds, the same region presented a magnificent night of auroral splendor. A veritable river of light flowed across the sky. A myriad of auroral forms decorated the heavens. Wherever you look, even behind you, it's a kaleidoscopic dance of celestial beauty.*

### **What are the greatest dangers in photographing the aurora?**

*A final challenge: to capture the tallest and bluest Aurora from Svalbard just 900 kilometers from the North Pole itself. The first night a polar wind 60 kilometers strong with blowing snow and a temperature of minus 30 Celsius prevented work. The next day was calm, but even colder. We explored to find a site good for photography and safe from polar bears. Here there are more bears than people. So while one of us worked the cameras, the other had to scout for the world's largest land carnivore.*

*We planned to use the low sun just below the horizon and the Moon to illuminate and stimulate Nitrogen hundreds of kilometers high. Sufficiently excited Nitrogen will emit purple and blue light, so rarely seen and photographed. Hundreds of kilometers away along the horizon, fingers of color stepped across the sky like soldiers on parade. After five hours, at minus forty Celsius, when we thought the cameras would seize, the sky came alive. Too soon, it was all over. We had survived a night of intense cold and immense delight. The next day was colder still, but the evening sky promised a night of celestial wonder. A bright half Moon couldn't dim this Aurora. Only after enduring extreme temperatures with the cameras and ourselves frozen at minus 50 Celsius, did we call it a night.*



### **Why is aurora observing over in April?**

*As we prepared to leave we thought of the fantastic scene from here in March 2015 when a total solar eclipse will grace the sky...possibly accompanied by a dazzling aurora – what a fabulous thought. Finally, in April, back to Tromso for the last auroras of the season before continuous daylight hides them from view. With the sun just below the horizon, the blue sky and snow-covered mountains provide the perfect backdrop to our farewell to seven months of the Northern Lights. What an amazing and unforgettable experience.*

## **Experience the Aurora Glossary**

### **The terms students will hear in the Experience the Aurora show**

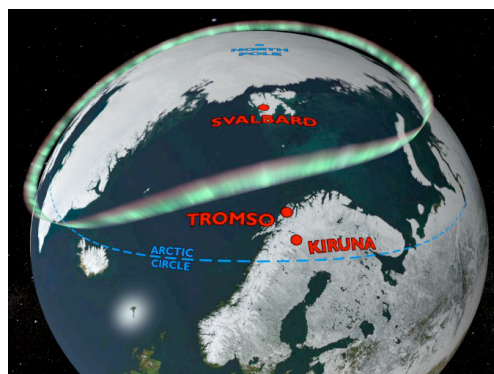
Antarctic	Region within 23.5 degrees of the geographic South Pole
Arctic	Region within 23.5 degrees of the geographic North Pole
Arctic Circle	Circle of latitude, 66.5 degrees north of the Equator
Aurora	“Northern Lights” (aurora borealis) or “Southern Lights” (aurora australis); glow in the sky caused by solar wind particles entering Earth’s atmosphere.
Auroral substorm	Increase in the aurora due to energy input from the solar wind.
Auroral oval	Location of auroras around the North and South Magnetic Poles
CME	Coronal mass ejection; a huge explosion in the corona sending a large amount of solar wind outward from the sun
Corona	Extremely hot outer layer of the solar atmosphere (visible during a total solar eclipse)
Coronal hole	Dark areas where the solar wind escapes easily into space
Geographic North Pole	Point where the spin axis of Earth intersects the surface
IMF	Interplanetary magnetic field; region of space where the solar magnetic field is the predominant field; the IMF dominates in most of the solar system, except near the planets
Magnetic field	An invisible force that is generated by electric current loops or by changing electric fields. It acts only on moving charged particles, causing them to turn.
Magnetic North Pole	Location on Earth of the south pole of the Earth’s internal magnet; at this point the magnetic field lines point straight down, and the north pole of a magnet is attracted to this pole.
Magnetosphere	Region where Earth’s magnetic field is the predominant field
Magnetotail	Part of the magnetosphere that extends from Earth away from the sun
Nitrogen	An element, a gas making up 78% of the Earth’s atmosphere, produces the blue color in the aurora

Oxygen	An element, a gas making up 21% of the Earth's atmosphere, produces the green and red colors in the aurora
Prominence	A large bright feature extending outward from the sun's surface, often in a loop shape
Solar flare	Explosion from the surface of the sun, throwing charged particles into space
Solar wind	Flow of charged particles from the sun
Sunspot	Cooler region on the surface of the sun, appears dark
Sunspot cycle	11-year cycle of the number of sunspots; causes variation in solar activity with more activity when more sunspots are present.

## ***After Experiencing the Aurora*** **Essay or Discussion Questions**

1. Which of these Big Sky experiences have you had?
  - Storm in the desert
  - Milky Way crossing the July sky
  - Electrical fireworks in a thunderstorm
  - Total solar eclipse
  - Auroras filling the skyUsing these examples as a model, describe a different Big Sky experience you have had.
2. Ancient people saw shapes and wrote myths about the aurora, including flickering torches leading the dead to heaven, dancing of the gods, bridge connecting Earth to the gods, fire foxes brushing up sparks with their tails, and a Viking goddess riding horseback. Think about the auroras you saw in the planetarium show. Write a myth describing what the aurora looks like to you. Why was the aurora named for the Aurora, goddess of the dawn?
3. You're a photographer with an assignment to capture an aurora. Where would you go? When would you go? What clothes would you pack? What equipment would you take? What environmental dangers would you face? And how would you predict when an aurora might occur?
4. Why does the Earth have auroras, but the moon does not?
5. If the auroral oval is so far south that auroras can be seen in Athens or Miami, could an aurora be seen where you live?

6. Auroras were photographed in 4 locations in *Experiencing the Aurora*. What do these 4 places have in common?  
Fairbanks, Alaska; Kiruna, Sweden; Tromso, Norway; and Svalbard, Norway.



7. This photograph from *Experiencing the Aurora* shows an aurora and the moon with a ring around it. From this image, what three of these elements must be in Earth's atmosphere?

Hydrogen, Helium, Carbon, Sulfur, Oxygen,  
Nitrogen, Chlorine, Iron, or Mercury





***After Experiencing the Aurora***  
**Multiple Choice Questions**

1. Why have most of us never seen an aurora?
  - a. They are very rare.
  - b. They are very faint.
  - c. They are the same color as city lights.
  - d. They are rarely over population centers.
  
2. Which of these places would you visit to see an aurora?
  - a. Egypt
  - b. Mexico
  - c. Norway
  - d. Arizona
  
3. When would you make a trip to see the Northern Lights?
  - a. May
  - b. June
  - c. August
  - d. January
  
4. Experience the Aurora is the first full dome film of the aurora. What had to happen before this film could be made?
  - a. An exceptionally warm winter
  - b. An exceptionally cold winter
  - c. A higher resolution camera
  - d. A sun without sunspots
  
5. Why don't we see auroras during warm weather?
  - a. It doesn't get dark.
  - b. The atmosphere is too warm to glow.
  - c. The sun is too active.
  - d. Polar Bears are too active.
  
6. Name a planet that has auroras.
  - a. Mercury
  - b. Mars
  - c. Saturn
  - d. Venus
  
7. Most auroras that Alaskans see are:
  - a. Red
  - b. White
  - c. Blue
  - d. Green

***After Experiencing the Aurora***  
**More Multiple Choice Questions**

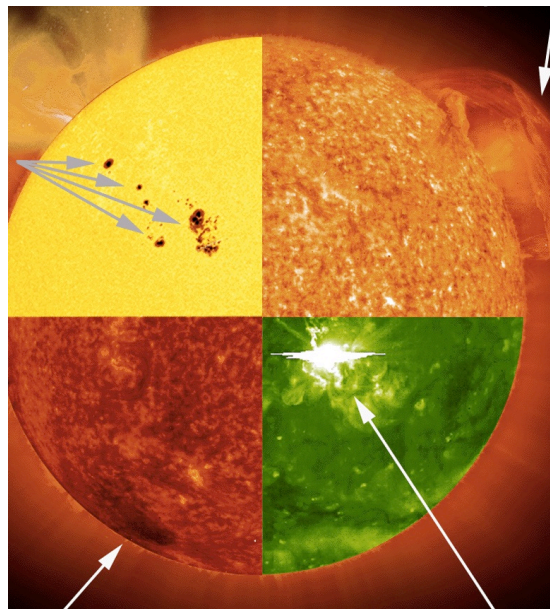
8. How many auroral ovals does the Earth have?
  - a. Two – one inside the other
  - b. One around the moon
  - c. One around each magnetic pole
  - d. One around the magnetic equator
  
9. What are auroral twins?
  - a. Matching auroras in different parts of the sky
  - b. Auroras on different nights that look alike
  - c. Identical auroras in Alaska and Norway
  - d. Matching auroras near North and South Poles
  
10. What does Earth's magnetic field do?
  - a. Accelerates charged particles toward magnetic poles
  - b. Protects us from charged particle radiation
  - c. Reconnects to accelerate particles for auroral substorms
  - d. All of the above
  
11. The auroral oval circles the
  - a. Equator.
  - b. Arctic Circle
  - c. North and South Magnetic Poles
  - d. North and South Geographic Poles
  
12. The auroral oval is really shaped like a
  - a. circle.
  - b. cylinder.
  - c. cone
  - d. all of the above
  
13. How high is the lowest aurora?
  - a. 1 kilometer
  - b. 10 kilometers
  - c. 100 kilometers
  - d. 1,000 kilometers
  
14. What is the largest land carnivore?
  - a. Human
  - b. Whale
  - c. Reindeer
  - d. Polar bear

## ***After Experiencing the Aurora*** **Fill-in-the-blank Questions**

1. Place these events in order by numbering them from 1 to 6
- \_\_\_\_\_ The number of particles in the solar wind increases.
  - \_\_\_\_\_ A coronal mass ejection occurs.
  - \_\_\_\_\_ Charged particles enter Earth's atmosphere.
  - \_\_\_\_\_ The Sun has a region of sunspots.
  - \_\_\_\_\_ Energy is transferred to the Earth's magnetic field.
  - \_\_\_\_\_ A solar flare occurs.

