Anne Arundel County

Public Schools

TRADITION & VISION

ANNE ARUNDEL COUNTY
PUBLIC SCHOOLS

Support provided by NASA Goddard Education Programs

Earth Space Systems Science

Unit 5: The Space Sphere

November 2000

DRAFT

Earth Space Systems Science
Unit 5: The Space Sphere

Description

Scientists assume that the laws governing the behavior of matter are the same in all parts of the universe and throughout the course of time- many billions of years. For this reason, it is possible to understand the behavior of objects in the solar system through laboratory experiments and current observations of events in the universe. Because direct experiment is usually not possible, it is important to maintain the spirit of inquiry by focusing teaching on questions that can be answered by using observational data, the knowledge of science, and the processes of reasoning. (NSES, pp. 188-189)

In grades 9-12, the study of the universe becomes more abstract. Students must build knowledge to understand huge distances and long time scales as well as the nature of nuclear reactions. There is a challenge to present evidence that allows students to expand their understanding of large distances, long time scales, and the nature of nuclear reactions. (NSES, p. 188)

This is the time for all the pieces to come together. Concepts from physics and chemistry, mathematical ways of thinking, and the role of technology all contribute to understanding the universe. Most importantly, the role of gravity in forming and maintaining the planets, stars, and the solar system should be come clear for the student. Students will have a better understanding of the scale of billions of years. The speed of light is used to express relative distances. (AAAS, p. 65)

Key questions for this unit are:

1. How have current technologies extended our knowledge of the Earth-Space system?
2. How are scientific ways of knowing and scientific knowledge different from other bodies of knowledge?
3. How can we describe the formation of the solar system?
4. What is the best scientific thinking about the origin of the universe?
5. What information does the big bang theory provide about the formation of the universe?
6. What understandings do we have about the evolution of the universe and cosmic bodies?
7. What evidence do scientists have to reinforce, and further our understandings of the Earth-Space system?

Earth Space Systems Science
Unit 5: The Space Sphere

Key Concepts

- Science often advances with the introduction of new technologies. Solving technological problems often results in new technological knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. (NSES, p. 192)

- Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and x-ray telescopes collect information from across the entire spectrum of electromagnetic waves. Computers handle an avalanche of data and increasingly complicated computations to interpret them. Space probes send back data and materials from the remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed. (AAAS, p. 65)

- Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism as scientists strive for best possible explanations about the natural world. (NSES, p. 201)

- Scientific explanations must meet certain criteria. First and foremost they must be consistent with experimental and observational evidence about nature and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific. (NSES, p. 201)

- The sun, earth, and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. The earth was very different from the planet we live on now. (NSES, p. 189)

- The origin of the universe remains one of the great questions in science. The "big bang" theory places the origin between 10 and 20 billions years ago, when the universe began in a hot dense state; according to this theory, the universe has been expanding ever since. (NSES, p. 190)

- Stars condensed by gravity out of clouds of molecules of the lightest elements until nuclear fusion of the light elements into the heavier ones began to occur. Fusion released great amounts of energy over millions of years. Eventually some stars exploded, producing clouds of heavy elements from which other stars and planets could later condense. The process of star formation and destruction continues. (AAAS, p. 65)

Earth Space Systems Science
Unit 5: The Space Sphere

- Early in the history of the universe, primarily the light atoms hydrogen and helium, clumped together by gravitational attraction to form countless trillions of stars. Billions of galaxies, each of which is a gravitationally bound cluster of billions of stars, now form most of the visible mass of the universe. (NSES, p. 190)

- Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. These and other processes in stars have led to the formation of all other elements. (NSES, p. 190)

- Stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements that are found on the earth and to behave according to the same physical principles. Unlike the sun, most stars are in systems of two or more stars orbiting around one another. (AAAS, p. 65)

- Mathematical and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe. (AAAS, p. 65)

Earth Space Systems Science
Unit 5: The Space Sphere

Earth / Space Systems *Sc*ience Instruction

1. What do students need to know or be able to do to understand events across spheres (subsystems of the Earth-space systems)?

5. Student Project for each sphere: analyze another event following modeling by the teacher of the exemplar event

Energy Balance/Conservation of Energy

Mass Balance/Conservation of Mass

Events

- What are some "events" that occur?
- events drive the system
- events happen when the system gets out of balance
- events help the system get back into balance

How do the systems and subsystems of each sphere behave and interact?

- atmosphere
- biosphere
- hydrosphere/cryosphere
- geosphere
- space sphere

2. What do we need to know to understand systems?

- parts/components (i.e. reservoir of matter or energy)
- state of the system or set of attributes that characterize a system (i.e. sea surface temperature)
- links between/among components (reflectivity of a surface [albedo] and surface temperature)
- feedback loops
- system in equilibrium (and stable and unstable conditions)
- how a system responds to disturbances

3. What are the tools that help us understand the spheres?

- remote sensing
- modeling
- observational networks
- system diagram or flow chart or concept map
- graphs and graph-making
- computer as an analysis tool

4.Track an event throughout the course to model intera***ctions for students.***
How does the event impact each sphere?
How do each of the other spheres impact the event?

Earth Space Systems Science
Unit 5: The Space Sphere

CONTENT OUTLINE
The Space Sphere

I. Origin of the Earth-Space System
   A. Historical perspective
   B. Basic science for studying the Space Sphere
      1. the electromagnetic spectrum
      2. astronomical scale
      3. orbital mechanics
      4. periodic motion
      5. the role of gravity
   C. Current thinking and supporting evidence
      1. Big Bang
      2. formation of stars and galaxies
      3. stars and star systems
      4. formation of the solar system

II. Comparative Geology of the Solar System

III. Technology Used to Learn about the Universe (Integrated)
   A. Visual, x-ray, and radio telescopes
   B. Space probes and remote sensing
   C. Information gained from accelerators
   D. Mathematical models and computer simulations form a scientific account of the universe

Earth Space Systems Science
Unit 5: The Space Sphere

Science Core Learning Goals

Goal 1: Skills and Processes

The student will demonstrate ways of thinking and acting inherent in the practice of science. The student will use the language and instruments of science to collect, organize, interpret, calculate, and communicate information.

Expectation 1.1
The student will explain why curiosity, honesty, openness, and skepticism are highly regarded in science.
Indicators
1.1.1 The student will recognize that real problems have more than one solution and decisions to accept one solution over another are made on the basis of many issues.
1.1.2 The student will modify or affirm scientific ideas according to accumulated evidence.
1.1.3 The student will critique arguments that are based on faulty, misleading data or on the incomplete use of numbers.

Expectation 1.2
The student will pose scientific questions and suggest experimental approaches to provide answers to questions.
Indicators
1.2.1 The student will identify meaningful, answerable scientific questions.
1.2.2 The student will pose meaningful, answerable scientific questions.
1.2.3 The student will formulate a working hypothesis.
1.2.4 The student will test a working hypothesis.
1.2.5 The student will select appropriate instruments and materials to conduct an investigation.
1.2.6 The student will identify appropriate methods for conducting an investigation and affirm the need for proper controls in an experiment.
1.2.7 The student will use relationships discovered in the lab to explain phenomena observed outside the laboratory.

Expectation 1.3
The student will carry out scientific investigations effectively and employ the instruments, systems of measurement, and materials of science appropriately.
Indicators
1.3.3 The student will demonstrate safe handling of the chemicals and materials of science.

Expectation 1.4
The student will demonstrate that data analysis is a vital aspect of the process of scientific inquiry and communication.

Earth Space Systems Science
Unit 5: The Space Sphere

Indicators

1.4.1 The student will organize data appropriately using techniques such as tables, graphs, and webs (for graphs: axes labeled with appropriate quantities, appropriate units on axes, axes labeled with appropriate intervals, independent and dependent variables on correct axes, appropriate title).
1.4.2 The student will analyze data to make predictions, decisions, or draw conclusions.
1.4.3 The student will use experimental data from various investigators to validate results.
1.4.5 The student will check graphs to determine that they do not misrepresent results.
1.4.6 The student will describe trends revealed by data.
1.4.8 The student will use models and computer simulations to extend his/her understanding of scientific concepts.
1.4.9 The student will use analyzed data to confirm, modify, or reject an hypothesis.

Expectation 1.5

The student will use appropriate methods for communicating in writing and orally the processes and results of scientific investigation.

Indicators

1.5.1 The student will demonstrate the ability to summarize data (measurements/observations).
1.5.2 The student will explain scientific concepts and processes through drawing, writing, and/or oral communication.
1.5.3 The student will produce the visual materials (tables, graphs, and spreadsheets) that will be used for communicating results.
1.5.4 The student will create and/or interpret graphics (scale drawings, photographs, digital images, etc.).
1.5.6 The student will read a technical selection and interpret it appropriately.
1.5.7 The student will describe similarities and differences when explaining concepts and/or principles.
1.5.9 The student will communicate conclusions derived through a synthesis of ideas.

Expectation 1.6

The student will use mathematical processes.

Indicators

1.6.4 The student will manipulate quantities and/or numerical values in algebraic equations.
1.6.5 The student will judge the reasonableness of an answer.
1.7.2 The student will identify and evaluate the impact of scientific ideas and/or advancements in technology on society.

Goal 2: Concepts of Earth/Space

The student will demonstrate the ability to use scientific skills and processes (Core Learning Goal 1) to explain the physical behavior of the environment, earth, and the universe.

Earth Space Systems Science
Unit 5: The Space Sphere

Expectation 2.1

The student will use a variety of resources to identify techniques used to investigate Earth and the Universe.

Indicators

2.1.2. The student will describe current efforts and technologies used to study the universe. At least-- optical telescopes, radiotelescopes, spectroscopes, satellites, space probes, manned missions.

Expectation 2.2

The student will describe and apply the concept of natural forces in the study of Earth/Space Science.

Indicators

2.2.1. The student will explain the role of natural forces in the universe. At least-- formation of planets, orbital mechanics, stellar evolution

Expectation 2.3

The student will explain how the transfer of energy affects weather and climate.

Indicators

2.3.1. The student will describe heat transfer systems in the atmosphere, on land, and in the oceans.
At least --convection, conduction, radiation from space and from within Earth

Expectation 2.6

The student will investigate how the political climate affects the development of a scientific theory or model.

Indicators

2.6.1. The student will research various planetary models.
At least: Ptolemy, Copernicus, Kepler, and Galileo

2.6.2 The student will research the change in the belief in the age of the earth.
At least-- fossil record, rock layers, radioactive dating, Big Bang theory

Expectation 2.7

The student will know how to use measurement of different orders of magnitude to construct an earth science model.

Indicators

2.6.3. The student will demonstrate the relative sizes and distances of planets in the solar system.

SCIENCE RUBRIC

LEVEL 4

There is evidence in this response that the student, using analysis, has a full and complete understanding of the question or problem.

- The student has synthesized information to provide a correct answer.
- The supporting evidence consists of an integration of ideas.
- The student has effectively applied the information to a practical problem in a related area of science, mathematics, or technology.
- The response is enhanced through the use of accurate terminology to explain scientific principles.

LEVEL 3

There is evidence in this response that the student, using analysis, has a good understanding of the question or problem.

- The student has synthesized information to provide a correct answer.
- The supporting evidence is complete.
- The student has applied the information to a practical problem within the particular concept area of science.
- The response uses mostly accurate terminology to explain scientific principles.

LEVEL 2

There is evidence in this response that the student has a basic understanding of the question or problem.

- The student provides a correct answer.
- The supporting evidence is only moderately effective.
- The student has applied the information to a practical problem within the scope of the question.
- The response uses limited accurate terminology to explain scientific principles.

LEVEL 1

There is evidence in this response that the student has some understanding of the question or problem.

- The student provides a partially correct answer.
- The supporting evidence is only minimally effective.
- The student has attempted to apply the information.
- The response makes little or no use of accurate terminology to explain scientific principles.

LEVEL 0

There is evidence that the student has no understanding of the question or problem.

- The response is completely incorrect or irrelevant, or there is no response

Earth Space Systems Science
Unit 5: The Space Sphere

Scoring Criteria for Graphs

The student will organize data appropriately using a graph.

Level 4
Data are accurately plotted (90-100%) and the graph includes nine of the ten elements.

Level 3
Data are accurately plotted and the graph includes seven of the ten elements,
OR
data are mostly accurate (80-89%) and the graph includes nine of the ten elements.

Level 2
Data are accurately plotted and the graph includes five of the ten elements,
OR
data are generally accurate (70-79%) and the graph includes seven of the ten elements.

Level 1
Data are accurately plotted and the graph includes three of the ten elements
OR
Data are somewhat accurate (60-69%) and the graph includes five of the ten elements.

Level 0
Data are inaccurately plotted (<60%) or the graph includes fewer than five elements.

ELEMENTS OF THE GRAPH

- Appropriate title
- X-axis labeled correctly with appropriate quantities/variables
- X-axis labeled correctly with appropriate units
- Appropriate intervals indicated on the X-axis
- Given the length of axes on the grid, the scale is appropriate for the range of data
- Y-axis labeled correctly with appropriate quantities/variables
- Y-axis labeled correctly with appropriate units
- Appropriate intervals indicated on the Y-axis
- Given the length of axes on the grid, the scale is appropriate for the range of data
- Origin correctly identified

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson Planning Organizer

Lesson	Topic	Approximate 45 Minute Class Periods	Outcomes
1	A History of Thinking about Planetary Models	3	Synthesize the history of ideas about planetary models by conducting research and preparing a presentation for peers.
1A	Revisiting The Electromagnetic Spectrum *Supplemental Lesson*	2	Describe the relation-ships of the waves of the electromagnetic spectrum by exploring a variety of electromagnetic waves.
1B	Astronomical Scale	2	Describe the huge scale of distance in the universe by using a computer simulation.
2	The Big Bang Theory	2	Construct knowledge of the big bang theory by performing a simulation activity; describe how data collected by space probes is being used to provide evidence for the Big Bang theory.
2A	Stellar Evolution	2-3	Compare the life cycles of high mass stars and low mass stars by creat-ing a systems diagram; interpret cosmic ray data and relate conclusions about the source of the particles to our knowl-edge of the formation of the universe.

Earth Space Systems Science
Unit 5: The Space Sphere

2B	PERIODIC MOTION	1	Determine periodicity within a set of data.
	LUNAR PHASES, ECLIPSES, AND SEASONS	1	In progress
2C	STARS AND STAR SYSTEMS *SUPPLEMENTAL LESSON* *HONORS/GT*	2	Apply the method of Folding to determine the rotation period of a star and/or the binary orbital period of the stellar system.
3	ORBITAL MECHANICS	2	Construct the orbits of planets by using knowledge of Kepler's Laws.
4A	GRASPING GRAVITY	1	Establish ratios of comparison of you weight on Earth to your weight on other bodies. by using Newton's Law of Universal Gravitation
4B	THE ROLE OF GRAVITY IN THE SPACE SYSTEM	2	Analyze the behavior of a satellite by constructing a model; describe the velocity a satellite must achieve in order to remain in orbit by using the mathematical formula for velocity.
5	COMPARATIVE GEOLOGY OF THE SOLAR SYSTEM: ATMOSPHERES	1-2	Interpret atmospheric patterns of solar system planets by applying knowledge of the Earth's atmosphere and using satellite imagery.
6	COMPARATIVE GEOLOGY OF THE SOLAR SYSTEM: LANDFORM MAPPING OF THE TERRESTRIAL PLANETS	1-2	Compare the global-scale surfaces of the terrestrial planets by using satellite imagery;

			make predictions about the age of the terrestrial planets based on a study of surface features.
7	GEOLOGIC FEATURES OF OUTER PLANET SATELLITES *SUPPLEMENTAL LESSON* *HONORS/GT*	3-4	Relate knowledge of geologic processes to features found on the outer planet satellites; compare geologic processes of the outer planet satellites by analyzing satellite imagery.
8	FORMATION OF THE SOLAR SYSTEM	2	Explain current thinking about the formation of the solar system by reading technical documents and viewing animation and Hubble Telescope images of the solar system.
9	THE SOLAR CONNECTION	3-4	Explain how the earth is affected by solar activity by analyzing data; describe how the IMAGE satellite is used to study the atmosphere and near space environment.
9A	THE SOLAR CONNECTION AND THE MAGNETOSPHERE	2-3	Compute the relative size of the Earth's magnetosphere by using satellite orbits and satellite data; identify the benefits of the magnetosphere by analyzing satellite data.
10	CONNECTING THE SPACE SPHERE TO OTHER		in progress

Earth Space Systems Science
Unit 5: The Space Sphere

	EARTH SPHERES		
Approximate Number of 45 minute Class Periods		**26**	

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 1: A History of Thinking about Planetary Models

Estimated Time: Three forty-five minute class periods

Indicators(s): Core Learning Goal 1

1.5.2 The student will explain scientific concepts and processes through drawing, writing, and/or oral communication.
1.5.3 The student will produce the visual materials (tables, graphs, and spreadsheets) that will be used for communicating results.
1.5.9 The student will communicate conclusions derived through a synthesis of ideas.
1.7.2 The student will identify and evaluate the impact of scientific ideas and/or advancements in technology on society

Indicators(s): Core Learning Goal 2

2.6.1. The student will research various planetary models.
At least: Ptolemy, Copernicus, Kepler, and Galileo

Student Outcome(s):
The student will be able to synthesize the history of ideas about planetary models by conducting research and preparing a presentation for peers.

Brief Description:
Students will gain an historical perspective of scientific thought with regard to planetary models and then present their findings to the class using a computer-generated presentation.

Background knowledge / teacher notes:
In the 16th century, the Polish astronomer Nicholas Copernicus replaced the traditional Earth-centered view of planetary motion with one in which the Sun is at the center and the planets move around it in circles. Although the Copernican model came quite close to correctly predicting planetary motion, discrepancies existed. This became particularly evident in the case of the planet Mars, whose orbit was very accurately measured by the Danish astronomer Tycho Brahe.

The German mathematician Johannes Kepler, who found that planetary orbits are not circles, but ellipses, solved the problem. Kepler described planetary motion according to three laws.
Law I: Each planet revolves around the Sun in an elliptical path, with the Sun occupying one of the foci of the ellipse.
Law II: The straight line joining the Sun and a planet sweeps out equal areas in equal intervals of time.
Law III: The squares of the planets' orbital periods are proportional to the cubes of the semimajor axes of their orbits.

Earth Space Systems Science
Unit 5: The Space Sphere

(NASA Observatorium Education-Reference Module, http://observe.ivv.nasa.gov/nasa/education/reference/orbits/orbit_sim.html)

The teacher may wish to begin this learning activity and then proceed to the next lesson to allow additional work time out of class for students to prepare their presentations.

Lesson Description:

ENGAGE	Students they have been hired by "The History of Science Channel" to create a presentation for viewers about our knowledge of the planetary system earth is a part of. Their "segment" will be the history of scientific thought leading up to out current view of the solar system model. Students should include how the political climate or cultural climate may have affected the work of the scientist. Divide the students into work groups investigating the work and contributions of each of the following: · Ptolemy · Galileo · Copernicus · Kepler · Other historical scientists as designated by instructor · Adaptive strategy: Work with students to develop a scoring tool for the final product. Presentations should be computer-generated, either in part or using presentation software. GT: Create a web page for the Earth/Space Systems Science curriculum as a result of this learning activity.
EXPLORE	Use the internet and other research opportunities to collect data for presentations.
EXPLAIN	Students create and present their TV segments of scientific models by each of the designated scientists.
EXTEND	Have students develop a graphic organizer to show the similarities and differences of the scientific ideas and the progression of scientific thought. *Accommodation: This could become a class or small group activity*.
EVALUATE	***Journal Write***: Explain how each of the scientists contributed to our current thinking. What role did political climate or cultural issues affect the progress of scientific thought?

Earth Space Systems Science
Unit 5: The Space Sphere

Materials:
Internet
Computer presentation software

Resources:
Claudius Ptolemaeus. Available:
http://ptolemy.berkeley.edu/

The Life and Works of Claudius Ptolemy. Available:
http://www.norfacad.pvt.k12.va.us/project/ptolemy/ptolemy.htm

Galileo. Available:
http://www.norfacad.pvt.k12.va.us/project/galileo/galilei.htm

Galileo GALILEI. Available
http://galileo.imss.firenze.it/museo/b/egalilg.html

The Scientific Revolution. Available:
http://mars.acnet.wnec.edu/~grempel/courses/wc2/lectures/scientificrev.html

Nicolas Copernicus. Available:
http://www.windows.umich.edu/cgi-bin/tour_def/people/ren_epoch/copernicus.html

Kepler's laws. Available:
http://www.cvc.org/science/kepler.htm

NASA Observatorium Education-Reference Module. Available:
http://observe.ivv.nasa.gov/nasa/education/reference/orbits/orbit_sim.html

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 1A: Revisiting the Electromagnetic Spectrum

Estimated Time: Two forty-five minute class periods

Indicators(s): Core Learning Goal 1

1.5.2 The student will explain scientific concepts and processes through drawing, writing, and/or oral communication.

Indicators(s): Core Learning Goal 2

2.1.2. The student will describe current efforts and technologies used to study the universe. At least-- optical telescopes, radiotelescopes, spectroscopes, satellites, space probes, manned missions.

