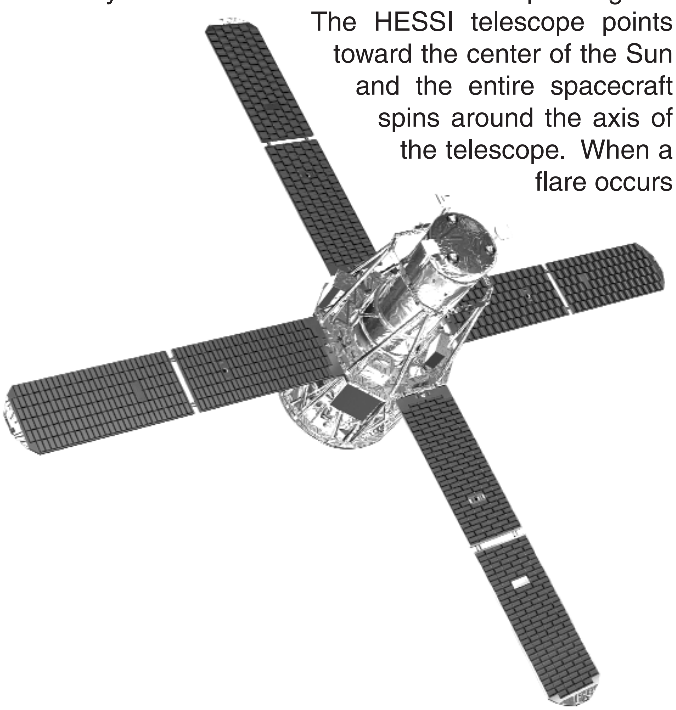
How Does HESSI Take a Picture?

Optical telescopes and cameras take a picture by using lenses or mirrors to focus an image onto photographic film, or onto an electronic device called a CCD (Charge-Coupled Device). Photographic film consists of a layer of fine grains of chemicals that respond to light. These grains are finer than the unaided human eye can see, so a developed photograph looks smooth, not grainy. A CCD consists of millions of tiny detectors that convert light into electrical signals. When the detectors are tiny enough and the CCD contains a large enough number of these detectors, the image from the CCD also looks smooth.

The High Energy Solar Spectroscopic Imager (HESSI) observes X rays and gamma rays, not visible light, from solar flares. This type of high-energy radiation cannot be focused with a lens or a mirror. So another approach is needed for HESSI to take pictures of solar flares. The HESSI telescope contains pairs of metal grids. These grids, similar to a picket fence, are made up of metal slats with open slits between them. The widths of the slats and slits are different for each of the nine pairs of grids.

Unlike the large number of detectors in the CCD, HESSI has only nine detectors – one behind each pair of grids. The HESSI telescope points toward the center of the Sun and the entire spacecraft spins around the axis of the telescope. When a flare occurs on the Sun, the radiation reaching the nine detectors increases and decreases as the slats and slits of the grids alternately block and allow passage of the radiation from the flare as the spacecraft rotates. The time variations of the signals from each of the nine detectors are used to produce a picture of the flare. HESSI can produce a full image about once every two seconds. Viewing these images in sequence provides a movie of the flare.



The following three activities demonstrate how HESSI's grids can provide the location and size of a flare on the Sun. These activities are primarily qualitative in nature; they emphasize the important concepts rather than numerical details. Consequently, they are appropriate for middle school students. These three activities address the following **National Science Education Standards:**

- Science as Inquiry – Content Standard A
  As a result of these activities, all students should develop:
  1. Abilities necessary to do scientific inquiry
  2. Understandings about scientific inquiry
- Earth and Space Science – Content Standard D:
  As a result of these activities, all students should develop an understanding of Earth in the solar system
- Science and Technology – Content Standard E:
  As a result of activities students should develop:
  1. Abilities of technological design
  2. Understandings about science and technology

The **materials** needed for these activities are

- Transparency of Figure 1 (the three grids)
- Paper copy of Figure 2 ("Flares" in three different locations on the Sun)
- Pin or Tack
- A surface into which the pin or tack can be inserted, such as a piece of cardboard or wood
- For Activity 3, a metric ruler with millimeter markings

More information about HESSI's imaging technique can be found at

http://hesperia.gsfc.nasa.gov/hessi/challenge.htm

Activity 1: Distance from the Center of the Sun's Disk

This activity demonstrates how scientists can use the signal from a detector behind a pair of rotating grids to determine the distance of a flare from the center of the Sun's disk. HESSI requires a pair of identical grids in front of each detector because it observes the Sun from a distance. For this activity a grid can be placed directly on the image of the Sun, so only one grid is required.

