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Solar Storms and You!

Exploring Satellite Design
An Educator Guide with Activities in Space Science



Acknowledgments

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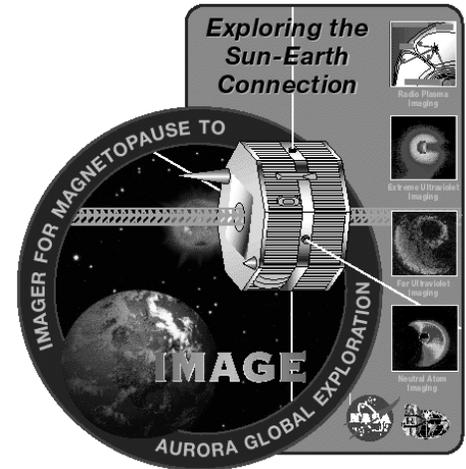
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Information about the IMAGE
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<http://image.gsfc.nasa.gov>
<http://pluto.space.swri.edu/IMAGE>

Resources for teachers and
students are available at:

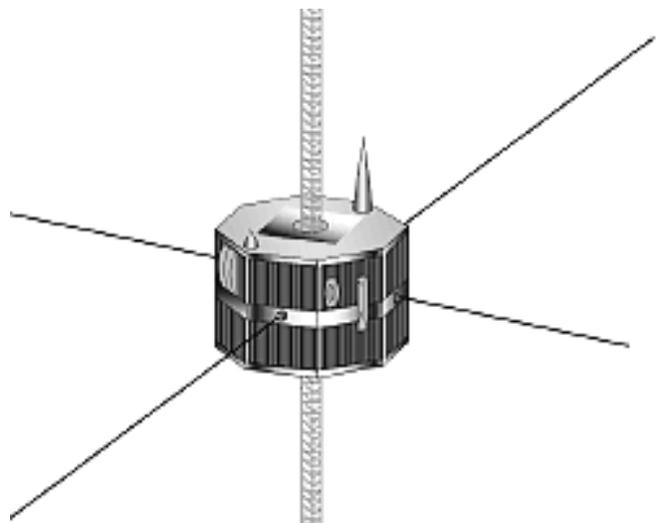
<http://image.gsfc.nasa.gov/poetry>



National Aeronautics and
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Goddard Space Flight Center

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Research satellites are designed to be as light-weight as possible without skimping on the necessary strength or radiation shielding, and to provide detailed data on a variety of space conditions including magnetic fields, electromagnetic radiation, and energetic particles. The above drawing shows the NASA, IMAGE satellite which will be launched in February 2000, to explore the Earth’s environment within the magnetosphere. It will be launched on a Delta 2 rocket like the one on the left.

I N T R O D U C T I O N

A gas pipeline in Russia explodes

killing hundreds of people.

A satellite mysteriously falls silent

interrupting TV and cellular phone traffic.

A power blackout

throws millions of people into darkness.

These are only a few of the many things that solar storms can do when they arrive at the earth unexpected. In an age where we have increasingly come to rely upon the smooth operation of our technology, we have also made ourselves vulnerable to the ebb and flow of the solar storm cycle. Most people are not even aware of these cycles, but long ago we used to be!

Ancient Chinese sun observers knew that, from time to time, dark spots would glide slowly across the face of the setting sun. Once seen only as portends of political upheaval, we now see them as natural phenomena that can forewarn us of impending storms that can have dire consequences for us if we ignore them.

In this activity book, your students will study five key stages in the lifecycle of a solar storm, from its emergence on the solar surface to its impact upon some aspect of our lives. The book may be used in its entirety to study solar activity and how it directly affects us, or you may use individual activities of your choice as stand-alone mini lessons as an enrichment for math and physical science courses.

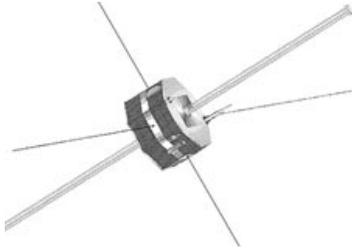
The student activities emphasize basic cognitive skills and higher-order processes such as plotting data, searching for patterns and correlations, and interpreting the results. By the end of the activity series, students will understand why we need to pay more attention to solar storms.

Visit the updated version of this workbook at:

<http://image.gsfc.nasa.gov/poetry/workbook/workbook.html>

Science Process Skills

for *Solar Storms and You!*



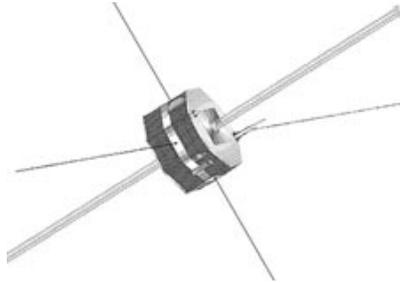
This chart is designed to assist teachers in integrating the activities contained in the guide with existing curricula.

Lesson 1 “IMAGE Satellite Scaling”	Lesson 2 “IMAGE Satellite Scale Model”	Lesson 3 “IMAGE Satellite 1/4-scale Model”	Lesson 4 “Pie Charts in Science”
--	--	--	--

Observing				
Classifying				
Communicating				
Measuring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Inferring				<input type="checkbox"/>
Predicting	<input type="checkbox"/>			<input type="checkbox"/>
Experimental Design				
Gathering Data				
Organizing Data				
Controlling Variables				
Developing a Hypothesis				
Extending Senses				
Researching				
Team Work	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Mathematics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Interdisciplinary	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Introductory Activity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Advanced Activity				

Science and Mathematics Standards

for *Solar Storms and You!*

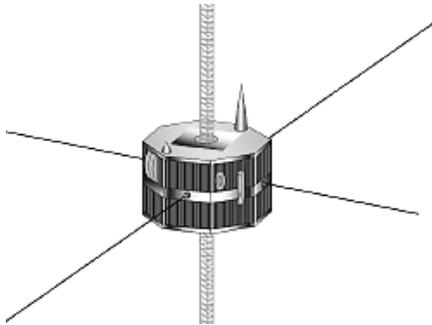


This chart is designed to assist teachers in integrating the activities contained in the guide with existing curricula.