Student Outcome(s):

The student will be able to describe the relationships of the waves of the electromagnetic spectrum by exploring a variety of electromagnetic waves.

Brief Description:

In this lesson students will review their knowledge of the electromagnetic spectrum and knowledge of the electromagnetic waves.

Background knowledge / teacher notes:

This lesson is an effort to bring all students up to a certain knowledge level about the electromagnetic spectrum. This knowledge will be important in understanding the experiments and activities that follow. The topics in this lesson have been taught in Science 8 in Anne Arundel County Schools. This is a new format for its presentation.

All objects in our Universe emit, reflect, and absorb electromagnetic radiation in their own distinctive ways. The way an object does this provides it special characteristics which scientists can use to probe an object's composition, temperature, density, age, motion, distance, and other chemical and physical characteristics. Astronomers can time events (for instance, recording exactly when a binary star system is eclipsed and for how long), can obtain the energy distribution of a source (by passing its electromagnetic radiation through a prism or grating to break it into component colors), or can record the appearance of a source (such as taking an image of the source). These three methods are by no means exclusive of each other, but each reveals different aspects of a source and each method gives the astronomer slightly different information.

From a physical science standpoint, all electromagnetic radiation can be thought of as originating from the motions of atomic particles. Gamma rays occur when atomic nuclei are split or fused. X-rays occur when an electron orbiting close to an atomic nucleus is pushed outward with such force that it escapes the atom; ultraviolet, when an electron is jolted from a near to a far orbit; and visible and infrared, when electrons are jolted a few orbits out. Photons in these three energy ranges (X-ray, UV, and optical) are emitted as one of the outer shell electrons loses enough energy to fall down to the replace the electron missing from the inner shell. Radio waves are generated by any electron movement; even the stream of electrons (electric current) in a common household wire creates radio waves ...albeit with wavelengths of hundreds of kilometers and very weak in amplitude.

Electromagnetic radiation can be described in terms of a stream of photons (massless packets of energy), each traveling in a wave-like pattern, moving at the speed of light. The only difference between radio waves, visible light, and gamma rays is the amount of energy in the photons. Radio waves have photons with low energies, microwaves have a little more energy than radio waves, and infrared has still more, then visible, ultraviolet, X-rays, and gamma rays.
Credit:
Imagine the Universe!
Probing the Structure & Evolution of the Cosmos. Available:
http://imagine.gsfc.nasa.gov

This article is an alternate technical document.
How Do the Properties of Light Help Us to Study Supernovae and Their Remnants? *What is Electromagnetic (EM) Radiation?* Available:
http://imagine.gsfc.nasa.gov/docs/teachers/lessons/xray_spectra/background-em.html

GT Connection
This would be a good place for curriculum compacting for those students who clearly are familiar with this material.

CD-ROM
This lesson uses the CD-ROM *Exploring the Extreme Universe!*. CD-ROM. Version 1. Goddard Space Flight Center. (March 1999). Laboratory for High Energy Astrophysics.
A large array of Web sites devoted to the science that the LHEA studies have been frozen in time and included on this CD.

Featured are four "Knowledge Hubs" which have explanations about cosmic ray and X-ray science and satellites, as well as cosmic distances. They also include activities that for helping students to learn more about science and basic physical principles.

The "Mission Hubs" are Web sites mainly about the satellite and balloon-borne missions from the GSFC laboratory that studies X-rays, gamma rays, and cosmic rays from the cosmos. There are also pages about an experiment that will be attached to the International Space Station and an experiment that measures Earth's UV light in preparation for a future cosmic ray experiment.

Earth Space Systems Science
Unit 5: The Space Sphere

All of the Mission Hubs on this CD (and some of our Knowledge Hubs) contain high-resolution images. This CD shows the Web sites as they existed in March of 1999. The WWW address for every site is included, so you will know where to go to access the most current versions of them.

<u>The Spectrum Experiment</u>
The following is the actual experiment used by Sir William Herschel to discover infrared light in the year 1800. Herschel was testing the Sun's spectrum by thermometer to see if he could find differences in the amount of heat that the different colors delivered. He found instead that the temperature rise was highest in no color at all, at a spot beyond the red end of the spectrum.
Try this yourself using a glass prism, several thermometers, a slotted piece of cardboard and sunlight (or a quartz bulb lamp). Set up your apparatus so that sunlight is streaming through the slit in the cardboard, passing only a beam of sunlight through the prism. Project the resultant spectrum onto a table or the floor.

For additional notes of how to set up a spectrum, go to
How to better project a visible spectrum.
Goddard Space Flight Center. (March 1999). Laboratory for High Energy Astrophysics.
Exploring the Extreme Universe!. CD-ROM. Version 1.

<u>Energy and Waves</u>
Wavelength and frequency are related by the speed of light (c), a fundamental constant. Energy is also mathematically related to wavelength and frequency by Planck's constant (h). It was Max Planck who demonstrated that light sometimes behaves, as a particle by showing that its energy (E), divided by its frequency (the Greek letter nu) is a constant. Since we know that frequency is equal to the speed of light (c) divided by wavelength (the Greek letter lambda), we also know the relationship between energy and wavelength.

Light can act like both a particle and a wave. light has particle-wave duality. Particles of light are called photons. Low-energy photons (i.e. radio) tend to behave more like waves, while higher energy photons (i.e. X-rays) behave more like particles. This is an important difference because it affects the way instruments to measure light are built.

Lesson Description:

ENGAGE	*Vocabulary: electromagnetic spectrum.* Enter the Knowledge Hubs (*Exploring the Extreme Universe!*. CD-ROM. Version 1.) and then go to the RXTE Learning Center. Then Go to "A New Light." Click on "Enter" to get to the Table of Contents and then click on "The Electromagnetic Spectrum." <u>Adaptive Strategy</u>

	Pre-reading questions: What types of light rays is part of the electromagnetic spectrum? How is each of the light rays related in terms of energy? Accommodation: The teacher may want to use a directed reading activity. ***Journal Write***: Create a concept map to take notes on the introductory reading activity. After reading the introduction, proceed to the Electromagnetic Spectrum Activity. Go back to the "Table of Contents." Students will now read about some parts of the electromagnetic spectrum. Read about " What if we could see Infrared Light? " and then click forward to " X-ray Vision?" Adaptive Strategy Pre-reading questions: How is our knowledge of the universe affected by seeing only the visible light portion of the electromagnetic spectrum? Add knowledge you have gained from this reading to the concept map.
EXPLORE	Have student(s) measure the temperature of the colors in the spectrum by leaving a thermometer in a different color for at least 5 minutes. [Place one thermometer in the violet range, one in the green range and one just barely past the red range (infrared). Put a thermometer elsewhere in the room (out of the Sun) to measure the ambient room temperature. Remember to calibrate your thermometers beforehand!
EXPLAIN	***Journal Write***: Students should use the data collected to explain how light is made up of different energies, some of them invisible.
EXTEND	Students should move to, " The Energetic Universe," an introduction to a mathematical description of waves. View the animation Add the mathematical descriptions about waves to the concept map. Work through the mathematical applications in "Frequency, Wavelength, and Energy Activity"
EVALUATE	***Journal Write***: 1. Describe how wavelength, frequency, and speed of light are related a) mathematically b) in words 2. Describe how energy is related to wavelength by a) using a mathematical equation b)using a written description Go to "The Multiwavelength Milky Way" from the Table of Contents

	and examine the images of the Milky Way galaxy. 3. Explain why scientists rely on waves other than those that are part of the visible spectrum for observing the universe.

Materials:
Computers with Internet access or CD-ROM

Goddard Space Flight Center. (March 1999). Laboratory for High Energy Astrophysics. *Exploring the Extreme Universe!* CD-ROM. Version 1.

<u>Per Lab Team</u>
Glass prism
Four thermometers
A slotted piece of cardboard and
Sunlight or a quartz bulb lamp

Resources:
Goddard Space Flight Center. (March 1999). Laboratory for High Energy Astrophysics. *Exploring the Extreme Universe!*. CD-ROM. Version 1.

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 1B: Astronomical Scale

Estimated Time: Two forty-five minute class periods.

Indicators(s): Core Learning Goal 1

1.4.8 The student will use models and computer simulations to extend his/her understanding of scientific concepts.

1.5.3 The student will produce the visual materials (tables, graphs, and spreadsheets) that will be used for communicating results.

1.6.3 The student will express and/or compare small and large quantities using scientific notation and relative order of magnitude.

Indicators(s): Core Learning Goal 2

2.1.2. The student will describe current efforts and technologies used to study the universe. At least-- optical telescopes, radiotelescopes, spectroscopes, satellites, space probes, manned missions.

Student Outcome(s):

The student will be able to describe the huge scale of distance in the universe by using a computer simulation.

Brief Description:

In this learning activity, students investigate the huge scale of the universe. This feature will give students an impression of how immense our Universe is by employing a method used many times in "Power of 10" films - that is, starting with an image of the Earth and then zooming out to the furthest visible reaches of our Universe.

This is not, however, an exercise in "powers of 10" - on the contrary, our goal is to show you astronomical distances without scientific notation. We instead focus on the large number of zeros that are in astronomical distances when we measure them with a familiar unit like the kilometer. The number of zeros increases with each zoom, though not at a constant rate.

As a by-product of this activity, students get a tour of the universe. Along the way they interact with the CD to determine information about their stops along the way and how scale and distance is determined.

Background knowledge / teacher notes:

Distance Information

- kilometer (km) - equal to 1000 meters.
- Astronomical Unit (AU) - the commonly used unit of distance in the Solar System; it is equal to the average Earth-Sun distance, or 149,000,000 km.

- light year (ly) - commonly used unit of distance outside the Solar System, equal to the length traveled by light in one year. It is equal to 9,460,000,000,000 km.
- parsec (pc) - preferred (by astronomers) unit of distance outside the Solar System. Defined as the distance at which 1 Astronomical Unit subtends an angle of 1 second of arc (1/3600 of a degree), or the distance an object has to be for its parallax to equal 1 second of arc. Equal to 3.26 light years or 30,800,000,000,000 km.
- kiloparsec (kpc) - 1000 parsecs.
- Megaparsec (Mpc) - 1 million parsecs.

(The Cosmic Distance Scale. Author: Maggie Masetti; Scientific Oversight: Dr. Koji Mukai)

Lesson Description:

ENGAGE	Ask students what ways we currently have to tour the universe. Tell students they are about to take a tour courtesy of the High Energy Astrophysics Lab at Goddard Space Flight Center. Tell the students they will record information from their journey through the cosmos in the form of a product. One strategy may be to have all students work through the activity but work in groups to complete the information for one particular stop. Information learned should be presented to the class by a format of choice. Enter the Knowledge Hubs (*Exploring the Extreme Universe!*. CD-ROM. Version 1.) and then go to "The Cosmic Distance Scale." Read the introduction and click on "Begin."
EXPLORE	Have students work through "The Cosmic Distance Scale." activity and create a poster, chart, or brochure (or new tour for a theme park) with the following categories listed below in the "A Cosmic Journey" table. Students may zoom in and zoom out as many times as necessary to collect the information necessary.
EXPLAIN	Create a graphic organizer that illustrates the relative distances on each of the cosmic journey stops.
EXTEND	Outside activity. Brainstorm with students to create the following model. One way to help visualize the relative sizes in the Solar System is to imagine a model in which it is reduced in size by a factor of a billion (109). Then the Earth is about 1.3 cm in diameter (the size of a grape). The Moon orbits about a foot away. The Sun is 1.5 meters in diameter (about the height of a man) and 150 meters (about a city block) from

	the Earth. Jupiter is 15 cm in diameter (the size of a large grapefruit) and 5 blocks away from the Sun. Saturn (the size of an orange) is 10 blocks away; Uranus and Neptune (lemons) are 20 and 30 blocks away. A human on this scale is the size of an atom; the nearest star would be over 40000 km away. (The Cosmic Distance Scale. Author: Maggie Masetti; Scientific Oversight: Dr. Koji Mukai)
EVALUATE	***Journal Write***: 1. Describe how each of the stops on the "Cosmic Journey" represents relative distances in terms of one of the units for measuring astronomical distances. 2. Why is it extremely difficult or impractical to use one unit of distance to describe each of the stops?

Materials:
Computer with Internet or CD-ROM

Goddard Space Flight Center. (March 1999). Laboratory for High Energy Astrophysics. *Exploring the Extreme Universe!* CD-ROM. Version 1.

Materials to create the product of choice.

Resources:
Goddard Space Flight Center. (March 1999). Laboratory for High Energy Astrophysics. *Exploring the Extreme Universe!* CD-ROM. Version 1.

University of Southern California. Department of Astronomy. *The ABC's of Distances.* Available:
http://www.astro.ucla.edu/~wright/distance.htm
Twenty-six methods of determining distance outside the solar system.

NASA. Goddard Space Flight Center. High Energy Astrophysics Science Archive Research Center. *Education and Public Outreach Activities at the HEASARC*
http://heasarc.gsfc.nasa.gov/docs/outreach.html
The HEASARC provides a number of facilities for students, educators, and the general public to learn more about the universe. Topics ranging from the solar system to black holes to distant galaxies. Education materials for teachers include activities and lesson plans that use concepts and data from high-energy astrophysics in interdisciplinary lessons appropriate for math and science classes.

Earth Space Systems Science
Unit 5: The Space Sphere

A Cosmic Journey

Stops in the Cosmic Journey	Distance Information	How Do We Calculate Distances of This Magnitude?	Travel Time	More About this Stop
Earth				
Solar system				
Nearest star system				
Solar Neighborhood				
Milky Way Galaxy				
The Nearest Galaxies				
The Local Group				
The Local Supercluster				
The Nearest Superclusters				
Sheets and Voids				
The Farthest visible Reaches of Space				

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 2: The Big Bang Theory

Estimated Time: Two forty-five minute class periods

Indicators(s): Core Learning Goal 1

1.5.2 The student will explain scientific concepts and processes through drawing, writing, and/or oral communication.

1.5.6 The student will read a technical selection and interpret it appropriately.

Indicators(s): Core Learning Goal 2

2.6.2 The student will research the change in the belief in the age of the earth. At least-- fossil record, rock layers, radioactive dating, Big Bang theory

2.1.2. The student will describe current efforts and technologies used to study the universe. At least-- optical telescopes, radiotelescopes, spectroscopes, satellites, space probes, manned missions.

Student Outcome(s):

1. The student will be able to construct knowledge of the big bang theory by performing a simulation activity.
2. The student will be able to explain how data collected by space probes is being used to provide evidence for the Big Bang theory.

Brief Description:

Students begin by reading a technical document to create a preliminary construct of the Big Bang theory. Students then do a simulation activity of the Big Bang to add to their understanding. Finally, students research one of the NASA missions in order to describe how space probes are adding to our understanding and providing evidence for the Big Bang theory.

Background knowledge / teacher notes:

This topic, and some of those that follow, may be sensitive in the same way that evolution of life is sensitive to some students and parents. Teachers should be sure to stress that the information and knowledge in these learning activities reflect widely accepted scientific thinking and do not reflect religious beliefs, which although important to our society, fall outside the realm of science.

The Big Bang Theory is a broadly accepted theory for the origin and evolution of our universe. It postulates that the observable universe started from an instantaneously expanding point, roughly ten to twenty billion years ago.

Foundations of the Big Bang Theory

The hot Big Bang Theory is a broadly accepted theory for the origin and evolution of our universe. It rests on two seeming sound pillars:

The General Theory of Relativity: Over eighty years ago, Einstein proposed this theory that describes how the distribution of mass in the universe determines the geometry of the space. Originally, the theory was able to account for peculiarities in the orbit of Mercury and the bending of light by the Sun. In recent years, the theory has passed a series of rigorous tests.

On the largest scales, the distribution of matter in the universe is nearly uniform. This assumption appears to confirmed both by galaxy surveys and by the low level of fluctuations in the cosmic microwave background radiation

In the hot Big Bang Theory, the observable universe began with an instantaneously expanding point, roughly ten to twenty billion years ago. Since then, the universe has continued to expand, gradually increasing the distance between our Galaxy and external galaxies. The expansion of the universe "stretches" light rays converting blue light into red light and red light into infrared light. Thus, distant galaxies, which are rapidly moving away from us, appear redder.
This expansion also cools the microwave background radiation. Thus, the cosmic microwave background radiation, which today has a temperature of 2.728 Kelvin, was hotter in the early universe. Gravity slows the expansion of the universe. If the universe is dense enough, the expansion of the universe will eventually reverse and the universe will collapse. If the density is not high enough, then the expansion will continue forever. Thus, the density of the universe will determine its ultimate fate.

Tests of the Big Bang Theory

The hot Big Bang Theory is consistent with a number of important observations:

- The observed expansion of the universe
- The observed abundances of helium, deuterium and lithium, three elements thought to be synthesized primarily in the first three minutes of the universe
- The thermal spectrum of the cosmic microwave background radiation
- The cosmic microwave background radiation appears hotter in distant clouds of gas. Since light travels at a finite speed, we see these distant clouds at an early time in the history of the universe, when it was denser and thus hotter.

Beyond the Big Bang Theory

In its current form, the big bang theory is not complete. It does not explain:

- The origin of galaxies and the observed large-scale clustering of galaxies
- The origin of the uniform distribution of matter on very large scales

Many cosmologists suspect that the Inflation Theory, an extension of the Big Bang Theory, may answer these questions.
(NASA GSFC. Microwave Anisotropy Probe, *The Big Bang Theory.* Available: http://map.gsfc.nasa.gov/html/big_bang.html)

The Cosmic Microwave Background Radiation

The universe is filled with the remnant heat from the Big Bang called the "cosmic microwave background radiation." Today, this radiation is very cold: only 2.728 degrees above absolute zero. It fills the universe and can be seen everywhere we look.

Why study the Cosmic Microwave Background?

Since light travels at a finite speed, astronomers observing distant objects are looking into the past. Most of the stars that are visible to the naked eye in the night sky are 10 to 100 light years away. Thus, we see them as they were 10 to 100 years ago. We observe Andromeda, the nearest big galaxy, as it was three million years ago. Astronomers observing distant galaxies with the Hubble Space Telescope can see them as they were only a few billion years after the Big Bang. (Most cosmologists believe that the universe is between ten and twenty billion years old.)

By observing the cosmic microwave background, cosmologists can study the physical conditions only a few hundred thousand years after the Big Bang, long before stars or galaxies even existed. By study these physical conditions, we can learn about the structure of the universe, its origin and evolution.

The Origin of the Cosmic Microwave Background

To understand the origin of the cosmic microwave background radiation, we must first review the history of the universe according to the Big Bang theory.

The Expanding Universe

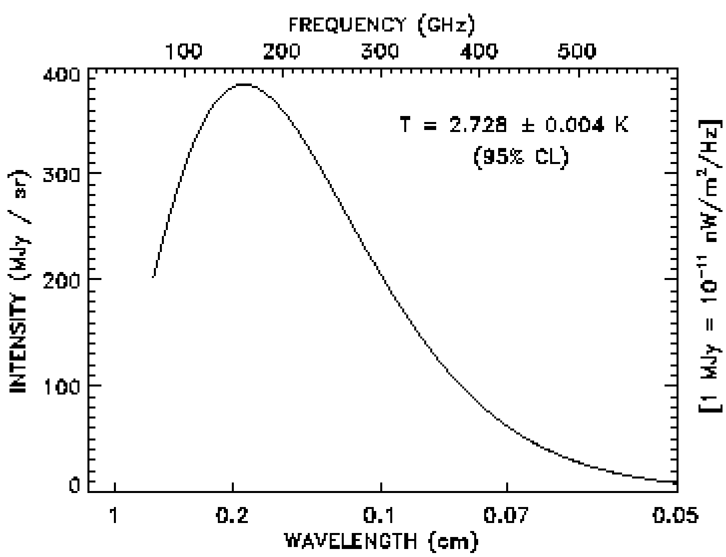
One of the basic predictions of the Big Bang theory is that the universe is expanding. Astronomers can look at distant galaxies can directly observe this expansion, originally detected by Edwin Hubble. Since the universe is expanding, it was denser and hotter in the distant past. When the visible universe was half its present size, the density of matter was eight times higher and the cosmic microwave background was twice as hot. When the visible universe was one hundredth of its present size, the cosmic microwave background was a hundred times hotter (273 degrees above absolute zero or 32 degrees Fahrenheit, the temperature at which water freezes to form ice on the Earth's surface).
In addition to this cosmic microwave background radiation, the early universe was filled with hot hydrogen gas with a density of about 1000 atoms per cubic centimeter (a teaspoon is roughly 3 cubic centimeters).

