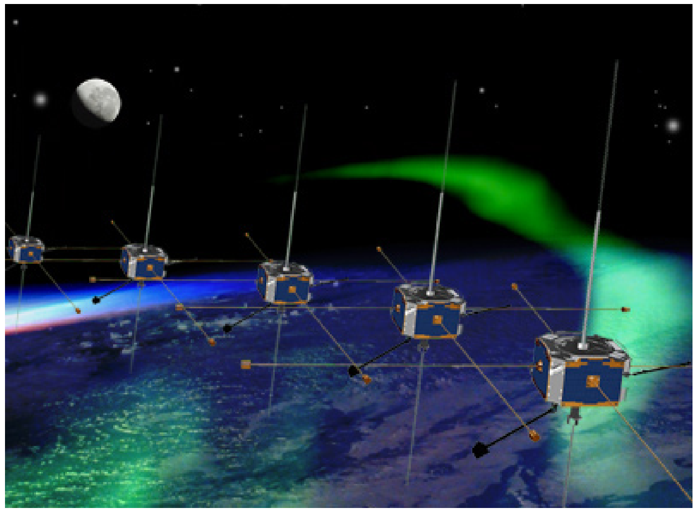
Planetarium Activities for Student Success

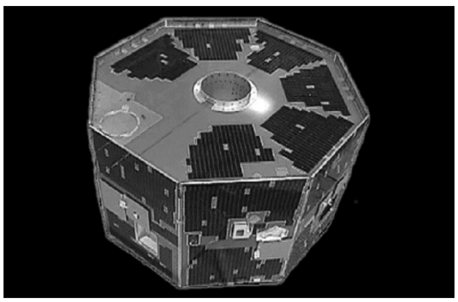
Northern Lights

by Franck Pettersen,
John Erickson,
Alan Gould,
and Roy Morris

Cover photograph of Aurora Borealis courtesy of Franck Pettersen



The Time History of Events and Macroscale Interactions during Substorms (THEMIS, above) spacecraft launched February 17, 2007. It answers key questions about when and where substorms begin and how substorms power the aurora.It employs 5 identical spacecraft whose orbits line up once every 4 days. More information on THEMIS at http://themis.ssl.berkeley.edu/



The IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) satellite (left), launched in March, 2000, was the first satellite mission dedicated to imaging the Earth's magnetosphere and the aurora from space.
See: http://image.gsfc.nasa.gov

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Lawrence Hall of Science
http://www.lhs.berkeley.edu/

Northern Lights Planetarium Show

Contents

In Memoriam

The author of this planetarium show, Franck Pettersen, passed away in August of the year 2000. His brilliance and dedication to furthering human understanding is recognized and treasured by those of us privileged to have been his colleagues in the planetarium field.

This planetarium program is dedicated to his memory. The program, and in particular aurora photographs and the narration for the aurora video made for this program, written and performed by Franck, serve as an everlasting tribute to his talents and contributions to our profession.

— from the editors of PASS:
Alan Friedman, Cary Sneider, Alan Gould

Introduction

Aurora borealis (northern lights) and aurora australis (southern lights) are beautiful displays of moving luminous colored patterns in the night sky, especially in far northerly or southerly latitudes.

To set the stage for observing northern lights, we first look at "Seasons & Sunsets Above the Arctic Circle" to find out at what latitudes and at what times of year aurora are most likely to be seen. This section of the program is highly useful in teaching students about characteristics of seasons and the amazing phenomenon of "midnight sun" which occurs at extreme north and south latitudes.

In the original version of this program, for a visual experience of aurora, Franck Pettersen supplied an excellent set of slides of an auroral substorm that he photographed in Norway. His taped narration describing the storm with the aurora slide sequence transports the audience to Norway for a few minutes of effective aurora "theater." Subsequently, when the University of Alaska produced superb aurora motion pictures, we found that Frank's narration could be set to some of that footage for an even more effective aurora experience for the audience. Franck's slides are still available for planetariums not equipped with video projection.

The "Scientific Explanation" of the program has changed much in recent years owing to revealing results from the spacecraft missions of NASA's Sun-Earth Connection Program, whose generous support has enabled the publication of this PASS Volume. The old model for the causes of aurorae envisioned solar wind particles streaming through the Earth's magnetic field and crashing directly into the Earth's atmosphere. In newer models, charged particles interact with the Earth's magnetosphere which acts as a sort of electromagnetic dynamo that accelerates the particles along magnetic field lines into the Earth's polar regions. Where the charged particles originate is an active research question now. Described in this section of the show are the Fast Auroral SnapshoT (FAST) satellite, the Polar satellite, the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) spacecraft, and most recently, the THEMIS (Time History of Events and Macroscale Interactions during Substorms) spacecraft designed to answer key questions about when and where substorms begin and how substorms power the aurora. We look forward to yet more interesting and valuable results from future space missions to study aurorae and Earth's magnetosphere.

Objectives

In this planetarium program, students will be able to:

1. **Describe the appearance of aurorae and sketch them.**
2. **Explain that aurorae are caused by charged particles interacting with the Earth's magnetic field and atmosphere and that the Earth's magnetic field is affected by the solar wind.**
3. **Identify what areas of Earth are best suited for aurora observation.**
4. **Describe how the Sun's apparent daily motion changes with the seasons.**
5. **Describe why extreme northerly and southerly latitudes can experience the phenomenon of "midnight Sun".**

Materials

1. **Movie of aurora with Franck Pettersen's narration.**

   This is currently available in two formats:

a. On the Northern Lights Video (VHS or DVD)

b. Aurora slide sequence with audio tape of Franck Pettersen's narration. The aurora slide sequence is a set of 26 slides which may be shown in sequence in a single slide projector, or shown in "animation" mode by loading alternate slides in two slide projectors and using a cross-fade unit if you have one.

2. **Earth Globes.**

   Class set of Earth globes between 2"–4" in diameter, each mounted on an axis (dowel or pencil works fine) for easy rotation by students. The equator should be clearly shown and you will need to make clearly visible marker dots at your city (or approximately 45° N.) and Tromsö, Norway (about 70° N.). On some globes, markers can be small wood or metal screws, with the head of the screw being the marker.

   Thirty globes will accommodate one globe per student for classes up to 30 students and one for every 2 students for shows with two classes (60 students). You may use either real Earth globes or Styrofoam balls with the following markings on each:

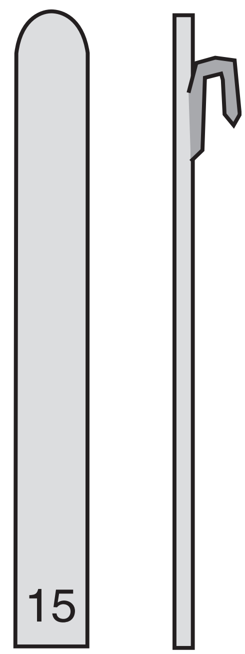
- equator line in black
- dot at approximately 45° N. in red
- dot at approximately 70° N. in blue.

   The precise color scheme is not crucial, as long as it is consistent for all the globes.

3. **Horizon markers.**

   You'll need one horizon marker per student. Students need to mark sunrise and sunset positions along the planetarium horizon. They need to be able to stand near the horizon in your planetarium to use these markers. In a STARLAB or other small planetarium that may be easy, but it is more difficult in a bigger planetarium with two or more rows of concentric seats, or in a planetarium with unidirectional seating. In those cases, you can adapt the program by assigning a different small group of students to stand at the horizon and mark objects for each round of the experiment. In very large planetariums, there can be a panorama of horizon sections (North, Northeast, etc.) created for the audience to refer to, or if an azimuth projector is available, the audience can make their guesses by azimuth numbers.

Figure 1



Horizon Marker Version I:
A marker that can hang from the cove.

The marker can be a wood, cardboard, reflective metal, or plastic strip, about 5 centimeters wide and 40 centimeters tall. Fasten a hook on the back so that the marker can be hung on the cove to mark a position on the horizon. The markers should be numbered or lettered, so that participants can remember which one is their own. See Figure 1. The markers could also be attached by having small pieces of Velcro® attached to the back, and a band of the mating material all around the dome at the horizon. In a STARLAB, it's best to attach the "hook" component of the Velcro™ on the markers, and the "loop" or fuzzy part on the dome.

Horizon Marker Version II: Sticky paper dots or squares.

This fast, cheap alternative to a prepared marker is being used by many planetariums, particularly small units and portables. Your nearest stationery store will have rectangles in various sizes (3M Post-it® notes), as well as self-adhesive disks in many sizes and colors (Avery is a major brand). Fluorescent red dots in the 3/4 inch diameter size work well for portables. A few dollars will purchase a supply of a thousand dots.