2. Check all of the events that indicate future auroras.
- \_\_\_\_\_ A coronal hole near the center of the sun
  - \_\_\_\_\_ No visible sunspots
  - \_\_\_\_\_ A flare eruption
  - \_\_\_\_\_ Low CME activity
  - \_\_\_\_\_ Strong solar wind

3. Match labels with the composite picture on the right:  
Label the 4 arrows and the object in the upper left.  
Sunspots, Flare, Prominence, CME, Coronal Hole



4. Match each number with its description:

10 billion	Rotation period of sun in Earth days
27	Arctic solar eclipse year
1-3	Tons of gas spewed out in a coronal mass ejection
50,000	Lowest altitude of a photographed aurora in show in kilometers
2015	Maximum speed of solar wind through a coronal hole in km/sec
900	Lowest temperature described for photographing aurora
-50	Days for particles from the sun to reach Earth
80	Population of Tromso, Norway

5. Match each aurora color with its elevation and source:

Green	Nitrogen, under 100 kilometers
Red	Nitrogen, 150 – 200 kilometers
Purple	Oxygen, 100-150 kilometers
Blue	Oxygen, over 200 kilometers

## *After Experiencing the Aurora*

### Essay or Discussion Questions

1. Which of these Big Sky experiences have you had? **Answers will vary.**  
Using these examples as a model, describe a different Big Sky experience you have had. **Students might talk about a mountain or ocean vista, a dramatic city skyline, a sunrise or sunset. There's no right answer – just an opportunity for discussion.**
2. Write a myth describing what the aurora looks like to you. **Answers will vary.**  
Why was the aurora named for the Aurora, goddess of the dawn? **Because in the distance the aurora can look like the coming dawn – especially a low red aurora as is seen in more southerly latitudes.**
3. You're a photographer with an assignment to capture an aurora. Where would you go? **Arctic or Antarctic** When would you go? **When the nights are long** What clothes would you pack? **Warm ones** What equipment would you take? **Low light cameras, fisheye lens, tripods flashlights**, What environmental dangers would you face? **Frostbite and polar bears** And how would you predict when an aurora might occur? **High solar activity, coronal holes facing Earth**
4. Why does the Earth have auroras, but the moon does not? **The moon does not have a magnetic field or an atmosphere to glow.**
5. If the auroral oval is so far south that auroras can be seen in Athens or Miami, could an aurora be seen where you live? **All of Europe and the US.**
6. Auroras were photographed in 4 locations. What do these 4 places have in common? **They are near the auroral oval (and near or above the Arctic Circle).**
7. This photograph from *Experiencing the Aurora* shows an aurora and the moon with a ring around it. From this image, what three of these elements must be in Earth's atmosphere? **Hydrogen and oxygen for water plus atomic nitrogen and oxygen for the auroras.**

### Multiple Choice Questions

1. Why have most of us never seen an aurora? **d. They are rarely over population centers.**
2. Which of these places would you visit to see an aurora? **c. Norway**
3. When would you make a trip to see the Northern Lights? **d. January**
4. Experience the Aurora is the first full dome film of the aurora. What had to happen before this film could be made? **c. A higher resolution camera**
5. Why don't we see auroras during warm weather? **a. It doesn't get dark.**
6. Name a planet that has auroras. **c. Saturn**
7. Most auroras that Alaskans see are: **d. Green**
8. How many auroral ovals does the Earth have? **c. One around each magnetic pole**
9. What are auroral twins? **d. Matching auroras near North and South Poles**

10. What does Earth's magnetic field do? **d. All of the above**  
 11. The auroral oval circles the **c. North and South Magnetic Poles**  
 12. The auroral oval is really shaped like a **b. cylinder.**  
 13. How high is the lowest aurora? **c. 100 kilometers**  
 14. What is the largest land carnivore? **d. Polar bear**

### Fill-in-the-blank Questions

1. Place these events in order by numbering them from 1 to 6  
 \_\_\_4\_\_\_ The number of particles in the solar wind increases.  
 \_\_\_3\_\_\_ A coronal mass ejection occurs.  
 \_\_\_6\_\_\_ Charged particles enter Earth's atmosphere.  
 \_\_\_1\_\_\_ The Sun has a region of sunspots.  
 \_\_\_5\_\_\_ Energy is transferred to the Earth's magnetic field.  
 \_\_\_2\_\_\_ A solar flare occurs.
2. Check all of the events that indicate future auroras.  
 \_\_\_X\_\_\_ A coronal hole near the center of the sun  
 \_\_\_ \_\_\_ No visible sunspots  
 \_\_\_X\_\_\_ A flare eruption  
 \_\_\_ \_\_\_ Low CME activity  
 \_\_\_X\_\_\_ Strong solar wind
3. Match labels with the composite picture on the right: **Sunspots (upper left arrows), Flare (lower right arrow), Prominence (upper right arrow), CME (upper left object), Coronal Hole (lower left arrow)**
4. Match each number with its description:  
**10 billion**      **Tons of gas spewed out in a coronal mass ejection**  
**27**              **Rotation period of sun in Earth days**  
**1-3**             **Days for particles from the sun to reach Earth**  
**50,000**        **Population of Tromso, Norway**  
**2015**         **Arctic solar eclipse year**  
**900**            **Maximum speed of solar wind through a coronal hole in km/sec**  
**-50**            **Lowest temperature described for photographing aurora**  
**80**             **Lowest altitude of a photographed aurora in show in kilometers**
5. Match each aurora color with its elevation and source:  
**Green**            **Oxygen, 100-150 kilometers**  
**Red**             **Oxygen, over 200 kilometers**  
**Purple**         **Nitrogen, under 100 kilometers**  
**Blue**            **Nitrogen, 150 – 200 kilometers**

## **Auroral Dictionary**

**By Prof. Patricia Reiff, Rice University**

**Courtesy of the Magnetospheric Multiscale Mission**

Note: for a good introduction to the magnetosphere with many more terms and diagrams, please see <http://www.phy6.org/Education/index.html> and its glossary <http://www.phy6.org/Education/gloss.html>

**Active Region:** Region of the Sun's surface and corona with strong magnetic fields, generally a sunspot group, which can cause a solar flare. Is bright when observed in UV and X-ray light.

**Aurora:** (From Latin "dawn") Glowing lights in the sky from bombardment from electrons or protons accelerated in the Earth's magnetosphere. The particles excite the atoms and molecules, which then emit light to drop back to an unexcited state.

**Aurora australis:** "southern dawn" – Aurora in the Southern hemisphere

**Aurora borealis:** "northern dawn" – Aurora in the Northern hemisphere

**Auroral blue line:** 391.4 nm (3914 Ångstroms), caused by band emission from molecular Nitrogen.

**Auroral curtains:** Sheets of light, vertically aligned with the local magnetic field and stretching generally east to west (very thin in the north-south direction). Can have folds.

**Auroral green line:** 557.7 nm (5577 Ångstroms) – caused by excited atomic Oxygen in the upper atmosphere. A "**forbidden**" line.

**Auroral oval:** Instantaneous ring of the aurora around the north and south magnetic poles

**Auroral rays:** Individual glowing lines, aligned with the local magnetic field direction. Named because they resemble light rays at sunset.

**Auroral red line:** 630.0 nm (6300 Ångstroms) – caused by excited atomic Oxygen in the upper atmosphere.

**Auroral substorm:** Violent explosive increase in auroral intensity, often moving both to higher and lower latitudes, with the curtains winding up into spirals. The auroral response to a **magnetospheric substorm**.

**Auroral zone:** Latitude band around the Earth where statistically, auroras are most common, between about 15 and 25 degrees from the north and south magnetic poles.

**Corona (solar corona):** Extremely hot outer layer of the Sun's atmosphere – millions of degrees C. Can be observed during total solar eclipses, or from space.

**Corona aurora:** An auroral curtain which is overhead, so the folds make a loop around you, and the rays appear to all converge to a point above you, making a “crown”.

**Coronal hole:** Area in the Sun’s corona where the magnetic field is “open”, extending out into space, allowing the free expansion of the solar wind. This causes **high-speed streams** that are associated with recurring aurora.

**Coronal Mass Ejection (CME):** An event when part of the Sun’s corona is explosively ejected into space, as a result of magnetic reconnection in the corona. Can take with it up to a million tons of material, creating a very dense, very fast solar wind. If it impacts the Earth, it can cause major **geomagnetic storms** with bright low latitude auroras.

**Forbidden line:** Light emission from a forbidden transition. The excited atom generally will lose its energy in collisions before emitting light, so these lines are not observed in a laboratory. In the upper atmosphere, however, the density is very low and there are so few collisions that these lines can be seen.

**Geographic Pole:** Location where the Earth’s spin axis intersects the surface of the Earth, at the North and South.

**Geomagnetic Storm:** Time of extended magnetospheric activity (1-2 days), associated with a series of auroral substorms, injection of particles into the ring current, and auroras observed closer to the equator than normal. Generally caused by a CME or a high-speed stream.

**High-speed streams:** Regions of the solar wind that are especially high velocity (600 km/s or more) and long lasting (a day or two). They can be associated with recurring aurora, once per solar rotation (27 days). Often are generated from **coronal holes**.