The early universe was a very hot place. When the visible universe was one hundred millionth its present size, its temperature was 273 million degrees above absolute zero and the density of matter was comparable to the density of air at the Earth's surface. At these high temperatures, the hydrogen was completely ionized into free protons and electrons. Most of the Deuterium and Helium in the universe was synthesized at these high temperatures.

The Interaction of Radiation with Matter
Since the universe was so very hot through most of its early history, there were no atoms in the early universe, only free electrons and nuclei. (Nuclei are made of neutrons and protons). The cosmic microwave background photons easily scatter off of electrons. Thus, photons wandered through the early universe, just as optical light wanders through a dense fog.

This process of multiple scattering produces what is called a "thermal" or "blackbody" spectrum. This thermal spectrum, predicted by the Big Bang theory, was measured with tremendous accuracy by the FIRAS detector aboard NASA's COBE satellite.

This figure compares the predictions of the Big Bang theory for the energy spectrum of the cosmic microwave background radiation to the observed energy spectrum. FIRAS measured the spectrum at 43 equally spaced points along the blackbody curve. The error bars are on the points are so small that they can not be seen in the figure. There is no alternative theory yet proposed that predicts this energy spectrum. The accurate measurement of its shape was an important test of the Big Bang theory.



Eventually, the universe cooled sufficiently that protons and electrons could combine to form neutral hydrogen. This was thought to occur roughly 500,000 years after the Big Bang when the universe was about one thirteen hundredth its present size. Cosmic microwave background photons interact very weakly with hydrogen.

The behavior of cosmic microwave background photons moving through the early universe is analogous to the propagation of optical light through the Earth's atmosphere. Water droplets are very effective at scattering light, while optical light moves freely through clear air. Thus, on a cloudy day, we can look through the air out towards the clouds, but can not see through the opaque clouds. Cosmologists studying the cosmic microwave background radiation can look through much of the universe back to when it was opaque: a view back to 500,000 years after the Big Bang.

Uniformity of the Cosmic Microwave Background

One of the most striking features about the cosmic microwave background is its uniformity. Unlike the optical sky with many bright regions, the cosmic microwave background temperature varies very little across the sky. While the Big Bang theory explains the origin of the cosmic microwave background radiation, it does not explain its uniformity. The theory of Inflation was proposed to explain this uniformity and to resolve other paradoxes associated with the Big Bang.

Only with very sensitive experiments, such as COBE and MAP, can cosmologists detect fluctuations in the cosmic microwave background. By studying these fluctuations, cosmologists can learn about the origin of galaxies and large-scale structures of galaxies and they can measure the basic parameters of the Big Bang theory:

- The geometry of the universe,
- The expansion rate of the universe,
- The age of the universe,
- The composition of the matter in the universe.

Credit: Microwave Anisotropy Probe. *The Cosmic Microwave Background Radiation*. Available: http://map.gsfc.nasa.gov/html/cbr.html

Extend Activity

The "Extend" activity focuses on one particular NASA mission. Other space missions may be selected to help students construct knowledge of how scientists collect information to provide evidence to support or not support current hypotheses and theories.

Anisotropy

The Microwave Anisotropy Probe measures the differences in temperature of the Cosmic Microwave Background (CMB) between adjacent points in the sky rather than the absolute temperature values themselves. This is because anisotropy measurements of the CMB are much more accurate than absolute measurements.

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson Description:

ENGAGE	*Vocabulary: Microwave Anistrophy Probe, cosmic microwave back-ground radiation, anistrophy.* Ask students to view the brief description of the Big Bang Theory and graphic from the University of Michigan available at: http://www.windows.umich.edu/cgi-bin/tour.cgi?link=/sun/Solar_interior/Nuclear_Reactions/Neutrinos/big_bang.html&sw=false&art=ok&cdp=/windows3.html&cd=false&fr=f&frp=/windows3.html&edu=high Ask students to create a concept map from the information at the above site. Ask students to list what questions they may have about the big bang theory.
EXPLORE	1. Using masking tape, divide the room or the center of the room into four to six equal parts. Class and room size will help determine this. 2. Take a balloon and insert punch out pieces of construction paper that have the colors of the visible spectrum and white. Use 30 pieces of each color. 3. Have one student stand in the center and blow up the balloon. The expansion of the balloon should be the same for each class so that comparisons can be made between classes. Obviously, the expan-sion of the balloon corresponds to the energy with which the pieces will spread across the room. 4. Pop the expanded balloon with a pin. 5. Using groups of students, have each group count the different col-ored pieces in a particular sectioned off area. 6. Graph the results, noting the number of each color represented in each area. 7. Analyze the results according to distribution of the colored pieces and how this distribution relates to the Big Bang Theory. 8. Make distribution comparisons for all classes.
EXPLAIN	The Big Bang Theory of the possible origin of the universe is very dif-ficult for students to understand. This particular activity was designed to show students that taking a given mass of material and applying a force to it can produce a pattern that replicates the material patterns noted when applying the Big Bang Theory. ***Journal Write***: Ask students to compare this activity and its results to what may have occurred during the "big bang."
EXTEND	Research the Microwave Anisotropy Probe (MAP) Mission. Describe the efforts of this mission to add to our knowledge of the formation of

	the universe. Guide questions: What science questions is the MAP Mission trying to answer? What is cosmic microwave background radiation and how does it relate to the Big Bang theory? What is anisotropy and how why is it important to this mission? *Accommodation: The teacher may want to direct students to the locations of answers to Guide Questions* To demonstrate anisotropy: The Microwave Anisotropy Probe measures the differences in temperature of the Cosmic Microwave Background between adjacent points in the sky rather than the absolute temperature values themselves. This is because anisotropy measurements of the CMB are much more accurate than absolute measurements. To illustrate this, students should separate into pairs and conduct the following experiment (each pair of students needs one small ruler -- the smaller the better): · Students are to take turns measuring each other's height using their small rulers. After recording the height of each student, the lower value is subtracted from the higher to find the difference in height between the two students. · For this step, each pair of students should work with another pair. The first pair of students stand back-to-back while the other pair measures the difference in their height and records it. Then, the first pair records the difference in height of the second pair of students. · After comparing the two values for the difference in height, students should be encouraged to discuss why the values are so different. Which value do they think is more accurate and why? (This experiment demonstrates very simply why MAP measures anisotropy rather than absolute temperatures: there is much less possible error with an anisotropy measurement.) MAP Mission Overview. Available: http://map.gsfc.nasa.gov/html/mission_overview.html

	The MAP scientists have produced a prediction of what their data may show. It is in the form of a computer-generated image. Examine the predicted image: *Fluctuations seen by MAP*. Available: http://map.gsfc.nasa.gov/html/fluct.html Be sure to scroll down to the second set of images generated by the MAP scientists. Describe the pattern of microwave radiation in this predicted map of the sky. GT: What is the COBE Mission and how does it lay the groundwork for the MAP mission?
EVALUATE	***Journal Write***: Describe how information from a space probe may provide evidence for the Big Bang theory. Use details from the learning activities and technical documents that were part of this lesson.

Materials:

Teacher Materials

- Balloons
- Colored paper punch outs
- Masking tape
- Pin
- Graph paper.

Student Materials

- Pencil
- Straight edge
- Colored pencils

Computer with Internet access

Resources:

NASA GSFC Microwave Anisotropy Probe. *MAP Glossary of Technical Terms*. Available: http://map.gsfc.nasa.gov/html/glossary.html

Peebles, P.J.E., Schramm, D.N., Turner, E.L. & R.G. Kron. (1994). "The Evolution of the Universe", *Scientific American*, 271, 29 - 33.

Introduction to the Big Bang Theory. Available:
http://www.bowdoin.edu/dept/physics/astro.1997/astro4/bigbang.html

Credit for Explore Activity: Judith I. Vandel, McCormick Junior High, Cheyenne, WY
Columbia Education Center's Summer Workshop. (1994). Ask Eric Lesson Plans, Lesson Plan #:AELP-SPA0010.

Credit for Extend Activity:
NASA GSFC. *MAP Educator's Page*. Available:
http://map.gsfc.nasa.gov/html/nf_outr_educators.html

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 2A: Stellar Evolution

Estimated Time: Two-three forty-five minute class periods

Indicators(s): Core Learning Goal 1

1.4.1 The student will organize data appropriately using techniques such as tables, graphs, and webs (for graphs: axes labeled with appropriate quantities, appropriate units on axes, axes labeled with appropriate intervals, independent and dependent variables on correct axes, appropriate title).

1.4.2 The student will analyze data to make predictions, decisions, or draw conclusions.

1.5.6 The student will read a technical selection and interpret it appropriately.

Indicators(s): Core Learning Goal 2

2.1.2. The student will describe current efforts and technologies used to study the universe. At least-- optical telescopes, radiotelescopes, spectroscopes, satellites, space probes, manned missions.

2.2.1. The student will explain the role of natural forces in the universe. At least-- formation of planets, orbital mechanics, stellar evolution.

Student Outcome(s):

1. The student will be able to compare the life cycles of high mass stars and low mass stars by creating a systems diagram.
2. The student will be able to interpret cosmic ray data and relate conclusions about the source of the particles to our knowledge of the formation of the universe.

Brief Description:

In the first part of this lesson, students review knowledge of the life cycle of stars which students learned about in middle school.

In the Extension, students interpret fluxes (rates of particle flow) for cosmic ray isotopes and relate conclusions about the source of the particles to our knowledge of the formation of the universe.

Background knowledge / teacher notes:

The Earth is constantly bombarded with a stream of accelerated particles arriving not only from the Sun, but also from interstellar and galactic sources. Study of these energetic particles will contribute to our understanding of the formation and evolution of the universe as well as the astrophysical processes involved. The Advanced Composition Explorer (ACE) spacecraft is sampling lower energy particles of solar origin and higher energy galactic particles with a collecting power

10 to 1000 times greater than similar past experiments. From a location approximately 1/100 of the distance from the Earth to the Sun, ACE is performing measurements of cosmic ray particles over a wide range of energies and nuclear masses. Scientists classify cosmic rays depending on their source. The three categories are:

SEPs (solar energetic particles) which are lower energy cosmic rays of **solar origin**, (measured by SIS) and, ACRs (anomalous cosmic rays) which originate within local interstellar space, and GCRs (galactic cosmic rays) which **originate far outside the solar system** but probably within the Milky Way galaxy. (measured by CRIS)

ACE provides near-real-time solar wind information. When reporting space weather ACE provides an advance warning (about one hour) of geomagnetic storms, which can overload power grids, disrupt communications on Earth, and present a hazard to astronauts.
Changes in the Sun's output of visible light, invisible electromagnetic radiation, solar wind (ions), and solar energetic particles (SEPs), is collectively classified as solar activity. A large percentage of the particles that travel toward Earth from the Sun are in the plasma state. These charged ions are the main constituent of the solar wind. These moving ions have small magnetic fields surrounding them just like all moving electrical charges. One of the main topics that is of interest to scientists is the interaction of the magnetic field generated by these ions with the Earth's magnetosphere (magnetic field). This interaction is rather complicated. The particles approach the magnetosphere causing it to be distorted slightly. The slight distortion, in turn, causes the flow of the particles to be altered since the magnetic field lines are the "highways in the sky" for these charged particles. The magnetic field lines of the magnetosphere become a highway because charged particles tend to flow along magnetic field lines. The net result is that the Earth's magnetosphere normally protects us from the stream of high-energy particles in this way.

Solar flares, coronal mass ejections (CMEs), and solar plumes can alter the composition of the solar wind. The solar flares are tremendous explosions in the Sun's atmosphere. These explosions are believed to result from the rapid release of energy stored in the magnetic fields around sunspots (darker and cooler areas on the Sun's surface created by expanding loops of plasma). These solar flares result in the acceleration of ions of elements such as carbon, nitrogen, oxygen, neon, magnesium, silicon, and iron. These accelerated particles are called solar energetic particles (SEPs) and are classified as solar cosmic rays. The largest solar flares are normally associated with coronal mass ejections (CMEs). These CMEs are tremendous ejections of mass from the Sun. These ejections expand as they climb and heat the solar plasma to tens of millions of degrees. These CMEs eventually accelerate electrons, protons, and heavy nuclei to velocities approaching the speed of light. The solar plumes are feathery jets that extend from near the poles to more than 13 million miles into space. These plumes may be the origin of the high-speed solar wind particles since they expel high-speed streams of plasma (that can reach one million degrees) from the corona.

Earth Space Systems Science
Unit 5: The Space Sphere

The interaction of the various solar events with each other creates a very complicated system. The frequency of solar activity generally follows the well-documented eleven-year solar activity cycle. At their peak they number several tens of flares per day. The CMEs occur only a few times during the period of maximum solar activity.

Credit: *Where do Cosmic Rays come From? The Sun or Supernova?* Daniel Hortert GESSEP Program, Pat Keeney GESSEP Program, Dr. Eric R. Christian ACE Deputy Project Scientist, Dr. John Krizmanic Astroparticle Physicist, Beth Jacob ACE Outreach Specialist.

Lesson Description:

ENGAGE	Discuss the following quote with students: "It is very poetic to say that we are made from the dust of the stars. Amazingly, it's also true! Much of our bodies, and our planet, are made of elements that were created in the explosions of massive stars." (The Life Cycles of Stars: How Supernovae Are Formed, http://imagine.gsfc.nasa.gov/docs/teachers/lessons/xray_spectra/background-lifecycles.html) What is the evidence for this statement?
EXPLORE	Adaptive strategy: Pre-reading vocabulary: protostar, life cycle, main sequence star, red giant, white dwarf, black dwarf, supernova, neutron star, pulsar, black hole, fusion, element, isotope, X-ray, gamma-ray. *Imagine the Universe! Dictionary*. Available: http://imagine.gsfc.nasa.gov/docs/dictionary.html#gravity Read the technical document and examine the accompanying images for "Life Cycles of Stars" at *The Life Cycles of Stars: How Supernovae Are Formed*, Available: http://imagine.gsfc.nasa.gov/docs/teachers/lessons/xray_spectra/background-lifecycles.html). *Accommodation: The teacher may want to use a directed reading activity here.* 3. View the animation of a supernovae: http://imagine.gsfc.nasa.gov/docs/science/know_l1/supernovae.html 4. View the photograph taken of a supernovae explosion and accompanying explanation. *Supernovae*. Available: http://imagine.gsfc.nasa.gov/docs/science/know_l2/supernovae.html
EXPLAIN	Create a system diagram that links the ideas in the above reading. Create a diagram that illustrates the life cycle a high mass star compared to a low mass star.

	Journal Write: 1. Compare the life cycle of a low mass star to the life cycle of a high mass star. 2. How are the waves of the electromagnetic spectrum related to our knowledge of the life cycle of stars? Explain how they fit into your systems diagram? *Modification: Working in pairs, one student could create the systems diagram for a high mass star while the other creates one for a low mass star. Together the two students could compare their diagrams.*
EXTEND	Provide students with background about the ACE mission (see above) and the related science. The teacher may wish to provide it both as a discussion and a handout for later reference in this activity. Ask students why it is important to compare the chemical elements found in near and far space to elements found here on Earth **or** Read the technical article Educational Brief Subject: ACE Mission Topic: *Composition of Matter, Atomic Structure* The Cosmic and Heliospheric Learning Center. Astrophysics Basics. Composition Activities. National Aeronautics and Space Administration CD-ROM NASA GSFC *Exploring the Extreme Universe!*. file:///LHEA_CD/docs/chlccd/ace2.htm *Accommodation: Use a directed reading lesson with the handout. Include a discussion of the questions developed when setting a purpose for reading.* Discuss or define the these terms with students: · flux · Mathematics Connection: review the concept or give a brief explanation of the concepts of logarithms and scientific notation. · UTC *Accommodation: If students are keeping a science dictionary or vocabulary section in their notebooks, the above terms and the terms in the Glossary that follows this lesson should be added to that section.* Adaptive strategy: review the chemical symbols for the elements in the data below. Assist students as they work through the data by modeling on a large monitor. *Accommodation: The teacher may want to model this process with students, then have students interpret one graph with guidance before interpreting one independently*.

1. Access *ACE Browse Data* at the web address below.
http://www.srl.caltech.edu/ACE/ASC/browse/brws_grphs.html

On the "element fluxes" chart click on the left half of the light blue rectangular section found to the right of O, N, and C, and "above 10 MeV/nucleon".

This links you to SIS data on fluxes for cosmic ray isotopes of those elements having 7 to 10 MeV/nucleon. Scroll down until you see the graph for "Daily averages". What appears to be the normal flux for CNO (carbon, nitrogen, oxygen) nuclei with 7 to 10 MeV?
See Hint below.

HINT: The y-axis is shown as a logarithmic plot. The 10^{-6} at the bottom of the y-axis corresponds with a particle flux of 1 X 10^{-6} . The next small line (going up the) axis corresponds with 2 X 10^{-6}, then 3 X 10^{-6}, and so on. When you get to the line labeled 10^{-5}, the particle flux has now increased to 1 X 10^{-5}.
A particle flux corresponding to this line is ten times higher than a flux corresponding with the 1 X 10^{-6} found at the bottom of the chart. Each increase on the chart of one power of ten is said to be an increase in magnitude of one. For example, a flux of 10^{-1} is said to be five orders of magnitude above a flux of 10^{-6}.

3. Click on images for the full-size graph. Study the graph to identify any peaks that are one or more orders of magnitude above the normal flux.

Accommodation: A print out of this graph would help students to see the whole graph at once instead of having to scroll around the page.

Journal Write: List the day(s) corresponding with these events and list how many orders of magnitude each varies from the normal.

Accommodation: Remind students and model for them that a list must have a title.

Journal Write: From information presented in the Background, what kinds of events may have caused this variation in the SIS data?

4. Scroll down through the graphs until you find a graph of C, N, and O

	with 10 to 15 MeV/nucleon for "Daily Averages". ***Journal Write***: What is the normal flux indicated on the graph for these cosmic rays isotopes? 5. Study the graph to identify any peaks that are one or more orders of magnitude above the normal flux. ***Journal Write***: List the day(s) corresponding with these events and list how many orders of magnitude each varies from the normal. 6. ***Journal Write***: How do the peak fluxes relate to the CNO nuclei having 7 to 10 MeV/nucleon that you studied in step #2 above? 7. ***Journal Write***: What conclusion(s) can you draw about the source of the event that caused the observed peaks for the two energy ranges? 8. Scroll down through the graphs until you find a graph showing SIS "Daily Averages" since launch for nuclei with atomic numbers (Z) > 10 and with 9 to 21 MeV/nucleon. ***Journal Write***: How do the peaks in their flux relate to the peaks for the CNO cosmic ray isotopes studied in procedure #2 and #5 above? What conclusion(s) would you draw about the source of these nuclei? 9. Click “Back” on your browser to again access the ACE Browse Data Element Fluxes chart. Click on the left half of the pink rectangular section of the chart found to the right of Fe, Si, Mg, and Ne and above 100 MeV/nucleon. This links you to CRIS data showing fluxes for cosmic ray isotopes with those characteristics. Scroll down until you see the first graph for “Daily averages" since launch”. ***Journal Write***: What appears to be the normal flux for these isotopes? 10. Study the graph to identify any peaks or valleys that are one or more orders of magnitude away from the normal flux. ***Journal Write***: List the day(s) corresponding with these events and list how many orders of magnitude each varies from the normal. Be specific about whether the magnitudes are greater than or less than the normal. 11. ***Journal Write***: Do the patterns in the fluxes of the cosmic ray particles measured by CRIS correlate in any way with the isotopes measured by SIS? Justify your answer.

	12. From the results of your investigations above, what conclusions might you draw about the variation in cosmic ray isotope fluxes from: a. solar activity b. activity outside our solar system
EVALUATE	***Journal Write***: How does the data collected by the ACE missions contribute to our knowledge of the universe. Make one or more hypotheses based on the data you have examined.

