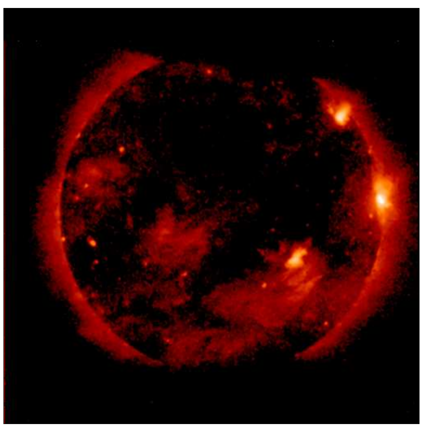
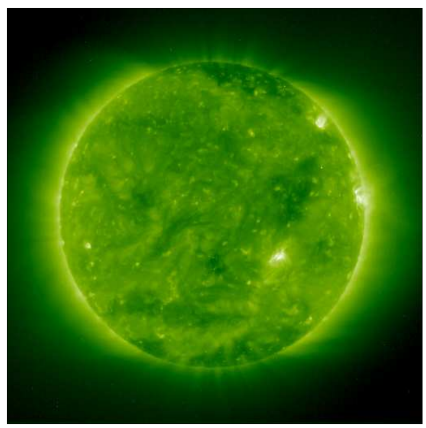
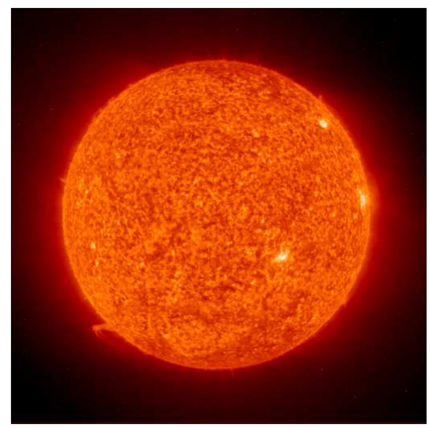
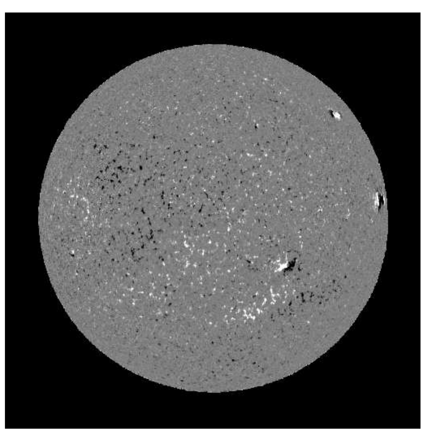
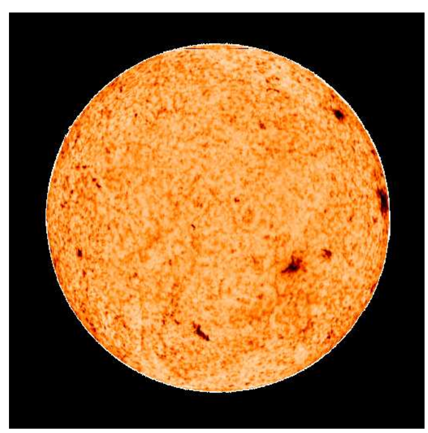
How Astronomers Use Spectra to Learn About the Sun and Other Stars

by Dr. Jeffrey W. Brosius

About the Cover: The cover shows five different pictures of the same star: our Sun. Because your eyes cannot see the kinds of light that were used to take four of them, the pictures are all shown in false color. The figure in the upper left is an X-ray picture. It was taken with the Soft X-ray Telescope (known as "SXT") aboard the Japanese *Yohkoh* satellite. The figures in the upper middle and upper right are ultraviolet pictures, and they show what the Sun looked like at two different ultraviolet wavelengths. They were taken with the Extreme-ultraviolet Imaging Telescope ("EIT") aboard the Solar and Heliospheric Observatory ("SOHO") spacecraft. This spacecraft was built as a joint effort between the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). The figure in the lower left shows the Sun's magnetic field. This image was derived from visible light observed at the U.S. National Solar Observatory at Kitt Peak, Arizona. The figure in the lower right shows an infrared picture of the Sun. It too was taken at Kitt Peak. Can you find any differences among all the pictures? Your eyes cannot see X-ray light, ultraviolet light, or infrared light, but astronomers must observe all of the different kinds of light that come from the Sun to understand how the Sun works, and how the Sun affects the Earth. Pictures like the ones on the cover provide clues to help solve some of the Sun's mysteries. However, other information, such as that from *spectra*, is also needed. This booklet describes how astronomers use spectra to learn about the Sun and other stars. You can find lots of information about SOHO and other NASA space missions by visiting the Goddard Space Flight Center homepage on the World Wide Web at "http://www.nasa.gov/goddard", or by visiting the SOHO homepage at "http://sohowww.nascom.nasa.gov/". A copy of this booklet, along with interactive activities and facts about the Sun and sounding rockets, can be found on the SERTS homepage at "http://serts.gsfc.nasa.gov/".

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1 How do astronomers get information about the Sun and other stars?

Astronomers unravel mysteries about objects out in space, far from Earth: the Sun; the Moon; planets; comets and asteroids; normal stars, stars being born, dying stars, exploding stars; black holes; galaxies of stars; and strange, hyperactive galaxies from the dawn of time. Astronomers have learned a lot about these objects, and every day discover new, exciting things. How do they do it? How do astronomers learn so much about objects that are either so far away or so dangerous to visit that they have never been explored directly by people or by man-made spacecraft?

The Moon is close enough that astronauts have gone there safely and returned to Earth with samples of rocks and soil. This means that pieces of the Moon can be touched and studied close-up. The planets in our solar system are much farther away than the Moon, and none of them has yet been visited by astronauts; however, all of the planets except Pluto have been landed on, or orbited, or flown near, by spacecraft built on Earth. This means that scientists have been able to get a fairly close look at the planets; in some cases, they use robots to study samples of soil, rocks, and atmosphere. Even Halley's Comet, a periodic guest from the outer reaches of the solar system, was approached closely by several spacecraft during its last visit. Perhaps astronauts will visit Mars in the 21st century.