**Interplanetary Magnetic Field:** The magnetic field, which is generated in the Sun, and extends through the solar system, to the edge of the heliosphere. Controls the access of energy and plasma to the Earth’s **magnetosphere** through a process called **magnetic reconnection**.

**Magnetic Field:** An invisible force that is generated by electric current loops or by changing electric fields. It acts only on moving charged particles, causing them to turn.

**Magnetic Field Line:** An invisible line of force that is aligned with the local direction of the magnetic field. Since the magnetic field guides the motion of charged particles, the aurora has vertical stripes aligned with the magnetic field. Essentially you can “see” the magnetic field line by the glow from the particles trapped on it. Similarly you can “see” magnetic field lines on the Sun by the particles trapped on it. Magnetic field lines never stop or start... they exist only as loops or as lines that extend far out into space.

**Magnetic Flux Tube:** A line of magnetic force that has particles associated with it. They spiral around the magnetic field line and travel up and down along the field line, but stay close to a single field line. Thus an auroral ray is the particles trapped on a single flux tube.

Similarly, a field line in the Sun's corona becomes visible if it has more particles trapped on it than a neighboring field line.

**Magnetic Pole:** Location where the Earth's magnetic dipole axis intersects the Earth's surface. Offset from the geographic pole by around 11 degrees of latitude, and wanders over time. The North magnetic pole the field points straight down towards the Earth. At the South magnetic pole, the magnetic field points away from the Earth.

**Magnetic Reconnection:** A process whereby magnetic fields interact and join one another, releasing magnetic energy. In the process, the magnetic fields can change topologies, changing from being a closed loop to a field extended out into space or vice versa. At the Earth, a southward-pointing IMF reconnects with the northward-pointing magnetic field of the Earth, allowing energy to transfer from the solar wind to the magnetosphere.

**Magnetopause:** The boundary of the magnetosphere. Nearly a parabolic shape, with the closest part being towards the Sun and a long tail away from the Sun. Separates the strong magnetic field of the Earth from the high-density plasma of the solar wind. A strong electric current flows along the sheet, which increases the Earth's magnetic field inside and reduces it outside.

**Magnetosphere:** The region of space dominated by the Earth's magnetic field. Starts at the upper atmosphere of Earth and extends far into space. Seen from space, it is the shape of a comet, with the nose pointing toward the Sun and the **magnetotail** pointing away from the Sun. The edge of the magnetosphere is the **magnetopause**.

**Magnetospheric Substorm:** the storage and release of magnetic energy in the magnetotail. The magnetic energy builds up as a result of **magnetic reconnection** on the dayside **magnetopause**. This energy gets explosively released in the expansion phase, when magnetic reconnection in the tail allows the outer portion of the magnetic tail to break off as a **plasmoid**, and the inner magnetic field snaps back toward earth, becoming more like a dipole field. This slingshot accelerates and energizes plasmas, creating beautiful aurora. The energy transfer to the magnetosphere is more effective when the **IMF** is southward and the solar wind velocity is high, thus we can often predict violent auroras by monitoring the solar wind velocity and magnetic field.

**Magnetotail:** The part of the Earth's magnetosphere that extends far downstream of the Earth, away from the Sun like a comet's tail. Extends well past the lunar distance to 250 or even 500 Earth radii. (In the sunward direction the magnetosphere is only 10-15 Earth radii in size).

**Parallel Electric Field:** An electric field, aligned with the magnetic field that allows acceleration of auroral particles to high energies. Takes an electron of  $\sim 100\text{eV}$  energy and can accelerate it to 2-10 keV or even up above 30 keV at times. The cause of the brightest aurora.



**Plasmoid:** A portion of the magnetic tail broken off by magnetic reconnection. The field, and the plasma on it, may be a closed loop, or it could be a long coil of magnetic field, called a flux rope.

**Prominence:** Loop of material hanging over the Sun's surface. Often appears red because it is mostly Hydrogen.

**Solar Corona:** Extremely hot outer layer of the Sun's atmosphere – millions of degrees C. Can be observed during total solar eclipses, or from space.

**Solar Cycle:** A cyclic time during which the Sun goes to high activity to low activity and back again. Generally about 11 years from one maximum to the next. At solar maximum the Sun's magnetic field reverses, so the solar magnetic cycle is actually 22 years.

**Solar Energetic Particles (SEP):** Very energetic particles that travel at nearly the speed of light from a solar flare. Can be dangerous to astronauts in space or to passengers on polar-flying aircraft. Very energetic so can penetrate the skin of spacecraft, unlike the solar wind, which is much less energetic.

**Solar Flare:** Explosion on the surface of the sun that accelerates energetic particles into space. Can also release a **Coronal Mass Ejection**.

**Solar Maximum:** Time of high solar activity, associated with many sunspots and many flares.

**Solar Minimum:** Time of low solar activity, associated with few sunspots and few flares.

**Sunspot:** Cool area on the surface of the sun, seen as dark regions of in the visible band of light. Generally contains strong magnetic fields, and can be associated with **active regions**.

## Pre or Post Visit Activities On the Space Weather CD

### Space Weather Program

This software is in the SpaceWeather folder of the Space Weather CD (the ClimaEspacial folder in Spanish). You can click on the application in the folder and run the software from the CD or CD disk image. If you want to update the software with new images, you must install it on your computer. Run the Setup program (Instalar in Spanish) for a version of the software that can be updated over the Internet. The SpaceWeatheractivities file has activities that accompany this Space Weather Program.



Thanks to support from the NASA Magnetospheric Multiscale Mission (<http://mms.rice.edu>), this software is free for teachers and students. Mac or PC installers of the software can be downloaded free from this website (but some of the images may be updated from those described in the activity pages). [http://earth.rice.edu/software/Space\\_Weather/installers/](http://earth.rice.edu/software/Space_Weather/installers/) All of the ancillary material described below can also be accessed online via [http://mms.rice.edu/mms/index\\_sw\\_resources.php](http://mms.rice.edu/mms/index_sw_resources.php)

### Space Weather CD Activities

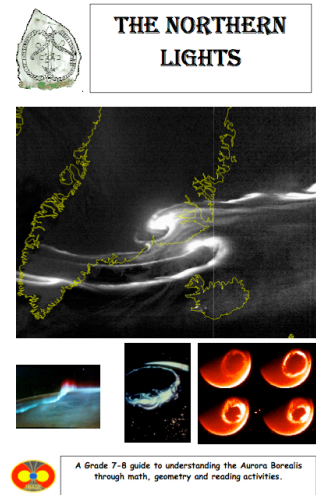
These activities are on the Space Weather CD in the Activities folder. These pdfs may be freely printed for the classroom.

### Northern Lights Workbook

**Level: grades 7-8, but very adaptable**

**Also provided in color and in black and white.**

These activities focus on the Aurora and make excellent classroom activities before or after the *Experience the Aurora* planetarium show.



### Spaceweather 1: Northern Lights and Solar Sprites

**Level: grades K-6**

**13 activities on 68 pages**

Many different areas in solar and space science are covered in these highly interactive exercises. These include studying convection on the Sun, solar flares, how to design a rocket payload, and the general subject of how the Sun affects the Earth. These activities were specifically designed to fill a gap in NASA's offerings for the lower grades and to do so in a way that is both fun, and well integrated with national science benchmarks and standards.

### Spaceweather 2: The Mission and Instruments of IMAGE

**Level: grades 9-12**

This activity is produced by the IMAGE satellite program and the satellite is no longer in operation. However, the graphing activities are excellent.



## Spaceweather 3a-f: Solar Storms and You!

### Level: grades 5-8

This series of six workbooks has been adopted in a number of school districts in Maryland, California and Illinois.

### Spaceweather 3a: Solar Storms and You

- Solar Activity Cycles
- The Sunspot Cycle
- Sunspot Activity and Ocean Temperature
- Sunspot Activity on other Stars

### Spaceweather 3b: Exploring the Solar Wind

- CME Plotting Activity
- Solar Activity and CMEs
- Anatomy of a CME

### Spaceweather 3c: Magnetic Storms

- Magnetic Storms from the Ground
- Motion of the Magnetic Pole
- A Soda Bottle Magnetometer

### Spaceweather 3d: Auroras and the Ionosphere

- AM Radio Ionosphere Station
- Auroras and Magnetic Storms
- Radio Waves and the Ionosphere

### Spaceweather 3e: Satellite Design

- IMAGE Satellite Scaling
- IMAGE Satellite Scale Model
- Pie Charts in Science

### Spaceweather 3f: Human Impacts

- Solar Storms and Satellites
- Cosmic Radiation Creates Unfriendly Skies
- Satellite Glitches and Cosmic Rays
- Radiation Exposure on a Trip to Mars

## Spaceweather 4a-e: IMAGE Explores

### Level: grades 10-12

This series of NASA Education Briefs contain information about a specific IMAGE instrument or technology on the front page. On the back of the page, there is a classroom activity that students can work on that picks up on some aspect of the main essay. Typical activities may exercise geometric skills, algebraic manipulation, or graphing.

