AEROSPACE PALACE ACADEMY, NIGERIA
(A subsidiary of Aerospace Palace International, Nigeria)

LESSON 75: SPACE WEATHER

At first glance, the idea of "space weather" seems very odd. Weather, after all, deals with wind, clouds, rain, and other similar things. Out in space there is no air to make a wind to blow and no water to make clouds and rain. But space is not completely empty. It has its own milieu that varies from place to place and from time to time. The changing conditions out in space affect satellites in orbit and even things on the ground. This lesson discusses space weather.

Next Generation Science Standards (NGSS):

- Discipline: Earth and Space Sciences
- Crosscutting Concept: Patterns
- Science & Engineering Practice: Developing and Using Models

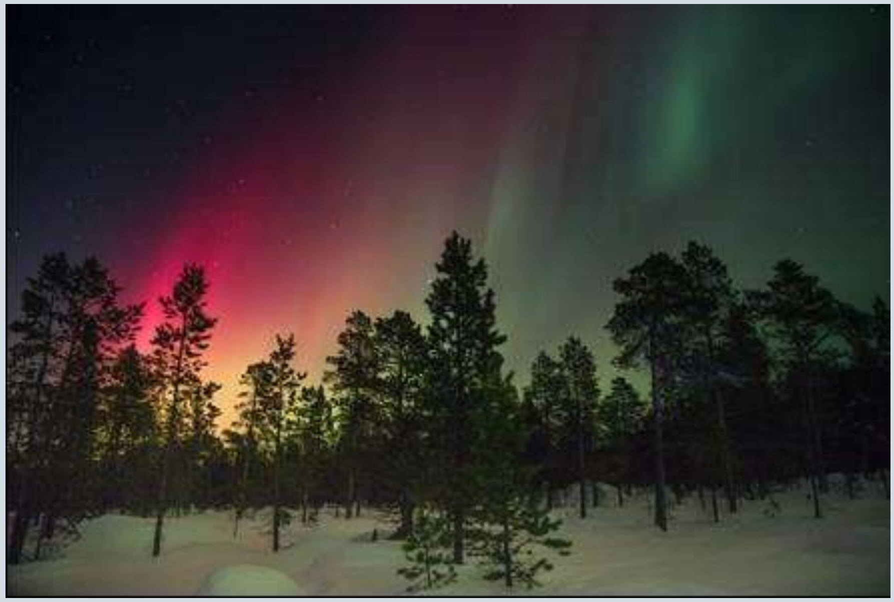
GRADES K-2

NGSS: Earth's Place in the Universe: Use observations of the sun, moon, and stars to describe patterns that can be predicted.

Have you ever heard a weather forecast for "scattered showers"? That means there may be rain in different places around your area during the day. But have you ever heard of meteor showers? Meteors are rocks from space that enter the atmosphere around Earth. We call it a meteor shower when many of those rocks encounter the Earth at the same time. You won't get wet from this type of shower, but it may seem that you are watching a fireworks display high overhead. The tiny bits of space rocks and dust burn up in the atmosphere and create streaks of light that can be seen as shooting stars crossing the night sky. Some of these showers happen each year and you can plan ahead for your family to see them. For example, the Geminid Meteor Shower will peak on December 14 this year. NASA has an excellent web page for children explaining what a meteor shower is. The Kids Astronomy site also has a page that discusses meteors.

While we usually speak of outer space as being empty with no air or anything else in it, this is not completely true. There are gas particles out in space but they are very far apart and one can ignore them when one is figuring out how a spaceship will travel. They do have an effect, though. The gas particles are electrically charged and if there are a lot of them in one place, it can interfere with radios and other electrical systems on a spacecraft.

GRADES K-2 (CONTINUED)



One effect in the Earth's atmosphere of the outer-space gas is the Aurora Borealis, or Northern Lights. (A recent Micro Lesson discussed the auroras at greater length.) Even though we see this display at night, it is caused by the sun. When the sun releases a large amount of electrically charged gas, some of the particles reach the Earth's atmosphere and cause a reaction in the gases there and cause a "solar storm." The nitrogen and oxygen that make up our atmosphere may glow blue, purple, red, and green. NASA also has a web page for children that describes the aurora.

Weather on the Earth includes sunshine. Weather in space also includes sunshine—and even more strongly than the weather on the Earth. Some of the Sun's radiation, called "ultraviolet," can cause sunburn; the Earth's atmosphere absorbs most of this radiation and protects us from it. (This is why you do not get sunburned if you go outside early in the morning or later in the afternoon: the Sun's rays have to pass through so much air that all of the harmful rays are absorbed.) The Sun's rays in space will heat up anything that it is shining on; if something is in the shade, it can get very cold.