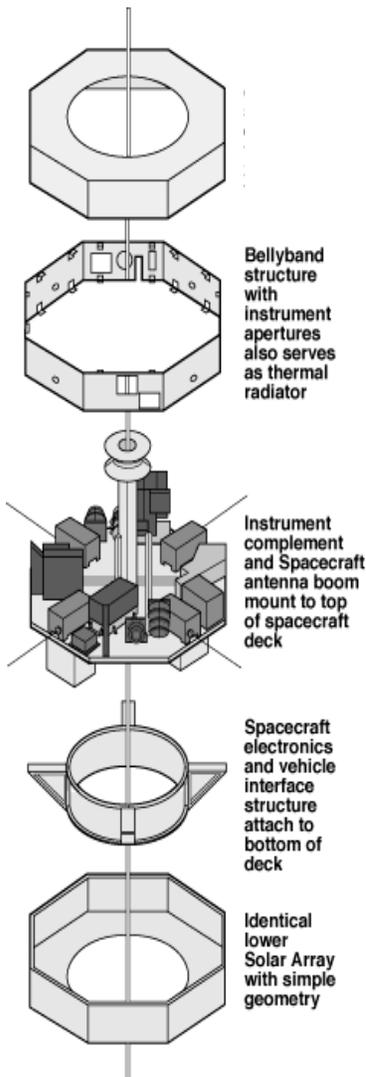
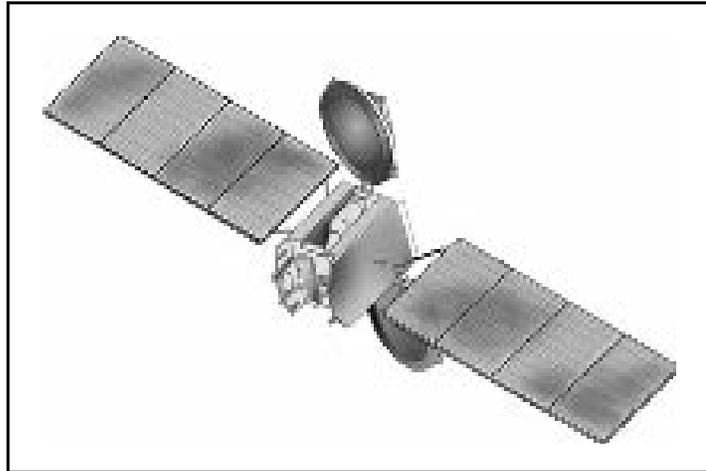
Lesson 1	Lesson 2	Lesson 3	Lesson 4
"IMAGE Satellite Scaling"	"IMAGE Scale Model"	"IMAGE 1/4-scale Model"	"Pie Charts in Science"

Science as Inquiry				
Structure and Energy of the Earth System				
Origin and History of the Earth				
Earth in the Solar System				
Geochemical Cycles				
Physical Science	○	○	○	○
Populations and Ecosystems				
Understanding about Science and Technol- ogy				
Science in Personal and Social Perspectives				
History and Nature of Science				
	○	○	○	○
Problem Solving	○	○	○	○
Measurement	○	○	○	○
Computation and Estimation				
Communication				
	○	○	○	○
Geometry and Advanced Mathematics				
Statistics and Probability				
Number and Number Relationships				
Patterns and Functions				

Satellite Design



The IMAGE Satellite



Satellites are the work horses of modern society. Virtually all economic forecasts predict that the 21st century will witness an explosion of new satellites to relay cellular phone, television and computer data. They will provide services to society that we cannot even imagine today. Currently, the satellite industry in both the civilian and military sectors has amassed over \$100 billion in space-based assets. Only a small fraction of this investment is in scientific research satellites, which are used to learn more about the space environment, and to safeguard all the other resources.

Satellites are vulnerable to many aspects of solar activity, particularly the streams of charged particles that flow in the magnetosphere. When you shuffle across a carpet, you pick up static electricity, which you then discharge in a painful 'zap' when you touch a grounded metal object. In space, satellites pick up charged particles constantly, but they cannot be so easily 'grounded' to discharge their load of static charge. As a result, satellites charge to thousands of volts. The smallest dust particle can cause a lightning bolt of discharge to 'zap' delicate electronic equipment. These discharges can cause false commands that can sometimes send the satellites into bizarre and unplanned 'states' which can cause the satellite to be lost.

Satellite designers work around this problem. They are making certain that as much as possible of the critical electronics in a satellite are 'radiation hardened'. They are designing radiation-hardened versions of many common components.

Introduction

Scientists need to consider size, mass and cost when designing a satellite. Although more data is returned by larger satellites, it isn't simply a matter of doubling or tripling the dimensions of a satellite that lead to a good design. When you double the size of a design, the volume increases by 8 times and so does the mass and cost of the satellite. The IMAGE satellite is designed to be built for under \$30 million, and has a mass of 70 kilograms, but doubling its size would cause the mass to increase to 1/2 ton and its cost to rise to \$240 million!

Objective

The student will calculate the volume of the satellite. Based on the results, the student will determine patterns and relationships to see how change affects the mass and the cost of the instruments.

Procedure

1) Read the students the introduction to the IMAGE Dimension Activity, or discuss the key points with the students.

2) Allow students to complete questions 1, 2 and 3. Discuss student responses to these questions and the implications of increasing the size of the instruments on the satellite. Refer to the Introduction as necessary.

3) Discuss how the change in the dimensions affects the mass. Allow students time to complete activity 4. Discuss the results.

4) Discuss how the cost of the satellite is affected by increasing the dimensions and how it is proportional to the mass. Allow students to complete question 5. Discuss the results.

