

# The Sun

## Introduction

We will meet in class for a brief discussion and review of background material. We will then go outside for approximately 1 hour of telescope observing.

The telescopes will already be set up - you will look a projection of the Sun onto paper, and you will observe the Sun with a solar filter and an H-alpha filter.

**Never look directly at the Sun,  
especially NOT through an unfiltered telescope!!**

Back in the lab, you will view movies of the Sun taken by the Solar and Heliospheric Observatory (SOHO) spacecraft. You will use them to estimate the rotation period of the Sun, and to find the velocity of matter leaving the Sun through a coronal mass ejection.

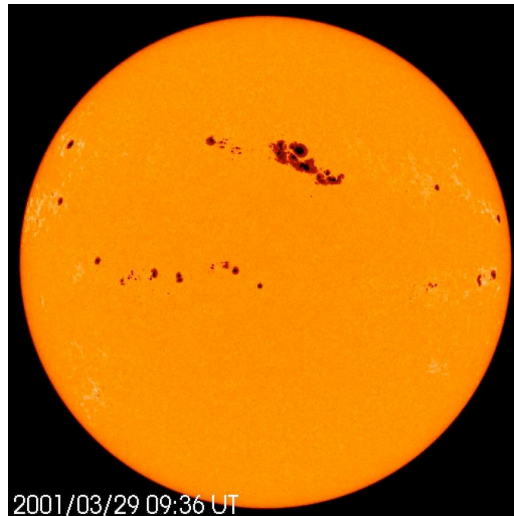
## Background Information

To a casual Earthbound observer, the Sun looks very different from a star: it appears as a bright disk in the daytime sky, while the stars twinkle as pinpoints of light in the night sky. As stars go, however, the Sun is rather mediocre. It is classed as a yellow dwarf star, because because its visible radiation is most intense in the yellow-green portion of the spectrum. The Sun lies about 32,000 light years from the center of our galaxy and takes 225 million years to complete one orbit of the galactic center.

In this lab, we will focus on the external features of the Sun that we can see from Earth and from space telescopes we have set up to observe the Sun. The internal properties of the Sun are inferred from the observations we make of the outer layers.

The visible surface of the sun is the photosphere (<http://solarscience.msfc.nasa.gov/surface.shtml>). Features of the photosphere include limb darkening, sunspots, granules, and faculae (<http://solarscience.msfc.nasa.gov/feature1.shtml>). If we could see sunspots in isolation, they would appear bright red. Compared to the bright surface around them, they appear as black spots.

1. Label examples of sunspot umbra and penumbra, faculae, and limb darkening in the following image, which is a visible-light image of the sun:



Above the photosphere is the chromosphere (<http://solarscience.msfc.nasa.gov/chromos.shtml>) where features like filaments and prominences can be seen (<http://solarscience.msfc.nasa.gov/feature2.shtml>)

2. We can observe the chromosphere by using a Hydrogen-alpha filter, which blocks all wavelengths of light except for one particular wavelength of red light that is emitted by very hot hydrogen in the chromosphere. A sample Hydrogen-alpha image is shown below. Label examples of filaments, prominences, and plage.



3. Is the hydrogen-alpha wavelength of light present in a visible-light image of the sun?
4. Why wouldn't we be able to see the features of the chromosphere in a simple visible light image of the sun?

Finally, the outer layer of the sun is the corona (<http://solar.physics.montana.edu/ypop/Program/corona1.html>) and has features like active regions (<http://solar.physics.montana.edu/ypop/Program/active1.html>) and loops (<http://solar.physics.montana.edu/ypop/Program/loops1.html>)

To see the corona, we can either look at x-ray images of the sun, since the corona emits strongly in x-rays, or we can block out the the face of the sun with a disk that obscures the image, so that the outer corona becomes visible. The disk is called an occulting disk and it creates an effect similar to a solar eclipse.

## Outdoor Observing of the Sun

There will be three stations set up outside to view the sun. You will record the visible features of the sun in on the following pages.

