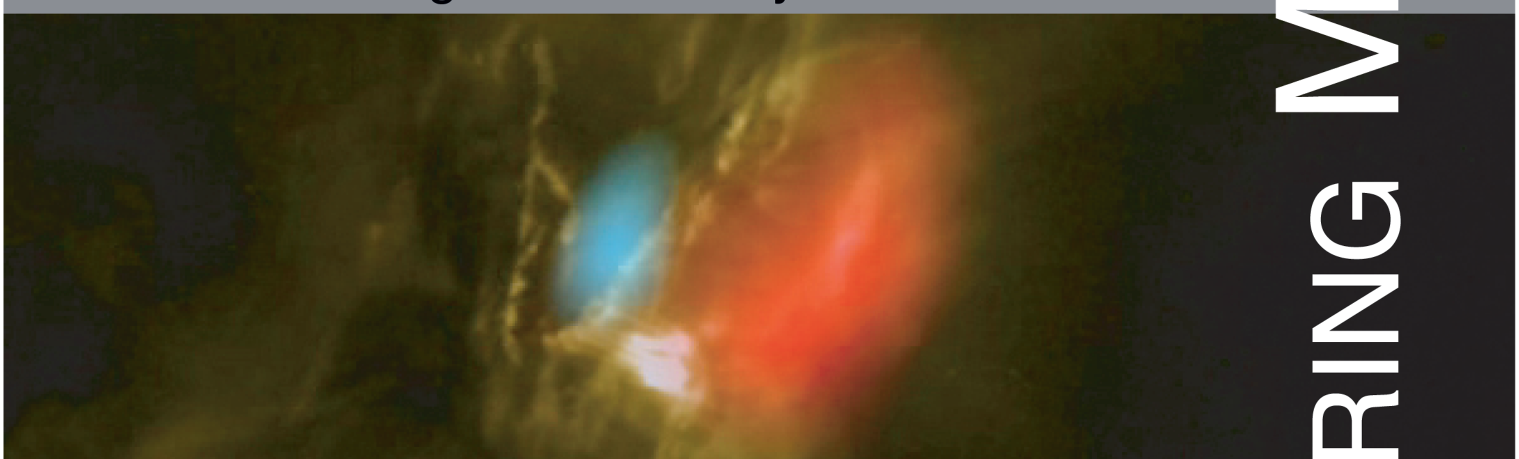
National Aeronautics and Space Administration

Exploring Magnetism in Solar Flares

A Teacher's Magnetism Activity Guide



Grades 8-12

EXPLORING MAGNETISM

Educational Product	
Educators & Students	Grades 8-12

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Acknowledgments

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in Solar Flares
An Educator's Activity Guide
for Grades 8-12

Introduction

Solar flares are the most powerful explosions in the Solar System and play an important role in the Sun-Earth connection. Solar flares are caused by sudden changes of strong magnetic fields in the Sun's corona. The changing magnetic field converts magnetic potential energy into kinetic energy by accelerating charged gases (plasmas) in the corona. The plasma is channeled by the magnetic field up and away from the Sun. Plasma is also accelerated back down along the magnetic field into the chromosphere. In the chromosphere, the plasma crashes into denser gas and releases its kinetic energy into thermal energy, sound, and light energy.

The activities in this guide are meant to teach students about the Sun and solar flares. Along the way they will learn about important basic concepts in physical science, and practice their mathematics and literacy skills. The chief physical science concept in these lessons is that of magnetism, or more generally electromagnetism.

This guide was developed for grades 8-12 and is intended to be used as a supplement to the original *Exploring Magnetism* lesson guide, which was developed at the UC Berkeley Space Sciences Laboratory for the Education and Public Outreach Programs of the NASA missions RHESSI, STEREO-IMPACT, THEMIS, and FAST. It is strongly recommended that *Exploring Magnetism* be used as a prerequisite to this guide. Sessions 1 and 2 of *Exploring Magnetism* are about magnetism in general and then its connection to electricity. Session 3 was developed in the first supplemental guide in the series, *Exploring Magnetism in the Solar Wind*, and is about how the STEREO mission will measure the magnetic field of the Solar Wind. This guide continues with Session 4.

Session 4: Solar Flares

Session Summary

Activity 1 - Magnetic Fields on the Surface of the Sun

- Students map the magnetic field around two opposing magnetic poles. They also make predictions of fields for other configurations and draw them.
- Students are given a worksheet with a drawing of sunspots on the surface of the Sun, which is labeled North and South. They are asked to draw what they think the magnetic field looks like above the surface.
- The teacher gives a lecture about magnetic fields on the surface of the Sun, explaining how they cause sunspots and form loops in the Sun's atmosphere. (Online version includes a

PowerPoint presentation with pictures and movies, for those that can make use of it. The printed guide includes lecture overheads and notes for each slide.)

Activity 2 – Magnetic Energy and the Cause of Solar Flares

- Students witness demonstrations that magnetic fields can store potential energy and then release it as kinetic energy. (Jumping coils, and galvanometer experiments from *Exploring Magnetism*).
- Students are assigned to read an essay about how magnetic fields on the Sun evolve, store energy, and then release them in Solar Flares (there is a focus on conservation of energy, and energy comparisons). Students complete a concept map to assess their understanding of the reading.

Activity 3 – Measuring the Speed of an Ejected Blob of Plasma

- Students examine image data from the RHESSI satellite of a Solar Flare that expels a blob of plasma, which eventually becomes part of a Coronal Mass Ejection (April 15, 2002, ~23:10 UT, # 2041509). They will predict the shape of the magnetic field in the flare region.
- Students measure the speed of the blob by measuring the change in its position in a timed sequence of RHESSI images, and then graphing the results.
- Advanced students may also estimate the energy of the blob by first estimating a mass for it, using its size and the density of plasma in coronal loops.
- Advanced students can also estimate the magnetic field strength that produced the solar flare and CME using the equation for magnetic energy density and a couple additional measurements.

Activity 4 – Science Conference

- Students submit abstracts of their findings for a presentation at a mock science conference about Solar Flare # 2041509.
- After the teacher selects which abstracts will be used for posters and which will be for oral presentations, the students work in their science teams to create and present their posters and talks at a mock science conference.

Standards

Science Topics

★ Force and Motion
★ Magnetism
★ Electromagnetism
★ Conservation of Energy
★ Space Science: The Sun

National Science Education Standards (Grades 5-8)

Science as Inquiry

★ Abilities necessary to do scientific inquiry
★ Understandings about scientific inquiry

Physical Science

★ Properties and changes of properties in matter

★ Motions and forces
★ Transfer of energy

Earth and Space Science
★ Structure of the Earth system
★ Earth's history
★ Earth in the Solar System

Science and Technology
★ Abilities of technological design
★ Understandings about science and technology

History and Nature of Science
★ Science as a human endeavor
★ Nature of science
★ History of science

National Science Education Standards (Grades 9-12)

Science as Inquiry
★ Abilities necessary to do scientific inquiry
★ Understandings about scientific inquiry

Physical Science
★ Motions and forces
★ Conservation of energy and increase in disorder
★ Interactions of energy and matter

Earth and Space Science
★ Origin and Evolution of the Earth system
★ Origin and evolution of the Universe

History and Nature of Science
★ Science as a human endeavor
★ Nature of science
★ History of science

Math Topics

Measurement
Graphing
Unit conversions
Ratios
Scientific Notation

National Council of Teachers of Mathematics Standards (Grades 6-8)

Number and Operations
★ Understand numbers, ways of representing numbers, relationships among numbers, and number systems

Algebra
★ Understand patterns, relations, and functions
★ Represent and analyze mathematical situations and structures using algebraic symbols
★ Use mathematical models to represent and understand quantitative relationships
★ Analyze change in various contexts

Measurements
★ Understand measurable attributes of objects and the units, systems, and processes of measurement

★ Apply appropriate techniques, tools, and formulas to determine measurements

Data Analysis and Probability

★ Select and use appropriate statistical methods to analyze data
★ Develop and evaluate inferences and predictions that are based on data

National Council of Teachers of Mathematics Standards (Grades 9-12)

Understand numbers, ways of representing numbers, relationships among numbers, and number systems

all students should–

★ develop a deeper understanding of very large and very small numbers and of various representations of them

Compute fluently and make reasonable estimates

all students should–

★ develop fluency in operations with real numbers, vectors, and matrices, using mental computation or paper-and-pencil calculations for simple cases and technology for more-complicated cases.
★ judge the reasonableness of numerical computations and their results.

Literacy Skills

Reading
Writing
Oral Presentation

National Council of Teachers of English Standards (All Grades)_

1. Students read a wide range of print and non-print texts to build an understanding of texts, of themselves, and of the cultures of the United States and the world; to acquire new information; to respond to the needs and demands of society and the workplace; and for personal fulfillment. Among these texts are fiction and nonfiction, classic and contemporary works.

3. Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and of other texts, their word identification strategies, and their understanding of textual features (e.g., sound-letter correspondence, sentence structure, context, graphics).

4. Students adjust their use of spoken, written, and visual language (e.g., conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes

6. Students apply knowledge of language structure, language conventions (e.g., spelling and punctuation), media techniques, figurative language, and genre to create, critique, and discuss print and non-print texts

7. Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.

Activity 1 – Magnetic Fields on the Surface of the Sun

Student Objectives

- Students will work collaboratively in a science team to explore magnetism in solar flares.
- Students will map the magnetic fields around a pair of sunspots on the Sun.
- Students will know what the Sun is and the physical properties of the Sun.
- Students will know what sunspots are and why they change appearance on the Sun.

Materials Needed
(per group of students)

- 1 simple magnetic compass per student
- 2 Alnico bar magnets
- 6 sheets of white paper
- 1 pencil per student

(for lecture)

- Computer with Microsoft PowerPoint installed
- Computer projector
- PowerPoint file from Exploring Magnetism website

Or

- Overhead projector and transparencies

Getting Ready

Assemble the materials needed. Examine the compasses and make sure that they have the proper polarity; i.e. the needle should point toward the south poles of the bar magnets (the blue end if you are working with red and blue colored magnets). If the polarity of the compass is reversed, you can correct it by dragging one end of the magnet over the top of the compass needle such that the needle does not turn on its pivot. This is probably how the compass needle had its polarity reversed in the first place.

For the lecture, if you are able to display PowerPoint presentations in your classroom, you will find a ready-made presentation with notes for the lecture about magnetic fields on the Sun located at http://cse.ssl.berkeley.edu/ExploringMagnetism/SolarFlares. Otherwise you should make transparencies from the pages in the *Lecture* section below and use the notes included with them.

Procedure

1. Assemble students into groups of about four. Explain that these will be their *Science Teams* that they will work with throughout the entire series of lessons. Mention that scientists today usually work in teams. Sometimes the teams are very large and international. They do this to share knowledge and resources in the most efficient way possible.

   [**Note:** It is strongly advised that this lesson guide be used after students have completed the activities found in the original *Exploring Magnetism* lesson guide. If the students have not experienced those activities, at the very least you should precede this activity with Activity 1 from Session 1 of *Exploring Magnetism*.]

2. As in the magnetic field mapping activities from *Exploring Magnetism,* instruct students to tape together several sheets of blank paper on their tables.

3. Have students arrange two bar magnets on the paper parallel to one another, about 3 inches apart, with opposite poles next to each other. Then have them tape the magnets in place. See **Figure 4.1.**

4. Using compasses and pencils, have students map the magnetic field lines around either ends of the pair of magnets.

   To make the tracings, have the students do the following:
   a. Draw a dot somewhere near the magnets and place the center of a compass over the dot.
   b. Draw a dot at the location of the arrow head (or tail) of the compass needle.
   c. Move the compass center to this new dot, and again draw a dot at the location of the compass needle head (or tail).
   d. Remove the compass from the paper and draw lines connecting the dots with arrows indicating the direction that the compass points.
   e. Continue steps b-d until the line meets the magnet or the edge of the paper.
   f. Pick another spot near the magnet and repeat the process (steps a-e).

5. Next give students **Worksheet 4.1**, with the illustration of a pair of sunspots on the surface of the Sun. The sunspots are labeled with an N and S indicating that each spot is has a magnetic polarity. Instruct students to draw what they think the magnetic field looks like above the surface of the Sun near the sunspots.

   As an optional extension, have students verify their predictions by taping bar magnets to another copy of **Worksheet 4.1** with the poles of the magnets aligned with the appropriate sunspots in the illustration. The students can then map the field with a compass as in step 4.

6. Give a lecture about magnetic fields on the surface of the Sun, using the materials and information given below. Have students take notes during the lecture using the **Sunspots Lecture Graphic Organizer** as their guide, which contains questions they should answer based on the lecture. Finally, pass out **Worksheet 4.2** for students to answer based on the lecture.

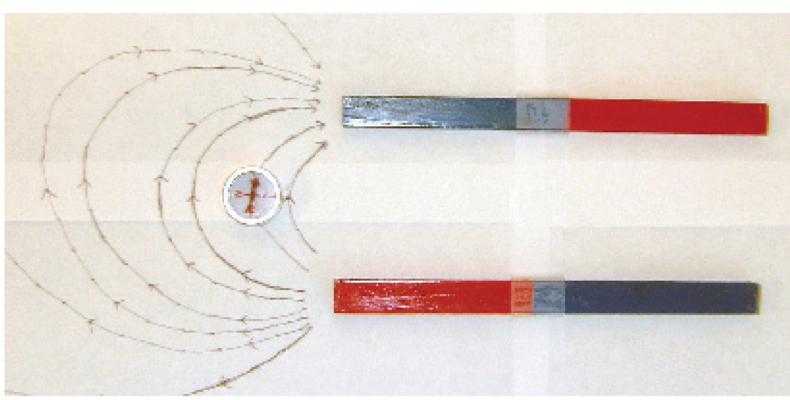


Figure 4.1: The student set-up for the magnetic field mapping activity. The magnetic field around one pair of poles is shown. Students may wish to map the area around both pairs of poles to discover the same shape for the magnetic field.

<u>Worksheet 4.1</u>

1. Below is a drawing of a pair of sunspots on the surface of the Sun. Scientists have found that sunspots are like magnetic poles of a bar magnet. Draw what you predict the magnetic field above the surface of the Sun looks like in the region around the sunspots.

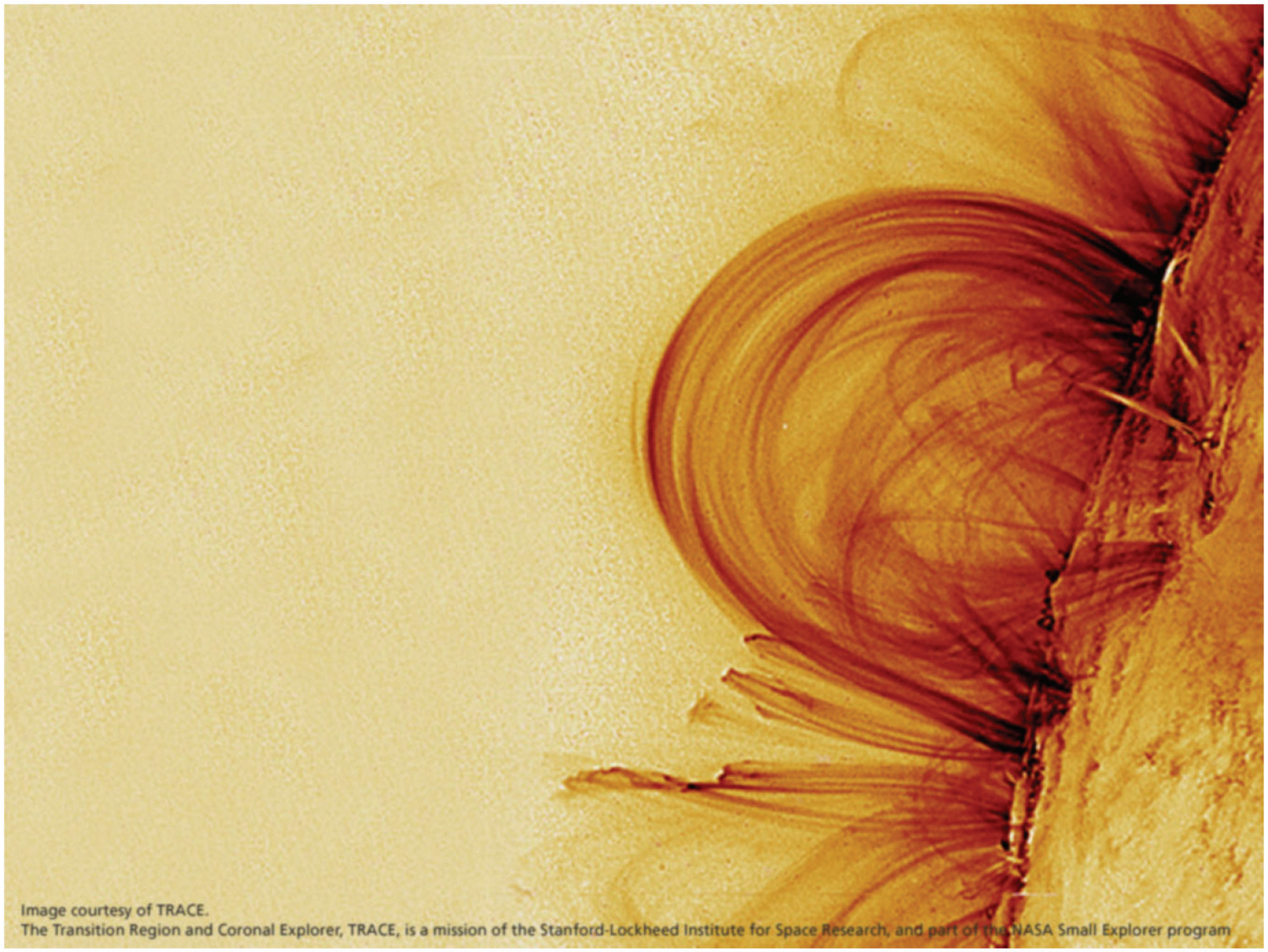
Sunspots Lecture

A lecture has been created for you to use to explain to your students how magnetic fields appear on the surface of the Sun and create sunspots and coronal loops. In the previous lesson guide, *Exploring Magnetism in the Solar Wind*, there is lecture prepared for teachers to explain what space weather is and how it affects Earth. Though there is some overlap in content between that lecture and the one presented here, the lecture here is focused on the Sun and how magnetism gives rise to sunspots.

For those who can make use of it there is an electronic version of the lecture at the Exploring Magnetism website (http://cse.ssl.berkeley.edu/ExploringMagnetism/SolarFlares). The lecture there can be found either as a PDF document or as a Microsoft PowerPoint file. The PowerPoint file contains slide notes that the instructor may use while giving the presentation along with some movies embedded in the presentation. The PDF document is a full color version of the print version of the lecture and may be used via a computer projection system or can be used to make overhead transparencies.

The following pages contain the lecture slides that you may use to create overhead transparency slides. Also included are notes for each slide. These notes are intended to give you background information necessary to give the lecture and answer potential questions from students. The notes follow the text on the slides, but do not repeat it. The notes are not meant to be read allowed to the students, but are a guide for the teacher.

The Magnetic Sun



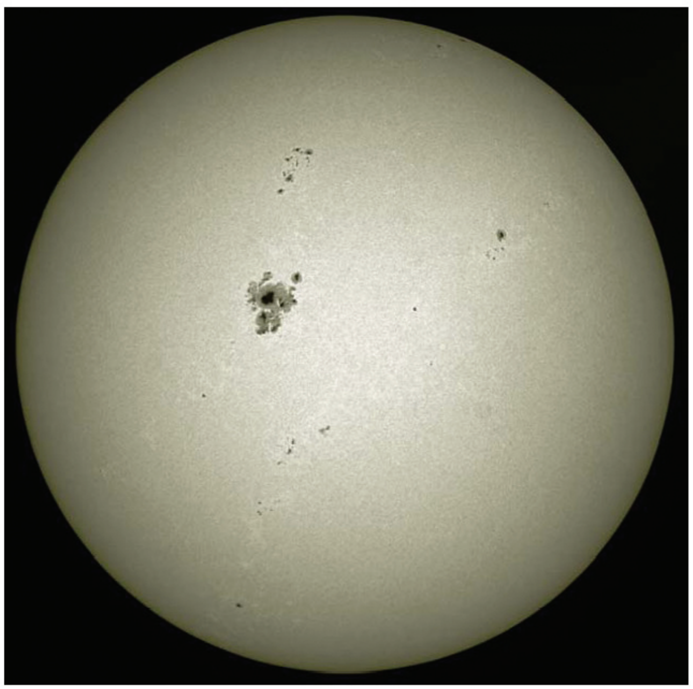
What is the Sun?

The Sun is a Star, but seen close-up.

The Stars are other Suns but very far away.

What is the Sun?

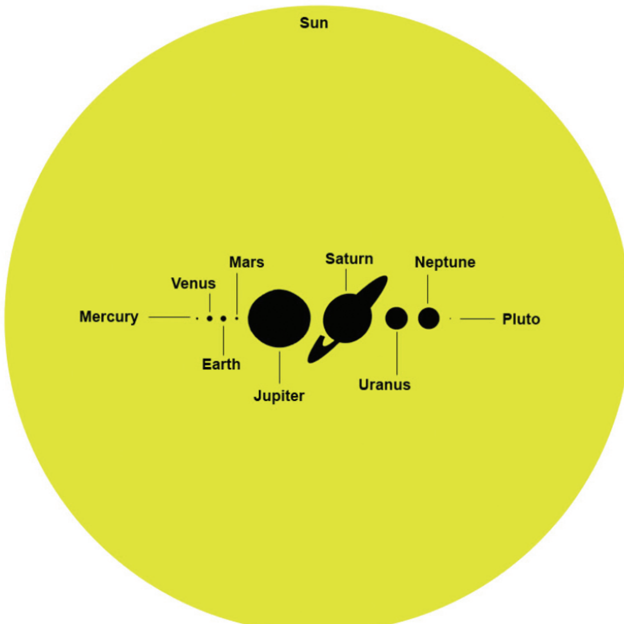
The Sun is giant ball of very hot, mostly ionized gas that shines under its own power.



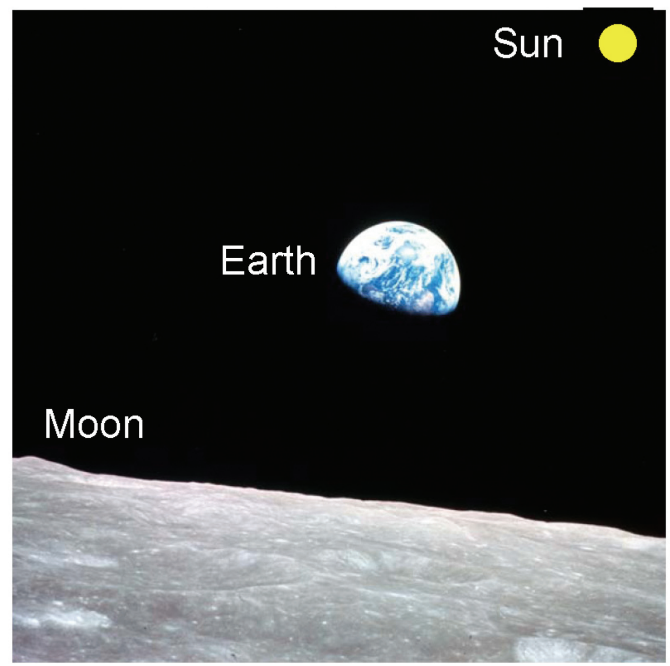
Solar Data

Radius	696,000 km (109 times Earth's radius)
Rotation Rate	27 days (equator) to 31 days (poles)
Luminosity (Power Output)	3.8 x 10^{26} watts (10 trillion times the power consumption of all Earth's nations combined)
Surface Temperature	5,800 K (average)
Mass	2 x 10^{30} kg (300,000 times Earth's mass)
Composition (by percentage of mass)	70% Hydrogen, 28% Helium, 2% heavier elements
Core Temperature	15 million K
Age	5 Billion Years (expected to live another 5 Billion)

Size and Distance of the Sun

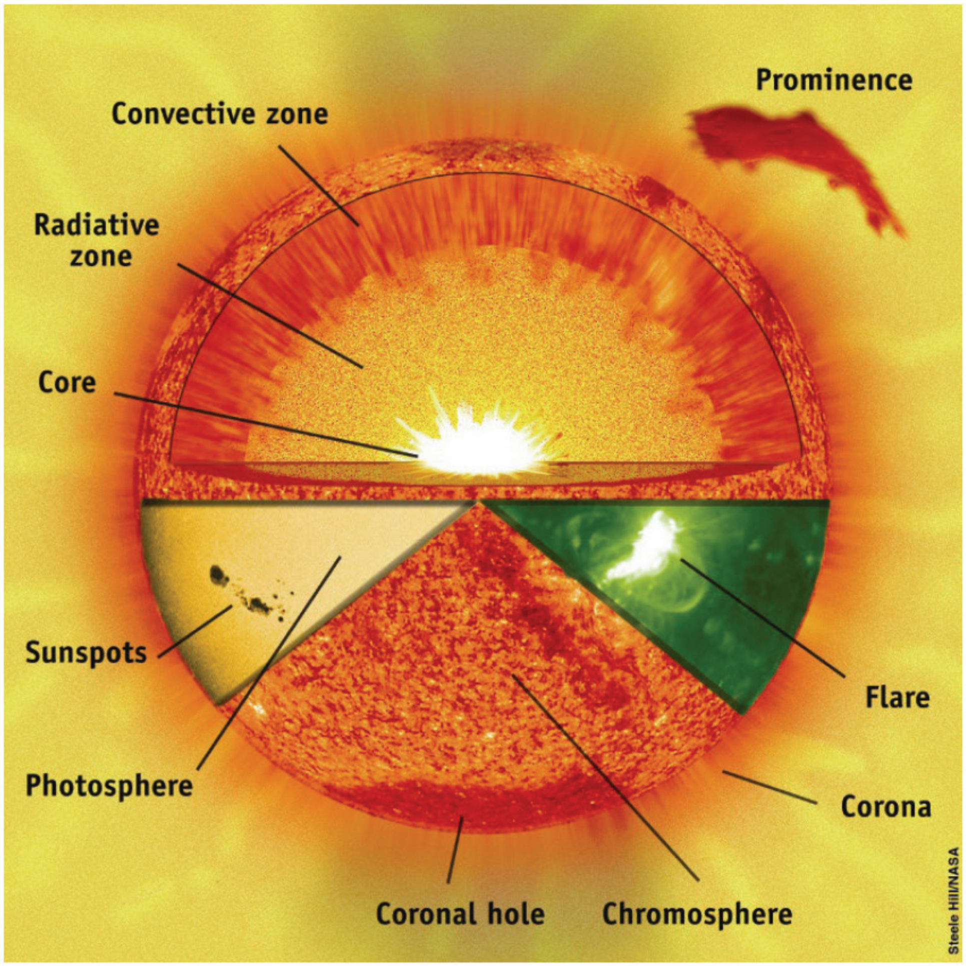


- The Sun is 109 times the diameter of Earth (10 times the diameter of Jupiter).
- Over 1,000,000 Earths could fit inside the Sun.



