15.E: The Sun- A Garden-Variety Star (Exercises)

For Further Exploration

Articles

Berman, B. “How Solar Storms Could Shut Down Earth.” *Astronomy* (September 2013): 22. Up-to-date review of how events on the Sun can hurt our civilization.

Frank, A. “Blowin’ in the Solar Wind.” *Astronomy* (October 1998): 60. On results from the SOHO spacecraft.

Holman, G. “The Mysterious Origins of Solar Flares.” *Scientific American* (April 2006): 38. New ideas involving magnetic reconnection and new observations of flares.

James, C. “Solar Forecast: Storm Ahead.” *Sky & Telescope* (July 2007): 24. Nice review on the effects of the Sun’s outbursts and on Earth and how we monitor “space weather.”

Schaefer, B. “Sunspots That Changed the World.” *Sky & Telescope* (April 1997): 34. Historical events connected with sunspots and solar activity.

Schrijver, C. and Title, A. “Today’s Science of the Sun.” *Sky & Telescope* (February 2001): 34; (March 2001): 34. Excellent reviews of recent results about the solar atmosphere.

Wadhwa, M. “Order from Chaos: Genesis Samples the Solar Wind.” *Astronomy* (October 2013): 54. On a satellite that returned samples of the Sun’s wind.

Websites

Dr. Sten Odenwald’s “Solar Storms” site: http://www.solarstorms.org/.

ESA/NASA’s Solar & Heliospheric Observatory: http://sohowww.nascom.nasa.gov. A satellite mission with a rich website to explore.

High Altitude Observatory Introduction to the Sun: www.hao.ucar.edu/education/basic.php. For beginners.

NASA’s Solar Missions: https://www.nasa.gov/mission_pages/s...ons/index.html. Good summary of the many satellites and missions NASA has.

NOAA Profile of Space Weather: www.swpc.noaa.gov/sites/defau...r_2010_new.pdf. A primer.

NOAA Space Weather Prediction Center Information Pages: www.swpc.noaa.gov/content/edu...n-and-outreach. Includes primers, videos, a curriculum and training modules.

Nova Sun Lab: http://www.pbs.org/wgbh/nova/labs/lab/sun/. Videos, scientist profiles, a research challenge related to the active Sun from the PBS science program.

Space Weather: Storms on the Sun: www.swpc.noaa.gov/sites/defau...wx_booklet.pdf. An illustrated booklet from NOAA.

Stanford Solar Center: http://solar-center.stanford.edu/. An excellent site with information for students and teachers.

Apps

These can tell you and your students more about what’s happening on the Sun in real time.

NASA’s 3-D Sun: http://3dsun.org/.

NASA Space Weather: itunes.apple.com/us/app/nasa...422621403?mt=8.

Solaris Alpha: play.google.com/store/apps/d...y.solarisalpha.

Solar Monitor Pro: www.solarmonitor.eu/.

Videos

Journey into the Sun: https://www.youtube.com/watch?v=fqKFQ7z0Nuk. 2010 KQED Quest TV Program mostly about the Solar Dynamics Observatory spacecraft, its launch and capabilities, but with good general information on how the Sun works (12:24).

NASA | SDO: Three Years in Three Minutes--With Expert Commentary: https://www.youtube.com/watch?v=QaCG0wAjJSY&src. Video of 3 years of observations of the Sun by the Solar Dynamics Observatory made into a speeded up movie, with commentary by solar physicist Alex Young (5:03).

Our Explosive Sun: http://www.youtube.com/watch?v=kI6YGSIJqrE. Video of a 2011 public lecture in the Silicon Valley Astronomy Lecture Series by Dr. Thomas Berger about solar activity and recent satellite missions to observe and understand it (1:20:22).

