

Name: \_\_\_\_\_

Date: \_\_\_\_\_

## 17 The Sun

### 17.1 Introduction

The Sun is a very important object for all life on Earth. The nuclear reactions that occur in its core produce the energy required by plants and animals for survival. We schedule our lives around the rising and setting of the Sun in the sky. During the summer, the Sun is higher in the sky and thus warms us more than during the winter, when the Sun stays low in the sky. But the Sun's effect on Earth is even more complicated than these simple examples.

The Sun is the nearest star to us, which is both an advantage and a disadvantage for astronomers who study stars. Since the Sun is very close, and very bright, we know much more about the Sun than we know about other distant stars. This complicates the picture quite a bit since we need to better understand the physics going on in the Sun in order to comprehend all of our detailed observations. This difference makes the job of solar astronomers in some ways more difficult than the job of stellar astronomers, and in some ways easier! It's a case of having lots of incredibly detailed data. But all of the phenomena associated with the Sun are occurring on other stars, so understanding the Sun's behavior provides insights to how other stars might behave.

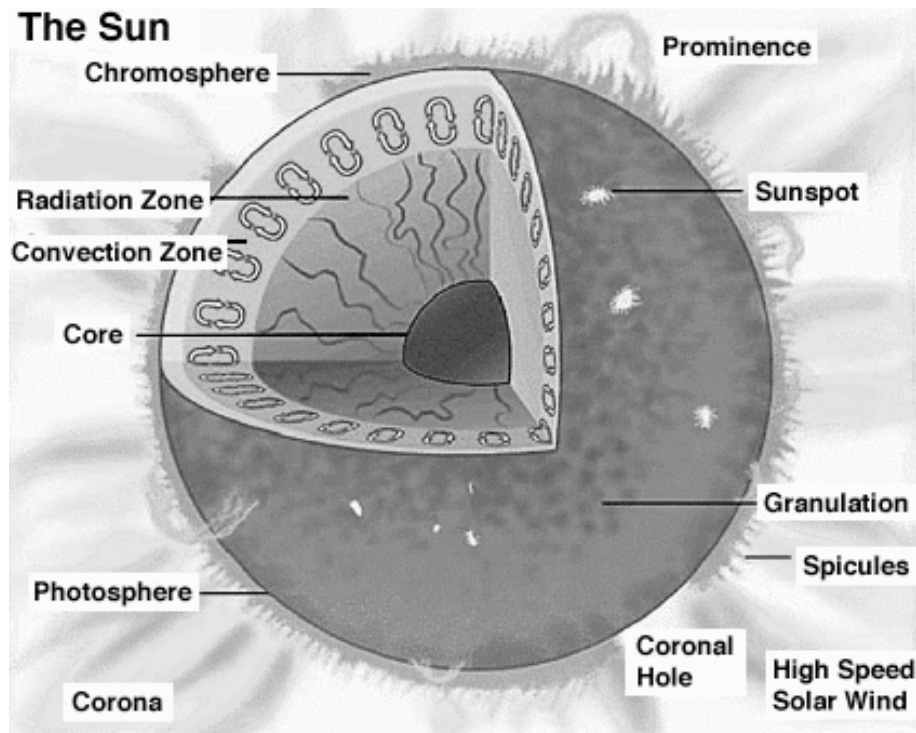


Figure 17.1: A diagram of the various layers/components of the Sun, as well as the appearance and location of other prominent solar features.

- *Goals:* to discuss the layers of the Sun and solar phenomena; to use these concepts in conjunction with pictures to deduce characteristics of solar flares, prominences, sunspots, and solar rotation
- *Materials:* You will be given a Sun image notebook, a bar magnet with iron filings and a plastic tray. You will need paper to write on, a ruler, and a calculator

## 17.2 Layers of the Sun

One of the things we know best about the Sun is its overall structure. Figure 17.1 is a schematic of the layers of the Sun's interior and atmosphere. The interior of the Sun is made up of three distinct regions: the core, the radiative zone, and the convective zone. The *core* of the Sun is very hot and dense. This is the only place in the Sun where the temperature and pressure are high enough to support nuclear reactions. The *radiative zone* is the region of the sun where the energy is transported through the process of radiation. Basically, the photons generated by the core are absorbed and emitted by the atoms found in the radiative zone like cars in stop and go traffic. This is a very slow process. The *convective zone* is the region of the Sun where energy is transported by rising "bubbles" of material. This is the same phenomenon that takes place when you boil a pot of water. The hot bubbles rise to the top, cool, and fall back down. This gives the the surface of the Sun a granular look. Granules are bright regions surrounded by darker narrow regions. These granules cover the entire surface of the Sun.