**Spaceweather 4a: Geomagnetic Storms**

**Spaceweather 4b: The Plasmasphere**

**Spaceweather 4c: Aurora**

**Spaceweather 4d: The Magnetosphere**

**Spaceweather 4e: Ring Currents**

## **Spaceweather 5: The Geomagnetic Field**

### **Measurements with a Graphing Calculator**

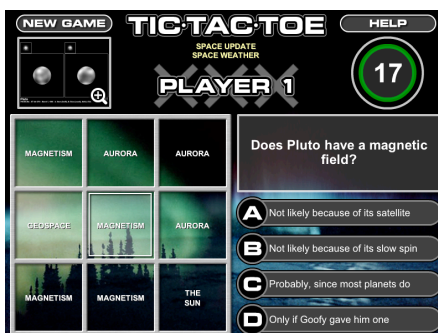
**Level: grades 9-12, but adaptable for some 6-8 classes**

This activity was developed at Rice University in Houston, TX. It uses magnetic field sensors with the "Texas Instrument" Graphing Calculator and CBL to measure and plot magnetic fields. This allows the student to prove that magnetic fields decrease as the negative cube of the distance. This was initially developed for IPC (Integrated Physics and Chemistry) classes, but some advanced middle school Earth science classes can use it. It requires the use of the following materials: (1.) TI-83 Plus graphing calculator, (2.) TI CBL 2 Calculator-Based Laboratory, (3.) Vernier<sup>a</sup> Magnetic Field Sensor (MFS), (4.) A permanent magnet (preferably a strong "cow" magnet), and (5.) Graph Paper and permanent marker.

## **Space Weather CD Games Folder**

### **Cindi comic books**

For the student who enjoys comic books, these offer a good textbook supplement. There are two comic books: *Cindi in Space* and *Cindi in the Electric Atmosphere*, both in the GAMES folder of the Space Weather CD. These pdfs may be freely printed for the classroom.



### **TicTacToe**

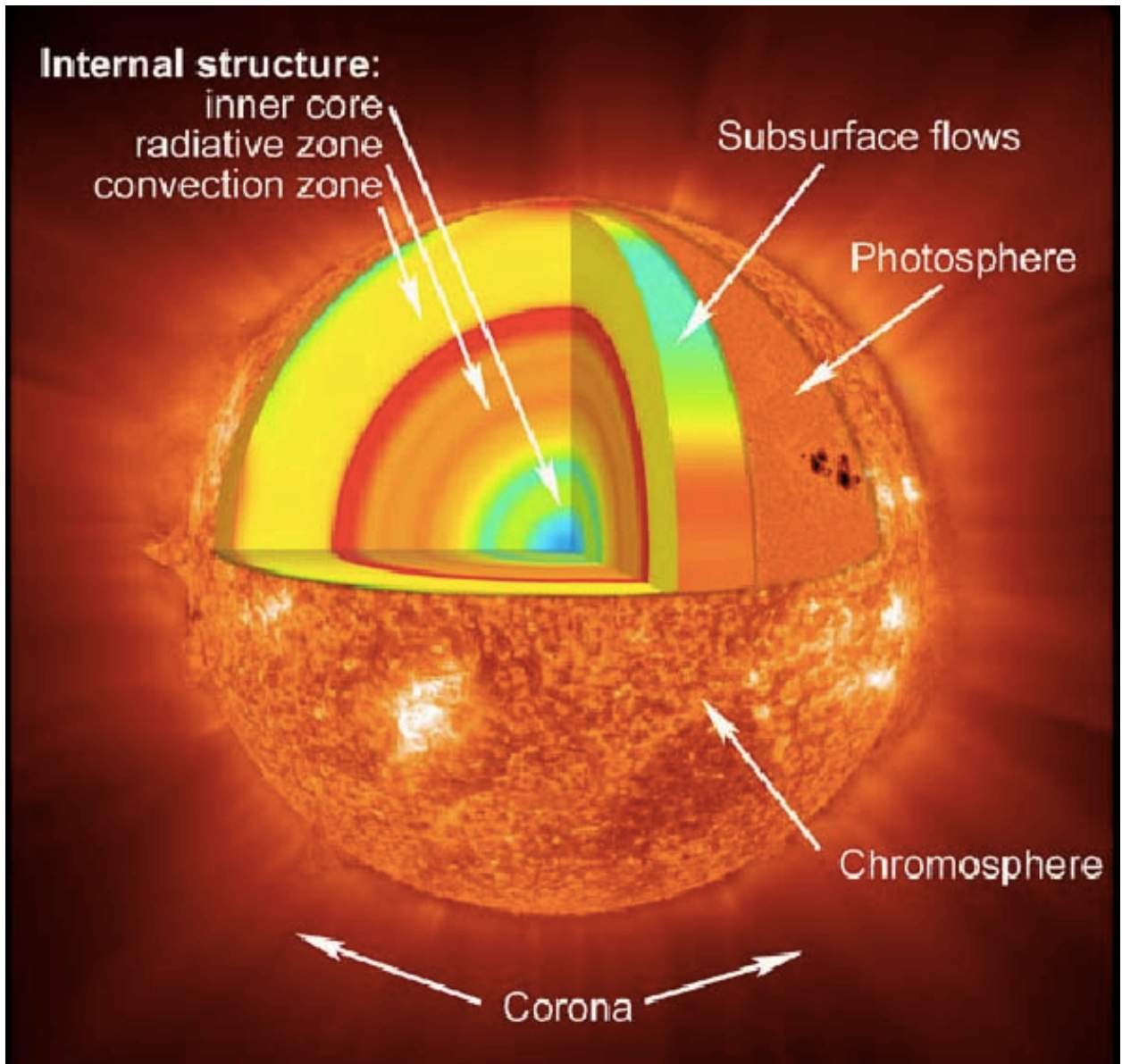
Click on the TicTacToe application in the TicTacToe folder. Then choose the Space Weather topic for the game. This game can be played by one or two students and is very popular as kiosk software at the Houston Museum of Natural Science. Students like to play the game and the questions are a good review of Space Weather topics.

## **Space Weather CD Resources**

Visit the resource folder ("swresources") to find references to more on-line activities and information. For Spanish resources, open "tormentassolares.html" for references.

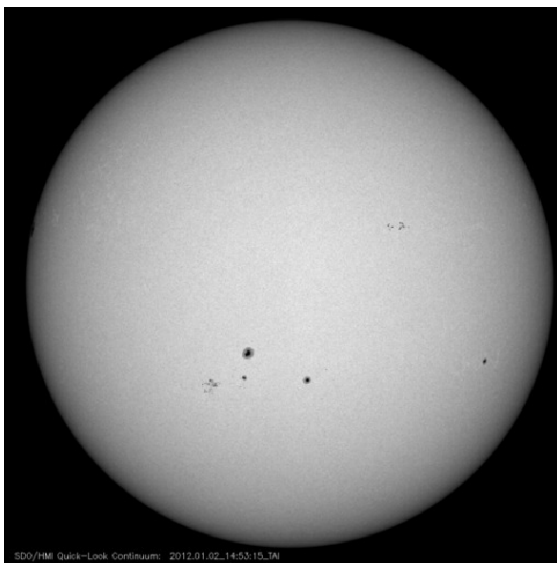
## Space Weather Discovery Solar Basics

Using this diagram and the information from the Sun Basics section of the Space Weather CD, describe “Why the Sun Shines” and “How Solar Energy Travels to the Earth”.

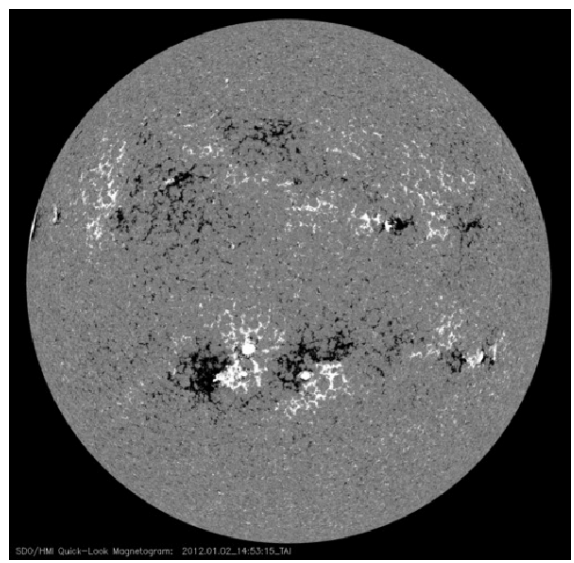


## Space Weather Discovery Faces of the sun

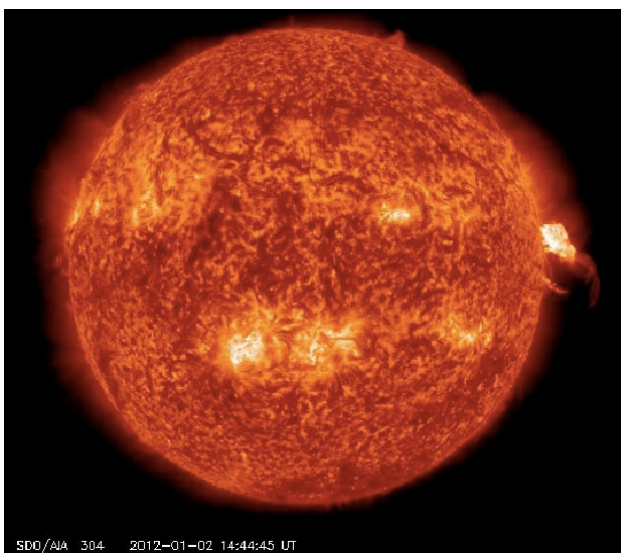
The Space Weather CD shows the sun taken on the same day through many different filters. The first photograph is the sun as you would see it through a safe solar filter or projected by a pinhole. This lower part of the atmosphere is called the Photosphere. The second image shows the sun's magnetic field with one polarity in white and the other in black. The third shows the sun through a Helium filter. It shows the middle layer of the atmosphere called the chromosphere and may have prominences along the limb. The fourth shows the corona with emission regions and dark coronal holes. Find the active region and see how it appears in the 4 photographs. If you have installed Space Weather on your computer and are connected to the Internet, you can update these images for today.