The Sun, however, is so hot that nothing can get very close to it without burning up. This is what happens to "Sun-grazing" comets, which disappear in the intense heat when they approach the Sun too closely. The question, then, is this: If astronomers can neither touch the Sun themselves nor send spacecraft there to touch it for them, how can they learn anything about the Sun? A related question is: How do astronomers discover secrets about other stars and other objects in space that are so far away that no spacecraft from Earth has ever been there?

2 Messengers from the Sun and other stars.

To get information about objects out in space far away from Earth, astronomers need something from those objects that carries information to the Earth. What is that something? What do things out in space send to Earth to tell us about themselves?

To answer these questions, think about how you know that the Sun, stars, and other objects in space exist. Imagine yourself looking toward the Sun on a clear day; your eyes see so much sunlight that they can actually hurt. (Never look directly at the Sun. The light is so bright that it can permanently damage your eyes.) Now imagine yourself looking up on a clear night far from city lights; your eyes see starlight from thousands of twinkling stars. How do you know that the Sun and stars are there? The answer, of course, is by the light that they send us!

Light carries a lot of information. It tells us not only that various objects exist and how bright they are, but also what they are made of (their composition), how hot they are, how dense they are, how they are moving, and how strong magnetic fields they have. With proper tools, astronomers can dig information like buried treasure out of light that they receive. Several of these tools will be described below, and the reader can use some of them to dig information out of real observations of the Sun obtained with NASA experiments.

3 The electromagnetic spectrum: a collection of waves with different wavelengths.

Light can be described as waves that travel through space, like the ripples that travel across a pond after a stone has been dropped into the water. For both light and pond ripples, the *wavelength* of the waves is the distance between wave peaks. (See Figure 1.) The light that your eyes can see is known as *visible light*. Different wavelengths of visible light are seen as different colors by your eyes. From longer to shorter wavelength, the various colors that your eyes can see are: red, orange, yellow, green, blue, and violet. Ordinary white light is a mix of all colors, or, in other words, a mix of light at all visible wavelengths. When a rainbow appears in the sky after a storm, you see ordinary white sunlight that has been separated into its individual colors by tiny droplets of water in the air. Next time you see a rainbow, notice that the colors appear in the order listed above.

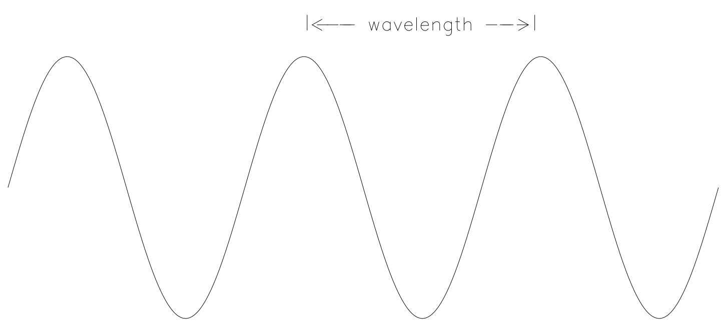

Figure 1: *Wavelength* is the distance between wave peaks.

But the Sun and stars send us more than just visible light: they send invisible light as well. Invisible light has either longer wavelengths (like infrared [pronounced in-fra-red], microwave, and radio waves) or shorter wavelengths (like ultraviolet, X-ray, and gamma ray) than the visible light that we can see with our eyes. The technical term for all these forms of light is *electromagnetic radiation*. When placed side by side in order of increasing or decreasing wavelength, the different forms of light make up the *electromagnetic spectrum*. A rainbow, which is a *visible light spectrum*, is just one small part of the whole electromagnetic spectrum. (See Figure 2.) Arranged in order of increasing wavelength, the electromagnetic spectrum consists of gamma ray, X-ray, ultraviolet, visible, infrared, microwave, and radio waves. To gather as much as possible of the information sent out by the Sun and stars, astronomers need to collect light from many different wavelengths over a wide range of the electromagnetic spectrum. Earth's atmosphere, however, causes big problems with this.

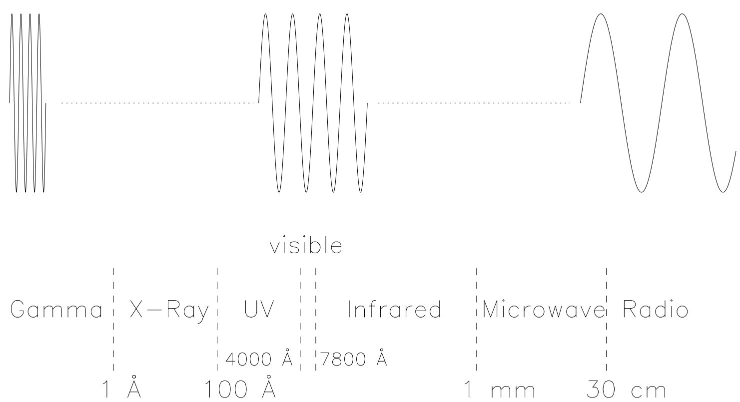

Figure 2: The *electromagnetic spectrum* contains light waves of all different wavelengths. The symbol "Å" means "Angstrom", a unit of length often used to describe wavelengths of light. One Angstrom is one ten-billionth, or 10^{-10}, of a meter. Notice that the fraction of the electromagnetic spectrum that is visible to the human eye is fairly small.

Earth's atmosphere absorbs most of the invisible light from the Sun and stars over much of the electromagnetic spectrum. This is good for life on Earth, since exposure to too much ultraviolet, X-ray, and gamma ray radiation would be harmful. However, this is bad for astronomers since information carried by light at these wavelengths cannot reach the ground. So astronomers send special telescopes above Earth's protective atmosphere to observe the Sun and stars at wavelengths that are absorbed by air. Depending on the wavelength range that astronomers wish to study and the length of time needed to study it, these special telescopes can be carried into the highest parts of the atmosphere by balloons, or sent above the atmosphere for a short period of time (less than 10 minutes) by small rockets known as "sounding rockets," or launched into orbit around Earth by large rockets. No single telescope can detect radiation over the entire electromagnetic spectrum: different equipment must be designed and built for different wavelength ranges.