- The Sun is 150 million kilometers away from Earth. 390 times farther away than the Moon.
- You would need to line up 11,700 Earths side by side to cover the distance between Earth and Sun.
- It takes light 8 minutes to travel to Earth from the Sun.

The Different Parts of the Sun



Core

- Nuclear Fusion H → He
- T = 15,000,000 K

Radiative Zone

- Energy transported by light
- T = 10,000,000 K

Convective Zone

- Energy transported by convection

Photosphere

- Visible surface
- Far less dense than Earth's atmosphere
- T = 5,800 K
- Sunspots: T = 4,000 K

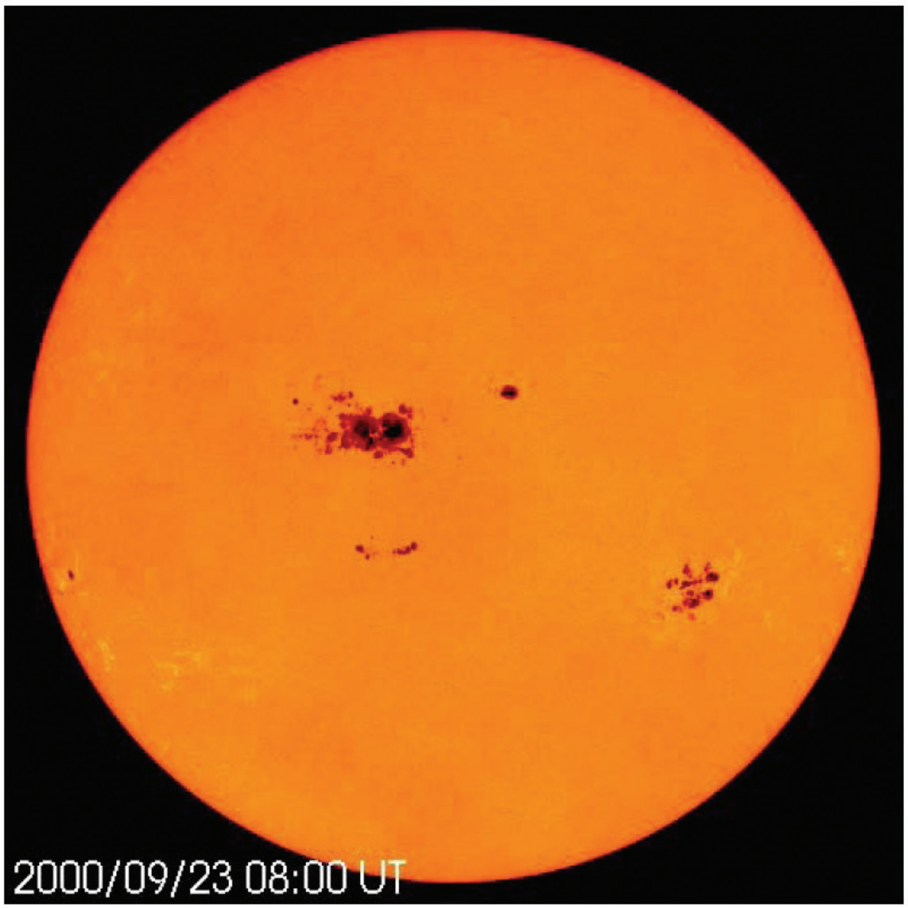
Chromosphere

- Thin layer above photosphere
- Produces most of Sun's UV light
- T = 10,000 K

Corona

- Tenuous, extends out millions of kilometers
- Emits X-rays
- T = 1,000,000 K

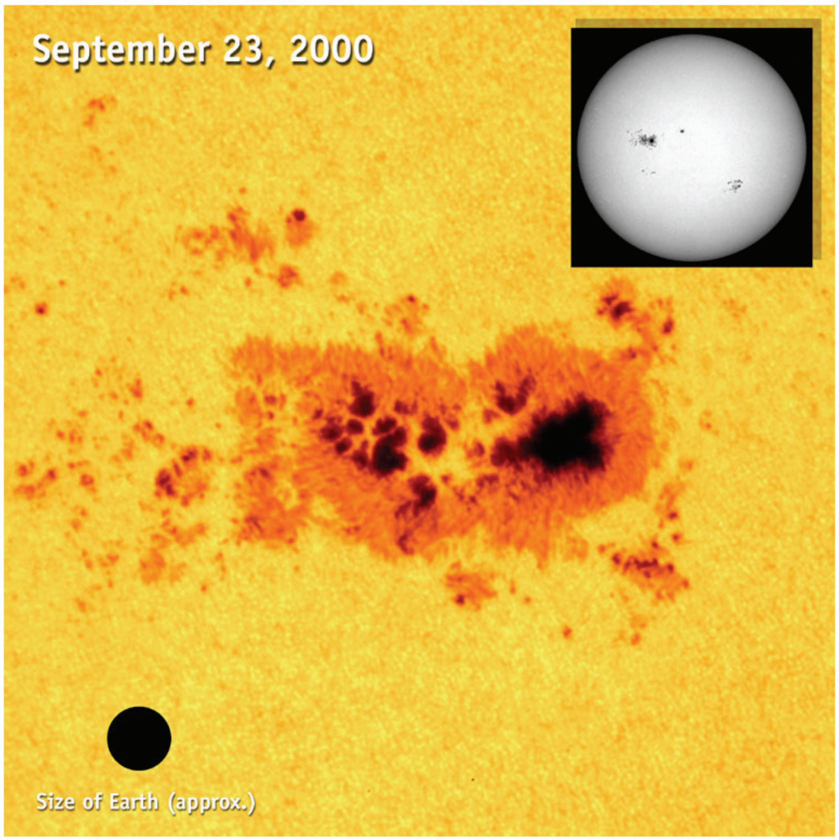
Sunspots



Sunspots are dark splotches on the face of the Sun. They are typically about, 2,000 degrees Kelvin cooler than the average temperature on the photosphere. This makes them appear to be dark in comparison to their very bright surroundings.

Following long-lived sunspots through time allows one to determine the rotation rate of the Sun. It turns out that the Sun spins faster at the equator than at the poles. The Italian astronomer Galileo was one of the first people to use Sunspots in this way.

The Sun Changes Its Spots



Sunspots are often Earth-sized or bigger.

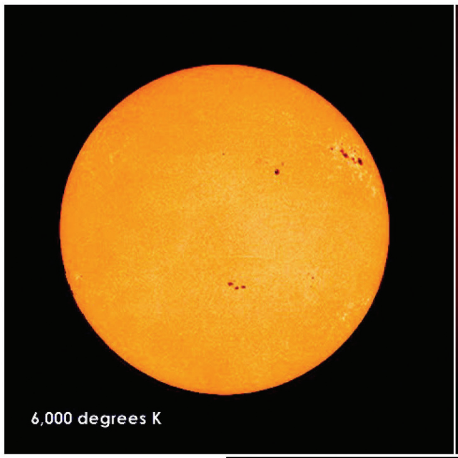
Sunspots change their shapes with time.

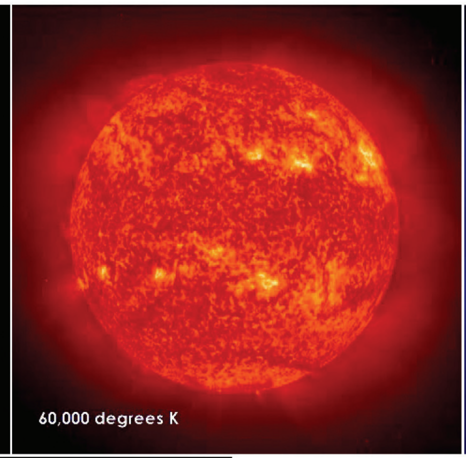
Inner dark parts called umbra, and outer lighter parts called penumbra.

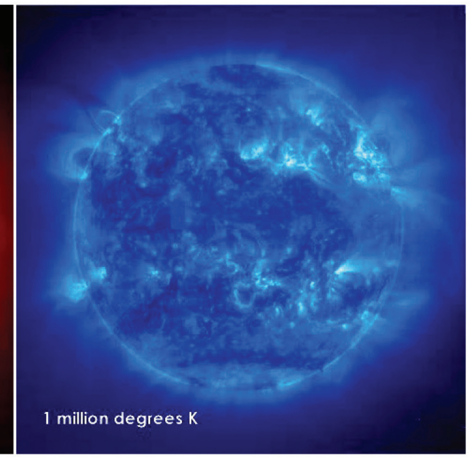
The Multiwavelength Sun

The **Photosphere** is seen in visible light.

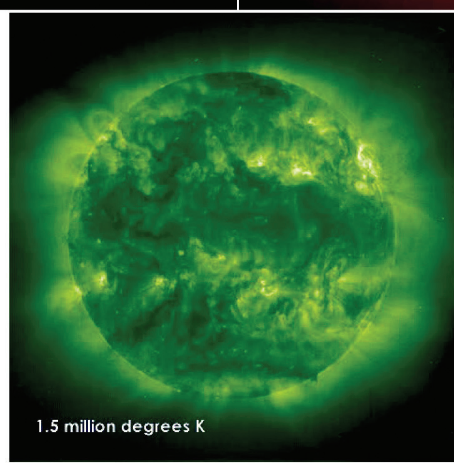
The **Chromosphere** and **Corona** are seen in UV light.

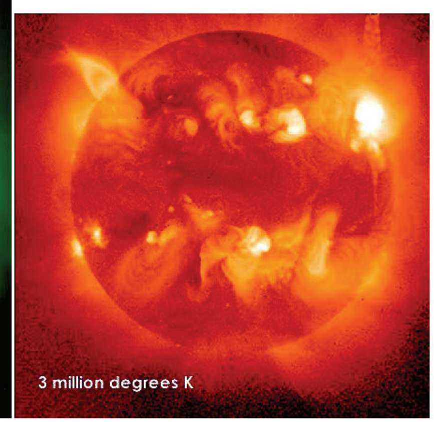






Very hot regions of the **Corona** are visible in extreme UV light.



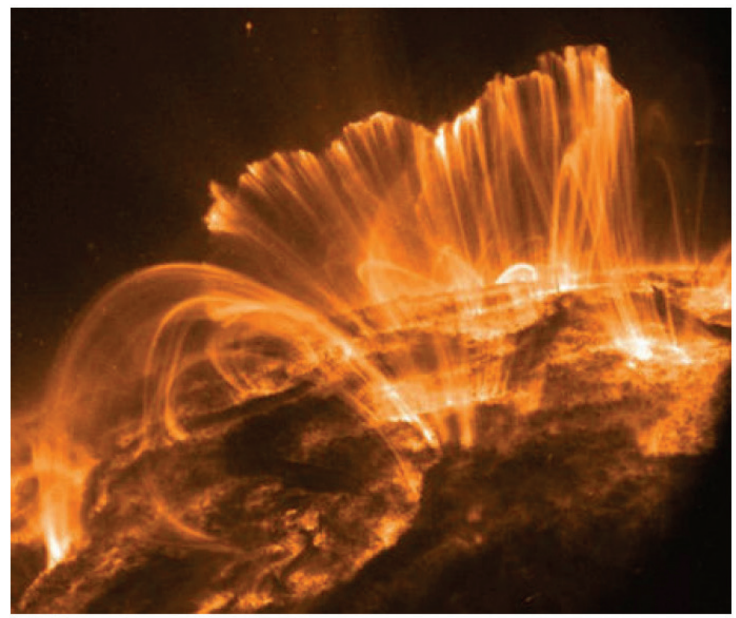


The hottest parts of the **Corona** are seen in X-rays

The Magnetic Sun

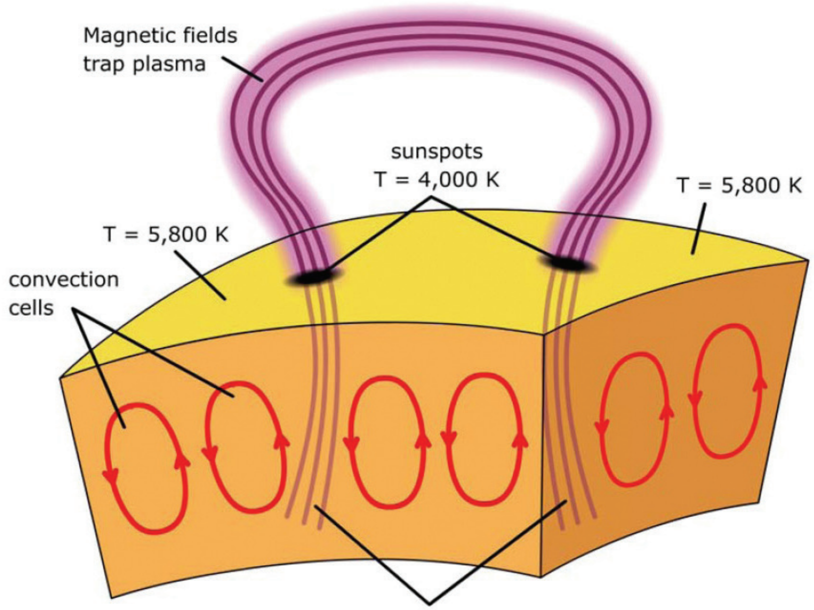
Images of the Sun in invisible light reveal loops of hot ionized gas (plasma) above the locations of Sunspots.

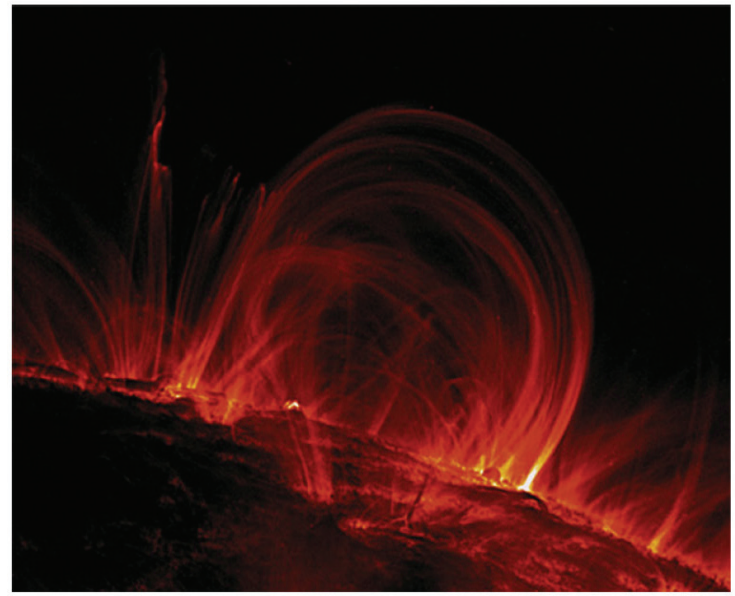
Notice that the shapes of these loops are just like the loops of force between two opposite poles of a magnetic field. The plasma acts just like iron filings and traces out the magnetic field on the Sun.



The plasma is trapped within the magnetic fields. It can flow lengthwise along the loops but it cannot flow sideways across the loops.

The Magnetic Sun

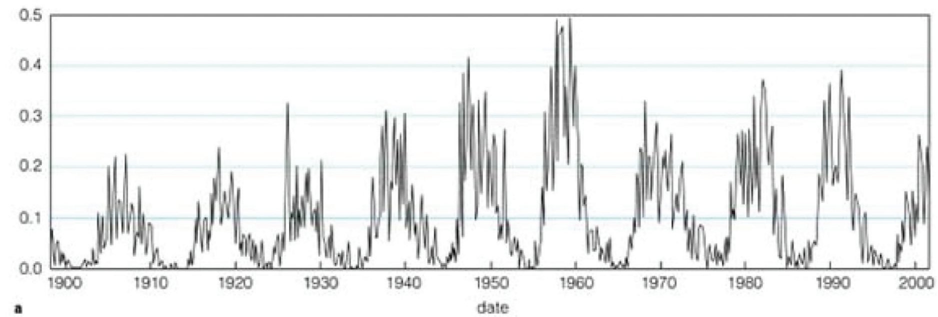


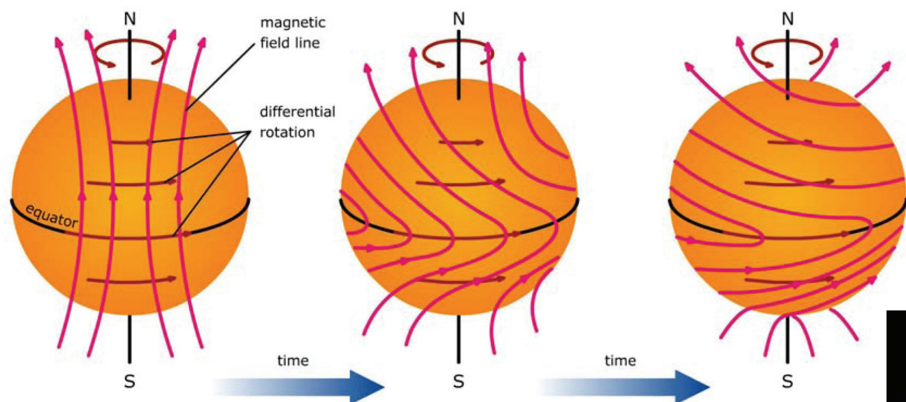


Sunspots are cooler because the magnetic fields do not allow plasma from the surrounding region to enter. The plasma pressure in the Sunspot drops and the temperature cools.

The magnetic field strength in a Sunspot is an average of 1,000 times stronger than the magnetic field at Earth's surface.

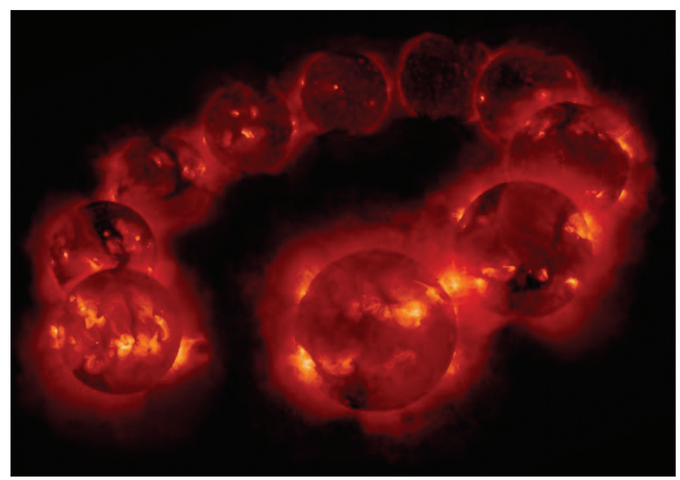
The Solar Cycle





The number of Sunspots and Solar flares increases and decreases on an 11 year cycle.

The Sun’s Magnetic field becomes more and more twisted and complex from differential rotation and finally breaks and flips every 11 years. So the total cycle is really 22 years from start to finish.



Slide 2: What is the Sun?

Remind students that when we look at an object nearby, it appears larger than when it is viewed from a distance. The stars are so far away that even the world's best telescopes only see them as unresolved points of light.

You can explain that the idea that the Sun is a star was theorized by several ancient astronomers, but the proof of this did not come until the late 19th/early 20th century when the light from the Sun and stars was split into its component colors (spectra), recorded, compared and found to be the same.

Slide 3: What is the Sun? (part 2)

The Sun is a ball of really hot gas. Because it is so hot, most of the gas within it is ionized, meaning the atoms have had some number of electrons stripped off. So the Sun has lots of free electrons buzzing about with positively charged ions. This state of matter is often called a plasma. So it is also correct to state that the Sun is a giant ball of hot plasma.

Why does it shine? Because it is hot. All objects that are hot give off light. Human bodies have a temperature close to 300 degrees Kelvin and they glow in invisible light called infrared. When a object gets hot enough it will glow in visible light. For example, the heating elements of an electric stove or oven begin to glow red and orange as they get hotter. The surface of the Sun is 5,800 degrees Kelvin and that makes it shine in the visible part of the electromagnetic spectrum.

How does it get so hot and stay that way? The story starts with how the Sun formed under the influence of gravity.

Gravity pulls all matter together and the more matter there is, the stronger the force of attraction. The Sun has an enormous mass, and hence gravity acts to pull it all together. In fact, it tries to concentrate all that mass in its center. If there were nothing to stop it, gravity would have collapsed the newborn Sun into a black hole 5 billion years ago. But, as gravity compresses the matter that makes up the Sun, it also heats it up. The heating of the matter creates a pressure that pushes outward and prevents it from collapsing under its own weight.

However, the conversion of gravitational energy into heat cannot account for all of the heat in the Sun. In a matter of thousands of years, a star without another source of heat would quickly cool off and collapse into a shrunken heap. In the mid-20th century it was realized that the densities and temperatures in the core of the Sun were probably so high that it was possible for nuclear fusion reactions to occur. The simplest fusion reaction that occurs in stars like the Sun involves four hydrogen nuclei (protons) fusing into a single Helium nucleus (two protons & two neutrons). The reaction creates a heavier element and releases energy. By this process the Sun can shine as it does now for some 10 billion years. Radioactive dating of meteorites left over from the formation of the Solar System place the Sun's age at about 5 billion years. So, it has another 5 billion to live on, much as it has for these past 5 billion years.

Slide 4: Size and Distance of the Sun

You may introduce your students to the term "Astronomical Unit" or AU. 1 AU is defined to be the average distance between Earth and the Sun (93 million miles; 150 million km).

When stating that over 1,000,000 Earths would fit inside the Sun, remind students of the difference between linear dimensions and volume. The diameter of the Sun is 109 times that of Earth, but its volume is 109x109x109 times bigger. If they have trouble with this concept ask them how many marbles they need to line up side by side to stretch from one wall of the classroom to the other side. It will probably be a few hundred. Then ask how many marbles it would take to cover the floor (a few tens of thousands). Finally, ask them to consider how many marbles they would need to fill the entire room with them: hundreds x hundreds x hundred = millions. (Note: the difference between rectangular and spherical volumes does not matter here. In a ratio between spherical volumes the factor of $(4/3)*\pi$ cancels out. So all that matters is the ratio between radii.)

In the image, a cartoon view of the Earth and Sun, as seen from the Moon, is shown. The point here is that once students understand how much bigger the Sun is than the Earth, this view should impress upon them that the Sun must be very far away in order for it to look so small. In the image the Earth actually appears bigger than the Sun. This is because it is much, much closer than the Sun.

