SPACE WEATHER

NASA SUMMER OF INNOVATION
UNIT
Physical Science—Properties of Matter

GRADE LEVELS
4 – 6

CONNECTION TO CURRICULUM
Science and Mathematics

TEACHER PREPARATION TIME
4 hours

LESSON TIME NEEDED
2–3 Days *Complexity: Advanced*

LESSON DESCRIPTION

This lesson explores the origins, processes, and risks associated with solar radiation including how it travels through the solar system, affects the Earth's magnetosphere and poses a threat to astronauts and spacecraft.

OBJECTIVES

Students will:

- Gather information about items that they cannot see, using limited senses.
- Explain why protecting people and astronauts from radiation is important.
- Investigate how solar storms occur and predict which ones will affect Earth.
- Describe how solar activity can be used in spaceflight mission planning.
- Construct a multimedia space weather report.

NATIONAL STANDARDS

National Science Education Standards (NSTA)

Science as Inquiry

- Understanding of scientific concepts
- An appreciation of 'how we know' what we know in science
- Understanding of the nature of science
- Skills necessary to become independent inquirers about the natural world
- The dispositions to use the skills, abilities, and attitudes associated with science

Physical Science

- Properties of objects and materials
- Light, heat, electricity, and magnetism

Earth and Space Science

- Objects in the sky

Science and Technology

- Abilities of Technological Design
- Understanding Science and Technology

Mathematics Standards (NCTM)

Measurement and Data

- Represent and interpret data

MANAGEMENT

It is always good to remind students about the importance of classroom and lab safety. Students should not taste any materials and should wear eye protection during the “What’s Hidden Inside” activity. Assign them to groups of two and on the day before the lesson assign the following for homework. Give each student a small paper bag. Ask them to place a simple, common item in the bag, write their name on the bag, and fold the top of the bag down. Stress that they are to keep the contents of the bag a secret. Encourage students to avoid putting any breakable or sharp objects in the bag. The students should prepare two clues about the item hidden inside their bag. You may want to prepare a few extra bags in case a student forgets to bring one. You will also need to modify the wooden skewers by cutting off the sharp tips.

The “Build a Magnetometer” activity should span several days at a minimum. Different classes could record data throughout the day. For schools in lower latitudes the goal is to familiarize students with the equipment and process. In higher latitudes the ideal is to do this activity every day, submit data to Students Observation network, and to predict auroras. The sequins and small mirrors called for in the materials section may be found in craft stores and the magnets can be purchased from science supply stores.

Depending on familiarity with the subject matter, many educators may feel overwhelmed by the large amount of available NASA data, or feel that there isn’t enough time to incorporate a meaningful experience into the existing classroom structure or curriculum. The Space Weather Action Center (SWAC) is specifically designed to address these concerns by introducing space weather concepts through the use of a familiar and very common classroom teaching strategy; the construction of a classroom-based “learning center.” As part of the SWAC setup, each center includes one computer with Internet access to current and archived NASA data. Student flip charts offer step-by-step instructions needed to quickly retrieve and transfer data to specified data collection sheets. Additional directions are provided to help your students transform all of the newly acquired information into regularly scheduled news reports.

Some educators might use the “Space Weather Action Center” activity as a stand-alone unit, whereas others might find that the Space Weather Action Centers provide a fabulous on-going activity for their students over a long term. It is recommended that a secure area of a classroom or a separate room be established exclusively for the Space Weather Action Center program. The purpose is to minimize the impact on the rest of the classroom space that is utilized for teaching. At least one Internet capable desktop or laptop computer should be available. This computer will be used to access all four data access points for the Space Weather Action Center. If technology in the classroom is limited and dedicated access to a technology/computer room is via a teacher’s computer, teachers can print daily data and have students develop weekly line or bar graphs in their journals. In classrooms with multiple computer stations, it is recommended that small groups of 2 to 4 students can rotate and share data collection responsibilities.

CONTENT RESEARCH

It may seem that astronomers and astrophysicists have a particularly difficult task. They have to study stars, including our Sun, from a great distance. However, we don't have to touch an object to learn about it. Scientists use an extremely powerful technique to study objects in space and have become quite naturally experienced at "remote sensing." It is how our sensors (eyes, ears, and nose) receive most of our information about the world around us from a distance. The most important tools for astronomers and astrophysicists are those that improve their sight. The invention of the telescope in the early 1600s was one critical step. However, the most important advances have come in receiving information from light at various wavelengths.