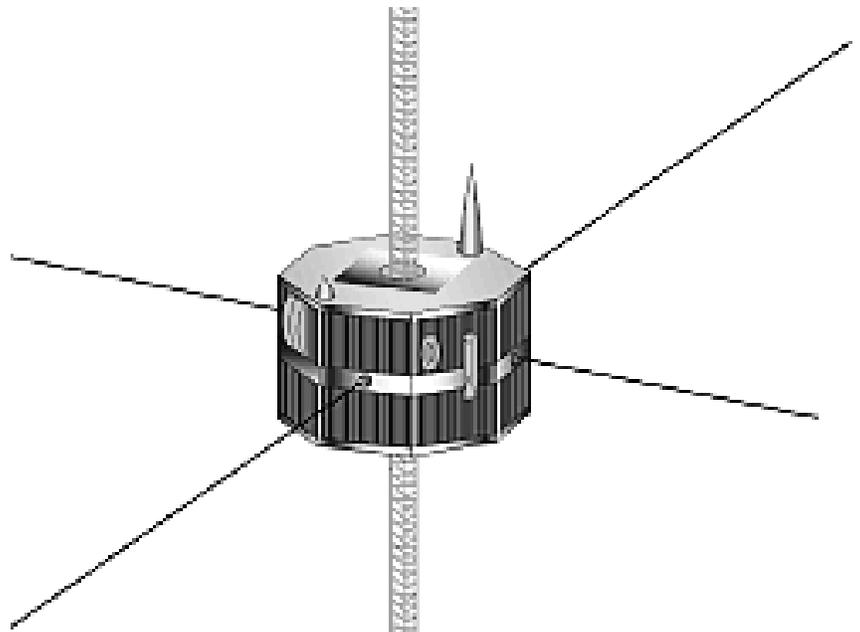
5) Have students complete question 6 and 7. Provide time for students to give possible responses. Discuss why a scientist may want a bigger satellite and the implications of scaling to the independent components.

Materials

- Introduction to the IMAGE Dimension Activity
- Teacher Answer Key
- Student Pages

Conclusion

When designing spacecraft, it is important to know how the cost and capabilities of the satellite will scale as you change its dimensions.



Introduction to the IMAGE Dimension Activity

The IMAGE satellite must meet certain requirements. It must meet a two year mission lifetime, and must be launched on a Delta II rocket with a payload mass limit of 1000 kilograms. It must also cost less than \$50 million.

The scientists need to consider mass, cost, and volume when designing a satellite. There are numerous instruments that need to be scaled, and all of the factors mentioned above must be considered.

For instance, if a detector is chosen, the dimensions need to be investigated to determine the final instrument cost. As in the following activity, if a dimension is doubled, the mass increases by $2 \times 2 \times 2$ or a factor of 8. In turn, the cost increases in proportion to the mass, which in this case is also a factor of 8.

In addition, any change in the dimensions impacts on the other instruments in the satellite, the labor needed to assemble it, salaries, and the launch vehicle required for the extra mass and size. The IMAGE satellite will require a rocket to launch it. If the satellite's size is quadrupled, it would require the Space Shuttle to launch it. The difference in the launch cost alone is \$50 million for the rocket compared to \$700 million for the Space Shuttle.

The major constraint on the IMAGE project is cost. The IMAGE satellite must be built, launched and operated for 2 years at a total cost less than or equal to \$60 million. Nearly all of the cost of any mission is in the salaries of the scientists and engineers needed to manufacture the satellite and the rocket.

In response to the question of why a scientist would want a bigger satellite, it is purely based on the amount of information that is being sought. The IMAGE satellite is designed to provide 2-D images of various phenomena in space. An increase in the dimensions will cause an increase in the size due to the need to acquire more data. Doubling the sizes of an electronic camera, in turn, quadruples the amount of data it can capture and send down to the scientists on the ground.

However, the question of size is more involved than this. The instruments of the IMAGE satellite, which have been the major focus, are not the only things to consider in satellite design. In terms of scaling, when the size of the instruments double, it does not necessarily mean that the size of the satellite will double. Actually, the instruments are only a small part of the total spacecraft size compared to the other satellite systems and hardware. The components of the satellite can also be scaled independently. Doubling the size of one instrument may not necessarily double the size of the electrical power required to operate it, and so, double the size of the power supply needed to provide the electricity.

Teacher's Answer Page

The IMAGE satellite's construction involves a number of different instruments. These instruments are analyzed to determine the dimensions that will provide the most efficient satellite while minimizing the weight and cost. In order to help you understand the possible factors involved in the dimensions, mass and cost; complete the following activities.

1. Calculate the volume of the following instruments and spacecraft components. The dimensions are given in cubic centimeters in the following table:

Instrument	1x Volume	8x Volume	27x Volume	64x Volume
LENA	8100	64800	218700	518400
MENA	8100	64800	218700	518400
HENA	9000	72000	243000	576000
TAC/ADC	1620	12960	43740	103680
HV Electronics	2592	20736	69984	165888
Spectrometer	35712	285696	964224	2285568
WB Camera	5070	40560	136890	324480
Electronics	5400	38400	129600	307200
Sensors	2250	18000	60750	144000

2. When the dimensions of the satellite are doubled, by what factor is the volume increased? What factor is the increase when the dimensions are tripled and quadrupled?

8, 27, 64

3. Is there any noticeable connection between two or more of these factors of increase?
Doubling and quadrupling are multiples of each other, and the results of 8 and 64 are multiples as well.

4. The mass of the IMAGE satellite increases proportional to the volume. If the dimensions are doubled, the mass increases by the cube of the factor or $2 \times 2 \times 2 = 8$. The mass of the satellite is 261 kg. Determine the mass increase when the dimensions are doubled, tripled and quadrupled.

