

*Open/Galactic and Globular Clusters*

# THE SUN

*Purpose:* This lab will acquaint you with the Sun, the star closest to Earth and the source of nearly all of the energy on Earth. We will look at a magnified view of the Sun to see much of the activity visible in its outer layers. The solar activity can have many direct consequences for life on Earth, which is one critical reason why scientists study the Sun constantly (literally).

## **Background**

Most of the light we see from the Sun is emitted because the Sun resembles a blackbody. That means the Sun shines light because it is hot. There are two important properties of blackbodies. One (Stefan's law) is that hotter things shine more light. (Mathematically, the power emitted per area depends on temperature<sup>4</sup>.) The other (Wien's law) says that things that are hotter emit most of their light at shorter wavelengths (e.g. towards the "blue" end of the spectrum) and things that are colder emit most of their light towards the "red" end. (Mathematically, the peak wavelength \* temperature is a constant.)

One of the most interesting results of solar activity is "solar flares" -- which we probably will not see. Flares are massive gas conglomerations that leave the Sun. If flares get near Earth, flares can have many effects detectable by humans. If the flare is sufficiently large, it can disrupt satellites, the International Space Station, or anything else in Earth orbit. Similarly, it can wreak havoc on satellites on the way to other places (e.g. Mars probes). During particularly active times, material (such as flares) from the Sun can disrupt cell-phone usage, cause radio and TV antennae to malfunction, and even cause garage door openers to open and close, though this last one is rare.

Our observations will almost definitely be limited to material that does not leave the Sun. Prominences may resemble your mental picture of a flare, but the two are very different phenomena. Prominences are usually falling back towards the Sun, not leaving it.

The Sun also emits a steady stream of matter called "solar wind." When such solar wind and other particles reach the Earth, the Earth's magnetic field usually diverts these particles to the north and south poles. When the diverted solar wind strikes the atmosphere, it causes the atmospheric atoms to fluoresce, causing the "northern" and "southern lights" (*aurorae borealis* or *aurorae australis*), arguably some of the most beautiful light displays ever seen. Solar wind is too faint for us to see with our equipment.

One last effect of the Sun: there seems to be a link between times when there are fewer-than-expected numbers of sunspots and terrestrial cold spells. The most famous such occurrence was between 1645 and 1715 when very few sunspots were observed. Up until that point, the 11-year sunspot cycle that had been "normal." This solar inactivity occurred during a particularly cold weather throughout much of the northern hemisphere. There are other examples of sunspot minima and cold spells, including one that devastated farmer's fruit crops in the mid 1800's. What links sunspots to cold weather is still not understood and is one of the more interesting mysteries in astronomy.

## **Directions**

Bring a PENCIL (not a pen), stopwatch, and a calculator to this lab. This lab will probably take between 1.5 and 2 hours. You will be sketching the Sun (more than once) and observing some of its most prominent features (listed below) just so you know what our star looks like. For homework, you will be computing sizes and speeds of things on the Sun and comparing it to familiar objects/sizes. *The homework portion of this lab is fairly involved – I sincerely suggest you start as soon as you can.*

**Eight solar features that will be visible during class that you should label on your drawings**

1. **Sunspots** – the dark inner part is called the umbra, while the outer, gray areas are the penumbra – do not confuse this context with eclipses, which use the same words. Label both parts when visible.
2. **Prominences** – cloudlike eruptions from the surface that usually fall back down; they look dark if seen in front of the Sun. They look bright if seen in front of empty space.
3. **Facula** – the inverse of sunspots; they look brighter than average on the Sun. Also called “*plages*.”
4. **Spicule** – small flame-like, quickly moving prominences (but NOT flares – they don’t leave the Sun’s surface as quickly or violently as flares. We probably won’t see any flares!)
5. **Granulation** – convection cells that visibly show energy transportation; this will look somewhat like the surface of the ocean, but it will “wave” much slower
6. **Limb darkening** – the edge of the Sun appears darker than its immediate surroundings. Do not confuse this with “seeing.” (See the vocabulary, page **Error! Bookmark not defined.**)
7. **Chromosphere** – the layer of the Sun just outside the photosphere
8. **Photosphere** (you do not need to draw this one separately – just label it.) – the part of the Sun where light escapes (i.e. the “surface”)

The Equipment

**Outdoor telescopes** - The outdoor telescopes are the same ones we have used throughout the class, except these are covered with a film of aluminized mylar (which looks like aluminum foil) or a similar filter located above the Schmidt corrector plate. The filter blocks most sunlight, allowing for safe viewing. The “regular” mylar does not change the apparent color of the Sun, while the more sophisticated-looking “solar filter” will make the Sun appear slightly orange. The true color of the Sun would be white through an uncolored filter!