The development of instruments capable of extending our “sight” into all wavelengths of the electromagnetic spectrum enables scientists to know so much more about the structure and dynamics of the universe. We now know that certain animals (like snakes) can "see" infrared light. This allows them to find prey in the dark because thermal energy is emitted in the infrared. Scientists have developed cameras that allow us to see infrared light. "False colors" have been used to indicate temperature. Infrared imaging has aided astronomers, too. Other animals (like bees) can see ultraviolet. A bee's view of flowers is remarkably different than ours. The pattern in ultraviolet guides a bee to pollen and nectar. Detectors sensitive to ultraviolet light guide astronomers to new information.

The **Solar and Heliospheric Observatory (SOHO)** is a project of international cooperation between the European Space Agency and NASA. Among its many scientific contributions, it enhances our knowledge by photographing the Sun in several wavelengths nearly at the same time. Images taken at the same time in different wavelengths allow scientists to look at different parts of the Sun. They can then make connections between events in different parts of the Sun. False colors are chosen and assigned to images to help scientists know what wavelength is being viewed. Knowing the wavelength of light emitted tells the scientists something about the temperature, the chemistry and the layer of the Sun being viewed.

People are also familiar with the use of x-rays to allow us to see things that are not visible. Astronomers, though, use x-rays far differently than doctors do. An x-ray of a broken bone does not show us the source of the x-ray. What we see in an x-ray picture shows different intensities of the x-rays coming through the object between the emitter and the film. Astronomers look directly at the source of x-rays and create images of the object emitting the x-ray.

Electromagnetic radiation with wavelengths longer than infrared include radio waves and microwaves. We are most familiar with these types of radiation as carriers of radio or television signals or to heat our food. However, radio waves coming from space are caused by electrons being accelerated by collisions or interactions with magnetic fields. Other radio wavelengths come from the behavior of molecules such as rotations or vibrations. Scientists are able to use radio emissions from space to determine the molecular structure and the surrounding environment of objects and clouds of dust and gas in space.

The Sun is an average variable star. The electromagnetic radiant energy from the Sun is responsible for life on Earth and conditions on Earth including climate, seasons, and weather. In addition to electromagnetic radiation, the Sun sometimes emits huge streams of particle radiation during events called Coronal Mass Ejections (CMEs). A CME is when the Sun sprays a fountain of plasma that consists mainly of electrons, protons, and other elements like helium, oxygen, and iron away from the solar surface. Abrupt changes from magnetic twisting of sunspots at the surface of the Sun cause solar flares and coronal mass ejections that blast brief but powerful “solar storms” into space.

Once thought to be unchanging, the Sun is now known to vary constantly. Sunspots can appear and disappear over days or weeks. Flares and large CMEs occur in time spans of minutes to hours. CMEs vary in size and speed. They can be much larger than the Earth, and the average speeds are about 424 km/s. Particle radiation from CMEs or “solar wind” constantly blows out as far as the extended atmosphere of the Sun. At the average speed, solar wind will reach the Earth (or the Earth’s Moon) in about 98 hours or Mars in 150 hours.

Changes in the activity of the Sun occur in 11-year cycles. During “solar minimum,” the Sun is relatively inactive and has a low number of sunspots. During “solar maximum,” the Sun is very active, has a large number of sunspots, and poses a particularly high risk for astronauts because of our inability to predict CMEs. CMEs occur about once every month during solar maximum and once every 8 months during solar minimum. During a trip to Mars, it is highly likely that astronauts might encounter three or more CMEs, and probably more while on the surface of Mars, depending upon the duration of their stay.

It has been estimated that if a major CME occurred while astronauts were on the Moon, their skin could receive an acute radiation dose up to 6 Sv, with bone marrow doses close to 0.9 Sv, which might cause some health problems such as tissue damage, cancer, and cataracts in space and on Earth. The underlying cause of many of these effects is damage to deoxyribonucleic acid (DNA). The degree of biological damage caused by ionizing radiation depends on many factors such as radiation dose, dose rate, type of radiation, the part of the body exposed, age, and health.