Materials:
Background for Extension activity
Computer with Internet connection and CD-ROM capability
Glossary

Glossary:

- ACE - (Advanced Composition Explorer) NASA spacecraft launched in August of 1997 with the purpose of sampling the matter that comes near the Earth from the Sun, the space between the planets, and the Milky Way galaxy beyond the solar system
- acronym - a word formed from the initial letter(s) of each successive part of a phrase
- alpha particle - positively charged particle consisting of two protons and two neutrons
- anomalous cosmic rays (ACRs) - ions that are tossed around in and out of the solar wind termination shock (the shock caused by the sudden slowing of solar wind as it approaches the heliopause) until some gain energy and are thrown back inside the heliosphere
- atomic number - represented by Z, equals the number of protons in the nucleus of an atom
- cosmic rays - particles and high-energy light that bombard the Earth from anywhere beyond its atmosphere
- coronal mass ejections (CMEs) - huge ejections of mass from the Sun; they are balloon-shaped bursts of solar wind rising above the solar corona, expanding as they climb; solar plasma is heated to tens of millions of degrees, and electrons, protons, and heavy nuclei are accelerated to near the speed of light
- electron - negatively charged particle, one of the three major building blocks for atoms
- electron volt - the energy acquired by an electron as a result of moving through a potential difference of 1 volt
- flux - measurement which describes the rate of particle flow
- galactic cosmic rays (GCRs) - cosmic ray particles that come from outside our solar system, but from within our galaxy; they have lost all of their electrons during their trip through the galaxy
- ions - an atom that carries a positive or negative electrical charge as a result of having lost or gained one or more electrons

- interstellar medium - the seemingly empty space between stars that is actually composed of particles from a variety of sources
- isotopes - different forms of an element (depending on the number of neutrons)
- kiloelectron volt (keV) - unit of electrical energy equivalent to 1000 electron volts
- logarithmic scale - a scale based on the fact that powers or exponents of base numbers are added when multiplying and subtracted when dividing, (math functions that range over a broad scale of magnitudes are usually graphed with a logarithmic axis)
- magnetic field - a region of space near a magnetized body or electrical current where magnetic forces can be detected
- magnetometer - instrument designed to measure magnetic field strength and/ or direction
- mass spectrometer - instrument designed to measure the mass of atomic and subatomic particles
- megaelectron volt (MeV) - unit of electrical energy equivalent to one million electron volts
- plasma - (from CHLC http://helios.gsfc.nasa.gov/gloss_op.html#P) a fourth state of matter--not a solid, liquid, or gas; in a plasma, the electrons are pulled free from the atoms and can move independently; the individual atoms are charged, even though the total number of positive and negative charges is equal, maintaining overall electrical neutrality
- proton - positively charged particle, one of the three major building blocks for atoms, the number of protons found in an atom's nucleus determines what element is present
- solar energetic particles (SEPs) - are atoms that are associated with solar flares; SEPs are a type of cosmic ray that move away from the Sun due to plasma heating, acceleration, and numerous other forces; on the scale of cosmic radiation, SEPs have relatively low energies
- solar flare - enormous explosion of gas in the solar atmosphere resulting in: a sudden acceleration of particles, the heating of plasma, and the eruption of large amounts of solar mass
- solar plumes - feathery jets that extend from near the poles of the Sun to more than 13 million miles into space solar wind - the plasma of charged particles(protons, electrons, and heavier ionized atoms) coming out of the Sun in all directions
- universal time (UT) - method of measuring time referenced to Greenwich, England; the time is kept using a zero to 24 hour scale with zero equaling midnight; also known as Greenwich Mean Time (GMT), or Zulu time

Resources:

Imagine the Universe! Dictionary. Available:
http://imagine.gsfc.nasa.gov/docs/dictionary.html#gravity

Credit: *Imagine the Universe!* The High Energy Astrophysics Science Archive Research Center (HEASARC), Dr. Nicholas E. White (Director), within the Laboratory for High Energy Astrophysics (LHEA) at NASA/ GSFC. Imagine the Universe! was originally created by Dr. Laura Whitlock. Website Text Authors: The Imagine! Team. Project Leader: Dr. James Lochner.

Earth Space Systems Science
Unit 5: The Space Sphere

Credit: *Where do Cosmic Rays come from? The Sun or Supernova?* Daniel Hortert GESSEP Program, Pat Keeney GESSEP Program, Dr. Eric R. Christian ACE Deputy Project Scientist, Dr. John Krizmanic, Astroparticle Physicist, and Beth Jacob ACE Outreach Specialist.

Credit: *X-ray Spectroscopy and the Chemistry of Supernova Remnants*.
A Series of Lesson Plans by Allie Hajian and Maggie Masetti, NASA/GSFC, Greenbelt, MD with teachers Rick Fowler, (Crossland High School Temple Hills, Maryland) and Angela Page, (Hyattsville Elementary School, Hyattsville, Maryland).

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 2B: Periodic Motion

Estimated Time: One forty-five minute class period

Indicators(s): Core Learning Goal 1

1.4.1 The student will organize data appropriately using techniques such as tables, graphs, and webs (for graphs: axes labeled with appropriate quantities, appropriate units on axes, axes labeled with appropriate

1.6.4 The student will manipulate quantities and/or numerical values in algebraic equations.

Indicators(s): Core Learning Goal 2

2.2.1. The student will explain the role of natural forces in the universe. At least-- formation of planets, orbital mechanics, stellar evolution.

Student Outcome(s):
The student will be able to determine periodicity within a set of data.

Brief Description:
Students should know how to graph/plot data and determine the mean from a set of data.

This lesson examines the idea of periodic behavior and how it is determined from a set of data. The students will examine this concept through a hands-on lab that involves a simple, student-made pendulum.

Background knowledge / teacher notes:

Lesson Description:

ENGAGE	*Vocabulary: periodicity*. Students should discuss the definition of a cycle or periodic behavior. Examples of periodic behavior could include the movement of a pendulum or clock, the brightness of a lighthouse beam as you observe it from a fixed location, or the shape of the Moon as a function of time.
EXPLORE	Graph periodic motion to obtain a graphic representation or picture of periodic motion. Carry out the following investigation of periodic motion and create a line plot of amplitude of each swing versus mean time it takes to make that swing. Experimental set up: Each student group should place two chairs back to back separated by

	about 20 cm. Place the hook into the wood/cardboard and tie the 60 cm string to the hook. Tie the 60-cm string around the mass in order that a simple pendulum is made. A meter stick should be taped on the floor and below the pendulum, so that when the pendulum is at rest, it actually dangles over the 50-cm mark on the meter stick. The mass of the pendulum should be gently "pulled out" to the 75-cm mark, making sure the string is taut. Now when the timer looks directly over it, he or she sees the 75-cm mark covered by the mass. Let time = 0 when the pendulum is released from being held over 75 cm. When the Time Keeper says go, pendulum is released and the watch started. When the pendulum reaches its maximum movement (roughly over 25 cm), someone says, "stop". The measured time should be considered to be t_1. The measurement is repeated 5 times. The procedure is repeated with someone now saying "stop" the second time the pendulum reaches its maximum movement near 25 cm (this measured time should be considered to be t_2) and then again for the third time (this measured time should be considered to be t_3). [You can even do this for the fourth time if the pendulum continues to reach its maximum movement!] Each measurement should be made five times, and the mean determined from the five trials. Again, let time = 0 when the pendulum is released from being held over 75 cm. When Time Keeper says "go", the pendulum is released and the watch started. When the pendulum reaches its maximum movement, this time when it swings back over 75 cm, someone says "stop". The measured time should be considered to be t_a. The measurement is repeated 5 times. The procedure is repeated with someone now saying "stop" the second time the pendulum reaches its maximum movement near 75 cm (this measured time should be considered to be t_b) and then again for the third time (this measured time should be considered to be t_c). Once more, you can even do this for the fourth time if the pendulum continues to reach its maximum movement! Record data for at least three complete swings of the pendulum (four is, of course, better!). Each measurement should be made five times, and the mean determined from the five trials. *Accommodation: The teacher may want to model this graph and them ask students to construct their own graph.*

	Provide clear directions and a data table for recording times.
EXPLAIN	***Journal Write***: After completing the graph, discuss the following: 1. How would the results be different if instead of a string 30 cm long, we used 10-cm string? a string 100 cm long? 2. Summarize the relationship that you may see with time or swings and the use of different length string.
EXTEND	Mathematically, the period may be defined as (2 π) (the square root of l/g) Where g is the acceleration due to gravity (here on Earth it has a value of 9.8 m/sec.), L is the length of the pendulum string from where it is tied at the top to where the center of mass is of the tied object, and pi = 3.14. Use the graph that was constructed to hypothesize the period of the pendulum. Calculate the period using the above equation.
EVALUATE	***Journal Write***: 1. How can periodicity be defined? 2. How is periodicity demonstrated by the graph? 3. How does the calculated value of period compare to the predicted value from the graph.

Materials:

<u>For "Explore" activity</u>

Teacher
- roll of masking tape
- a few extra meter sticks to aid in measuring

For each group of students
- two pieces of string (one approx. 60cm, one approx. 30cm)
- mass of about 1/4 to 1 kg that would serve as the pendulum bob (e.g. rubber ball, piece of clay, large key, etc.)
- wood block (recommended) or a piece of thick cardboard at least 30 cm x 30 cm
- small brass hook that would screw into the wood or cardboard
- two metric rulers
- three sheets of graph paper

- one data table
- one metric tape measure
- stop watch or digital wrist watch with sub-second timing (you will be timing swings of a pendulum in fractions of seconds)

Resources:
Credit: Imagine the Universe! CD-ROM. Version 4. High Energy Astrophysics Science Archive Research Center (HEASARC), Dr. Nicholas E. White (Director), within the Laboratory for High Energy Astrophysics (LHEA) at NASA/GSFC. Imagine the Universe! was originally created by Dr. Laura Whitlock.
Website Text Authors: The Imagine the Universe! Team. Project Leader: Dr. James Lochner
Lesson: *Time that Period.*
Kara C. Granger, New Technology High School
920 Yount Street, Napa, California 94559

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 2C: Stars and Star Systems

Estimated Time: Two forty-five minute class periods

Indicators(s): Core Learning Goal 1

1.6.2 The student will use computers and/or graphing calculators to perform calculations for tables, graphs, or spreadsheets.

Indicators(s): Core Learning Goal 2

2.1.2. The student will describe current efforts and technologies used to study the universe. At least-- optical telescopes, radiotelescopes, spectroscopes, satellites, space probes, manned missions.

Student Outcome(s):
The student will be able to apply the method of Folding to determine the rotation period of a star and/or the binary orbital period of the stellar system.

Brief Description:
This lesson builds on knowledge students have gained in the lesson on periodic motion. Students will analyze data received from high-energy satellites of various binary star systems' orbital periods or stellar rotation periods.

Background knowledge / teacher notes:
This lesson is a continuation of *Time that Period!*.on the Imagine the Universe! CD
Kara C. Granger, New Technology High School
920 Yount Street, Napa, California 94559

Students will practice finding the period of sample data using a method known as folding.

The material that follows is from the *Imagine the Universe!* CD but may also be accessed from the website listed under Resources section. The student may access these descriptions.

Binary Stars
http://imagine.gsfc.nasa.gov/docs/teachers/lessons/time/binary_stars.html
About half of the stars visible in the night sky are multiple star systems or double stars. The gravitational force between the two stars in a binary system keeps them in orbit about each other. Our star "The Sun" is not in a binary system, although it is considered to be a typical single star. The next nearest star is Alpha Centauri, which is 3 x 1013 kilometers away.

When astronomers can actually see the two stars orbiting each other, the binary is called a visual binary. This binary system is Kruger 60 in the constellation Cepheus and has an orbital period of

44.5 years. In most binary systems, both stars follow an elliptical orbit about their common center of mass.

After many years of observation, astronomers can plot the orbits of the stars in a visual binary.

X-ray binaries are a special class of binary star systems that emit X-rays. X-ray binaries are made up of a normal star and a collapsed star (a white dwarf, neutron star, or black hole). These pairs of stars produce X-rays if the stars are close enough together that material is pulled off the normal star by the gravity of the dense, collapsed star. The X-rays come from the area around the collapsed star where the material that is falling toward it is heated to very high temperatures (over a million degrees!).

Pulsars and Neutron stars
http://imagine.gsfc.nasa.gov/docs/teachers/lessons/time/pulsars.html
Sometimes these objects emit X-rays in a very rapid regular, periodic pattern. These objects are called X-ray pulsars. Pulsars, it is believed, are spinning neutron stars. A neutron star is the super -dense remains of an exploded star that gravitationally collapsed back in on itself to form a small, compressed core of neutrons. When a neutron star is in a binary system with a sun-like star, matter is gravitationally pulled off this stellar companion. We can think of it this way: "It's the sound of matter going splat," says UC Berkeley astrophysicist Jonathan Arons. During this process, X-rays are emitted.

More specifically, pulsars have jets of particles moving at the speed of light streaming out of their two magnetic poles. These jets produce very powerful beams of light. We know that on Earth, the spin axis (true north) is not the same as the magnetic axis. This is also seen in X-ray pulsars. Therefore, the beam of light from the jet sweeps around as the pulsar rotates, like the spotlight in a lighthouse does. As a ship in the ocean that sees only regular flashes of light, we on Earth see pulsars turn on and off as the beam sweeps over the Earth.

How much mass the star had when it died determines what it becomes. Stars about the same size as the Sun become white dwarfs, which glow from left over heat. Stars that have about three times or more the mass of the Sun compact into neutron stars. A star with a mass many, many times the Sun's gets crushed into a single point, which we call a black hole.

The characteristics of such stars are also going to be features of the types of stars that the students will be examining today's lesson with Folding.

A neutron star is the super dense remains of an exploded star that gravitationally collapsed back in on itself to form a small, compressed core of neutrons. It is not unusual for a neutron star to emit X-rays. When a neutron star is in a binary system with a sun-like star, matter is gravitationally pulled off this stellar companion. As the matter falls toward the neutron star, it emits X-rays. We can think of it this way: "It's the sound of matter going splat," says UC Berkeley astrophysicist Jonathan Arons.

Sometimes the emitted X-rays are pulsed, or modulated, by the spinning of the neutron star.

Light Curves
http://imagine.gsfc.nasa.gov/docs/teachers/lessons/time/light_curves.html

A light curve is a graph that shows the brightness of an object over a period of time. In the study of objects that change their brightness over time such as novae, supernovae, and variable stars, the light curve is a simple, but valuable tool to a scientist.

WHEN THE STUDENTS COMPLETE THE EIGHT STEPS OF FOLDING WITHIN THEIR INDEPENDENT PRACTICE, THEY WILL ACTUALLY BE CREATING A LIGHT CURVE.

If the light curve measured looked like the plot below, then you could identify your object as an eclipsing binary star. Notice that there are "dips" in the plot. This is actually happening because the stars are eclipsing each other. The larger "dips" occur when the smallest star is being totally eclipsed (smallest star is behind the largest star) and the smaller "dips" occur when the largest star is being totally eclipsed (largest star is behind the smallest star).

We can also tell from this light curve that it takes 10 days for one of the stars in the binary to orbit around the other one complete time. Astronomers would say this as "the orbital period of the binary system is ten days". Earth has an orbital period. It is "one year" or "365.25 days".

Extend Activity
GX 301-2
The GX 301-2 rotational period data were retrieved from the HEAO-1 satellite's A2 instrument. The orbital period data were retrieved from the Vela 5B satellite's All Sky Monitor. The students will determine the orbital period and the stellar rotation period, which are 41.5 days and 700 seconds, respectively. This is a system where a rotating neutron star is in orbit with a supergiant B star.

Lesson Description:

ENGAGE	*Vocabulary: binary star system, orbital period.* Students should again be encouraged to discuss the definition of a cycle or periodicity. Students should recall the lab that was completed on periodic motion and how it relates to determining the " periodicity". In the lab, they should have determined the length of time it took the pendulum to complete one full cycle of its movement. That length of time is called the "period" of the pendulum's behavior. The students should now be ready to apply previous learning to data received by high-energy satellites from various binary star systems. By properly analyzing the data, they will be able to determine the rotation period of a star and/or the binary orbital period of the stellar system. Students will need background information on the topics below. (See Teacher Background). Description and graphics related to these topics may be accessed from the CD-ROM Imagine the Universe or *Time that Period*. Available: http://imagine.gsfc.nasa.gov/docs/teachers/lessons/time/time_period_cover.html Lesson: *Time That Period!* Day 2. Double stars / binary stars Pulsars / neutron stars Light curves / plots from data Demonstration: Visualize the behavior of a pulsar and its relation to a light curve is by having a student holding a flashlight, the Calculator Based Laboratory (CBL), its light probe, CHEMBIO program, and the Texas Instruments (http://www.TI.com/) 83 graphing calculator (TI-83). Have the student hold the light and rotate around with it pointed out toward his classmates... sweeping across the light probe as she/he rotates. As the rotating beam of light sweeps past the observer/probe, one is able to detect an increase in the intensity of light you see from the flashlight. If some measure of this brightness is observed over time and then plotted, a periodic behavior can be noticed. The period of the behavior is a measure of the spin rate of the person holding the flashlight. Have you students then consider how this demonstration provides insight into the behavior of pulsars. *Accommodation: Print outs from the cited web pages could be used for the directed reading of background information. The pictures and diagrams are important to student understanding of the information and*

	should be discussed during the directed reading activity.
EXPLORE	Use the graph: GX301-2 Light Curve Ask, "Do you see the measured brightness of the source 'repeating' itself? Where? Describe what seems to be happening", and "Can you determine the period here?" By being able to interpret the graphed data, students will respond with answers close to 700 seconds - which is the correct length of the period. Mention to students that there has to be a way to be more mathematical method to determining a period within a set of data --something better than just guessing or being able to see it with your eyes! Provide sample data points and have students create a line plot. (see Student Pages below) Now the students are ready to determine the true, mathematical period through the method of Folding. See the Student Pages at the end of this lesson for the description of the Explore "folding" activity.
EXPLAIN	***Journal Write***: Compare your plot to the plot of your guessed period. 1. Does the data make a curve? If so, you have the period! 2. Does it make a straight line, or an approximate straight line? If so, the period you guessed is wrong and you need to go back to step one of the Folding instructions and begin again.
EXTEND	Now that students have had practice using sample data, they will use The GX 301-2 rotational period data retrieved from the HEAO-1 satellite's A2 instrument and the orbital period data retrieved from the Vela 5B satellite's All Sky Monitor. The students will determine the orbital period and the stellar rotation period, which are 41.5 days and 700 seconds, respectively. This is a system where a rotating neutron star is in orbit with a supergiant B star. To determine the orbital period: 1. Retrieve the GX 301-2 data set available: *GX 301-2 orbital period data.*

	http://imagine.gsfc.nasa.gov/docs/teachers/lessons/time/gx301s2_orbital.html 2. Graph the data and then use the folding instructions to determine the orbital period. *Accommodation: Provide guidance in setting up each axis for the graph.* To determine the stellar rotation period: 1. Retrieve the GX 301-2 data set available: *GX 301-2 stellar rotation period data.* http://imagine.gsfc.nasa.gov/docs/teachers/lessons/time/gx301s2_rotation.html 2. Graph the data and then use the folding instructions to determine the stellar rotation period. 3. For The GX 301-2 stellar rotation period data here, trying the following periods; start at 650 seconds and add multiples of 25 seconds after that, such as 650, 675, 700 etc. GT Connection: Another option for this lesson is to follow the procedure of Folding, but now the teacher should use spreadsheet software or the graphing calculator. For directions go to: *Epoch Folding*. Available: http://imagine.gsfc.nasa.gov/docs/teachers/lessons/time/epoch.html GT Connection: Analyze the data for the star systems below. Data available for Cir X-1 and Cen X-3 Time that Period! Day 2 Available: http://imagine.gsfc.nasa.gov/docs/teachers/lessons/time/time_day2.html For orbital period Cir X-1 is an X-ray binary with an orbital period of 16.6 days. It is a system where a neutron star is in orbit with a low mass companion (possibly an M star). The Cir X-1 orbital data were retrieved from the RXTE satellite's All Sky Monitor. The rotational period of the neutron star is currently not known. For stellar rotation: Cen X-3 These data were retrieved from the EXOSAT satellite through their Medium Energy experiment. The students will determine the pulsar rotation period here, which is 4.8 seconds. This is a system where a pulsar is in orbit around a 17 solar mass (17 x the mass of the Sun) O

	star (very large blue star). This is a peculiar source where long term variations are seen in both the pulsar period and the orbital period. It has been hypothesized that this is due to a third "body" that may exist within this system
EVALUATE	***Journal Write***: Explain how data retrieved by satellites allow scientists to mathematically describe the orbital period and stellar rotation of star systems. *Accommodation: A graphic organizer for prewriting may be helpful here.*

Materials:

Teacher

Texas Instruments 83 graphing calculator
Calculator Based Laboratory with light probe
CHEMBIO program
headlight
Calculator
Set of Cen X-3 data (optional)
Plot of Cen X-3 data (optional)
Set of Cir X-1 data (optional)
Plot of Cir X-1 data (optional)
Set of GX 301-2 orbital period data
Plot of GX 301-2 orbital period data
Set of GX 301-2 stellar rotation period data
Plot of GX 301-2 stellar rotation period data
plot of sample/practice data
set of sample/practice data

Student Groups (groups of 3-4)

Texas Instruments 83 graphing calculator
Metric ruler
Graph paper
Set of Cen X-3 data (optional)
Set of Cir X-1 data (optional)
Set of GX 301-2 orbital period data
Set of GX 301-2 stellar rotation period data
Plot of sample/practice data (one for each student)
Set of sample/practice data (one for each student)
Worksheet titled "Plot of a Period" (for each student)

Red and blue pencils (for each student)

Resources:
Imagine the Universe! CD-ROM. Version 4. High Energy Astrophysics Science Archive Research Center (HEASARC), Dr. Nicholas E. White (Director), within the Laboratory for High Energy Astrophysics (LHEA) at NASA/GSFC. Imagine the Universe! was originally created by Dr. Laura Whitlock. Website Text Authors: The Imagine! Team. Project Leader: Dr. James Lochner

Earth Space Systems Science
Unit 5: The Space Sphere

Explore Activity
Student Page

Here are some sample data points (in increments of 100,000) over time (in months). Is there periodic behavior in these data? If so, what is the period?

