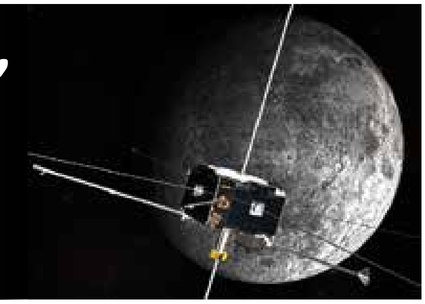
A New Spin on Solar Wind: The Moon, Magnetosphere, and ARTEMIS



LESSON SUMMARY

Grade Level: Middle School

Time: Two to three 50-minute class sessions

Overview:

In this activity, students work in groups of 2 or 3 to build their own model of the Sun-Earth-Moon system. Students will use the model to demonstrate that the Earth is protected from particles streaming out of the Sun (solar wind) by a magnetic shield called the magnetosphere, and that the Moon is periodically protected from these particles as it moves in its orbit around the Earth. Students will learn that the NASA ARTEMIS mission is a pair of satellites orbiting the Moon, measuring the intensity of solar particles streaming from the Sun.

Recommended Sequencing:

It is recommended that this lesson be used immediately after teaching about the phases of the Moon because it will reinforce and extend that learning.

NASA is the National Aeronautics and Space Administration is the agency of the United States government that is responsible for the nation's civilian space program and for aeronautics and aerospace research.

ARTEMIS – ARTEMIS is the acronym for Acceleration Reconnection Turbulence & Electrodynamics of Moon's Interaction with the Sun. It is the name of the two-spacecraft NASA mission enabled by two spacecraft of the THEMIS (NASA) mission. The primary purpose of ARTEMIS is to collect data regarding the various effects of space weather on the Moon and the Moon's influence on the environment around it.

THEMIS – THEMIS is the acronym for Time History of Events and Macroscale Interactions during Substorms. Launched in 2007, THEMIS is a NASA mission that consisted of five spacecraft in orbit around the Earth. THEMIS investigated what causes the auroras in the Earth's atmosphere. After its prime mission, two of the THEMIS satellites were redeployed to the Moon to become the ARTEMIS mission.

STANDARDS

- AAAS Benchmarks: Simulations are often useful in modeling events and processes (11B/M4);
  Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information (3A/M2)
- Next Generation Science Standards: MS-ESS1-1. Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.
    - Science and Engineering Practices: Asking questions and defining problems
    - Crosscutting Concepts: Systems and system models

OBJECTIVES

Students will…

1. Be able to describe at a basic level the interaction between the solar wind and the Earth's magnetosphere. (Knowledge)
2. Build a model of the Moon-Earth-Sun system and use it to demonstrate how the Moon is affected by the solar wind at various points in its orbit around the Earth. (Skills)
3. Understand that when the Moon is in its full phase, it is within the Earth's magnetotail and protected from the solar wind. (Knowledge)

4. Appreciate that the information collected by NASA's ARTEMIS spacecraft helps us to better understand how the Earth and the Moon are affected by the solar wind. (Attitude)

PROCEDURES

I. Engagement

Activate students' prior knowledge about Moon phases by asking some of the following questions:

What do you know about the Moon?

ANSWER: Many possible answers regarding distance, phases, craters, human exploration, myths.

Does the Moon always look the same?

ANSWER: No. Encourage discussion regarding whether it is only seen at nighttime, whether it seems to appear in different areas of the sky, etc.

Why does the Moon look different in the sky at different times of the month?

ANSWER: there are various ways to explain this (including via separate lesson plans); briefly, the Moon is illuminated by varying angles of the Sun.

What are the relative positions of the Sun, Earth, and Moon during full Moon phase? During new Moon phase?

*ANSWER (Refrain from giving the answer because students should learn it via the activity): See "**The Moon's phases**" in the* **BACKGROUND INFORMATION** *section.*

Show students an image of a footprint on the Moon and explain that in 1969, Neil Armstrong and Buzz Aldrin were the first humans to walk on the Moon. Point out that their footprints are still there and ask students why do they think that is? Guide students towards the idea that because there is no atmospheric wind or weather like we have on Earth to blow the dust up, the footprint will sit untouched until impacted, e.g., by a meteor or comet.

http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/a11_h_40_5878.html
Credit: NASA – Edwin Aldrin - Footprint on the Moon

Let students know that although there is no atmospheric wind, the Moon is still affected by another kind of "wind" – the solar wind. Have students generate a list of questions that they have about the solar wind – i.e., What is the solar wind? Where does it come from? How does it impact the Moon? *TEACHER: Review PowerPoint "NASA's ARTEMIS mission" and the video "What Is the Solar Wind?" (in the* ***Explanation*** *section).*

Tell students that they will be making a model of the Sun-Earth-Moon system to explore what the solar wind is and how it affects the Moon in its orbit around the Earth.

II. Exploration

TEACHER: Review terminology found in **<u>GLOSSARY</u>***, putting some of the terms from Parts I-III of this section – i.e.,* ***<u>Exploration</u>*** *– on the classroom board.*

<u>Part I: Exploring the Lunar Orbit – Solar Wind Template</u>

Divide students up into pairs or groups of three. Give each student a copy of the Lunar Orbit – Solar Wind Template (Appendix A). Have students discuss the diagram and record their observations. Guiding questions could include:

What Moon phase is represented in the diagram?

ANSWER: full Moon; TEACHER: To make this question more challenging, cover up the term "Full Moon" on the template with a piece of paper and removable tape; the Moon's image is in the magnetotail.) ***magnetotail*** *– [pronunciation: the second syllable sounds like "neat" and not "net"] The long, trailing limb of the Earth's magnetosphere on the side facing away from the Sun, generated as the solar wind pushes on the Earth's magnetosphere.*

Do you think that the diagram is showing the Earth and Moon to scale? Why or why not? What are some other aspects of the diagram that may not be accurate?

ANSWERS: The diagram is not to scale in terms of the vastness of Earth's magnetosphere, nor in terms of the sizes of the Moon's and Earth's graphics; however, the scale is fairly accurate in terms of distance between the Moon and Earth.

What do the dashed red lines represent? Where are they coming from? How do you suppose they are interacting with the area represented by the light purple coloring (magnetosheath)?

ANSWERS: The red lines represent the solar wind. They are coming from the Sun. ***magnetosheath*** *– [pronunciation: the second syllable sounds like "neat" and not "net"] The region of space between the magnetopause and the bow shock of a planet's/moon's magnetosphere. The magnetosheath can be considered as the transition zone between the Earth's magnetosphere and the ambient solar wind.*

Why do you think few or none of the dashed red lines are found in the Earth's magnetotail?

ANSWER: See **<u>BACKGROUND INFORMATION</u>** *section.*

<u>Part II: Making the Model</u>

Give each pair/group of students the instructions on how to make the model and help them construct the model. See instructions for <u>Constructing the Sun-Earth-Moon Model</u> (Appendix C).

<u>Part III: Using the Model</u>

Once the students have built their models, have students work in their pairs/groups to demonstrate how the Earth's magnetosphere protects the Earth from the solar wind and how the Moon moves in & out of this protected area in its orbit around the Earth.

