Physics 10293 Online Lab #3:
Stellar Parallax

Due Date: Thu Apr 16, 11:59pm CDT

Online Lab Instructions

Although we will not be doing these labs together in the classroom, please remember as you work through this that you are not alone. Your lab instructor will be happy to help answer any questions you have about the lab, either via email or in the discussion forum on your D2L course shell.

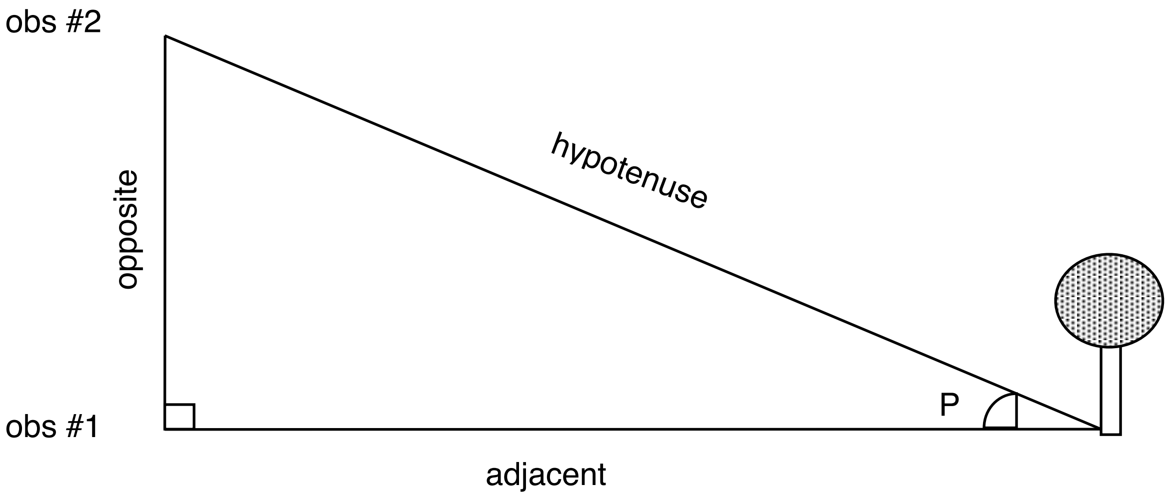
Ideally, you should print out this lab, answer the questions, and then scan it or take pictures of each page, and send that completed work to your TA by the deadline. If you are unable to print out the lab, please just answer each question on your own paper and submit that work to your TA by the deadline.

Introduction

Parallax is a distance determination technique that uses geometry to measure the distance to some object when other means (such as a ruler or tape measure) won't suffice. On Earth, surveyors call this technique triangulation. In this lab, we will learn about parallax and how it applies to stars. You will need to use a calculator for this lab, one capable of performing trig functions like sin, cos and tan.

Part 1

In the diagram below, we want to measure the distance to a tree that we cannot walk to (perhaps a river is in the way). So we measure its position from two different observation points, drawing a line from each point to the tree and a line connecting our two observation points as shown below.

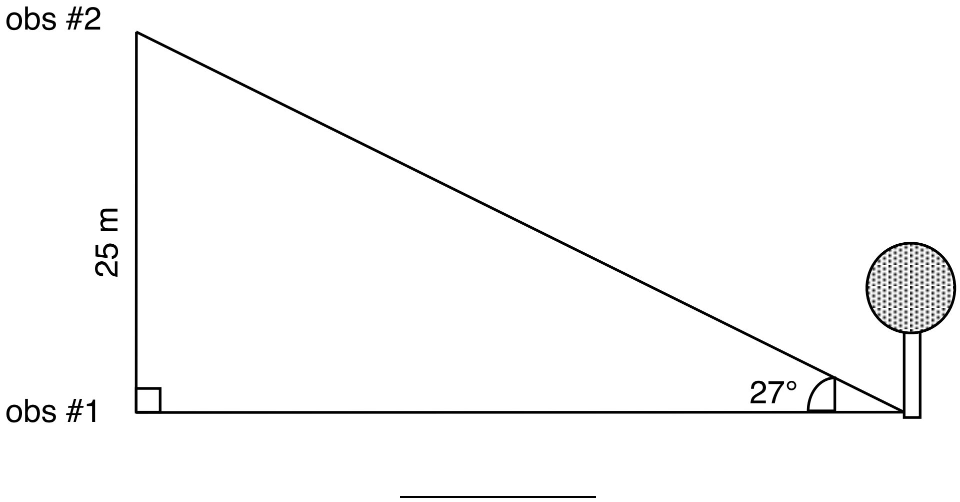


If we physically walk from observation point #1 to observation point #2, then we know that distance. Let's assume it is 25 meters. Using a protractor or other angular measuring device, we can also determine angle P. Let's assume that angle P is 27 degrees.