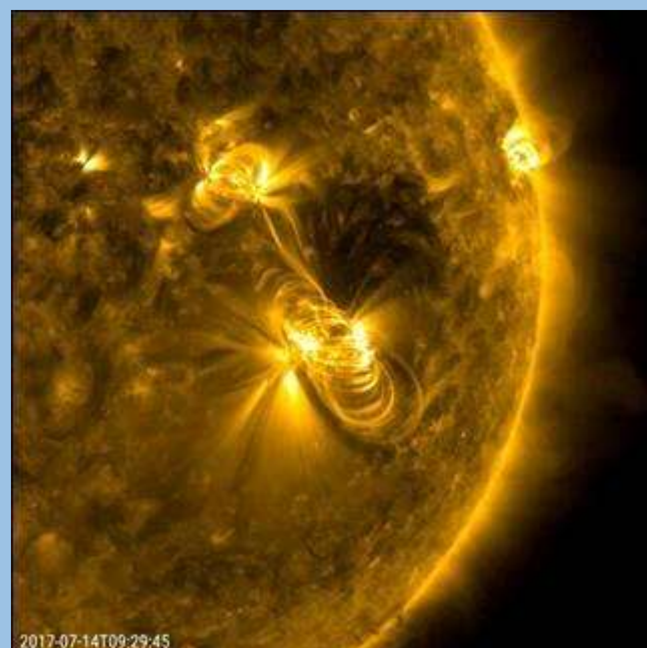
GRADES 3-5

NGSS: Earth's Place in the Universe: Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

We usually speak of outer space as being completely empty (except for planets, comets, asteroids, and the like). But it is not absolutely empty: the Sun, which is the star at the center of the Solar System, is surrounded by an intensely hot outer atmosphere (the "corona") made of hydrogen and helium gas, both neutral atoms and ions (which are atoms which have lost one or more electrons and are electrically charged). At the outer edge of the corona, many of

GRADES 3-5 (CONTINUED)

these atoms and ions flow out into space away from the Sun, forming a stream called the "solar wind." Just as our normal weather on Earth is caused by the flow of the air in the Earth's atmosphere, "space weather" is caused by the flow of this solar wind from the Sun out toward the planets. The solar wind is very thin and rarefied; while the density of the Earth's atmosphere is 0.0765 lb/ft^3 (or 1.225 Kg/m^3) at the Earth's surface, the density of the solar wind near the Earth is only about 3-6 atoms per cubic centimeter, which calculates out to between about 3×10^{-22} and 6×10^{-22} lb/ft^3 (or between about 5×10^{-21} and 10×10^{-21} Kg/m^3).



The Earth has magnetic fields and so does the Sun. When those fields on the Sun build up too much energy, they can erupt outward suddenly in a "solar flare." The solar wind carries the Sun's magnetic fields outward from the Sun; the magnetic field from the flare causes much more gas than usual to be flung away from the Sun. If the gas and the magnetic fields from a solar flare hit the Earth, they can cause problems—especially with communications and with utility power grids. Flares can also cause radiation storms which the Earth's own magnetic fields protect us from, but which may cause danger to astronauts in space. (For a fictional example, in the original comic books, the Fantastic Four all received their super powers during a solar flare while they were on a space exploration mission. In reality, a solar flare would not give a person super powers; it would simply make him sick.)

GRADES 6-8

NGSS: Earth's Place in the Universe: Analyze and interpret data to determine scale properties of objects in the solar system.

Space weather is partly caused by the solar wind coming from the surface of the Sun. This solar wind is made up of hydrogen and helium atoms, both neutral atoms and charged ions, and also the electrons that were lost from the ions. The solar wind also carries with it part of the Sun's magnetic field.

GRADES 6-8 (CONTINUED)

The solar wind has different effects in different places. Out in interplanetary space, the fast-moving particles can punch through the thin skin of a spacecraft, harming astronauts and upsetting sensitive electronics. (They are small enough—atomic-sized—that they do not put holes in the skin of the spacecraft when they go through it.) Protecting astronauts from the solar wind is a primary concern when planning crewed missions to other planets. (The solar wind was also an issue with the Apollo missions to the Moon, but those missions only lasted a few days rather than the months that a mission to Mars will take and the risk to the astronauts was small enough that NASA considered it acceptable.) When a charged particle hits a charged memory bit on a computer, it can change the value of the bit from zero to one or vice versa. This can corrupt the data and the programming on the computer and cause it to malfunction.