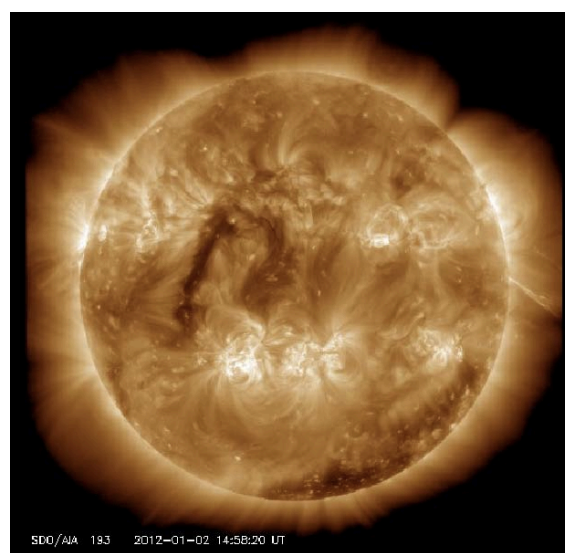
Photosphere (above) & Chromosphere (below)



Magnetogram (above) & Corona (below)



SDO/AIA 304 2012-01-02 14:44:45 UT

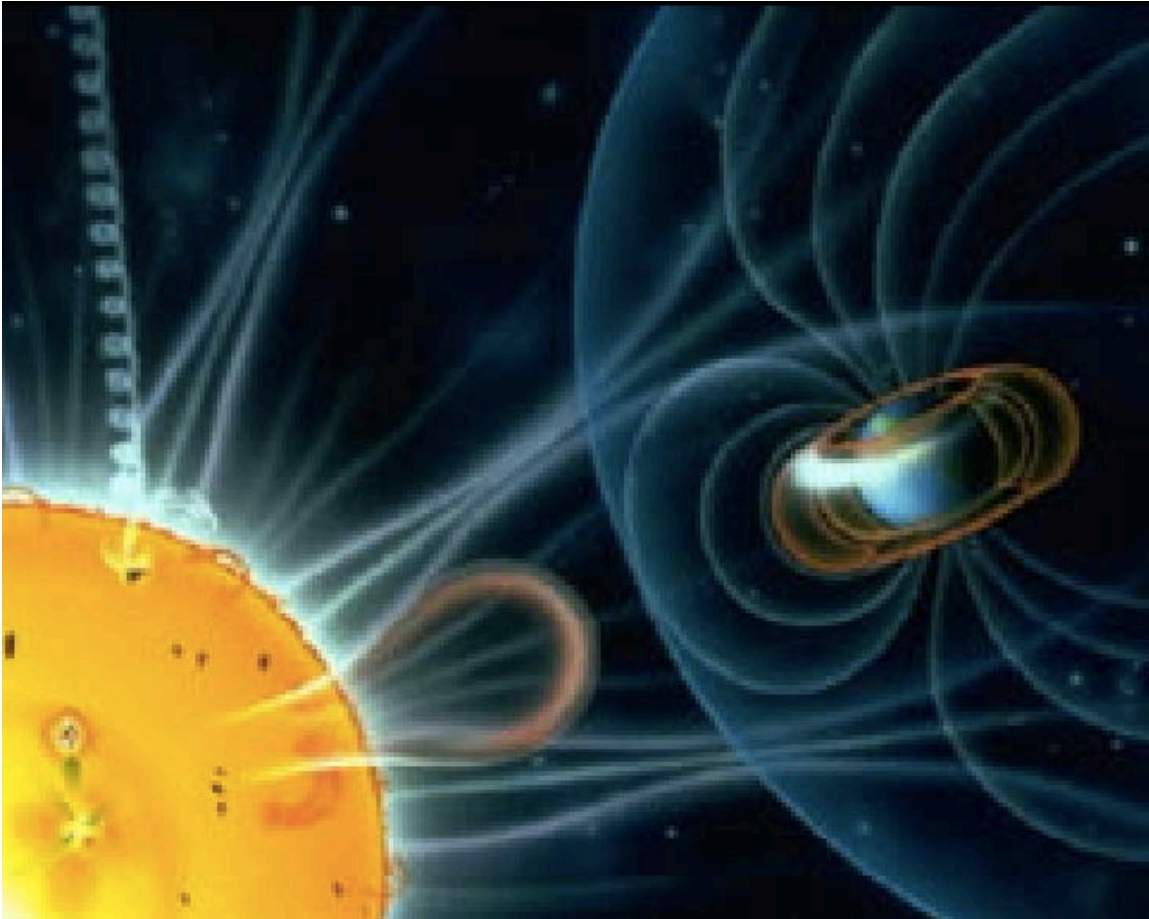


SDO/AIA 193 2012-01-02 14:58:20 UT

## Space Weather Discovery The Space Weather Story

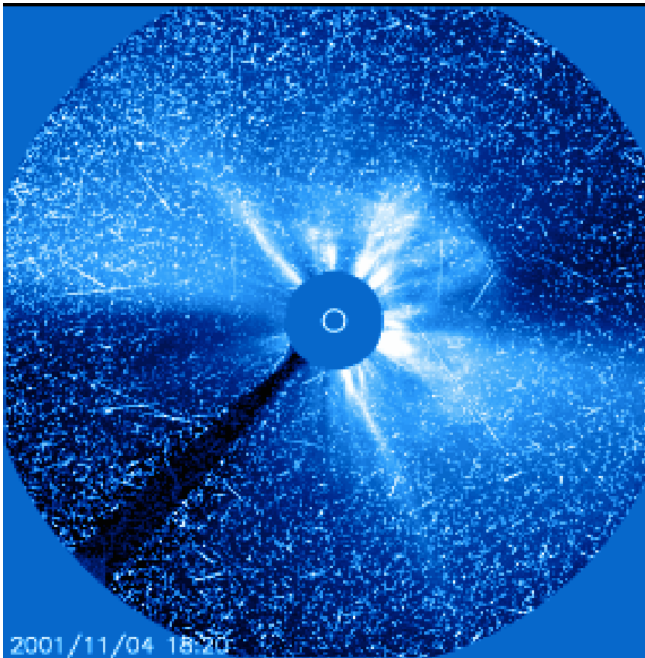
This picture from the Space Weather CD shows what Space Weather is. Identify the following items in the drawing and describe what is happening in the drawing.

Items to identify: *Sun, Earth, Aurora, Sunspot, Coronal Mass Ejection (CME), Flare, Prominence, Earth's Magnetic Field lines, Solar Wind.*

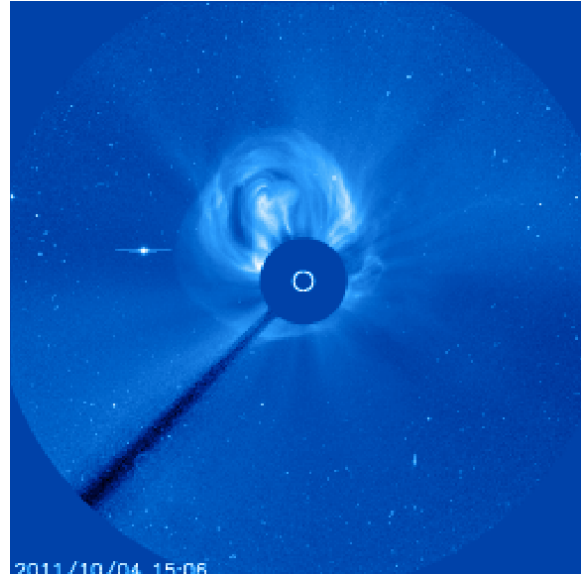


Describe the action in the drawing.

## Space Weather Discovery CMEs and Coronal Holes



In these two images, taken through a blue filter, we see two different CMEs or Coronal Mass Ejections leaving the sun. These are the charged particles that can cause auroras. Which one is coming toward the Earth?

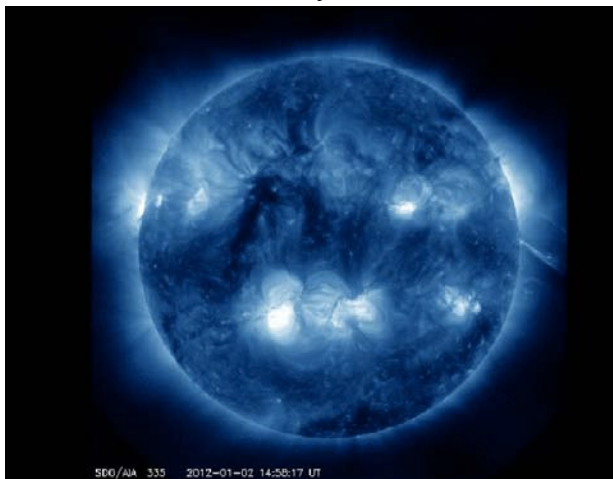


Below are two images of the sun's corona taken 6 days apart. Study the images and decide which way the sun rotates – toward the right (east) or toward the left (west)?

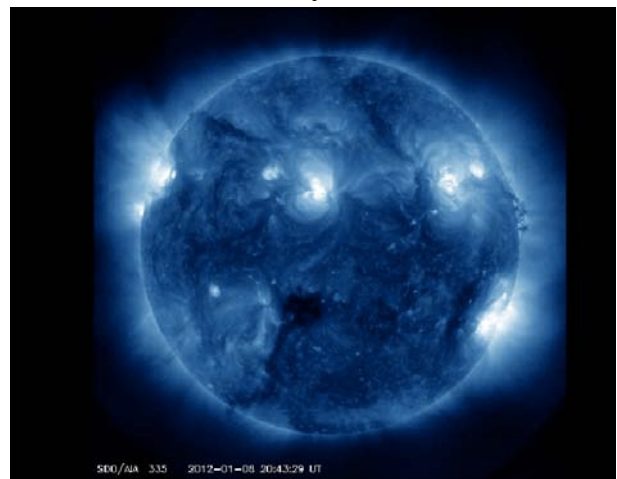
Which has the larger coronal hole?