Earth is surrounded by a magnetic field (magnetosphere) that protects us from the worst effects of solar storms. However, solar storms can cause fluctuations in the magnetosphere called magnetic storms. Magnetic storms have disabled satellites and burned out transformers shutting down power grids. These storms also can endanger astronauts and contribute to more intense auroras that can be seen closer to the equator than is usual.

Like a winter weather forecast, space weather forecasts help plan for spaceflight missions and reduce dangers and problems associated with radiation while exploring space. The information we know and gather about sunspots allows scientists to predict when the Sun will be most active and when it will be least active, which in turn allows us to determine when the radiation environment of the solar system will be potentially less harmful for astronaut explorers. We can develop space weather forecasts that can be used to help in planning when a mission should take place. The forecast can also be used to identify periods of time when astronauts and sensitive electronics or hardware might need more protection from harmful blasts of solar radiation.

Key Concepts:

- We don't have to touch an object to learn about it. Scientist use remote sensing.
- Instruments are designed to detect varying wavelengths of the electromagnetic spectrum.
- Energy from the Sun is responsible for life on Earth and conditions on Earth including climate, seasons, and weather.
- Solar storms originate at the surface of the Sun (sunspot regions), flare (explode), and extend to the edge of the solar system as solar wind (CMEs).
- Solar wind can alter the Earth's magnetosphere causing magnetic storms seen as auroras.
- The Earth's magnetosphere protects us from high-energy particles from the Sun called CMEs.
- Solar electromagnetic radiation and particulate radiation (CMEs) are dangerous to astronauts and spacecraft.

Misconceptions:

- Electromagnetic radiation is the same as particulate radiation.
- The magnetosphere is visible.
- The Sun is inactive.

LESSON ACTIVITIES

Activity 1: What's Hidden Inside?

Students are challenged to gather information about items they cannot see.
http://www.nasa.gov/pdf/146856main_Hidden_Inside_Educator.pdf

Activity 2: Radiation Exposure on Earth

Students look at different sources of radiation and calculate their exposure levels.
http://www.nasa.gov/pdf/284277main_Radiation_MS.pdf

Activity 3: Build a Magnetometer

Students build a magnetometer using a soda bottle and a bar magnet to understand how to monitor and study magnetic fields and storms.
http://son.nasa.gov/tass/magnetosphere/stu_build_e.htm

Activity 4: Space Weather Action Center

Students monitor the progress of an entire solar storm from the time it erupts from our Sun until it sweeps past our small planet effecting enormous changes in our magnetic field.
http://sunearthday.nasa.gov/swac/materials/instructional_guide_V4.pdf

ADDITIONAL RESOURCES

Use this page for a deeper look at the electromagnetic spectrum.
http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html

Use this movie on the electromagnetic spectrum.
http://imagine.gsfc.nasa.gov/docs/science/know_l2/emspectrum.html
Find here a supplemental and more detailed explanation of constructing and using a soda bottle magnetometer.

http://image.gsfc.nasa.gov/poetry/workbook/magnet.html

A sample Space Weather video report can be viewed on the SWAC Web site at:
http://sunearthday.nasa.gov/swac/

This is a site where K – 4 students can learn about the Sun!
http://starchild.gsfc.nasa.gov/docs/StarChild/solar_system_level1/sun.html

All about the Sun for the 5 – 8 grader.
http://starchild.gsfc.nasa.gov/docs/StarChild/solar_system_level2/sun.html

This site gives a daily picture of the Sun, allowing you to observe the current sunspot population. Topics include recent solar flares, aurora, and coronal mass ejection. Lots of great pictures and time-lapse videos. Great for any age (K – 12).
http://www.spaceweather.com

The Space Weather Web site offers daily news and information about the Sun-Earth environment.
http://spaceweather3.com/

DISCUSSION QUESTIONS

- What Is radiation?
  Radiation is a form of energy that is emitted or transmitted in the form of rays, electromagnetic waves, and/or particles. In some cases, radiation can be seen (visible light) or felt (infrared radiation), whereas other forms like x-rays and gamma rays are not visible and can only be observed directly or indirectly with special equipment. Although radiation can have negative affects both on biological and mechanical systems, it can also be carefully used to learn more about each of those systems.