The only trick is to choose material in a color and size that is easily visible in a dim planetarium, and has the right degree of stickiness. Too weak an adhesive can mean markers not sticking or falling off too soon, especially if the dome is dirty; too strong an adhesive might mean work for you cleaning them off after each program.

4. Model of Earth's Magnetic Field, for overhead projector.

This is a classic demonstration using a bar magnet and iron filings. Mount the bar magnet on a thin stick so that it may be manipulated from the side of the overhead projector to disturb and re-orient the iron filings without your hand getting in the way of the overhead projector light path. A clear plastic disc that has blue ocean and brown/green continents drawn on with permanent ink colored pens can represent the Earth.

You may either purchase a commercially available magnetic field demonstration unit from a science supply company or prepare your own using one of the following strategies to make an iron filings display:

a. Put a small amount of iron filings in each pocket of a plastic slide protector sheet and seal with clear packaging tape.

b. Lay out a grid of thin double stick tape on a sheet of overhead transparency, forming squares about 3–4 cm on a side. It's best if the tape is cut into narrow strips (5 mm or so) before applying. Pour a tiny quantity of iron filings into each square, then lay another sheet of transparency over and press down to secure it to all parts of the double stick tape grid. Put the whole assembly in a clear large Ziplock™ bag to contain any iron filings that might escape in an "accident."

c. For a deluxe version, construct a flat plexiglass enclosure, filled with mineral oil and iron filings.

d. Use the videotaped version on the Northern Lights videotape.

In use, the iron filings display is laid on an overhead projector and the "Earth" bar magnet is place on top of it. The overhead projector itself needs to be carefully baffled to eliminate lights leaks if you want to maintain a dark planetarium setting, but take care that any baffling system not impede the ventilation air flow of the cooling fan for the overhead projector. A filter on the projector or a "dimmable" projector can help preserve the audience's dark vision.

5. Ultraviolet lights.

Place ultraviolet lights (black lights) in strategic locations to flood the planetarium with UV light. Use only long wavelength bulbs—short wavelength UV light can cause eye damage.

6. Fluorescent chalk for aurora drawing.

This is useful if you have UV light(s), otherwise normal chalk, colored pencils, or pens will do. Sources of UV chalk:

- Your local art supply store.
- Teuling Enterprises Inc.; 231-798-2444; http://teulingenterprises.com/orders.htm; chalklady@juno.com
- Dick Blick Art Materials; P. O. Box 1267, Galesburg, IL 61402-1267; 800-828-4548 or International 309-343-618; http://www.dickblick. comcategories/chalk/; info@dickblick.com
- Gary Means Chalk Art Supplies, 121 Heath Drive, Bayden, PA 15005; 724-869-9536; http://chalkstuff.com/Orders/means.html

7. Optional: Garden Hose Effect (with overhead projector).

Make your own hand-powered special effects projector as follows:

a. Copy pages 10 (Radial Pattern) and 11 (Spiral Pattern) onto transparency plastic.

b. Make a holder/mask, consisting of a piece of posterboard or heavy cardstock, about 28 cm x 28 cm, and cut a 17.5 cm diameter circle in the center of it. Tape the "Radial Pattern" transparency to the holder piece. Optional: make an extra copy of the Spiral Pattern (p. 11) on plain paper to cut a mask for the spiral to better shield light.

c. Make a "stick" out of thin transparent plastic, about 2-3 cm x 28 cm., to rotate the Spiral Pattern. One way is to cut a piece of transparency 9 cm x 28 cm and fold it in thirds. Use a push pin to make a small hole about 2 cm from one end of the transparency "stick."

d. With a push pin, make a hole in the centers of the Spiral and Radial Patterns.

e. Assemble Garden Hose Effect projector as shown in Figure 2. Use a very small nut and bolt to fasten the stick to the edge of spiral pattern piece and another small nut and bolt to fasten the center of the spiral pattern piece to the center of the radial pattern piece, Holes may need to be enlarged slightly with a compass point, pen point, or other sharp pointed object. Other ways of fastening are possible also, such as very small nails stuck into small pieces of wood, cork or rubber. The simplest fastener is a small brad paper fastener.

To operate the garden hose effect, move the stick to make the spiral rotate. You may want to design a motorized apparatus to turn the spiral.

Option

Make a motorized Garden Hose Effect by mounting the transparencies on plexiglas disks and making a motor with a rubber wheel or rubber tubing on its axle bear against the edge of the Spiral Pattern disk. The light source can be something much fainter than an overhead projector, such as a mag lite bulb or the venerable #6 bulb so often used for planetarium special effects.

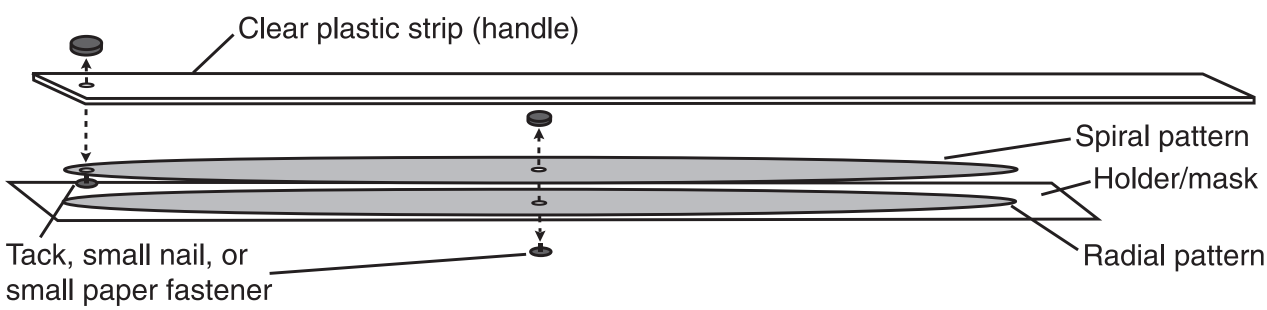


Figure 2

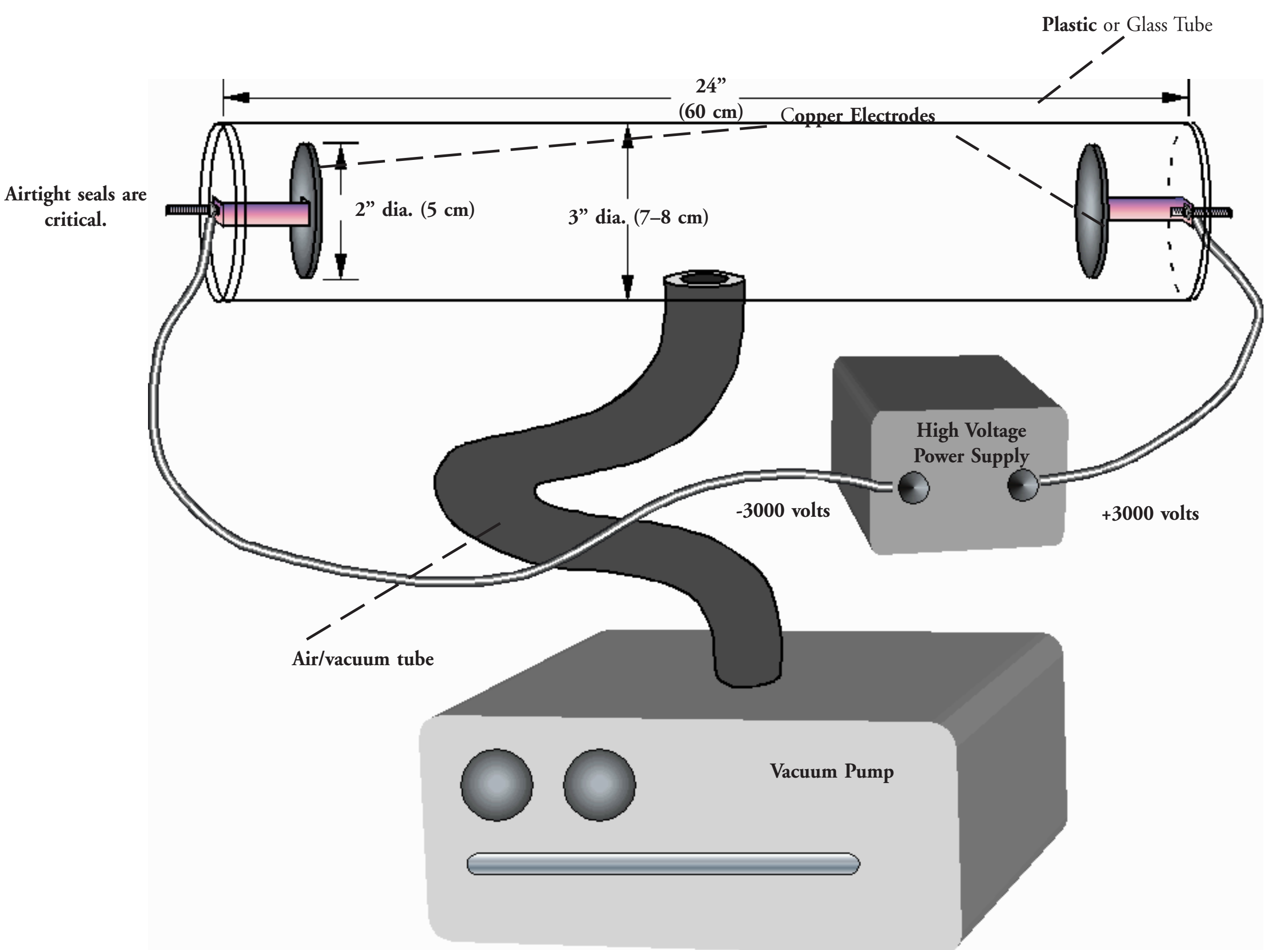
8. **Optional: Aurora in a vacuum tube.**

   Build a tube with high voltage electrodes mounted at each end, sealed and attached to vacuum pump.