Have one student in each group be in charge of the solar wind (i.e., pouring the dry sand through the funnel or using a cup to monitor amount of sand per "pour"). Have another student in the group hold the Moon in place on a designated spot in the Moon's orbit.

> *TEACHER: Refer to "**The Moon's phases**" section of the* **BACKGROUND INFORMATION** *portion of the lesson plan*

Start with new Moon phase, then moving in a counter-clockwise direction to first quarter Moon, full Moon, third quarter Moon, and back to new. At each phase, the student in charge of the solar wind pours the sand through the funnel's mouth positioned & held inside the Sun so that the sand streams through all the "teeth" of the Sun, not just the center area. If the sand doesn't pour out easily, gently tap the back of the base to get it to flow, careful not to tip base off-kilter.

At each phase, have students record their observations by drawing pictures or making graphs, symbolizing the varying amounts of solar wind particles that pile up on the Moon's surface as it moves in & out of the Earth's magnetosphere.

NOTE: After each "pour" of the solar wind, the students should clean the board and recycle the sand by gathering it and putting it back in the container. This process can be mildly dusty, so the students should be advised.

III. Explanation

[See **BACKGROUND INFORMATION** and **GLOSSARY** for more information about the solar wind and the Earth's magnetosphere.]

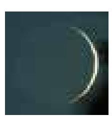
- Show students the video "What is the Solar Wind?"
  http://www.sciencechannel.com/video-topics/space-videos/the-planets-the-sun-solar-wind.htm

- Show students the video: "Mysteries of the Sun: Magnetosphere"
  http://missionscience.nasa.gov/sun/sunVideo_04magnetosphere.html

As a class, have students compare and discuss their results. Ask students:

At which point in the Moon's orbit is there the ***most*** pile-up of solar wind particles on the Moon?

ANSWER: new Moon

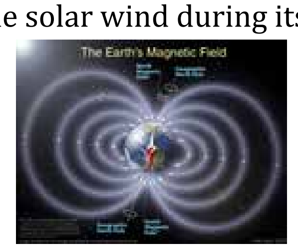


At which point in the Moon's orbit is there the ***least*** pile-up of solar wind particles on the Moon?

ANSWER: full Moon

What is protecting the Moon from the solar wind during its full phase?

ANSWER: Earth's magnetosphere



Credit/Copyright: Peter Reid, The University of Edinburgh
Schematic illustration of Earth's magnetic field. 2009

IV. Elaboration

Introduce students to the NASA ARTEMIS mission using the PowerPoint presentation, which can be found at http://cse.ssl.berkeley.edu/artemis/epo-classroom-g69_NewSpinSolarWind.html.
Additional information about the ARTEMIS mission can be found via the following links:

- ARTEMIS Overview and Goals:
  http://artemis.ssl.berkeley.edu/overview.shtml

- How to Recycle a Spacecraft: Interview with Daniel Cosgrove, Mission Operation Lead at UC Berkeley's Space Sciences Laboratory:
  http://cse.ssl.berkeley.edu/artemis/epo-interviews-how-to-recycle-a-spacecraft.html

- ARTEMIS Trajectory Movie:
  http://svs.gsfc.nasa.gov/vis/a000000/a003600/a003682/ARTEMISdeluxeC_HD720.mov

After introducing ARTEMIS, have students add the two ARTEMIS spacecraft to their models by placing two quilter's "T" pins at approx. 45 degrees in the top area of the Moon. *(TEACHER: There are two ARTEMIS spacecraft due to factors pertinent to their orbits around the Moon; review the ARTEMIS Trajectory Movie and the PowerPoint NASA's ARTEMIS mission for further explanation.)* Have the students repeat the procedure of pouring the sand to observe how the ARTEMIS spacecraft are able to collect data about the solar wind as the Moon moves in & out of the Earth's magnetotail.

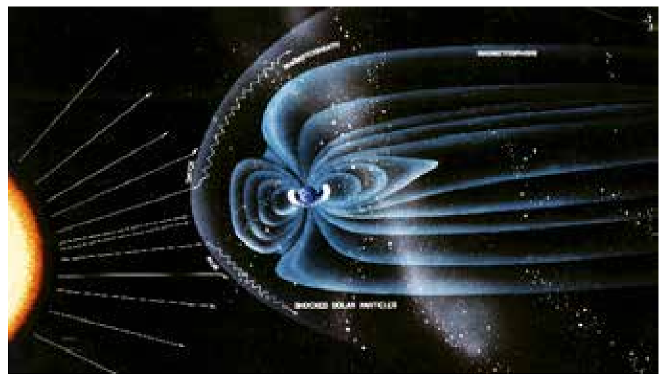
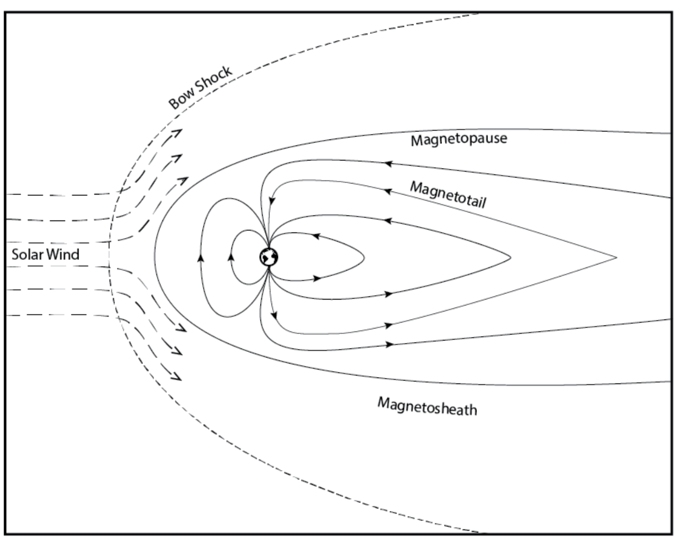


Fig. A http://airandspace.si.edu/etp/earth/earth_mag.html
Credit: NASA Image from MSFC Space Plasma Physics – The Solar Wind and Earth's Magnetosphere



Credit: Leitha Thrall, UC Berkeley, Space Sciences Lab, Center for Science Education Magnetosphere Illustration

Discuss how the information collected by NASA's ARTEMIS spacecraft helps us to better understand how rocky celestial objects with magnetic fields (planets, moons, and asteroids) are affected by the solar wind. ARTEMIS provides data on a daily basis, and we can all access it.

V. Evaluation

1. Find out what the current phase of the Moon is today. Use your model to illustrate today's Moon phase. Where is today's Moon located relative to the Earth's magnetosphere? Would you expect that the Moon will encounter more or less solar wind particles two weeks from now – Why or why not?

   ANSWER: See **BACKGROUND INFORMATION** *section.*

2. Fold a piece of paper in half. On one half of the paper, label "FULL MOON." On the other half of the paper, label "NEW MOON." On each side of the paper, draw a picture of the Moon as affected by the

solar wind for that FULL/NEW phase. Your drawing should indicate the direction of the Sun, label the solar wind particles and Earth's magnetosphere (if appropriate).

