Background Material: Research Activity

Please be sure to read all the lesson pages, as they provide background for the research activity. Open the folder SUNSPOTS to start the lesson, and use the navigation links at upper right to access all sections.

Activity
Read these lesson pages by selecting the "ACTIVITY" tab near the upper right corner of the screen.

Scientists compare images taken in different wavelengths of light and try to find relationships between the images. They look for correlations that may point to physical relationships and processes that were previously unknown. Visible light images of the Sun show sunspots on the photosphere, while x-ray images show us x-ray active regions in the corona.

Scientists would like to know more about whether and how the x-ray active regions are connected to sunspots. Finding a correlation between their respective areas on the solar disk would be evidence suggesting a physical connection; for example, possibly the x-rays are emitted by coronal plasma interacting with the magnetic field loops that terminate in the sunspots. However, this may be difficult to investigate, even with the latest data. Imagine trying to establish a correlation between the size of a flame and the size of a burning match tip on a rotating sphere, especially if conditions like the air around the flame are not constant. In this analogy, the flame is like the x-ray active areas; the match tip corresponds to the sunspots seen in visible light images.

In our interviews on this project, solar scientist George Fisher suggested the idea of trying to measure and quantify the relationship between sunspots and x-ray activity. It is commonly assumed among scientists that the hot active regions in coronal images and visible sunspots are somehow two views of the same structure, but Fisher believes no one has yet established the connection with a formal investigation. If the correlation were well established, and especially if it could be well quantified, this would be a very useful tool for inferring levels of x-ray activity from older, visible light images. The Yohkoh satellite produces daily images in both visible and x-ray light which can be compared over a number of days to address this question, so a Java "applet" program was written to measure the areas and plot the data. (The term applet is a diminutive form of "application."

The QuickTime movies in the first page (click the "Activity" tab) show the Sun over a period of about 2 months, as a series of images in soft (relatively low-energy) x-rays on the left, and in visible light on the right. The Sun makes a complete rotation about every 28 days. You may notice that the x-ray areas seem to change rapidly in brightness. This may be partly due to a "beacon" effect, dependent on whether the hot region, which may be at some altitude above the solar surface, is rotated toward the satellite's telescope. The interview with George Fisher presents the correlation problem in terms of several quantities, which he thinks are likely to be correlated, and possibly proportional: sunspot area, magnetic flux, and x-ray energy emitted.

NOTE: the same movie sequences appear in the RealMedia interview clip.

The Java applet program is launched from the second page, activity2.html. Activity2 also serves as a self-contained "quick-start" guide for using the applet. Three more pages of supporting material, can be accessed from links in the sidebars of pages 2 and 3. These pages are also displayed sequentially if one continues to use the "next" arrows at the top and bottom of each page. These links are shown, and the page contents summarized briefly in the table below.
Page 3 gives a detailed account of how to operate the applet. This is important for students who are less experienced computer users, or otherwise have a hard time starting.

Page 4 describes how the data are gathered using the Soft X-ray Telescope (SXT) aboard the Yohkoh satellite and how the images are created. Supplementary material.

Page 5 gives detailed descriptions of what the features in the x-ray images represent. This information is important for standardizing the measurements from one student or group to another, and for understanding what areas seem most likely to be related to sunspots.

Students should be urged to use these pages, as the information will help them make better decisions about their experimental procedure in measuring the images. Having the applet in a separate window allows students to keep navigating through the pages of supporting material as they work.

**The Java applet program** is a tool for comparing sunspot and x-ray active areas using the image pixels as your unit of measurement. Each pixel represents an area roughly the size of the earth superimposed on the Sun. Here are some tips that may be helpful:

- Practice using the applet yourself before guiding students.
- The applet loads in a separate window and may require patience with some older machines.
- The applet has data loaded as pairs of daily images in a single list. Both the visible and an x-ray image for each date must be measured to plot a point.
- Students will paint over sunspots and active x-ray regions to measure sunspot or x-ray active area. This may require "erasing" as well as painting, and using various brush sizes. Pixels will be quite small on screens with a resolution greater than 800 x 600 pixels.
- The number that appears in the display is the number of pixels painted. Students should also keep their own records of area measurements.
- Any time an image is reloaded, its previous measurement is erased. This is fine while perfecting measuring technique, but if students want to review which areas they painted in a previous image, they should take care not to lose the data.
- After reloading an image, data can be restored to the values table by referring to written records and repainting the same number of pixels in the image.
- View measured values by clicking the "values" button. This is the best way to see quickly which measurements have been done.
- The program plots x-ray areas on the vertical and sunspot areas on the horizontal axis. Examine the plot to see whether the data points suggest a line or simple curve. An obvious graphical relation is a signature of correlation, which would suggest the two quantities are physically connected.
- Ruled and labeled graph sheets are provided for hand plotting the points if this is desired: "X-ray vs. Sunspot Area"
The x-ray images used come from the Yohkoh satellite's Soft X-ray Telescope (SXT). Visible (white) light images are from a camera, also on Yohkoh. All images are from a solar maximum (January, 1992), and so are similar to what the Sun may look like as we approach a new maximum in the year 2000. Current daily images are available at:

http://solar.physics.montana.edu/YPOP/ProjectionRoom/latest.html (goes to Yohkoh/YPOP)