Could these coronal holes send particles toward the Earth? How do you know?

January 2, 012



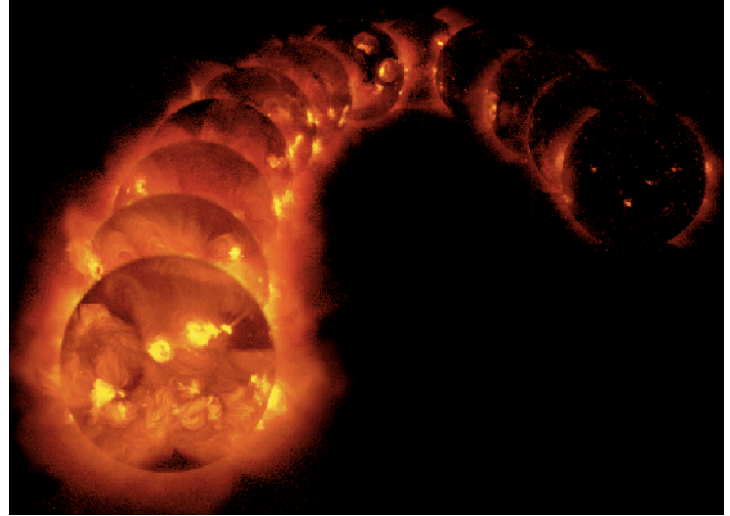
January 8, 2012



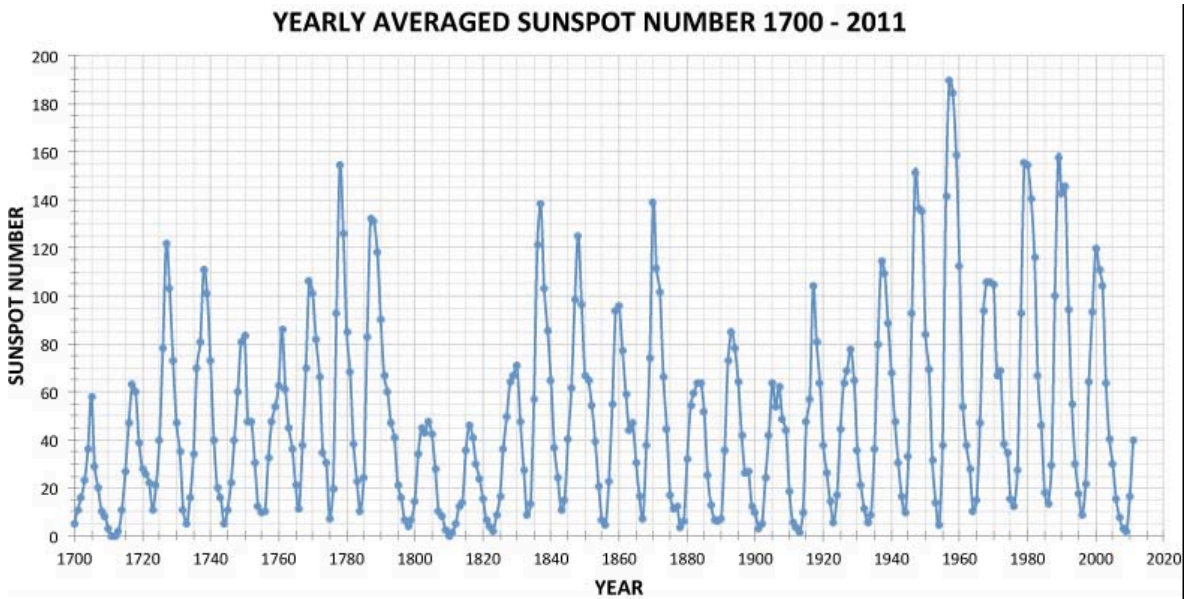


## Space Weather Discovery The Solar Cycle

The sun's activity goes in cycles. Active regions feature sunspots, so counting sunspot numbers is a way of measuring the activity level on the sun. Auroras are more frequent and intense when the sun is more active. The composite image shows the sun at different times. Notice how much more active the sun is in some years than in others.



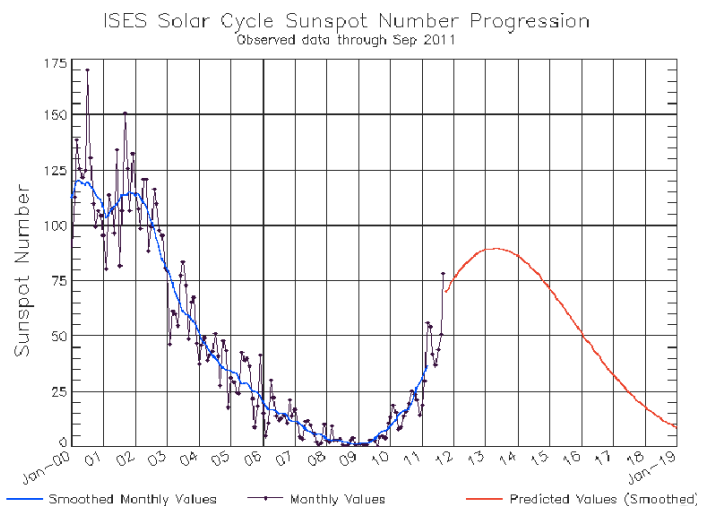
We have been keeping records of sunspot numbers since 1700. Is the cycle exactly 11 years?  
Does the sunspot maximum always have the same number of sunspots?



When is the next sunspot maximum projected to occur?

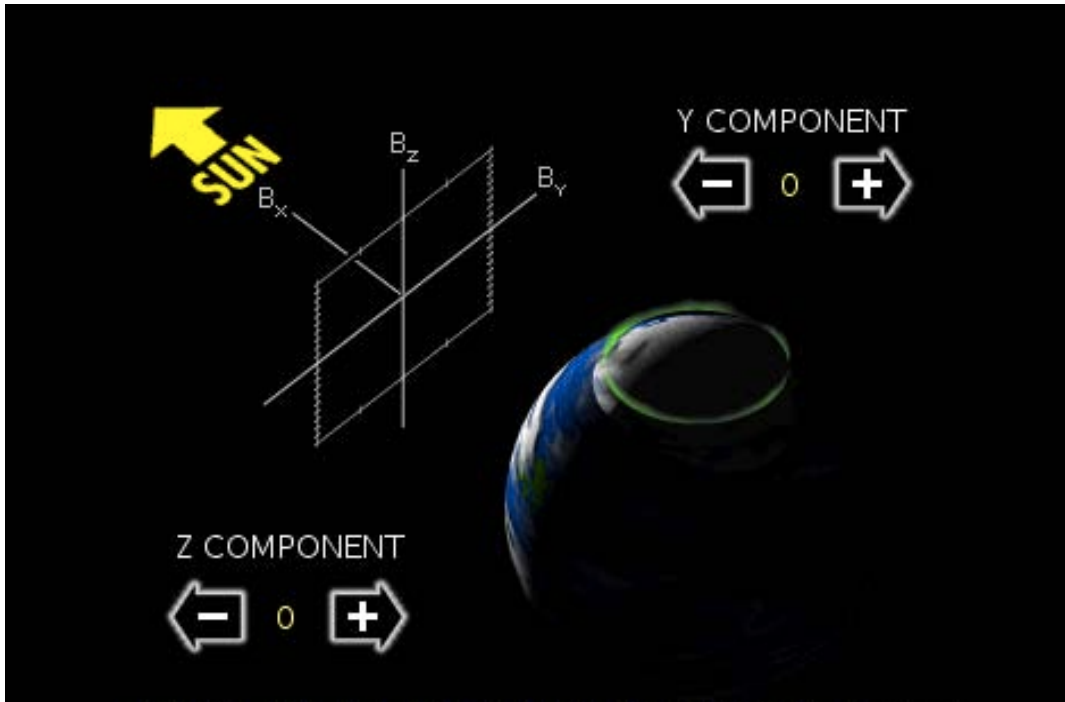
Will the sun be as active as it was 2000?

When would be a good time to observe the aurora?

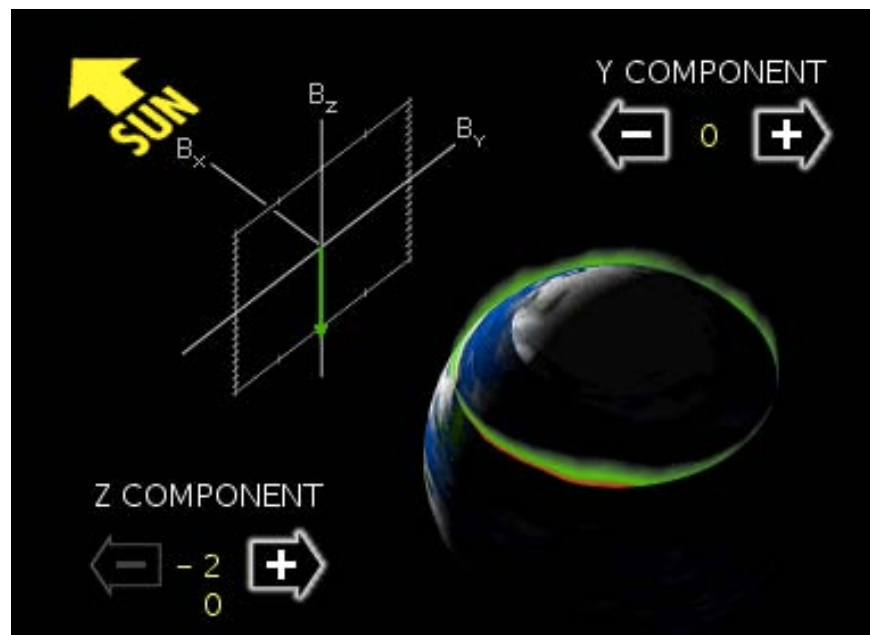


## Space Weather Discovery The Sun's Magnetic Field (IMF)

The Sun's magnetic field does affect where the aurora appears. Although it comes from the sun, this Interplanetary Magnetic Field can be more to the north or south (Z component) or more to the west or east (Y component) when it reaches Earth. Adjust the components of the Sun's magnetic field to see the effect on the auroral oval.