*ANSWER: See **Explanation** section.*

3. Imagine that you are a scientist working on the ARTEMIS mission. Two weeks ago, you received data from the ARTEMIS spacecraft that indicated a steady stream of solar wind particles was hitting the spacecraft detectors. Today is full Moon phase. If you want to examine data of the solar wind when the Moon moves between the Earth's magnetotail and magnetopause, how many days from now should you download data from the ARTEMIS spacecraft? Explain your answer in writing.

ANSWER: See **BACKGROUND INFORMATION** *section.*

BACKGROUND INFORMATION

Earth's magnetosphere and solar wind:

The Sun is constantly producing a stream of charged particles that flow from it in all directions, including toward Earth and the Moon. This is called the solar wind (although it is not like wind we have here on Earth).

A special shield called the magnetosphere protects the Earth from both the solar wind and coronal mass ejections. (See **GLOSSARY** for definition of Earth's magnetosphere.)

The magnetosphere behaves in a similar manner to water flowing around a rock in a stream.

Credit: ©Brenda Tharp Photography

As the particles stream out from the Sun, they gather up in front of the magnetosphere. This helps to protect the Earth—and its inhabitants!—from any harmful particles coming from the Sun. It is important to note that these particles are not the same as harmful radiation that can cause sunburn and skin cancer. It is the atmosphere (and ozone layer) that helps protect us from radiation.

The shape of the Earth's magnetosphere is like a teardrop, with the blunt round side pointing toward the Sun, and the long pointy side flowing away from the Sun. The day side (facing the Sun) of the magnetosphere is much smaller than the night side (facing away from the Sun). Your diorama includes the day side, and a little part of the night side of the magnetosphere.

Watch video: "Mysteries of the Sun: Magnetosphere"
http://missionscience.nasa.gov/sun/sunVideo_04magnetosphere.html

However, the Moon does not have a magnetosphere like the Earth does. That means many of the particles streaming our direction from the Sun directly impact the Moon's surface. We know that the Moon orbits around the Earth. As it orbits between the Earth and the Sun, the Moon is exposed to particles coming from the Sun, with no protection. However, as it passes behind the Earth (so the Earth is between the Sun and the Moon), the Moon passes through the Earth's magnetosphere, in the region called the magnetotail. When the Moon is in the magnetotail, the Earth's magnetotail acts as a shield for the Moon, as well as the Earth.

As the Moon moves out of the magnetotail, it orbits into a region called the magnetosheath (which is on either side of the magnetotail). The amount of solar wind that hits the Moon is even more than when it is directly in front of the Earth! Why is this?

Well, pretend you are cycling along beside a truck in the rain. If you are directly in front of the truck, then you are being hit by the regular amount of rain. If you are behind the truck, the truck protects you from the rain. However, if you are cycling right beside the truck, then all the rain that it hitting the front of the truck is getting pushed around to the sides, and bombards you, our unfortunate cyclist. The same thing happens with the Moon. As the solar wind hits the Earth's magnetosphere, it gets pushed out of the way and flows down the sides. So, ARTEMIS should (and does) see even more solar wind right at the edge of the magnetosphere, and you should as well!

ARTEMIS spacecraft, Earth and Moon
Credit: NASA - artemis_John Moore_moonposter.ie.jpg

How NASA's ARTEMIS came to be and its mission:

*TEACHER: The terms "NASA," "ARTEMIS," and "THEMIS" used in the following paragraphs are explained in the **LESSON SUMMARY** as well as the* **GLOSSARY**.

A group of five satellites, called the NASA THEMIS Mission, was launched in 2007. These special satellites help scientists to unlock the mystery of how Earth's magnetosphere stores and releases energy from the Sun and generate aurora.

In 2010, THEMIS scientists had the opportunity to repurpose two of the satellites on a new mission to study the interaction between the Moon and the solar wind. Using the small amount of remaining fuel, and taking advantage of the Moon's gravity, they sent two of the satellites on a two-year journey from Earth orbit into lunar orbit.

ARTEMIS is the NASA acronym for Acceleration, Reconnection, Turbulence and Electrodynamics of Moon's Interactions with the Sun. As the name suggests, the two spacecraft measure what happens when the Sun's charged particles hit our rocky Moon, where there is no magnetic field to protect it. As the Moon orbits the Earth, it moves into and out of Earth's magnetosphere. What happens to the Moon when it is within Earth's magnetosphere? What happens to the Moon when it is outside of Earth's magnetosphere? These are some of the mysteries scientists are using ARTEMIS to solve!

Watch video called ARTEMIS Trajectory Movie:
http://svs.gsfc.nasa.gov/vis/a000000/a003600/a003682/ARTEMISdeluxeC_HD720.mov

The Moon's phases:

The Moon has many phases that relate to the position of the Moon relative to the Earth and the Sun. It turns out that these phases can help us to understand how much of an effect the Sun is having on the Moon at a given time, too.

full Moon: Moon is behind the Earth and is within the Earth's magnetosphere.

Minimum amount of solar wind observed by ARTEMIS.

waxing/waning Moon: Moon is close to full but is now in the magnetopause.

Maximum amount of solar wind observed by ARTEMIS.

new Moon: Moon is between the Earth and the Sun (and not visible in the sky).

Moon is directly bombarded by particles from the Sun.
Medium amount of solar wind observed by ARTEMIS.

Science In Action: NASA's New Moon Program

GLOSSARY

ARTEMIS – ARTEMIS is the acronym for Acceleration Reconnection Turbulence & Electrodynamics of Moon's Interaction with the Sun. It is the name of the two-spacecraft NASA mission enabled by two spacecraft of the THEMIS (NASA) mission. The primary purpose of ARTEMIS is to collect data regarding the various effects of space weather on the Moon and the Moon's influence on the environment around it. Artemis was the Ancient Greek Goddess of the Moon.

bow shock – [pronunciation: "bow" rhymes with "cow"] The boundary between a magnetosphere (in this case, the Earth's) and an ambient medium.

charged particle – An elementary particle, such as a proton or electron, with a positive or negative electric charge. The solar wind is made up of charged particles. Charged particles respond to electric and magnetic fields in space.

coronal mass ejections (CMEs) – A CME is a plasma cloud or "tidal wave" of charged particles that is flung outward from the Sun. CME's are often associated with sunspots, which are concentrated areas of magnetic fields on the surface of the Sun. A large CME can contain a billion tons of matter that can be accelerated to several million miles per hour in a spectacular explosion. This is an example of space weather (see **GLOSSARY**, **space weather**).

Earth's magnetosphere – [pronunciation: the second syllable sounds like "neat" and not "net"] Magnetic fields exist throughout all of interplanetary space. The magnetosphere is the region within which the magnetic field generated by Earth is dominating over all other magnetic fields generated by, for example, the Sun.

magnetopause – [pronunciation: the second syllable sounds like "neat" and not "net"] The boundary between a magnetosphere and the surrounding plasma. At Earth, the magnetopause denotes the greatest extent of the influence of Earth's magnetic fields.

magnetosheath – [pronunciation: the second syllable sounds like "neat" and not "net"] The region of space between the magnetopause and the bow shock of a planet's/moon's magnetosphere. The magnetosheath can be considered as the transition zone between the Earth's magnetosphere and the ambient solar wind.

magnetosphere – See **Earth's magnetosphere**.

magnetotail – [pronunciation: the second syllable sounds like "neat" and not "net"] The long, trailing limb of the Earth's magnetosphere on the side facing away from the Sun, generated as the solar wind pushes on the Earth's magnetosphere.

