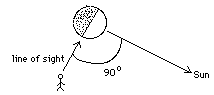
Union College Spring 2016

**Astronomy 50 Lab: Distance and Size of the Sun**

**Introduction:**

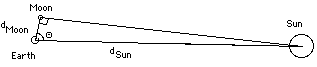
In this lab, you make use of a special geometrical arrangement involving the Earth, Moon, and Sun, and trigonometry to infer the distance of the Sun, and then use that to infer the diameter of the Sun as well.

The special arrangement occurs when we see exactly half of the lit side of the Moon, as shown in Figure 1. In this situation, the angle between our line of sight to the Moon and the direction to the Sun from the Moon is 90o.



**Figure 1**: When we see exactly half of the lit side of the Moon, our line of sight to the Moon makes a 90o angle with the line from the Moon to the Sun.

So, then, when we see the Moon exactly half lit (i.e. lunar phase of “1st quarter”), we know that the Earth, Moon, and Sun must make a right triangle with the right angle at the Moon (as depicted in the Figure 2).



**Figure 2**: The right triangle of the Earth-Moon-Sun system when we see exactly half of the lit side of the Moon.

We can, then, measure the angle, , between the Sun and Moon from our perspective on the Earth and use trigonometry to determine the ratio of any two sides. As you can see in Figure 2, the distance from the Earth to the Moon is the angle adjacent to  and the distance from the Earth to the Sun is the hypotenuse. Therefore, we get a relation between the distance of the Moon and the distance of the Sun through the cosine of this angle, as given in Equation 1.

**cos= dMoon/dSun . (1)**

**Historical Perspective:**

Aristarchus, an astronomer residing in Alexandria during the Greek empire, used this method to determine that the Sun is about 20 times further than the Moon. And, since the Moon and Sun appear to be the same angular size, or we wouldn’t get such perfect solar eclipses, the Sun must be at least 20 times larger than the Moon. Furthermore, from the shape of the Earth’s shadow on the Moon during lunar eclipses, the Earth was known to not be *that* much bigger than the Moon, so Aristarchus’ measurements also indicated that the Sun was also significantly larger than the Earth. Aristarchus did not believe that it was reasonable for such a large object to be orbiting around a significantly smaller one and so proposed a Heliocentric (Sun-centered) model of the Universe. His arguments went unheeded, however, and most of his writings have been lost through the years. His measurement was qualitatively correct, but much smaller than the correct value.

**Measuring the Angle:**

Fortunately, the Moon is visible in the daylight, so the angle between the Moon and Sun can be measured directly whenever both objects are above the horizon at the same time. This measurement, actually, requires high accuracy, because the angle that we observe will be very close to 90o, and if we obtain an angle larger than 90o, then the whole analysis makes no sense. The fact that Aristarchus only measured the ratio of the distances to be 20 (when it is, in fact, much greater) shows just how difficult this measurement is. To improve the accuracy of this lab, you will use a specially designed instrument (provided). The instrument uses the shadow cast by a washer onto another washer to get a precise determination of the Sun’s direction, and a camera to yield an accurate sighting angle of the Moon. Use this instrument as instructed to obtain the angle between the Sun and Moon.

**The Time of Half-Moon:**

The most difficult part of this measurement is knowing the exact moment when we are viewing exactly half of the lit side of the Moon. Because this observation requires great accuracy, we’ll cheat a bit on this one lab and use the exact time of “1st quarter Moon” listed on the astronomical almanac web page (<http://aa.usno.navy.mil/data/docs/MoonPhase.php>). This month, the 1st quarter moon occurs at April 13th at 11:59 pm (Eastern Daylight-Savings time). By knowing the exact moment for this measurement, one of the largest sources of error has been removed and so, hopefully, you should get a measure of the relative distances better than Aristarchus did.