Out There Raining Fire: www.nytimes.com/video/science....html?emc=eta1. Nice overview and introduction to the Sun by science reporter Dennis Overbye of the NY Times (2:28)

Space Weather Impacts: www.swpc.noaa.gov/content/edu...n-and-outreach. Video from NOAA (2:47); https://www.youtube.com/playlist?lis...bIUzBO6JI0Pvx0. Videos from the National Weather Service (four short videos) (14:41).

Space Weather: Storms on the Sun: http://www.youtube.com/watch?v=vWsmp4o-qVg. Science bulletin from the American Museum of Natural History, giving the background to what happens on the Sun to cause space weather (6:10).

Sun Storms: www.livescience.com/11754-sun...nic-world.html. From the Starry Night company about storms from the Sun now and in the past (4:49).

Sunspot Group AR 2339 Crosses the Sun: http://apod.nasa.gov/apod/ap150629.html. Short video (with music) animates Solar Dynamics Observatory images of an especially large sunspot group going across the Sun's face (1:15).

What Happens on the Sun Doesn't Stay on the Sun: https://www.youtube.com/watch?v=bg_gD2-ujCk. From the National Oceanic and Atmospheric Administration: introduction to the Sun, space weather, its effects, and how we monitor it (4:56).

Collaborative Group Activities

1. Have your group make a list of all the ways the Sun personally affects your life on Earth. (Consider the everyday effects as well as the unusual effects due to high solar activity.)
2. Long before the nature of the Sun was fully understood, astronomer (and planet discoverer) William Herschel (1738–1822) proposed that the hot Sun may have a cool interior and may be inhabited. Have your group discuss this proposal and come up with modern arguments against it.
3. We discussed how the migration of Europeans to North America was apparently affected by short-term climate change. If Earth were to become significantly hotter, either because of changes in the Sun or because of greenhouse warming, one effect would be an increase in the rate of melting of the polar ice caps. How would this affect modern civilization?
4. Suppose we experience another Maunder Minimum on Earth, and it is accompanied by a drop in the average temperature like the Little Ice Age in Europe. Have your group discuss how this would affect civilization and international politics. Make a list of the most serious effects that you can think of.
5. Watching sunspots move across the disk of the Sun is one way to show that our star rotates on its axis. Can your group come up with other ways to show the Sun's rotation?
6. Suppose in the future, we are able to forecast space weather as well as we forecast weather on Earth. And suppose we have a few days of warning that a big solar storm is coming that will overload Earth's magnetosphere with charged particles and send more ultraviolet and X-rays toward our planet. Have your group discuss what steps we might take to protect our civilization?
7. Have your group members research online to find out what satellites are in space to help astronomers study the Sun. In addition to searching for NASA satellites, you might also check for satellites launched by the European Space Agency and the Japanese Space Agency.
8. Some scientists and engineers are thinking about building a "solar sail"—something that can use the Sun's wind or energy to propel a spacecraft away from the Sun. The Planetary Society is a nonprofit organization that is trying to get solar sails launched, for example. Have your group do a report on the current state of solar-sail projects and what people are dreaming about for the future.

Review Questions

1. Describe the main differences between the composition of Earth and that of the Sun.
2. Describe how energy makes its way from the nuclear core of the Sun to the atmosphere. Include the name of each layer and how energy moves through the layer.
3. Make a sketch of the Sun's atmosphere showing the locations of the photosphere, chromosphere, and corona. What is the approximate temperature of each of these regions?

4. Why do sunspots look dark?
5. Which aspects of the Sun's activity cycle have a period of about 11 years? Which vary during intervals of about 22 years?
6. Summarize the evidence indicating that over several hundreds of years or more there have been variations in the level of the solar activity.
7. What it the Zeeman effect and what does it tell us about the Sun?
8. Explain how the theory of the Sun's dynamo results in an average 22-year solar activity cycle. Include the location and mechanism for the dynamo.
9. Compare and contrast the four different types of solar activity above the photosphere.
10. What are the two sources of particles coming from the Sun that cause space weather? How are they different?
11. How does activity on the Sun affect human technology on Earth and in the rest of the solar system?
12. How does activity on the Sun affect natural phenomena on Earth?