Introduce the idea that light travels at a finite and set speed. Light does not instantaneously move from one point to the next. It takes time for light to move from place to place. Light is pretty fast though. It moves at a speed of 300,000 km/s (186,000 miles per second). When talking about how long it takes light to travel to the Earth from the Sun, point out to students that this means that when we look at the Sun here on Earth, we see it as it was eight minutes ago. For probes that travel deep out into the Solar System, it takes light even longer to travel between them and Earth. We use radio communications (which is another form of invisible light) to talk to these probes. But there is a long delay since the signals have to travel such great distances. The nearest star to our Sun, Alpha Centauri, is so far away that it takes light four years to travel the distance. We see it as it was four years ago.

<u>Slide 5: The Different Parts of the Sun</u>

The Sun has layers, like an onion—or an ogre (like from the movie *Shrek*). The layer that our eyes can see is called the photosphere. It is the layer of the Sun that outputs visible light. We call the photosphere the Sun's surface. However, it is not a solid surface that one could stand on. The density of gas there is much less than the density of air in Earth's atmosphere. [Note: remind students not to stare at the Sun as it can cause permanent damage to their eyes.]

The layers beneath the photosphere are not visible. We determine their properties by carefully studying waves on the surface of the Sun that pass through its interior. Just as geologists infer the structure of the interior of Earth by studying how seismic waves produced by earthquakes travel and reflect throughout it, so, too, do solar scientists study how similar waves travel through the Sun's interior. The study is called Helioseismology. Using this technique, along with physical theory about how gases behave under certain temperatures and pressure, solar scientists construct models of the Sun's interior.

The core is extremely hot and dense. There, it is 15 million degrees Kelvin and the densities are so high that nuclear fusion reactions can occur. The reactions produce energetic gamma rays. Gamma rays are an invisible form of light and have the highest energy of all the kinds of light. To interest students who are into comics and superheroes, you might mention that it is gamma rays that transformed Bruce Banner into the *Incredible Hulk*. The gamma rays produced by nuclear fusion carry energy away from the core, out into the rest of the Sun.

Above the core, densities and temperatures drop and nuclear fusion reactions are not possible. Energetic light interacts with the matter here and heats it up, continuing to carry outward the energy produced from the core. This region is called the radiative zone, because electromagnetic radiation transports the energy out here. The way this happens is that light created in the core bumps into particles matter giving them some energy and randomly changing direction, somewhat like the puck in the game "Plinko" on the CBS game show *The Price is Right*.

Above the radiative zone, temperatures and densities are again lower—so far the Sun is just like other hot objects it gets cooler as you move away from the source of the heat. In this next layer, large parcels of gas carry energy outward through convection. Pockets of hot gas rise from low in this zone and cool as they rise, then fall back down, heating up as they go. Convection like this can easily be seen in lava lamps or miso soup when it is served hot. This region is known as the convective zone.

The top of the convective zone is the photosphere. High-resolution observations of the photosphere reveal the surface to be churning, due to the convective motions of the gas beneath it. The photosphere often appears splotchy-the technical term is granulation. This is caused by the hotter and cooler convection cells at the surface. Again, the average temperature of the photosphere is 5,800 K.

Above the photosphere, the density of gas continues to drop, but its temperature actually begins to rise. The thin layer just above the photosphere is called the chromosphere. Here the temperature rises to about 10,000 degrees Kelvin. Unlike most hot things, it actually starts getting hotter as you move away from the surface. This layer produces most of the ultraviolet light that leaves the Sun. The chromosphere is visible to special telescopes that can make images using ultraviolet light. It is also visible in a specific red color of visible light produced by hydrogen; scientists often refer to this color as H-alpha (wavelength = 656.3 nanometers—1 nanometer is a billionth of a meter). Some optical telescopes are made with special filters that block all light except this red color, allowing the observer to see the chromosphere.

Above the chromosphere is the Sun's outer atmosphere. It is called the corona and can be seen in visible light during total eclipses of the Sun. It extends far out into interplanetary space. In fact, it extends out to as much as 100 times the distance between the Earth and the Sun. The density of the corona is very low (around 1 proton per cubic centimeter), but the temperature is very high, around 1,000,000 degrees Kelvin. The corona is so hot that it emits extremely energetic ultraviolet light as well as X-rays.

Note: Even though the corona has a very high temperature, it has very little thermal energy. This is because its density is very low. Temperature measures the average energy of particles in a substance, but thermal energy measures the total energy of all the particles. Even when all the particles individually have a lot of energy, if there are very few of them, then the total energy is low. Think about the difference between an oven and boiling pot of water. The temperatures used for cooking in an oven are often much hotter than the temperature of boiling water (373 K). Yet one regularly can stick their hand into a hot oven to remove the contents without getting burned, whereas one would not even think about sticking their hand in a pot of boiling water to remove the contents. The water has a lower temperature, but its density is so much greater. So the thermal energy in the water is actually greater than the thermal energy in the oven.

Slide 6: Sunspots

The rate of energy output (called luminosity) of a hot object is a function of its temperature. The hotter the object, the greater the luminosity. But the proportionality between luminosity and temperature is not linear. The luminosity of an object is proportional to its temperature to the fourth-power. So, doubling the temperature of an object increases its luminosity by a factor of 16. This is why sunspots are so much darker than the surrounding photosphere. They are on average 2,000 K cooler than the photosphere and 5 times dimmer.

However, 4,000 K is nothing to scoff at. The temperature of the elements in common light bulbs are often at around 4,000 K and clearly produce plenty of visible light. Sunspots are actually quite bright. In fact, if one could block out all of the light from the normal photosphere of the Sun and just allow the light from sunspots to come through, our daytime sky would appear almost as bright is it does normally.

The reason we see sunspots as dark splotches, with our eyes and with our electronic imaging devices is a matter of contrast. The photosphere is so much brighter than the sunspots that the dynamic range of images cannot account for the large difference in brightness, and so we see the sunspots as dark.

Slide 7: The Sun Changes Its Spots

Sunspots are not permanent features on the Sun; they come and go and change in appearance.

In this high-resolution image, you can see the enormous sizes that some sunspots reach. You can also see the mottled appearance of the photosphere, which is a result of the convection of huge parcels of gas beneath. Note that the sizes of the convection cells are quite large themselves in relation to the size of Earth.

Slide 8: The Multiwavelength Sun

Note in this sequence of images that the bright spots in the ultraviolet and X-ray images of the Sun's Chromosphere and corona correspond to the locations of sunspots on the photosphere.

Slide 9: The Magnetic Sun

The image on the left is from the SOHO (SOlar and Heliospheric Observatory) spacecraft. The wavelength of light is lower energy ultraviolet, which reveals the Sun's chromosphere. Seen here is an enormous loop of gas trapped in a magnetic field. Loops of this size are called prominences.

The image on the right is from the TRACE (Transition Region And Coronal Explorer) spacecraft and uses higher energy UV light to study the Sun's corona. The image reveals ribbon-like coronal loops. Again we are seeing plasma flowing through a magnetic field.

Remember that plasma is charged gas, and that a charged gas in motion is an electrical current. Electrical currents, in turn, generate magnetic fields. Likewise, magnetic fields that change with time can generate electric fields which push charges around. The complex interaction of these effects creates the tangled mess of coronal loops seen in these images, and affects how they change with time.

Slide 10: The Magnetic Sun (part 2)
Putting all the information together creates a picture where sunspots are the "footprints" of the coronal loops. The coronal loops are made of plasma trapped in a very strong magnetic field. That same magnetic field penetrates down into the convection zone and inhibits the convection of gas in that region. This causes the gas there to cool faster than the surrounding region.

The average strength of the magnetic fields in sunspots is around 1,000 Gauss (Gauss is a unit of magnetic field strength). The average field strength on the surface of Earth is about ½ Gauss, and the average magnetic field strength on the surface of the Sun is about 1 Gauss. So the magnetic fields in sunspots are extremely strong.

Slide 11: The Solar Cycle
The Sun has an overall magnetic field much as Earth does. In general, it resembles the dipole field of a bar magnet. It is thought that the field is generated by currents of electric charges in the convection zone of the Sun.

Because the Sun is gaseous it does not rotate like a solid body. It rotates differentially; the equator rotates faster than the poles. In a plasma, charged particles cannot cross from one magnetic field line of force to another neighboring field line. So, in this way the magnetic field becomes "frozen" into the plasma. If the particles move with some bulk motion due to a different force they will drag the magnetic field with them. This can distort the magnetic field if different parts of the gas move at different rates or in different directions. This is what happens to the Sun. The regular dipole magnetic field gets twisted and wrapped up as a result of the differential rotation of the Sun.

As the field becomes more and more twisted, little loops of the magnetic field push up through the surface forming sunspots and coronal loops. Eventually, the field becomes so complex that it essentially breaks and reforms into a simpler shape. This process is what is thought to be behind the observed solar cycle. The Sun goes through a cycle of periods when it has many sunspots and active regions in its corona and then it has periods where it is relatively free of sunspots and is very quiet. The period of the cycle is 11 years and has now been observed for several centuries.

The polarity of the Sun's magnetic field flips every 11 years, and so the complete solar cycle is actually 22 years for the Sun to return to its original state.

Sunspots Lecture – Graphic Organizer

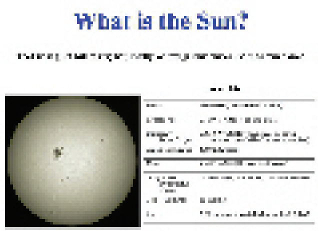
Title Slide

Slide 2- What is the Sun?

How are the starts we see at night related to the Sun?

How are they different?

Slide 3- What is the Sun?



What is the Sun?

Why does it shine?

How does it get so hot and stay that way?

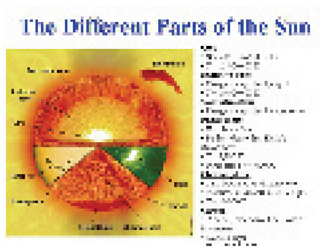
Slide 4- Size and Distance of the Sun

Define and Astronomical Unit.

What is the size of the Sun compared to the Earth?

How long does it take light to reach the Earth from the Sun?

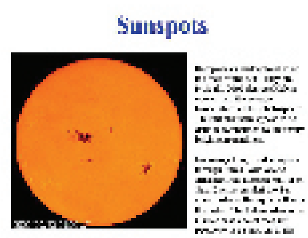
Slide 5- The Different Parts of the Sun



Describe the different layers of the Sun.

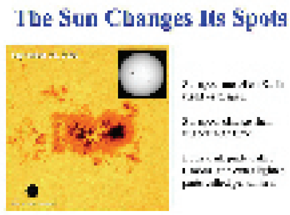
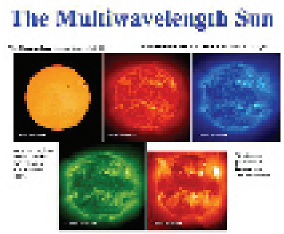
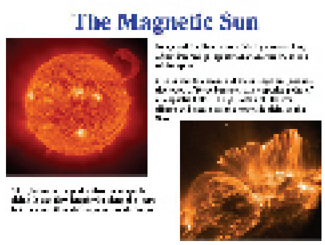
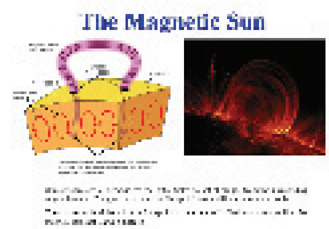
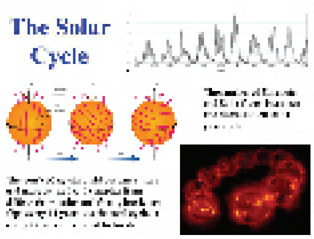
How does the density and temperaure of the Sun vary as one moves from the center outward?

Slide 6- Sunspots



What are sunspots?

What does temperature have to do with luminosity?

Slide 7- The Sun Changes Its Spots  Are sunspots permanent features on the Sun? Explain.	Slide 8- The Multiwavelength Sun  What wavelengths are you viewing from these images? What parts of the Sun are revealed by using invisible forms of light to observe it?
Slide 9- The Magnetic Sun  What are prominences? What are we viewing in the image on the left? Describe plasma and its connection to electric currents.	Slide 10- The Magnetic Sun  What are coronal loops made of? Are the magnetic fields in sunspots strong? Explain.
Slide 11- The Solar Cycle  Compare the Sun's overall magnetic field to Earth's. How is the magnetic field of the Sun created?	Reflection: Describe the main ideas you have learned about the Sun, sunspots, and the magnetism of the Sun.

Worksheet 4.2

1. How are the stars we see at night related to the Sun? How are they different?

2. How big is the Sun relative to Earth? How far away is it?

3. How do the density and temperature of the Sun vary from the center outward?

4. How does the Sun produce the energy it needs to stay hot?

5. Why does the Sun shine?

6. What parts of the Sun are revealed by using invisible forms of light to observe it?

7. Can plasma move freely in the presence of a magnetic field? Why not?

8. What are sunspots?

9. What happens to the Sun's magnetic field with time, and how does that affect the number of sunspots and solar flares?

Worksheet 4.2 (Answer Key)

1. How are the stars we see at night related to the Sun? How are they different?
The Sun *is* a star, but the Sun is very close and the stars are very, very far away.

2. How big is the Sun relative to Earth? How far away is it?
The Sun's diameter is 109 times larger than Earth. The volume is over 1 million times greater than Earth's. The Earth is 150 million km from the Sun (or 93 million miles, or 8.3 light-minutes, or 1 Astronomical Unit, or 11,700 Earth diameters, or 390 times the distance between the Earth and the Moon).

3. How do the density and temperature of the Sun vary from the center outward.?
The Sun is very dense at its core, and the density steadily decreases out toward its surface, where it is less dense than Earth's atmosphere. It continues to decrease out into the corona where the density is about 1 particle per cubic centimeter. The temperature at the core is 15 million Kelvin and decreases steadily out to about 5,000 K at the photosphere. It then rises again to about 1 million Kelvin in the corona. [Student answers need not be this detailed]

4. How does the Sun produce the energy it needs to stay hot?
It uses nuclear fusion at its core to stay hot.

5. Why does the Sun shine?
The Sun shines because it is hot.

6. What parts of the Sun are revealed by using invisible forms of light to observe it?
The chromosphere is visible using UV and H-Alpha (which is visible). The corona is visible using visible light, extreme ultraviolet, and x-ray light.

7. Can plasma move freely in the presence of a magnetic field? Why not?
No, plasma cannot move freely in a magnetic field because it is charged gas. When charged gas moves it creates an electrical current. Electrical currents are constrained to move along magnetic lines of force.

8. What are sunspots?
Sunspots are cooler places than average on the Sun's photosphere where strong magnetic fields inhibit convection.

9. What happens to the Sun's magnetic field with time and how does that affect the number of sunspots and solar flares?
The Sun's magnetic field gets twisted up due to the differential rotation of the Sun. As it gets twisted, parts of it poke through the surface, forming sunspots and causing solar flares. The magnetic field gets the most twisted every 11 years and flips polarity.

Assessment Rubric

With an additive rubric, students have to learn more content in greater depth to achieve higher levels. Teachers should introduce the rubric to students before the activities begin and encourage students to achieve to their highest potential. Teachers use the rubrics at the end of the unit to assess whether students have learned the science content.

	1	2	3 (Level 2+)	4 (Level 3+)	5 (Level 4+)
Science Content: Activity 1 Magnetic Fields on the Surface of the Sun	* Level 2 tasks attempted, but not completed or mastered	*Students are able to set up the magnets on a piece of paper and map the magnetic field lines around either end of the pair of magnets. *Students, through successful completion of this activity, demonstrate their understanding of magnetic field lines around a pair of magnets.	*Using what they know about magnetic field lines from magnets, students are able to predict the magnetic field lines around two Sunspots on Worksheet 4.1. *Students, through the successful completion of Worksheet 4.1, are able to make the connection between magnetic field lines around magnets and those around two Sunspots on the Sun.	*Students take notes on the Sunspots lecture. *Students are able to answer 100% of the questions presented on the graphic organizer for the Sunspots lecture. *Students are able to answer the questions on Worksheet 4.2 with 80-94% accuracy. *Students, through successful completion of Worksheet 4.2, are able to demonstrate their knowledge of the basics of the Sun, solar flares, Sunspots, and magnetism of the Sun.	*Students are able to answer the questions on the Worksheet 4.2 with 95% accuracy and above. *Student fully demonstrates comprehension of the magnetic fields on the surface of the Sun and the cause for magnetism on the Sun.
Collaborative Worker	Participates but does not successfully complete one or more requirements of Level 2	Arrives on time with materials. Shows respect for others; cares for equipment and resources.	Stays focused on assigned task and helps others do the same. Shares work equally.	Facilitates the participation of all in the group. Tutors and/or supports other students.	Takes all group roles with equal skill. Assists others as they learn to do the same.

Activity 2 – Magnetic Energy and the Cause of Solar Flares

Student Objectives

- Students will know the physical properties of electromagnetism.
- Students will know the law of conservation of energy.
- Students will know the difference between potential and kinetic energy.
- Students will know that solar flares are caused by magnetic fields in the atmosphere of the sun.
- Students will know that solar flares release energy in the forms of light, heat, and the kinetic energy of large clouds of plasma.

Materials Needed

- A coil of copper wire (about 7 meters long, covered with an insulating enamel)
- Small patch of sand paper for removing wire enamel at connection points
- 2 insulated wires with alligator clips
- 3 or more batteries (D-cells, 9-volt, etc.) with battery holders.
- 1 knife switch
- 1 Ammeter or Galvanometer
- 1 bar magnet and/or cow magnet

Getting Ready

Gather materials listed above. Set up an electrical circuit with the coil of wire in the circuit. Leave the knife switch open. Also assemble the set-up for *Exploring Magnetism*: *Session 2: Activity 5: Electric Current Generated with a Moving Magnet*. This will be a circuit with a coil and ammeter and no voltage source or knife switch. See **Figure 4.2**.

Procedure

1. If you have not done the activities from *Exploring Magnetism* it is advised that you consider doing at least Activities 4 and 5 from Session 2 in that lesson guide. These activities allow students to discover that electrical currents create magnetic fields, which push on a magnet, and that moving magnets create electrical fields which push on charges and create a current.

2. Review with your students the outcomes from the experiments in Activities 4 and 5 in Session 2 of *Exploring Magnetism*. The basic concepts to stress are that changing electric fields create magnetic fields and that changing magnetic fields create electric fields.

3. Demonstrate that moving electric fields (current) create magnetic fields with the jumping coil circuit. Rest the coil of wire on the edge of a strong magnet and close the knife switch. The coil will become a magnet and will either jump off the coil (due to the magnetic repulsion of like poles) or pull toward the center of the magnet (due to the attraction of opposite poles). Simply turn the magnet around to make the coil either jump or pull toward the center of the magnet.

4. Demonstrate that moving magnetic fields create electric fields that push charges (and create electric currents) using the galvanometer set-up. Here, simply move a magnet through

the center of the coil. As you are moving the magnet back and forth, the needle on the galvanometer will register current moving through the circuit. You'll notice that as the direction of the magnet changes so, too, does the direction of the current.

5. Remind students that these two basic experiments were the ones that helped scientists in the 19^{th} century realize that electricity and magnetism were not separate phenomena, but actually two different manifestations of a single force field, which they called the electromagnetic field.

6. While doing the previous step discuss with students the concept of energy. Ask them, "Am I creating energy by moving this magnet through the wire?" Many will likely think so, but the answer is, "No." You are merely transforming one form of energy into another. Talk with students about how chemical reactions in your muscles are converting chemical potential energy into kinetic energy of your hand and the magnet. Some of the kinetic energy of the magnet is being converted into electric potential energy (creating a voltage) which is then converted into the kinetic energy of the charges moving in the wire.

   You might also discuss with students how the transfer of energy is not perfect. Much of the chemical energy produced in your muscles goes into heating them up, just as much of the kinetic energy of the charges in the wire is also lost to heating it up. You can ask, "When something is heated up, is the energy really lost?" Again, the answer is "No. Energy is never lost only transformed." When energy goes toward heating something up it is transformed into the kinetic energy of individual particles all moving in random directions, called thermal energy.

   Heated objects, such as your arm or the wires, can also "lose" energy (cool) by giving off light. If the students scoff at this, noting that neither your arm nor the wire are glowing, tell them that objects glow whenever they have some thermal energy. However, your arm and the wire are not hot enough to glow in visible light. But they are hot enough (about 300 K) to glow in infrared light. The cooler an object is, the lower the energy is of light that it gives off. So, your arm and the wire are not hot enough to glow in visible light, but light bulbs are. The filament of a light bulb is just a really hot piece of metal. It gets hot when an electrical current runs through it and heats it up to about 4,000 K.

7. Finally, pass out the **Solar Flares** essay, **Solar Flare Cornell Notes**, and **Worksheet 4.3**. Assign them to read the essay as homework, filling out the Cornell Notes as they do. When they have finished reading the essay they should complete the worksheet for the next class session. **Worksheet 4.3** can be used as an assessment of the student's understanding of the material in this activity. Note that this essay has a Flesch-Kincaid Reading Grade Level of 9.7.

   Suggestion: to save time or to help English language learners you could split up the text and assign different students to read different sections and then have students assemble in groups to jigsaw the text and complete the Cornell Notes and Worksheet.

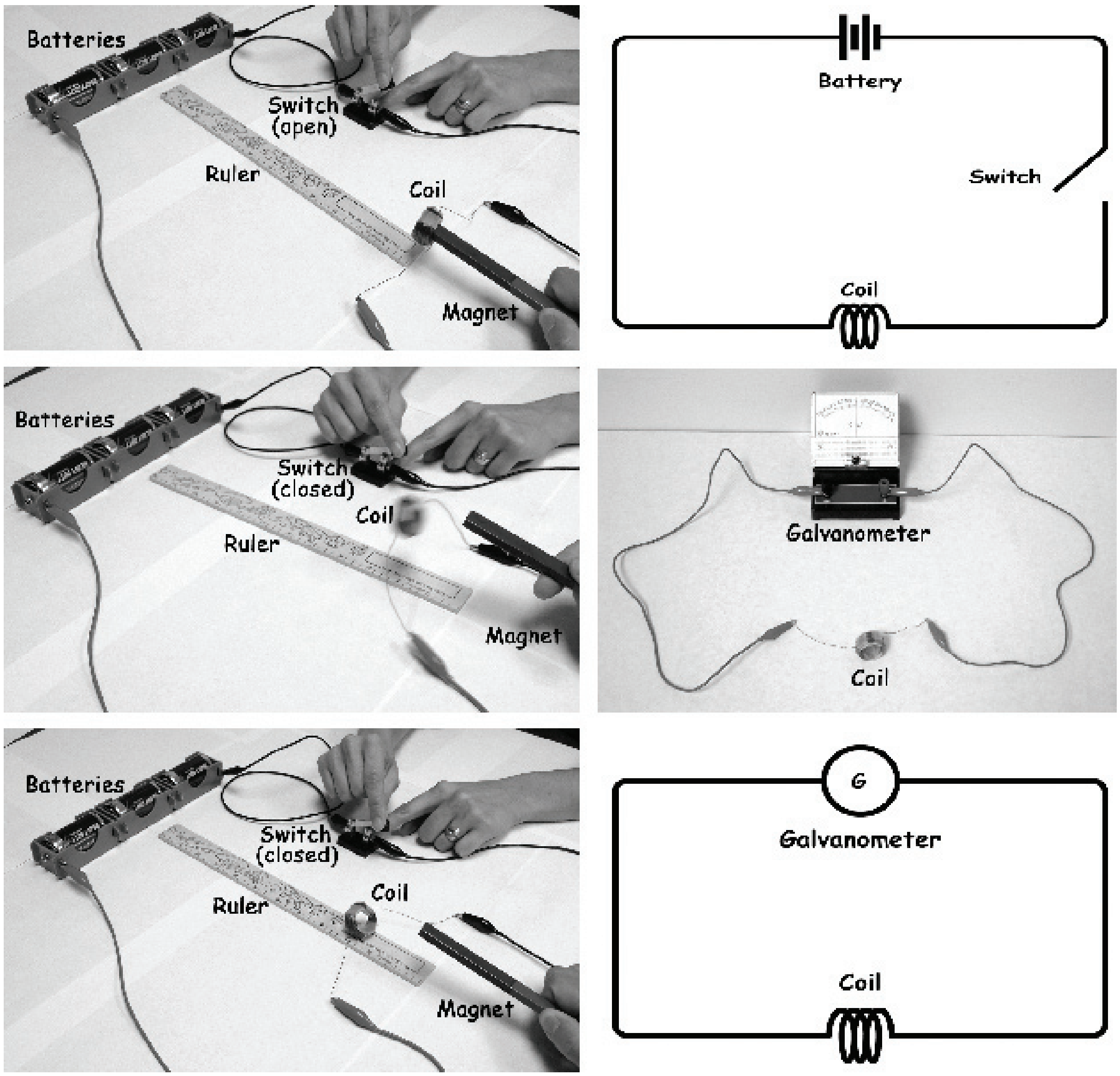


Figure 4.2: Set up for the demonstrations. The three panels on the left show the set-up for the jumping coil. The circuit diagram in the top of the right column is for the jumping coil. The set-up for the galvanometer demo is shown in the bottom two images of the right column.