- Where does radiation come from?
  In our daily lives we are exposed to electromagnetic radiation through the use of microwaves, cell phones, and diagnostic medical applications such as x-rays. In addition to human-created technologies that emit electromagnetic radiation such as radio transmitters, light bulbs, heaters, and gamma ray sterilizers (tools that kill microbes in fresh or packaged food), there are many naturally occurring sources of electromagnetic and ionizing radiation. These include radioactive elements in the Earth's crust, radiation trapped in the Earth's magnetic field, stars, and other astrophysical objects like quasars or galactic centers.

- What are the different kinds of radiation?
  Radiation can be either non-ionizing (low energy) or ionizing (high energy). Ionizing radiation consists of particles or photons that have enough energy to ionize an atom or molecule by completely removing an electron from its orbit, thus creating a more positively charged atom. Less energetic non-ionizing radiation does not have enough energy to remove electrons from the material it traverses. Examples of ionizing radiation include alpha particles (a helium atom nucleus moving at very high speeds), beta particles (a high-speed electron or positron), gamma rays, x-rays, and galactic cosmic radiation (GCR). Examples of non-ionizing radiation include radio frequencies, microwaves, infrared, visible light, and ultraviolet light. While many forms of non-ionizing and ionizing radiation have become essential to our everyday life, each kind of radiation can cause damage to living and non-living objects, and precautions are required to prevent unnecessary risks.

- Are we protected from space radiation on Earth?
  Yes, but not entirely. Life on Earth is protected from the full impact of solar and cosmic radiation by the magnetic fields that surround the Earth and by the Earth's atmosphere. The Earth also has radiation belts caused by its magnetic field. The inner radiation belt or Van Allen Belt consists of ionizing radiation in the form of very energetic protons—by-products of collisions between GCR and atoms of Earth's atmosphere. The outer radiation belts contain ions and electrons of much lower energy. As we

travel farther from Earth's protective shields we are exposed to the full radiation spectrum and its damaging effects.

- What factors determine the amount of radiation astronauts receive?
  There are three main factors that determine the amount of radiation that astronauts receive. They include

  - *Altitude above the Earth – at higher altitudes the Earth's magnetic field is weaker, so there is less protection against ionizing particles, and spacecraft pass through the trapped radiation belts more often.*
  - *Solar cycle – the Sun has an 11-year cycle, which culminates in a dramatic increase in the number and intensity of solar flares, especially during periods when there are numerous sunspots.*
  - *Individual's susceptibility – researchers are still working to determine what makes one person more susceptible to the effects of space radiation than another person. This is an area of active investigation.*

- Does Space Weather Affect Astronauts?
  Absolutely. Space weather is closely related to solar activity and this is important for astronauts traveling through space. Scientists have discovered that over an 11-year cycle the number of sunspots increase and decrease . Interestingly, the Sun is slightly brighter when there are many sunspots. During one of these periods, the Sun is more actively producing SPE and CME so the amount of radiation in the solar system is slightly increased. The number of CMEs varies with the solar cycle, going from about one per day at solar minimum, up to two or three per day at solar maximum. Although scientists can predict that the Sun can produce more SPE and CME during this period, they are unable to determine specifically when SPE and CME will occur.

ASSESSMENT ACTIVITIES
For Activity 1: What's Hidden Inside?—Leaders can observe and assess student performance throughout the activity using the included Scientific Investigation Rubric.

For Activity 2: Radiation Exposure on Earth—student worksheets are enclosed in the class activity plan.

For Activity 3: Build a Magnetometer—leaders may assess student knowledge through questioning or see assessment as it is described in the data collection part of the activity write-up.

For Activity 4: Space Weather Action Center—there is a Space Weather Pre-assessment Tool. The data sheets that are completed as students use the flip charts also serve as an assessment tool. Finally, the comprehensive multimedia project should serve for assessment.

ENRICHMENT
Consider using the following activities to enrich the concepts taught in this lesson.

Perform the Herschel Experiment at home or in the classroom.
(http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/herschel_experiment2.html)

Additional research can be done on the following science topics:
- Unscrewed space probes
- Robotics at NASA
- Robotic and human exploration
- Solar activity
- The SOHO spacecraft
- Space weather on the Moon and Mars
- The Maunder Minimum
- The history of sunspot observation