High Voltage Aurora Simulator

Here is the general layout and components for a vacuum chamber simulation of an auroral display based on a model built by Franck Pettersen for use in the Lawrence Hall of Science Holt Planetarium.

The electrodes should be round with smooth edges. They may be soldered to copper "L" brackets which are then attached to screw terminals that protrude from the ends of the tube.

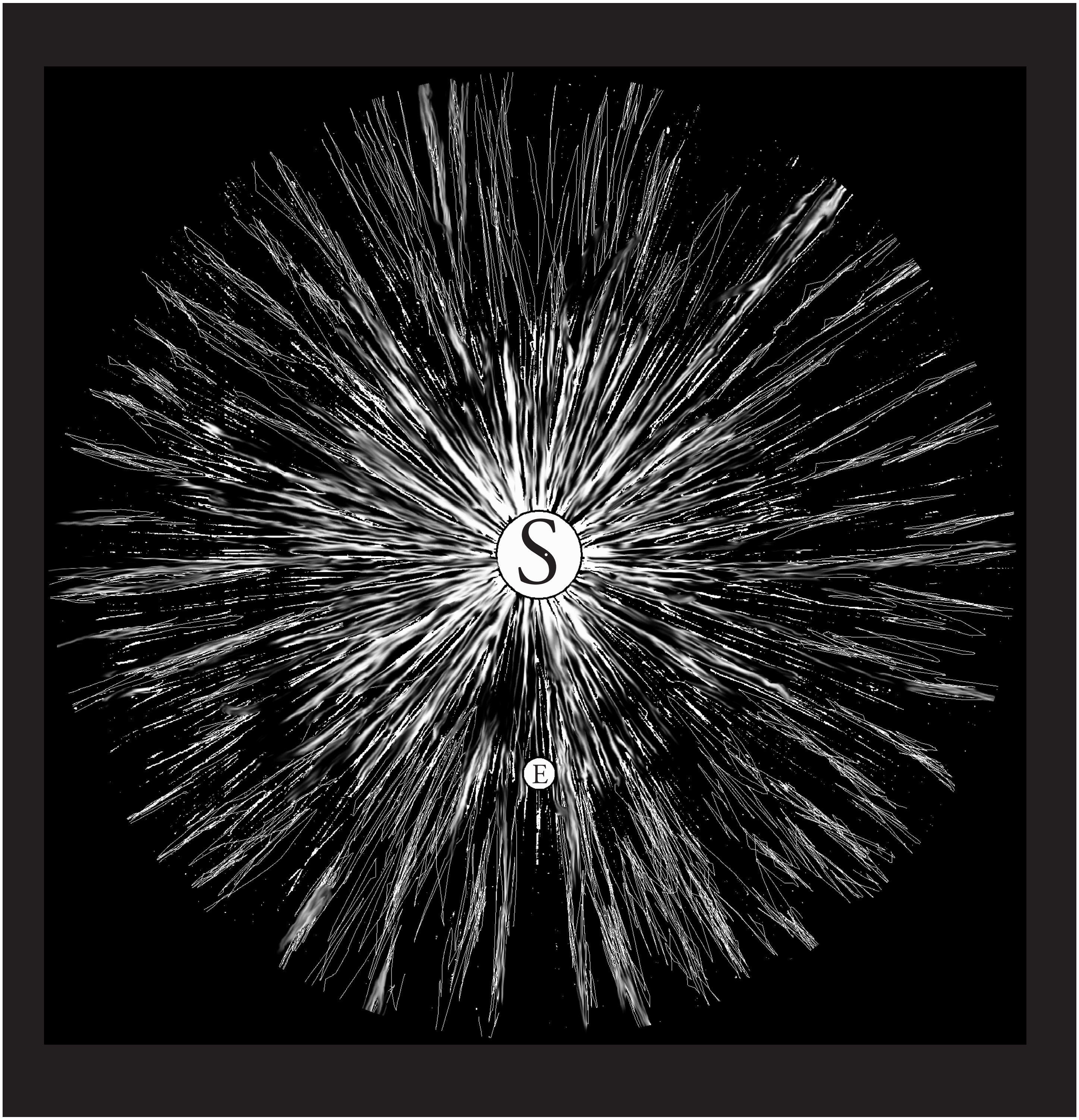


The key components are:

- Plexiglas or glass tube, about 8 cm (3") diameter and 60 cm (2') long.
- Copper electrodes fastened to each end of the tube with terminal for wire connection extending outside the tube. Must be absolutely airtight seal.
- High voltage power supply (6000 V) with high voltage wires.
- Vacuum pump with rubber or plastic hose inserted in the plexiglas (or glass) tube. Must be absolutely airtight seal.

CAUTION:
High voltage electricity can be dangerous. Find and follow proper safety precautions for using high voltage electrical devices.

Radial Pattern



Spiral Pattern

Photocopy this sheet onto transparency and onto regular paper.

Cut transparency around edge of black disc and along dashed lines (except for the "Fasten Pivot Arm" circle).

To create a paper mask for better light shield, cut around outer solid circle. Then cut out the spiral pattern and the outer edge of the clear ring.

9. Slides

Image	Source
1. World Map	LHS
2. Midnight Sun in Tromsø	Franck Pettersen
Movie 1—Movie of Aurora (or special aurora slide sequence*)	U. of Alaska*/Pettersen
3. Drawing of auroral goats (by Gemma, De Naturae DivinisCharacterismis)	Gemma (1575)
4. Drawing with people watching aurora	Germanic National Museum in Nuremburg
5. Drawing of aurorae with swords and faces	Pettersen
6. Spirits playing football with walrus skull	LHS
7. Sun	NASA/SOHO
8. Solar granulation	NOAO/NSO/Dunn
9. Solar corona during eclipse	NOAO/AURA/NSF
10. Coronal holes in UV	NASA/YOHKOH
11. Coronal mass ejection (Optional: **Movie 2—Animation**)	NASA/SOHO
12. Earth with symmetrical magnetic field (Optional: **Movie 3—Iron Filings**)	NASA/IMAGE
13. Earth with symmetrical magnetic field unaffected solar wind	LHS
14. Unaffected solar wind and Earth with "pushed" magnetic field	LHS
15. Earth with "pushed" magnetic field and solar wind streaming around Earth	LHS
16. Magnetotail (Optional: **Movie 4—Magnetotail/solar wind animation**)	NASA/IMAGE
17. Satellite view of aurorae	NASA
18. Auroral oval	NASA
19. Northern and southern lights	NASA
20. Colors in the aurorae—green	Franck Pettersen
21. Colors in the aurorae—blue	Jan Curtis
22. Colors in the aurorae—red	Jan Curtis
23. Polar Spacecraft	NASA
24a. FAST Spacecraft	NASA
24b. IMAGE Spacecraft	NASA
25. THEMIS Spacecraft	NASA**
(Optional: **Movie 5—THEMIS discovery**	NASA**
26. Sun with sunspots	NOAO/NSO/Hilltop
Movie 6—Aurora drawing inspiration	various
27. Aurora in Norway	Franck Pettersen
28. Aurora near Tromsø, Norway	Franck Pettersen

* Aurora source video available from University of Alaska, Color Aurora Video Project.