Solar Flares

Solar flares are the most powerful explosions in all the Solar System. They appear as sudden, rapid, and intense increases in brightness in relatively small regions in the Sun's atmosphere. They can have impacts on our lives here on Earth and on astronauts living and working in space. The amount of energy released in a single solar flare is ten million times greater than the energy released from a volcanic explosion here on Earth.

Solar flares occur when magnetic fields in the Sun's atmosphere rapidly change shape and generate currents of electrically charged plasmas. The energy released by flares takes the form of light, heat, and the movement of large amounts of plasma. Light from across the entire electromagnetic spectrum, from radio waves to gamma rays, can be generated in the biggest flares. Some flares also seem to generate gigantic eruptions of matter that are ejected out into interplanetary space. Such eruptions are called Coronal Mass Ejections (or CME for short). The name is very descriptive as these events are literally ejections of mass from the Sun's corona. Flares also heat up the plasma in the corona and chromosphere of the Sun. The temperature of the corona is very high. This is unusual since most hot objects get cooler as distance from the heat source increases (the source of the Sun's heat is in its core). New observations from the NASA spacecraft RHESSI (Ramaty High Energy Solar Spectroscopic Imager) suggest that the curiously high temperature of the corona may be caused by large numbers of very small solar flares that occur frequently.

Scientists have known for a long time that magnetic fields play a major role in solar flares, but they do not yet have a complete understanding of how. The simplest model that scientists have proposed for how magnetic fields on the Sun cause solar flares involves sunspots. Sunspots are places where strong loops of the Sun's magnetic fields poke through the Sun's surface (called the photosphere). The magnetic fields trap plasma inside them and do not allow plasma outside the loops inside. This causes the area to be cooler than average on the photosphere and makes sunspots appear darker. Above the sunspots, the magnetic field loop also traps hot plasmas, these are called *coronal loops*. See the image in **Figure 4.3** for an example of a coronal loop viewed in ultraviolet light. So, sunspots can be thought of as the visible "footprints" of coronal loops.

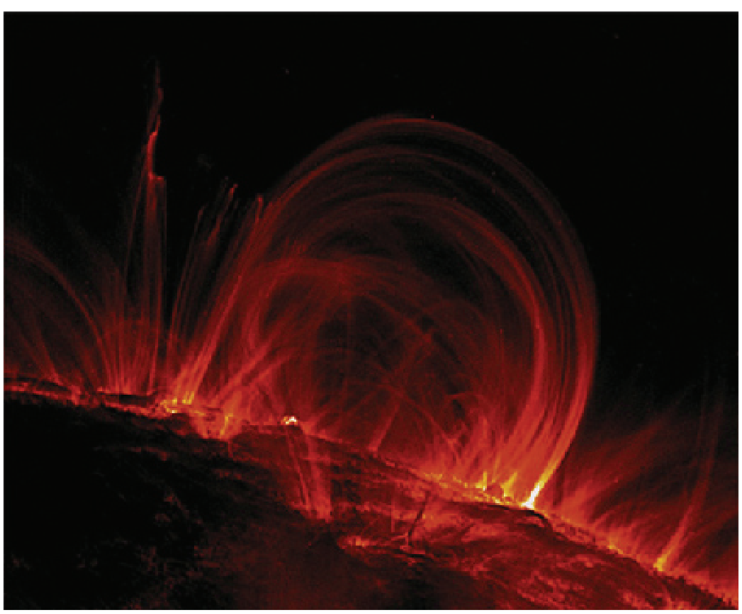


Figure 4.3: This is an image of hot plasma trapped in magnetic fields in the Sun's corona, called *coronal loops*. The image was taken in Ultraviolet light by NASA's TRACE satellite. The red color is for illustrative purposes only; ultraviolet light has no color, since it is invisible to the human eye.

Sunspots drift in position relative to one another on the photosphere because of convection beneath the photosphere plus the differential rotation of the Sun. All of these motions distort the sunspots' magnetic fields and cause them to twist up and become more and more complicated in shape. The more complicated the magnetic fields shape become, the more energy they store.

In the simplest scenario for what occurs during a solar flare, a coronal loop starts out with the basic shape (**Figure 4.4, panel 1**) and then begins to change in such a way that it looks as though it is a rubber band being pulled upward (**Figure 4.4, panel 2**). As the field stretches, it creates electric fields that start pushing the plasma trapped inside in a variety of directions. The plasma can still only travel along the field lines. When the field becomes stretched enough a point forms in the loop where the magnetic field is pointing in opposite directions; it's called an *X-point* because the shape of the magnetic field there is like an X (**Figure 4.4, panel 4**). At this place in the magnetic field the shape suddenly changes. Plasma is forced into the X-point and then accelerated both up and down along the field lines (**Figure 4.4, panel 5**). When plasma crashes into the denser gas of the Chromosphere it heats it up and releases a great deal of light, sometimes even X-rays and gamma rays. Plasma from above the loop is squirted down to the top of the loop, where another hot spot forms glowing in X-rays (**Figure 4.5**). In some cases a magnetic bubble forms above the loop, into which matter is also squirted. Plasma piles up near the bottom of the bubble and heats up causing it to glow in X-rays also. At the end of the process, the bubble separates from the loop and is pushed away from the Sun at incredible speeds (**Figure 4.4, panel 6**). The loop returns to a more simple shape since it has released much of the energy that was stored up in its more complicated shape.

Follow the Energy

Solar flares release enormous amounts of energy. But where does it all come from? Do the magnetic fields generate the energy? No. Recall that one of the fundamental principles of physics is that energy and matter can neither be created nor destroyed. However, they can change form.

Energy is an abstract concept. One way to think of it is as a measure of a system's ability to change motion. There are two fundamental forms of energy:
Kinetic Energy – the energy of motion
Potential Energy – the energy an object has because of its position; stored energy

The total amount of energy in any closed system never changes; it only changes form. There are many forms of energy that you have probably heard of or encountered: electrical, magnetic, chemical, nuclear, light, gravitational, thermal, heat, etc... All of these forms are really just different kinds of the two basic forms of energy: Kinetic and Potential. For example, chemical energy stored in foods is potential energy of electrons in atoms and molecules. Light is another very important form of energy. In a sense it is pure kinetic energy. It is always in motion, moving electric and magnetic energy through space. Thermal Energy is also a very important form of energy. It is the kinetic energy of all the particles making up a substance as they vibrate and move around in random directions. Heat is energy that flows from hot to cool objects. When it is said that something is being heated this means that its thermal energy is being increased.

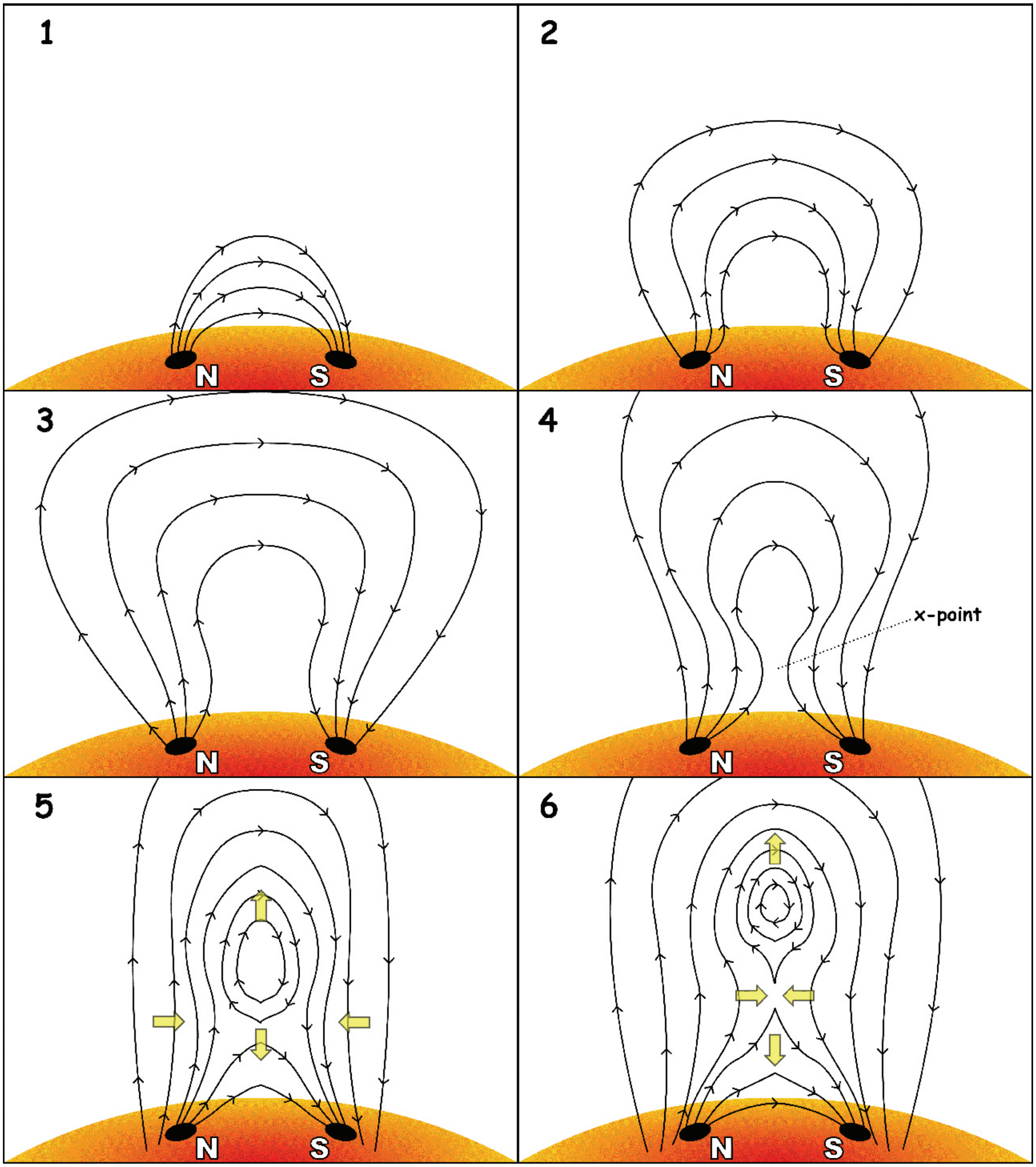


Figure 4.4: A sequence of diagrams shows the evolution of a magnetic field during a solar flare. The yellow arrows indicate the directions that plasma moves during the flare.

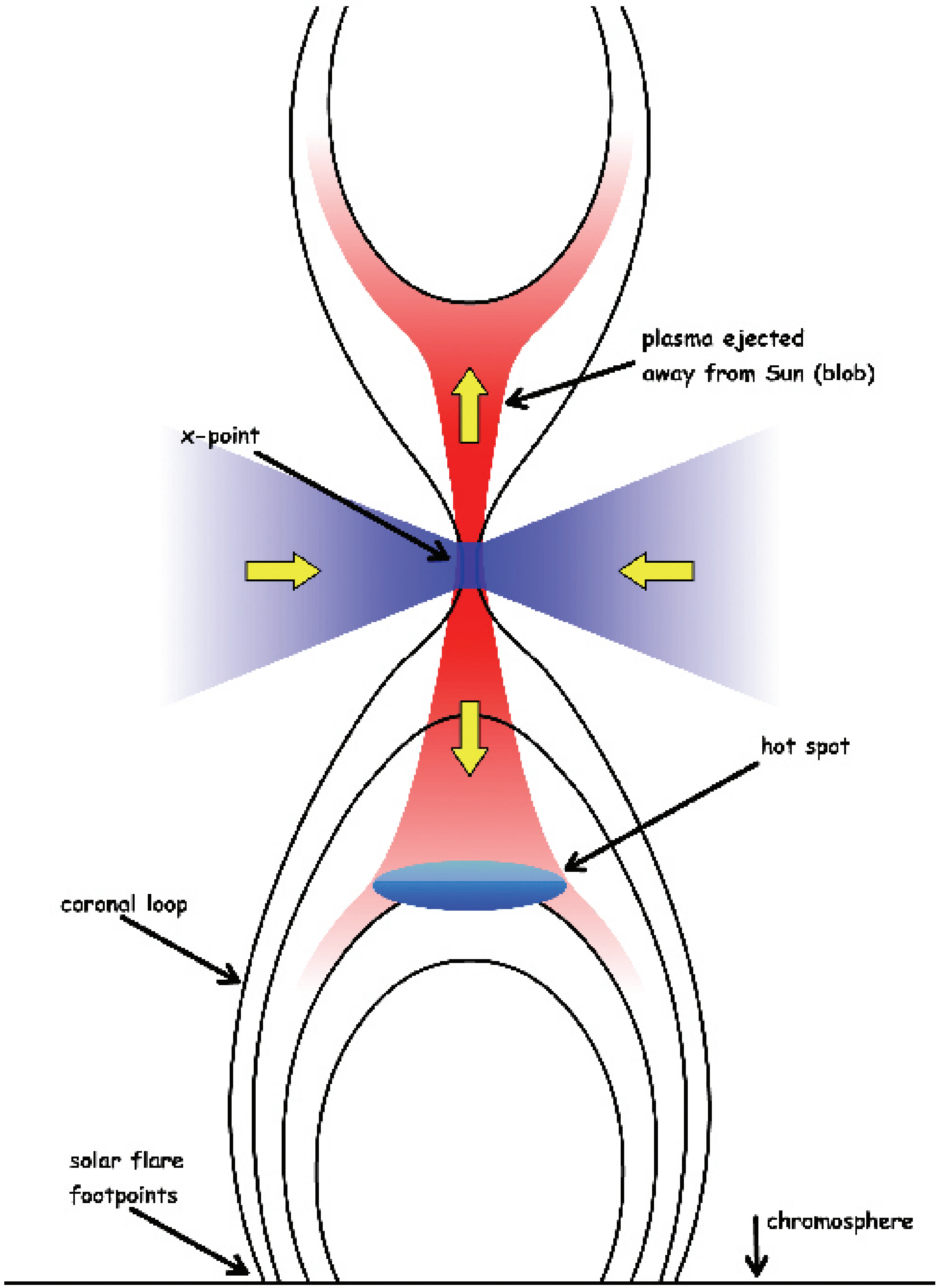


Figure 4.5: An annotated diagram illustrates the magnetic field and plasma movement during a solar flare. The yellow arrows indicate moving plasma due to the changing magnetic field.

There are several different units that people use to measure energy: Joules, ergs, electron-volts, or calories. Physicists, astronomers, and engineers often use the units of Joules, ergs, or electron-volts (eV) to measure energy. However, chemists and biologists might more often use calories to measure energy.

Some definitions:
1 Joule = 1 kg m^2/s^2 = 10^7 ergs = 6.242 x 10^{18} eV
1,000 calories = 1 Food Calorie = 4,186.8 Joules.

Note that nutritionists use the unit of Food Calories, which is equal to 1 kilocalorie (1,000 calories). But, they do not use the term kilocalories. Instead, they use Calorie (with a capital C to indicate a kilocalorie). This is admittedly very confusing. 1 Calorie (with a capital C) is defined as the amount of energy required to raise the temperature of 1 kg (i.e. 1 liter) of water by 1 degree Celsius (or Kelvin).

When you buy food in a store the label often tells you how many Calories there are in that food. For example, a typical candy bar contains 250 Calories. The label is telling you how much potential energy is chemically stored in the food. If you eat the food, your body will use chemical reactions to convert that potential energy into other forms of energy to do work for your body. The typical person needs to consume 2,000 Calories per day for normal functioning.

To equal the energy in one solar flare (See **Table 4.1**) you would have to eat 100 quintillion candy bars, *or* every human being on the planet would have to eat one candy bar every minute for the next one billion years!

Tracing the Energy of a Solar Flare

When a solar flare occurs it releases energy in several different forms. First, there is the overall kinetic energy of tons upon tons of moving plasma. When that plasma crashes into other matter in the corona and chromosphere it transfers its kinetic energy into the chaotic and random motions of particles in the surrounding matter. This is what we call *thermal energy*, the sum of the all the kinetic energy of all of those particles moving in a disordered way.

Light is also produced in solar flares. It comes from two sources; one source is the plasma moving through a magnetic field. When charged particles move through a magnetic field they do not follow straight paths but spiral around. This spiraling motion is an acceleration that causes the charged particles to radiate light away. The second source of the light is the heated matter. One way that heated matter cools is by releasing energy in the form of light.

If a CME erupts following a solar flare then there will also be kinetic energy in the bulk motion of the several billion tons of matter that are spewed out into interplanetary space.

Where does the solar flare get all the energy that it releases? It comes from the energy stored in the twisted and tangled magnetic field. However, tangling and twisting a magnetic field also takes energy. Where does that energy come from?

Energy Comparisons:			
	Calories	Joules	# of Candy Bars (250 Cal each)
Lifting a lemon 1 meter	2.388×10^{-4}	1	9.55×10^{-7}
Car moving at 60 mph	86	3.6×10^{5}	0.34
Burning a liter of Oil	287	1.6×10^{6}	1
Human daily diet	2×10^{3}	8.4×10^{6}	8
Lightening bolt	10^{6}	10^{10}	10^{4}
Heat a house (1 year)	10^{7}	10^{11}	10^{5}
1-megaton H bomb	1×10^{12}	5×10^{15}	4×10^{9}
Earthquake (magnitude 8.0)	6×10^{12}	2.5×10^{16}	2.4×10^{10}
Annual U.S. energy usage	10^{16}	10^{20}	10^{14}
Impact of dinosaur extinction asteroid	10^{19}	10^{23}	10^{17}
Annual sunlight on Earth	10^{21}	10^{25}	10^{19}
Large solar flare	$\mathbf{10^{22}}$	$\mathbf{10^{26}}$	$\mathbf{10^{20}}$
Earth spinning	10^{25}	10^{29}	10^{23}
Earth moving in orbit	10^{29}	10^{33}	10^{27}
Annual solar energy output	10^{30}	10^{34}	10^{28}
Supernova (exploding star)	10^{40}	10^{44}	10^{36}

Table 4.1: A comparison of the amount of energy in a variety of systems or phenomena.

The Sun's magnetic field is thought to be generated in the convection zone of the Sun where giant blobs of hot gas rise, cool, and then sink back down in the process called convection. The rising and sinking motion of the charged gas along with the Sun's rotation generates large electrical currents. Those currents create the magnetic field. Where does the energy to cause convection and the Sun to spin come from?

The amount of energy in the Sun's rotation is a combination of the mass of the Sun, its size, and how fast it spins. The faster it spins, the more energy it has. Those three properties of the Sun were a result of the way in which the Solar System itself formed.

Thermal energy, generated by interactions with matter deeper inside the Sun, leads to the convection of gas in the Sun. In the Sun's core, temperatures are very high and matter is very dense. Under these conditions nuclear fusion takes place. Nuclear fusion is a reaction where nuclei of hydrogen fuse together to create helium. The reaction releases high-energy light in the form of gamma rays. The gamma rays randomly collide with particles in the surrounding matter and give them some random kinetic energy. This heats up the core (increasing its thermal energy). Where did the energy come from to make the core so hot and dense and produce nuclear fusion?

The core is so dense and hot because of the Sun's mass. It is so massive that gravity pulls all the matter together, compressing it with great force. Compressing the gas acts to heat it up and make it dense.

So, when we trace the energy that is released in a solar flare (and all the other energy released by the Sun as well) we find that the Sun's mass is a common source of it all. Of course, the energy wasn't created with the Sun's mass either. But that is another story…

Solar Flares Cornell Notes

Directions: *As you read the essay on Solar Flares, find answers to the questions on the left hand column. Write your answers to these questions on the right hand column. When you are finished, write a five sentence summary about the main ideas you learned in your reading.*

Name: ____________________
Class:____________________
Period/Block:______________
Date:_____________________

	Solar Flares
What is a solar flare?	
When do solar flares occur?	
What are coronal mass ejections?	
How do sunspots give scientists clues about the Sun's magnetic field and the cause of solar flares?	
What causes the sunspots to drift on the surface of th Sun?	
	Follow the Energy
Define energy, kinetic energy, and potential energy.	
List the basic forms of energy.	

Summary, Reflection, Analysis

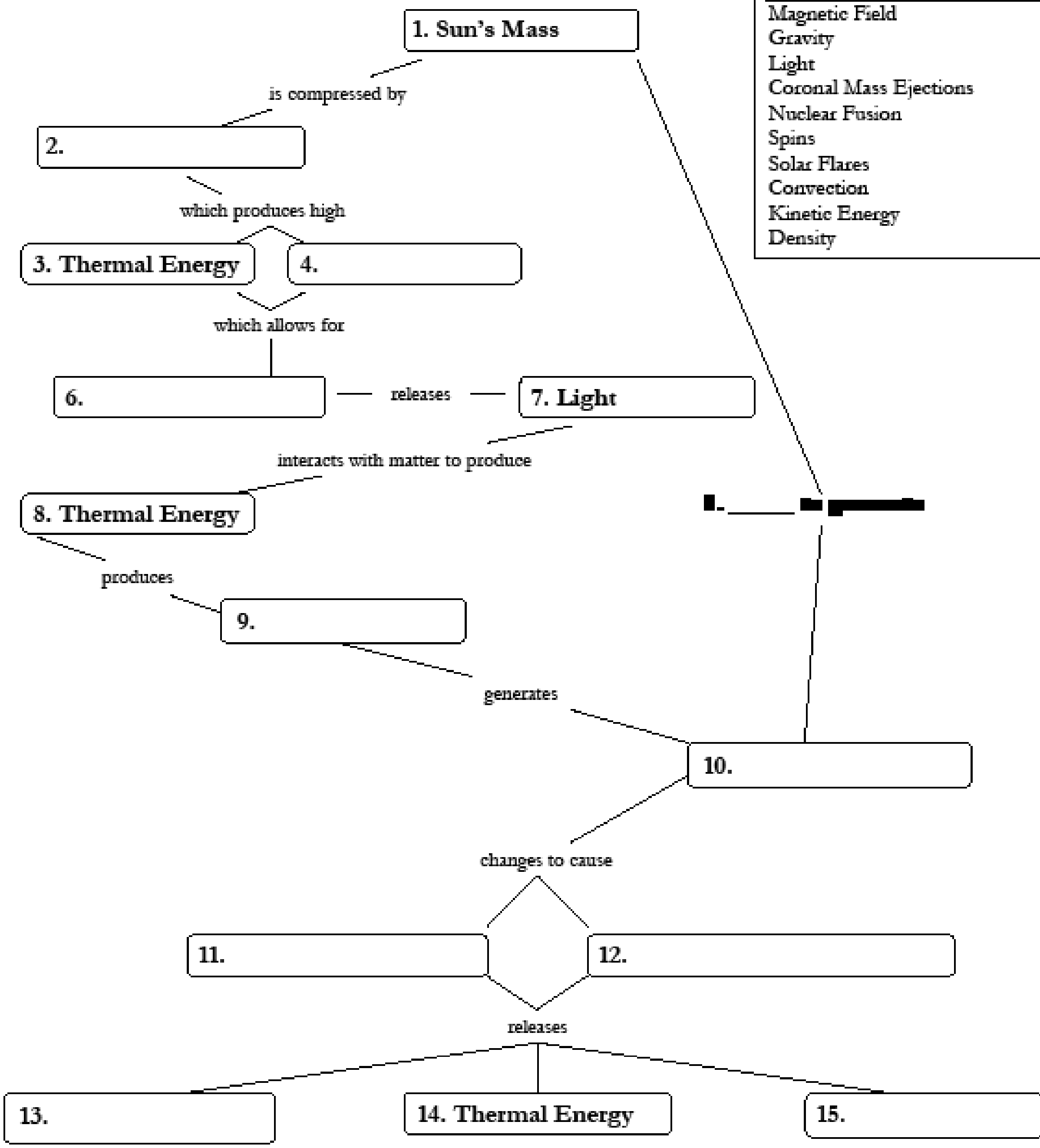
What units of measurement are used to represent energy?	
What type of energy is being represented on food labels?	
What does your body do with the potential energy?	
	Tracing the Energy of a Solar Flare
What form is the energy released from solar flares?	
Describe how thermal energy is produced in solar flares.	
How are large electrical currents created in the convection zone of the Sun?	
Describe nuclear fusion.	
Why is the core of the Sun so dense and hot?	