Create a line plot on graph paper.

Time	**Intensity**
1	**11**
2	**9**
3	**7**
4	**5**
5	**3**
6	**1**
7	**3**
8	**5**
9	**7**
10	**9**
11	**11**
12	**9**
13	**7**
14	**5**
15	**3**
16	**1**
17	**3**
18	**5**
19	**7**
20	**9**
21	**11**
22	**9**
23	**7**
24	**5**

Folding Activity

1. Guess the length of the period.
2. Locate that section of the plot. Color over the line it makes with a red pencil.
3. Locate the exact and adjacent match to that curve. Color over the line it makes with a blue pencil.
4. Always starting from the left end of the x-axis, find the 1st data point on the red curve and the 1st data point on the blue curve and determine the mean of their y values (in this case, intensity is the y value). We will call its x-axis value "Time Bin #1".
5. Continue to do this with the remaining points on the curves, calling the x- axis values "Time Bin #2", "Time Bin #3", etc. and associating the y value of mean with the x value "Time Bin".

6. Complete the chart with the appropriate, calculated data.

Time Bin	Intensity
1	
2	
3	
4	
5	
6	
7	
8	
etc.	

7. Plot the data from the chart.

Journal Write:
Does the data make a curve? Compare your plot to the plot of your guessed period? If so, you have the period!

Does it make a straight line, or an approximate straight line? If so, the period you guessed is wrong and you need to go back to step one of the Folding instructions and begin again. (see below)

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 3: Orbital Mechanics

Estimated Time: Two forty-five minute class periods

Indicators(s): Core Learning Goal 1
1.6.4 The student will manipulate quantities and/or numerical values in algebraic equations.

Indicators(s): Core Learning Goal 2
2.2.1. The student will explain the role of natural forces in the universe.
At least-- formation of planets, orbital mechanics, stellar evolution.

Student Outcome(s):
The student will be able to construct the orbits of planets by using knowledge of Kepler's Laws.

Brief Description:
Students will review knowledge of ellipses and then apply knowledge of ellipses to construct orbits of planets and calculate the eccentricities of the orbits.

Background knowledge / teacher notes:
Copernicus assumed all planets moved at constant velocities along circles, centered on the Sun, because the circle was the perfect curve, and the Sun was the center of the universe.

Kepler tried to test this and he used very precise observations, made by Tycho Brahe--the most precise astronomical observations before the invention of the telescope. Assuming that the planets moved in circles as Copernicus had proposed, Kepler calculated their expected positions. The expected positions differed from the observed ones. Kepler concluded that the world was not as perfect as Copernicus had suggested. The planets speed up and slow down. Their orbits are not exact circles, and the Sun is not at the center of their orbits. Searching for a more accurate representation, he deduced what we call Kepler's laws.

About 70 years later Newton showed that all three of these laws were a consequence of the laws of motion and of gravitation, which Newton himself was the first to formulate.

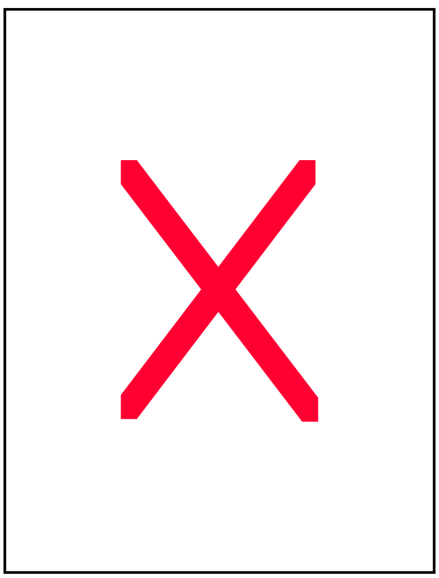
In fitting the observed motion of the planets to the theory of Copernicus, as modified by his own two laws, Kepler also had to estimate the relative size of the orbits. Copernicus already knew that the further away from the Sun a planet was, the slower it moved. Kepler found a mathematical law, which connected the mean distance from the Sun and the time needed to complete one orbit. This was Kepler's third law.

Kepler's 3rd law
The third law states that the square of the orbital period is proportional to the third power ("cube") of the average distance from the Sun.

As Newton showed nearly 70 years later, any objects held in orbit by the gravity of a large central object follow Kepler's laws.

The ellipse, the shape of a flattened circle, was well known to the ancient Greeks. It belonged to the family of "conic sections," of curves produced by the intersections of a plane and a cone. When the plane is perpendicular to the axis of the cone, the result is a circle. When it is moderately inclined, an ellipse is formed. When it is inclined so much that it is parallel to one side of the cone, a parabola is formed. When it is inclined even more, a hyperbola is formed.

A flashlight in a moderately dark room (drawing below) easily produces all these shapes. The flashlight creates a cone of light and when that cone hits a wall, the shape produced is a conic section--the intersection of the cone of light with the flat wall.



Kepler's first law states that the orbits of the planets and other celestial bodies around the Sun are ellipses. An ellipse is defined as a figure drawn around two points called the foci such that the distance from one focus to any point on the figure back to the other focus equals a constant. This constant is the measure of the long diameter of the ellipse, the major axis. Half of this segment is called the semimajor axis. The short diameter, the minor axis, is a perpendicular bisector of the major axis. Half of the minor axis is called the semiminor axis. For planets, the Sun is at one focus, nothing is at the other.

The eccentricity of an ellipse is a measure of its flatness. Numerically, it is the distance between the foci divided by the length of the major axis. The following is a series of ellipses having the same major axis but different eccentricities:

As the eccentricity approaches 1, the ellipse approaches a straight line. As the eccentricity approaches 0, the foci come closer together and the ellipse becomes more circular. A circle has an eccentricity of zero.

Kepler's second law states that a line from the planet to the Sun sweeps over equal areas in equal amounts of time. These areas in the ellipse are called sectors.

According to Kepler, the time it takes for the planet to get from A to B (see diagram below) is equal to the time it takes the planet to get from C to D. This means that a planet orbits slower as it moves further from the Sun.

Kepler's third law deals with the length of time a planet takes to orbit the Sun, called the period of revolution. The law states that the square of the period of revolution is proportional to the cube of the planet's average distance to the sun:

$$P^2=a^3$$

Because of the way a planet moves along its orbit, its average distance from the Sun is half of the long diameter of the elliptical orbit (the semimajor axis.) The period, P, is measured in years and the semimajor axis, a, is measured in astronomical units (AU), the average distance from the Earth to the Sun.

An example for using this formula would be to calculate how long it takes the near-Earth asteroid called Eros to orbit the Sun. The closest distance to the Sun that Eros orbits is 1.13 AU, and the farthest away from the Sun that it orbits is 1.78 AU. So, the average distance from Eros to the Sun, the semimajor axis, is (1.13 + 1.78)/2 = 1.46 AU. Substituting this in for a in the formula

$$P^2=a^3$$

and solving for P it takes Eros about 1.76 years to orbit the Sun.

Lesson Description:

ENGAGE	*Vocabulary: ellipse, focus (plural foci), eccentricity.* Ask students to refer to their research of planetary models (Lesson 1 in this unit) and review what they learned about Kepler and his laws of motion. Relate their knowledge to shape and motion of an orbiting planet or satellite.

	Shape: that the orbits were ellipses--elongated circles [for the planets, very slightly elongated], and the Sun was at one focus--off center, shifted towards one end. That is Kepler's first law. Motion: That the speed of a planet in its orbit depended on its distance from the Sun--the greater the distance from the Sun, the slower the motion. This relation could be expressed mathematically, and that expression was Kepler's second law. *Accommodation: A diagram of an ellipse with all parts labeled should be displayed and discussed.*
EXPLORE	Demonstrate different types of ellipses with a flashlight. Have students construct a paper cone and then cut the cone into sections to create an ellipse. Several types of conic sections may be constructed. ▪ How do you cut a cone to produce an **elliptic** cross section? Cut the cone with a plane inclined less steeply than the straight lines that form the cone. [Those lines, also called "generators", are like the poles, which hold up an Native American lodge or "teepee. The "lodgepole pine" was favored by the Indians for this use; it is a type of pine growing in the western US with straight thin trunks.] ▪ --How do you cut a cone to produce a parabolic cross section? Cut the cone with a plane parallel to the straight lines that form the cone. [Orbits of non-periodic comets, the ones that appear unexpectedly, are often very close to parabolas; their sides become closer and closer to parallel as the distance gets larger. They come from the very edges of the solar system. Their orbits may really be very long ellipses, too close to parabolas to be told apart. Periodic comets like Halley's, which moves in an elongated ellipse and returns every 75 years, presumably started that way, too, but were diverted by the pull of some planet, most likely by Jupiter, into elliptical orbits.] ▪ How do you cut a cone to produce a hyperbolic cross section? Cut the cone with a plane inclined more steeply than the straight lines that form the cone. [The sides of a hyperbola diverge at an angle: the graph y=12/x for instance is a hyperbola whose sides diverge at 90 degrees. An object approaching the Sun in a hyperbolic orbit is probably coming from

	outside the solar system, and will never come back.] Have students construct planetary orbits. A student handout is available from Glencoe Division of Macmillan/McGraw-Hill: *Construct Planetary Orbits Around the Sun Student Activity Sheet*. Available: http://near.jhuapl.edu/Education/lessonKepler/worksheet.html
EXPLAIN	Calculate the eccentricities of each of the ellipses constructed. ***Journal Write***: How does the length of string or placement of the tacks affect the eccentricity of the orbit?
EXTEND	Use the data from the chart of eccentricities to construct an ellipse with the same eccentricity as Earth's orbit and the orbits of Pluto and Mercury. Using Kepler's third law and the (L) from your chart for Earth, Mercury, and Pluto, calculate the period of revolution for these three planets.
EVALUATE	***Journal Write***: Describe how our knowledge of Kepler's Laws allows us to construct the orbital of a plant.

Materials:
Thumbtacks or pins, string, cardboard (21.5 cm x 28 cm), metric ruler, pencil, paper, student lab handout.

Resources:
Credit: *Construct Planetary Orbits Around the Sun Student Activity Sheet*. Available:
http://near.jhuapl.edu/Education/lessonKepler/worksheet.html
Source: Glencoe Division of Macmillan/McGraw-Hill

NASA JPL. *Activity: Constructing Orbits. Available:*
http://near.jhuapl.edu/Education/lessonKepler/actkepler.html

Lesson Plan #18 Kepler and his Laws. Available:
http://www-spof.gsfc.nasa.gov/Stargaze/Lkeplaws.htm
Part of a high school course on astronomy, Newtonian mechanics and spaceflight by David P. Stern, Code 695, Goddard Space Flight Center, Greenbelt, MD

From Stargazers to Starships. Available:
http://www-spof.gsfc.nasa.gov/stargaze/Sintro.htm

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 4A: Grasping Gravity

Estimated Time: One forty-five minute class period

Indicators(s): Core Learning Goal 1
1.6.4 The student will manipulate quantities and/or numerical values in algebraic equations.

Indicators(s): Core Learning Goal 2
2.2.2. The student will explain the role of natural forces in the universe.
At least-- retention of an atmosphere, an agent of erosion and deposition, tides and deep ocean currents

Student Outcome(s):
The student will be able to establish ratios of comparison of weight on Earth to weight on other bodies by using Newton's Law of Universal Gravitation.

Brief Description:
This is a NASA Ambassador lesson. (see outcome)

Background knowledge / teacher notes:
Students will need access to the website to view the technical reading and graphics.

Gravity is the attraction between all masses dependent on distance and the object's mass. All objects produce some amount of gravity. The more mass an object has the more gravity it produces. There is no official measure for gravity in this sense of the word. You can, however, speak in relative terms: "Earth's gravity is about six times that of the moon." Because the moon has less mass than the Earth, it also has less gravity.

One can compare properties such as these for the different planets, etc.. and hypothesize how the solar system formed, look for patterns in its structure, and contrast conditions on other planets and asteroids to those on Earth.

Mass is a measure of how much material is in an object, but weight is a measure of the attraction force exerted on that material to another mass; thus, mass and weight are proportional to each other.

Credit: *Grasping Gravity*. Background. Available:
http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/gravity.abstract.html
Lisa Bruck

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson Description:

ENGAGE	*Vocabulary: gravity, mass, weight.* Have students review their knowledge of gravity by listing what they already know. *Accommodation: Round Robin is a cooperative learning structure for accessing prior knowledge.* Students will then read the background information on gravity available: http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/gravity.html#Background
EXPLORE	Students should proceed to the online exploration: *Grasping Gravity*. Procedure. Available: http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/gravity.html#Procedure *Accommodation: If this investigation were printed for students they can use highlighters to note vocabulary definitions and/ or the outcome for the investigation.*
EXPLAIN	***Journal Write***: Complete the Assessment/ Reflection. Omit Question 5 1. Which body had the smallest gravity ratio number? Why do you believe it was so small? 2. Which body had the largest gravity ratio? Why do you believe it was so large? 3. Which asteroid has the smallest gravity ratio number? What doe this tell us about the difference between the two asteroids? 4. How did your original hypothesis compare to your results concerning gravity?
EXTEND	1. Can you make any correlation between gravity and composition and density of a planet or asteroid? 2. Go back to your planet information buttons on the planets and asteroids. Could gravity have any affect on the composition and density of the body? Explain your answer.
EVALUATE	***Journal Write***: Explain how the Law of Universal Gravitation allows you to compare your weight on Earth to weight on other celestial bodies in the solar system.

Earth Space Systems Science
Unit 5: The Space Sphere

Materials:
Computer access and Internet access
Calculator
Pen/pencil

Resources:
Credit: Goddard Space Flight Center Earth and Space Sciences Education Project (GESSEP)
Principal Investigator: Steve Gilligan. Co-Investigator: Vern Smith
Grasping Gravity. Background. Available:
http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/gravity.abstract.html
Lisa Bruck

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 4B: The Role of Gravity in the Space System

Estimated Time: Two forty-five minute class periods

Indicators(s): Core Learning Goal 1

1.2.7 The student will use relationships discovered in the lab to explain phenomena observed outside the laboratory.

1.4.8 The student will use models and computer simulations to extend his/her understanding of scientific concepts.

1.6.4 The student will manipulate quantities and/or numerical values in algebraic equations.

Indicators(s): Core Learning Goal 2

2.2.1. The student will explain the role of natural forces in the universe.
At least-- formation of planets, orbital mechanics, stellar evolution.

Student Outcome(s):

1. The student will be able to analyze the behavior of a satellite by constructing a model.
2. The student will be able to describe the velocity a satellite must achieve in order to remain in orbit by using the mathematical formula for velocity.

Brief Description:
In this lesson, students will construct a model of a satellite in orbit around the earth and calculate the velocity needed for a satellite to stay in orbit.

Background knowledge / teacher notes:
Gravitational attraction is a fundamental property of matter that exists throughout the known universe. Physicists identify gravity as one of the four types of forces in the universe. The others are the strong and weak nuclear forces and the electromagnetic force.

A microgravity environment is one in which the apparent weight of a system is small compared to its actual weight due to gravity. In practice, the microgravity environments used by scientific researchers range from about one percent of Earth’s gravitational acceleration (aboard aircraft in parabolic flight) to better than one part in a million (for example, onboard Earth-orbiting research satellites).

The effects of gravity (apparent weight) can be removed quite easily by putting anything (a person, an object, an experiment) into a state of freefall.

Kepler's discoveries about elliptical orbits and the planets' non-uniform speeds made it impossible to maintain the idea of planetary motion as a natural one requiring no explanation.

Newton asked these questions:
What keeps the planets in their elliptical orbits?
On our spinning Earth what prevents objects from flying away when they are thrown in the air?
What keeps you from being hurled off the spinning Earth?
Newton said that a fundamental force called "gravity" operating between all objects made them move the way they does. Newton developed rules governing the motion of all objects. He used these laws and Kepler's laws to derive his unifying Law of Gravity.

Gravity is the attraction between all masses dependent on distance and the object’s mass. All objects produce some amount of gravity. The more mass an object has the more gravity it produces. There is no official measure for gravity. Gravity may be described in relative terms. “Earth’s gravity is about six times that of the moon.” the moon has less mass than the Earth, and so it has less gravity.

When you think of motion, you may first think of something moving at a uniform speed.
Speed = (distance traveled)/(time)

There is a direct relation between the speed and the distance: the greater the distance traveled in a given time, the greater is the speed.

To describe motion of an object, one must consider its direction and speed. Velocity includes both the numerical value of the speed and the direction something is moving.

Galileo conducted several experiments to understand how something's velocity can be changed. He found that an object's velocity could be changed only if a force acts on the object. Newton took this as the beginning of his description of how things move, This is Newton's 1st law of motion. A force causes a change in something's velocity (acceleration).

Acceleration is a change in the speed and/or direction of motion in a given amount of time:
Acceleration = (the velocity change)/(the time interval of the change).
Something at rest is not accelerating and something moving at a constant speed in a straight line is not accelerating.

Acceleration is a change in speed. a satellite orbiting a planet is constantly being accelerated even if its speed is constant because its direction is constantly being deflected. The satellite must be experiencing a force since it is accelerating. The force is gravity. If the force of gravity is removed the satellite will move in a straight line along a path tangent to the original circular orbit.

In Newton's second law of motion, he said that the force applied = mass of an object _ acceleration. Mass is the amount of material an object has and is a way of measuring how much inertia the object has.

Newton also found that for every action force exerted on an object, there is an equal but opposite force by the object. This is Newton's Third Law of Motion.

Using Kepler's third law and his own second law, Newton found that the attractive force, gravity, between a planet and Sun a distance d apart is
Force = kp _ (planet mass) / $(d)^2$, where kp is a number that is the same for all the planets.

In the same way he found that the amount of the gravity between the Sun and a planet is
Force = ks _ (Sun mass) / $(d)^{2.}$

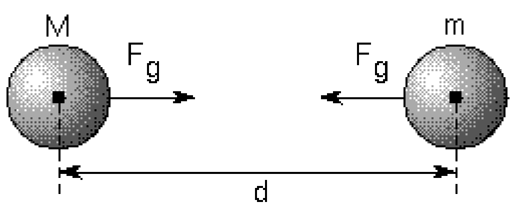
Using his third law of motion, Newton reasoned that these forces must be the same (but acting in the opposite directions).

The Law of Gravity:
The force of gravity = G _ (mass 1) _(mass 2) / $(\text{distance between them})^2$

The term G is a universal constant. If you use the units of kilograms (kg) for mass and meters (m) for distance:

G = 6.672 _ 10^{-11} m^3 /(kg sec^2).

Spherically symmetric objects such as planets, stars, moons, behave as if their mass is concentrated at their centers. When using Newton's Law of Gravity, measure the distance between the centers of the objects.



$$F_g = \frac{GMm}{d^2}$$

Newton stated that the law of gravity works for any two objects. It applies to motions on the Earth, and motions in space.

Gravity depends on the masses of the two attracting objects and their distance from each other. It does not depend on their chemical composition or density. Gravity is always attractive, never repulsive.

Gravity never becomes zero. Stars feel the gravity from other stars, galaxies feel gravity from other galaxies, galaxy clusters feel gravity from other galaxies, etc. Gravity acts over the huge distances in the universe.

Mass is a measure of how much material is in an object, but weight is a measure of the attraction force exerted on that material to another mass; mass and weight are proportional to each other.

In the metric system there is no confusion of terms. A kilogram is a quantity of mass and a newton is a quantity of force. One kilogram (kg) = 2.205 pounds of mass and 4.45 newtons (N) = 1 pound of force.

Lesson Description:

ENGAGE	*Vocabulary: velocity, acceleration.* Ask students to brainstorm 1. Why are planets and other space satellites able to remain in orbit without spinning wildly off in to space? 2. Where will this knowledge be important in space science?
EXPLORE	Set up your equipment as shown in the picture. *Around the World.* p. 100. Available: http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Microgravity/ One team member stands above the large ball and holds the end of the string. The second team member's job is to move the small ball in different ways to answer the following questions. Draw pictures to show what happened. Draw the pictures looking straight down on the two balls. *Accommodation: Provide a lab activity sheet with space for recording the sketches.*
EXPLAIN	1. What path does the satellite (small ball) follow when it is launched straight out from Earth? Show what happened looking down from above. 2. What path does the satellite follow when it is launched at different angles from Earth's surface? 3. What effect is there from launching the satellite at different speeds? 4. What must you do to launch the satellite so it completely orbits Earth?