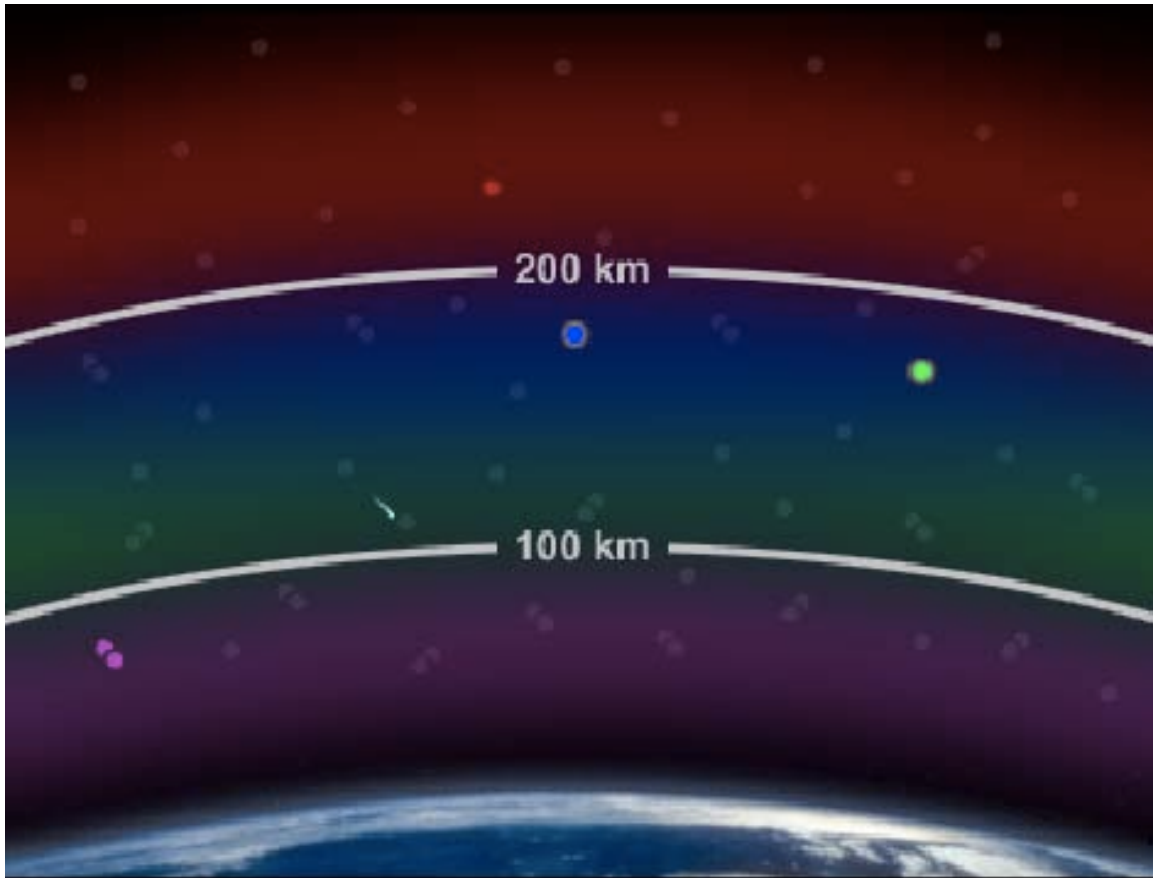
When an aurora is seen in the southern United States or Europe, what is the direction of the Sun's Magnetic Field?





## Space Weather Discovery Colors in the Aurora

Find this animation in the Space Weather program. Watch it and discover what elements are causing the different colors of the aurora.



Red aurora: \_\_\_\_\_

Green aurora: \_\_\_\_\_

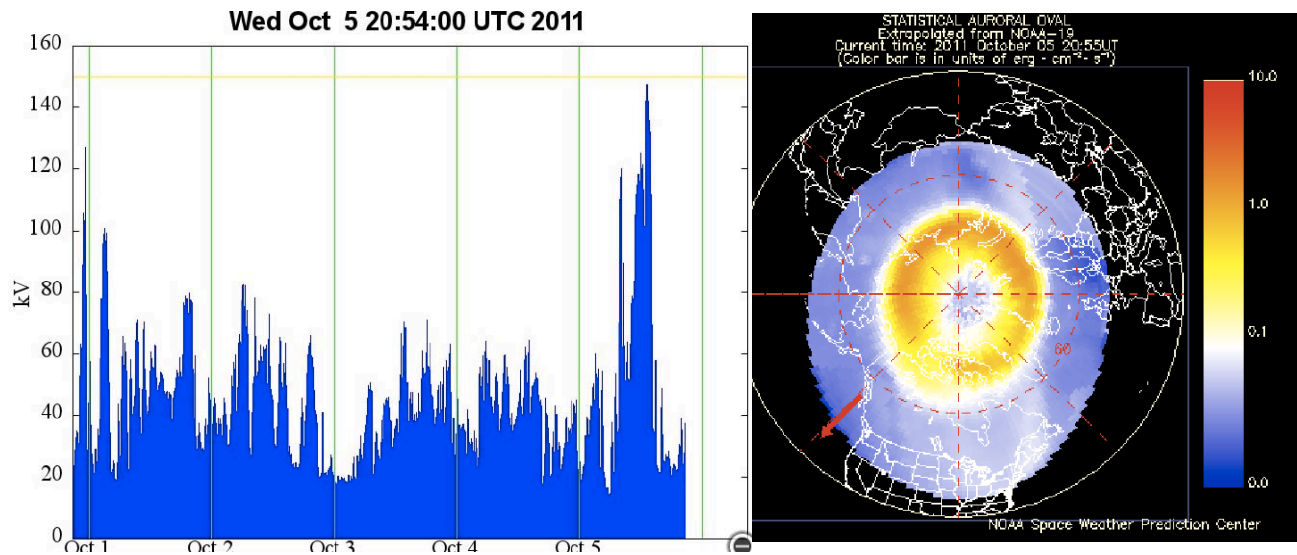
Blue aurora: \_\_\_\_\_

Purple aurora: \_\_\_\_\_

What atoms are glowing  
in the aurora to the right?



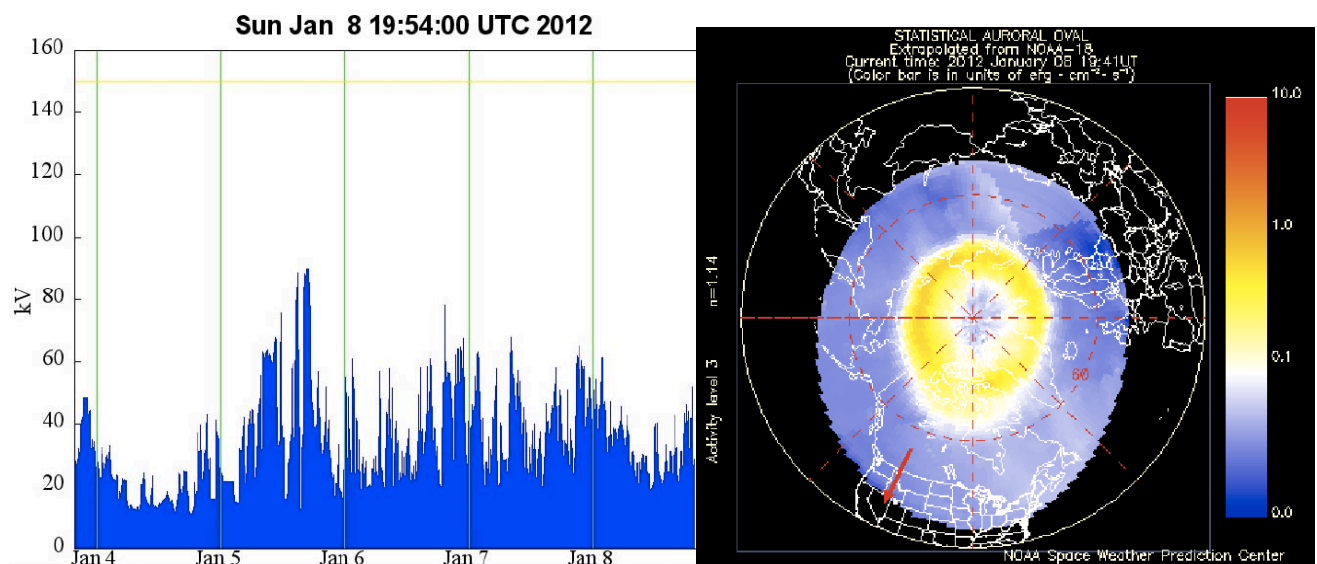
## Space Weather Discovery Predicting an Aurora



Above is a graph of the strength of the Earth's magnetic field in kilovolts during October 1-6, 2010. The image on the right shows the extent of the auroral oval on Oct. 5, 2010.