Summary, Reflection, Analysis

Worksheet 4.3

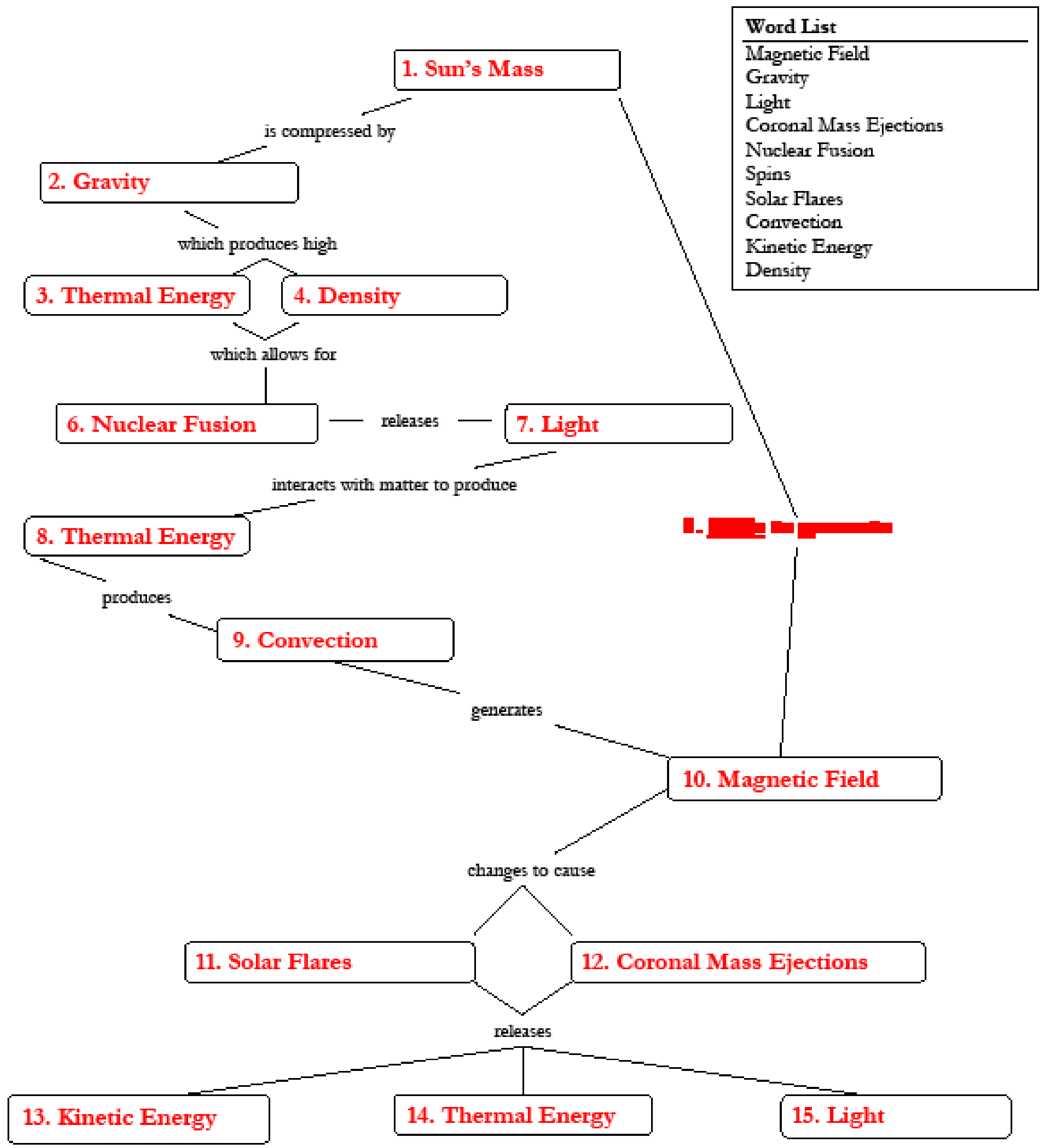
Now that you have read the essay about solar flares, and where the energy comes from that produces them, examine the concept map below and fill in the boxes with the appropriate words from the following list.

Word List
- Magnetic Field
- Gravity
- Light
- Coronal Mass Ejections
- Nuclear Fusion
- Spins
- Solar Flares
- Convection
- Kinetic Energy
- Density



<u>Worksheet 4.3</u> <u>(Answer Key)</u>

Now that you have read the essay about solar flares, and where the energy comes from that produces them, examine the concept map below and fill in the boxes with the appropriate words from the following list.



Assessment Rubric

With an additive rubric, students have to learn more content in greater depth to achieve higher levels. Teachers should introduce the rubric to students before the activities begin and encourage students to achieve to their highest potential. Teachers use the rubrics at the end of the unit to assess whether students have learned the science content.

	1	2	3 (Level 2+)	4 (Level 3+)	5 (Level 4+)
Science Content: Activity 2 Magnetic Energy and the Cause of Solar Flares	* Level 2 tasks attempted, but not completed or mastered	*Students successfully complete activities 4 and 5 from Session 2 in Exploring Magnetism. *Students, through successful completion of Activity 4 and 5, know that electrical currents create magnetic fields and that moving magnets create electrical fields that push on charges and create a current. *Student, through successful completion of Activity 4 and 5, know that moving electric fields create magnetic fields and that moving magnetic fields create electric fields.	*Students understand, primarily through discussion, that energy is not being created in the magnet, but transformed from one form of energy to another. *Students know the differences between kinetic and potential energy and are able to demonstrate an example of it in their world.	*Students read the Solar Flares essay and complete Worksheet 4.3 with 80-94% accuracy. *Students, through successful completion of Worksheet 4.3, are able to demonstrate that they know the basic concepts of a magnetic field, coronal mass ejection, light, nuclear fusion, the Sun's spin, solar flares, convection, kinetic energy, Sun's mass, gravity, and heat.	*Students read the Solar Flares essay and complete Worksheet 4.3 with 95% accuracy and above. *Student fully demonstrates comprehension of magnetic energy and the cause of solar flares.
Collaborative Worker	Participates but does not successfully complete one or more requirements of Level 2	Arrives on time with materials. Shows respect for others; cares for equipment and resources.	Stays focused on assigned task and helps others do the same. Shares work equally.	Facilitates the participation of all in the group. Tutors and/or supports other students.	Takes all group roles with equal skill. Assists others as they learn to do the same.

<u>Activity 3</u> – Measuring the Speed of an Ejected Ball of Plasma

Student Objectives

- Students will evaluate real images of solar flares.
- Students will recall and apply what they learned from Activity 2 to predict the magnetic field around a sunspot.
- Students will graph position versus time of a blob of coronal plasma from RHESSI images.
- Students will use real data and one of two methods for determining the speed of an ejected ball of plasma.
- Students will calculate the kinetic energy of a blob that was ejected from a solar flare moving away from the sun as a coronal mass ejection.
- Students will calculate the strength of the magnetic field that caused a solar flare and CME.

Materials Needed

- 1 set per group of RHESSI images of flare # 2041509
- rulers
- pencils
- graph paper
- calculators (optional, a brain works pretty good too)

Getting Ready

Make photocopies of the Worksheets, the **RHESSI Flare Images** info sheet, and a set of RHESSI flare images per group. You may also wish to prepare several overheads from example images provided in this activity and in the **Background Section.** If your classroom has a computer and internet connectivity, you can also set this up so that you can show students videos of the solar flare #2041509 at http://cse.ssl.berkeley.edu/ExploringMagnetism/SolarFlares.

Procedure

1. Begin by explaining to students that now that they have learned about how magnetic fields are thought to cause solar flares, they will work with some real NASA data to see if it is consistent with this idea. Tell them about Solar flare # 2041509, which occurred on April 15th, 2002. See the **Background Section** for a full explanation of this flare and for online resources (such as images and movies) that you can use to introduce the activity.

2. Have students break up into their Science Teams. Pass out **Worksheet 4.4** and the **RHESSI Solar Flare Images** information sheet.

3. Explain what the images represent and how RHESSI is a NASA satellite in space that records X-ray and Gamma-rays from the Sun. Tell them that these images are a sequence of pictures taken at 20.75 second intervals of the solar flare on April 15th. Explain the features seen in the flare and relate the image to the others from the **Background Section** and in the online resources, this should help them understand that the image is a zoomed in section of the Sun and that the curved line running through it is the edge of the Sun. Point out the arc-shaped coronal loop and the blob of plasma separating from it (see Figure 4.7).

4. Ask students to use what they have learned from the first two activities and to predict what they think the magnetic field looks like for this flare. Have them draw their predictions on **Worksheet 4.4**. Have the Science Teams report out to the other students what they think the magnetic field looks like. Their drawings should look very much like the **Figure 4.6**.

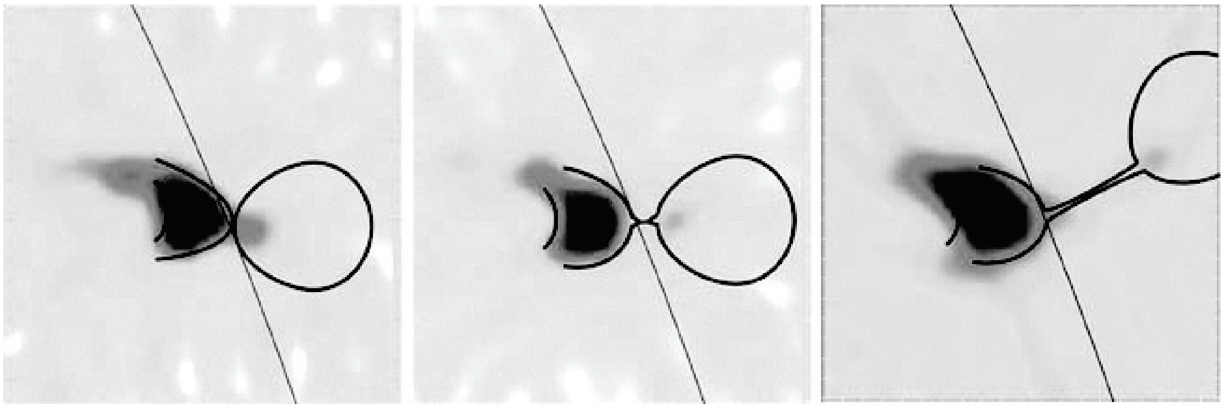


Figure 4.6: The shape of the magnetic field around flare # 2041509 as determined by RHESSI scientists. These images are the same as the other RHESSI images and represent a scale of 94,250 km x 94,250 km near the edge of the western side of the Sun.

5. Next, hand out **Worksheet 4.5**, a set of **RHESSI images** of flare # 2041509, and graph paper to the Science Teams. Tell them that they will now act like scientists and will analyze their data to determine some characteristics of the solar flare. *Note that there are two versions of the images provided.* One set has the locations of the "footprints" of the coronal loop causing the flare marked with X's. Also a circle is marked in the images to indicate the midpoint between the footprints. This point is to be used as the reference point from which the students will measure the height of the X-ray blob. The second set does not have these points marked and it is left up to the students to determine how to locate the footprints and midpoint. They will essentially have to make an educated guess at the locations of the footprints based on the coronal loop. Then they can use those points and the midpoint formula to find the midpoint. You may use whichever set you think will work best for your class.

   In their teams, students should examine each image and determine the location of the brightest spot in the coronal X-ray source (a.k.a. "the blob"), which is above the coronal loop. Using a ruler, they should then draw cross hairs through that spot reaching the axes so that they can read off the coordinates of the spot (See the example on the next page, which you can use to make an overhead for demonstration purposes).

   Next, students will need to determine the height of the blob above the surface of the Sun. This can be done in a number of ways.

   <u>Method 1</u>: Students use a ruler to measure the distance between the midpoint of the coronal loop footprints and the blob. They will then need to convert their measurement into arc-seconds and then into kilometers. To convert their measurement into arc-seconds, they should line up their ruler (whichever side they used, centimeters or inches) with one of the axes of the image. They can read off how many arc-seconds there are per either inch or centimeter. Then they can multiply their measurements by that factor. Finally, they need to multiply the number of arc-

seconds by the conversion factor of 725 km/arcsec (See the explanation in the **RHESSI Solar Flare Images** info sheet).

Method 2: Students use the formula for the distance between two points to calculate the height, since they already have the coordinates for the blob.

$$\textbf{height}^2 = (x_1 - x_2)^2 + (y_1 - y_2)^2$$

The coordinates for the midpoint is (852, 360) arc-seconds. For reference, the coordinates of the footprints are: (840, 372) & (864, 348) arc-seconds. Following that they must once again convert the height in arc-seconds into kilometers using the image scale of 725 km/arcsec.

Students should then plot the data on a graph. The x-axis will be time and the y-axis will be height above the surface of the Sun in kilometers. They will not draw lines through the points, just plot the points.

Students should return to their data table and calculate the distance moved between each pair of points, and then use that information in connection with the time interval between each image to calculate the average speed of the blob between pairs of points.

Finally, students will take a ruler and draw a line segment that goes through the last three points, when the blob takes off. They will calculate the slope of that line. The value of the slope will be the speed with which the blob ejected away from the Sun.

Example Data are given in **Table 4.2** and plotted in **Figure 4.8**.

Students will lastly be asked about when the blob separates from the coronal loop, when the blob experiences the greatest acceleration and strongest net force. All these things happen around the 7^{th} frame or around 23:12:00 UT. That is when there is the most extreme change in the speed (slope) of the blob in the graph. Students with training in calculus will recognize this spot as where the derivative is maximized. Newton's second law of motion states that force is directly proportional to acceleration (where mass of the object is the constant of proportionality, F = ma). The source of that force is the magnetic field. As the magnetic field evolves, it creates an electric field which pushes the charged gas away from the Sun at quite a fast speed. Your students should find the speed to be 250-300 km/s.

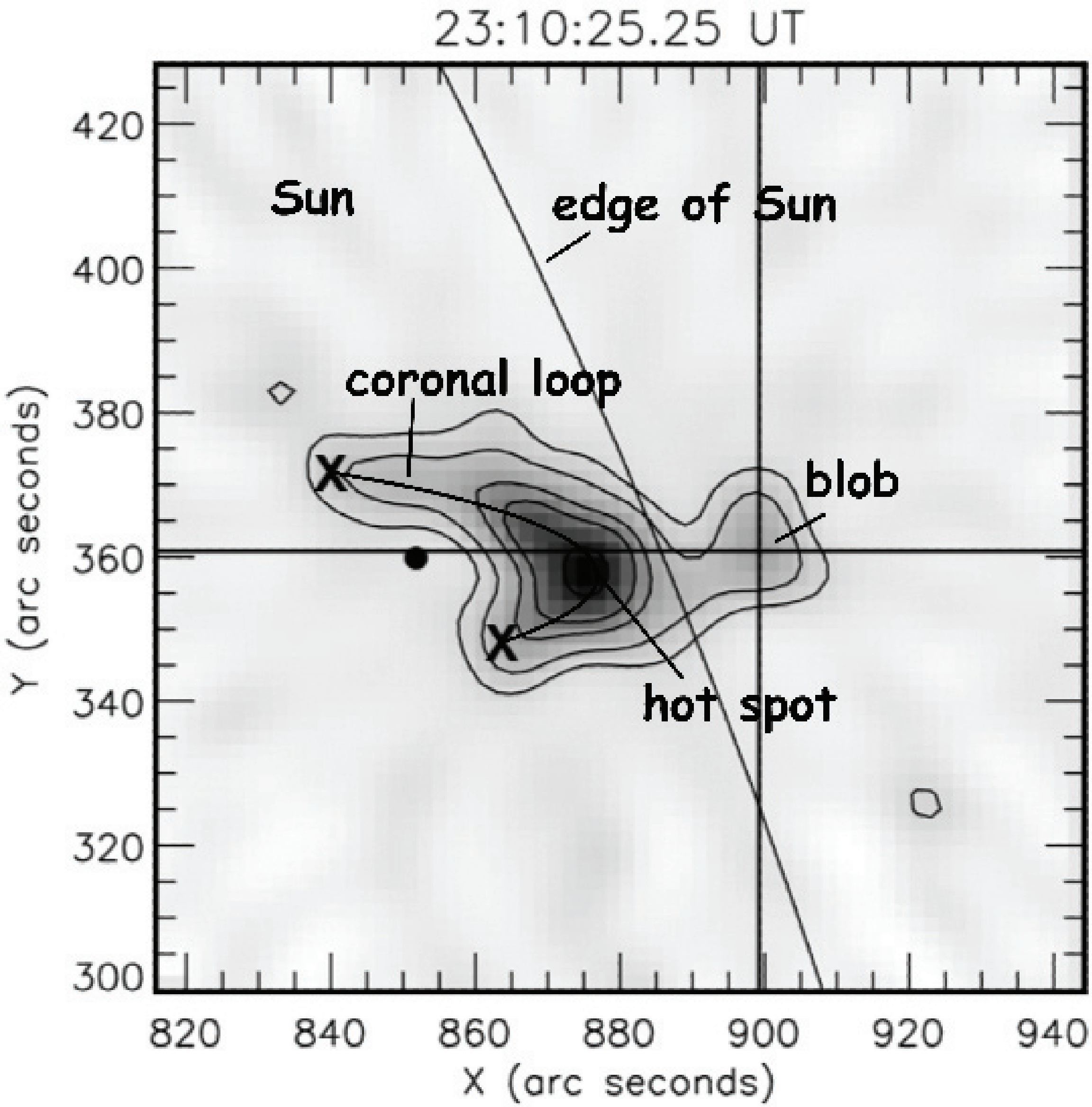


Figure 4.7: Drawing cross-hairs through the brightest point of the blob

Time	Time Interval (sec)	X-Ray Source Position		Height (arc sec)	Height (km)	Distance Moved (km)	Speed (km/s)
		X	Y				
23:10:04.50		897	359	45.0	32,633		
23:10:25.25	20.75	899	361	47.0	34,083	1,450	70
23:10:46.00	20.75	899	361	47.0	34,083	0	0
23:11:06.75	20.75	896	359	44.0	31,908	-2,174	-105
23:11:27.50	20.75	899	364	47.2	34,198	2,290	110
23:11:48.25	20.75	900*	366*	48.4	35,071	873	42
23:12:09.00	20.75	903	361	51.0	36,982	1,911	92
23:12:29.75	20.75	909	369	57.7	41,837	4,855	234
23:12:50.50	20.75	915	374	64.5	46,789	4,952	239

Table 4.2: Example Data for Worksheet 4.5. Note that the measurement for the image taken at 23:11:48.25 is a difficult one; student measurements of this image should be expected to vary by a large amount.

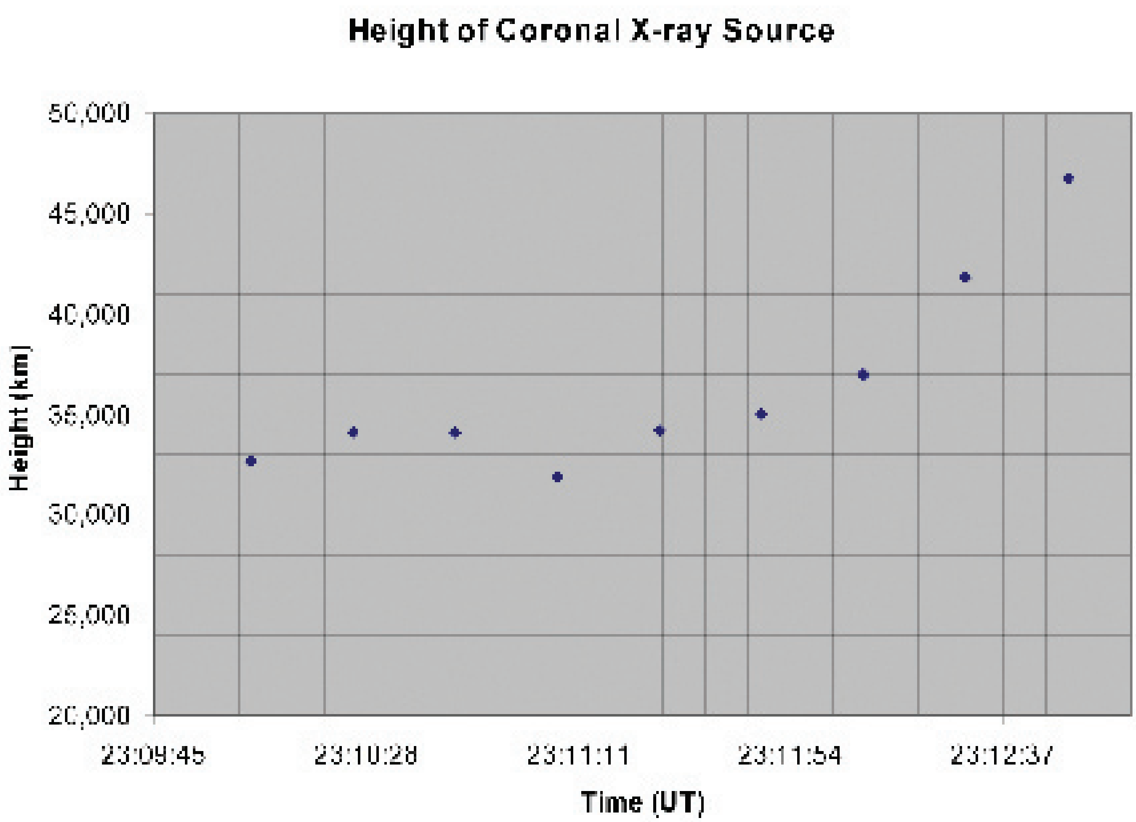


Figure 4.8: Plot of Example Data in Activity 3

Going Further

6. If your students have studied the concept of kinetic energy, then they can go one step further and make an estimate of the kinetic energy that the blob has as it is ejected by the flare. Hand out **Worksheet 4.6** to have students make the necessary measurements and calculations. When they have a number, they can compare it to the total light energy that the flare released as well as the energy of other events discussed in the essay from Activity 2.

7. Finally, your students can estimate the minimum strength of the magnetic field in the coronal loop. They will do this by using the equation for magnetic energy density and equating the energy released by the flare with the amount of magnetic energy contained in the coronal loop. They will be asked to take the equation and algebraically solve for the magnetic field strength, **B**. They will then have to estimate the volume of the coronal loop by assuming it to be a cylinder curved into a semicircle. Handout **Worksheet 4.7** for students to do the necessary measurements and calculations. Afterward discuss with students the strength of the field they calculate relative to the strengths of other magnetic fields, as shown in the **Table 4.3**.

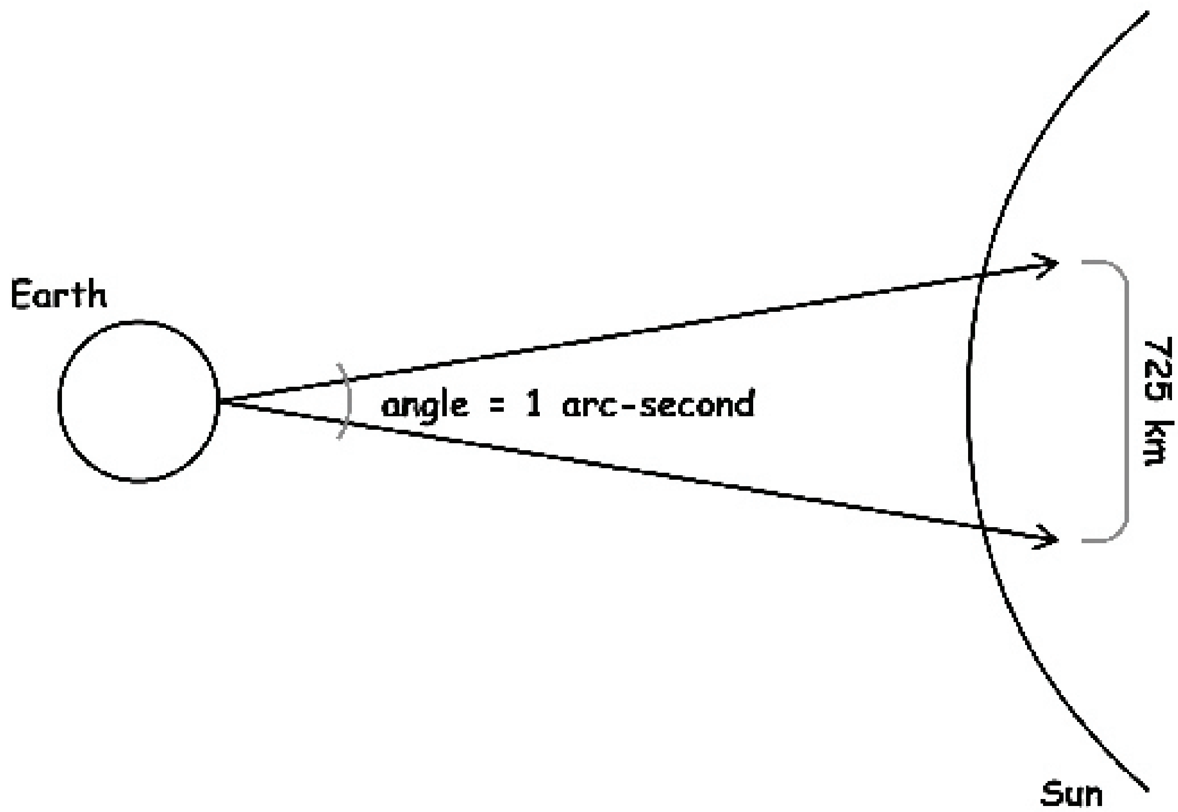
Magnetic Field Comparison:	
Object	Magnetic field strength (Gauss)
Earth's field at surface	0.6
Common bar magnet	100
Strong Sunspots	4000
Strongest Manufactured Magnets	4.5×10^5
Strongest Stellar Magnetic Fields	1×10^8
Normal Neutron Star (radio pulsars)	10^{12} - 10^{13}
Strongest Neutron Star fields (magnetars)	10^{14} - 10^{15}

Table 4.3: Comparison of magnetic field strengths of various objects.