The atmosphere of the Sun is also comprised of three layers: the photosphere, the chromosphere, and the corona. The *photosphere* is a thin layer that forms the visible surface of the Sun. This layer acts as a kind of insulation, and helps the Sun retain some of its heat and slow its consumption of fuel in the core. The *chromosphere* is the Sun's lower atmosphere. This layer can only be seen during a solar eclipse since the photosphere is so bright. The *corona* is the outer atmosphere of the Sun. It is very hot, but has a very low density, so this layer can only be seen during a solar eclipse. More information on the layers of the Sun can be found in your textbook.

## 17.3 Sunspots

Sunspots appear as dark spots on the photosphere (surface) of the Sun (see Figure 17.2). They last from a few days to over a month. Their average size is about the size of the Earth, although they have been observed to be over twice the size of the Earth! Sunspots are commonly found in pairs. How do these spots form?

The formation of sunspots is attributed to the Sun's *differential rotation*. The Sun is a ball of gas, and therefore does not rotate like the Earth or any other solid object. The Sun's equator rotates faster than its poles. It takes roughly 25 days for something to travel once around the equator, but about 35 days for it to travel once around the north or south pole. This differential rotation acts to twist up the magnetic field lines inside the Sun. At times, the lines can get so twisted that they pop out of the photosphere. Figure 17.3 illustrates this concept. When a magnetic field loop pops out, the places where it leaves and re-enters the

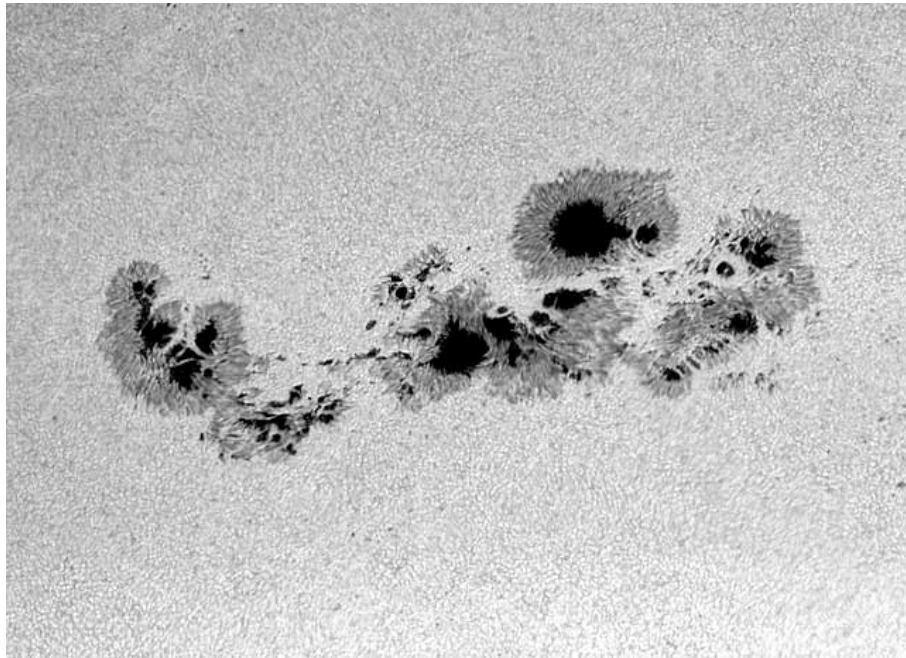


Figure 17.2: A large, complex group of sunspots.

photosphere are cooler than the rest of the Sun's surface. These cool places appear darker, and therefore are called "sunspots."

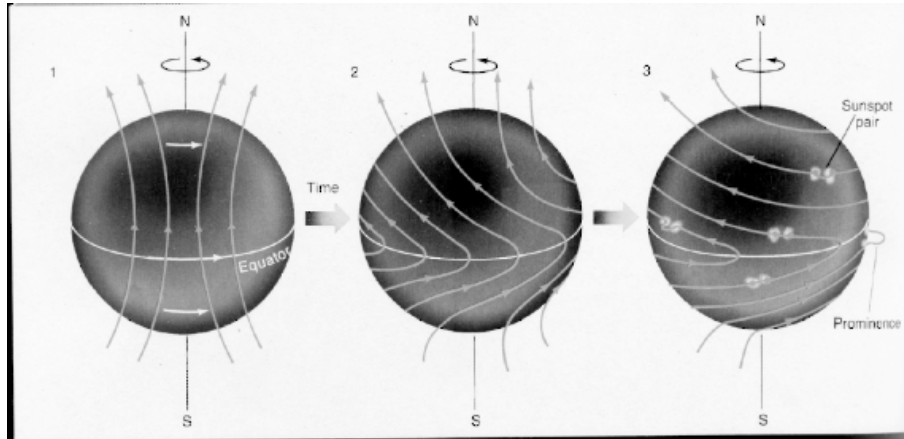


Figure 17.3: Sunspots are a result of the Sun's differential rotation.