**Never look directly at the Sun!**

The three stations are:

- A. The Projection of the Sun
- B. Telescope with solar filter
- C. The H-alpha Image of the Sun

You will need to bring:

- A ruler
- Your lab printout
- A writing utensil

**Before you return to the lab, make sure you complete questions 1, 2, and 3 and 4 for the projection, question 10 and 11 for the filtered white light telescope, and questions 12 and 13 for the H-alpha image.**

## A. The Projection of the Sun

The solar image can be projected onto a piece of paper using a simple lens system. Instead of focusing the Sun's light to a point (which can set the paper on fire), we use a combination of lenses and mirrors to create a magnified image and spread the light out over a larger area.

1. Measure the size of the projected image's diameter in cm with a ruler. Compare with other student measurements and include an estimate of the uncertainty in your measurement:
2. Measure the size of the largest sunspot in the projected image. Compare with other student measurements and include an estimate of the uncertainty in your measurement:
3. Carefully draw an image of the Sun in visible light. Including any features you see (sunspots, faculae, granulation, limb darkening).

<b>Date:</b>	
<b>Time:</b>	
<b>Scale of image:</b>	

4. Give a brief written description of the features in your drawing.
  
  
  
  
  
  
  
  
  
  
5. The diameter of the Sun is  $1.4 \times 10^6$  km. Divide the actual diameter of the Sun in km by your measurement of the diameter in the projected image. How many km are there in 1 cm of the projected image?
  
  
  
  
  
  
  
  
  
  
6. Calculate the diameter of the sunspot on the Sun in km.
  
  
  
  
  
  
  
  
  
  
7. Calculate the scale of the image you drew on the previous page. How many km are there in 1 cm of your drawing? Write the scale below your drawing.
  
  
  
  
  
  
  
  
  
  
8. The diameter of the Earth is 13,000 km. What size would the Earth be in your drawing?
  
  
  
  
  
  
  
  
  
  
9. How many Earths can you fit into the largest Sun spot? Draw an Earth into your picture for scale.

## **B. The visible light filter**

A strong filter is used to evenly dim the light coming from the sun before it enters the telescope. The filter appears to be a reflective film, since it blocks such a large fraction of light. The telescope then magnifies the solar image for viewing by eye.

10. Carefully draw an image of the Sun in visible light. Including any features you see (sunspots, faculae, granulation, limb darkening). Draw the sunspot groups including the umbra and penumbra (label the umbra, penumbra).

**Date:**

**Time:**

11. Give a brief written description of the features in your drawing:

### C. The H-alpha filter

A H-alpha ( $H\alpha$ ) filter can also be used to block all wavelengths except 656.28 nm. It lets through the light that is emitted by hot hydrogen gas in the chromosphere of the sun.

12. Sketch the filtered image of the Sun including any features you see (sunspots, filaments, prominences). You may be able to see the same sunspot groups as the projection, but they will be dimmer.

<b>Date:</b>	
<b>Time:</b>	
<b>Scale of image:</b>	

13.

14. Estimate the height of the prominences compared the Sun's diameter (a fraction of the Sun's diameter). Measure your drawing for an accurate estimate.

15. The diameter of the Sun is  $1.4 \times 10^6$  km. Calculate the scale of the image you drew above. How many km are there in 1 cm of your drawing? Write the scale below your drawing.

16. What is the estimated size of a prominence in km?

17. The diameter of the Earth is 13,000 km. How many Earths high is a prominence?



# The changing Sun

We will use movies made from multiple observations to see how the sun behaves over a longer period of time than our single observing period.

## Rotation of the sun

The rotation period of an object is the time it takes to spin on its axis once. For example, the rotation period of the Earth is one (sidereal) day. In order to observe the rotation period of any rotating sphere, we can measure how many degrees of longitude a surface feature moves in a given time interval. We then solve for the period by taking the ratio of one full rotation (360 degrees) to the observed angular motion, and multiplying by the time interval. For example, if we observe that a given feature moves 30 degrees of longitude in 2 hours, then the rotation period  $P$  is:

$$P = 2 \text{ hours} \times 360^\circ / 30^\circ = 24 \text{ hours.}$$

(1)

This method can be applied to the rotation of the Sun by observing active regions as they are carried across the disk by the Sun's rotation.