RHESSI Solar Flare Images

The images for the activity in **Worksheets 4.4 & 4.5** are a sequence of images, constructed from observations of high energy X-rays from the Sun made by the RHESSI spacecraft on April 15th, 2002. The images are zoomed in on a region in northwest quadrant of the Sun. The long curved line running through the center of the images is the edge of the Sun.

In the images, the axes are given in arc-seconds. Arc-seconds are a unit of angle. They are a subdivision of degrees. There are 60 arc-seconds in an arc-minute and 60 arc-minutes in a degree. Thus, there are 3,600 arc-seconds in a degree. Imagine a right-triangle with two points on the surface of the Sun and one point on Earth. If the angle between the two lines connecting Earth and the Sun were one arc-second then the distance between the two points on the Sun would be 725 kilometers. So in the images, one arc-second equals 725 kilometers. The center of the coordinate system is the center of the Sun.

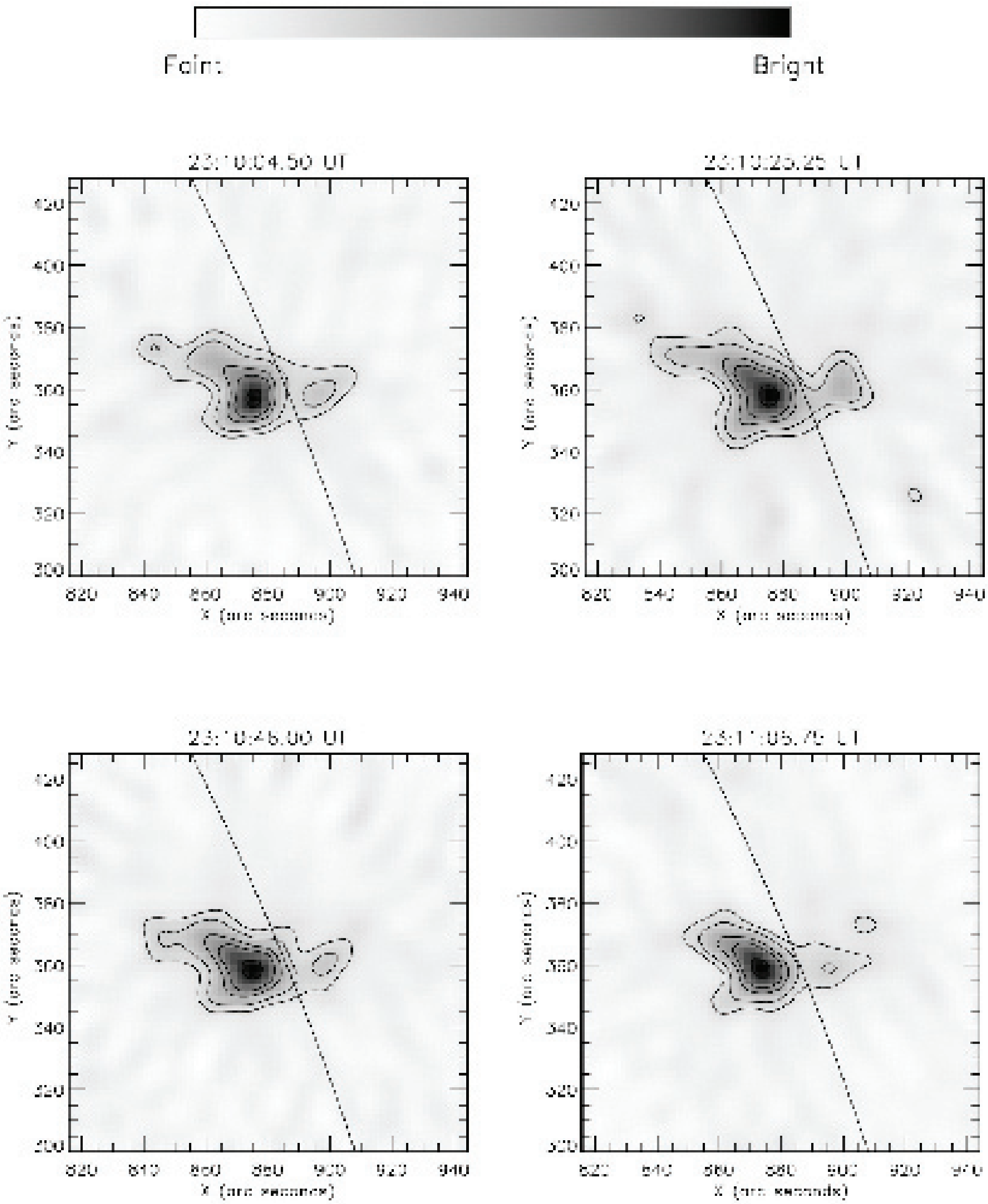


The time that the image was taken is given at the top of each image in Universal Time (UT). Universal Time is the time kept in the time zone centered on Greenwich, England (longitude zero). Universal Time does not participate in daylight savings time, so there is no springing forward or falling back one hour during the year. UT times are given in terms of a 24-hour clock. Thus, 14:42 is 2:42 p.m., and 21:17 is 9:17 p.m. For example, in the winter, when it is 6:00 am Pacific Standard Time in Oregon, it is 7:00 am in Montana, 9:00 am in Pennsylvania, and 14:00 Universal Time.

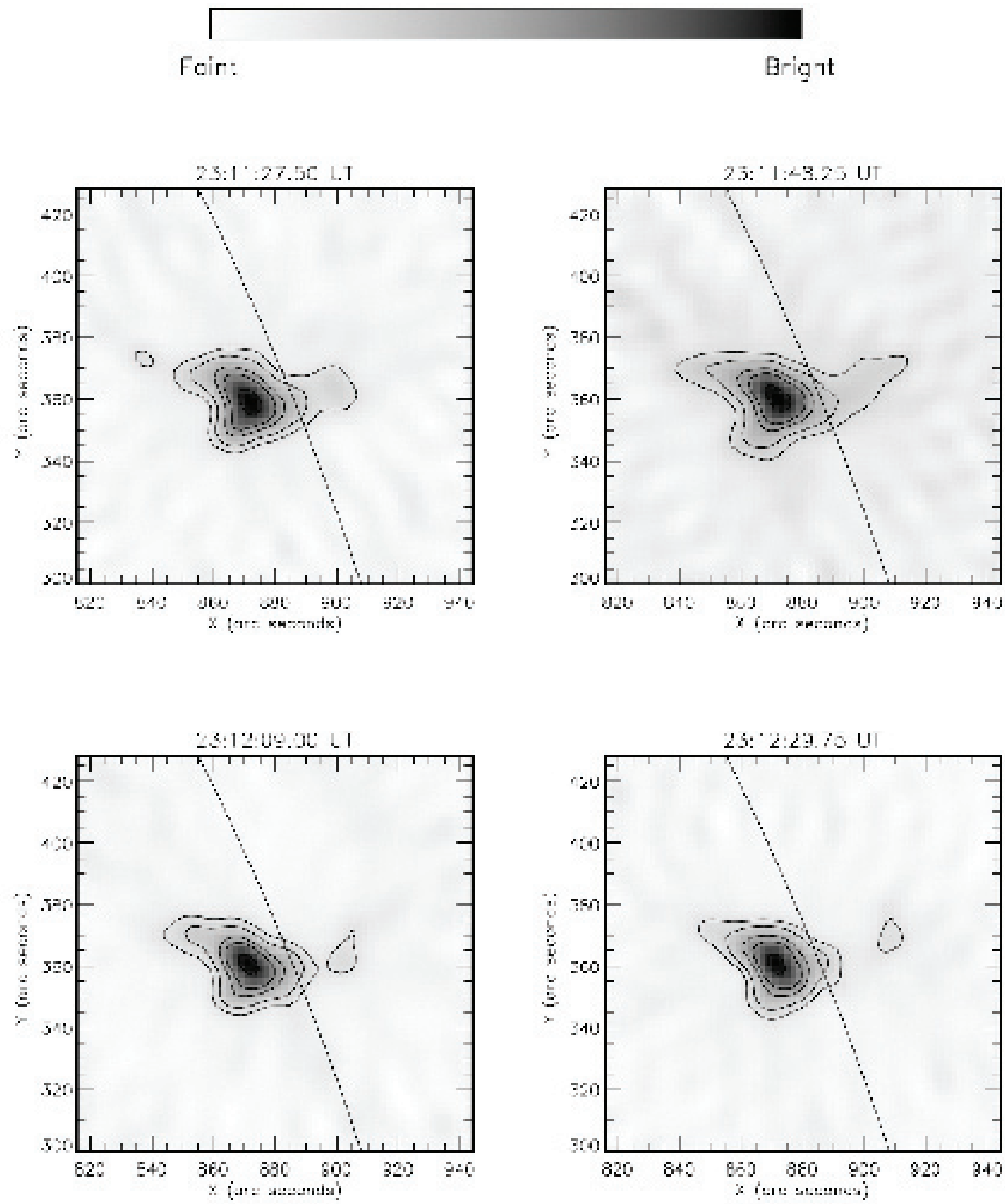
The image is black and white. To make the solar flare more visible, and for the ease of this activity, white represents faint emission of X-rays and black indicates bright emission of X-rays. This is like a photo-negative. For further clarity, contour lines have been added to the images to accentuate the shape of X-ray emission at certain brightness values. This is similar to contour lines drawn on maps, where each line represents a certain height. Here the contour lines represent a specific level of X-rays brightness. The outer lines are fainter and the inner lines are brighter.

The shape of the contours outline the coronal loop that is the source of the flare. The brightest spot in the image is the top of the coronal loop where plasma is being squirted down and crashing into it. There is a secondary bright spot above the loop that slowly lifts away from it, and in the last frames, is ejected up and away from the coronal loop and the Sun. A coronal mass ejection (CME) was later observed by the SOHO spacecraft (see the movie online) originating from that part of the Sun.

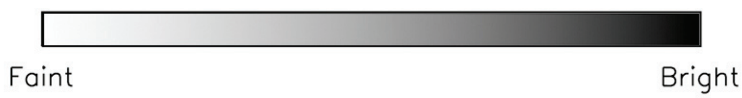
RHESSI Images of flare # 2041509
(page 1 of 3)

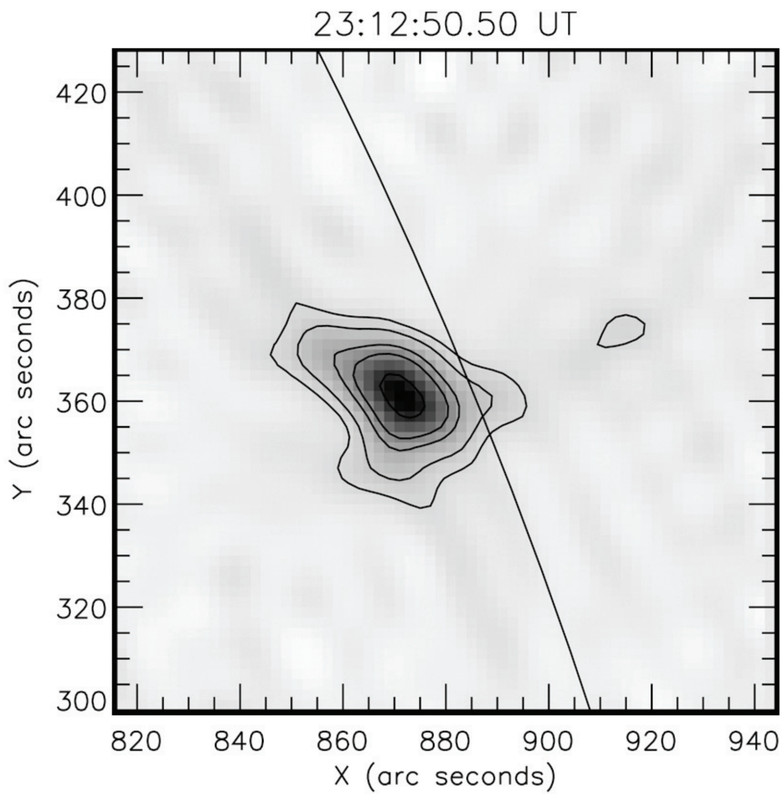


RHESSI Images of flare # 2041509
(page 2 of 3)

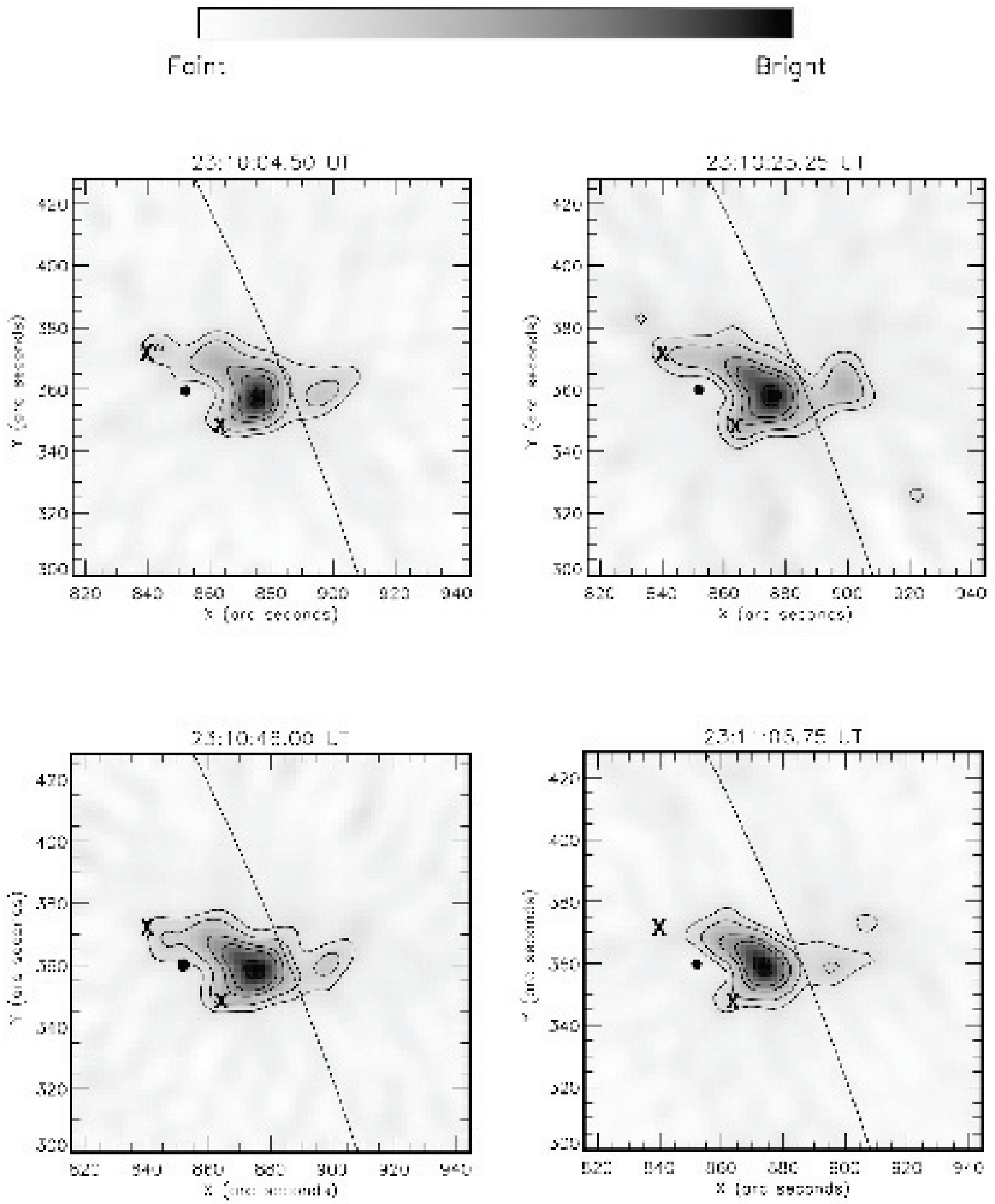


RHESSI Images of flare # 2041509
(page 3 of 3)

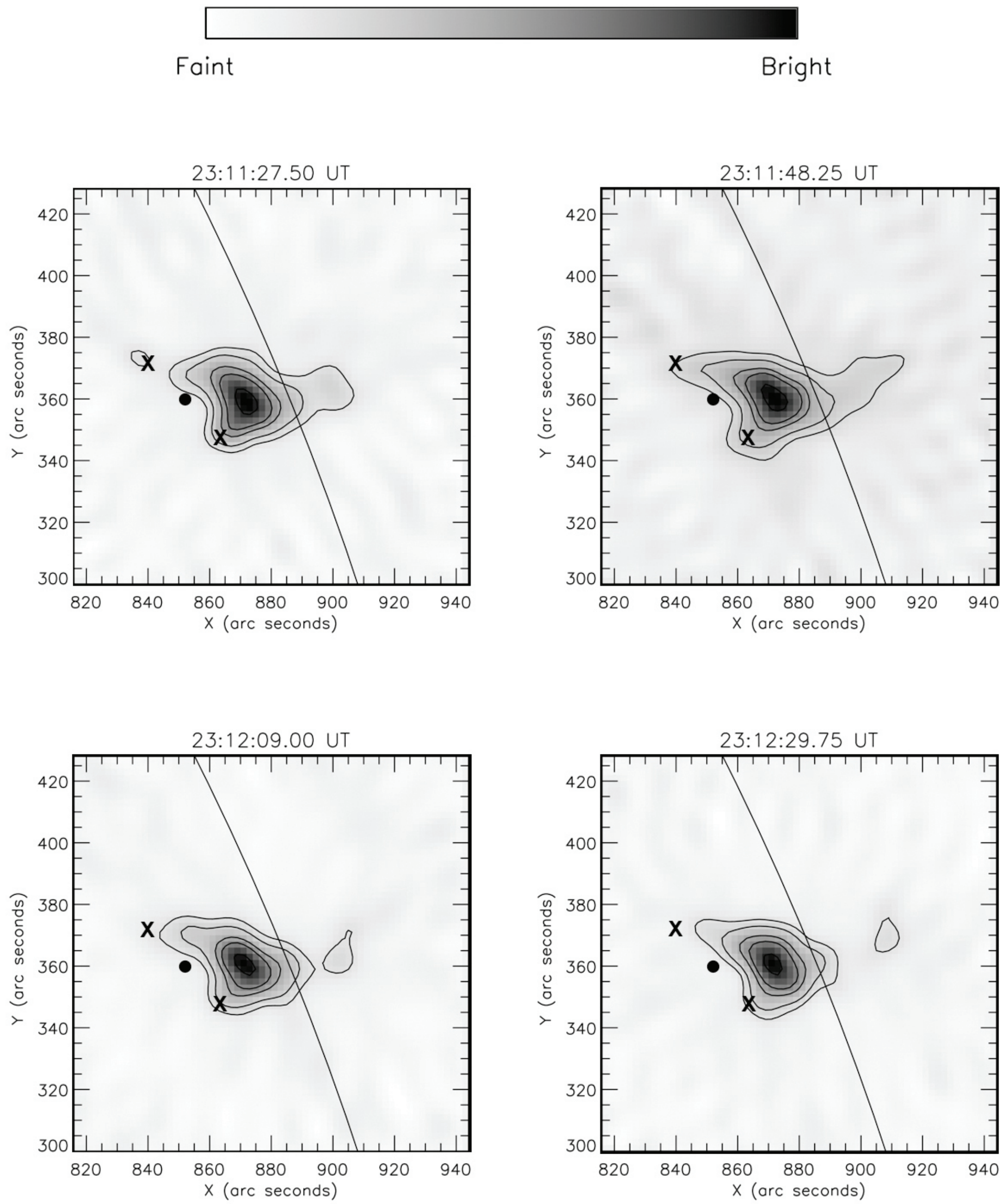




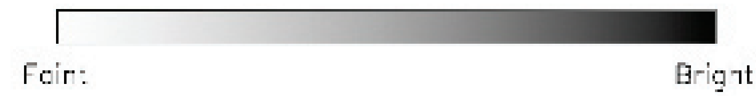
RHESSI Images of flare # 2041509 with footprints (page 1 of 3)

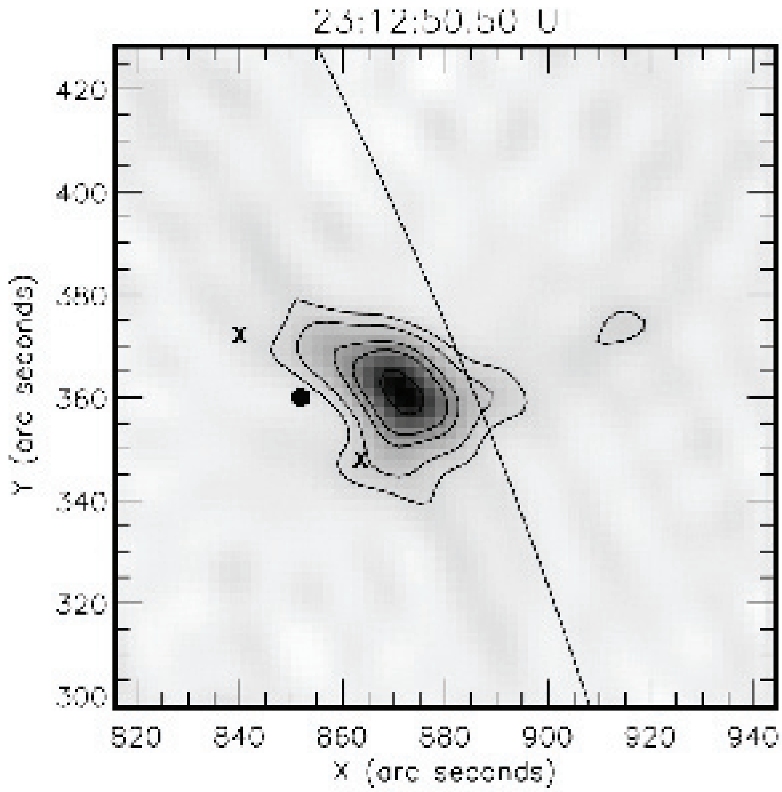


RHESSI Images of flare # 2041509 with footprints (page 2 of 3)



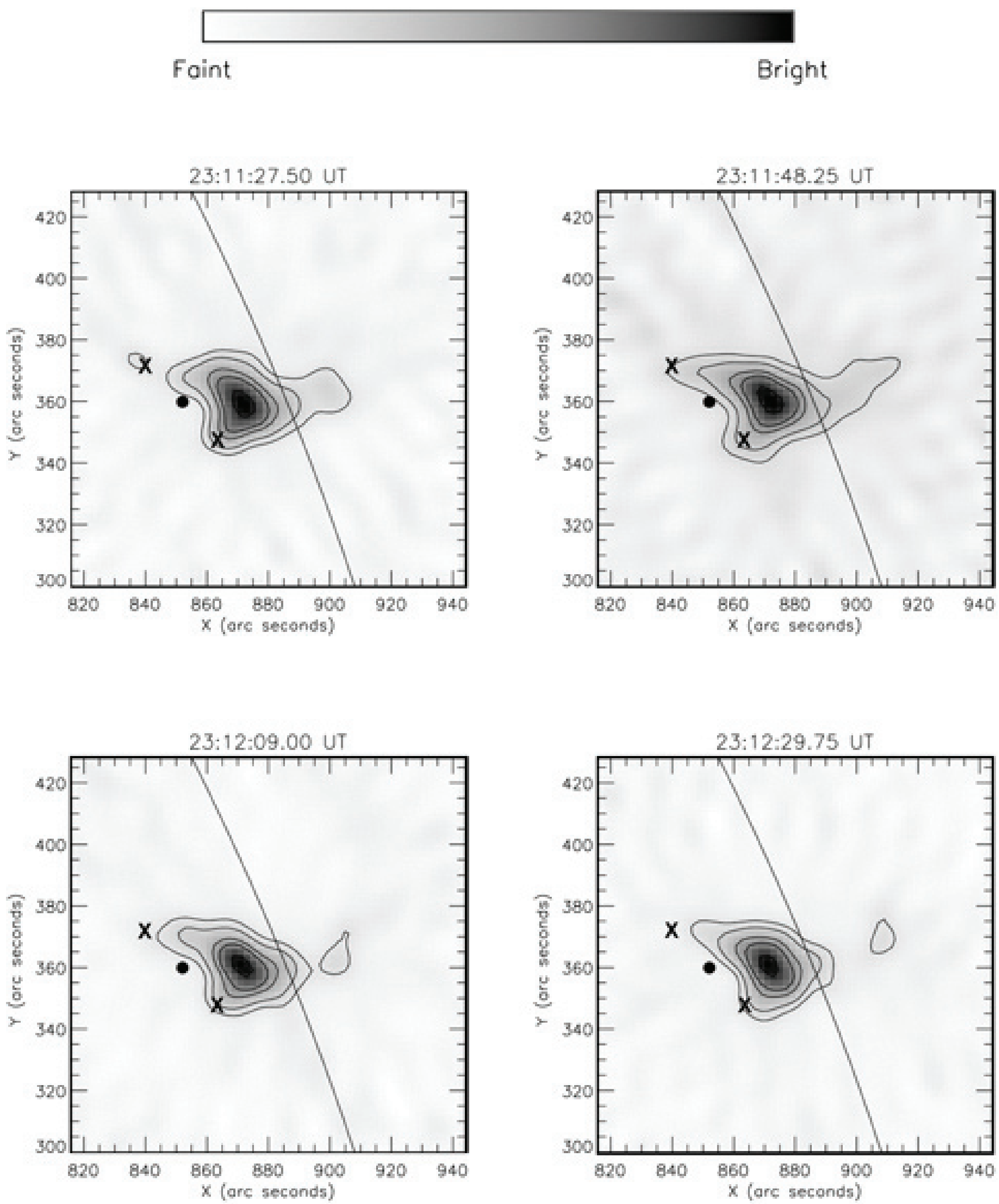
RHESSI Images of flare # 2041509 with footprints (page 3 of 3)





Worksheet 4.4

1. Below is a sequence of images of a solar flare, which occurred on April 15th, 2002, as observed in X-rays by the RHESSI spacecraft. In each of the images, predict what you think the shape of the magnetic field will look like and draw it on top of the image. The X's in the image indicate the location of the "footprints" of the coronal loop.