Doubled = **2088 kg** Tripled = **7047 kg** Quadrupled = **16704 kg**

5. The cost of the satellite also increases proportional to the mass. The cost for the original dimensions is \$28.4 million. What is the cost for each of the various increases?

Doubled = **\$227.2 million** Tripled = **\$766.8 million** Quadrupled = **\$1.818 billion**

6. In your own words, please write the process involved in determining the volume, mass and cost of the IMAGE satellite. Why would a scientist want a 'bigger' satellite?
Students response will vary. The bigger the satellite, the more information that is being sent to the scientists. Bigger does not necessarily mean better.

Name _____

Date _____

The IMAGE satellite's construction involves a number of different instruments. These instruments are analyzed to determine the dimensions that will provide the most efficient satellite while minimizing the weight and cost. In order to help you understand the possible factors involved in the dimensions, mass and cost; complete the following activities.

1. Calculate the volume of the following instruments and spacecraft components. The dimensions are given in centimeters in the following table:

Instrument	Dimension	Double	Triple	Quadruple
LENA	36x15x15	72x30x30	108x45x45	144x60x60
MENA	36x15x15	72x30x30	108x45x45	144x60x60
HENA	30x10x30	60x20x60	90x30x90	120x40x120
TAC/ADC	18x18x5	36x36x10	54x54x15	72x72x20
HV Electronics	18x18x8	36x36x16	54x54x24	72x72x32
Spectrometer	62x36x16	124x72x32	186x108x48	248x144x64
WB Camera	26x15x13	52x30x26	78x45x39	104x60x52
Electronics	15x20x18	30x40x32	45x60x48	60x80x64
Sensors	15x15x10	30x30x20	45x45x30	60x60x40

2. When the dimensions of the satellite are doubled, by what factor is the volume increased? What factor is the increase when the dimensions are tripled and quadrupled?
3. Is there any noticeable connection between two or more of these factors of increase?
4. The mass of the IMAGE satellite increases proportional to the volume. If the dimensions are doubled, the mass increases by the cube of the factor or $2 \times 2 \times 2 = 8$. The mass of the satellite is 261 kg. Determine the mass increase when the dimensions are doubled, tripled and quadrupled.

Doubled = Tripled = Quadrupled =

5. The cost of the satellite also increases proportional to the mass. The cost for the original dimensions is \$28.4 million. What is the cost for each of the various increases?

Doubled = Tripled = Quadrupled =

6. In your own words, please write the process involved in determining the volume, mass and cost of the IMAGE satellite. Why would a scientist want a 'bigger' satellite?

Introduction

The construction of scale models of spacecraft has, historically, been an important engineering tool in designing spacecraft. Today, powerful 'CAD/CAM' software programs have become popular, but scale model building is still considered an important method of verifying satellite dimensions, tolerances and clearances.

Objective

The students will construct a scale model of the IMAGE satellite.

Procedure

1) Students will use the Spacecraft Dimensions Sheet to determine the scale model size. Note: When students are determining the diameter of the circle to construct the octagon, make sure that the measurement that is being used is from the opposite vertices.

2) Students will construct a pattern of the IMAGE satellite. They may opt to construct the pattern in a variety of ways; three methods are given below:

A—Students can inscribe an octagon using perpendicular and angle bisectors. Then they can cut the octagon out, and then use this to trace the second octagon. Students can create a rectangle using the corner of a sheet of paper, cut it out, and then trace

the design seven more times. Students can then piece the design together using the tape.

B—The more advanced students may opt to determine how to construct the pattern in one piece. The students will need to determine the position on the paper to best fit the design. Students will then construct the design, cut it out, and then fold and tape it to complete the model.

C—Teachers may opt to use the included pattern. Cut out the satellite model, fold and tape it to complete the model.

3) Students can draw the IMAGE components on the model according to the Students Guide Sheet using the colored pencils.

Materials

- Compass
- Ruler
- 8 1/2 x 11 paper
- Scissors
- Tape
- Spacecraft Dimensions
- Student Direction Guide
- Colored pencils

Conclusion

Scale model making is still an important tool for engineers and scientists to visualize how the various pieces of their spacecraft fit together.

Teacher Scaling Notes

The actual diameter for the NASA IMAGE satellite is 238 centimeters or 7.8 feet. The actual length of the rectangular side panels is 136 centimeters or 4.5 feet. The scale factor becomes 238 centimeters divided by 9 centimeters, which means that each centimeter on the diagram is equal to 26.4 centimeters on the actual IMAGE satellite.

The diameter of the Spacecraft Dimensions Sheet is 9 centimeters, which in turn makes the radius of the circle to be 4.5 centimeters. The width of the rectangle is 3.4 centimeters and the length is 5.1 centimeters. The length of the sides of the octagon will be 3.4 centimeters, the same as the width of the rectangular side panels.

NOTE!!!

Students may not be aware of the correct rectangle to measure. It would be hoped that they would realize that the width should be consistent with the length of the sides of the octagon. However, students may question why the top and the bottom rectangle 'look' different. Explain that this is due to the perspective of the drawing. When a side view of a three dimensional model is shown, the drawing tends to look distorted due to the perspective and the viewing angle.

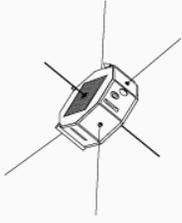
Teacher, Pattern Construction Notes

- 1) With a compass, construct a circle with a 4.5 centimeter radius. Be sure to mark the center. Students should be aware that the sides of the octagon are 3.4 centimeters.
- 2) Use the ruler to draw a horizontal diameter.
- 3) Place the compass tip in the center of the circle. Open the compass a little and with the pencil end, mark an arc on both sides of the center of the circle.
- 4) Open the compass wider. (Note: If this step is forgotten, the marks will fail to cross.) From each of the arcs, swing the compass to make a large arc on both sides of the diameter. Where the two arcs cross is the point needed to draw the perpendicular diameter.
- 5) Draw the perpendicular diameter.
- 6) Place the compass point on the center mark. Construct a small concentric circle.
- 7) Using one of the angles created, open the compass wider, place the point on the spot where the new circle intersects the diameters. Swing the compass to create a semicircle. Place the point on the other diameter where the little circle meets, and construct another semicircle that intersects the previous one. Where the two semicircles meet will be two points. Connect the two points forming a new diameter. (Note: The new diameter will bisect the two angles.)
- 8) Repeat the process in Step 7 with the other two angles.
- 9) Connect the edges of the diameters drawn to construct the inscribed octagon.
- 10) Students will need to construct two octagons for the pattern.