4 Some tools for digging information out of solar and stellar spectra.

When light from the Sun or stars is displayed according to wavelength, the result is said to be a *spectrum*. More than one spectrum are called *spectra* (not spectrums). Astronomers get a lot of information about the Sun and stars from solar (which means "of the Sun") and stellar (which means "of the stars") spectra.

Like everything on Earth, the Sun, stars, and other objects out in space are made of atoms. An atom is the smallest unit that can be identified as any particular element (like hydrogen, helium, carbon, nitrogen, oxygen, iron, and so on). Since there are about 100 different elements, there are also about 100 different kinds of atoms.

The center of an atom is its nucleus, which is a tightly packed collection of protons and neutrons. Electrons surround the nucleus. An atom is neutral if it has as many electrons outside the nucleus as protons in the nucleus. But sometimes an atom loses one or more of its electrons. This happens when the atom is bumped by something with enough energy to kick the electrons out. In the outer atmospheres of the Sun and stars, which are quite hot, the atoms all move fast and get bumped very hard. This causes most of the atoms to lose some of their electrons. Atoms that have one or more of their electrons removed are called *ions*. The higher the temperature, the more electrons are missing from the ions. If an ion moves to a cooler place, nearby electrons will be captured again. This means that each different kind of ion can survive only in places where the temperature is just right. (The "missing" electrons do not disappear: they are free to roam around and bump into atoms, ions, and other electrons.)

Astronomers rely upon *atomic physics* in order to dig information out of solar and stellar spectra. Atomic physics is the branch of science that deals with atoms and ions, and the light that comes from them. Each different type of atom or ion emits light waves at a combination of wavelengths that are special to that particular type of atom or ion, and different from the wavelengths of light waves that are sent out by any other kind of atom or ion. These light waves have become known as *emission lines* because light at these particular wavelengths looked like many straight lines in a spectrum when astronomers first obtained them. (See Figure 3.)

Each different type of atom or ion has its own special, unique set of emission lines. Astronomers use these emission lines to identify the atoms or ions that send out light from the Sun and stars. This is similar to the way a detective uses fingerprints to determine whose hands have touched an object. Once astronomers have determined what ions are present on the Sun and stars, they know immediately what elements are there. (Remember that ions are just atoms of a given element that have lost one or more of their electrons.) Furthermore, astronomers know how hot the Sun and stars are because each different type of ion is found only in a certain temperature range.

In addition to providing information about (1) the composition of the Sun and stars and (2) temperatures on the Sun and stars, emission lines also provide information about (3) densities (the number of atoms, ions, or electrons in a given volume), (4) motions, and (5) magnetic fields, as well as other quantities. For example, astronomers can sometimes measure densities by comparing how bright some emission lines are relative to others. Astronomers can also measure motions on the Sun and stars by measuring changes in the wavelengths of emission lines, or by the shapes of emission lines in the spectra. Motions can be measured because of the *Doppler effect*, which changes the wavelength of sound waves or light waves from a moving source. The wavelength appears shorter when the source approaches, and longer when the source moves away. (For example, a car horn's pitch sounds different when the car is approaching than it does when the car is going away.) Finally, magnetic fields on the Sun and on some stars can be measured because the magnetic fields change the wavelengths of some emission lines in a known way.

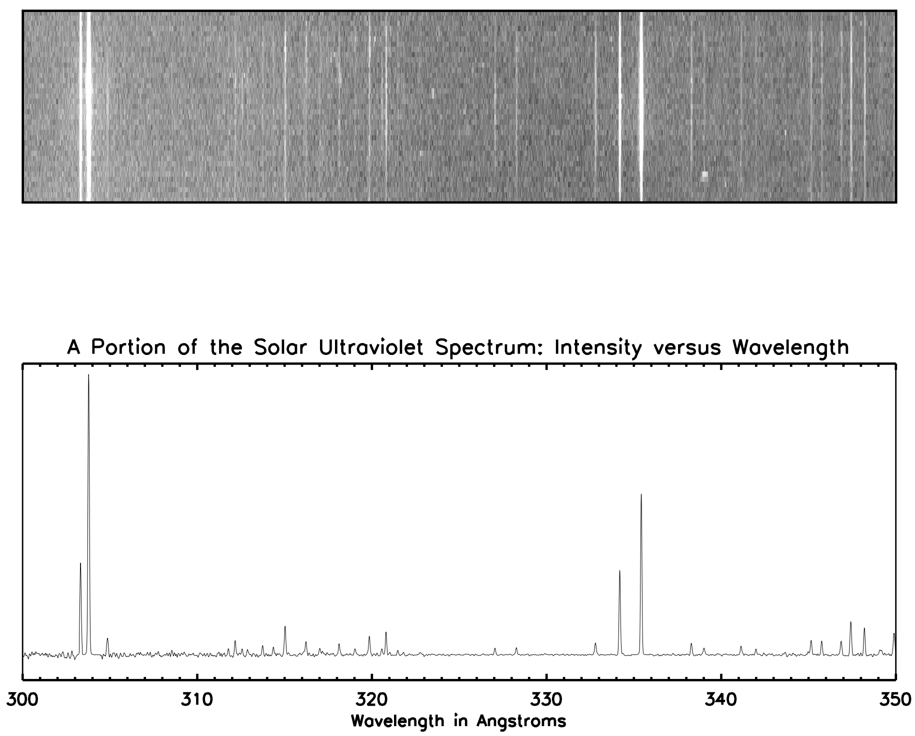

Figure 3: The top frame shows part of a solar ultraviolet emission line spectrum obtained with NASA's Solar Extreme-ultraviolet Research Telescope and Spectrograph (known as "SERTS") sounding rocket experiment. Wavelength increases from 300 Å on the far left to 350 Å on the far right. Clearly, some lines are very bright while others are very faint. The graph in the bottom frame is a different way to show how bright the lines are at each different wavelength. *Intensity* (how bright the line is) is in the vertical direction (the "y-axis"), and wavelength is in the horizontal direction (the "x-axis"). Notice that higher peaks in the bottom frame match up with brighter lines in the top frame. Astronomers use spectra like these to learn all sorts of things about the Sun and stars.