Worksheet 4.5

1. Your teacher will hand out a sequence of nine images from the RHESSI spacecraft as well as some graph paper. Examine each image and determine the location of the brightest spot in the coronal X-ray source (a.k.a. "the blob"), which is above the coronal loop.

2. Using a ruler, draw one horizontal and one vertical line through that spot (cross hairs) reaching the axes so that you can read off the coordinates of the spot. Record the data in the table provided below.

3. Determine the height of the blob above the surface of the Sun (in arc seconds). This can be done a number of ways. Discuss which ways are possible with your Science Team (and possibly your teacher) and decide how you will make this measurement. Describe your method below and show all calculations. Record the data in the table.

4. Convert the height that you calculated above from units of arc-seconds to kilometers. In all the images, the scale is 725 km/arc-sec. Show your calculations below and record the data in the table.

5. Plot the data on a graph above the surface of the sun. The x-axis should be **Time** and the y-axis should be **Height** in kilometers. Be sure to label the axes and include units. Do not draw lines through the points in the graph, just plot the points.

6. Return to the data table and calculate the distance moved between each pair of consecutive points. Show all work and record the data in the Table.

7. Use the distance moved between each pair of points and divide it by the time interval between each image to calculate the average speed of the blob at each point. Show all work and record the data in the Table.

8. Finally, use a ruler to draw a line through the last 3 points in your graph. If you cannot get a straight line to go through all three points, draw the line such that it comes as close to all three points as possible. Now, measure the slope of the line, displacement in the y-direction divided by the displacement in the x-direction ("rise over run"). The slope of this line is the average speed of the blob as it was ejected from the Sun. Show all work and record your result below.

9. At what time did the blob finally separate from the coronal loop and eject away from the Sun?

10. When did the blob experience the greatest acceleration (change in speed with time)? Explain.

11. When did the blob experience the greatest net force, and what was the source of the force? Explain.

Time	Time Interval (sec)	X-Ray Source Position		Height (arc sec)	Height (km)	Distance Moved (km)	Speed (km/s)
		X	Y				

Worksheet 4.6

The blob that was ejected from the solar flare later moved completely away from the Sun as a Coronal Mass Ejection (CME) moving with the same speed that you calculated in Worksheet 4.5. This blob has mass and a speed, so we can calculate its kinetic energy. The formula for kinetic energy is:

$$\mathbf{KE = \tfrac{1}{2}mv^2}$$

where *m* is mass and *v* is speed.

1. The mass of the blob can be estimated by first estimating its volume and using the typical density of plasma in a coronal loop. Examine the 9th flare image in the series (23:12:50.50 UT) and estimate the diameter of the blob in kilometers. Show your work and record the number below.

2. Assume that the blob is a sphere and calculate its volume. Show all work.

3. The typical density of plasma in a coronal loop is 2×10^{-14} g/cm^3. Use this value to calculate the mass of the blob. Show all work.

4. Now, calculate the kinetic energy of the blob in Joules. Show all work, and be mindful of units.

5. The actual amount of mass that was ejected from the Sun was 10 times larger than what the X-ray image shows. The total amount of mass ejected from the Sun was estimated by NASA scientists to be 5 x 10^{13} g. Calculate the kinetic energy of the CME in Joules. Show all work and be mindful of units.

6. The total amount of energy released by the flare that went into heating and accelerating matter was estimated by NASA scientists to be 2 x10^{23} Joules. How does this compare to the amount of kinetic energy given to the CME? How many candy bars would you have to eat to equal the total amount of energy? Show all work and be mindful of units.

Worksheet 4.6 (Answer Key)

The blob that was ejected from the solar flare later moved completely away from the Sun as a Coronal Mass Ejection (CME) moving with the same speed that you calculated in Worksheet 4.5. This blob has mass and a speed, so we can calculate its kinetic energy. The formula for kinetic energy is:

$$\mathbf{KE = \tfrac{1}{2}mv^2}$$

where *m* is mass and *v* is speed.

(Note: *v* is used for velocity, which is speed and direction, but in this formula there is no direction, so speed and velocity are the same.)

1. The mass of the blob can be estimated by first estimating its volume and using the typical density of plasma in a coronal loop. Examine the 9th flare image in the series (23:12:50.50 UT) and estimate the diameter of the blob in kilometers. Show your work and record the number below.

Diameter of blob = 1 cm
1 cm x 11 arcsec/cm = 11 arcsec
11 arcsec x 725 km/arcsec = **7,975 km**

2. Assume that the blob is a sphere and calculate its volume. Show all work.

$V = 4/3\ \pi r^3$
$r = D/2 = 7975\text{ km}/2 = 3988\text{ km}$
$V = 4/3 \times \pi \times (3988\text{ km})^3 = \mathbf{2.66 \times 10^{11}\ km^3}$

3. The typical density of plasma in a coronal loop is 2×10^{-14} g/cm^3. Use this value to calculate the mass of the blob. Show all work.

$m = \rho V$
$V = 2.66 \times 10^{11}\text{ km}^3 \times (10^5\text{ cm/km})^3 = 2.66 \times 10^{26}\text{ cm}^3$
$m = 2 \times 10^{-14}\text{ g/cm}^3 \times 2.66 \times 10^{26}\text{ cm}^3 = \mathbf{5.32 \times 10^{12}\ g}$

4. Now, calculate the kinetic energy of the blob in Joules. Show all work, and be mindful of units.

$KE = \tfrac{1}{2} mv^2$
$m = (5.32 \times 10^{12}\text{ g}) \times 1\text{ kg}/10^3\text{g} = 5.32 \times 10^9\text{ kg}$
$v = 240\text{ km/s} \times 10^3\text{ m/km} = 2.4 \times 10^5\text{ m/s}$
$KE = 0.5 \times (5.32 \times 10^9\text{ kg}) \times (2.4 \times 10^5\text{ m/s})^2 = 1.53 \times 10^{20}\text{ kg m}^2/\text{s}^2$
$= \mathbf{1.53 \times 10^{20}\ Joules}$

5. The actual amount of mass that was ejected from the Sun was 10 times larger than just that seen in the X-ray image. The total amount of mass ejected from the Sun was estimated by NASA scientists to be 5×10^{13} g. Calculate the kinetic energy of the CME in Joules. Show all work and be mindful of units.

$m = (5 \times 10^{13}\ g) \times 1\ kg/10^3 g = 5 \times 10^{10}\ kg$
$v = 2.4 \times 10^5\ m/s$
$KE = 0.5 \times (5 \times 10^{10}\ kg) \times (2.4 \times 10^5\ m/s)^2 = 1.44 \times 10^{21}\ kg\ m^2/s^2$
= **1.44×10^{21} Joules.**

7. The total amount of energy released by the flare that went into heating and accelerating matter was estimated by NASA scientists to be 2×10^{23} Joules. How does this compare to the amount of kinetic energy given to the CME? How many candy bars would you have to eat to equal the total amount of energy? Show all work and be mindful of units.

1.44×10^{21} Joules / 2×10^{23} Joules = 0.0072 = **0.7% of total flare**
(rather small)

1 candy bar = 250 Calories
250 Cal x 4,186.8 Joules/Cal = 1.05×10^6 Joules
2×10^{23} Joules x (1 Candy Bar)/(1.05×10^6 Joules) = **1.9×10^{17} candy bars**

That's **190 quadrillion candy bars**. Whew!

Worksheet 4.7

1. Now that you have found out how much energy was released by the Solar flare, you will estimate how strong the magnetic field was inside the coronal loop. To do this you will use the following equation that relates the amount of magnetic energy contained within a region of space where a magnetic field is present:

$$\mathbf{E = B^2/(2\mu_0) \times V}$$

where **B** is the magnetic field strength, **E** is energy, **V** is volume of the coronal loop, and $\mu_0 = 4\pi \times 10^{-7}$ kg•m/Coulomb^2 which is called the permeability of free space. Algebraically solve the equation for **B**. Show your work.

2. Now you need to estimate the volume of the coronal loop. To make the estimate simple, assume that the loop is a cylinder that has been bent into a semicircle. The volume of a cylinder is $\mathbf{V = \pi R^2 l}$, where **R** is the radius of the cylinder and **l** is its length. Because, you are assuming that the shape of a coronal loop is a semicircle, then the length of the cylinder is half of the circumference of a full circle. The diameter of the full circle would be the distance, **d**, between the footprints of the coronal loops. So the length of the cylinder is

$$\mathbf{l = \pi/2 \times d.}$$

Examine the 9th flare image in the series (23:12:50.50 UT) and find the distance, **d**, between the footprints in kilometers. You can do this by either measuring the distance with a ruler or using the coordinates of the footprints. Show all work and be mindful of units.

3. Now examine the same image and use a ruler to measure the diameter of the coronal loop, use the contours as a guide. The radius of the cylinder, **R**, will be half of that diameter. Calculate the radius in kilometers. Show all work and be mindful of units.

4. Now calculate the volume, **V**, of the cylinder in cubic kilometers. Show all work and be mindful of units.

5. Return to your equation for the magnetic field strength in part 1. We are hoping to estimate the strength of the magnetic field that produced the solar flare and CME from this equation. If you use the amount of energy that the NASA scientists found as the total energy released by the flare in **Worksheet 4.6** in this equation, then that will mean that all of the energy contained in the coronal loop would have been transformed from magnetic energy into heat, kinetic, and light energy. Since the loop still exists after the flare, clearly not all of the energy within it was used. So, using this method will actually calculate the minimum magnetic strength of the coronal loop. Set **E** equal to 2×10^{23} Joules and calculate **B** in units of Gauss. Show all work and be mindful of units. Note on units: 1 Gauss = 10^{-4} Tesla, and 1 Tesla = 1 kg/(Coulomb•seconds).

Worksheet 4.7 (Answer Key)

1. Now that you have found out how much energy was released by the Solar flare, you will estimate how strong the magnetic field was inside the coronal loop. To do this you will use the following equation that relates the amount of magnetic energy contained within a region of space where a magnetic field is present:

$$\mathbf{E = B^2/(2\mu_0) \times V}$$

where **B** is the magnetic field strength, **E** is energy, **V** is volume of the coronal loop, and $\mu_0 = 4\pi \times 10^{-7}$ kg•m/Coulomb^2 which is called the permeability of free space. Algebraically solve the equation for **B**. Show your work.

$E = B^2/(2\mu_0) \times V$
$B^2/(2\mu_0) = E/V$
$B^2 = 2\mu_0(E/V)$
$\mathbf{B = [2\mu_0(E/V)]^{1/2}}$ or $\mathbf{B = SQRT[2\mu_0(E/V)]}$

2. Now you need to estimate the volume of the coronal loop. To make the estimate simple, assume that the loop is a cylinder that has been bent into a semicircle. The volume of a cylinder is $\mathbf{V = \pi R^2 l}$, where **R** is the radius of the cylinder and **l** is its length. Because, you are assuming that the shape of a coronal loop is a semicircle, then the length of the cylinder is half of the circumference of a full circle. The diameter of the full circle would be the distance, **d**, between the footprints of the coronal loops. So the length of the cylinder is

$$\mathbf{l = \pi/2 \times d.}$$

Examine the 9th flare image in the series (23:12:50.50 UT) and find the distance, **d**, between the footprints in kilometers. You can do this by either measuring the distance with a ruler or using the coordinates of the footprints. Show all work and be mindful of units.

The coordinates of the footprints are: (840, 372) & (864, 348) arc-seconds, so using the formula for the distance between two points gives
d = SQRT[$(864 – 840)^2$ + $(348-372)^2$] = SQRT(1152 arc-sec) = 34 arc-sec
d = 34 arc-sec x 725 km/arc-sec = **2.5 x 10^4 km**

For students who measure the distance with a ruler they should find that the distance is approximately 2.5 cm. The scale of that image is 13.3 arc-sec/cm.
2.5 cm x 13.3 arc-sec/cm x 725 km/arc-sec = **2.4 x 10^4 km**

3. Now examine the same image and use a ruler to measure the diameter of the coronal loop, use the contours as a guide. The radius of the cylinder, **R**, will be half of that diameter. Calculate the radius in kilometers. Show all work and be mindful of units.

Using the contours near the top footprint they should find that the width of the loop is about 1 cm.
1 cm x 13.3 arc-sec/cm x 725 km/arc-sec = 9.6 x 10^3 km
R = ½ x 9.6 x 10^3 km = **4.8 x 10^3 km**

4. Now calculate the volume, **V**, of the cylinder in cubic kilometers. Show all work and be mindful of units.

$V = \pi R^2 l$ and $l = \pi/2 \times d$

$V = \pi R^2(\pi/2 \times d) = (\pi^2/2) \times R^2 d$

$V = (\pi^2/2) \times (4.8 \times 10^3\ km)^2 \times 2.5 \times 10^4\ km$ = **$2.8 \times 10^{12}\ km^3$**

5. Return to your equation for the magnetic field strength in part 1. We are hoping to estimate the strength of the magnetic field that produced the solar flare and CME from this equation. If you use the amount of energy that the NASA scientists found as the total energy released by the flare in **Worksheet 4.6** in this equation, then that will mean that all of the energy contained in the coronal loop would have been transformed from magnetic energy into heat, kinetic, and light energy. Since the loop still exists after the flare, clearly not all of the energy within it was used. So, using this method will actually calculate the minimum magnetic strength of the coronal loop. Set **E** equal to 2×10^{23} Joules and calculate **B** in units of Gauss. Show all work and be mindful of units. Note on units: 1 Gauss = 10^{-4} Tesla, and 1 Tesla = 1 kg/(Coulomb•seconds).

$B = [2\mu_0(E/V)]^{1/2}$

$V = 2.8 \times 10^{12}\ km^3 \times (10^3\ m/km)^3 = 2.8 \times 10^{18}\ m^3$

$E = 2 \times 10^{23}$ Joules $= 2 \times 10^{23}\ kg \cdot m^2/s^2$

$B = [2 \times 4\pi \times 10^{-7}\ kg \cdot m/Coulomb^2 \times 2 \times 10^{23}\ kg \cdot m^2/s^2 / (2.8 \times 10^{18}\ m^3)]^{1/2}$

B = 4.2×10^{-1} kg/(Coulomb•s) **=** 4.2×10^{-1} Tesla x 10^4 Gauss/Tesla

B = 4.2×10^3 Gauss

Assessment Rubric

With an additive rubric, students have to learn more content in greater depth to achieve higher levels. Teachers should introduce the rubric to students before the activities begin and encourage students to achieve to their highest potential. Teachers use the rubrics at the end of the unit to assess whether students have learned the science content.

	1	2	3 (Level 2+)	4 (Level 3+)	5 (Level 4+)
Science Content: Activity 3 Measuring the Speed of an Ejected Ball of Plasma	* Level 2 tasks attempted, but not completed or mastered	*Students are able to identify the RHESSI images as solar flares. *From the RHESSI images, Students are able to identify the coronal loop and the blob of plasma separating from it.	*Students, through successful completion of Worksheet 4.4, are able to predict the magnetic field lines of a solar flare.	*Students are able to identify the footprints of a coronal loop from Worksheet 4.5. *Students are able to identify the solar flares marked by an "X" from Worksheet 4.5. *Students are able to identify the circle marked on the images as the midpoint between the footprints from Worksheet 4.5. *Students are able to determine the location of the brightest spot in the coronal x-ray source and draw cross hairs through that spot using a ruler and determine the coordinates from Worksheet 4.5. *Students are able to determine the speed of the blob using at least 1 of 2 methods taught by the instructor. *Students complete Worksheet 4.5 with at least 80-94% accuracy.	*Students complete Worksheet 4.5 with at least 95% accuracy and above. *Students, through successfully completion of Worksheet 4.6, demonstrate that they can determine the kinetic energy of a blob that has that has been ejected by a solar flare. *Students fully demonstrate the ability to calculate the speed and kinetic energy of a blob that has been ejected by a solar flare.
Collaborative Worker	Participates but does not successfully complete one or more requirements of Level 2	Arrives on time with materials. Shows respect for others; cares for equipment and resources.	Stays focused on assigned task and helps others do the same. Shares work equally.	Facilitates the participation of all in the group. Tutors and/or supports other students.	Takes all group roles with equal skill. Assists others as they learn to do the same.

Activity 4 – Science Conference

Student Objectives

- Students will work collaboratively in creating an abstract containing the information they feel is important in their studies of the Sun, sunspots, and solar flares.
- Students will orally present what they have learned about solar flares and sunspots using their abstract and a poster board.

Materials Needed

- Colored construction paper
- Graph paper
- Glue
- Scissors
- Colored pens, pencils, markers, etc.
- Project boards
- Overhead transparencies
- Overhead projector
- Name tags

(optional)

- Computers with presentation software installed (such as Microsoft PowerPoint) as well as spreadsheet and graphing software (such as Microsoft Excel).
- Computer projector
- Color printers
- Poster printer

Getting Ready

Gather the materials needed and make copies of the information sheets to be handed out to students: **Guidelines for Science Conference Abstracts,** and **Guidelines for Science Conference Presentations.**

Procedure

1. Assemble students once more into their science teams. Explain that one of the professional activities of scientists is communicating their work to their colleagues across the nation and the world. One of the common ways that they do this is by attending science conferences and presenting their work usually through oral or poster presentations. Explain that the class will have a mock science conference where the topic of the conference will be the role of magnetic fields in solar flares.

2. The first step in preparing to present at a conference is to decide what aspect of your research to report on. Then decide whether to present a poster or to give a talk, and then submit a proposal abstract to the conference organizing committee (a.k.a. you). Have the students consider all the work they have done for this past three activities and decide which aspects they would like to report on. Hand out to them the **Science Conference Project Sheet** to help them organize their work. Tell students that they should work together in their teams in preparing their abstracts that they will submit to you for either talks or posters. Limit them to 250 words. Hand out to students the **Guidelines for Science Conference Abstracts** instructions. If you would like your students to see real examples of scientific abstracts, you can use NASA's Astrophysics

Data System Abstract Service (http://adsabs.harvard.edu/ads_abstracts.html) to search through thousands of abstracts in Astronomy, Physics, and Geology.

3. After you collect the abstracts, decide for yourself which ones will make for good talks and which should be posters, and then inform the students of your decision. This is often done by conference session organizers. If time allows, it is ideal if all groups develop both a poster and an oral presentation.

4. Have the students work in the science teams to prepare either talks or posters to present at the conference. Hand out to students the **Guidelines for Science Conference Presentations** instructions for students to follow when creating science posters or talks. For example, the talks should be about five minutes long, with three minutes left after for questions. Or the posters should be 4 feet wide by 3 feet tall, etc.

5. Conduct the science conference! Have the science teams elect who from their group will give the oral presentations. Perhaps they will decide to give the talk as a group (this in not usually done in practice). Encourage the students to listen carefully during the talks and to ask questions about the work being reported on. During the poster session, have students rotate who will stand by their own poster and present it, while the others from their team mingle through the poster displays. Students should again think of what interests or confuses them about the posters they see from their colleagues and should be encouraged to ask lots of questions of the presenters.

Guidelines For Science Conference Abstracts

When scientists organize a conference they advertise it to their fellow scientists and encourage them to submit their ideas for presentations. Scientists from all around will submit to the conference organizers an *abstract* of the presentation they are proposing to give at the conference. An abstract is a short summary of the work that will be reported on in the presentation. Abstracts are usually 150-250 words in length. An abstract should contain a brief introductory sentence or two that gives some background about the work being reported on. It should then summarize the work that was done and give the major findings from the work. The abstract should begin with a descriptive title for your proposed presentation. After the title, list the names of the authors involved in creating the proposed presentation along with information on their affiliations. The names are usually given as initials for first and (optionally) middle names followed by surnames.

The science conference organizers use the abstracts to select which scientists will get to present at the conference. Sometimes the organizers also chose what format the presentations will be in: oral or poster. Often the scientists chose for themselves which they would rather do. When all the decisions are made the abstracts are published in a program for the conference. Scientists attending the conference read the abstracts to decide which presentations they would like to attend.

Here are two examples of how an abstract for a science conference might look:

The Rate of Coffee Cooling is Fastest When it is Really Hot!
J.B. Smith, T. Elliot (our school, Idaho)

Without a source of heat, it is well known that coffee cools off after some time. We studied how fast coffee cools off as a function of how hot it is. With five different starting temperatures, we measured the temperature of the coffee as it cooled off until it was 2 degrees Fahrenheit above room temperature. The coffee was in a paper cup. The rate of cooling was fastest at the hottest starting temperature. We propose that this is a fundamental property of heat transfer and will discuss our data and future possible studies that can be done to test our idea of heat transfer.

The Slingshot Effect: Using the Sun's Gravity To Create A Time Vortex While at Warp Speed
F.O. Spock, M. Scott, J.T. Kirk (U.S.S Enterprise)

There are many ways to travel through time: using chronoton particles, stepping through the guardian of forever, using the orb of time, getting caught up in the Nexus, etc. One of the most simple, but not entirely accurate methods of time travel, is to use the gravitational well of the Sun to generate a time vortex while traveling at warp velocities in a parabolic orbit with a close perihelion approach. On three separate occasions the crew of the Starship Enterprise used this method to travel back in time to the 20th century. The first was entirely by accident, and the second two were intentional. Logical measures were taken to prevent interruptions in the timeline. The most recent time journey was for the purpose of gathering two humpback whales from San Francisco in the 1980s. The whales, George and Gracie, were successfully transported to the present where they have begun to repopulate the species. We will present the flight parameters and theoretical background for this fascinating method of time travel.

Guidelines For Science Conference Presentations

Presentations usually are in one of two forms at a scientific conference: Oral or Poster. Your conference organizer(s) will decide in what format your team will present your research.

Oral Presentations

Five minutes will be allowed for the normal oral presentation and three minutes for open discussion and a question and answer period. Your presentation should include visuals to help your audience follow your presentation. The visuals can be overhead slides, or a computer presentation using software such as Microsoft PowerPoint. When preparing your presentation, try to use a maximum of three slides or transparencies for a five-minute talk. Slides should be uncluttered and easy to read; only essential information should be presented on the slides. A good rule of thumb: if you cannot read your slide without magnification, the lettering is too small to be read by your audience. Clearly label and explain all graphs or images presented. Practice a few times so the presentation fits comfortably into the five-minute slot. Have members of your science team help you during the practice to get you used to answering questions about your work.