Figure 2 shows three circles, each representing an image of the solar disk. Within each circle is a dot, indicating the location of a flare. Each of the three flares is located at a different distance from the center of the disk. Flare A is located at the edge of the disk (solar astronomers call this the *solar limb*). Flare C is closest to the center. The labels "N" and "S" mark the north and south poles of the Sun.

This exercise uses a transparency of the center grid, labeled "5.2-mm slats". The three grids in Figure 1 can be copied onto a single transparency. You may find it convenient to cut out the three grid images, but it is not necessary to do so. Line up the small circle at the center of the grid image with the small circle at the center of the solar disk image labeled "FLARE A". Place these on a surface into which you can stick a pin or tack (such as a piece of cardboard or wood). Securely insert a pin or tack into the surface through the small circles in the two sheets. Make sure you can rotate the grid transparency around the pin with the solar disk image remaining stationary. The dot representing the flare will alternately appear in the transparent slits and disappear behind the black slats as you rotate the grid.

Carefully make one complete rotation of the grid, counting the number of times the "flare" becomes visible in a slit. If the dot is only partly visible at the edge of a slat, count it. Record your count in the second column of the table below in the row for Flare A.

After you have checked and recorded your visibility count for "Flare A", remove the pin and move the "5.2-mm slats" grid to the image labeled "Flare B". Repeat the above procedure and record your count in the third row of the seond column of the table. Repeat again for "Flare C" and record your count in the last row.

Which "flare" gave the highest count? Which gave the smallest?

What is the relationship between the count and the distance of the flare from the center of the Sun?

What would your count be if the flare were located at the center of the Sun?

How do your counts differ when you used the "9-mm slats" grid or the "3-mm slats" grid instead of the "5.2-mm slats" grid? Record your results in the table below.

What would happen if HESSI were not pointing at the center of the Sun? Move the center of the 5.2 mm grid to a position that is not located at the center of the solar disk. Insert the pin at this location and repeat your counts. How do they differ from your previous counts? Why? **How important is it to know where HESSI is pointing?**

Just as the "flares" appeared and disappeared as you rotated the grid, each of HESSI's detectors produces a signal that rises and falls as the grid pairs rotate on the spinning spacecraft. The spacecraft is outfitted with sensors that detect the edge of the visible disk of the Sun, the so-called solar limb. This gives the solar scientists back on the ground all the information they need to find out where the flare is occurring and ultimately, to make a picture of it using the X rays and gamma rays that it produces.

Flare	Count 5.2-mm	Count 9-mm	Count 3-mm
A			
B			
C			

Activity 2: Angular Position on the Sun's Disk

Activity 1 demonstrated how scientists can use HESSI's rotating grids to determine the distance of a flare from the center of the Sun's disk. The position of the flare on the Sun is not completely determined, however, until we know its *angular* position as well.

Look at the image of Flare A on the solar disk. Imagine a clock dial on the disk, with 12 o'clock located at "N" and 6 o'clock located at "S". You can see that Flare A is located near 2 o'clock. Flare B is located near 10 o'clock. What is the location of Flare C on this imaginary clock?