** THEMIS movie and news:
http://www.nasa.gov/mission_pages/themis/news/themis_leaky_shield.html
http://themis.ssl.berkeley.edu

Setup

1. Set latitude to your home latitude, e.g. Berkeley is 38° N.
2. Set time to noon on June 21.
3. Turn on directional lights.
4. Cue up slides to first slide.
5. Get the video *Movie of Aurora* ready to play. If you are using cross-fade slide projectors for the *Movie of Aurora*, adjust the alignment of projectors for proper cross-fade action, and cue the audio tape of Franck Pettersen describing the northern lights.
6. Get the Earth globes for the midnight Sun activity.
7. Get fluorescent oil pastels and black paper.
8. Get horizon markers.
9. Set up the Garden Hose Effect on the overhead projector. Plug it into the special effects 120V socket.
10. Set up the overhead projector to display the iron filings model of Earth's magnetic field. Alternatively, cue separate videotape copy to Earth magnetic field model segment.

Recommendations for Using the Script

We don't expect the script which follows to be memorized (as an actor might memorize a part) but to be used as a guide in learning, rehearsing, and improving presentations. We recommend that you read the script once or twice, then work with it in the planetarium, practicing the projector controls, slides, special effects, and music. You should be able to imagine yourself presenting information, asking questions, and responding to participants. For your first few presentations, you can have the script on hand, using major headings as reminders of what to do next.

The script is organized in blocks or sections. The purpose of these separations is only to help you learn and remember what comes next. Once you have begun a section, the slides or special effects and your own train of thought will keep you on track. When beginning a new section, make the transition logically and smoothly.

Directions for the instructor are printed in *italics* in the side column, the instructor's narrative is printed in regular type, and directions and questions to which the audience is expected to respond are printed in ***bold italics***. There is no point in memorizing narration word-for-word since what you need to say will depend upon the participants. The language you use and the number and kinds of questions you ask will depend on how old the participants are, how willing they are to respond, and how easily they seem to understand what is going on.

We believe that the most important elements of the program are the questions and the activities since these involve the audience in active learning. If you must shorten your presentation, we recommend that you borrow time from the narration.

Planetarium Show Script

Introduction to the Northern Lights

Hello, and Welcome to the _____ Planetarium. My name is ______. Feel free to ask questions or let me know if you have anything you want to say. This program is about seasons and light above the arctic circle. One kind of light that is not familiar to many people in most of the United States is called the aurora borealis, or the northern lights.

> ***Have any of you seen the northern lights? Yes? Where were you when you saw them? How far north have people in the audience been?***

Image 1: World Map ►

Have people point on the world map to the northern (or also, if you wish, southern) places they have been. Let them describe what days and nights were like.

This mark on the map is called the arctic circle. We will imagine that we are looking at the sky from somewhere north of, or above, the arctic circle. With the help of the Planetarium star projector we will see what the sky looks like in a town in northern Norway called Tromsø.

Seasons and Sunsets Above the Arctic Circle: Predicting Sunsets

Before I take you north of the arctic circle, let us observe the sky as it appears here in [your city] in the middle of summer. It is noon.

> ***How would you describe the position of the Sun? [It is in the south but very high in the sky.] Do you know where the Sun will set?***

Start the diurnal motion and let it run until sunset. Explain what the horizon markers do and have someone mark the position of the Sun as it sets. Turn down the daylight and bring up the star light.

A group of stars that is familiar to stargazers at our latitude is called the Summer Triangle.

> ***Can any of you find three bright stars overhead that form a large triangle?***

Once the Summer Triangle has been located move the Sun back to due south, the noon position. Optional: Have someone mark the sunrise.

Now I want to take you to 70° North. To do that we will find the star that is called the North Star, or Polaris. Other stars may seem to move, but this star always lies along a line that astronomers call the meridian.

Turn on the meridian.

The meridian stretches from the north to the south going directly overhead. In [YOUR CITY], which is at a latitude of [YOUR LATITUDE]° North, the north star is at an angle of [YOUR LATITUDE]° above the horizon.

Where would we see the north star if we traveled to Tromsø, which is at a latitude of 70°?

Formulate a rule with the audience about how high the north star is above the horizon when it is observed at different latitudes on Earth. Change the latitude to 70°, and note that the North Star is almost straight above our heads. Put the daylight and Sun on.

This is the position the Sun would be in at noon in the middle of summer in Tromsø.

What is different from what we saw in [YOUR CITY]? [The Sun is lower.] Will it set in the same direction as it did in [YOUR CITY], or further to the south, or further to the north?

Invite visitors to answer this question by hanging up horizon markers to mark their predictions.

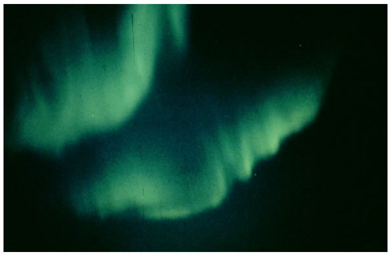
Let us start the daily motion of the Sun and see if it sets close to anyone's marker.

Start the diurnal motion.

We can already see that the Sun's path across the sky is much more flat than it was in [YOUR CITY]. It passes the western horizon, it passes the direction it set in [YOUR CITY], and it goes all the way to the north, closer and closer to the horizon, but it does not set at all!

What should we call a Sun that is up and shining all night?

Image 2: The Midnight Sun in Tromsø. ►



This is the midnight Sun in Tromsø. We found the Summer Triangle earlier, but this name is not well known to the people who live north of the arctic circle.

Can you figure out why? [There are no stars to be seen from the last days of April to the first days of August.]

It is not quite true, then, that the Sun always rises in the east and sets in the west. For people who live far to the north (or to the south) the direction of the sunrise and sunset depends on the time of the year. In the summer, in the arctic, it does not set at all. Then, at the beginning and at the end of the summer, the Sun rises and sets almost due north.

Optional

Show the sunset point on the horizon on the equinox (due west).

If there is time move the Sun to July 25, and demonstrate that the Sun sets and rises almost due north.

With time passing from summer into autumn, the points of rising and setting move gradually to the east and the west. Around the twenty-first of March and the twenty-first of September sunrise and sunset are due east and west. They continue moving towards the south until finally the Sun rises and sets due south. In the middle of winter the Sun does not rise at all.

Light on the World

In order to see why the midnight Sun shines in Tromsø and not in [YOUR CITY], we will each need to look at a globe. The globe is a model of the Earth and this light can serve as the Sun.

Pass out the globes (students may help). Turn up bright light in the center of the room, and darken all other lights.

The pole sticking through the globe represents the axis about which the Earth turns. To make our model accurate the pole should not point straight up and down. It should be tilted.

The Earth's axis tilts 23° with respect to the plane of the Earth's orbit. Exaggerating the tilt to about 45° makes this activity more effective.

In the summer the north part of the Earth's axis is tilted toward the Sun. It is daytime on the Earth where the Sun's light is shining. On the side of the Earth that is dark it is night.

[Your city] is marked on your globe.

> ***What happens to [your city] as you spin your globe about its axis? [It goes into the light sometimes and sometimes it is in the dark.]***

Optional

Explain that at the equinoxes, the terminator (dividing line between night and day) is perpendicular to the equator giving days and nights of equal length at all places on Earth.

Tromsø is also marked on your globe.

> ***What do you observe happening to Tromsø as the world turns? [As night approaches, Tromsø approaches the dark part of the Earth, but it stays in the light.]***

The "top of the world," the region within the arctic circle is always lit by the Sun.

Half a year later it is winter and the Earth has gone half way around the Sun. Please stay right where you are and simply tilt the north end of the globes away from the Sun.

> ***What happens now? [As the Earth turns [YOUR CITY] still goes in and out of the light, but Tromsø never reaches the light even in the day time.]***

In winter in Tromsø, the Sun can not be seen for two months.

Living in the Arctic

(Include as time and interest indicate)

You might wonder how it is possible to sleep in the two and a half months of daylight. One can easily become adapted to sleep when the Sun is shining. It is the darkest time of the year when sleeping habits are disturbed. For about three to four weeks there is no bright daylight. It is more like a twilight in the middle of the day. But the mechanism of sleeping, the hormones that cause sleep, are triggered by the bright daylight we get early in the day and not by the dark hours of the night. So, in the north where there is no Sun for two months, and really no daylight for three to four weeks, the body does not know when to sleep and when to be awake.

Climate in the north varies from place to place. Tromsø, for instance, is as far north as the northernmost parts of Alaska, yet the winters in Tromsø are warmer than those in much of the United States. This is because of the Gulf Stream, a strong ocean current that carries warm water from the Gulf of Mexico, across the Atlantic Ocean, to the coast of Norway. The lowest temperature ever measured in Tromsø was 5°F. Northerners need not always be covered with fur.

What the Northern Lights Look Like

Those who stay up late during the dark time of year above the arctic circle may witness the aurora borealis, a spectacular display of light. Let us watch and listen as a Norwegian from Tromsø (named Franck Pettersen), who has photographed the northern lights, describes the event.

Movie 1: Aurora (or audio tape with special slide set)

Show the aurora movie or special aurora slide set. If using slides, whether as single set, or cross-fading in two overlapped slide projectors, advance slides every three seconds or so, as the tape plays.