NASA – the National Aeronautics and Space Administration is the agency of the United States government that is responsible for the nation's civilian space program and for aeronautics and aerospace research.

photon – An elementary particle with zero mass that transmits electromagnetic energy or what we commonly refer to as light.

plasma – a collection of positively and negatively charged particles that respond to electric and magnetic fields.

solar wind – A flow of charged particles coming from the Sun.

space weather – the stream of particles from the Sun, or solar wind which constantly changes due to the Sun's activity. Sometimes there are things called CME's (see **GLOSSARY, coronal mass ejections**) that are like a tidal wave of particles and radiation that burst from the Sun and flows through space.

THEMIS – THEMIS is the acronym for Time History of Events and Macroscale Interactions during Substorms. Launched in 2007, THEMIS is a NASA mission that consisted of five spacecraft in orbit around the Earth. THEMIS investigated what causes the auroras in the Earth's atmosphere. Following the success of its prime mission, two of the THEMIS satellites were redeployed to the Moon and repurposed to become the ARTEMIS mission.

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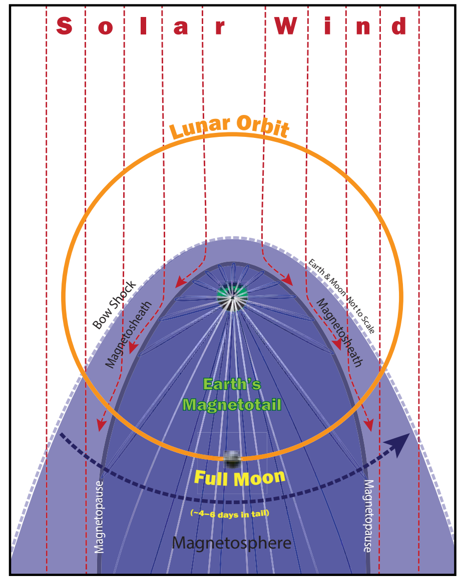
Finally, we would like to thank Dr. Vassilis Angelopoulos, the PrincipalInvestigator of the THEMIS-ARTEMIS Mission, for his ongoing support of Education/Public Outreach efforts.

MATERIALS LIST

The following is based on amounts per model. There should be 2-3 students per model.

For rectangular base (including magnetosphere and magnetotail):

- solar wind template for drawing: see Appendix A; same as image shown here.



- Elmer's Foam Board® or similar product – 76.2 cm x 50.8 cm (30" x 20"), one board cut into 3 equal pieces, 1 piece per group

  ALTERNATIVE: Cardboard with smooth, flat paper added on top, such as butcher paper or a large drawing paper. the surface should not be susceptible to indentations; this will become clear in the section called "Construction of the rectangular base" in Appendix C.

- shoelace – not flat but thick, round (men's waxed dress shoelace (color unimportant)) – minimum 36.83 cm (14.5");

  ALTERNATIVE: pipe cleaner/chenille stem of same length (color unimportant); rope or cord.
  NOTE: A 2nd piece (36.83 cm (14.5")) of shoelace or pipe cleaner/chenille stem might be needed, depending the students' design of the model.

- glue – Elmer's Glue-All® or other brand of glue similar to Elmer's
- pair of scissors
- utility knife (for cutting foam board); ALTERNATIVE: X-Acto® knife
- cutting mat for protecting surface table as you cut; ALTERNATIVE: large, flat cardboard
- binder clips – 1.905 cm (¾"), 4 per group
- pencil
- marking pen, i.e., Sharpie Fine Point Permanent Marker® - something that doesn't dent the board or paper
- compass for making circles
- ruler (with metric and standard (imperial) measurements) preferably, one longer than a foot
- sewing pins (for securing the gluing of the shoelace or other alternative resource)

For Earth:

- clay (dry modeling clay, e.g., Model Magic® blue, yellow, white) – perhaps blending blue and yellow to make green; brown (optional), and white for the ocean, continents, polar caps

  OPTIONAL: quarter (coin) for sense of size for modeling Earth
  ALTERNATIVE: use all white clay and paint Earth

For Moon including ARTEMIS:

- clay (dry modeling clay, e.g., white or gray Model Magic®)
- wooden skewer (inserted in Moon as a handle) 12.7cm (5") preferred; if longer, cut in half;
  ALTERNATIVE: plastic coffee stir straw
- quilter's "T" pins (two) 3.175 cm (1¼") – This can be used to represent the ARTEMIS spacecraft;
  NOTE: These pins should be different than the pins used for securing shoelace.

OPTIONAL: dime (coin) for sense of size for modeling Moon

OPTIONAL: pencil (tip and/or eraser) to make "craters" on the Moon

For Sun:

- paper plate – 25.4 cm (10") diameter with minimal .635 cm (¼") rim
- pen or pencil for marking ridges ("teeth")
- ruler for measuring "wing" and ridges; centering Sun on board
- scissors
- glue - see materials for rectangular base
- binder clips - see materials for rectangular base

  OPTIONAL: crayons, paint, color print of half Sun (size to fit over half-plate), pipe cleaners/chenille stems, glitter (for decorating Sun, e.g., pipe cleaners/chenille stems for coronal loops) (Have the students look at the Sun and its different aspects, sunspots, coronal loops, and add that to their model.)
- dry sand – Creatology®; Any color of sand as long as it is not the same color of the poster board or "Earth" or "Moon.";

  ALTERNATIVE: granular substances of various colors and texture gradients (stored in separate containers), e.g., ground pepper, salt, granulated sugar, cayenne pepper, celery seed.
- dry sponge or small paintbrush for wiping residue from sand; cloth rag might not suffice because it might smear the dust of the sand, lessening the quality of the foam board's surface.
- paper (for funnel) – This can be made with a piece of construction paper 21.59 cm x 27.94 cm (8½" x 11")(color unimportant); curve the sheet like a cone, stapling or taping it, then cutting the "mouth" of it (like an icing/frosting funnel). NOTE: a funnel, a measuring cup or large spoon can be used to monitor the amount of solar wind blasted from the Sun, i.e., how much sand is poured per movement of the Moon.

  OPTIONAL: stapler and staples (to make funnel), staple Sun on rectangular base; tape works just as well.