Open the movie called `MDI-Sunspot-Crossings-2001-large.mpg` on the desktop and play the movie through a couple of times. The movie was made by combining images taken by the MDI camera. Notice at the top left there is a clock which shows the day and time each frame of the movie was taken. You should be able to see *sunspots* move across the Sun's photosphere.

1. The Sun's north pole, pointing towards Polaris, is towards the top of the movie image. Which way does the Sun rotate, as viewed from above its North pole?

Clockwise

Counterclockwise

2. We will now pick one sunspot near the Sun's equator and use it to measure the Sun's rotation period. Play the movie until you see a clearly identifiable sunspot near the equator of the Sun.
3. Pause the movie so that the sunspot is in the center of the Solar image (you may need to move the movie backwards and forwards to do this). Make a sketch of the Sun at this time in the chart on the following page. Label the sunspot that you have chosen. Make sure you label the date and time of your image.

<b>Date/time:</b>
<b>Appearance of sunspots:</b>

4. Press play and watch the sunspot move across the surface of the sun. Pause the movie at the point where the sunspot just disappears from view. What is the date and time when this happens?
5. How long (in days) did your sunspot take to move from the center of the Sun to just out of view? Include partial days (1 hour = 1/24 of a day).
6. How many degrees of longitude did the sunspot move through in this time?
7. Use equation (1) to compute the rotation period of the Sun (in days).

# Coronal Mass Ejections

A coronal mass ejection (CME) is an ejection of material from the solar corona, usually observed with a white-light coronagraph, such as SOHO's LASCO instrument. The ejected material is a plasma consisting primarily of electrons and protons (in addition to small quantities of heavier elements such as helium, oxygen, and iron). It is magnetized by the coronal magnetic field.

When the ejection reaches the Earth as an ICME (Interplanetary CME), it can disrupt the Earth's magnetosphere. The resulting geomagnetic storm leads to particularly bright and widespread aurora (the Northern Lights, an emission spectrum from energized gas in the upper atmosphere). CME events, along with solar flares, can also disrupt radio transmissions, cause power outages (blackouts), and cause damage to satellites and electrical transmission lines.

Open the movie called `C2_triple_best.mov` and watch it a couple of times. This movie is made from pictures of the Sun's corona taken by SOHO's LASCO Instrument. The C2 coronagraphs caught the action as three, separate coronal mass ejections (CMEs) blasted out in succession from the Sun (Dec. 12, 2010). These were each distinct and unconnected events. The first CME event (directly on the right) occurred when a magnetic filament erupted near the equator; the second one erupted near the Sun's north pole, and the last CME erupted on the far side of the Sun.

8. Notice the date and time display in the bottom left of the image. The white circle in the center of the image represents the size of the Sun. Using a ruler, measure the size of the white disk on your screen (in mm) and record your answer below.
  
9. The diameter of the Sun is  $1.4 \times 10^6$  km. Divide the actual diameter of the Sun in km by your measurement in mm to obtain the scale of the movie. How many km are there in 1 mm?
  
  
  
  
  
  
  
  
  
  
10. Pause the movie at 2010/12/12 04:00 and watch the next few frames of the movie. You can see a large coronal mass ejection consisting of the Sun's plasma eject from the right part of the Sun and move outward to the right.

Focus on the plasma in the middle of the loop. At what time does the loop mass of plasma becomes visible from behind the LASCO occulting disk? At what time does this plasma leave the region visible in the movie?

visible:

leaves:

11. How long (in seconds) did it take for the plasma to travel from the edge of the occulting disk to the edge of the image?
  
12. Measure the distance from the edge of the occulting disk where the plasma appeared to the edge of the image where it disappeared in mm and record your answer below. Then use your scale from Question 3 to convert this to km.
  
13. How fast did the plasma travel in km/s? Divide the distance it traveled in km by the time it took in seconds.
  
8. Using the formula below to convert this to miles per hour (mph):  
$$(\text{Speed in km/s}) \times (3600 \text{ s/hour}) / (1.6 \text{ km/mile}) = \text{speed in mph.}$$
  
9. How does this speed compare to a typical highway speed?