5 Try it yourself.

The spectrum on page 8 is an enlarged version of the bottom frame of Figure 3. This is part of an actual solar ultraviolet spectrum. The device that was used to obtain this spectrum is called the Solar Extreme-ultraviolet Research Telescope and Spectrograph, or SERTS for short. SERTS was built in the Laboratory for Astronomy and Solar Physics at Goddard Space Flight Center in Greenbelt, Maryland. The "sounding" rocket that carried it above Earth's atmosphere was launched from White Sands Missile Range, New Mexico. SERTS stayed above the atmosphere for about $6\frac{1}{2}$ minutes, and reached a maximum height of about 320 kilometers (200 miles) above the ground. It parachuted back onto the desert in New Mexico, where it was picked up and returned to Goddard. SERTS flew in 1989, 1991, 1993, 1995, 1996, 1997, 1999, and 2000. As of this writing (2005) its successor, EUNIS, is being prepared for launch. Since building and launching devices like SERTS and EUNIS is much less expensive than building and launching Earth-orbiting satellites or interplanetary spacecraft, sounding rockets are often used to test new technology before the new technology is used on more expensive space missions. Several kinds of new technology have been developed and used for SERTS. More information about SERTS and EUNIS can be found on the SERTS homepage on the World Wide Web at "http://serts.gsfc.nasa.gov/".

Table 1 gives a list of 39 ultraviolet emission lines that are found in a small portion of the Sun's spectrum. This table gives the wavelength in Å, the element making the line, the number of electrons that have been lost by atoms of that element, and the temperature in °C. (If the temperature were in °F, these numbers would be 80% larger.) Notice that, for any particular element, a higher temperature means a greater number of electrons are missing from the ions.

The emission lines in the spectrum on the following page look like narrow mountains. Some of them are very tall, and some of them are very short. The tallest ones are the brightest emission lines, and the shortest ones are the faintest. The bumps and wiggles toward the bottom of the figure are *noise*. Every scientific measurement contains noise of some sort. Sometimes the signal that scientists look for is much stronger than the noise, and sometimes the noise can hide the signal. Here, for example, the noise limits our ability to see faint emission lines. Emission lines that are so faint that they do not stand out above the noise are hard to find and even harder to measure.

Using Table 1 and the spectrum, can you say what are the two strongest emission lines in this part of the Sun's spectrum? How many other emission lines can you match with the lines listed in the table? What can you say about the Sun's composition, based on these ultraviolet observations? What can you say about the Sun's temperature, based on these observations? Can the Sun have more than one temperature at the same time?

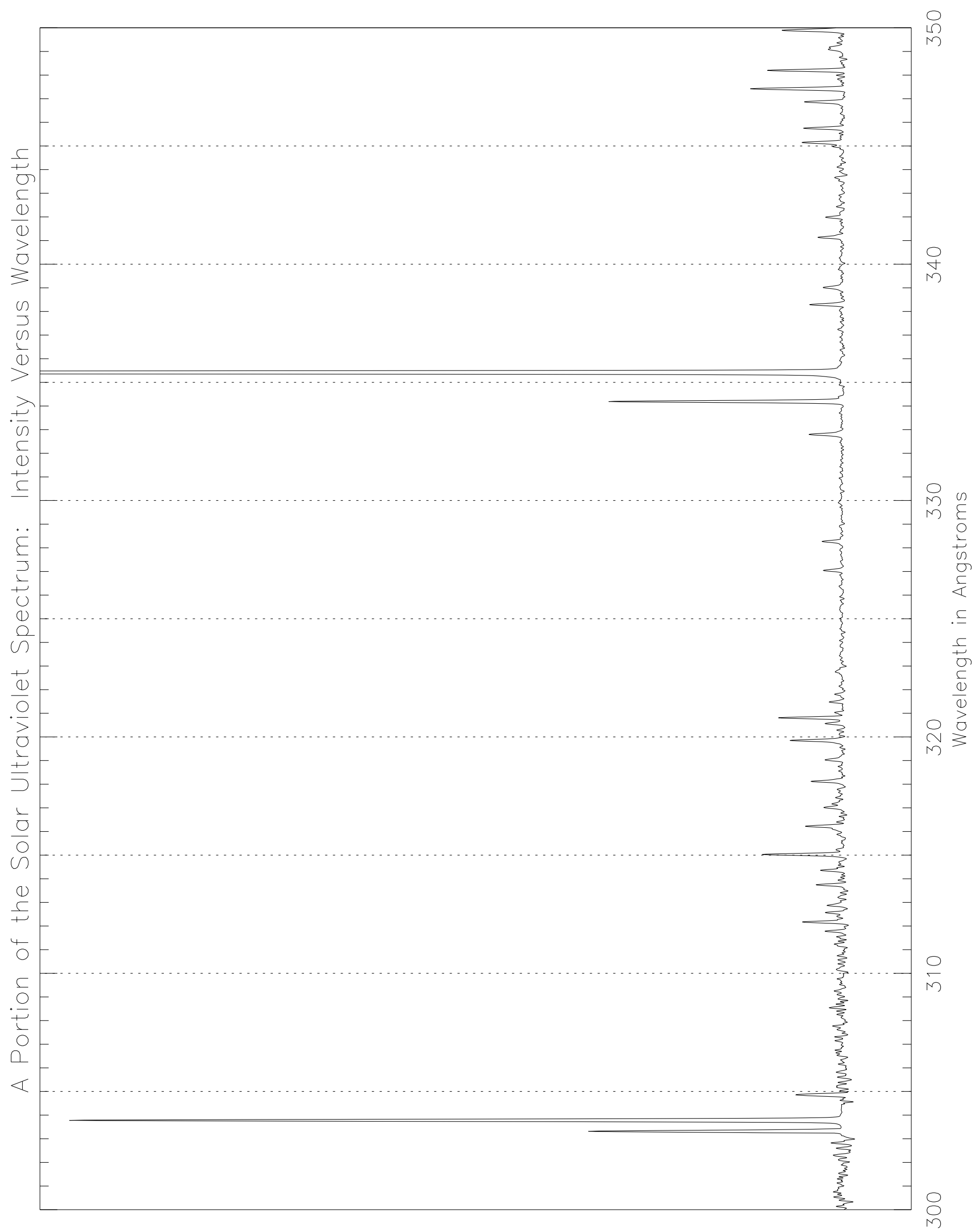
A Portion of the Solar Ultraviolet Spectrum: Intensity Versus Wavelength
Wavelength in Angstroms
300
310
320
330
340
350