To further enhance the reliability of your result, we will also make many measurements at many times. We will make use of all these measurements by plotting them. Making and plotting measurements at many different times is helpful also because the time of half-moon happens to occur at midnight for us, and we can't see the Sun at this time. By measuring the angle at other times and creating a plot, we can interpolate the value of the angle for any time. To make our many measurements this week, we must schedule meeting times based on the times when both the Moon and Sun are visible. The Sun sets shortly after 7:35 this week, so times between one hour after the Moonrise times listed in Table 1 and 7:30 pm should work. (The one hour after Moonrise is to give the Moon time to rise over the buildings on the eastern end of campus).

**Table 1**: Sunset and Moonrise times this week.

|  |  |  |
| --- | --- | --- |
| **day** | **moonrise** | **time(s) to meet:** |
| Tue, 12-Apr | 10:36 am | in class + |
| Wed | 11:34 |  |
| Thur | 12:33 pm |  |
| Fri | 1:33 pm |  |
| Sat | 2:32 pm |  |
| Sun | 3:31 pm |  |

**Making the Plot** (to be done in lab, April 19)

Plot angle on the y-axis and time on the x-axis. In Excel one can plot times AND dates on one axis. However, this will not be useful for our analysis. Instead you need to convert all your dates and time to numbers (with decimals) in units of days. That is, choose some day and time to be time 0. And then each second is a 1/60 of a minute and each minute is a 1/60 of an hour. Similarly, each hour is 1/24 of a day.

When you have all your numbers ready for plotting, plot them with Excel and have the program determine the best fit line (use “linear”) for the data. Your program should give you an equation for that line in the form y = mx+b. Then you need only to determine what x corresponds to your half-moon time, put it into the equation for the best-fit line and solve for y. This is your angle between the Sun and Moon at the half-moon, or angle  in figure 1.

Your final value of , hopefully, is less than 90o. If not, then your conclusion (and what you should say in your report) is that this experiment was not successful with the measuring method used. A more sensitive device is needed. If your final angle is less than 90o, follow through the analysis using equation (1) to find the distance of the Sun. You will need to use the distance of the Moon. This is being measured by another lab section. So, watch for that report in the Ast50 lab journal, and that use the distance given there, and cite that report as your reference.

**Determining the Diameter of the Sun**

You can also infer the diameter of the Sun. The physical size of an object is related to its angular size and its distance. If  is the angular size, D is the diameter, and d is the distance, then

(in radians)=D/d. (2)

However, DO NOT measure the angular size of the Sun directly (I don’t want you to lose your eyesight just for this lab). Because of the fact that we get such wonderful solar eclipses, we know that the Sun has the same angular size as the Moon, so you need only to measure the angular size of the Moon and use that in Equation 2. To measure the angular size of the Moon, use your cross-staff (from lab 1), which gives the angle in degrees. Before using Equation 2, you need to convert from degrees to radians (by multplying by /180). Plug the angular size in radians into Equation 2, along with your distance of the Sun to obtain a determination of the diameter of the Sun.

**Questions to Consider for Discussion in Report:**

1. Considering how close the half-moon angle is to 90o, how difficult is it to accurately measure the distance to the Sun by this method? As a demonstration, increase your angle by just 0.1o and recalculate the distance to Sun and note by how much it changes. How accurately do you think you were able to measure the angles?

2. According to your results, how many times further is the Sun than the Moon? Since it took the Apollo astronauts 3 days to travel to the Moon, roughly how long it would it take astronauts to travel a distance equal to the of the Sun?

3. Using your measured values and that reported in the Astro 50 lab journal, in terms of diameter, how much larger is the Sun than the Earth? Considering that we now know that gravity dictates the motions of astronomical bodies, and that gravity depends on a body’s mass, which is related to its size, does the size of the Sun relative to the Earth make a strong argument for a heliocentric (Sun-centered) model over a geocentric (Earth-centered) model of our Solar system?

**Table 2**: Measured values of angle between Sun and Moon

|  |  |  |
| --- | --- | --- |
| Date and Time | Number of days since start | Angle between Sun and Moon (degrees) |
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Best fit line equation to data: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Number of days since start that 1st quarter Moon occurs = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Angle between Sun and Moon at 1st quarter = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Distance of Moon = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (reference = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_)

Distance of Sun = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Angular size of Moon in degrees = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Angular size of Sun in radians = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Diameter of Sun = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_