Box frame (for propping up the rectangular base and for catching the "solar wind"):

- cardboard box – minimum size, inner dimensions 35.56 cm x 25.4 cm x 20.32 cm (14" length x 10" width x 8" height) ALTERNATIVE: cookie pan – 33.02 cm x 22.86 cm x 5.08 cm (13" length x 9" width x 2" height); lip of pan is necessary for runoff sand/"solar wind." If using a cookie pan, find objects to pile behind base to add height, such as wood blocks, books, etc.
- cardboard remnants (to create more height to end of box to help with slope of rectangle base)

- tape (2 - 3" packing tape, blue painter's tape, Scotch® tape, masking tape) for securing gaps in the box flaps and edges so sand does not accumulate in crevices and for adding cardboard remnants to box.
- scissors - see materials for rectangular base

Other Materials:

- paper and pencils/pens for writing notes/drawing pictures/making graphs regarding what is observed in the activity; OPTIONAL: clipboard

Visuals of Materials List:

- Appendix A: printout of Lunar Orbit – Single Page Solar Wind Template, showing Moon's orbit, the magnetotail, magnetopause, magnetosheath, bow shock, and solar wind (top, to be used)

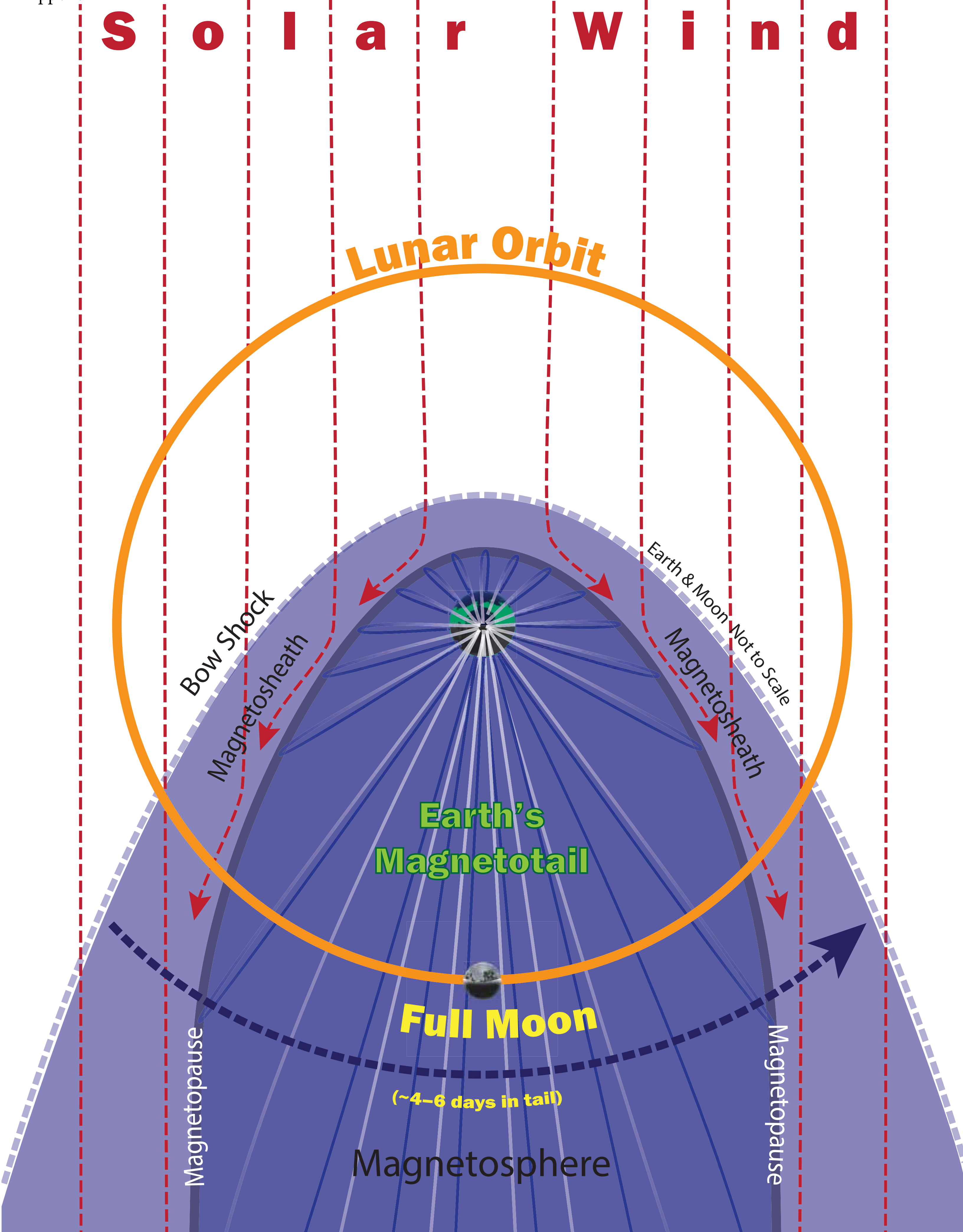
  NOTE: This model is looking down at the Earth directly above the North Pole
- Appendix B: printout of Magnetotail – Single Page Template (bottom, optional)
- Appendix C: printout of instructions for Constructing the Sun-Earth-Moon Model

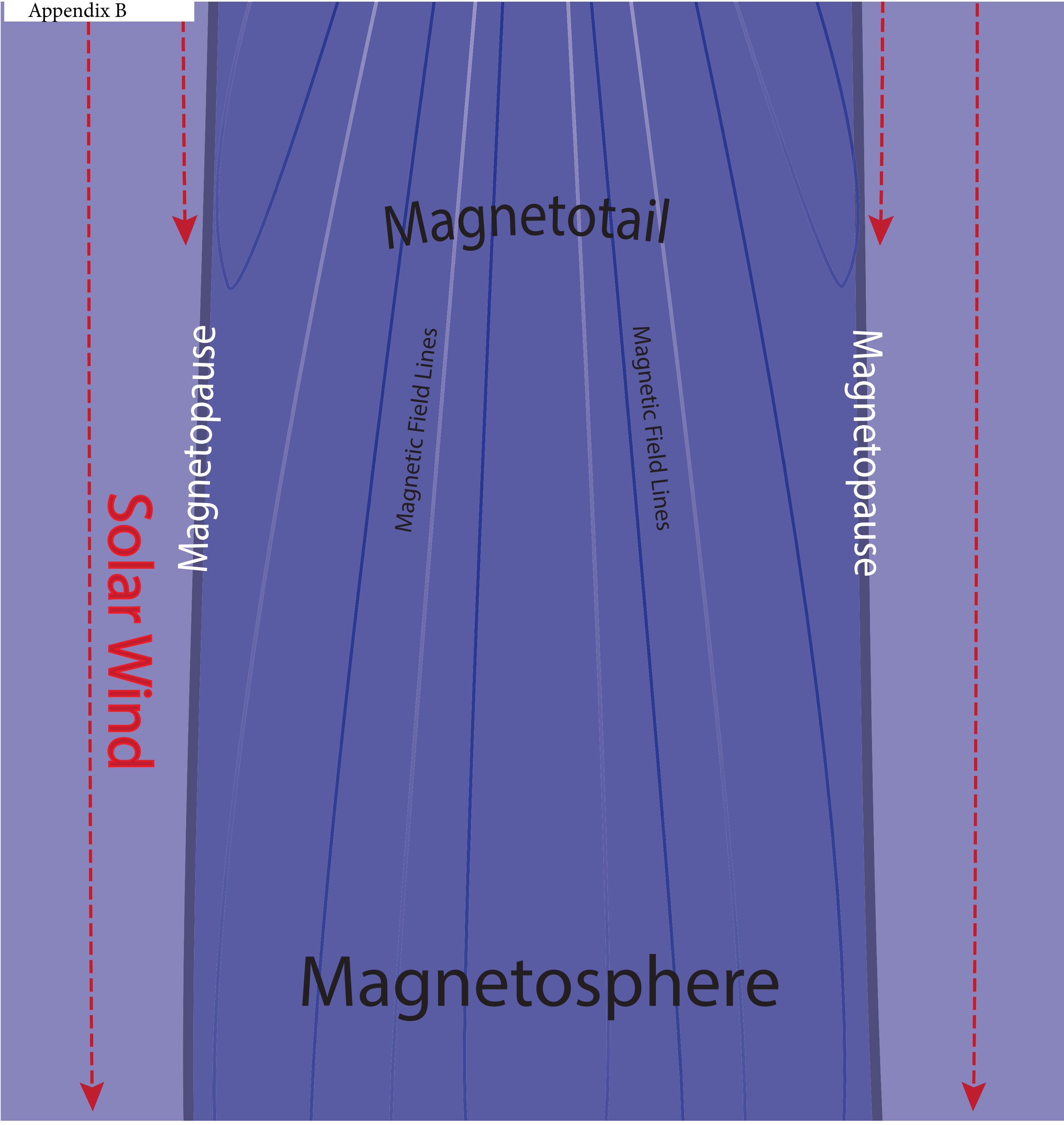
Appendix A: Lunar Orbit – Single Page Solar Wind Template (top) to be used