Posters

The poster format affords the author(s) far more time and flexibility in presenting information. Posters are ideal for those using charts, graphs or detailed visual aids. The poster area serves as the social center of the meeting. Also, to avoid too many oral sessions running simultaneously, the number of oral presentation time slots is limited.

- Your presentation should fit within an approximate 4' wide x 3' tall area.
- You may use individual sheets to construct the poster or one large sheet.
- When planning your poster, remember to use bold graphs, photographs, figures, and tables.
- Include a title and the names of authors in large type. Text should be large enough to be legible from a distance of 3 to 4 feet (about 20 point font or 0.3 inches tall).
- Keep the poster simple and easy to read.
- Sections in the poster should include: Abstract, Materials and Methods, Results, and Discussion/Conclusions.

Science Conference Project Sheet

Purpose: You will work with your science team in order to present the information you learned about the Sun, solar flares, and the magnetism of the Sun. Remember, you are a scientist who must report what you have discovered about the Sun to your colleagues in order to pass on your information and have others critique it for accuracy.

Checklist:

__ Review the rubric for the science conference. Know what is expected of you for this activity.
__ Review the expectations for your abstract.
__ Brainstorm with your science team about the information you want to include in your abstract.
__ Create your abstract and review for content, spelling, and grammar.
__ Submit your abstract to your teacher.
__ Once your teacher has decided what you will do, review the expectations for the poster and/or oral presentation.
__ Work with your science team in order to meet all the expectations for your presentation.

Assessment Rubrics

With an additive rubric, students have to learn more content in greater depth to achieve higher levels. Teachers should introduce the rubric to students before the activities begin and encourage students to achieve to their highest potential. Teachers use the rubrics at the end of the unit to assess whether students have learned the science content.

	1	2	3 (Level 2+)	4 (Level 3+)	5 (Level 4+)
Science Content: **Activity 4** **Science Conference**	* Level 2 tasks attempted, but not completed or mastered	*Students are able to decide what aspect of their research to report on. *Students are able to follow the guidelines for creating a science conference abstract and submit an abstract of at most 250 words.	*Students are able to follow the guidelines for the science conference presentations. *Students submit a poster that meets all the requirements outlined in the guidelines for the science conference presentations.	*Students are able to orally present their poster and information to the class. *Students demonstrate, through information on the poster and oral presentation, ***some understanding*** of the concepts surrounding magnetism in solar flares.	*Students demonstrate, through information on the poster and oral presentation, that they ***fully understand*** the concepts surrounding magnetism in solar flares.
Collaborative Worker	Participates but does not successfully complete one or more requirements of Level 2	Arrives on time with materials. Shows respect for others; cares for equipment and resources.	Stays focused on assigned task and helps others do the same. Shares work equally.	Facilitates the participation of all in the group. Tutors and/or supports other students.	Takes all group roles with equal skill. Assists others as they learn to do the same.

	1	2	3 (Level 2+)	4 (Level 3+)	5 (Level 4+)
Science Content: **Activity 4** **Poster Presentation**	* Level 2 tasks attempted, but not completed or mastered	*Students include all of the information outlined on the guidelines for their science conference poster presentation.	*Students include detailed text that describes the bold graphs, photographs, figures, and tables. *Information on the poster board is at least 80% accurate. *Students include some important information that demonstrates they ***know basic concepts*** learned in Session 4.	*Students include lots of color and detail on their poster. *Students organize the information on the poster board in a creative and logical manner. *Information on the poster board is at least 90% accurate. *Students include the majority of important information with enough detail to demonstrate they ***somewhat understand the concepts*** taught in Session 4.	*Students go above and beyond the expectations of the poster project and include vivid detail and text. *Information on the poster board is 100% accurate and encourages dialogue from those students evaluating the poster. *Students demonstrate that they ***fully understand all of the concepts*** of magnetism in solar flares.
Collaborative Worker	Participates but does not successfully complete one or more requirements of Level 2	Arrives on time with materials. Shows respect for others; cares for equipment and resources.	Stays focused on assigned task and helps others do the same. Shares work equally.	Facilitates the participation of all in the group. Tutors and/or supports other students.	Takes all group roles with equal skill. Assists others as they learn to do the same.

	1	2	3 (Level 2+)	4 (Level 3+)	5 (Level 4+)
Science Content: Activity 4 Oral Presentation	* Level 2 tasks attempted, but not completed or mastered	* Students include all of the information outlined on the guidelines in their science conference oral presentation.	*Students include bold visuals that support the information they are presenting to the class. *Students demonstrate that they have practiced their presentation and are ***fairly comfortable*** in the delivery of their presentation. *All students involved in the science group participate in the oral presentation. *Students include some important information that demonstrates they ***know basic concepts*** learned in Session 4.	*Students demonstrate that they have practiced their presentation and are ***very comfortable*** in the delivery of their presentation. *Students project their voices so that all audience members can here the oral presentation and make good eye contact with the audience. *Students are able to answer questions asked by the audience with at least 80-94% accuracy. *Students include the majority of important information with enough detail to demonstrate they ***somewhat understand the concepts*** taught in Session 4.	*Students demonstrate that they have practiced their presentation and ***are confident*** in the delivery of their presentation. *Students go above and beyond the expectations of the oral presentation and include vivid detail and oral description of concepts. *Students are able to answer questions asked by the audience with at least 95% accuracy and above. *Students demonstrate that they ***fully understand all of the concepts*** of magnetism in solar flares.
Collaborative Worker	Participates but does not successfully complete one or more requirements of Level 2	Arrives on time with materials. Shows respect for others; cares for equipment and resources.	Stays focused on assigned task and helps others do the same. Shares work equally.	Facilitates the participation of all in the group. Tutors and/or supports other students.	Takes all group roles with equal skill. Assists others as they learn to do the same.

Background Information
Solar Flare # 2041509

NASA's Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) was launched on February 5th, 2002. Its mission is to study solar flares. It is a space telescope that observes the highest energy forms of invisible light, X-rays and gamma rays. Images cannot be made in X-rays and gamma rays as easily as they are in visible light. For one thing, you can't use normal mirrors to focus X-rays and gamma rays into an image. X-rays and gamma rays pass right through mirrors. So the scientists and engineers that conceived and built RHESSI came up with a way to make images without mirrors. The images that are made are of emission of X-rays and sometimes gamma rays from the hottest places of a solar flare. Sometimes they look like nothing more than fuzzy blobs. So, scientists often use images from other satellites in space such as the SOHO or TRACE satellite to compare the images that they receive from RHESSI.

One of RHESSI's main goals is to understand how magnetic fields on the Sun accelerate plasma in the Corona and cause solar flares. On April 15th, 2002, RHESSI observed a solar flare, officially designated at solar flare # 2041509. This flare was special for RHESSI scientists because it clearly illustrated that one model they had predicted for the cause of solar flares was very accurate. Scientists saw a coronal loop erupt and eject a blob of matter out into interplanetary space. Observations from the SOHO spacecraft following the RHESSI observations showed a CME erupting from the Sun in the same region where the solar flare had occurred. There are movies from observations of SOHO and TRACE of this solar flare available on the *Exploring Magnetism* website (http://cse.ssl.berkeley.edu/ExploringMagnetism/SolarFlares).

On the following page are two figures that illustrate how the flare appeared in several different telescopes and wavelengths of light.

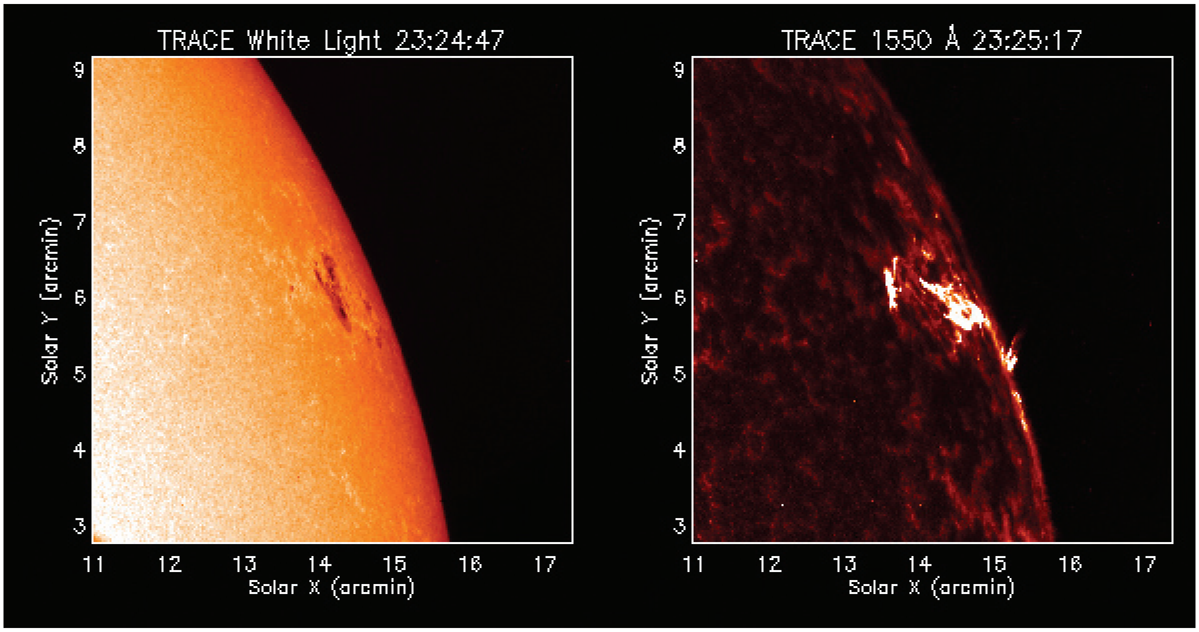


Figure BSF.1: These images of solar flare #2041509 were taken by the TRACE spacecraft. The image on the left is in visible light. The sunspot group containing the footprints of the solar flare are visible in the image. The image on the right is of the same region of the Sun seen in ultraviolet light (which is invisible to the human eye, but not to TRACE).

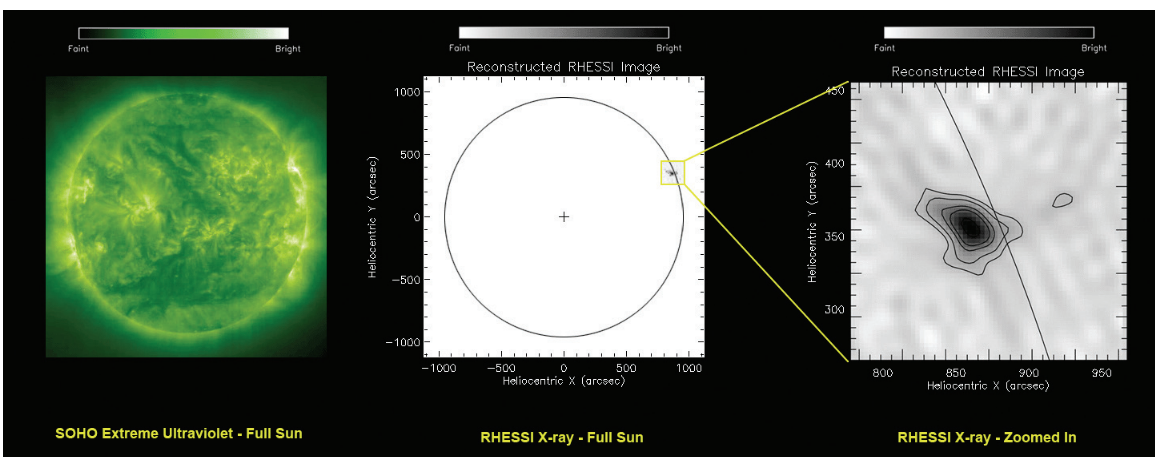


Figure BSF.2: The image on the far left is a view of the entire Sun seen in extreme ultraviolet light by the SOHO spacecraft. The solar flare occurred in the upper right portion of the Sun. A bright spot where the coronal loop is present can clearly be seen. The middle image is the view the RHESSI had of the Sun during the solar flare. The image on the right is a zoom-in of the solar flare as seen by RHESSI in X-ray light. This image is the same as those used in Activity 3.

Glossary[1]

Astronomical Unit: The average distance between the Earth and Sun, about 150 million kilometers.

Atmosphere: The mixture of gases that surround an object in space, such as a planet, moon or star, held near it by gravity.

Atom: A basic unit of matter. Every atom has a positively charged center called a nucleus that is surrounded by a number of negatively charged electrons.

Attract: To draw to or toward itself.

Aurora: (plural = **aurorae or auroras**) Light radiated by ions and atoms in Earth's upper atmosphere, in the region of Earth's poles. Aurora can be an extremely impressive spectacle. The *Aurora australis*, or "Southern Lights" occur near the South Pole while the *Aurora borealis*, or "Northern Lights" occur near the North Pole.

Cause: Something that produces an effect.

Chromosphere: The layer of the solar atmosphere that is located above the photosphere and beneath the corona. The chromosphere is hotter than the photosphere but not as hot as the corona.

Compass: A device that determines the presence of a magnetic field and its direction.

Convection: The organized flow of large groups of molecules based on their relative densities or temperatures. A hot fluid or gas will move upward, and a cooler liquid or gas will sink downward.

Convective Zone: The solar layer just below the photosphere, in which plasmas circulate between the Sun's radiative zone and the solar atmosphere, carrying energy outward.

Corona: The outer part of the Sun's "atmosphere." In the outer region of the corona, particles travel away from the Sun and stretch far out into space. The corona can only be seen during total solar eclipses, appearing as a halo around the moon.

Coronal Loop: A loop structure near the Sun's surface. Magnetic field lines emerging from the photosphere and returning to it in a region of opposite magnetic polarity organize the hot (one million degree Kelvin) plasma of the corona into these loop structures.

Coronal mass ejections (CMEs): Huge bursts of solar wind rising above the Sun's corona. These are one of the biggest explosions in the Solar System.

Density: The amount of mass or number of particles per unit volume. In c-g-s units mass density has units of $gm\ cm^{-3}$. Number density has units cm^{-3} (particles per cubic centimeter).

Dipole: Two electric charges or magnetic poles that have the same strength but are opposite in sign or polarity (North versus South) and are separated by a relatively small distance.

Earth: The third planet from the Sun on which we all live.

Eclipse: The blocking of some or all of the light from one object by another.

Effect: Something brought about by a cause; a result.

Electric charge: A physical state based on the amount and location of electrons and protons in matter. Matter with more electrons than protons is negatively charged. Matter that attracts free electrons is positively charged.

Electric circuit: A system that connects electrical components so that they will operate.

Electric current: A flow of electric charge.

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[1] This Glossary was adopted from the Helios glossary found at the URL: http://helios.gsfc.nasa.gov/glossary.html
Underlined words represent words that are defined in this Glossary.

Electromagnetic Field: The region in which electromagnetic radiation from a source exerts an influence on another object with or without there being contact between them.

Electromagnetic Radiation: Form of radiant energy that travels through space at 300,000 km/s and propagates by the interplay of oscillating electric and magnetic fields. This radiation has a wavelength and a frequency. (See also Light)

Electron: The negatively charged part of an atom and one of the smallest particles in the universe. It surrounds the atom's nucleus. Electrons are very light compared to protons and neutrons.

Element: A material consisting of atoms, all with the same atomic number. Approximately 90 different elements are known to exist in nature and several others have been created in nuclear reactions.

Experiment: A test under controlled conditions that is made to determine how something in nature works.

Gamma Ray: Extremely high-energy radiation observed during large, very energetic solar flares. Gamma rays are more energetic, and have shorter wavelengths than all other types of electromagnetic radiation.

Gas: A low number of atoms or molecules in a relatively large volume of space so that their interaction is small.

Geographic North Pole: The northern point on Earth where the axis, around which Earth rotates, intersects Earth's surface.

Granulation: Appearance on the Sun's photosphere of roughly circular regions on the Sun whose bright centers indicate hot gases rising to the surface, and whose dark edges indicate cooled gases that are descending towards the interior. Individual granules appear and disappear on time scales of about 5 minutes and are typically about 1000 km.

Gravity: A physical force that attracts objects to one another. This force is very weak and only objects made of a lot of matter will have enough gravity to affect other objects. For example Earth has enough atoms that its gravity holds us on this planet. But a teacher does not have enough atoms to attract a coffee mug with gravity.

H-alpha : Light emitted at a wavelength of 656.3 nanometers from an atomic transition in hydrogen. This wavelength is in the red portion of the visible spectrum and is emitted by plasma at about 10,000 K, mainly in the solar chromosphere.

Heat: The transfer of thermal energy between two systems of particles that are at different temperatures.

Hydrogen: The most common element in the universe. Each atom of hydrogen contains one proton and one electron.

Infrared: The infrared includes electromagnetic radiation at wavelengths just beyond the visible spectrum. Infrared wavelengths are longer than visible radiation and shorter than radio radiation.

Interplanetary: Between the planets in our solar system.

Instrument: An electrical and/or mechanical device that collects data as part of an experiment.

Ion: An atom that carries a positive or negative electric charge as a result of having lost or gained one or more electrons.

Iron: An element that has an un-paired electron making it able to align with a nearby magnetic field.

Kinetic Energy: The energy of motion, observable as the movement of an object, particle, or set of particles.

Light: Form of radiant energy transmitted at a velocity of about 300,000 km/s by wavelike or vibrational motions in electromagnetic fields. (See also Electromagnetic Radiation)

Luminosity: The amount of light energy output per unit time by an object.

Magnet, solenoid: A solenoid magnet is a coil of insulated wire, usually cylindrical in shape and with a length greater than its diameter. An electric current passing through the solenoid produces a magnetic field similar to that of a bar magnet.

Magnetic field: A region of space near a magnetized body or electrical current where magnetic forces can be detected.

Magnetic field lines: These lines are a way to show the structure of a magnetic field. A compass needle will always point along a field line. The lines are close together where the magnetic force is strong, and spread out where it is weak.

Magnetic Pole: A location in a magnetic field where lines of force all converge.

Magnetism (Electromagnetism): A physical property of an object that shows attraction for iron, as in a magnet. Electromagnetism acts between particles with an electric charge, such as electrons, protons, and ions. It is associated with moving electricity, and it creates fields of force.

Magnetometer: An instrument that measures the magnitude (strength) and/or direction of a magnetic field.

Magnetosphere: The region surrounding a planet where the planet's magnetic field dominates the motion of charged particles.

Meteorite: The remains of a meteoroid that plunges to the Earth's surface. A meteorite is a stony or metallic mass of matter that did not completely vaporize when it entered the Earth's atmosphere.

Meteoroid: A small, rocky object left over from the formation of the Solar System moving through interplanetary space. A meteoroid produces a meteor when it enters the Earth's atmosphere.

Molecule: Two or more atoms bound together. As an example, a molecule of water consists of two atoms of hydrogen and one of oxygen.

Neutron: An electrically neutral elementary particle. It is often part of the nucleus of an atom and is 1839 times heavier than an electron.

Nuclear Fusion: The joining of atomic nuclei under tremendous temperatures and pressures to create nuclei of heavier elements. In the Sun, four hydrogen nuclei are fused to create a single helium nucleus. Two of the hydrogen's protons become neutrons in the process.

Nucleus: (plural=nuclei) The small, massive center of an atom containing its protons and neutrons bound together by nuclear force, the strongest force known in nature.

Orbit: The path a body takes around another object or point in space under the influence of various physical forces, including gravity.

Photosphere: The lowest layer of the solar atmosphere, where the Sun's visible spectrum of light (electromagnetic radiation) is released. It is the visible "surface" we see in white-light images of the Sun.

Physics: The science dealing with matter and energy and their interaction.

Planet: A body that orbits a star such as the Sun.

Plasma: A gas of charged particles, such as electrons and ionized (charged) nuclei, often hydrogen nuclei (protons). This occurs when atoms of a gas are torn apart by high temperatures, pressures, and/or electromagnetic fields.

Potential Energy: The energy associated with a configuration of particles, as distinct from their motions. In macroscopic systems, potential energy can be increased (for example) by stretching a spring or by lifting a mass against a gravitational force; in microscopic systems, potential energy can be increased (for example) by stretching a molecular bond or by separating molecules against an electromagnetic attraction.

Pressure: Force applied over a surface.

Prominence: A structure in the corona consisting of cool plasma supported by magnetic fields. In visible light, prominences are bright structures when seen over the solar limb, but appear dark when seen against the bright solar disk. Prominences seen on the disk are also known as filaments. Prominences may become parts of CME's if they lift off of the Sun.

Proton: The positively charged part of an atom.

Radiative Zone: Layer just outside the Sun's core, where energy is transported mostly in the form of radiation. This region, while too cool for fusion to occur, is still very dense and hot- about 4 million degrees Kelvin.

Radio: A kind of electromagnetic radiation, like visible light, but with wavelengths far longer than the red or even the infrared portion of the spectrum.

Radioactive: A substance is said to be radioactive if the atomic nuclei it contains exhibit spontaneous disintegration or decay by emission of particles, and/or electromagnetic radiation.

Satellite: An object that revolves around a larger object. Planetary moons are natural satellites.

Satellite bus: The body of a man-made satellite that the control functions of the satellite and most of the scientific instruments.

Solar: Having to do with the Sun.

Solar Cycle: Regular increase and decrease of sunspots and other solar activity, such as solar flares and CMEs, which are thought to be physically related. Sunspots go through one cycle of activity in approximately 11 years. The Sun's magnetic polarity reverses between every cycle.

Solar Flare: A sudden eruption in the vicinity of a sunspot, lasting minutes to hours, caused by the release of large amounts of magnetic energy in small volume above the solar surface.

Solar wind: Plasma that come out of the Sun in all directions at very fast speeds.

Solar System: The Sun and its associated planets and their moons, and all other objects that are held by the Sun's gravity and orbit around it.

Space: The volume between all of the bodies in the Universe. It is not empty! It contains electromagnetic fields, electromagnetic radiation (i.e. light), gases, dust and other particles.

Star: A huge ball of gas held together by gravity. The central core of a star is extremely hot and produces energy via nuclear fusion. Some of this energy is released as visible light, which makes the star glow. Stars come in different sizes, colors, and temperatures. Our Sun, the center of our Solar System, is a yellow star of average temperature and size.

Sun: The star at the center of the Solar System. It is made mostly of hydrogen and helium with a very small amount of heavier elements.

Sunspot: A temporary concentration in the magnetic field on the Sun, where convection of hot matter from the Sun's interior is inhibited, resulting in a cooler, darker area on the photosphere of the Sun. The average sunspot is about the same diameter as Earth.

Temperature: A measure of the average kinetic energy of a system of particles.

Thermal Energy: The total kinetic energy due to disordered motions and vibrations of a system of microscopic particles such as molecules and atoms.

Ultraviolet: Electromagnetic radiation at shorter wavelengths and higher energies than the violet part of visible light.

Visible Light: Electromagnetic radiation (light) that is visible to the human eye. Visible light wavelengths are shorter than ultraviolet and longer than infrared.

X-ray: Electromagnetic radiation of very short wavelength, and very high energy. X-rays have shorter wavelengths than ultraviolet light, but longer wavelengths than gamma rays.

Resources

Online Vendors with Classroom Supplies

Arbor Scientific: http://www.arborsci.com/

Edmund Scientifics: http://www.scientificsonline.com/

Educational Innovations: http://www.teachersource.com/

Ward's Natural Scientific: http://wardsci.com/

Science Kit & Boreal Laboratories: http://www.sciencekit.com/

1 on 1 School Supplies: http://www.1on1schoolsupplies.com/index.html

Home Training Tools: http://www.hometrainingtools.com/index.php

The PhysLink eStore: http://www.physlink.com/estore/

Cow Magnets can be purchased cheapest from pet/farm supply stores: E.g. http://www.petvetsupply.com , http://www.valleyvet.com , http://www.americanlivestock.com
Slaughter houses may also give away recovered magnets.

Related Curriculum Materials

Electric Circuits, National Science Resources Center, Carolina Biological Supply Company, Burlington, NC.

Electric Circuits: Inventive Physical Science Activities, Great Explorations in Math and Science (GEMS), Lawrence Hall of Science, University of California at Berkeley, CA, 2004, grades 3-6.

Magnets and Motors, National Science Resources Center, Carolina Biological Supply Company, Burlington, NC, 2002.

Websites

http://cse.ssl.berkeley.edu/hessi_epo/ : The education and public outreach website for the RHESSI mission.

http://www.eia.doe.gov/kids/energyfacts/science/formsofenergy.html : Energy Kid's Page from U.S. Department Of Energy

http://www.nasa.gov : NASA's web page with links to information on NASA missions and educational materials.

http://www-spof.gsfc.nasa.gov/Education/Intro.html : Overview of space physics with good links to other educational web sites.

http://www.agu.org/sci_soc/cowley.html : A guide to Earth's Magnetosphere.

http://www.windows.ucar.edu/tour/link=/teacher_resources/magnetometer_edu.html&edu=high : K-12 lesson to make a magnetometer

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