Stop when a black slide is displayed.

Text of the Tape

Then a faint light low in the northwest draws an attention. It is just above the mountains and is like a green phosphorescent band. It just sits there, or moves very slowly. It dies out. But if you are used to northern lights, you know that this was not the end. This was just the beginning.

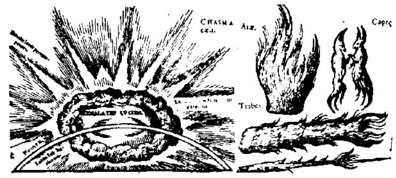
Half an hour later, a new band appears. This time it moves from northwest, where we first saw it, higher up in the sky. It curls, and the curl floats along the band from west to east like a wave. A new band is lit in the north west and moves upward, and another band. Waves and curls are moving along the bands. You can see they are composed of rays as the bands are getting broader. Is there a red color there too? The light is getting stronger and you can see only the brightest stars through the bands and arches of the northern lights.

Then, within a few minutes the sky seems to explode. There is a dramatic change in the events up there. An auroral substorm has started. Rays of light shoot down rapidly, forming bands like draperies which spread all over the sky. And they really remind us of draperies or curtains which are flickering in the wind. The curtains are still green, but now they are decorated with a violet and a red trimming at the lower and upper ends. The draperies and bands are moving and undulating vigorously all over the sky, disappearing and forming all over again by new rays shooting down from space. Above our heads we can see rays going out in all directions forming what is called an auroral corona. This is the peak in the show that nature has set up for us, caused by a cosmic magnetic field and the solar wind. In this crescendo the corona dies out and new coronas can form. The mountains in the setting are now illuminated by the light and energy from space.

After ten to twenty minutes the activity decreases again. The substorm is over. The bands are spread out, getting weaker, and are finally dissolved in a diffuse light all over the sky. We cannot see any more bands or arches, but we discover that the sky background looks grayish-green, and we can’t see very many stars. The light reaching us from all directions is so strong that we can easily see details around us, even far away from the city or other light sources. And if we observe the sky carefully, we can see the last part of the Northern lights display like clouds being switched on and off as though by an electric light switch every five to ten seconds. It is now between twelve and two o’clock in the morning, and the play is over.

Historical Interpretations of the Northern Lights

Image 3: Old Drawings with Goats ►



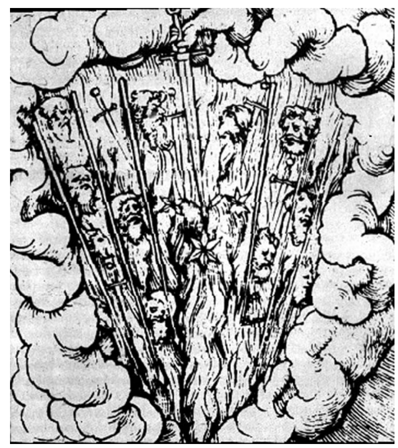
Aristotle: "Exhalations of fiery vapors that form various chasms."

The writings of Aristotle, who lived over two thousand years ago in Greece, are the earliest known records of a sound scientific attempt to discuss the northern lights, although he described the patterns using fantastical terms such as "light torches," "barrels," and even "jumping goats."

Image 4: Drawing with People in Nuremburg, Germany Watching Aurorae, 1591 ►

Throughout history there has been a great deal of superstition about the northern lights. When they were seen in the middle ages in Europe they were interpreted as a flaming heavenly castle or a marching army. The red northern lights were then seen as the bloodstream from the battlefield.

Image 5: Drawing of Aurorae with Swords and Faces ►



When the northern lights were seen, many people thought that war and disasters were about to take place.

In the polar region it is a much more frequent phenomenon, and people knew that it could not always be followed by misfortunes, but there are fascinating beliefs in the polar region too. Kids in Northern Norway used to believe that if they waved with a napkin to the northern lights the lights would come and take them away. The Eskimos of the Hudson Bay area of Canada tell this story: The ends of the land and sea are bounded by an immense abyss, over which a narrow and dangerous pathway leads to the heavenly regions. The sky is a great dome of hard material arched over the Earth. There are holes in it through which the spirits pass to the heavens. Only the raven and the spirits of those who have died violently have been over this pathway. The spirits who live there, light torches to guide the feet of the new arrivals. This is the light of the aurorae. They can be seen there, feasting and playing football with a walrus skull.

Image 6: Playing Football with Walrus Skull ►

While these ideas may seem strange to us, they are all reasonable ideas given what people of those times knew about, given their fear of such uncontrollable forces as war, diseases and death, and given the dramatic display of the true northern lights.

Scientific Explanation of the Aurorae

The Sun

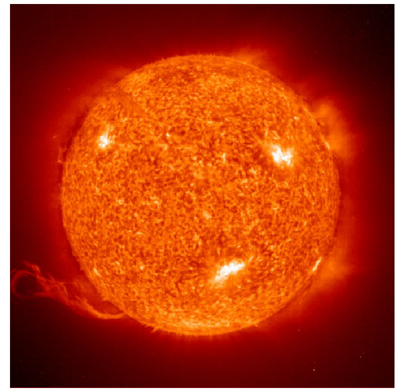


Image 7: Sun ►

A key player in the origin of these lights in our Earth's sky is the Sun, a huge ball of gas converting enormous amounts of energy in its core by a nuclear reaction. It is like millions of nuclear bombs going off every second. Only a very small portion of this energy reaches the Earth, but it is enough to sustain all life on Earth.

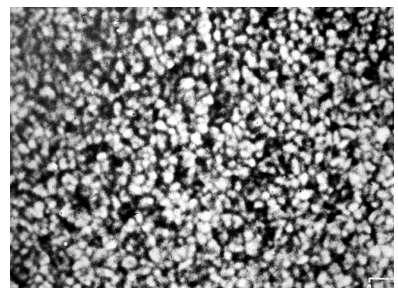


Image 8: Solar Granulation ►

Energy from the core of the Sun can take a long time, perhaps even several hundred thousand years to reach the surface. On the Sun's surface, hot gas bubbles form like the bubbles that form on the surface of a cooking pan. The bubbles are packed very closely, covering all of the Sun's surface. Each granule seen in this photograph is comparable in size to North America.

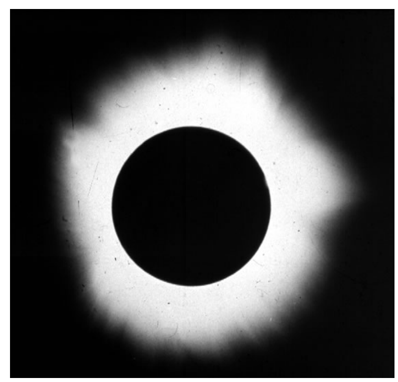


Image 9: Solar Corona During Eclipse ►

The upper most layer of gasses surrounding the Sun is called the corona. It can be seen during a total eclipse of the Sun. Particles are streaming out of the corona. The flow of particles is called "solar wind." Instead of air molecules, the solar wind particles are mostly electrons and protons—electrically charged particles that are the tiny building blocks of all matter. That wind is very different from wind we experience on Earth.

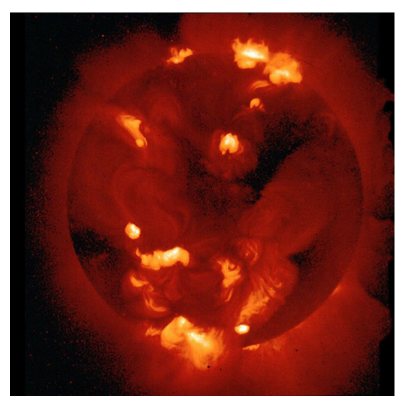
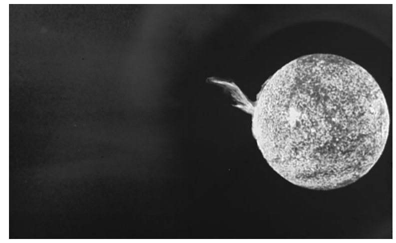


Image 10: Coronal Holes In UV ►

It was a surprise to some scientists when they discovered some years ago that there are holes in the Sun's upper atmosphere. Such coronal holes can be seen in this picture as darker parts on the Sun. Through these holes particles from deeper in the Sun are squirting out into space at even higher speed than normal solar wind. Fluctuations in solar wind can result in different apparitions of the northern lights.

The Sun rotates about once every twenty six days. The coronal holes are rotating with it, acting as "nozzles" of higher speed solar wind. If the scene could be viewed from "above" the solar system it would have the same appearance as a garden hose being swung around in a circle.



Movie 2: Coronal Mass Ejections (or Image 11).