	5. Using the results of your investigation and the information contained in the student reader, write a paragraph that explains how satellites remain in orbit. *Accommodation: A simple graphic organizer will be helpful to organize ideas before writing.*
EXTEND	Research some of the ways scientists use microgravity to investigate real world applications. pp. 13-43. The teacher may wish to assign a different topic to each group. Mathematics Connection: Calculate how fast a space shuttle orbiter and the International Space Station travel in order to orbit earth. Solve for velocity (v) using this data: V = square root of *GM/r* G= universal constant of gravitation = $6.67 \times 10^{-11} m^3 kg/s^2$ M_{Earth} = Earth's mass = 5.98×10^{24} kg r = radius of Earth + spacecraft's orbit r_{Earth} = 6.67×10^6 m orbiter altitude = 290 km International Space Station altitude = 350 km
EVALUATE	Draw a diagram that shows the effect of gravity on satellite orbiting the Earth. Include the moon and the sun and any other planets you wish in your diagram. ***Journal Write***: Write a short paragraph to explain the diagram.

Materials:
Large ball*
Small ball
2 meters of string
Flower pot*

* A world globe can substitute for the large ball and flower pot

Resources:
Microgravity — A Teacher's Guide with Activities in Science, Mathematics, and Technology, EG-1997-08-110-HQ, *Around The World*. Available:
http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Microgravity/

Earth Space Systems Science
Unit 5: The Space Sphere

National Aeronautics and Space Administration. Office of Life and Microgravity Sciences and Applications. Microgravity Research Division. Office of Human Resources and Education. Education Division

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 5: Comparative Geology of the Solar System- Atmospheres

Estimated Time: One to two forty-five minute class periods

Indicators(s): Core Learning Goal 1

1.4.2 The student will analyze data to make predictions, decisions, or draw conclusions.

1.5.4 The student will create and/or interpret graphics (scale drawings, photographs, digital images, etc.).

Indicators(s): Core Learning Goal 2

2.2.1. The student will explain the role of natural forces in the universe.
At least-- formation of planets, orbital mechanics, stellar evolution.

Student Outcome(s):

The student will be able to interpret atmospheric patterns of solar system planets by applying knowledge of the Earth's atmosphere and using satellite imagery.

Brief Description:

Students will recall their knowledge of the behavior of the Earth's atmosphere and global circulation patterns. Students will use this knowledge to interpret atmospheric patterns of other planets in our solar system.

Background knowledge / teacher notes:

Teachers will need to provide access to the PDF document *Storm Systems*. Exercise Eight. pp. 95-102. Planetary Geology: A Teacher's Guide with Activities in Physical and Earth Sciences EG-1998-03-109-HQ. Available in PDF format:
http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/.index.html#EG
NASA Headquarters. Solar System Exploration Division. Office of Planetary Geoscience. Education Office.
Planetary Geology will be posted at the AACPS/GSFC website. A better alternative is to print copies of the activity for the student. A class set should suffice. There is no copyright restriction on this document for teachers and students.

Few processes can be understood in isolation from other natural phenomena. Planet Earth is no exception. The forces that drive Earth's evolution and shape its surface have most likely operated elsewhere in the solar system. Earth scientists attempt to recognize those forces on all planets and explain why they are manifested on our world in ways that seem familiar, and on other worlds in ways that may not. Earth scientists are also concerned with earth materials, the building blocks of this planet. If there is one illuminating result of space exploration, it is the emergence of a unifying vision of the birth and growth of planets. Pictures of the planets sent back by spacecraft strongly suggest a close relationship among the inner planets. Rocks and soil brought back from the Moon bear remarkable similarity to Earth materials. Even spacecraft pictures of the outer planet satellites, many of which are planets themselves by virtue of their size, have astounded scientists with their exotic, but recognizable surfaces. Consider the other planets as great experiments running under conditions different from those on Earth. The result is to gain insight into planetary scale problems and to escape the limited earthbound view of nature.

A major goal of science is prediction. Once generalized theories are formulated, then experiments are designed to test the theories through their predictions. Some experiments that could address the questions of earth scientists simply cannot be performed on Earth because of their monumental proportions. We may have found those requirements in the atmospheres of Venus, Mars, and the outer planets.

Earth scientists are painfully aware that the processes active on Earth today have wiped clean much of the record of Earth's own history. However, relics and indirect evidence of our own past are often preserved on other planetary surfaces. A common tactic used by scientists to understand complex systems is to study simpler, analogous systems.

Earth is not unique in possessing an atmosphere. Venus, Mars, Pluto, and two of the satellites of the outer planets-Titan (a moon of Saturn) and Triton (a moon of Neptune) have atmospheres that envelop their surfaces. In addition, the giant planets of the outer solar system- Jupiter, Saturn, Uranus, and Neptune- are composed predominantly of gases. Other bodies in the solar system possess extremely thin atmospheres. Such bodies are the Moon (sodium gas), Mercury (sodium gas), Europa (oxygen) and Io (sulfur). The compositions of planetary atmospheres are different, for a variety of reasons. First, surface gravity, the force that holds down an atmosphere, differs significantly among the planets. For example, the large gravitational force of the giant planet Jupiter is able to retain light gases such as hydrogen and helium that escape from lower gravity objects. Second, the distance from the sun determines the energy available to heat atmospheric gas to a planet's escape velocity, the speed at which gas molecules overcome a planet's gravitational grasp. Thus, the distant and cold Titan, Triton, and Pluto are able to retain their atmospheres despite relatively low gravities. Finally, we know that the chemistry and geologic history are different for each planet. Because atmospheric makeup is generally related to chemistry and temperature during planetary formation and the subsequent escape of interior gases, the constituents and total pressures of planetary atmospheres are likely to be different. Moreover, on Earth, atmospheric composition is largely governed by the by-products of the life that it sustains. From the perspective of the planetary geologist, atmospheres are important in the ways they shape planetary surfaces. Wind can transport particles, both eroding the surface and leaving deposits. Frost and precipitation can leave direct and indirect marks on a planetary surface. Climate changes can influence a planet's geological history. Conversely, studying surface geology leads to an understanding of the atmosphere and climate of a planet- both its present state and its past.

The fundamentals of atmospheric circulation apply to other planets as well as Earth. In this lesson the student should understand the fundamental controls on atmospheric circulation, especially planetary rotation and the Coriolis effect.

The earth's weather patterns are complex, but some basic meteorological concepts can be understood by examining photographs of the Earth taken from space. Furthermore, comparing earth's cloud patterns to those of other planets that have very different atmospheres- Mars, Venus, and Jupiter- sheds light on some basic principles of atmospheric circulation. Air moves from areas of high pressure toward areas of lower pressure. The simple Hadley cell circulation model introduces atmospheric circulation. The pattern is driven by solar energy, which heats the equatorial regions. As the planetary comparisons of this activity indicate, rapid planetary rotation disrupts this simple pattern into multiple circulation cells and turbulent eddies. This occurs on Earth giving rise to cyclonic storms, which are low-pressure centers that result in inclement weather. The tilt of a planet can also affect the atmospheric circulation pattern, because the region of maximum solar heating will change with the season of the year. Venus rotates very slowly (once in 243 Earth days) and is tilted only 3° with respect to the plane of its orbit. Thus, Venus has a relatively simple pattern of atmospheric circulation that approximates a Hadley cell. The Coriolis effect is an imaginary force that causes deflection of air parcels due to a planet's rotation. On a planet rotating toward the east (such as the Earth and most other planets), this causes rightward deflection and counterclockwise rotation of winds in the Northern Hemisphere, and the opposite effect in the southern. The slow rotation of Venus makes the Coriolis effect unimportant there. However, like Earth, Mars has a 24-hour rotation period and the Coriolis effect is important.

To some students it will be readily apparent which way a storm is spiraling. Others may first want to sketch the spiraling clouds. If your pencil moves clockwise as it moves in toward the center of the spiral, then the clouds spiral clockwise, and vice versa.

Jupiter is a giant gas planet that has no solid surface; instead its atmosphere gets progressively denser with depth. At great depth within the atmosphere the pressure is so tremendous that the gases of the atmosphere are compressed into a liquid, and below this is the solid core of the planet. Jupiter rotates very rapidly, once in about 9 hours 55 minutes; Jupiter also has a large supply of internal heat. These factors contribute to complex, turbulent flow in the atmosphere. Neighboring bands in Jupiter's atmosphere typically have winds that blow in opposite directions. Vortices (spots) in the atmosphere are generally not Coriolis-induced; instead they develop along boundaries between bands as a result of the opposing winds. Imagining that a storm rotates like a pinwheel can help to reveal the directions that winds to either side are blowing. Most of Jupiter's spots are temporary features, appearing and disappearing as winds and eddies shift slightly.
The Great Red Spot of Jupiter, observed from Earth for more than 300 years, is a notable exception.

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson Description:

ENGAGE	Have students recall their knowledge of wind circulation, Coriolis Effect, and atmospheric circulation from Unit II. Have students read the Introduction to *Storm Systems*. Exercise Eight. <u>Activities in Planetary Geology for the Physical and Earth Sciences</u>. Available in PDF format: http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Planetary.Geology/ *Accommodation: Use a directed reading activity. The teacher may want to have the class complete questions 1 – 5 as a directed activity.*
EXPLORE	Have students use the photograph taken by the GOES-7 included in this activity to analyze weather patterns in questions 1-5.
EXPLAIN	***Journal Write***: Create a systems diagram to show the variety of forces that affect global circulation. (Students may wish to review what they have previously done in Unit II.) <u>GT Connection</u>: this is a place where the teacher might employ curriculum compacting. If the students can easily demonstrate the skills involved in interpreting global wind circulation, move on to the Extension activity (application to other planets).
EXTEND	Proceed to the analysis of Mars, Venus and Jupiter (questions 6-9).
EVALUATE	***Journal Write***: Explain what knowledge was used to interpret the planetary atmosphere of Venus, Mars, and Jupiter. Using information from the reading and the analysis activities, create a chart that compares each of the planetary atmospheres.

Materials:
Desk size world map for each student pair.
Resource packet, *Storm Systems*. Exercise Eight. (class set)

Resources:
Storm Systems. Exercise Eight. <u>Planetary Geology</u>: <u>A Teacher's Guide with Activities in Physical and Earth Sciences</u>
EG-1998-03-109-HQ. Available in PDF format:
http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/.index.html#EG
NASA Headquarters. Solar System Exploration Division. Office of Planetary Geoscience. Education Office.

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 6: Comparative Geology of the Solar System-- Landform Mapping of the Terrestrial Planets

Estimated Time: One to two forty five minute class periods

Indicators(s): Core Learning Goal 1

1.4.9 The student will use analyzed data to confirm, modify, or reject an hypothesis.
1.5.4 The student will create and/or interpret graphics (scale drawings, photographs, digital images, etc.).

Indicators(s): Core Learning Goal 2

2.2.1. The student will explain the role of natural forces in the universe.
At least-- formation of planets, orbital mechanics, stellar evolution.

Student Outcome(s):

1. The student will be able to compare the global-scale surfaces of the terrestrial planets by using satellite imagery.
2. The student will be able to make predictions about the age of the terrestrial planets based on a study of surface features.

Brief Description:

Students will use satellite images and knowledge of geologic processes to compare the terrestrial planets and make a prediction about the relative ages of the surfaces.

Background knowledge / teacher notes:

This lesson views Mercury, Venus, Earth, Moon, and Mars at the global scale. At this scale only the largest and most prominent landforms and terrains are visible. This provides a starting point for more detailed study of planetary surfaces. The Moon, although not actually a planet, is typically grouped with the terrestrial planets when considering its geology. An answer key is provided on page 116 of A Teacher's Guide with Activities in Physical and Earth Sciences (see reference list below).

At a global scale, only the largest planetary **landforms** and regions are visible and can be identified. Such landforms include large volcanoes, canyons, impact craters, plains regions, mountains, and highlands (topographically "high standing" regions). Although the Moon and planets formed at the same time (about 4.5 billion years ago) their surfaces differ in age. This difference is a variation in the levels of geologic activity on each body since their formation. The four main geologic processes **(volcanism, tectonism, gradation,** and **impact craterin**g) have worked to alter the original surfaces. In comparing planetary surfaces, relative ages are usually determined from impact craters. In general, older surfaces show more craters, larger craters, and more degraded craters than younger surfaces.

Credit: Teacher notes and student Introduction. Planetary Geology. *Landform Mapping*. Exercise Ten. Full reference below)

Lesson Description:

ENGAGE	*Vocabulary: terrestrial, rift zone, eject, impact crater.* Ask students to predict 1. What kinds of surface features that might expect to find on the moon and planets of the solar system 2. What kinds of clues might they get from surface features that would give clues to the age of the moon or planets. Ask students to give a rationale for their predictions.
EXPLORE	Have students read the introduction to the activity. How does the information in the Introduction compare to the students' predictions? *Accommodation: Directed reading may be needed to guide reading of the introduction.* *Analyzing the Moon:* Examine Figure 10.1. Place a piece of clear acetate over the photo. Trace the outline of the Moon. Divide the Moon by its two major regions- highlands (light) and plains (dark)- by outlining the light-toned and dark-toned areas.(On the Moon, the plains are called "maria" (which means "seas" in Latin) for their fanciful resemblance to oceans.)
EXPLAIN	***Journal Write***: 1. Which of the two regions appears to be most heavily cratered? 2. Which region on the Moon is older- the plains or the highlands? 3. Some large, young craters have bright ejecta deposits that form a star-like pattern of rays around them. 4. Trace two such craters and their deposits onto your acetate map. Are these craters older or younger than the plains?
EXTEND	*Analyzing the Planets:* Mercury Examine Figure 10.2. Answer each of these observational questions in your ***Journal*** What landforms and regions do you observe on Mercury? Based on the number of craters, do you think the surface of Mercury is older, younger, or about the same age as the plains on the Moon?

<u>Mars</u>

Examine Figure 10.3. Mars has a thin atmosphere, seasonal dust storms and polar ice caps (notice the bright south polar ice cap near the bottom of the figure). At one time, Mars had liquid water on its surface, although today Mars is too cold to have liquid water and only has ice. The darker spots within the bright region of the upper left of the image (marked A_D) are large volcanoes. Images sent back from surface landers and other remotely acquired data show that the lighter toned areas are relatively dusty and the darker toned areas are sandy or bare rock. Near the center of the image is Valles Marineris (marked E), a large canyon system of probable tectonic origin.

1. List similarities and differences in the features found on Mars compared to those on the Moon and Mercury.
2. Why is the surface of Mars different from the Moon? (List reasons to support your answer.)
3. Based on the number of impact craters, do you think the surface of Mars seen here is older, younger, or about the same age as the highlands on the Moon?
4. Based on the number of impact craters, which part of Mars is older, the northern or the southern region?

<u>Venus</u>

Although the atmosphere of Mars is relatively cloud free, the thick cloud cover on Venus completely hides the surface from viewing by cameras. Using **radar,** which can penetrate through clouds, the Magellan spacecraft sent back radar images of the surface of Venus. In general, these radar images show rough topography (such as mountains, **rift zones,** crater rims and **eject**a) as bright, and smoother material (plains) as dark. A volcano (A), a crater (B), and a canyon (C) have been labeled on the image.

1. Which planet looks more like Venus at the global scale: Mercury or Mars?

Compare Valles Marineris on Mars to Artemis Corona (the canyon marked C) on Venus.

2. How are their morphologies the same? How are they different?
3. Based on the number of craters, do you think the surface of Venus is older, younger, or about the same age as the highlands on the Moon?

<u>Earth</u>

Figure 10.5 shows a digital representation of the Earth, shown as it

	might look from space if it had no clouds and no oceans. In this way, Earth's landforms can be compared to those of other planets. 1. List some major landforms on Earth that are comparable to what you have seen on the other planets. *2.* List some different types of landforms you can see. *Accommodation: A Venn Diagram could be used when comparing planets.* *The questions about each planet could be discussed in a large group or as a small group activity.*
EVALUATE	1. List some similarities and differences between the landforms of the Earth and: a. Moon b. Mercury c. Mars d. Venus *Modification: Venn Diagrams comparing Earth to two other planets could be assigned instead of all four. (The teacher could assign one and the student could choose the other)* 2. Based on the number of craters, the number of geologic processes evident and the different types of landforms seen on the images, list the five surfaces you have examined in order : a. From oldest to youngest. b. From least complex to most complex. 3. Examine the table in the packet. Using a compass, draw circles showing the relative sizes of Mercury, Venus, Mars, the Moon, and Earth in your ***Journal***. Let the diameter of Earth equal 6 cm. 4. Before the initial reconnaissance of the solar system by spacecraft was completed, it was traditionally believed that the geological complexity of surface features on a solar system body would be related to the size of the body, larger planets being more geologically complex. Is this true of the terrestrial planets? Support your answer. GT Connection: Investigate the following as enrichment activities in Planetary Geology. *Geologic Features of Mars*. Exercise Eleven. *Geologic Features of Venus*. Exercise Twelve.

Earth Space Systems Science
Unit 5: The Space Sphere

Materials:
Landform Mapping. Exercise Ten. (class set)
Clear acetate sheets
Overhead projector markers
Metric ruler
Compass

Resources:
Landform Mapping. Exercise Ten. Planetary Geology: A Teacher's Guide with Activities in Physical and Earth Sciences
EG-1998-03-109-HQ. Available in pdf format:
http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/.index.html#EG
NASA Headquarters. Solar System Exploration Division. Office of Planetary Geoscience. Education Office.

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 7: Geologic Features of Outer Planet Satellites

SUPPLEMENTAL LESSON HONORS/GT

Estimated Time: Three to four forty five minute class periods

Indicators(s): Core Learning Goal 1

1.4.2 The student will analyze data to make predictions, decisions, or draw conclusions.
1.5.4 The student will create and/or interpret graphics (scale drawings, photographs, digital images, etc.).
1.5.8 The student will describe similarities and differences when explaining concepts and/or principles.

Indicators(s): Core Learning Goal 2

2.2.1. The student will explain the role of natural forces in the universe.
At least-- formation of planets, orbital mechanics, stellar evolution.

Student Outcome(s):

1. The student will be able to recognize the landforms associated with impact cratering by conducting a simulation.
2. The student will be able to relate knowledge of geologic processes to features found on the outer planet satellites.
3. The student will be able to compare geologic processes of the outer planet satellites by analyzing satellite imagery.

Brief Description:

Students will analyze a variety of data in order to make predictions about the geologic processes that have shaped the geologic features of the outer planet satellites. This lesson allows the student to develop skills in image interpretation and comparative planetology by analyzing similarities and differences in the landforms and the geological histories of four outer planet satellites. Incorporated are skills of geological mapping, description, and interpretation of tables.

Background knowledge / teacher notes:

The two Voyager spacecraft, launched in 1977 undertook reconnaissance of the giant, gaseous outer planets of the solar system and their major satellites. Voyagers 1 and 2 flew past Jupiter and its major satellites in 1979, then explored Saturn and its moons in 1980 and 1981. Voyager 2 flew past Uranus and its satellites in 1986 and explored the Neptune system in 1989. These spacecraft enabled the discovery of the spectacular diversity in the geology of the outer planet satellites. This exercise uses Voyager images of four of these moons- Ganymede and Io at Jupiter, and Enceladus and Rhea at Saturn- to illustrate this diversity. Most of the outer planet satellites

are composed of mixtures of rock and ice. The ice typically is water ice, but more exotic ices, such as methane, are present in some satellites, especially those circling
planets farthest from the sun. Io is unusual in being a rocky world, and in the predominance of active volcanism (Unit IV) which shapes its surface today. Ganymede and Enceladus show widespread evidence for past volcanism, but the "lava" that once flowed on these satellites is comprised of ice, rather than rock. Ganymede and Enceladus show clear evidence for tectonism, expressed as grooves and ridges. Tectonism has affected Io and Rhea to lesser degrees, and its expression will probably not be apparent to students from the images supplied in this exercise. The most observant students, however, may notice small grooves on Rhea and Io. The abundant cliffs on Io may be tectonic in origin, or they may be related to sublimation of a volatile material and subsequent collapse, a form of gradation. In general, gradational processes on outer planet satellites are not apparent at the scale of Voyager images and are not specifically addressed in this exercise. However, in discussing the morphologies of craters on Rhea, it would be useful to point out to students that the principal cause of crater degradation on that satellite is the redistribution of material by impact cratering. New craters pelt older ones, creating ejecta and redistributing material to subdue the forms of fresh craters over time. To a lesser extent, mass wasting probably acts to modify crater shapes through the action of gravity.

Planetary geologists study the solid surfaces of solar system objects. This includes the planets of the inner solar system and the moons, or **satellite**s, of all the planets. The giant gaseous planets of the outer solar system-Jupiter, Saturn, Uranus, and Neptune- have a total of 62 satellites.
The outer planets are far from the warmth of the Sun, so the satellites that circle them are very cold- so cold that many are composed partly or mostly of **ic**e. Much of the ice in these satellites is water ice. But some satellites probably contain other types of ice, including ammonia, methane, carbon monoxide, and nitrogen ices. Some outer planet satellites display many **impact crater**s, and some are less cratered. In general, an older surface shows more and larger impact craters than a younger surface. Also, younger features and surfaces will cut across or lie on top of older features and surfaces. Relatively fresh or large craters commonly show a blanket of bright **eject**a, material thrown from the crater as it was formed.