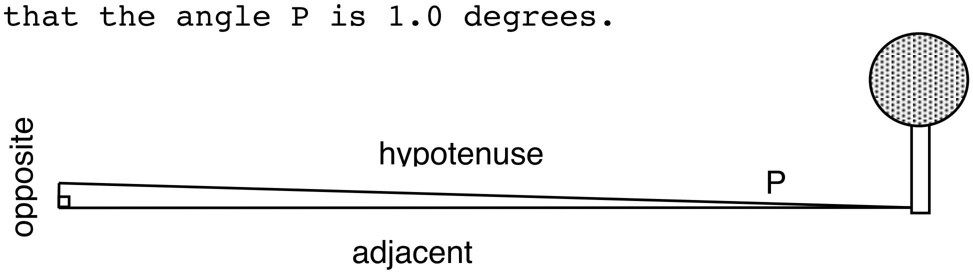
Basic geometry tells us that for angle P,

sin (P) = opposite / hypotenuse
cos (P) = adjacent / hypotenuse
tan (P) = opposite / adjacent

Q1. Use the sin, cos or tan equations to help determine the lengths of the hypotenuse and adjacent side of this triangle and write those values next to the corresponding sides on the diagram below.

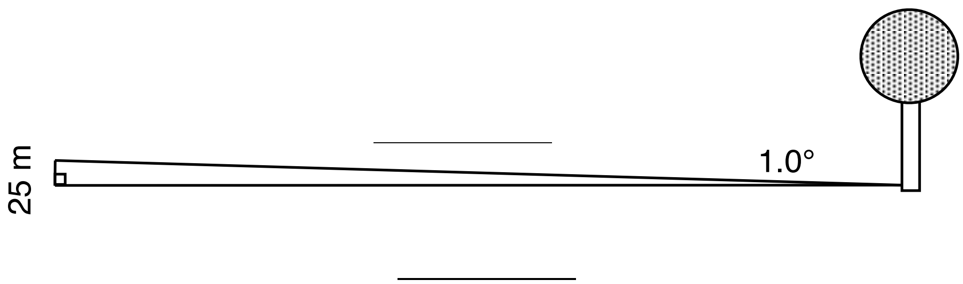


In Astronomy, the angles we measure are much smaller. On the diagram below, assume the opposite side is 25 meters and that the angle P is 1.0 degrees.



Notice that in the second case, the values for the adjacent side and the hypotenuse are nearly identical. For very small angles, this will always be the case, so it doesn't really matter in our triangle which of the two sides we calculate.

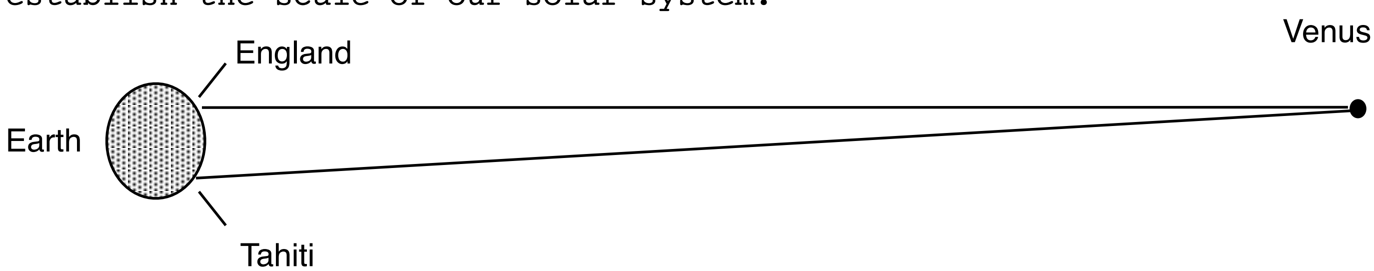
Q2. Use the sin, cos or tan equations to determine the lengths of the hypotenuse (upper) and the adjacent side (lower) and fill these values in next to the corresponding sides on the diagram below.



Part 2

Historically, parallax played a significant role in our study of the solar system and our galaxy. In a famous story from the history of Astronomy, an explorer named Captain James Cook sailed to the distant island of Tahiti. Part of his mission was to measure the timing of the transit of Venus across the Sun.