The solar wind is not constant. Sometimes there are enormous eruptions of material from the Sun. These tremendous outpourings of material are called "coronal mass ejections" (sometimes called CMEs) creating even more dramatic variations in the solar wind.

Optional

Use the garden hose effect projector.

The solar wind appears to leave the Sun in a spiral pattern. This is called the "garden hose effect." Watch above as the solar wind sweeps toward the Earth. *Call out when the Earth is in the solar wind.*

The Earth's Magnetic Field

The solar wind particles carry magnetism along with the solar wind. When the solar wind reaches the Earth the wind particles do not simply bump into our planet. The Earth is surrounded by a magnetic field. It is like a bar magnet with the poles of the magnet near the Earth's north and south poles. To illustrate, here is a tray of iron filings and a bar magnet.

Turn on the overhead projector. Place the magnet on the overhead projector and move it around slightly to get the iron filings to line up along the magnetic field lines. Overlay the transparent plastic Earth disc to visually and in words make the connection that Earth has a magnetic field. Alternatively, show Movie 3 of the model of Earth's magnetic field (iron filings).

The magnetic field is invisible, but the tiny bits of iron line up to show how the magnetic field is arranged. It follows lines.

What part of the Earth do most of the lines come from?

Most of the field lines touch the Earth at the poles.

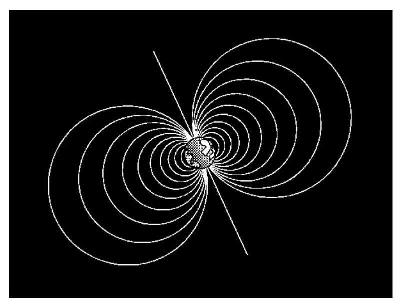


Image 12: Earth with Symmetrical Magnetic Field ►

If the Earth were alone in space and its magnetic field were visible it might look something like this. The Earth, however is not alone. The Sun is nearby and the solar wind is blowing.

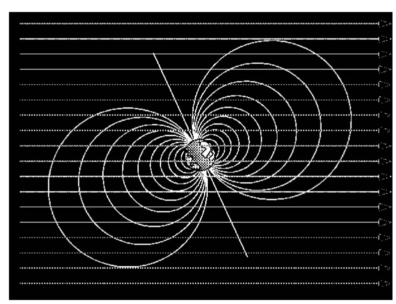
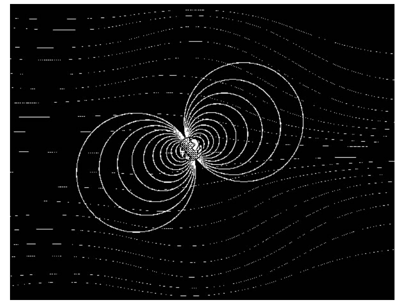


Image 13: Earth with Symmetrical Magnetic Field Unaffected Solar Wind ►

But the charged particles in the solar wind cannot just flow straight by the Earth as shown here. The particles get deflected by Earth's magnetic field.

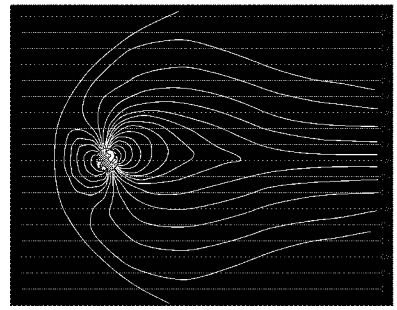
Image 14: "Pushed" Solar Wind and Unaffected Magnetic Field of Earth ►



The solar wind streams around the Earth, like we see here.

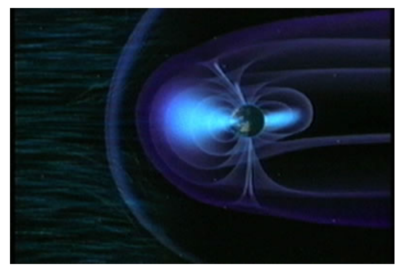
Also, the solar wind changes the Earth's magnetic field. The field gets pushed and stretched away from the Sun into a long tail called the magnetotail.

Image 15: Earth with "Pushed" Magnetic Field and Solar Wind Streaming Around Earth ►



The solar wind hits the Earth's magnetic field at a million miles per hour (400 km/sec). A turbulent shock wave forms in front of the Earth, on the daytime side of the Earth facing the Sun. Some of the solar wind particles can become trapped within the Earth's magnetic field. But the solar wind can also trigger more obvious effects as well.

Image 16: Magnetotail ►



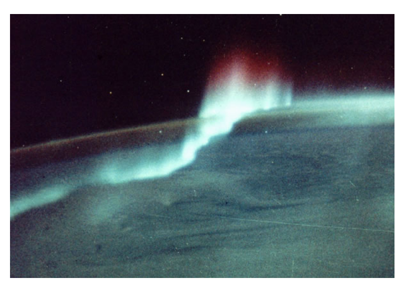
The flow of the solar wind pushing and stretching the Earth's magnetic field can release stored energy within the magnetotail. Like taffy stretched to its breaking point, the magnetotail snaps and ejects a huge cloud of charged particles into the depths of interplanetary space. Such a "bag" of electric particles was actually observed by the spacecraft "Voyager" as far out in the solar system as Jupiter.

Movie 4: Magnetotail Animation (from Blackout)

The other part of the electrical cloud is driven along magnetic field lines down to Earth. These lines lead to the polar regions, as we saw with the bar magnet and the iron filings. The electrical cloud deposits electric power into the Earth's upper atmosphere sort of like a giant dynamo or electric generator. A high speed flow of charged particles hits the thin upper atmosphere. A glowing halo of light, centered on the magnetic pole, forms at the boundary between open magnetic field lines (connected to Earth at one end and the solar wind at the other) and "closed field lines" (both ends connected to the Earth).

In the Atmosphere

Image 17: Satellite View of Aurorae ►



In collisions between the electrons which come from the Earth's magnetotail and the atoms in the atmosphere, the electrons give their energy to these atoms and make them glow. This light, as seen by a satellite, hangs like curtains from space.

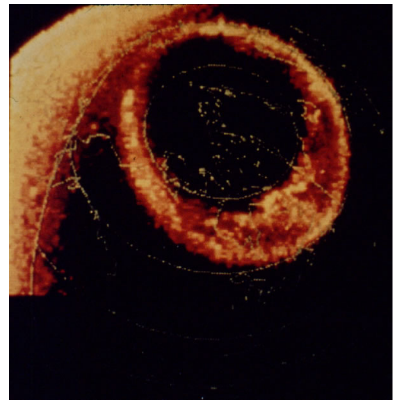


Image 18: Auroral Oval ►

The arrangement of lights around the north pole can be seen in this view from a satellite. They ring the magnetic pole in an oval that is slightly pushed back from the daylight side of the Earth. This is the auroral oval.

The process that makes lights in the north also makes lights in the south at the same time. They are the southern lights, or the *aurora australis*.

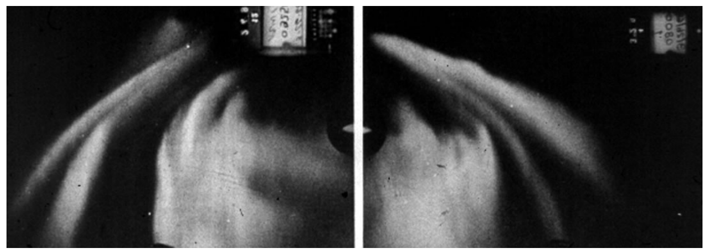


Image 19: Northern and Southern Lights ►

The patterns of the northern and southern lights, as shown in these satellite views, mirror each other.

A hundred years ago people did not know whether the aurorae were just above the tree tops, as high as the clouds, or even higher. A Norwegian physicist, Carl Stormer, solved this problem at the beginning of this century (by using parallax measurements.)

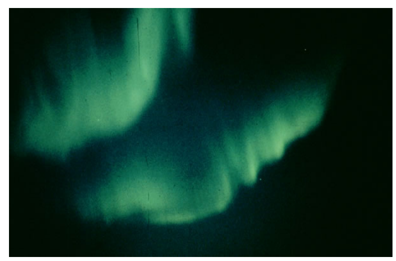


Image 20: Colors in the Aurorae—Green ►

The height is very stable at the lower end at about 65 miles (110 km.) Typically the fast moving rays at the lower end are green and are caused by electrically excited oxygen atoms.

Image 21: Colors in the Aurorae—Blue ►

Blue and magenta colors come from excited nitrogen atoms (ions) at very high altitudes—600 mi (1000 km).