Volcanism and tectonism (Unit IV) can also shape the surfaces of outer planet satellites. Volcanism can erase craters while creating regions that appear smooth. On a rocky satellite, the volcanic lava will be rocky; on an icy satellite, an icy or slushy "lava" might emerge from the satellite's relatively warm interior. An irregularly shaped volcanic crater termed a caldera sometimes marks a center of volcanism. Tectonism can create straight or gently curving grooves and ridges by faulting of the surface. Commonly, an area smoothed by volcanism will be concurrently or subsequently affected by tectonism. A volcanic or tectonic feature must be younger than the surface on which it lies.

The **density** (Unit II) of a planet or satellite provides information about its composition. Density is a measure of the amount of mass in a given volume. Rock has a density of about 3.5 g/cm 3, and most ices have a density of about 1 g/cm 3 . This means that a satellite with a density of 3.5 g/cm 3 probably is composed mostly of rock, while a satellite of density 1 g/cm 3 is composed mostly of ice. A satellite with a density of 2 g/cm 3 probably is composed of a mixture of nearly equal amounts of rock and ice.

The **albedo** (Unit II) of a satellite is a measure of the percentage of sunlight that the surface reflects. A bright satellite has a high albedo, and a dark satellite has a low albedo. Pure ice or frost has a very high albedo. If a satellite's surface is icy but has a low albedo, there is probably some dark material (such as rock) mixed in with the ice. Even if the albedo of a satellite is completely uniform, the apparent brightness of the surface can change based on the positions of the Sun and the observer. The lit edge, or **lim**b, of a planet or satellite typically appears bright. The surface looks darker as the day/night line, or **terminato**r, is approached because that is where shadows are longest.

An answer key is provided on page 116 of A Teacher's Guide with Activities in Physical and Earth Sciences (see reference list below).

(Credit: Teacher notes and student Introduction. *Geologic Features of Outer Planet Satellites*. Exercise Thirteen. Additional background notes and suggestions in Instructor material, p. 150 of this guide. Answer key to questions available on pp. 151-153 of the guide. Full reference below)

Impact craters

Impact craters are found on nearly all solid surface planets and satellites. Although this exercise simulates the impact process, it must be noted that the physical variables do not scale in a simple way to compare with full-size crater formation. In other words, this exercise is a good approximation but not the real thing. Impact craters form when objects from space, such as asteroids, impact the surface of a planet or moon. The size of the crater formed depends on the amount of kinetic energy possessed by the impacting object. Kinetic energy (energy in motion) is defined as: KE = 1/2 (mv 2), in which m = mass and v = velocity. Weight is related to the mass of an object. During impact the kinetic energy of the object is transferred to the target surface.

Lesson Description:

ENGAGE	Ask students to discus what they know about how scientists gain knowledge of the outer planets and their satellites. Ask them to brainstorm how the outer planets and their satellites might be different from the inner planets.
EXPLORE	Place the tray on the drop cloth. Fill the tray with sand, then smooth the surface by scraping the ruler across the sand. Sprinkle a very thin layer of the colored sand over the surface (just enough to hide the sand

	below) using the flour sifter. Divide the tray (target area) into four square shaped sections, using the ruler to mark shallow lines in the sand. In one section produce a crater. Drop an intermediate sized steel ball bearing straight down (at 90-degree vertical) into the target surface. Hold the ball at arms length from sand surface (70 to 90 cm) facing straight down into the tray. Do not remove the projectiles after launch. Journal: Make a sketch of the plan (map) view and of the cross section view of the crater. Be sure to sketch the pattern of the light-colored sand around the crater. This material is called **eject**a. Label the crater floor, crater wall, crater rim, and ejecta on the sketch. Divide the target into four sections. Find the mass of each projectile and enter the values in a data table (shown below). Produce four craters by dropping 4 different sized steel ball bearings from a height of 2 meters above the target surface. Measure the crater diameter produced by each impact. Enter the projectile mass and resultant crater diameters in the table below. Calculate the kinetic energy of each projectile and enter the values in the table (provided). Remove the projectiles and smooth the target surface with the ruler. Divide the target into three sections. Produce three craters by dropping 3 identical size, but different mass, projectiles from a height of 2 meters above the target surface. Find the mass of each projectile and enter the values in the table below. Measure the crater diameter produced by each impact. Enter the projectile mass and resultant crater diameters in the table below. Calculate the kinetic energy of each projectile and enter the values in the table (provided). ***Journal Write***: According to the data collected, explain any relationship you may have found between 1. kinetic energy of the projectile and crater diameter 2. mass and crater size

<table>
<tr>
<td>EXPLORE
and
EXPLAIN</td>
<td>Students will now investigate a variety of landforms (including craters) which have been observed on satellites in the outer portion of the solar system.
Read the introductory material in the packet and examine the table of information.
Journal Write:
<u>Ganymede</u>
1. From what you have read, and using the information in the table, write a paragraph giving a description of Ganymede.

Examine Figure 13.1a, which shows part of the Sippar Sulcus region of Ganymede, and compare what you see to the geomorphic sketch map of the area (Figure 13.1b). Notice that the surface of Ganymede can be divided into two principal geologic units, bright terrain and dark terrain. The dark terrain is believed to be a mixture of ice and rock, while the bright terrain is probably composed mostly of ice.

Discuss with your team the similarities and differences of the bright and dark terrains.

Use your knowledge and the documents of satellite images provided to answer the questions.

2. List and describe the many characteristics of the bright and dark terrains. Be as detailed as possible. Include factors such as albedo, number of craters, general surface appearance, and other characteristics that are apparent.
3. Which of Ganymede's two principal terrain types is older? What is the evidence for this?
4. What is the age of the ejecta for the crater marked "A" relative to the bright and dark terrain? What is the evidence for this?
5. Many researchers believe that both volcanism and tectonism shaped the bright terrain of Ganymede. What is some evidence that this is true?
All the craters you can see in Figure 13.1a probably formed by the impacts of comets or asteroids. Many show small central pits, created as a result of impact into an icy target.

Four craters that show unusual morphologies are indicated in Figure 13.1b with the letters A through D.</td>
</tr>
</table>

6. Describe the shapes and characteristics of these interesting craters. Include the *dimensions* of each crater using the scale bar, and also describe the *characteristics* that make it peculiar compared to most other craters on Ganymede.

Enceladus

1. From what you have read, and using the information in the table, write a paragraph giving a description of Enceladus.
2. Make a geological sketch map of Enceladus. Use as a guide the map of Ganymede in Figure 13.1. Tape a piece of acetate over the photograph of Enceladus, Figure 13.2. Trace the outline of the satellite. You will find that it is simple to trace the satellite's limb, but the terminator is not as clearly defined.
3. Outline the most prominent craters on the satellite. You will have to decide which craters should be included.
4. Locate and describe two unusual looking craters.
5. Grooves on Enceladus are probably tectonic features; next map their locations. Draw a thin line along each groove you see, and place a dot near the center of each line to indicate it is a groove.
6. Where do grooves (and the ridges between them) occur on Enceladus?
7. The surface of Enceladus can be divided into three different types of terrain. Think about the features you have mapped so far, and decide on how to divide the surface into three terrains. Decide on names that describe your units. (For example, "cratered terrain.") Draw boundaries around the different units. There might be only one patch of each unit, or there could be more than one patch. To complete the map of Enceladus, label the units with the descriptive names that you have given them.
8. List the names of your three units. Following each name, describe the characteristics of each unit as *you* defined it in making your map of Enceladus.
9. Which is the oldest of these three major units on Enceladus? Which is the youngest of these three major units on Enceladus? Provide the evidence for your prediction.

Rhea

1. From what you have read, and using the information in the table, write a paragraph giving a description of Rhea.
2. Examine Figure 13.3, which shows a part of Rhea's surface. What is

the principal geologic process that has shaped this part of Rhea? Give evidence from the data for your response.

Notice the **morphologies** (shapes) of the craters that you see in Figure 13.3. The 60-km crater **A** shows a sharp and distinct morphology, with steep and well-defined slopes. On the other hand, the 65 km crater **B** is more difficult to identify, as it is rounded and indistinct. Keep in mind that the cratered surface of Rhea seen is probably about 4 billion years old.

3. Lay a piece of acetate over Figure 13.3, taping it at the top. Trace the rectangular outline of the photo, and also trace and label the scale bar. With a solid line, trace the outline of crater A, and label the crater "sharp." Next locate and trace the outline of crater B, but this time use a dashed line. Label this crater "subdued." Locate one additional sharp crater, outlining it with a solid line. Find an additional subdued crater, and outline it with a dashed line.

The terms "sharp" and "subdued" are descriptive terms, used to describe the morphologies of craters. Sharp-appearing craters are sometimes referred to as "fresh," while subdued-appearing craters are commonly referred to as "degraded."

4. What do the terms "fresh" and "degraded" imply about how a crater's morphology changes with time on Rhea?

Notice that some of Rhea's craters, including crater A, show central peaks. These peaks form upon impact, due to rebound of the floor during the "modification stage" of the cratering process.
On the acetate, outline as many central peak craters as you can confidently identify. Continue outlining each sharp crater with a solid line, and each subdued crater with a dashed line. Put a dark dot in the middle of each central peak crater that you identify.

5. Are central peaks more recognizable in sharp or subdued craters?
6. Based on your answer to the above, what can you infer about how the topography of a central peak changes over time?

Central peaks form only in craters above a certain diameter. This "transition diameter" from simple, bowl-shaped craters to more complex, central peak craters depends on surface gravity and material properties,

<table>
<tr><td></td><td>so it is different for each planet and satellite. Estimate the transition diameter for craters on Rhea based on the smallest central peak craters that you are able to identify.

<u>Io</u>
1. From what you have read, and using the information in the table, write a paragraph giving a description of Io.

Examine Figure 13.4, which shows part of the surface of Io. The very high albedo material is considered to be sulfur dioxide frost. When the two Voyager spacecraft flew by Io in 1979, they photographed nine actively erupting volcanoes.

2. Examine the feature in the far northeast corner of the image, which shows a central depression with relatively low albedo (dark) material radiating from it. What process created this feature? What is the evidence or rationale for your response?
3. Describe in detail the shape of the central depression. Use a labeled sketch.
4. Examine the other craters and surface features seen in Figure 13.4. What is the principal process shaping the surface of Io? List some observations that support your answer.</td></tr>
<tr><td>EXTEND</td><td>Consider the surface of Rhea (Figure 13.3) in comparison to the surfaces of Ganymede (Figure 13.1) and Enceladus (see Figure 13.3 and your sketch map).
Journal Write:
1. Compare the general appearance of the surface of Rhea to the surfaces of Ganymede and Enceladus.
2. What do the differences in surface appearance suggest about the geological history of Rhea as compared to the histories of Ganymede and Enceladus?
3. Contrast the characteristics of craters that you see on Io to those on Rhea. List at least four differences between Io's volcanic craters and Rhea's impact craters.
4. Construct a chart to rank the relative importance of impact cratering, volcanism, and tectonism on the four outer planet satellites that you have studied, based on the images you have seen. Use numbers from 1 (for the satellite most affected) to 4 (for the satellite least affected).</td></tr>
</table>

EVALUATE	Journal Write: 1. Create a systems diagram which relates geologic processes and land-forms found on the outer planet satellites. 2. Use the information you have learned in this activity and previous activities to compare geologic processes of the inner planets (including Earth) to the geologic processes of the outer planets. Use the Science Rubric to guide your response. GT Extension *What's On Mars and How Do We Know?* NASA GSFC. Available: http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/mola.abstract.html Students will review tectonic and erosional features prior to a treasure hunt to find them on the Martian surface using new data from the MOLA instrument on the Mars Global Surveyor (MGS) spacecraft. They will be able to ground truth their work to online images.

Materials:
Explore activity
For each student group: Sand, tray, colored sand, drop cloth, screen or flour sifter, safety goggles(one for each student), triple beam balance, ruler, lamp, calculator
Projectiles: 4 different sizes of steel ball bearings; 3 identical sized objects with different densities (large ball bearing, marble, wood or foam ball, rubber superball)

Planetary Geology. *Geologic Features of Outer Planet Satellites*. Exercise Thirteen. (Class set)

Clear acetate or overhead projector transparencies (2 sheets per student or group), overhead projector markers (colored markers can be used for added clarity)
Substitutions: Tracing paper, pencils (colored pencils for added clarity)

Resources:
Geologic Features of Outer Planet Satellites. Exercise Thirteen. Planetary Geology: A Teacher's Guide with Activities in Physical and Earth Sciences
EG-1998-03-109-HQ. Available in PDF format:
http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/.index.html#EG
NASA Headquarters. Solar System Exploration Division. Office of Planetary Geoscience. Education Office.

What's On Mars and How Do We Know? NASA GSFC. Available:
http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/mola.abstract.html

Earth Space Systems Science
Unit 5: The Space Sphere

Students will review tectonic and erosional features prior to a treasure hunt to find them on the Martian surface using new data from the MOLA instrument on the Mars Global Surveyor (MGS) spacecraft. They will be able to ground truth their work to online images.

Explore Activity: Data Tables

Part 1

	Velocity (m/sec)	Mass (kg)	KE (Nm = kg m2/sec2)	Crater Diameter (cm)
Shot 1 (smallest)	6.3			
Shot 2 (next larger)	6.3			
Shot 3 (next larger)	6.3			
Shot 4 (largest)	6.3			

Part 2

	Velocity (m/sec)	Mass (kg)	KE (Nm = kg m2/sec2)	Crater Diameter (cm)
Shot 1 (steel)	6.3			
Shot 2 (wool)	6.3			
Shot 1 (wood)	6.3			

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 8: Formation of the Solar System

Estimated Time: Two forty five minute class periods

Indicators(s): Core Learning Goal 1
1.4.9 The student will use analyzed data to confirm, modify, or reject an hypothesis.
1.5.4 The student will create and/or interpret graphics (scale drawings, photographs, digital images, etc.).
1.5.9 The student will communicate conclusions derived through a synthesis of ideas.
1.7.2 The student will identify and evaluate the impact of scientific ideas and/or advancements in technology on society.

Indicators(s): Core Learning Goal 2
2.2.1. The student will explain the role of natural forces in the universe.
At least-- formation of planets, orbital mechanics, stellar evolution.

Student Outcome(s):
1. The student will be able to explain current thinking about the formation of the solar system by reading technical documents and viewing animation and Hubble Telescope Images of the solar system.
2. The student will be able to explain how evidence from satellite data supports or refutes current thinking on the formation of the solar system

Brief Description:
In this lesson students retrieve what they already have learned about the solar system and then read a variety of technical documents and graphics to add to their knowledge base. There is also a connection made to contributions of a variety of cultures to our knowledge base. Finally, students are asked to refer back to their journal writings from the comparative geology of the solar system to support or refute current thinking about the formation of the solar system.

Background knowledge / teacher notes:
Each of the short video clips in this lesson may be downloaded and saved to the server for student viewing and reviewing.

Lesson Description:

ENGAGE	*Vocabulary: nebula, planetsimals.* Engage students by having them retrieve what they know about our solar system. Ask students to include prior knowledge as well as knowledge from current learning activities. Ask students to organize the knowledge or create a concept map about the formation of the solar

	system. *Accommodation: The class could construct this concept map as a group if teacher guidance is needed.*
EXPLORE	Have students go to the University of Texas McDonald Observatory website, StarDate Online. *Solar System Guide: Planet Formation*. Available: http://stardate.utexas.edu/resources/ssguide/planet_form.html Ask student to compare the information in the article to what they have in their concept map. Students should add information they do not have and delete any misinformation. Students may then click on the hot links to the right to continue to put together key ideas on solar system formation. Ask students to click on the enlarged image of the Orion nebula to view an actual nebula. Students may use this photograph from the Hubble Telescope to add details to the concept map. View Cloud collapse: face-on, and edge-on (1.7 Mbyte mpegs). both are quite short (seconds) but may be reviewed several times. *Formation of the Solar System*. Scroll down to Web Resources: and click on **Cloud collapse**. Available: http://www.ifa.hawaii.edu/faculty/barnes/ast110/fotss.html Computer simulations of a cloud of gas collapsing to a thin rotating disk. Separate views face-on and edge-on to the disk are shown. Color indicates gas density, with blue for the lowest densities and red for the highest densities. NOTE: THESE MAY BE DOWNLOADED IN ADVANCE AND SAVED ON THE SERVER FOR STUDENT VIEWING. After viewing these video clips students should add details to their concept maps. View **Planetary Motion- Inner planets**, 231K**, Inner planets 30 degrees tilt**, 182K, **All planets, 2 Earth revolutions**, 297K**, All planets, 4 Earth revolutions**, 528K. Our Solar System: *The Planets and Their Motion*. Scroll down to **Planetary Motion**. Available: http://athena.wednet.edu/curric/space/planets/index.html EACH OF THESE IS A SHORT VIDEO CLIP AND MAY BE DOWNLOADED TO THE SERVER IN ADVANCE. After viewing these video clips students should add details to their concept maps. *Accommodation: Remind students to preview reading before reading*

	as they click on the links *The teacher may want to begin to model this activity by demonstrating how the explanation can be written using the systems diagram as the graphic organizer and following the sequence of the diagram.*
EXPLAIN	***Journal Write***: Students should work in their groups to construct a systems diagram that illustrates the formation of the solar system. Write an explanation of the formation of the solar system using the concepts learned in the exploration and organized in the systems diagram.
EXTEND	Multicultural Connection: Investigate the contributions of other cultures to our knowledge of astronomy. Ancient Egyptian culture: *Creation and Cosmic Order*. Available: http://stardate.utexas.edu/radio/features/egypt/s_intro.html Latino Community: *StarDate Online Celebrates Hispanic Heritage Month.* Available: http://stardate.utexas.edu/radio/features/hhm/intro1.html Ancient Muslim culture: *Ulugh-Beg*. Available: http://stardate.utexas.edu/radio/sd_search.taf?f=detail&id=19970900 The Mayan culture. *The Mayan Astronomy Page*. Available: http://www.michielb.nl/maya/astro.html ***Journal Write***: Compare your investigation of cultural contributions to current thinking on the solar system.
EVALUATE	***Journal Write***: Think about and review the evidence gathered about the solar system in your Earth/Space Journal from satellites in the following activities: Comparative Geology of the Solar System: Atmospheres, Comparative Geology of the Solar System: Landform Mapping of the Terrestrial Planets, and Geologic Features of Outer Planet Satellites. Explain how the evidence from satellites gathered in these previous activities supports or refutes current thinking about the formation of the solar system. *Modification: Complete a graphic organizer with the class before writing.*

Earth Space Systems Science
Unit 5: The Space Sphere

Materials:
Computer and Internet connection
Newsprint and markers for concept maps

Resources:
Ancient Egyptian culture: *Creation and Cosmic Order*. Available:
http://stardate.utexas.edu/radio/features/egypt/s_intro.html

Ancient Muslim culture: *Ulugh-Beg*. Available:
http://stardate.utexas.edu/radio/sd_search.taf?f=detail&id=19970900

Cloud collapse. Available:
http://www.ifa.hawaii.edu/faculty/barnes/ast110/fotss.html

Latino Community: *StarDate Online Celebrates Hispanic Heritage Month*. Available:
http://stardate.utexas.edu/radio/features/hhm/intro1.html

The Mayan culture. *The Mayan Astronomy Page*. Available:
http://www.michielb.nl/maya/astro.html

Planetary Motion. Available:
http://athena.wednet.edu/curric/space/planets/index.html

University of Texas McDonald Observatory website, StarDate Online. *Solar System Guide: Planet Formation*. Available:
http://stardate.utexas.edu/resources/ssguide/planet_form.html

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 9: The Solar Connection

Estimated Time: Three to four forty five minute class periods

Indicators(s): Core Learning Goal 1

1.5.6 The student will read a technical selection and interpret it appropriately.

1.7.6 The student will explain how development of scientific knowledge leads to the creation of new technology and how technological advances allow for additional scientific accomplishments.

Indicators(s): Core Learning Goal 2

2.1.1. The student will describe current efforts and technologies used to study the atmosphere, land, and oceans of the Earth.
At least-- remote sensing from space, undersea exploration, seismology, weather data collection

2.1.2. The student will describe current efforts and technologies used to study the universe.
At least-- optical telescopes, radiotelescopes, spectroscopes, satellites, space probes, manned missions.

Student Outcome(s):

1. The student will be able to explain how the earth is affected by solar activity by analyzing data.
2. The student will be able to describe how the IMAGE satellite is used to study the atmosphere and near space environment.