TABLE 1

Sample of Ultraviolet Emission Lines in a Solar Spectrum

No.	Element	Wavelength (A)	Electrons Lost	Temperature (C)
1	Silicon	303.317	10	1,600,000
2	Helium	303.782	1	47,000
3	Iron	304.860	14	2,100,000
4	Iron	308.543	10	1,100,000
5	Iron	311.574	12	1,600,000
6	Magnesium	311.783	7	790,000
7	Iron	312.171	12	1,600,000
8	Iron	312.569	14	2,100,000
9	Iron	312.874	12	1,600,000
10	Magnesium	313.744	7	790,000
11	Silicon	314.358	7	790,000
12	Magnesium	315.029	7	790,000
13	Silicon	316.223	7	790,000
14	Magnesium	317.018	7	790,000
15	Iron	318.121	12	1,600,000
16	Magnesium	319.033	6	630,000
17	Silicon	319.852	7	790,000
18	Nickel	320.568	17	3,300,000
19	Iron	320.809	12	1,600,000
20	Iron	321.479	12	1,600,000
21	Iron	321.809	14	2,100,000
22	Iron	327.045	14	2,100,000
23	Chromium	328.270	12	1,600,000
24	Aluminum	332.799	9	1,300,000
25	Iron	334.191	13	1,900,000
26	Iron	335.418	15	2,700,000
27	Iron	338.290	11	1,400,000
28	Magnesium	339.014	7	790,000
29	Iron	341.136	10	1,100,000
30	Silicon	341.987	8	1,000,000
31	Silicon	344.974	8	1,000,000
32	Silicon	345.148	8	1,000,000
33	Iron	345.753	9	950,000
34	Iron	346.867	11	1,400,000
35	Silicon	347.421	9	1,300,000
36	Iron	347.823	16	4,000,000
37	Iron	348.199	12	1,600,000
38	Magnesium	349.124	5	400,000
39	Silicon	349.895	8	1,000,000

6 Measuring motions.

Astronomers can measure motions on the Sun and stars by measuring changes in the wavelengths of emission lines. Motions can be measured because of the *Doppler effect*, which makes the wavelength of waves from an emitter appear shorter when the source approaches, and longer when the source moves away. When the emitting source is at rest, moving neither toward nor away from the observer, the measured wavelength is referred to as the *rest wavelength*.

Let's take a closer look at an emission line "mountain" like those in Figure 3. Astronomers refer to these as *profiles* because they outline the shapes of emission lines. Figure 4 shows the profile of an emission line emitted by an oxygen atom that has lost four electrons. This profile was observed with the Coronal Diagnostic Spectrometer aboard the SOHO spacecraft. The horizontal axis (x-axis) shows the wavelength, and the vertical axis (y-axis) shows the intensity (same as in Figure 3). The dashed vertical line shows the location of the profile's peak intensity; this is the wavelength of the line. Wavelength can often be measured to three decimal places, and in this case is 629.732 Å. Since the source here was moving neither toward nor away from the observer, the observed wavelength of 629.732 Å is the rest wavelength.

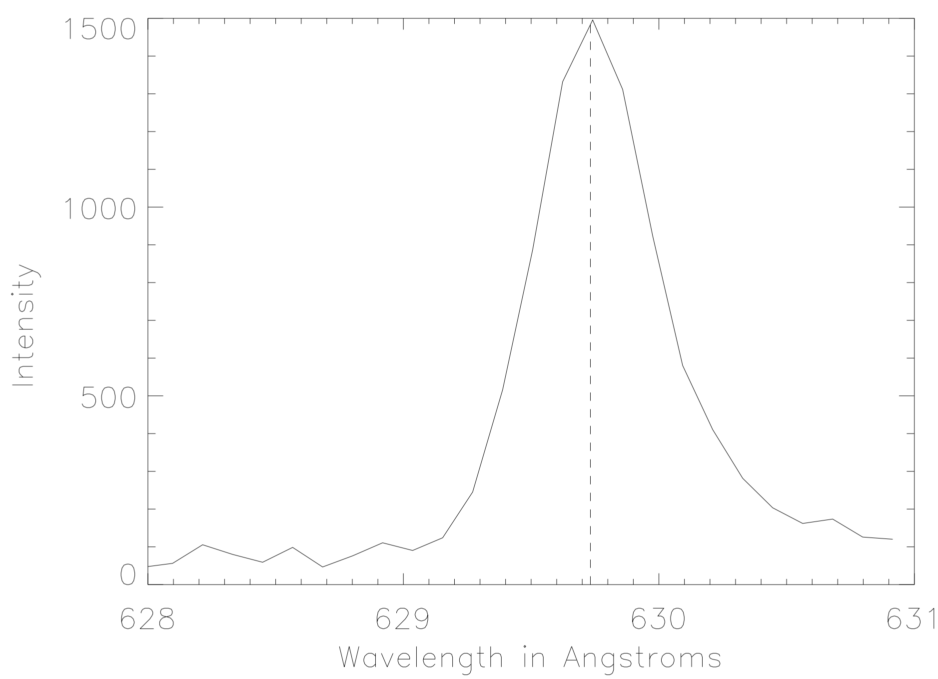

Figure 4: Emission line profile for an oxygen atom that has lost four electrons, when the emitting source is moving neither toward nor away from the observer. The peak intensity is shown by the dashed vertical line at 629.732 Å, which is the rest wavelength of the line.