**Observatory telescope** - This telescope is a 16-inch telescope similar to the C-8’s outdoors. This telescope is equipped with a Hydrogen-alpha (H- $\alpha$ ) filter, which allows only one specific wavelength (a magenta color) of light to pass. This wavelength is at 656 nm, the same wavelength as light emitted by ionized or excited hydrogen as electrons are jumping back down to a lower state. Many of the clearly defined features you see on the Sun are due to ionized hydrogen, while others are just “regular” hot hydrogen.

**What to do during the lab session**

Indoor telescope – do this first!

- 1) Draw a detailed sketch of the Sun and label as many of the eight items listed as possible. You should accurately draw the size, shape, and location of the items. You may not see the faculae or limb darkening through this telescope, but you should see the other items.
- 2) When drawing the Sun, make sure that the circle on the sketch sheet represents the entire field of view (as always). Also make sure that you draw things to scale, as much as possible, including the curvature of the Sun. You will be estimating the physical size and speed of the observed features by comparing this drawing to your other drawings. You will need to be able to estimate how big the Sun would appear on your sheet if you could see the entire Sun.
- 3) Label the NSEW directions.
- 4) **Drift time at least one prominence for each indoor drawing.** Feel free to drift time other features according to your curiosity.
- 5) Do a second drawing, paying careful attention to the prominences, an hour (or more) after you first sketch them. The reason for this is to look for changes. During this second look, make a sketch and carefully note any changes in the prominence shapes that you observe. Don’t forget to **drift-time the prominence again** after that hour, so you can later determine how quickly it moved/change shape.

You will use these drift-time calculations to estimate the size of several features. As there is only one of the high-magnification hydrogen-filtered telescopes, and you must use it twice, I suggest you get into the 16-inch telescope line as soon as you arrive.

Outdoor telescopes: Look through the eyepiece and draw a detailed sketch of the entire solar surface as seen through the telescopes. This sketch should include any visible large sunspots, including the penumbrae and umbrae, any visible faculae, and limb darkening. A careful eye will see all of these. Switch to high magnification and draw detailed sketches of the visible items listed above. Also do a drift timing across the Sun's diameter three times.

### What to submit

- A) [6 pts] All of four (or more) of your sketches and accompanying notes. Two drawings will be indoors, one will be outdoors with low-magnification, and at least 1 more will be outdoors on high magnification to highlight the listed features.
- B) A note about the drift times for the Sun's entire disk (measured 3 times in the outdoor telescope). This will be necessary to answer many of the questions below.

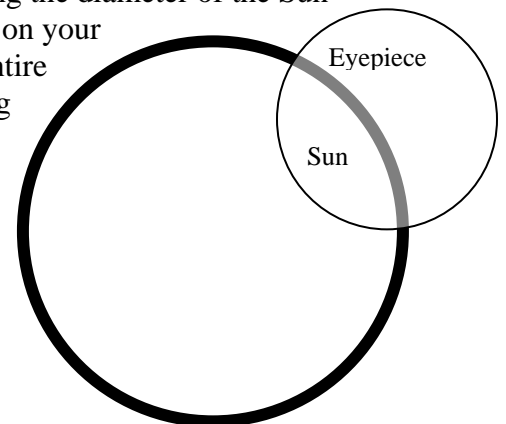
Each sketch should include:

- C) Any features large enough to see and measure
- D) Any drift times measured
- E) Anything that you saw but had trouble drawing should be described in as much detail as possible in the notes of the observation sheet.