The number of sunspots rises and falls over an 11 year period. This is the amount of time it takes for the magnetic lines to tangle up and then become untangled again. This is called the *Solar Cycle*. Look in your textbook for more information on sunspots and the solar cycle.

## 17.4 Solar Phenomenon

The Sun is a very exciting place. All sorts of activity and eruptions take place in it and around it. We will now briefly discuss a few of these interesting phenomena. You will be analyzing pictures of prominences and flares during your lab.

*Prominences* are huge loops of glowing gas protruding from the chromosphere. Charged particles spiral around the magnetic field lines that loop out over the surface of the Sun, and therefore we see bright loops above the Sun's surface. Very energetic prominences can break free from the magnetic field lines and shoot out into space.

*Flares* are brief but bright eruptions of hot gas in the Sun's atmosphere. These eruptions occur near sunspot groups and are associated with the Sun's intertwined magnetic field lines. A large flare can release as much energy as 10 billion megatons of TNT! The charged particles that flares emit can disrupt communication systems here on Earth.

Another result of charged particles bombarding the Earth is the Northern Lights. When the particles reach the Earth, they latch on to the Earth's magnetic field lines. These lines enter the Earth's atmosphere near the poles. The charged particles from the Sun then excite the molecules in Earth's atmosphere and cause them to glow. Your textbook will have more fascinating information about these solar phenomena.

## 17.5 Lab Exercises

There are two main exercises in this lab. The first part consists of a series of "stations" in a three ring binder where you examine some pictures of the Sun and answer some questions about the images that you see. In the second exercise you will actually look at the Sun using a special telescope to see some of the phenomena that were detailed in the images in the first exercise of this lab. During this lab you will use your own insight and knowledge of basic physics and astronomy to obtain important information about the phenomena that we see on the Sun, just as solar astronomers do. If there is not sufficient room to write in your answers into this lab, do not hesitate to use additional sheets of paper. Do not try to squeeze your answers into the tiny blank spaces in this lab description if you need more space than provided! Don't forget to **SHOW ALL OF YOUR WORK**.

One note of caution about the images that you see: the colors of the pictures (especially those taken by SOHO) are *not* true colors, but are simply colors used by the observatories' image processing teams to best enhance the features shown in the image.

### 17.5.1 Exercise #1: Getting familiar with the Size and Appearance of the Sun

**Station 1:** In this first station we simply present some images of the Sun to familiarize yourself with what you will be seeing during the remainder of this lab. Note that this station has no questions that you have to answer, but you still should take time to familiarize yourself with the various features visible on/near the Sun, and get comfortable with the specialized, filtered image shown here.

- The first image in this station is a simple "white light" picture of the Sun as it would appear to you if you were to look at it in a telescope that was designed for viewing the

Sun. Note the dark spots on the surface of the Sun. These are “sunspots,” and are dark because they are cooler than the rest of the photosphere.

- When we take a very close-up view of the Sun’s photosphere we see that it is broken up into much smaller “cells.” This is the “solar granulation,” and is shown in picture #2. Note the size of these granules. These convection cells are about the size of New Mexico!
- To explore what is happening on the Sun more fully requires special tools. If you have had the spectroscopy lab, you will have seen the spectral lines of elements. By choosing the right element, we can actually probe different regions in the Sun’s atmosphere. In our first example, we look at the Sun in the light of the hydrogen atom (“H-alpha”). This is the red line in the spectrum of hydrogen. If you have a daytime lab, and the weather is good, you will get to see the Sun just like it appears in picture #3. The dark regions in this image is where cool gas is present (the dark spot at the center is a sunspot). The dark linear, and curved features are “prominences,” and are due to gas caught in the magnetic field lines of the underlying sunspots. They are above the surface of the Sun, so they are a little bit cooler than the photosphere, and therefore darker.
- Picture #4 shows a “loop” prominence located at the edge (or “limb”) of the Sun (the disk of the Sun has been blocked out using a special telescope called a “coronagraph” to allow us to see activity near its limb). If the Sun cooperates, you may be able to see several of these prominences with the solar telescope.

**Station 2:** Here are two images of the Sun taken by the SOHO satellite several days apart (the exact times are at the top of the image).