Sometimes astronomers see profiles like the one shown in Figure 5. The dashed vertical line in Figure 5 again marks the rest wavelength seen in Figure 4, but the peak of this new profile (shown by the dotted vertical line) is shifted to the left of the dashed line (the rest wavelength). This change in wavelength is referred to as a *Doppler shift*. The new profile's wavelength, 629.450 Å, is shorter than (less than) the rest wavelength, which tells us that the emitting source is moving toward the observer. The Doppler shift is simply the difference between the rest wavelength (629.732 Å) and the shifted profile's wavelength (629.450 Å) which, in this example, is 0.282 Å. The Doppler shift can easily be converted from wavelength in Å to speed: multiply the wavelength shift (0.282 Å) by the speed of light (300,000 kilometers per second, or 186,000 miles per second), and divide by the rest wavelength in Å (629.732). In this case, the speed is $0.282 \times 300,000/629.732 = 134$ kilometers per second, or $0.282 \times 186,000/629.732 = 83$ miles per second.

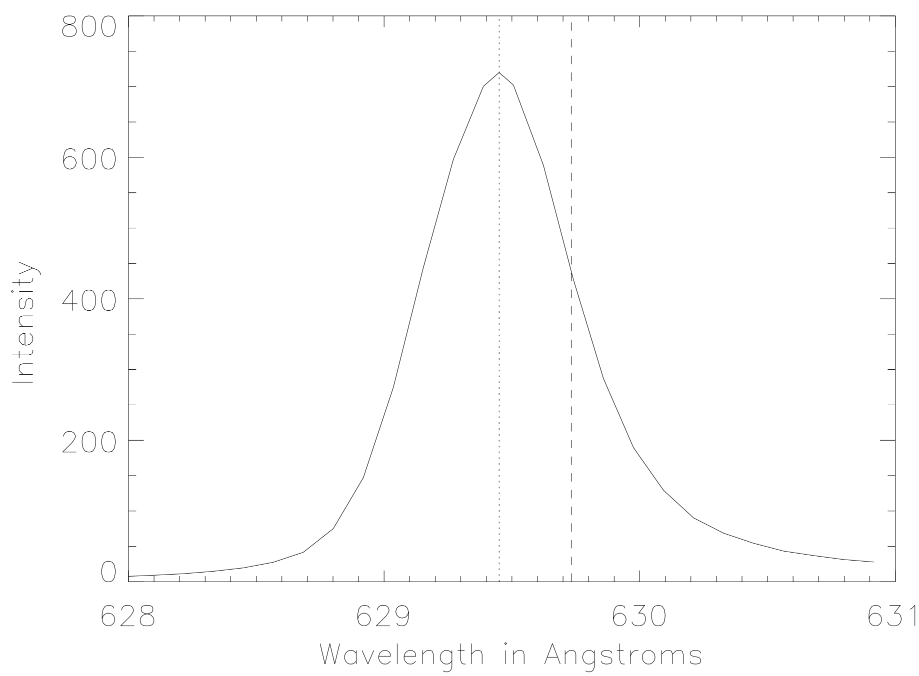

Figure 5: Emission line profile for an oxygen atom that has lost four electrons, when the source of the line is moving toward the observer. The peak intensity is shown by the dotted vertical line, and occurs at 629.450 Å. The rest wavelength of the line, 629.732 Å, is shown by the dashed vertical line.

Figure 6 shows another example of an emission line profile for the same oxygen ion that we discussed above. Here, however, the measured wavelength is 629.809 Å, which is 0.077 Å *longer* than the rest wavelength. For this Doppler shift, is the emitting source moving toward or away from the observer? How fast is the source moving?

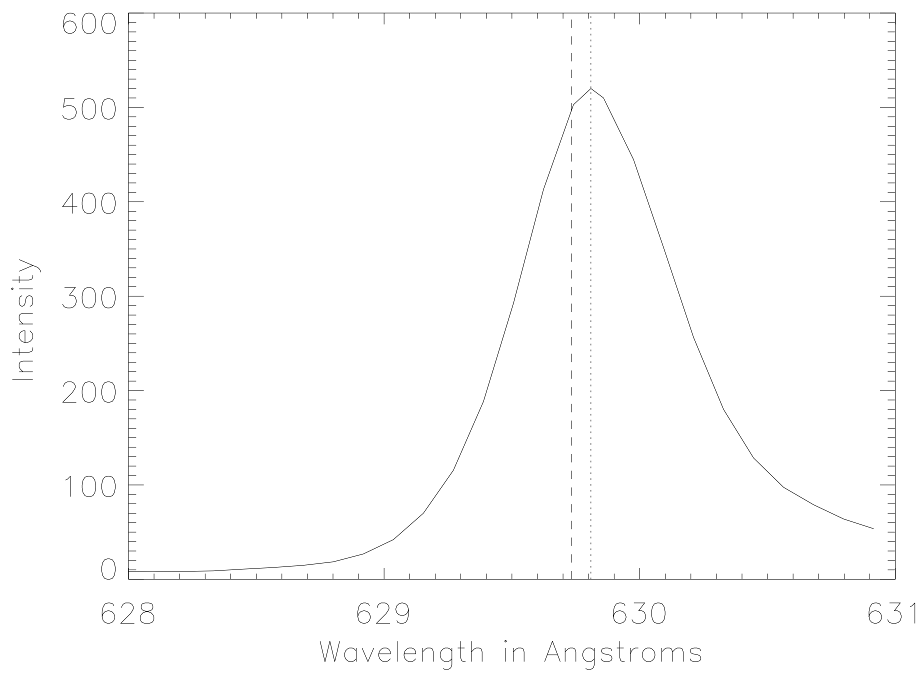

Figure 6: Emission line profile for an oxygen atom that has lost four electrons. The peak intensity is shown by the dotted vertical line, and occurs at 629.809 Å. The rest wavelength of the line, 629.732 Å, is shown by the dashed vertical line.

7 Measuring densities.

Density is the amount of something or the number of something contained in a given volume. For example, the density of air at sea level is 1.22 kilograms per cubic meter. Astronomers frequently find it convenient to work with a quantity called *electron density*, which is the number of free electrons (electrons that are not bound to atoms or ions) within a given volume. Astronomers can measure electron densities on the Sun and stars by using emission lines whose intensities are especially sensitive to the electron density within the emitting source. This can be done by measuring the ratios of the intensities of certain emission lines, and comparing those measured ratios with theoretical values. In order to do this reliably, astronomers must know the properties of the emitting ions fairly accurately. This again underscores the important role of atomic physics in using spectra to diagnose conditions in the outer layers of the Sun and other stars.