Constructing the Rectangles

11) The eight rectangles need to be 3.4 centimeters by 5.1 centimeters. Some students may need to use the corner of a sheet of paper as the first two sides, and they can measure for the other two sides. The more advanced students can use perpendicular bisectors to construct parallel sides, and then they can do their measurements.

Note: If the pattern is being constructed entirely by hand, the given scale dimensions will fit on an 8 1/2 x 11 sheet of paper. The student will need to determine the lay-out of the the pattern.



IMAGE

Spacecraft Drawings

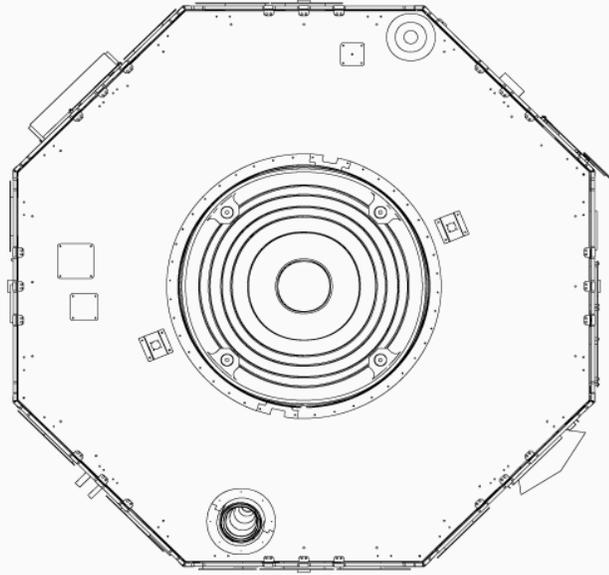
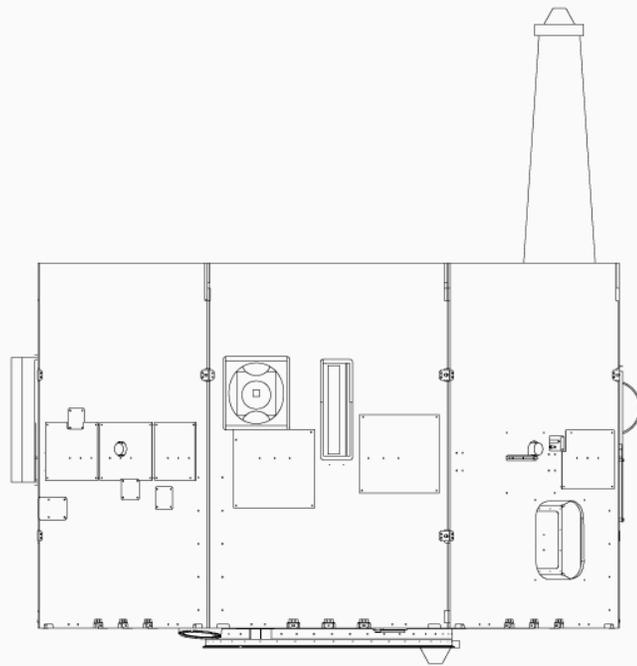
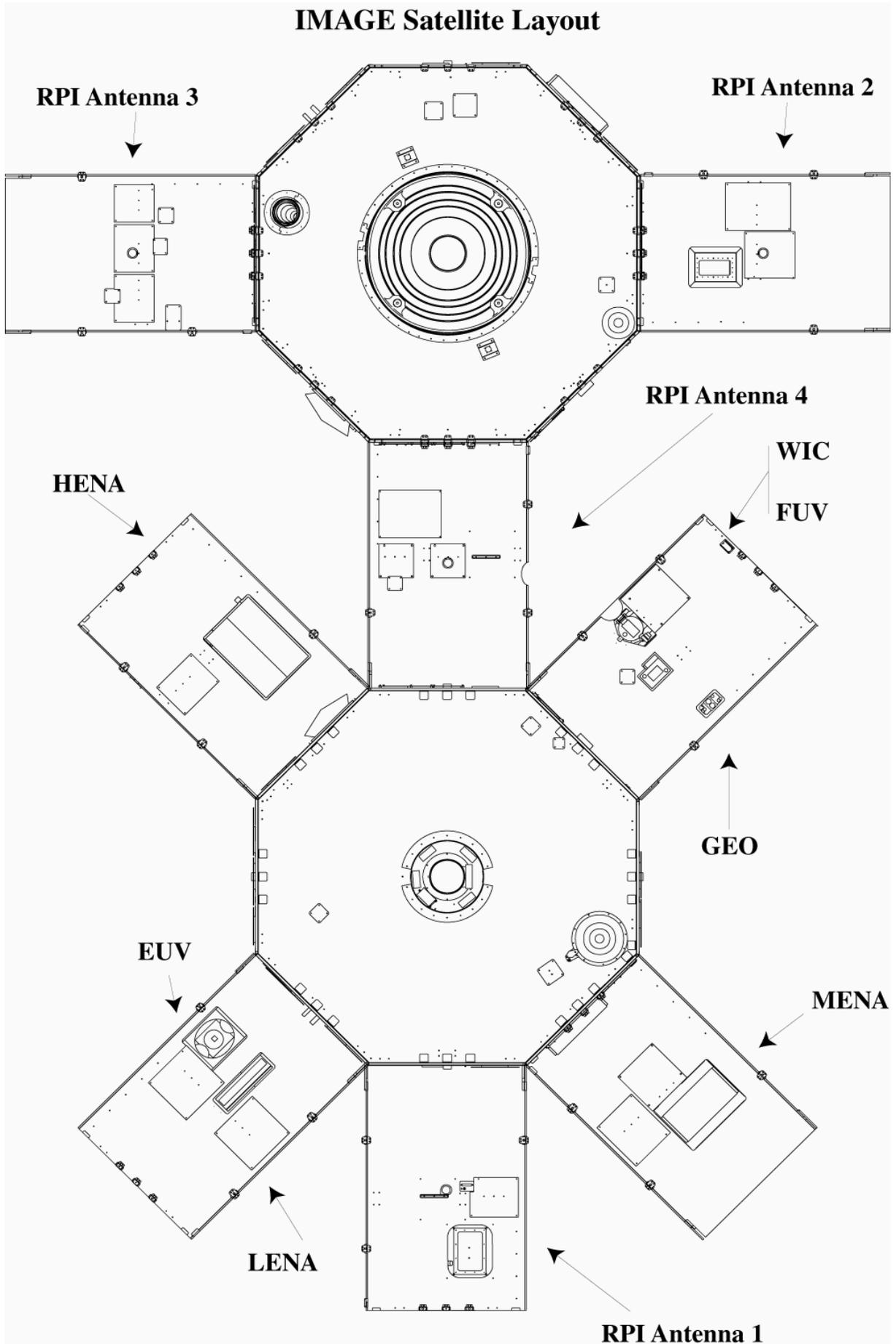