Earth and Moon not to scale

Appendix B: Magnetotail – Single Page Template (bottom) optional

Appendix C: Constructing the Sun-Earth-Moon Model


Solar Wind
Lunar Orbit
Bow Shock
Magnetosheath
Earth & Moon Not to Scale
Magnetosheath
Earth's Magnetotail
Full Moon
(~4–6 days in tail)
Magnetopause
Magnetopause
Magnetosphere



Please note: For this activity, the sizes and distances of the Sun, Earth, and Moon are not to scale.

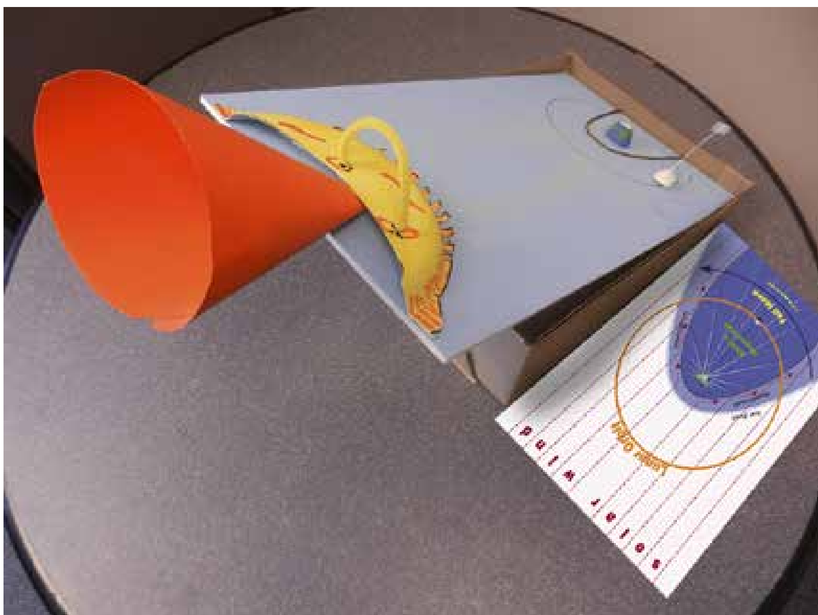
However, the Lunar Orbit is fairly accurate in its positioning from the Earth, as well as the Bow Shock and Magnetosheath.

NOTES:

- See the **MATERIALS LIST** for clarification.
- There are 5 components to this model:
    - rectangular base (including magnetosphere and its magnetotail)
    - Sun
    - Earth
    - Moon (including ARTEMIS)
    - box frame (for propping up the rectangular base and for catching the "solar wind")

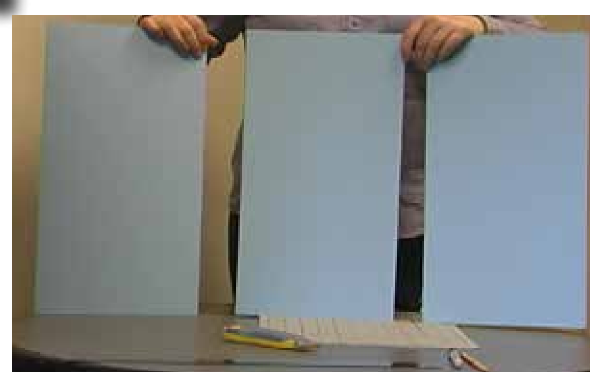
Photos of completed model

NOTE: The sizes and distances of the Sun, Earth, and Moon will not be to scale. However, the Lunar Orbit, Bow Shock, and Magnetosheath is fairly accurate as far as scale.



All components of completed model:

- light blue rectangular base
- orange funnel (optional)
- Sun (with optional coronal loop and other decorations)
- clay model of Earth
- clay model of Moon with ARTEMIS
- cardboard box frame
- Lunar Orbit – Solar Wind Template



Constructing the Sun-Earth-Moon Model

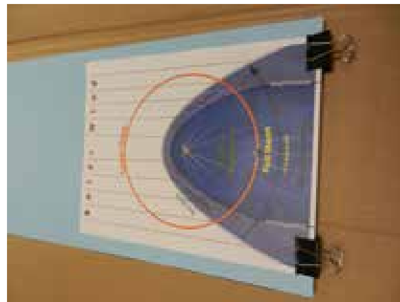
Preparation:

- Prepare cutting surface with something that will protect the surface such as a large piece of cardboard or a cutting mat.
- Measure, draw, and then cut Elmer's Foam Board® (originally 50.8 cm x 76.2 cm (20" x 30")) into three equal pieces. Each student duo/group should have a board that is approximately 25.4 cm x 50.8cm x .47625cm (10" x 20" x $\frac{3}{16}$"). It is better to measure, draw and cut on the front side of the board. Please make sure you do not make any indentations on the board when cutting.
- Print out the Lunar Orbit – Solar Wind Template (App. A) and the Magnetotail Template (App. B), (1 for each group of students). NOTE: It does not have to be printed in color. Black and white is fine.