The angular position of a flare is usually measured in degrees rather than hours. Remember that the angular distance all the way around a circle is 360 degrees so that one hour corresponds to 15 degrees. Taking "N" to be at 0 degrees, "S" is located at 180 degrees. Flare A is located at approximately 70 degrees. **What are the approximate angular positions of Flares B and C?**

Center the grid labeled as "5.2-mm slats" on the Flare B image and reinsert your pin or tack. Rotate the grid several times, noticing the relative range of angles over which the flare remains visible or invisible as you rotate the grid. Notice that as you uniformly rotate the grid around a full rotation of 360 degrees the flare does not become visible and invisible with a constant period. There are times (and, therefore, ranges of angles) for which the flare remains visible or invisible longer than at other times. **How do these times relate to the angular position of the flare? How can this variation with time and, equivalently, angle of rotation be used to determine the angular position of a flare on the Sun? How important is it to know HESSI's angle of rotation (that is, the orientation of HESSI's grids at all times as it spins)?**

If the center of rotation of the grid were located at the center of a slit or a slat, would the angular position of the flare be uniquely determined? Why?

HESSI is outfitted with an instrument that looks at right angles to the Sun. This instrument detects bright stars in the sky as it spins around with the spacecraft. By knowing when these bright stars were detected, solar scientists back on the ground can determine HESSI's angle of rotation all the time.

Activity 3: Flare Size

The modulation of a flare by the rotating grids is different if the flare is extended – that is, if the flare is not a really small source as in the previous activities.

Use a compass to draw a circle around Flare B that has a diameter of 7 mm (about the size a hole punch makes). Fill in the circle with a crayon, using a color of your choice. If you don't have a compass, the 7-mm diameter circle shown here can be traced or pasted onto Figure 2.

Center the grid labeled as "9-mm slats" on the Flare B image and, as in Activity 1, attach it with a pin or tack. Rotate the grid, watching the 7 mm diameter "flare" as the grid rotates. **Is the flare completely hidden at times and completely visible at other times?** Now repeat with the "5.2-mm slats" grid and the "3-mm slats" grid. **Is the flare completely hidden or completely visible at times as you rotate these grids? If you did not already know the diameter of the flare, how would you use the response of the rotating grids to estimate the size of the flare?**

The apparent size of a distant object depends on its distance from the observer. The further away the object is, the smaller it appears. We know that a feature on the Sun that has a size of one-hundredth the diameter of the Sun is about 14,000 km across (slightly larger than the diameter of the Earth). The widths of the slits and slats for HESSI's nine pairs of grids were chosen to correspond to the range of flare sizes that we expect to see on the Sun. HESSI images features ranging from about one-thousandth to one-tenth the Sun's diameter. Scientists use computers back on the Earth to deduce the size of a flare from the response of all nine of HESSI's rotating grid pairs and detectors. In fact, with all of the information from the nine detectors and the optical sensors, they can actually make pictures of the flare using X rays and gamma rays that it produces.