Brief Description:

This lesson builds from some simple introductory activities dealing with analysis of solar activity to the study of a current NASA mission. Student teams tackle a variety of activities and then share their findings with the class.

Background knowledge / teacher notes:

There are a variety of suggested activities in this lesson plan. The teacher will have to chose those that are best suited to the class. Other satellite missions may be investigated in place of the IMAGE mission. It was chosen because it is current at the writing of this curriculum and will investigate the solar connection.

The outer layers of the Sun, called the Corona, are not stable but are constantly escaping into space. Although the magnetic field of the Sun 'bottles up' some of the hot gases near the solar surface to make spectacular prominences, in other regions the magnetic field opens into interplanetary space and allows the million-degree gases to escape as a Solar Wind.

Within the equatorial region of the Sun, the solar wind travels outwards in a pinwheel- shaped spiral pattern due to the combination of the outward gas motion, at over 400 kilometers/sec (1 million miles/hour), and the rotational motion of the Sun. Although its normal density is less than 10 atoms per cubic centimeter, because the wind is spread out over such a vast volume of space, it amounts to over 50 billion tons of mass lost per day (50 trillion kilograms/day), mostly in the form of high- speed electrons and protons - the components of the most abundant element in the Sun: hydrogen.

On occasion, and for reasons not fully understood by scientists, the magnetically trapped gases in the Sun's corona can become unstable and get ejected into space as Coronal Mass Ejections, or CMES. These clouds are carried by the solar wind. They are often as big as the Sun itself, and they contain upwards of one billion tons of matter in a single event that may last only a few hours. Traveling at speeds from 450 to 1000 kilometers/sec, the trip from the Sun to the Earth's orbit takes only a few days. Most of these clouds dissipate quickly and merge into the solar wind while others can remain cohesive, though substantially diluted by the time they reach the Earth. Most of these CMEs never collide with the Earth, but those that do can cause satellite damage and brilliant auroral displays, so their effects are not inconsequential.

Like Stealth Bombers, it is not the ones we can detect on the limb of the Sun that pose a hazard to us here on Earth, it is the ones that are lost in the glare of the solar surface that can potentially reach Earth. NASA has stationed satellites in space between the Earth and the Sun to provide advanced warning for stealthy CME events, but even so, only about 1-2 hours of warning is possible from such distant outposts.

The Earth is the only one of the four inner planets (Mercury, Venus, Earth and Mars) that has a substantial magnetic field. Shaped very much like a bar magnet, and powered by enormous currents of electricity in the molten core of the Earth, this field extends millions of miles into space to form the magnetosphere. Outside this region, charged particles from the Sun and deep space, may be deflected or may leak into the interior of this region to form the Van Allen Belts, or produce auroral activity. This field changes in complex ways as CMEs find their way to the Earth and impact the magnetic field. Observatories on the ground have kept track of the strength and direction of the Earth's magnetic field for over a century. Their records show that rapidly changing field conditions are common, especially when the Sun is active. The most dramatic of these episodes are called the geomagnetic storms which can last several days. Less intense changes can last hours or minutes and are called geomagnetic sub-storms. Navigation by compass is especially difficult during either of these magnetic storms because compass bearings can change by 10 degrees or more during the course of a few hours. As anyone familiar with using a map and compass can tell you, without knowing the 'magnetic deviation', it is impossible to use a compass to determine where geographic north is located. As a result, surface navigation can become dangerously imprecise.

Earth Space Systems Science
Unit 5: The Space Sphere

Aurora have been observed for thousands of years and they are the most dramatic indications of solar activity. They are produced when flows of energetic charged particles collide with the upper atmosphere. The brilliant colors from reds to purples indicate atoms of oxygen and nitrogen being stimulated by these collisions to give off specific wavelengths of light. They are produced at elevations from 65 kilometers to 1000 kilometers, under conditions where the atmosphere is a better vacuum than you would find inside a TV picture tube. Because of the specific way in which the light is produced, it is impossible for aurora to happen in the higher-density layers of the atmosphere below 50 kilometers. Despite the appearances to casual observers, the aurora never reach the ground. Auroral activity is most intense during times when solar activity is the highest and the Coronal Mass Ejections make their way to Earth to impact the magnetosphere. They can also be produced as various parts of the magnetosphere rearrange in the so-called geo-tail region, which extends millions of miles into space on the opposite 'night time' side of the earth from the sun.

The ionosphere is a narrow zone of charged particles in the earth's atmosphere. It was not discovered until 'wireless' radio communication was invented around the turn of the century. It has an average density of about 1O electrons per cubic centimeter, but can be 10 to 100 times as 'charged' during solar storms. At low frequencies below 10 megacycles, the ionosphere acts like a mirror and allows ground to ground signals to be 'bounced' long distances around the earth. At higher frequencies the ionosphere becomes transparent so that communication via ionosphere bounce becomes impossible. Instead, we must rely on satellite communication to relay signals from point to point on the earth. The properties of the ionosphere change with the time of day, the season, and especially with the level of solar activity. In the later case, solar flares can cause radio signal 'fade outs' which are well-known to amateur radio operators.

Lesson Description:

ENGAGE	*Vocabulary: prominence, solar wind, Coronal Mass Ejections, aurora, sunspots, solar flares, magnetic storms.* Ask students to brainstorm the effects of the sun on Earth and our human activities. Have students read the on-line document the NASA GSFC *Solar Activity and You!* Available: http://image.gsfc.nasa.gov/poetry/workbook/primer.html Ask students to create a concept map that details the main ideas of the article.
EXPLORE	Divide the class into teams to explore and analyze data and then report on a solar connection: **Solar Activity Cycles** *Activity 1: The Sunspot Cycle*. Available: http://image.gsfc.nasa.gov/poetry/workbook/page1.html

	The student will create a list and construct a graph of the number of sunspots using both technology and paper. The student will explore patterns in the data and locate the maximum and minimum. **The Solar Wind** *Activity 4: Coronal Mass Ejection Plotting Activity*. Available: http://image.gsfc.nasa.gov/poetry/workbook/page4.html Students will construct a table of values and plot the points in order to make a prediction *Activity 5: Solar Activity and Coronal Mass Ejections*. Available: http://image.gsfc.nasa.gov/poetry/workbook/page5.html Students will construct a graph to compare the sunspot cycle with Coronal Mass Ejection events. **Magnetic Storms** *Activity 6: Anatomy of a CME Storm*. Available: http://image.gsfc.nasa.gov/poetry/workbook/page6.html Students will compare and interpret four graphs involving the speed, temperature, density and magnetic field strength of a Coronal Mass Ejection. *Activity 7: Magnetic Storms from the Ground*. Available: http://image.gsfc.nasa.gov/poetry/workbook/page7.html By analyzing graphical data, students will become familiar with the Earth's changing magnetic field through solar storm activity plots. *Accommodation: Assistance from honors students or parent volunteers may be needed to facilitate these five groups.* *Modification: The teacher may need to eliminate some groups if students need support during this activity.*
EXPLAIN	***Journal Write***: Students will explain the topic they explored by discussing how they used data to determine a relationship. The teacher should provide time for a representative group of students to share their explorations and analyses. *Accommodation: Each group should prepare a presentation (oral and visual) to share with the class.*
EXTEND	Investigate the Imager for Magnetopause to Auroral Global Exploration (IMAGE) spacecraft mission. Students may be divided into groups to report on the following aspects of this mission: · *Activity 14: IMAGE Satellite Scale Model*. Available:

	http://image.gsfc.nasa.gov/poetry/workbook/page14.html The students will construct a scale model of the IMAGE satellite. · Report and explain the Image mission facts and scientific objectives this mission will address. *Image Science Center*. Available: http://image.gsfc.nasa.gov/ *NASA Facts Image Factsheet*. Available: http://pao.gsfc.nasa.gov/gsfc/spacesci/image/factsheet.htm Report and explain current mission findings by reading the Image press releases. *IMAGE: Press Releases*. Available: http://image.gsfc.nasa.gov/press_release/ *Accommodation: Again assistance from honors students or parent volunteers may be helpful to facilitate groups.*
EVALUATE	1. Use your concept map and findings from your team and other teams to create a systems diagram of how solar activity affects the Earth. 2. Write a brief press release to explain the importance of the IMAGE satellite mission to the general public.

Materials:
All activities: Computer with Internet access

Explore Activity
Activity 1: The Sunspot Cycle
Graph paper (18 kby) - available online
Ruler
Colored pencils
Sunspot data table -available online
Optional:
Graphing calculator
Teacher notes on the graphing calculator.... - Available online Part 1(19 kby).....Part 2(16 kby)

Activity 4: Coronal Mass Ejection Plotting Activity
Student page and Teacher Answer Key -available online
Calculator
Colored pencils

Activity 5: Solar Activity and Coronal Mass Ejections
Graph paper
Colored pencils
Student worksheet -available online
Optional:
Teacher notes on the graphing calculator, Part 1 and Part 2. -available online
Graphing calculator

Activity 6: Anatomy of a CME Storm
Graph paper
Prepared transparencies -available online
Graph Summaries -available online
Combining the Clues -available online

Activity 7: Magnetic Storms from the Ground
5-station magnetic field data sheet for Students and Teacher's Answer Key -available online
Calculator
Map of Canada for Students and Teacher's Answer Key. -Available online

<u>Extend Activity</u>
Activity 14: IMAGE Satellite Scale Model
Compass
Ruler
8 1/2 x 11 paper
Scissors
Tape
Spacecraft Design Dimensions -Available online
Student Direction Guide -Available online
Colored pencils

Resources:
Activity 1: The Sunspot Cycle. Available:
http://image.gsfc.nasa.gov/poetry/workbook/page1.html

Activity 4: Coronal Mass Ejection Plotting Activity. Available:
http://image.gsfc.nasa.gov/poetry/workbook/page4.html

Activity 5: Solar Activity and Coronal Mass Ejections. Available:
http://image.gsfc.nasa.gov/poetry/workbook/page5.html

Activity 6: Anatomy of a CME Storm. Available:
http://image.gsfc.nasa.gov/poetry/workbook/page6.html

Activity 7: Magnetic Storms from the Ground. Available:
http://image.gsfc.nasa.gov/poetry/workbook/page7.html

Activity 14: IMAGE Satellite Scale Model. Available:
http://image.gsfc.nasa.gov/poetry/workbook/page14.html

Image Science Center. Available:
http://image.gsfc.nasa.gov/

NASA Facts Image Factsheet. Available:
http://pao.gsfc.nasa.gov/gsfc/spacesci/image/factsheet.htm

NASA GSFC *Solar Activity and You!* Available:
http://image.gsfc.nasa.gov/poetry/workbook/primer.html

POETRY. *Background information about space science*. Available:
http://image.gsfc.nasa.gov/poetry/resources.html
A list of essays and other articles that describe the IMAGE mission, the importance of space science research, and how solar storms can influence our technology in many ways. Includes a glossary of hundreds of terms used in space science and solar physics.

Earth Space Systems Science
Unit 5: The Space Sphere

Lesson 9A: The Solar Connection and the Magnetosphere

Estimated Time: Two to three forty-five minute class periods

Indicators(s): Core Learning Goal 1

1.4.1 The student will organize data appropriately using techniques such as tables, graphs, and webs (for graphs: axes labeled with appropriate quantities, appropriate units on axes, axes labeled with appropriate intervals, independent and dependent variables on correct axes, appropriate title).

1.4.2 The student will analyze data to make predictions, decisions, or draw conclusions.

1.4.3 The student will use experimental data from various investigators to validate results.

Indicators(s): Core Learning Goal 2

2.1.1. The student will describe current efforts and technologies used to study the atmosphere, land, and oceans of the Earth.
At least-- remote sensing from space, undersea exploration, seismology, weather data collection

2.1.2. The student will describe current efforts and technologies used to study the universe.
At least-- optical telescopes, radiotelescopes, spectroscopes, satellites, space probes, manned missions.

Student Outcome(s):

1. The student will be able to compute the relative size of the Earth's magnetosphere by using satellite orbits and satellite data.
2. The student will be able to identify the benefits of the magnetosphere by analyzing satellite data.

Brief Description:

In this lesson students examine one relationship between sun and Earth- solar storms and the protection the magnetosphere provides. This activity is largely a NASA Ambassador lesson, *Magnetosphere, Protector of the Earth* (a look at solar storms has been added). See reference and credit below. Students use current satellite data to examine the magnetosphere and associated radiation from solar storms.

Background knowledge / teacher notes:

Solar X-rays

When quiet, the Sun does not produce many X-rays, but when active, X-rays are generally the first warning that some potentially damaging increase in solar wind is possible. Because Earth's atmosphere absorbs X-rays, satellites in high orbit must sense them. Instruments onboard a GOES weather satellite observe X-rays within 8 minutes of the activity on the Sun that caused

the increase. Like visible light and all electromagnetic radiation, X-rays travel at a speed of 3 x 10^8 m/sec. Recently it has become possible to obtain an image of the Sun at X-ray wavelengths from a telescope on a satellite. Today's space weather has today's X-ray plot and image. Observe the active and quiet Sun with the corresponding X-ray plot in the NASA image *from Solar Output*. Available:
http://athena.wednet.edu/curric/space/solterr/output.html

Further information
Solar Storm Eyed as Satellite Killer. Dr. Sten Odenwald (Raytheon STX, NASA Goddard Space Flight Center) is available at http://image.gsfc.nasa.gov/poetry/workbook/p63.html

Terrestrial Effects of Magnetic Storms. Available:
http://ssdoo.gsfc.nasa.gov/education/lectures/magnetosphere.html#storms

IF THERE IS SUFFICIENT INTERNET ACCESS, STUDENTS MAY WORK RIGHT FROM THE COMPUTER AND THERE S NO NEED TO PRINT OUT THE STUDENT PROCEDURES.

Lesson Description:

ENGAGE	Have students view today's images of the sun by going to *Observe Today's Space Weather.* Available: http://athena.wednet.edu/curric/space/solterr/todaysp.html Scroll down and focus on Today's Images and Plots and then X-ray Image. This is of special interest because the bright spots are indications of solar wind. Scroll down further to Planetary K-index and click on the graph. This will give you an update graph of solar wind. K-indices of 5 or greater indicate storm-level geomagnetic activity. The page is updated dynamically every 15 minutes. Ask students of what importance solar storms are to us hereon Earth. Students may have heard of disruption of satellites and power grids during severe solar storms.
EXPLORE	Now view the diagram of the Earth's magnetic field by going to *MAGNETOSPHERE -- PROTECTOR OF THE EARTH.* Available: http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/earth-sunconnections/inv1/magnet.abstract.html Have students read to be informed and discuss the article *The Magnetosphere*. (Dr. James L. Green) Section 2. The Shape of the Magnetosphere. (See glossary below.)

EXPLAIN	***Journal Write***: Create a concept map that organizes the information you have learned about the magnetosphere from viewing images of the sun and magnetosphere and reading about the magnetosphere.
EXTEND	Step 1. Go to http://www-spof.gsfc.nasa.gov/cgi-bin/gif_walk and view the picture of the magnetic field of the Earth. The picture shows the relative distance of the magnetopause and bow shock from Earth in RE (Earth Radii). Using this diagram you will convert the distance into kilometers. Step 2. This image is the most current satellite trajectory. Scroll down to the date box at the bottom of the page, change date format to YYMMDD. (For a sample orbit path set the date to June 14 - June 17, 1999). Answer questions 1-3 on the Student Worksheet. Click on the update date/plot type to give you your trajectory. The dots on the orbits of the satellites represent the day of the year, where the days are in numeric order, beginning with day 1 being January 1 and day 365 being December 31. Look at the sample chart for Question 4 on the student work sheet. For each day of Geotail's flight, an X was placed in each region showing where the satellite was on that particular day. Step 3. To determine the importance of the bow shock and the magnetopause, scientists have to analyze data collected both inside and outside of these areas. NASA uses a series of satellites to measure the amount of ion concentration and the strength of the magnetic fields to identify changes between the Earth's magnetosphere and the interplanetary space. This massive amount of data is entered into a program that produces graphs for scientists to use in their analysis. The site is called Coordinated Data Analysis Web (CDAWeb) and will be used for your investigation. Go to the Coordinated Data Analysis Web (CDAWeb) http://cdaweb.gsfc.nasa.gov/ and click on ISTP Key Parameters publicly available data. Click on the boxes <u>Sources</u>: · Geotail <u>Instrument Types</u>:

	· Magnetic Field · Plasma and Solar Field After you have selected the correct boxes, click on the submit button. Step 4. Now that you have selected the satellite and the instruments that you will be analyzing, you must select the data from those instruments that you want to see on a graph. Click on the buttons: · GE_K0_CPI: Geotail Comprehensive Plasma Inst (CPI), Key Parameters (U. Iowa) · GE_K0_MGF: Geotail Magnetic Field Instrument - S. Kokubun (STELAB Nagoya Univ., Japan) This will show you ion density and velocity and the magnetic fields. After you have made your selections, click on the submit button. Step 5. Now you are ready to set your time span. In the CDA Web Data Explorer at the top of your screen, set a start time and stop time date that corresponds to the dates from the satellite trajectory. Leave the time set at 00:00:00 so that you will begin on one day and end at the last day. Scroll down until to select the parameters for the graphs. <u>Variable parameters (required for Listing and Plotting data only)</u> <u>GE_K0_CPI</u> <u>Geotail Comprehensive Plasma Inst (CPI), Key Parameters (U. Iowa)</u> · Ion number density (Solar Wind Analyzer), scalar · Ion bulk flow velocity, 3 ~GSE Cartesian components (SWA) <u>GE_K0_MGF</u> · Magnetic Field Magnitude After you have set the parameters, click on the submit button to create your graphs. Step 6. Step 6: Look at the sample graphs at http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/magnet.html#procedure ions pile up at the magnetopause much like cars pile up in a

	traffic jam. When you compare this graph with the orbit plots from Step 2, you should be able to identify what region the satellite is at any given time. Knowing the region you can then identify the ion concentrations and the magnetic field strength of each of these regions. The two important graphs to view are the two top graphs which show ion density concentration, and the main component of the solar wind speed, respectively. Normal density outside bow shock is around 5, and speed is around 400 km per second. Next you will see a graph labeled GE_KO_MGF, which shows magnetic field strength. Look at the sample completed chart in Question 4. Step 7. Now that you have looked at the sample, go back and repeat steps 2-6 selecting your own data. Fill in the data chart on Question 4 and answer Questions 5-12 on the student worksheet. Step 8: Space Radiation is high energy radiation originating from solar flares or the explosion of supernovas in or around the Galaxy. They consist of protons, electrons and positrons and are classified into three types with difference in originating source or domain, solar cosmic ray, galactic cosmic ray and extragalactic cosmic ray. If astronauts on board a space station are exposed to these space radiation particles for a long time, it could result in producing skin cancer or harmful effects on their genes. As humans begin to stay in space for longer and longer periods of time, the effects of space radiation exposure will need to be studied further. Go to http://www.sel.noaa.gov/primer/primer.html for an explanation on radiation hazards to humans. Step 9. Go to http://windows.engin.umich.edu/ click on Enter the Site, click on Solar System, click on Mars. After reading this selection, answer the final questions on the student worksheet.
EVALUATE	***Journal Write***: Explain 1. How does satellite data provides information about the magnetosphere 2. Why is the magnetosphere of benefit to the Earth

Earth Space Systems Science
Unit 5: The Space Sphere

Materials:

Computer with Internet access
Calculator
Student worksheet. Available:
http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/earth-sunconnections/inv1/magnet.wksheet.html
Print out of procedure
Print out of Mars activity
Print out of magnet activity

Resources:

Credit: Goddard Space Flight Center Earth and Space Sciences Education Project (GESSEP)
Principal Investigator: Steve Gilligan. Co-Investigator: Vern Smith
Magnetosphere - Protector of the Earth. Available:
http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/earth-sunconnections/inv1/magnet.abstract.html
Cheryl Overington, Principal Investigator
Marilyn Tupis, Principal Investigator
Dr. Ramona Kessel, NASA Science Advisor
Dr. Sten Odenwald, NASA Science Advisor

Earth Space Systems Science
Unit 5: The Space Sphere

GLOSSARY

Bow Shock - The region just outside the Sunward magnetic field where the direction and speed of solar wind particles is changed abruptly. A bow wave (similar to that of a boat moving through water) forms just outside the magnetopause and causes the solar wind to be slowed, heated and deflected around Earth.

Magnetopause - The outer boundary of the magnetosphere. Inside the boundary the magnetic field is due to Earth's magnetic field, and outside the boundary the field is the interplanetary extension of the Sun's magnetic field.

Plasma - A gaseous state of matter consisting of freely moving ions and electrons which is very nearly electrically neutral overall.

RE - An abbreviation for the Earth's radius.

Solar Wind - A continuous outflow of plasma from the solar atmosphere (corona) into the solar system. The average speed of the solar wind is 450 km per second. Therefore, it takes on the average, 2 or 3 days for the solar winds to reach the Earth.

Trajectories - The pathway of satellite orbits.