The Earth's magnetic field protects it from the direct effects of the solar wind. When the charged particles from the Sun meet the Earth's magnetic field, it deflects them away from the Earth and toward the Earth's magnetic poles. The interaction of the solar wind and the atmosphere near the North and South Poles causes the auroras. There is also a region over the southern Atlantic Ocean, called the South Atlantic Anomaly, where the Earth's magnetic field allows the solar wind to reach down to low-orbiting satellites.

~~When the solar wind hits the Earth's atmosphere~~, the fast-moving particles hit molecules in the air and heat them up. (The temperature of a gas is a manifestation of how fast its molecules are moving around; the faster the molecules are moving, the hotter the gas is.) The hotter air is less dense and when the solar wind is denser than usual, the atmosphere actually expands. The expanded atmosphere can actually reach up to the orbits of the lowest satellites and cause those orbits to decay, either forcing the satellite operators to use fuel to raise the orbits or taking years off the orbital lifetimes of the satellites.

GRADES 9-12

NGSS: Earth's Place in the Universe: Analyze and interpret data to determine scale properties of objects in the solar system.

Just as people figured out how to use the winds in the Earth's atmosphere to power their sailing ships, people are also figuring out how to use the Sun's radiation to power spacecraft. Scientists first speculated that something from the Sun pushed on heavenly bodies by looking at the tails of comets. Probably the first scientists to suggest using sails were Kepler and Galileo in the early 1600s. As physics developed and people began to realize that light exerts a pressure, the idea became quantifiable. The pressure exerted by the Sun's radiation on a spacecraft is extremely slight, but for interplanetary missions it may become practical.

A NASA web page solves a simple problem that calculates the pressure exerted by sunlight on a spacecraft near the Earth. Given the total radiance of the Sun's light of 1.36×10^{3} W/m^2 (or 1.36×10^{3} Kg/s^3) and the speed of light of about 3×10^{8} m/s, absorbed sunlight exerts a pressure of about 4.5×10^{-6} N/m^2 (or 4.5×10^{-6} Kg/m-s^2). Reflected sunlight, which pushes off as it leaves just as hard as it pushes as it arrives, exerts a pressure of about 9×10^{-6} N/m^2. If a spacecraft has a one-kilometer-by-one-kilometer solar sail, the force on that sail will be 4.5 Kg-m/s^2. A 100-Kg spacecraft (quite light, given the million-square-meter solar sail) will therefore receive an acceleration from solar radiation of 4.5×10^{-2} m/s^2.

This acceleration is quite small, but it has the advantage of being sustained: rather than accelerating for a few minutes and then coasting, a spacecraft with a solar sail is constantly accelerating. Over the course of a day, the spacecraft's speed will change by almost four kilometers per second; over the course of a month, the change in speed will be over 100 kilometers per second. By comparison, the change in speed needed to move a spacecraft from low Earth orbit to a trajectory towards Mars is about 4.3 Km/s.

The acceleration from the solar wind is much smaller than that caused by the pressure of the Sun's light. Consider a solar wind of three hydrogen atoms per cubic centimeter of space, moving at a speed of 700 Km/sec. If our one-kilometer-by-one-kilometer solar sail stops the solar wind (a dubious assumption at best, given the atoms' penetration capabilities at that speed), it will stop 2.1×10^{18} hydrogen atoms per second (the number of atoms in 700 Km^3 of volume). Since the mass of a single hydrogen atom is $(1 / 6.022\times10^{26})$ Kg, these hydrogen atoms have a total mass of 3.5×10^{-9} Kg and will give the spacecraft a change in momentum of about 2.4×10^{-6} Kg-m/s in that one second. A 100-Kg spacecraft (again quite light, given the size of the solar sail) will therefore receive an acceleration from the solar wind of about 2.4×10^{-8} m/s^2. This is about six orders of magnitude smaller than the acceleration caused by radiation pressure.

Sixty Years Ago in the Space Race:

December 4: A Soviet "Luna" rocket was launched toward the Moon but an engine failure prevented it from reaching escape velocity.

December 6: The American Pioneer 3 spacecraft was launched toward the Moon but after an early engine shutdown it reached a peak altitude of 102,322 kilometers and re-entered after 38 hours.