- Look at the sunspot group just below center of the Sun in **image 1**, and then note that it has rotated to the western (right-hand) limb of the Sun in **image 2**. Since the sunspot group has moved from center to limb, you then know that the Sun has rotated by one quarter of a turn ( $90^\circ$ ).
- Determine the precise time difference between the images. Use this information plus the fact that the Sun has turned by 90 degrees in that time to determine the rotation rate of the Sun. If the Sun turns by 90 degrees in time  $t$ , it would complete one revolution of 360 degrees in how much time? **(5 points)**



- If the photospheric diameter of the Sun is 1.4 million kilometers ( $1.4 \times 10^6$  km), how big is the corona? (HINT: use unit conversion!) **(7 points)**

- How many times larger than the Earth is the corona? (Earth diameter=12,500 km) **(5 points)**

**Station 4:** This image shows a time-series of exposures by the SOHO satellite showing an *eruptive prominence*.

- As in station 3, measure the diameter of the Sun and then measure the distance of the top of the prominence from the edge of the Sun in the first (earliest) image. Then measure the distance of the top of the prominence from the edge of the Sun in the last image. **(3 points)**

- Convert these values into real distances based on the linear scale of the images. The diameter of the Sun is  $1.4 \times 10^6$  kilometers. **(7 points)**

- The velocity of an object is the distance it travels in a certain amount of time (velocity=distance/time). Find the velocity of the prominence by subtracting the two

distances and dividing the answer by the amount of time between the two images. (5 points)

- In the most severe of solar storms, those that cause flares, and “coronal mass ejections” (and can disrupt communications on Earth), the material ejected in the prominence (or flare) can reach velocities of 2,000 kilometers per second. If the Earth is  $150 \times 10^6$  kilometers from the Sun, how long (hours or days) would it take for this ejected material to reach the Earth? (5 points)

**Station 5:** This is a plot of where sunspots tend to occur on the Sun as a function of *latitude* (top plot) and time (bottom plot). What do you notice about the distribution sunspots? How long does it take the pattern to repeat? What does this length of time correspond to? (5 points)

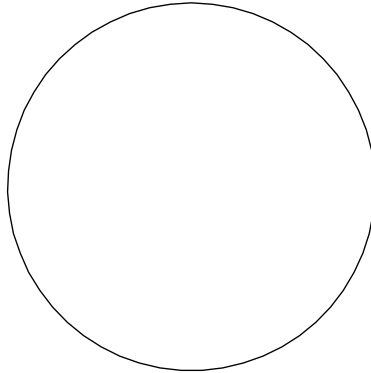
### 17.5.2 Exercise #2: Looking at the Sun

The Sun is very bright, and looking at it with either the naked eye or any optical device is dangerous—special precautions are necessary to enable you to actually look at the Sun. To make the viewing safe, we must eliminate 99.999% of the light from the Sun to reduce it to safe levels. In this exercise you will be using a very special telescope designed for viewing the Sun. This telescope is equipped with a hydrogen light filter. It only allows a tiny amount of light through, isolating a single emission line from hydrogen (“H-alpha”). In your lecture session you will learn about the emission spectrum of hydrogen, and in the spectroscopy lab you get to see this red line of hydrogen using a spectroscope. Several of the pictures in Exercise #1 were actually obtained using a similar filter system. This filter system gives

us a unique view of the Sun that allows us to better see certain types of solar phenomena, especially the “prominences” you encountered in Exercise #1.

- In the “Solar Observation Worksheet” below, draw what you see on and near the Sun as seen through the special solar telescope. **(10 points)**

# Solar Observation Worksheet



Name: \_\_\_\_\_

Lab Sec.: \_\_\_\_\_

Date: \_\_\_\_\_

TA: \_\_\_\_\_

Note: Kitt Peak Vacuum Telescope images are courtesy of KPNO/NOAO. SOHO Extreme Ultraviolet Imaging Telescope images courtesy of the SOHO/EIT consortium. SOHO Michelson Doppler Imager images courtesy of the SOHO/MDI consortium. SOHO is a project of international cooperation between the European Space Agency (ESA) and NASA.

Name: \_\_\_\_\_  
Date: \_\_\_\_\_

## 17.6 Summary

(30 points) Summarize the important concepts discussed in this lab.

- Discuss the different types of phenomena and structures you looked at in the lab
- Explain how you can understand what causes a phenomenon to occur by looking at the right kind of data
- List the six layers of the Sun (in order). What are the temperatures of the core and photosphere.
- What causes the Northern (and Southern) Lights, also known as “Aurorae”?

Use complete sentences and proofread your summary before turning it in.