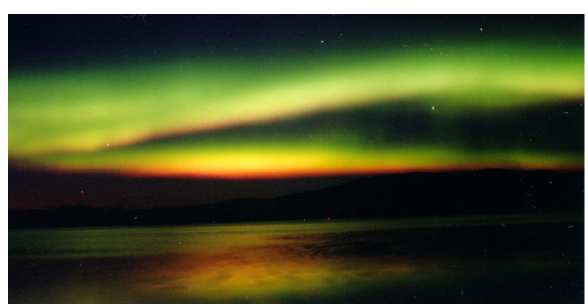


Image 22: Colors in the Aurorae—Red ►

Red colors can come from two sources: excited nitrogen molecules at low altitudes, 40–55 mi (60–90 km) and oxygen atoms at altitudes higher than 90 mi (150 km) where they are excited by particles with less energy and give off a steady "blood-red" glow. On the rare occasions when the aurorae are seen from far away in the south, such as in central North America, the red color may be the most visible, since only the tops of the aurorae are visible from those southerly locales. Low altitude red fringes are caused by higher energy particles penetrating the atmosphere and exciting nitrogen molecules.

Quick-Reference Table of Aurora Colors and Heights

Visual color	Emitting ion, atom or molecule	Wavelength (nm)	Height (km)
violet-purple	N+ (nitrogen ion)	391.4	1000
violet-purple	N+	427.8	1000
red	O	630.0 and 636.4	> 150
green	O (oxygen atom)	557.7	90-150
red	N2 (nitrogen molecule)	661.1, 669.6, 676.8, and 686.1	65-90

Gray-colored aurorae may be seen also. Such observations are a result of light levels below the color threshold of the eye.

Optional: High Voltage Aurora Simulation

Here in the planetarium we can recreate some of these colors. We need some fast moving electrons, so I will turn on a 3000 volt power supply. The electric current through the air is contained, happily for us, in this tube.

Turn on the power supply.

Any light? Why not?

The air in the tube is too thick and the electrons bump into molecules in the air before they get enough speed. We have a vacuum pump that will pull air out of the tube to make it thinner.

Turn on the vacuum pump.

Now that the electrons get longer distances to speed up, the air molecules glow. (This is the less energetic red light. We would need a more sophisticated apparatus to create the green light.) We can now see the northern lights in a bottle. Watch as I show how a magnet affects the pattern of light.

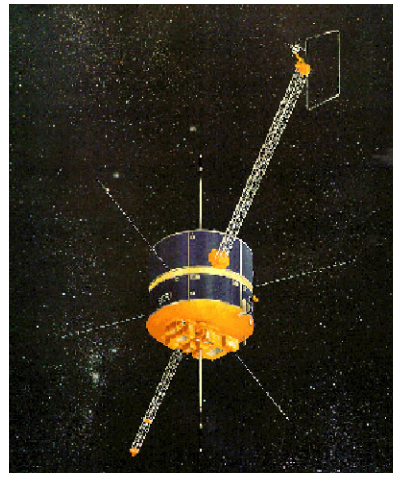
Wave a magnet near the tube.

See the lights flicker and fade as I let the air back into the tube.

Turn off the vacuum pump. When the glow has faded turn off the power supply.

Spacecraft Studies of Aurorae

n Image 23: POLAR Spacecraft

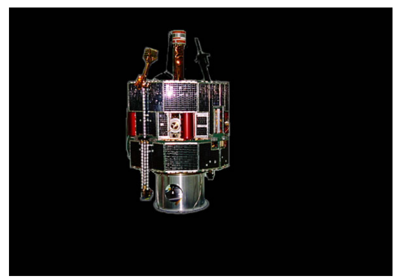


The Polar spacecraft was launched in February of 1996 to obtain data from both high- and low-altitude perspectives of the active polar regions of space near Earth. In its polar orbit around the Earth, the satellite also passes nearer the equator through the Earth's trapped radiation, the Van Allen belts.

Optional Information about Polar

Using the spacecraft, we study particles of the solar wind both high above the poles and at lesser altitudes where energy is transferred from electric fields and electromagnetic waves to electrons that then plunge into the atmosphere to create the aurora. The satellite detects the flow of particles from the Earth's upper atmosphere into the magnetosphere and particles and energy flow from the magnetotail back into the atmosphere.

Image 24a: FAST Spacecraft ►

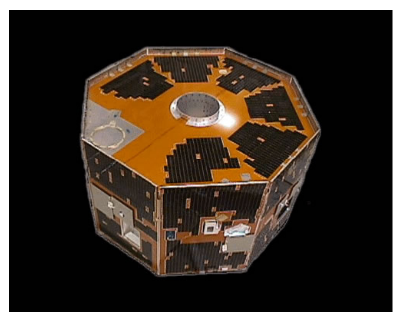


The Fast Auroral SnapshoT (FAST) explorer, launched in August of 1996, studies the details of the Earth's auroral regions. Several ground support "campaigns" coordinated satellite measurements with ground observations of the aurora borealis from locations in Alaska and Sweden.

Optional Information about FAST

FAST is in an elliptical polar orbit (400 by 4000 km). The science instruments on board FAST measure the magnetic and electric fields in the upper atmosphere, as well as particles' mass, charge, and velocity in order to determine their origin. This information allows scientists to learn about the interaction of the solar wind with the Earth's magnetosphere. Science instruments on the spacecraft were conceived and designed by a team of collaborators from across the country: the Space Sciences Lab on the campus of the University of California at Berkeley, the University of New Hampshire, Lockheed PA (for the TEAMS), UCLA, and Los Alamos.

Image 24b: IMAGE Spacecraft ►



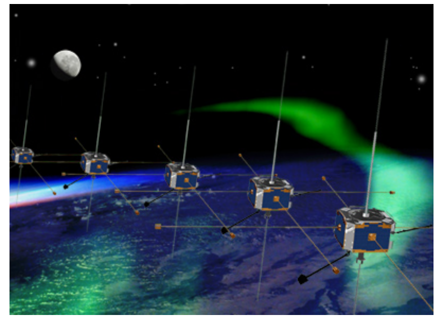
The Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) mission is the first satellite mission dedicated to imaging the region of space controlled by the Earth's magnetic field—the Earth's magnetosphere and the effects of the solar wind on the Earth's magnetosphere.

Optional Information about IMAGE

IMAGE was launched in March, 2000. In the magnetosphere, invisible to traditional astronomical observing techniques, there are ionized atoms and electrons. IMAGE employs a variety of imaging techniques to "see the invisible" and to produce the first-ever global images of the magnetosphere. The IMAGE mission addresses questions such as:

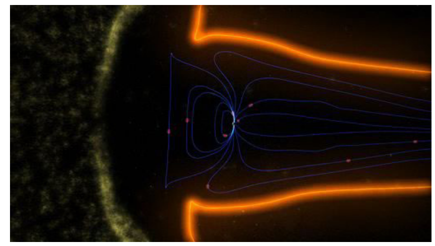
- **How are particles injected into the magnetosphere on the time scales of substorms and geomagnetic storms?**
- **How does the magnetosphere respond to changes in the solar wind?**

Image 24b: THEMIS Spacecraft ►



The Time History of Events and Macroscale Interactions during Substorms (THEMIS) spacecraft launched in February of 2007. The mission has 5 identical spacecraft whose orbits lined up once every 4 days. One of THEMIS's key discoveries overturned a long-standing belief about how and when most of the solar particles penetrate Earth's magnetic field. We have seen how Earth's magnetic field acts as a shield against the solar wind particles. However, our magnetic field is a leaky shield and the number of particles breaching this shield depends on the orientation of the sun's magnetic field. It had been thought that when the sun's magnetic field is aligned with that of the Earth, the door is shut and that few if any solar particles enter Earth's magnetic shield. The door was thought to open up when the solar magnetic field direction points opposite to Earth's field, leading to more solar particles inside the shield.

Optional Movie 5: THEMIS Discovery ►



Observations by the THEMIS spacecraft fleet demonstrate that the opposite is true. Twenty times more solar particles cross the Earth's leaky magnetic shield when the Sun's magnetic field is aligned with that of the Earth compared to when the two magnetic fields are oppositely directed.

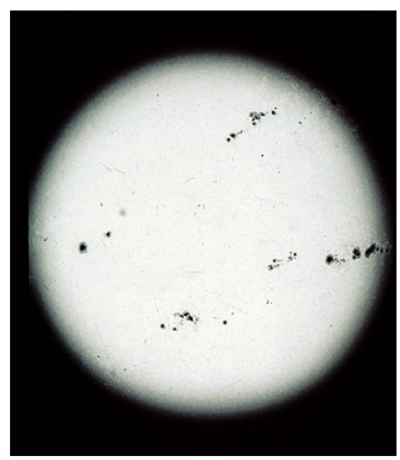
The most spectacular images of the Sun that we see today come from the SOHO and TRACE spacecraft. You can view many splendid images of the Sun by visiting the Websites of those satellite missions.