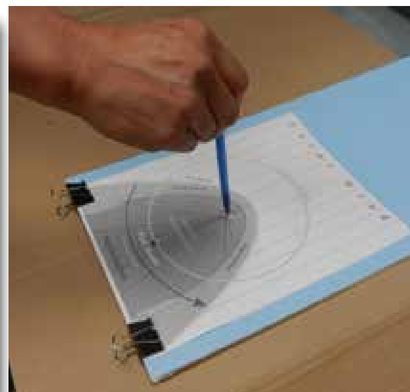
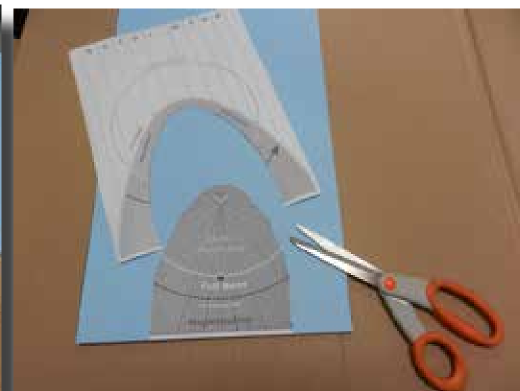
Construct the rectangular base:

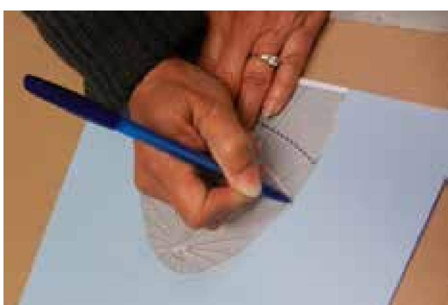
1. Give each pair or group of 3 students one cut part of the foam board and a copy of the Lunar Orbit – Solar Wind Template (App. A). Instruct students to center the template at one end of the foam board and secure with 1.905 cm (¾”) binder clips.

Two versions of the template below. 1) color 2) black and white


2. Have students trace out magnetopause on template, using a pencil or pen, so an ***indentation is*** left on the foam board. Have them put a pinpoint indentation at the center of the Earth's location.



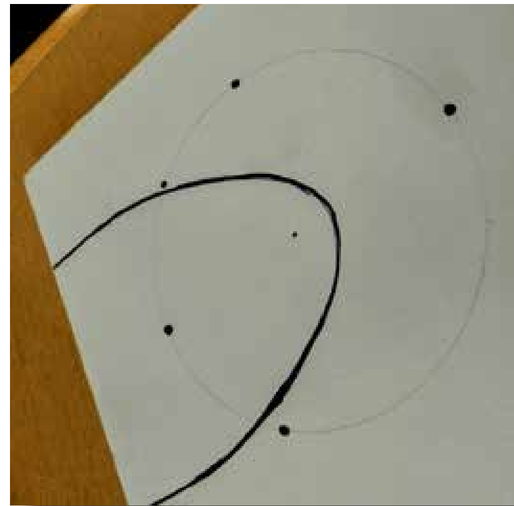

ALTERNATIVE:
Cut out magnetopause and trace around the template. Keep both cut pieces for next step with compass or do after measuring with the compass.

3. Have the students remove blinder clips and template. Have the students determine the distance they need from the Earth’s center point to the Lunar Orbit. Using a compass have them either lightly draw the Lunar Orbit from the marked center of the Earth with a pencil or have them do it with a marker.

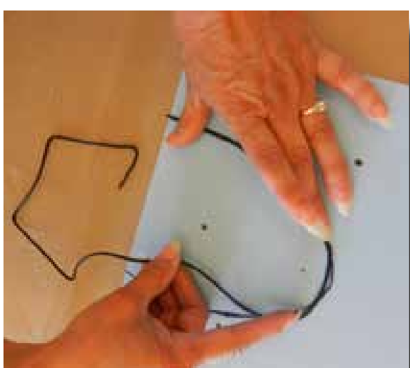
NOTE: DO NOT MAKE ANY INDENTATIONS IN THE FOAM BOARD DURING THIS PROCESS.
Use a Sharpie Fine Point Permanent Marker® or other marker to draw the remainder of the Moon’s orbit and the line (magnetopause) onto the foam board.

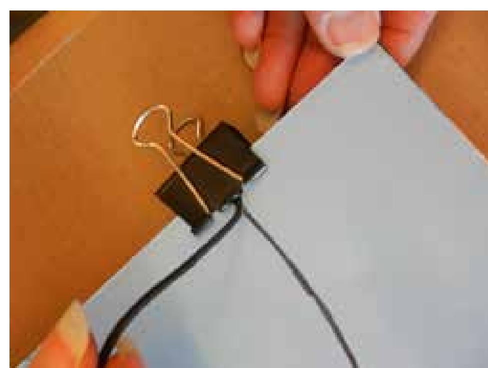
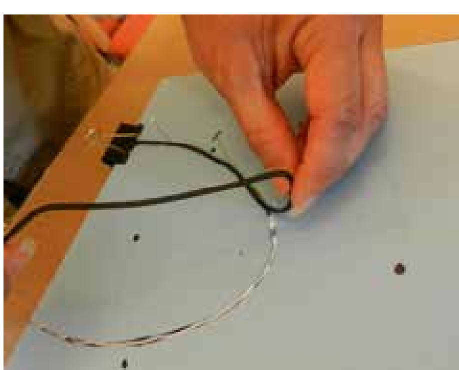
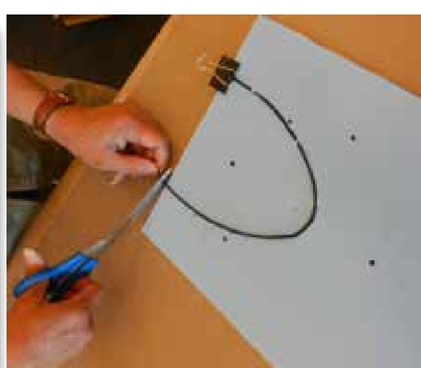
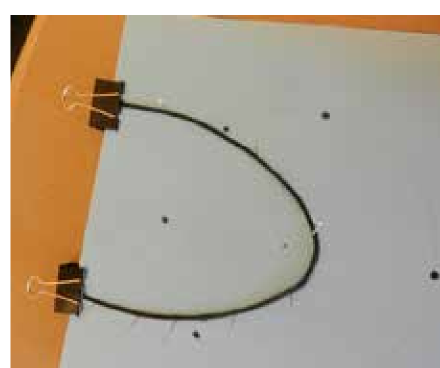
4. Again, without denting the board, clearly mark at least five distinct points in the Moon's orbit: a) one should be well outside of the magnetosphere; b) one at the bow shock (i.e., the dashed light purple line of Appendix A – the Lunar Orbit – Solar Wind Template); c) one in the magnetosheath; d) one in the magnetotail; and e) one in the magnetosheath on the other side of the magnetotail.

   NOTE: When the students move the Moon around its orbit, they can choose to place the Moon at other points outside the magnetosphere. By trying five (or more points, the students will have a better understanding of the varying amounts of solar wind.