Thought Questions

1. Table 15.1.1 indicates that the density of the Sun is 1.41 g/cm^3. Since other materials, such as ice, have similar densities, how do you know that the Sun is not made of ice?
2. Starting from the core of the Sun and going outward, the temperature decreases. Yet, above the photosphere, the temperature increases. How can this be?
3. Since the rotation period of the Sun can be determined by observing the apparent motions of sunspots, a correction must be made for the orbital motion of Earth. Explain what the correction is and how it arises. Making some sketches may help answer this question.
4. Suppose an (extremely hypothetical) elongated sunspot forms that extends from a latitude of 30° to a latitude of 40° along a fixed of longitude on the Sun. How will the appearance of that sunspot change as the Sun rotates? (Figure 15.2.5 should help you figure this out.)
5. The text explains that plages are found near sunspots, but Figure 15.2.6 shows that they appear even in areas without sunspots. What might be the explanation for this?
6. Why would a flare be observed in visible light, when they are so much brighter in X-ray and ultraviolet light?
7. How can the prominences, which are so big and 'float' in the corona, stay gravitationally attached to the Sun while flares can escape?
8. If you were concerned about space weather and wanted to avoid it, where would be the safest place on Earth for you to live?
9. Suppose you live in northern Canada and an extremely strong flare is reported on the Sun. What precautions might you take? What might be a positive result?

Figuring for Yourself

1. The edge of the Sun doesn't have to be absolutely sharp in order to look that way to us. It just has to go from being transparent to being completely opaque in a distance that is smaller than your eye can resolve. Remember from Astronomical Instruments that the ability to resolve detail depends on the size of the telescope's aperture. The pupil of your eye is very small relative to the size of a telescope and therefore is very limited in the amount of detail you can see. In fact, your eye cannot see details that are smaller than 1/30 of the diameter of the Sun (about 1 arcminute). Nearly all the light from the Sun emerges from a layer that is only about 400 km thick. What fraction is this of the diameter of the Sun? How does this compare with the ability of the human eye to resolve detail? Suppose we could see light emerging directly from a layer that was 300,000 km thick. Would the Sun appear to have a sharp edge?
2. Show that the statement that 92% of the Sun's atoms are hydrogen is consistent with the statement that 73% of the Sun's mass is made up of hydrogen, as found in Table 15.1.2 (Hint: Make the simplifying assumption, which is nearly correct, that the Sun is made up entirely of hydrogen and helium.)
3. From Doppler shifts of the spectral lines in the light coming from the east and west edges of the Sun, astronomers find that the radial velocities of the two edges differ by about 4 km/s, meaning that the Sun's rotation rate is 2 km/s. Find the approximate period of rotation of the Sun in days. The circumference of a sphere is given by $2\pi R$, where R is the radius of the sphere.
4. Assuming an average sunspot cycle of 11 years, how many revolutions does the equator of the Sun make during that one cycle? Do higher latitudes make more or fewer revolutions compared to the equator?
5. This chapter gives the average sunspot cycle as 11 years. Verify this using Figure 15.4.3
6. The escape velocity from any astronomical object can be calculated as $v_{\text{escape}} = \sqrt{2GM/R}$. Using the data in Appendix E, calculate the escape velocity from the photosphere of the Sun. Since coronal mass ejections escape from the corona, would the

escape velocity from there be more or less than from the photosphere?

7. Suppose you observe a major solar flare while astronauts are orbiting Earth. Use the data in the text to calculate how long it will before the charged particles ejected from the Sun during the flare reach them.
8. Suppose an eruptive prominence rises at a speed of 150 km/s. If it does not change speed, how far from the photosphere will it extend after 3 hours? How does this distance compare with the diameter of Earth?
9. From the information in Figure 15.3.4, estimate the speed with which the particles in the CME in parts (c) and (d) are moving away from the Sun.