NASA has extended the THEMIS mission to the year 2012. In addition, ARTEMIS, a new mission that will take the two outer THEMIS probes into lunar orbits and perform solar wind, magnetotail, and lunar science.

Sunspots

Whether you see the northern lights depends on many factors. Being far to the north makes northern lights viewing more likely, except in the summer. But if the Sun becomes very active, the solar wind can be strong enough to cause northern lights to occur surprisingly farther south than normal—visible from southern United States and even Mexico. Activity on the Sun and strength of the solar wind are related to the number of sunspots, dark patches on the surface of the Sun.

Image 26: Sun with Sunspots ►



Sunspots have been known of for thousands of years. Chinese astrologers observed them large enough to be seen without optical aids as early as 1000 BC. Early observers watched for sunspots as the Sun was setting, when the Sun's rays were not as intense harmful to the eye. *Nowadays, proper solar filters make direct viewing of the Sun safe.* Since 1850 it has been known that the number of sunspots varies in an eleven year cycle. The most recent peaks in the cycle, called the solar maximum, happened around 1990 and 2001. We expect a sunspot peak in 2013.

During a solar maximum, there is a possibility for seeing aurora in more of the United States than just northern Alaska. It's usually rare to see the northern lights in [your city], but let's watch them again one more time before it's time to go. This time see if you can capture them on paper!

If the latitude of your planetarium is below about 50°, seeing northern lights is a big deal—maybe even 60°.

Drawing the Northern Lights

As a memento of your visit to northern lights we have all the tools you need to make a chalk sketch of your impression of the aurora borealis. I'll give you black paper for the night sky.

What chalk colors should we use?

(This part makes an excellent interdisciplinary project with school art programs.)

Show Image 27 and point out the various colors: green, red, blue.

Hand out black paper and clipboards. Distribute fluorescent oil pastels. Show Images 28–41 and/or play the Movie 6 of aurora: "Inspiration for Aurora Drawings." Encourage the "artists" saying how nice their drawings are and that the real northern lights can look that way, which is probably true! It should be dark to see the northern lights at their best. Turn down all bright lights and turn up the ultraviolet light. Let them admire their work and explain fluorescence if you wish.

Image 27 (Franck Pettersen)

Image 29 (Jan Curtis)

Image 28 (Franck Pettersen)

Image 30 (Franck Pettersen)

Image 33 (Franck Pettersen)

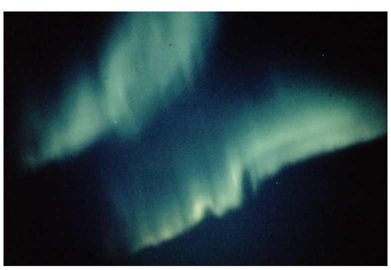


Image 31 (Franck Pettersen)

Image 32 (Jan Curtis)

Image 34 (Franck Pettersen)

Image 35 (Franck Pettersen)

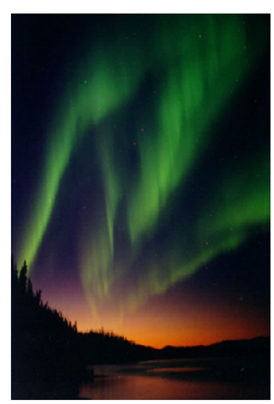


Image 36 (Jan Curtis)


Image 37 (Franck Pettersen)


Image 38 (Franck Pettersen)

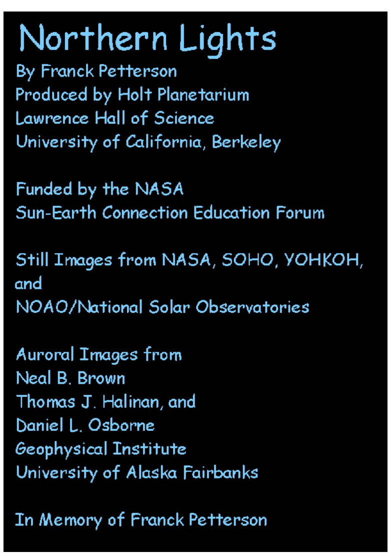

Image 39 (Franck Pettersen)


Image 40 (Franck Pettersen)


Image 41 (Jan Curtis)

Would you like to plan a trip to see the northern lights some day? Where would you go? What time of year?

In general, seeing aurora is rare if you are not at least 50 degrees latitude north or south. Have the audience recall the midnight Sun phenomenon. Since one can't see aurora in the daytime, summertime is not a good time to see aurora in either high latitudes of Northern Hemisphere (May through August) or Southern Hemisphere (November through February). Also, it's a bonus to make an aurora watching visit close to the peak of the 11-year solar activity cycle.



Thank you for coming to our planetarium today and may you always have safe and successful journeys for your aurora-watching!

Image 42: Credits.

To Learn More About Aurora

Aurora Websites

Visit http://www.lawrencehallofscience.org/pass/PASSv13updates.html
for the latest updates, books, articles, and a number of interesting Websites and online articles concerning aurora.

Explore the North
http://www.explorenorth.com/aurora.html

Exploratorium Website
http://exploratorium.edu/auroras

Articles by Franck Pettersen
http://www.imv.uit.no/english/science/publicat/waynorth/wn1/contents.htm

Sun-Earth Connection Education Forum (SECEF)
http://sunearth.gsfc.nasa.gov/

Satellite Missions

Sun-Earth Connection missions
http://sunearth.gsfc.nasa.gov/scimissn.htm

Solar Heliospheric Observatory (SOHO)
http://sohowww.nascom.nasa.gov
http://lasco-www.nrl.navy.mil/lasco.html

Transition Region and Coronal Explorer (TRACE)
http://sunland.gsfc.nasa.gov/smex/trace/

Imager for Magnetopause-to-Aurora Global Exploration (IMAGE)
http://image.gsfc.nasa.gov/ also
http://pluto.space.swri.edu/IMAGE/

IMAGE Education and Public Outreach (POETRY)
http://image.gsfc.nasa.gov/poetry/

Polar mission
http://www-istp.gsfc.nasa.gov/istp/polar/
(has "sounds" of the magnetosphere)

Polar outreach page
http://www-istp.gsfc.nasa.gov/istp/outreach/

Fast Auroral Snapshot (FAST) Explorer satellite
http://sunland.gsfc.nasa.gov/smex/fast/

Time History of Events and Macroscale Interactions during Substorms (THEMIS)
http://themis.ssl.berkeley.edu

Books

Bone, Neil, *The Aurora: Sun-Earth Interactions,* John Wiley & Sons, New York, 1996.

Falck-Ytter, Harald, *Aurora: the Northern Lights in Mythology, History, & Science*. Floris Books, Edinburgh, 1985.

Jago, Lucy, *The Northern Lights,* Alfred A. Knopf, New York, 2001. True story of Kristian Birkeland and his theories about the aurora borealis.

Savage, Candace, Aurora: the Mysterious Northern Lights. Sierra Club, 1994.

Articles

Burtnyk, Kimberly, "Anatomy of an Aurora," *Sky & Telescope* magazine, March 2000.

Eather, Robert H., "An Aurora Watcher's Guide," *Sky & Telescope* magazine, March, 2000.

Frank, Adam, "Blowin' in the Solar Wind," *Astronomy* magazine, October, 1998, p. 60. Scientists are using the latest satellites and supercomputers to predict the onslaught of space storms.

Videos

Aurora by Neal Brown, Tom Hallinan, Dan Osborne of the Aurora Color Television Project, Geophysical institute, University of Alaska-Fairbanks, 903 Koyukuk Avenue, P.O. Box 757320, Fairbanks, AK 99775-7320; 907-474-7107

Aurora—Rivers Of Light In The Sky from Skyriver Films, Anchorage, Alaska; 800-248-9453.

Blackout! Contact: Request Coordination Center, Code 633, Goddard Space Flight Center; 301-286-6695; request@nssdc.gsfc.nasa.gov

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In 1987, Franck Pettersen spent a sabbatical year with the Astronomy department of Lawrence Hall of Science (LHS), University of California at Berkeley. One of his goals in that year was to develop concepts in audience participatory planetarium programs and in particular, develop a program on the aurora borealis. This program is largely a result of Franck's work that year with the LHS astronomy staff.

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Photos, Illustrations and Other Credits

Credits and sources for slide images are given in the Slide list in the Materials section. All other illustrations in this volume are by Alan Gould or from NASA as noted.

The video for Northern Lights includes narration and photos by Franck Pettersen; aurora motion picture footage from the Aurora Television Project, University of Alaska; clips from the movie Blackout from the IMAGE satellite mission; movies from the SOHO and TRACE spacecraft—observations of the Sun; music by Iasos (http://www.iasos.com); Music for Norway by Egil Storbekken.