5. Have students measure a shoelace so it matches the length of the magnetopause (36.83 cm (14.5")). Students glue one end of the shoelace to the edge of the poster board and secure it with 1.095 cm (¾") binder clips.
6. Carefully apply glue to the traced, indented line of the magnetopause (i.e., at the arc so that it looks like the Gateway Arch of St. Louis, Missouri) and place the shoelace onto the glue-traced magnetopause. Secure with drawing pins or thumbtacks. Binder clip down the other end as the first end.
   NOTE: During the activity, there is the possibility of too much sand (solar wind) moving across the board too quickly; the sand grains might stream over the magnetopause and enter the magnetotail, thereby hitting the Earth. Part of the experimental process in constructing the Sun-Earth-Moon Model involves the students deciding the height of the magnetopause, ensuring that the sand (solar wind) does not enter the magnetotail. A second shoelace piece (or pipe cleaner piece) can be glued on top of the first piece of shoelace/pipe cleaner/chenille stem in order to heighten the magnetopause.



7. Remove binder clips, pins and/or tacks once glue has dried.
   OPTIONAL: To help visualize how the magnetosphere is truly vast, you can reveal the Magnetotail Template (App. B), i.e., showing more of the magnetotail. This paper extension can be folded under the board when doing the activity.

Construct the Sun:

NOTE: The size of the Sun will not be to scale, as well as its relationship to the Earth and Moon.

1. Cut a paper plate in half. (The paper plate should have a minimum .635cm (¼”) rim.) Each half can go to one group, so each full plate makes two suns.

2. Draw a curved line – like a smile – across the straight edge of your half-plate. This will allow for ease in pouring the sand (solar wind).

3. At the lip of the plate closest to the straight edge, measure 2.54 cm (1”) from the straight edge, at the inside edge of the lip. (See Figure 1 (image of completed model).)
4. Draw a straight line from the 2.54 cm (1”) mark, to the corner of the outer edge to form a “wing” on each side.
5. Remove all but 1 mm (.04”) of the plate’s lip. (Make sure to leave the wings intact.)
6. Draw and cut fringe or slits along the arc of the plate (not concentrated in center of plate), with each section about 1.27 cm (½”) wide. The Sun should have ridges or wedges, cut in half, like alternating “teeth.”

7. Fold every other fringe piece upwards, to form a row of exposed gaps.
   OPTIONAL: Decorate your Sun, ideally before all the cutting. For example, to create a coronal loop, a pipe clean can be bent, poking it through two holes of the Sun’s surface. Or students can draw with marking pens and crayons to indicate sunspots, etc.

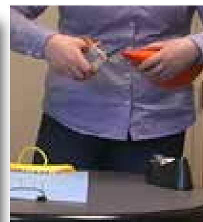
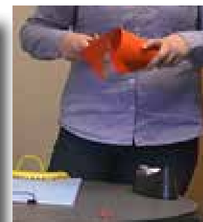
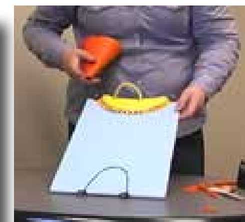
8. Center the Sun at the opposite end of the foam board and mark the location of the wings, so the fringe is facing the shoelace/pipe cleaner magnetotail.

9. Glue the wings of the Sun securely to foam board and secure dry with 1.905 cm (¾”) binder clips. Remove binder clips when glue has dried.

10. Use a funnel for pouring sand through the Sun. If you don't use a store-bought funnel, you can make one out of paper. Use a 21.59 cm x 27.94 cm (8½" x 11") piece of paper (any color). Gently wrap funnel into a cone shape and allow for a hole that is approximately the size of a dime's (coin) perimeter. Tape or staple it in that shape. The student may cut the tip of the cone to get it to the shape but be careful not to cut too much. The key to the funnel is that the mouth is not too large and can easily control the flow of sand. Keep Sun secure on the board, not weighted down by too much sand. The funnel is made with smaller ring at the end that is nestled in the curve of the Sun.

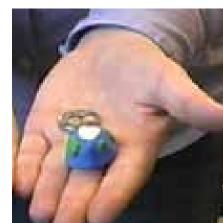
NOTE: Funnel is not necessary if measuring cup or large spoon is used to monitor how much sand is poured per movement of the Moon.



Construct the Earth:

NOTE: The size of the Earth will not be to scale.



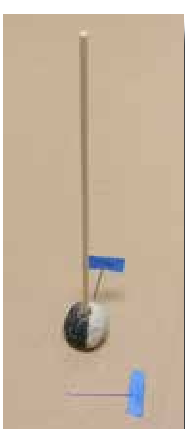
1. Make a hemisphere Earth out of clay, approximately the size of a quarter's perimeter. One edge must be flat to stick to the poster board.
2. Stick the Earth in the center of the Moon's orbit. If it doesn't stick automatically, you can fold some tape and place it between the board and the base of the Earth. Gluing the base works as well.

Construct the Moon (including ARTEMIS):

NOTE: The size of the Moon will not be to scale.

1. Make a Moon out of clay. Feel free to elaborate with craters by using a pencil, e.g., the pencil's eraser for craters or the pencil tip for coloring. Ensure the Moon is also as hemisphere, approximately the size of a dime's perimeter.

2. Insert a wooden skewer or plastic coffee stir straw through top of the center of the Moon, so it can be used as a handle when the students move the Moon in its orbit. Make sure the bottom of the hemisphere is still completely flat. See the example of what it should look like in the styrofoam/skewer photo.



3. Place two 3.175 cm (1¼") quilter's "T" pins at approx. 45 degrees in the top area of the Moon to represent the ARTEMIS spacecraft. To soften the ends of the "T" pins' handles, attach tiny pieces of tape or little pieces of construction paper folded over and glued to the tiny "T" section of the pins.

OPTION: Students can shade in the dark side of the Moon (and Earth) to simulate the Sun's direction.

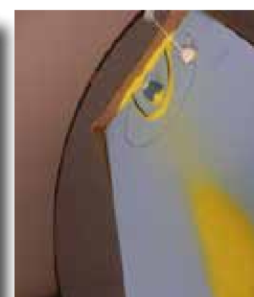
Construct the Box Frame:

1. Box measurements: 25.4 cm x 35.56 cm x 20.32 cm (10” height x 14” length x 8” width). Measure a 30’-35’ degree angle for slope of foam board. (25.4 cm (10”) is the height for where the Sun rests.)
   OPTIONAL: cookie pan – 33.02 cm x 22.86 cm x 5.08 cm (13” length x 9” width x 2” depth); lip of pan is necessary for runoff sand/“solar wind”.
2. Allow for at least 3.81 cm (1½”) at the base of the board, so that there’s that much of a gap between the magnetosphere and the lip of the cookie sheet. You want to be able to see the Moon with ARTEMIS without the cookie sheet impeding the view.
3. A lip on the bottom of the board should be in place so the sand will collect in that area to show the bow shock area. Create a 5.08 cm (2”) spacer area between the side edge of the box and the side edge of the board to allow for ease of movement of the Moon.
4. With a large 2" roll of packing tape, cut and place over any miscellaneous gaps in the box that may collect the sand particles.
5. Add height to the box with the remainder of the cut cardboard box. Fold to various heights to obtain the best flow of the sand.



IMAGES OF FINAL PRODUCT - top view



IMAGES OF ACTIVITY IN PROGRESS


View some short step-by-step video instructions on the activity process as an added resource for clarification at:

http://cse.ssl.berkeley.edu/artemis/epo-classroom-g69_NewSpinSolarWind.html