Below is a graph of the strength of the Earth's magnetic field in kilowatts during Jan 4-8, 2012. The image shows the auroral oval on Jan. 8,

What is the relationship between the energy in the magnetic field and the strength of the aurora? Discover the strength and auroral oval today by updating the files in the program. You must have the program installed on your hard drive and be connected to the Internet to do this. Will tonight be a good night to look for an aurora? Based on the oval, where should you go to see it?

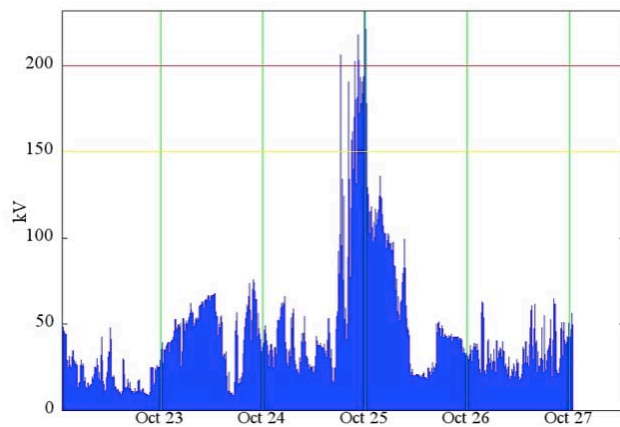




## Space Weather Discovery Predicting a Strong Aurora

Terence Murtagh, the director of the *Experience the Aurora* full-dome movie, captured a very rare red aurora in October 2011. The aurora was predicted 3 hours before it happened by the increase in the energy in the Earth's magnetic field (see graph below).

Often an aurora looks green because the red and blue auroras are much fainter. Notice what happens when red and green are both strong. Do research to find out what color is produced when you mix red and green light.



# Space Weather Discovery

## Aurora Stories

Identify the photographer for these auroral displays from the Space Weather CD. Also add any interesting facts that accompany the images.

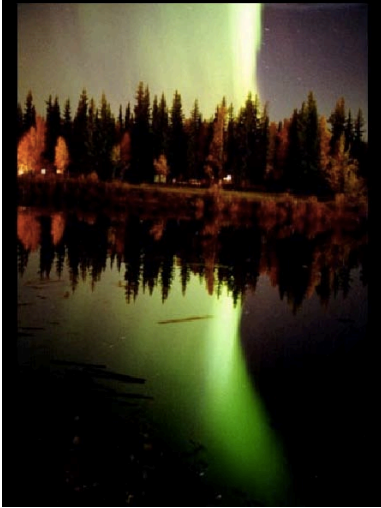


Photo 1 (far left):

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Photo 2 (near left):

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Photo 3 (below): \_\_\_\_\_

Photo 4 (below): \_\_\_\_\_



Photo 5 (below): \_\_\_\_\_



Photo 6 (above): \_\_\_\_\_

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## Space Weather Discovery Aurora Missions

Many missions have been funded to study the Sun and Space Weather. Identify each spacecraft and describe what it is designed to discover.



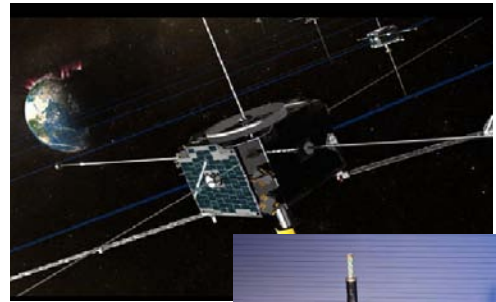
**Craft 1**



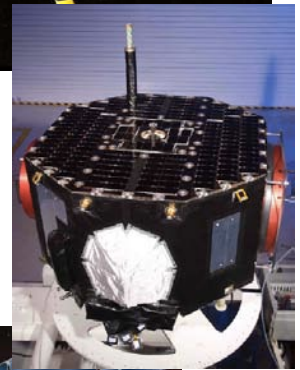
**Craft 2**



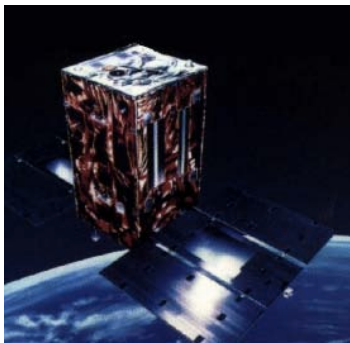
**Craft 3**



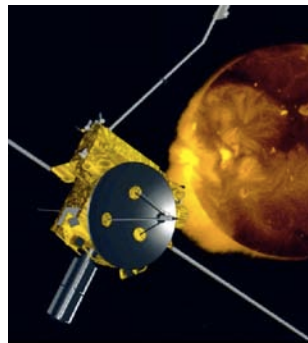
**Craft 4**



**Craft 5**



**Craft 6**



**Craft 7**



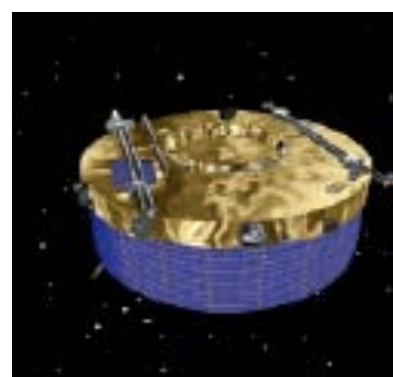
**Craft 8**



**Craft 9**



**Craft 10**



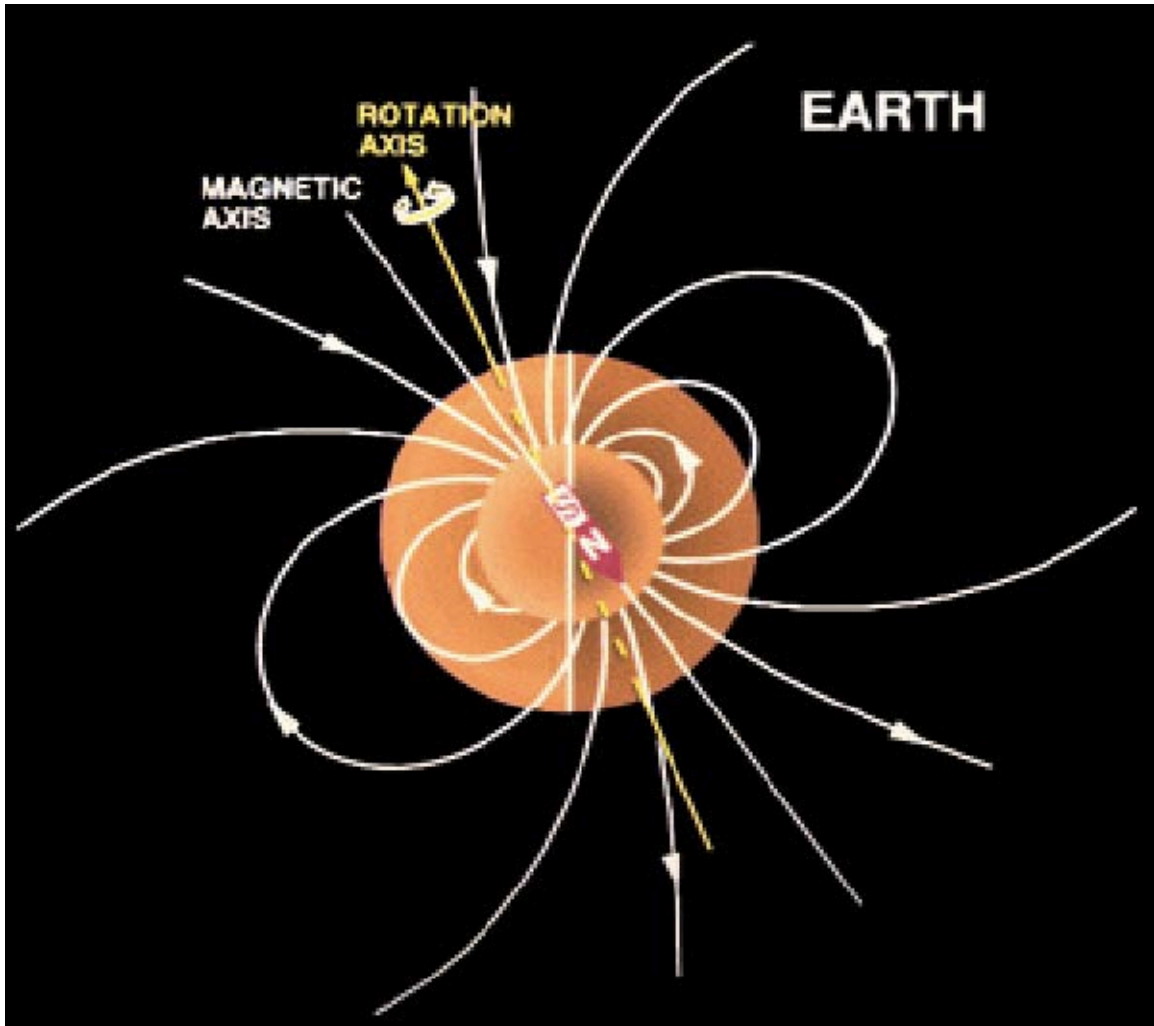
**Craft 11**



## Space Weather Discovery

### Planet Auroras

Read about the magnetic fields and atmospheres of each planet. Then look at the photographs with each planet and decide which planets have auroras and which ones do not. Which planets have magnetic fields like Earth's, centered in the middle of the planet?



Planets with a central magnetic field: \_\_\_\_\_

Planets with an atmosphere that can make auroras: \_\_\_\_\_

Planets where we have photographed auroras: \_\_\_\_\_

\_\_\_\_\_