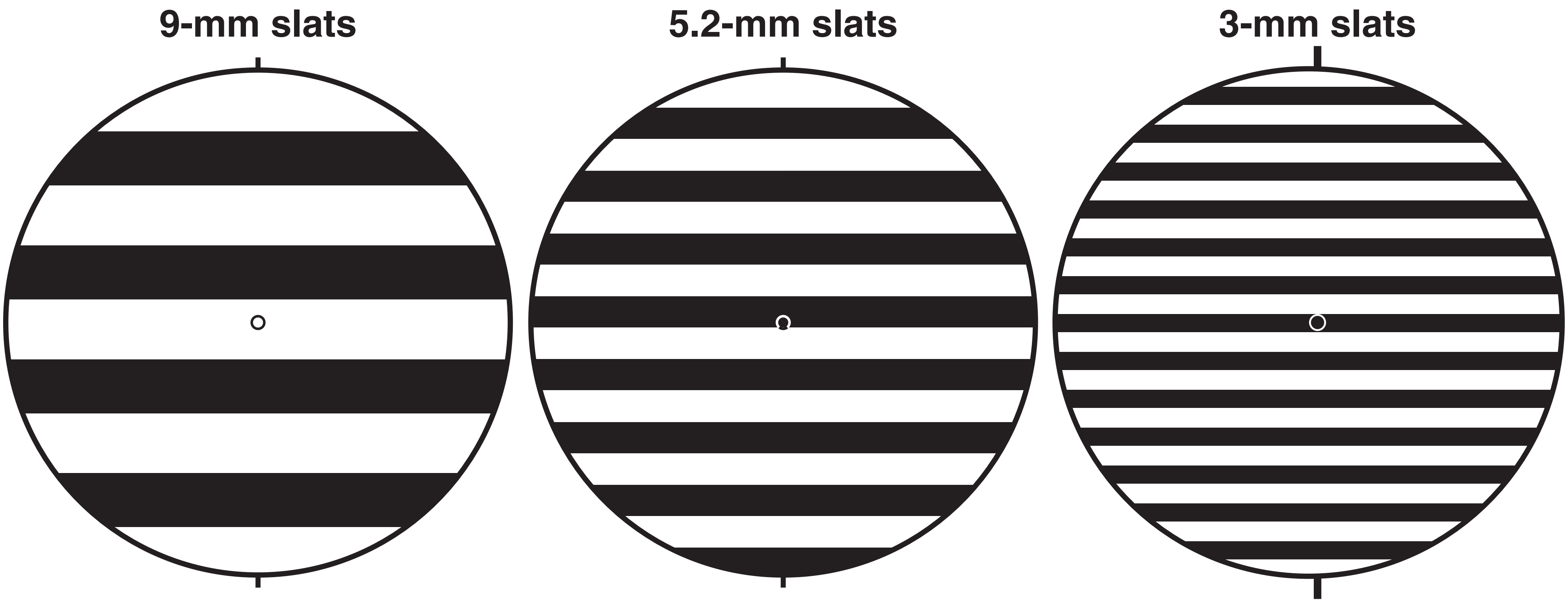
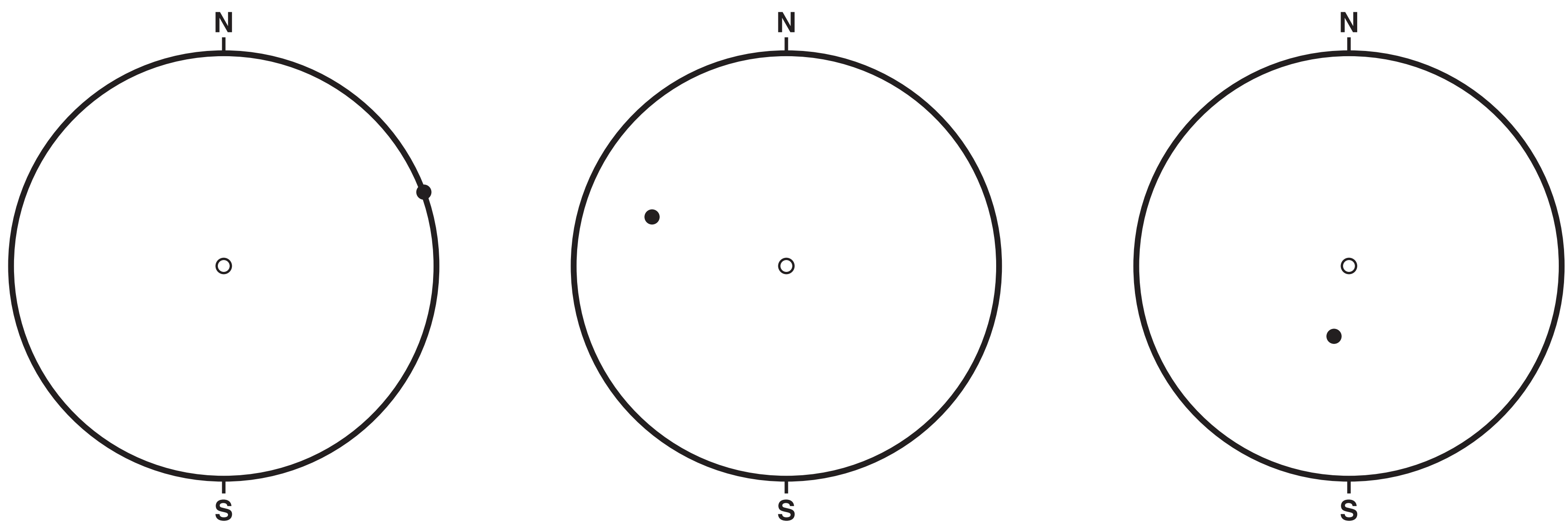


Figure 1



Flare A **Flare B** **Flare C**

Figure 2