IMAGE Satellite Layout



Teacher's Guide

IMAGE Satellite Scale Model (One Fourth Actual Size)

Introduction

The construction of scale models of spacecraft has, historically, been an important engineering tool in designing spacecraft. Today, powerful 'CAD/CAM' software programs have become popular, but scale model building is still considered an important method of verifying satellite dimensions, tolerances and clearances.

Objective

The students will be able to construct a scale model of the IMAGE Satellite one-fourth of the original size.

Procedure

- 1) Students are given the scale drawing and the actual measurements.
- 2) Students are to determine the scale used in the schematic drawing.
- 3) Students are to determine the dimensions that are needed to construct a scale model one fourth of the original size.
- 4) Students determine the materials that will be necessary to construct the scale model.
- 5) Student may begin the construction with either the octagonal top and bottom, or the rectangular side panels:
 - i) Construct an octagonal panel and cut it out. Trace the second to save time.
 - ii) Construct one rectangular side panel and cut it out.

- iii) Trace the other seven and cut them out to save time.

For reasons of safety- again- only the teacher uses the utility knife. Students will need a lot of room to work. Remind the students that when they measure the diameter, the measurement must be from opposite vertices. Duct tape will help to hold the model together better than regular or masking tape.

- 6) Students construct the scale model.

7) Students will write a summary describing the process required to construct the scale model from the beginning, with the schematic drawing, and concluding with the steps necessary to finish the model.

Materials

- Compass, very big and/or a string and a nail to simulate a compass
 - Ruler/ yardsticks
 - Cardboard and /or wood
 - Duct tape
 - Spacecraft Dimension Worksheet
 - Colored or regular aluminum foil
 - Paper towel rolls or pipe cleaners
 - Scissors or utility knives
- Note: The teacher may want to be the only one to handle the utility knife for safety reasons.

Conclusions

Students apply concepts in mathematics to a real life event. Students enjoy the hands on activity and are very competitive in making sure that their satellite is the best and the most accurate. Students apply the concept of innovation in creating their scale model, and they are not willing to accept a model that is not constructed correctly. They persevere even when the task is difficult.

Introduction

As part of the IMAGE satellite program, there has been a web site created for teachers and students called POETRY. One of the links is titled 'Ask the Space Scientist'. From this link students may ask a scientist questions about space and read the posted answers. Each topic contains specific questions and their appropriate answers at the site. This activity explores the frequency of specific topics to determine the categories that have the most frequently asked questions.

Objective

By completing the data table, students should be able to construct and interpret a graph which includes data from the table.

Procedure

1) Students should finish the table by filling in the blank central angle column.

2) Students should create a circle graph to represent the topic request percentages.

3) Students should answer the accompanying questions based on the information in the pie chart.

NOTE: When students have completed the activity, they may want to visit the POETRY web site and have a look at

some of the questions and answers they find at "Ask the Space Scientist."

—Calculator
—Protractor

Materials

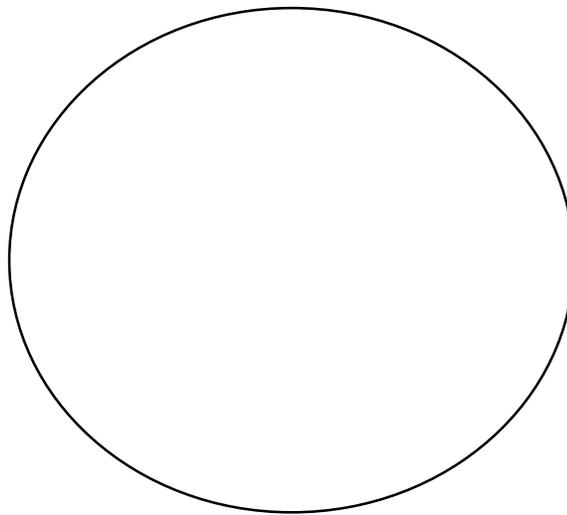


<http://image.gsfc.nasa.gov/poetry>

Name _____

Date _____

Topic	Percent	Central Angle
The Earth	5	
The Planets	12	
Stars	18	
Black Holes	23	
The Big Bang	25	
Space Travel	9	
Careers	8	



Questions:

- 1) What topic areas have the most popular questions?
- 2) Which topic areas have the least popular questions?
- 3) Can you think of a question you might “Ask the Space Scientist” in each of the topic areas?
- 4) If this web site recorded 12,340 visitors during a week, how many would probably ask about Black Holes?
- 5) If the web site has limited resources, which topic areas would you consider dropping to operate more economically?
- 6) If the web site had only 20 visitors, which topic area would have the least chance of being visited?