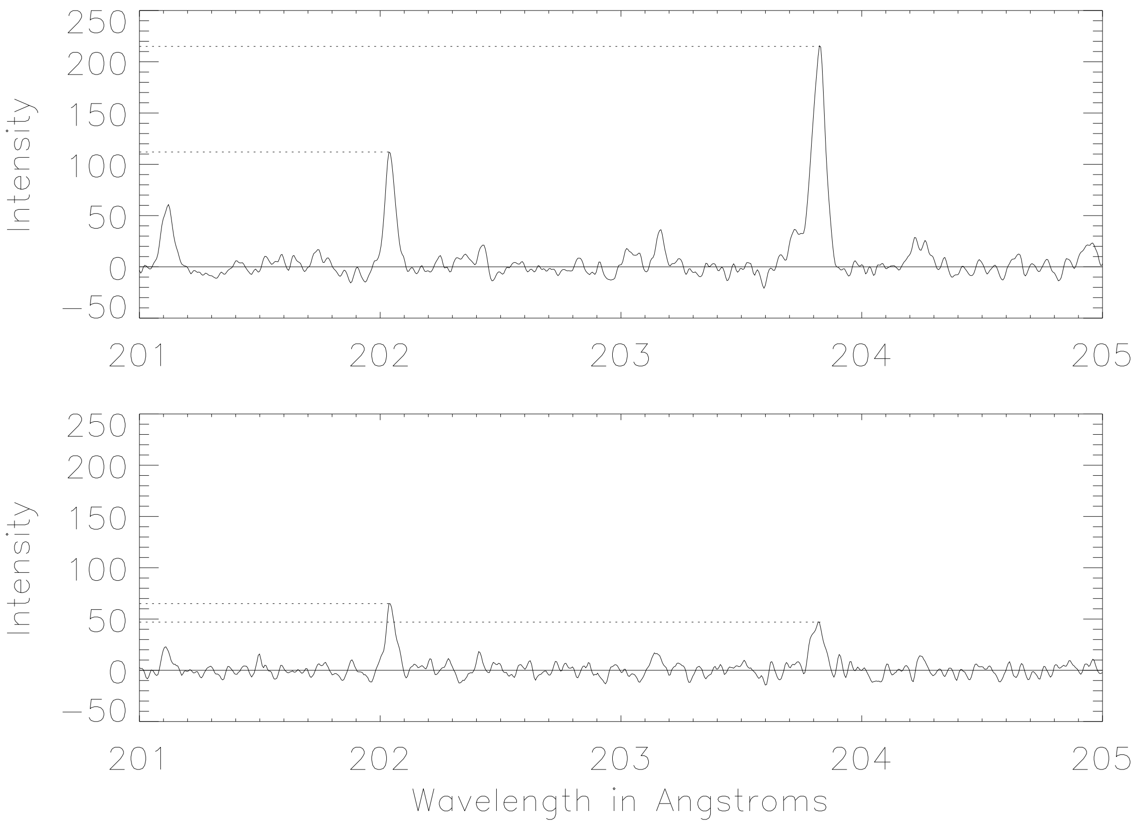

Figure 7: A pair of iron emission lines that can be used to measure the electron density on the Sun. The top and bottom frames show ultraviolet spectra from two different areas on the Sun.

Figure 7 shows more examples of solar ultraviolet spectra from SERTS. The x-axis gives the wavelength in Angstroms, and the y-axis gives the intensity. The top and bottom frames correspond to two different areas on the Sun. Each spectrum shows two prominent emission lines from iron atoms that have lost 12 electrons. These lines appear at wavelengths of 202.044 and 203.829 Å. Dotted horizontal lines in each frame mark the intensity of each line's peak. In the top frame the line at 203.829 Å is clearly brighter than the line at 202.044 Å. Both lines are less bright in the bottom frame than they are in the top, but here the line at 202.044 Å is brighter than the line at 203.829 Å. This indicates a significant difference in density between these two areas on the Sun.

From atomic physics calculations, astronomers know how the emission line intensity ratios for various ions depend on the electron density in the emitting source. For example, Figure 8 shows the relation between the electron density and the intensity ratio of the 203.829 to 202.044 Å lines. The line intensity ratio is given along the x-axis, and the electron density along the y-axis.

Consider the following example. The top frame of Figure 7 shows that the peak intensity of the line at 203.829 Å is about 215, while that at 202.044 Å is about 112. This gives an intensity ratio of 215/112=1.92. Find 1.92 along the x-axis in Figure 8, and go straight up until the solid curve is reached. This is marked with a dotted line in Figure 8. The