Not all features in the X-ray images are "active regions" for our purposes. Like the shades of gray in a medical x-ray film, the colors in the x-ray images represent varying levels of non-visible x-ray emissions. Large spots in white-to-bright-yellow that are completely within the disk are active regions. They can be much larger than the visible sunspots. Tiny bright spots of 1 or 2 pixels are not showing the same kind of activity as the larger regions, and shouldn't be counted. Areas extending outside the disk shouldn't be counted, because they would be connected to sunspots that have rotated to the edge of the visible disk, and don't show in visible images. Students may want to study the QuickTime movie on page activity5.html to get a better idea of the dynamic changes of the x-ray active areas from day to day.

Examples of values and a plot generated by a teacher using the Java applet are shown below. The plot indicates a roughly linear correlation. Each point in the plot shows white light area vs. areas of intense x-ray activity. Although the scatter of the points looks bi- or even tri-modal (3 different slopes), the plot has a consistent average slope, with about the same number of points falling above and below a central line. Since the scale of the x-ray axis is an order of magnitude (x10) greater than the sunspot axis, the degree of vertical scatter is not too surprising. The sample and graph also appear in pages activity 2 and activity 3. These are meant as a rough guide only. Students should not be saddled with the idea that their data should look just like the sample; every researcher's measurements will be a little different.

Linear Correlation is the simplest case of correlation. This seems to be the case in our example plot, where the points with \( x = \) sunspot area and \( y = \) x-ray area seem to cluster about a line with a definite slope. The relationship between the two quantities can be expressed in an algebraic expression, like the linear equation \( y = mx + b \), where \( b = y \) intercept (value of \( y \) at \( x = 0 \)). If
**y intercept** $b = 0$  
the slope $m = y/x$

<table>
<thead>
<tr>
<th>$y$ intercept $b &gt; 0$</th>
<th>the slope $m = (y - b)/x$ may be positive or negative</th>
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<tbody>
<tr>
<td>$y$ intercept $b &lt; 0$</td>
<td>the slope $m = (y - b)/x$ must be positive.*</td>
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*However, this implies some negative values of $y$ correspond to positive values of $x$, a non-physical situation, since area cannot be negative. Some unknown quantity, such as a systematic error, is probably not taken into account.

In a linear relation with $b = 0$, the best measurement of the slope $m$ is the average factor by which the x-ray area is proportional to the sunspot area for all the points measured: $1/n \sum_{i=1}^{n} \frac{y_i}{x_i}$. Note also that the slope is then without units, as it should be, since both $x$ and $y$ are in units of pixels and these cancel out when divided. You may wish to have students perform a least squares fit to a straight line, if calculators or a computer program are available.

Note also that time does not appear as one of the variables in the correlation plot. These relationships do not depend on the passage of time; it is assumed that if the (sunspots vs. x-ray active area) correlation exists, it is time invariant. The absence of a time axis may also disorient students who have not done much graphing. If your students need to approach the goal of the research activity more slowly, start with plotting the areas measured on the images against time.

Plotting sheets are included for graphing the white light and x-ray areas against time: "X-ray Active Area vs. Date" and "Sunspot Area vs. Date," on pages 29 and 31. Horizontal time axes span the month of January 1992, and vertical axes have appropriate scales for the two types of images. The time graphs will have some shape, not necessarily linear or smoothly curved-- they may have sudden jumps as spots and x-ray areas appear and disappear because of the Sun's rotation, or as active areas become brighter and dimmer. Both the evolution of the sunspots or active regions and the rotation of the Sun (once per 28 days) affects each day's data. For sunspots, the effect of rotation will likely dominate, as the sunspots evolve on a time-scale of several weeks or months. X-ray regions may vary on much shorter time scales.

Compare the two time graphs: if the two graphs show a similar overall shape, comparing them may help students discover the correlation themselves. The more the shapes are alike, the closer the correlation graph would be to a straight line. Remember that the vertical scales of the two time graphs are different, so that a similarity indicates the x-ray and sunspot areas are proportional, not identical. Encourage students to make guesses about what the x-ray vs. sunspot graph would look like.

The applet program does not "do science" by itself. Students must learn how to use the program correctly. A great deal of the benefit of this activity lies in the use of critical thinking required to interpret the images and the resulting graphs, with some accounting for sources of error. Team and class presentations, or discussions, using questions like those suggested in the lesson plan, are useful in completing the lesson.

- Each student or team should know which images they are measuring and why.
- They should use good scientific practices like setting and following consistent standards in making measurements.
- They should keep their own data records in a notebook, or on the "datalog" sheets provided; each time an image is loaded, any previous measurement is erased.
- They should learn to troubleshoot their own processes, for example: checking that the number of points on the plot reflects the number of pairs of images measured.
• The program plots a point for each PAIR of images measured, IF both the measurements are within the limits to the plot area.

• Finally, if enough measurements have been done, it may be fruitful to try averaging several teams' work together, to see whether the form of the correlation graph is less scattered.