What is Solar Activity?

The Sun, our nearest star, provides us with warmth and light. Until Galileo invented the telescope, it was once thought to be a perfect orb, free of blemishes, eternal and changeless. **Sunspots** are the most well known hints that the Sun's surface is constantly changing. Larger than the Earth, and with magnetic fields that are 10,000 times stronger than the Earth's, sunspots are the breeding grounds for some of the most violent storms in the solar system!

The number of sunspots increases and decreases in cycles that last from 6 to 17 years; the **Sunspot Cycle**. With modern technology and space satellites, this solar activity cycle can now be detected in the ebb and flow of other phenomena on the Sun and on the Earth. Among the most enigmatic storms are the **solar flares** that erupt near sunspots. In a matter of 20 minutes, magnetic fields can heat gases to tens of thousands of degrees and release more energy than a thousand atomic bombs. Some of this gas can be hurled out from the Sun at millions of kilometers per hour in what are called **coronal mass ejections**. Both solar flares and coronal mass ejections can be very disruptive to human activity on earth and in space.

The outer atmosphere of the Sun, the **corona**, is familiar to many people who have watched total eclipses of the sun. The solar wind extends billions of kilometers further out into space than the corona. Like invisible roadways spanning the solar system, the magnetic field from the Sun flows out from the solar surface. Matter ejected from the Sun flows radially outwards from the solar surface. From the time a solar storm is seen on the Sun, it can take 2-3 days for the gas to travel to the orbit of the Earth, and if the Earth happens to be in the wrong place at the wrong time, it will be hit by a million-kilometer wide wall of high temperature gases and magnetic fields.

Anyone can tell you that a compass points 'north' because the Earth has a magnetic field, but until the advent of the Space Age, no one understood what this field really looked like or was capable of doing. Since Gilbert proposed in the 17th century that the Earth was a giant magnet, scientists have wondered just how this field is shaped, and how it has changed with time. The geomagnetic field which gives us our familiar compass bearings, also extends thousands of kilometers out into space in a region called the **magnetosphere**. On the Sun-side, it forms a protective boundary called the **bow shock**. Stretching millions of kilometers in the opposite direction behind the Earth is the **magnetotail**.

The solar wind blows upon the magnetosphere and gives it a wind-swept shape, but when solar storms and solar wind streams reach the Earth, the magnetosphere reacts violently. On the side nearest the impact, the magnetosphere compresses like squeezing a balloon, leaving communications satellites exposed. On the opposite side, it is stretched out, past the orbit of the Moon, or Mars and even Jupiter! The geomagnetic field is remarkably stiff, and so most of the solar wind is deflected or just slips by without notice. But some of the matter leaks in and takes up residence in donut-shaped clouds of trapped particles, or can penetrate to the atmosphere to produce the Aurora Borealis.

For thousands of years, humans have been treated to spectacles of glowing clouds above the northern horizon at night. Reports of these mysterious Northern Lights abound in the oral histories of the northern natives. On rare occasions, even ancient Greek and Chinese texts have mentioned them. It wasn't until 1896 that the Norwegian physicist Kristian Birkeland deduced that flows of electrons from the Sun were channeled into the polar regions by the geomagnetic field, and upon colliding with the outer atmosphere, would stimulate oxygen and nitrogen atoms to cast their ghostly and inspiring curtains of light.

The **Aurora Borealis** (near the north pole) and the **Aurora Australis** (near the south pole), as the 'Northern Lights' are more formally called, are seen most often in a band located at a latitude of 65 degrees, and about 10 - 15 degrees wide in latitude. From space, the auroral zone looks like a ghostly, glowing donut of light hovering over the north and south poles. This **auroral oval** can easily be seen in images from satellites designed to detect it. Its brightness and size change with the level of solar activity. Auroras come in many shapes and colors depending on what is happening to the geomagnetic field and the flows of charged particles and plasmas trapped in this field.

Magnetic sub-storms happen when the geomagnetic field is suddenly changed because of small changes in the magnetic polarity of the solar wind as it passes the Earth. Typically, magnetic storm aurora, also called **auroral storms**, last only a few hours. They begin in the evening as arcs of colored light which slowly change into rayed-arcs and the familiar folded ribbons or bands. Expanding over the whole sky, the folded bands are colorful, with green rays and red lower borders which change from minute to minute and move rapidly across the sky like some phantasmagoric serpent. After an hour, the auroral shapes become more diffuse and less distinct.

Geomagnetic storms are more severe than magnetic sub-storms and are caused by major changes in the direction and density of the solar wind as it reaches the Earth. These events are the most remembered historically as 'Great Aurora' or as the most disruptive to radio communications. The entire geomagnetic storm can last for many days as the particles and fields around the Earth continue to readjust themselves to the passing and ebbing solar wind. They begin with an ejection of mass by the Sun, and the impact of this plasma on the magnetosphere. Fast-moving coronal mass ejections produce shock waves in the solar wind, and this compression intensifies the density of particles impacting the magnetosphere. As the solar wind shock passes across the magnetosphere and magnetotail, magnetic fields re-orient and reconnect, releasing enormous amounts of energy and accelerating trapped particles to high speeds. These charged particles then travel down the geomagnetic field in huge currents, which cause bright and long lasting auroral displays.

Solar storms and the effects they produce in the Earth's environment, have been known for decades to be responsible for many harmful effects upon human technology on the ground and in space. Solar storms are known to do far more than just paint the sky with pretty colors! The multi-billion dollar 'Global Positioning System' consists of a constellation of over a dozen navigation satellites orbiting within the Van Allen radiation belts. These satellites let humans find their position anywhere on Earth using a hand-held receiver no bigger than a pocket calculator.