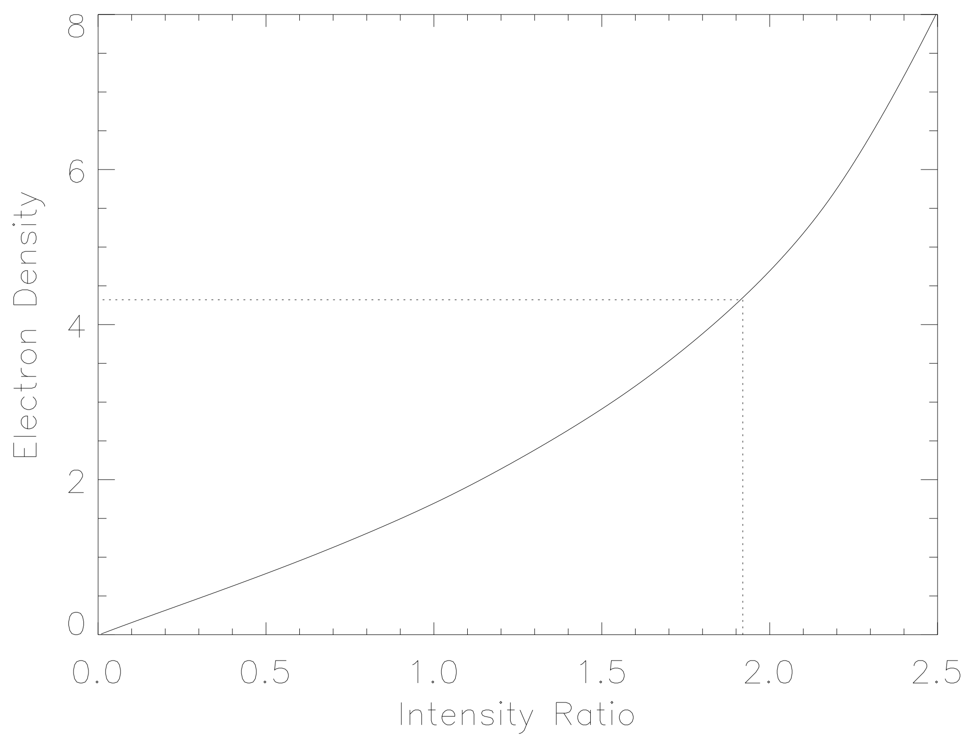

Figure 8: Electron density (billions of electrons per cubic centimeter) as a function of iron line intensity ratio. The iron line intensity ratio is simply the intensity of the iron line at 203.829 Å divided by the intensity of the iron line at 202.044 Å.

height at which the dotted line intersects the solid curve yields the electron density. This is indicated with another dotted line that intersects the y-axis at about 4.3 billion electrons per cubic centimeter. This is much less than (about one hundred-billionth of) the density of air particles that you breathe at sea level!

Repeat the procedure yourself for the lower frame of Figure 7. Again the peak intensities are indicated with dotted horizontal lines. Is the intensity ratio of the 203.829 to the 202.044 Å lines greater than or less than one in this case? Can you find the corresponding electron density in Figure 8?

8 Summary of main ideas.

• Light behaves like waves that travel through space. The distance between wave peaks is the wavelength of the light.

• Visible light, such as the colors of a rainbow, can be seen by human eyes. Other kinds of light, such as radio, microwave, infrared, ultraviolet, X-ray, and gamma ray, are invisible to human eyes.

• The different kinds of light all carry information about the Sun and other stars to Earth.

• Earth's atmosphere absorbs much of the invisible kinds of light from the Sun and stars. Therefore, astronomers must use rockets to send special telescopes above Earth's air. These special telescopes can "see" light that is invisible to human eyes and that is blocked out by Earth's air.

• Every different kind of atom and ion sends out light at combinations of wavelengths that are special to that kind of atom or ion. Light at these wavelengths, known as emission lines, can be used like fingerprints to identify the atom or ion that sent out the light.

• Different ions of any element survive only in certain temperature ranges.

• When astronomers identify which atoms or ions exist on the Sun and stars from solar and stellar spectra, astronomers know both *what elements* are there and *what temperatures* are there.

• The Doppler effect is used to measure motions on the Sun and stars. The wavelength of an emitting source appears shorter (smaller) when the source approaches, and longer (larger) when the source moves away.

• Astronomers can measure electron densities on the Sun and stars with intensity ratios of especially sensitive emission lines.

Information for Educators

This lesson includes interpretation of scientific data displayed as graphs.

After completing this lesson, students should be able to:

• define the terms "electromagnetic radiation," "spectrum," and "wavelength," as well as give examples of different types of radiation that are emitted by the Sun and other stars.
• explain the role of the Earth's atmosphere in protecting humans and other living organisms from the harmful types of radiation emitted by the Sun.
• describe the different types of information astronomers can obtain by studying light emitted from the Sun and other stars.
• identify elements present in a portion of the solar ultraviolet spectrum.

This lesson supports the following National Science Education Standards for grades 5-8:

• **Content Standard A** – All students should develop the abilities necessary to do scientific inquiry and understandings about scientific inquiry.
• **Content Standard B** – All students should develop an understanding of the transfer of energy.
• **Content Standard C** – All students should develop an understanding of Earth in the solar system.

This lesson supports the following National Science Education Standards for grades 9-12:

• **Content Standard A** – All students should develop the abilities necessary to do scientific inquiry and understandings about scientific inquiry.
• **Content Standard B** – All students should develop an understanding of the structure of atoms, the structure and properties of matter, and the interactions of energy and matter.
• **Content Standard C** – All students should develop an understanding of energy within the Earth system and the origin and evolution of the universe.

Additional information can be found at the following web sites:
http://www.nasa.gov/goddard
http://sohowww.nascom.nasa.gov/
http://serts.gsfc.nasa.gov/

Name ______________________________ Date ______________________________

Analyzing Solar Spectra: Student Worksheet

Directions: Using the spectrum on page 8 and Table 1 on page 9, identify emission lines in the solar spectrum. Can you identify 30 or more emission lines? Not all of the emission lines represent different elements. After you have finished, answer the questions below.

1. What are the two strongest emission lines in this part of the Sun's spectrum?

2. The Sun is made mostly of hydrogen. List the names of other elements you were able to identify. What can you say about the composition of the Sun based on your observations of this portion of the spectrum?

3. What can you say about the temperature of the Sun based on your observations of this portion of the spectrum? How does this compare with the temperature of the Earth?

4. Which portion of the electromagnetic spectrum can human eyes see? Which portions cannot be seen?

5. Many portions of the electromagnetic spectrum are harmful to living things. Why doesn't the Sun's radiation cause more damage to life on Earth?

6. What do astronomers need to do in order to study portions of the electromagnetic spectrum that are not observable from Earth?

7. Name two things that astronomers can learn about a star from studying its spectrum.

8. Match the terms on the left with the definitions on the right.

Angstrom	Energy produced by the Sun and stars that travels in waves.
Emission lines	The process in which wavelengths from an emitting source appear shorter when the source approaches, and longer when it moves away.
Light	The number of “free” electrons in a given volume.
Spectrum	Each atom or ion emits a unique combination of these in its spectrum.
Wavelength	Light separated into the wavelengths of which it is composed.
Rest wavelength	The wavelength of light from an emitting source that appears to be standing still.
Electron density	The distance between two consecutive peaks of a wave.
Doppler effect	A unit of length equal to one ten-billionth of a meter.