### *Questions*

#### **Sizes and speeds – these questions require a calculator**

- [1.5 pt] Knowing that the Sun is  $1.5 \times 10^{11}$  meters away (i.e. 150 million kilometers or 93 million miles) from Earth, compute the physical size of the Sun. Refer to page **Error! Bookmark not defined.** about computing sizes from angles to aid with this calculation. Show your work.
- [1/2 pt] What is the real diameter of the Sun, according to your research? Convert your answer to the same units you used in question #1. Cite your source or you will receive no credit!
- [1 pt] What was the percent difference between your answer and the true answer? Why might these answers be different? Why shouldn't they be too different? [Refer to the "Percents" section of the "Rounding, Ratios, and Percents" on page **Error! Bookmark not defined.** to compute percent difference.]
- [1/2 pt] Knowing that the Earth's diameter is 12800 km (8000 miles), A) how many Earths could fit across the Sun? Show your work. B) The Earth's diameter is what percent of the Sun's diameter? (In other words, if 20 Earths fit across the Sun, the Earth's diameter is  $1/20 \times 100\% = 5\%$  the diameter of the Sun.)
- [1.5 pt] Compute the physical size of one sunspot on your drawing. Indicate which sunspot you are using and show your work.
- [1.5 pt] Using the angle measured by drift timing, compute the physical size of a prominence on your drawing. Show your work and note which direction was east/west on the prominence, since you can only drift-time in the E/W direction. [See "Computing distances" on page **Error! Bookmark not defined.** for this question and the next.]
- [2.5 pts] Use your indoor drawing (not drift timing) for this part. Knowing the diameter of the Sun (see question 1 or 2), compute the size of a prominence based on its size on your drawing. NOTE: your indoor drawing probably does NOT contain the entire Sun. You will need to estimate the size of the Sun's diameter by guessing how big the Sun would be if you could see all of it through the eyepiece. You can make this estimate by filling in the rest of the Sun, as shown to the right. The thick black line would be the estimated Sun diameter, while the gray portion, inside the eyepiece's FOV, would be what you drew. For instance, if the Sun's diameter, in your estimated drawing is 8 inches, and the prominence is  $1/2$  inch, the Sun's physical size is  $8 \div 1/2 = 16$  times larger than the prominence. Refer to page **Error! Bookmark not defined.**





8. [1 pt] Which method – drift timing or drawing (as done in the previous question) do you think is more accurate and precise for making size measurements? Why?
9. [1/2 pt] Is the Earth larger or smaller than your prominence? How many of the smaller objects (i.e. the Earth or the prominence) can fit across the larger object (i.e. the prominence or the Earth?)
10. [2.5 pts] Hopefully, you saw your prominence change noticeably during the 1-hour timespan. Figure out the physical speed of the material in the prominence by determining how much it moved/grew/shrunk during the one hour. Convert your answers to miles per hour. (Notes: 1 mile = 1.6 km and 1 hr = 3600 sec, 1 min = 60 sec.)

### Solar appearance

11. [1.5 pt] Based on the fact that sunspots and the edge of the Sun appear darker than the average parts of the Sun, what can you conclude about the sunspots and limb darkened areas? For 2.5 pts **Extra Credit**, explain why the limb of the Sun looks darker, even though the Sun is a symmetric sphere. (In other words why does the edge LOOK darker, even though it isn't really.) You'll have to do some research for this extra credit question, probably. *Hint*: blackbody property.
12. [1 pt] Based on your answer to the previous question, what kind of light do sunspots emit the most of? (Hint: the regular surface of the Sun emits mostly visible [yellow] light.)
13. [1 pt] Explain why if the Sun is darker than average in some places (i.e. sunspots) it must be brighter than average in other parts. (This is not a question that requires any research – think about what average means.)
14. [1.5 pt] Using your drawings and/or timings, estimate the observed thickness of the chromosphere in physical units (e.g. meters, kilometers, or miles). Show your work.
15. [1 pt] According to your research, approximately what is the thickness of the chromosphere? What is the percent error in your measurement? What do you think caused this difference?

This lab is due not this upcoming week, but the week after that. Bring questions about it to class this week. Because there are a lot of questions and calculations, DO NOT PUT THIS OFF TO THE LAST MINUTE!