During solar storms, these positions are quite a bit less accurate than under calm conditions, which in turn impacts the navigation of ships at sea and jets in the air. Solar storms have disabled multi-million dollar communication and navigation satellites such as Anik-A, Molynia, Marecs-A, and they have been implicated in many electrical problems that were experienced by other satellites.

Solar storms were responsible for causing the Skylab to burn up in the atmosphere sooner than expected, and for altering the orbits of hundreds of other satellites and even the Space Shuttle itself. A storm on March 13, 1989 knocked out the Quebec-Hydro power system, plunging 6 million people into darkness for 9 hours. Geomagnetic storms cause the magnetic field near the Earth's surface to change rapidly in just a matter of minutes or hours. These changes cause electrical currents to flow within long power transmission lines, telephone wires, and even in pipelines which makes the pipes corrode, sometimes with tragic consequences. On June 5, 1991 a natural gas pipeline in Russia was weakened by corrosion and began to leak its deadly, flammable cargo. A passenger train, loaded with 1,200 people, ignited the liquefied gas and caused an explosion equal to 10,000 tons of TNT. Over 500 people were killed, and 700 more were badly injured.

Would you believe...

Aurora can never get closer to the ground than about 60 kilometers.

A sunspot has a temperature of nearly 4000 C, and would be brighter than the full moon if placed in the night sky.

Sunspots are often several times larger than the entire earth.

The Sun rotates once every 25 days at the equator, but takes up to 36 days to rotate once around at the poles.

The corona of the Sun is over 5 million degrees hotter than the surface of the Sun.

The Earth's magnetic north pole is actually a magnetic south pole because the north end of a bar magnet is attracted to it.

The total power produced by an auroral event can exceed 1 million megawatts and produce voltages over 100,000 volts in the upper atmosphere.

Aurora are produced where the atmosphere has the same density as the vacuum inside a light bulb.

Some aurora occur at altitudes of over 1000 kilometers above the Earth's surface.

Lightning storms can eject particles into space at nearly the speed of light, and they are seen as 'sprites' on the top side of a thundercloud.

A single lightning storm can be detected on the other side of the earth because some of its energy travels along the local magnetic field lines that connect the pairs of points on the surface of the Earth that can be thousands of kilometers apart.

Glossary

Aurora : Also called the ‘Northern Lights’ in the Northern hemisphere, or the ‘Southern Lights’ in the Southern hemisphere. These wispy curtains of light in the sky are caused by energetic electrons which collide with atoms of oxygen and nitrogen in the air to cause these atoms to emit shades of green, red and blue light. They never descend nearer than 50 miles from the Earth’s surface.

Corona : The very tenuous outer layers of the Sun which are seen during a total eclipse of the sun, but extending millions of miles into interplanetary space. It is heated to temperatures of over one million degrees by magnetic activity at the surface of the Sun. For decades, scientists puzzled over why the Corona could be so much hotter than the balmy 5770 degree Kelvin surface of the Sun.

Coronal Mass Ejection : The sudden expulsion of matter from the coronal regions of the sun, often involving billions of tons of plasma ejected at over one million miles per hour. During sunspot minimum conditions, about one ‘CME’ can be expelled every few days. During sunspot maximum conditions, as many as 3-5 can occur each day.

Magnetopause : A region that defines the outer edge of the magnetosphere where the pressure of the solar wind is balanced by the pressure of the earth’s own magnetic field.

Magnetosphere : The region surrounding the Earth in space where its magnetic field is important in controlling the movements of charged particles. Also sometimes referred to as ‘Geospace’.

Magnetotail : The solar wind pulls the magnetosphere into a comet-like shape. The long tail of this field, called the magnetotail’ or also the ‘geotail’, extends millions of miles into space in a direction opposite to the Sun from the Earth.

Solar flare : A powerful release of energy on the surface of the sun usually lasting less than a few hours, but releasing as much energy as 1000 hydrogen bombs. These are often associated with active regions of the solar surface where magnetic fields have become badly tangled, and then snap, releasing energy and heating local gases to over 1 million degrees.

Solar storm : Although scientists prefer not to use this term because it is technically rather vague, it has come to mean any of a number of active conditions on the Sun’s surface including flare activity or coronal mass ejections.

Sunspot : A dark spot on the Sun’s surface that indicates a concentration of magnetic forces. They are actually about 2000 degrees cooler than the solar surface, and only look dark because they emit light faintly.

Sunspot Cycle : The change in the number of sunspots from one period of its maximum to the next, over the course of about 11 years.

Sunspot Maximum : The period during the sunspot cycle when you will see the largest number of sunspots. Also called the ‘Solar Maximum’.

Sunspot Minimum: The period during the sunspot cycle when you will see the fewest number of sunspots. Also called the ‘Solar Minimum’

Resources

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Magnetic North Pole	http://www.nrcan.gc.ca/gsc/cpdnew/magnet.html
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Satellite Data	http://cdaweb.gsfc.nasa.gov
Space Weather Resources	http://image.gsfc.nasa.gov/poetry/weather.html
Magnetic Observatories and Data	http://image.gsfc.nasa.gov/poetry/maglab/magobs.html
Space Environments and Effects	http://see.msfc.nasa.gov/sparkman/Section_Docs/sparkman.html
Sun-Earth Classroom Activities Archive	http://sunearth.gsfc.nasa.gov/educators/class.html
Storms from the Sun	http://www.istp.gsfc.nasa.gov/istp/outreach/learn.html
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Space Weather Human Impacts	http://image.gsfc.nasa.gov/poetry/storm/storms.html
Ionosphere density and sunspot numbers	http://julius.ngdc.noaa.gov:8080/production/html/IONO/ionocontour_90.html
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