While Cook was making his measurements, astronomers were also timing the transit from England. We know the staight-line distance (through the Earth) between England and Tahiti. We can also calculate the angle P (**the parallax angle**) based on the time delay between transits. We then use this information to deduce the distance from Earth to Venus and, for the first time, establish the scale of our solar system.



Prior to this, Astronomers couldn’t reliably use parallax to measure the distances to planets because the positions of the planets could not be measured precisely enough from two different locations simultaneously. Even if one person tried to do both measurements with the same instruments, it took time to travel across the Earth from one observation point to another, and in that time, the planet would inevitably move on its own against the starry background, making the parallax measurement impossible.

The stars themselves, however, do not move significantly in the sky over time, and so there was some hope we could use parallax to determine how far away the stars are. Sirius is the brightest star in the sky, and astronomers (correctly) deduced that one reason for its brightness is that it is closer to the Earth than most other stars.

A quick aside about angular measurements: for small angles, we do not use degrees but instead arcminutes and arcseconds.

1 degree = 60 arcminutes = 3600 arcseconds.
1 arcmin = 0.167 degrees
1 arcsec = 0.000278 degrees

Attempts were made to accurately measure the position of the star Sirius from two different locations on the Earth. Our most accurate observations at the time, however, could only measure angles as small as 1/120th of a degree, which is 30 arcsec.

Work through the example below to determine the parallax angle of Sirius if it is viewed from two places on the Earth approximately 3000 miles apart.

Q3. The distance to Sirius is 50.5 trillion miles, or 5.05 x 10^{13} miles. Use this for your hypotenuse and 3000 miles for your opposite side (we call this the baseline) and determine the parallax angle (P in our triangles on the first two pages of the lab) for Sirius in degrees. Use scientific notation to express this answer, ask your lab instructor for help if you need it. Convert this value to arcseconds using the formula above that tells you how many degrees equals an arcsecond.

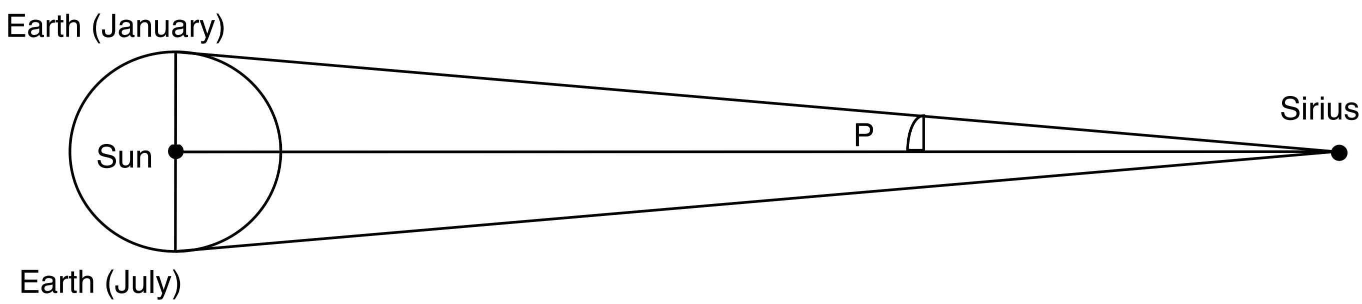
P = _________x $10^{\_\_\_\_}$ degrees

P = ____________________ arcsec

Since we could at that time only measure angles as small as 30 arcsec, you can see from your answer that the parallax angle of Sirius measured in this way is about a million times too small.

In fact, Astronomers tried in vain to measure parallax angles for many stars and were completely unsuccessful at this time. We know today that the reason for this lack of success is due to the great distances to stars (hence, extremely small parallax angles).

According to the ideas promoted by Galileo, Copernicus and Kepler, the Earth orbits around the Sun. Astronomers realized that we could use this to our advantage in measuring parallax angles.



Instead of using 3000 miles on the Earth as a baseline, we can use the radius of Earth's orbit (93 million miles). To improve accuracy, we can even use the whole diameter of Earth's orbit so that the tiny angle we are trying to measure is twice as big, but to keep it simple, let's stick with the radius.

Use the radius of Earth's orbit as your opposite side (baseline) and the distance to Sirius as your hypotenuse to determine the parallax angle (P) of Sirius. This is the proper way to determine parallax and the method Astronomers still use today.

Q4. Redo the parallax angle for Sirius using 93,000,000 miles as your baseline distance (this uses the Earth's orbit as the baseline rather than two points on Earth). Use this to determine the parallax angle for Sirius in degrees and arcseconds.

P = ________________ degrees

P = ________________ arcsec

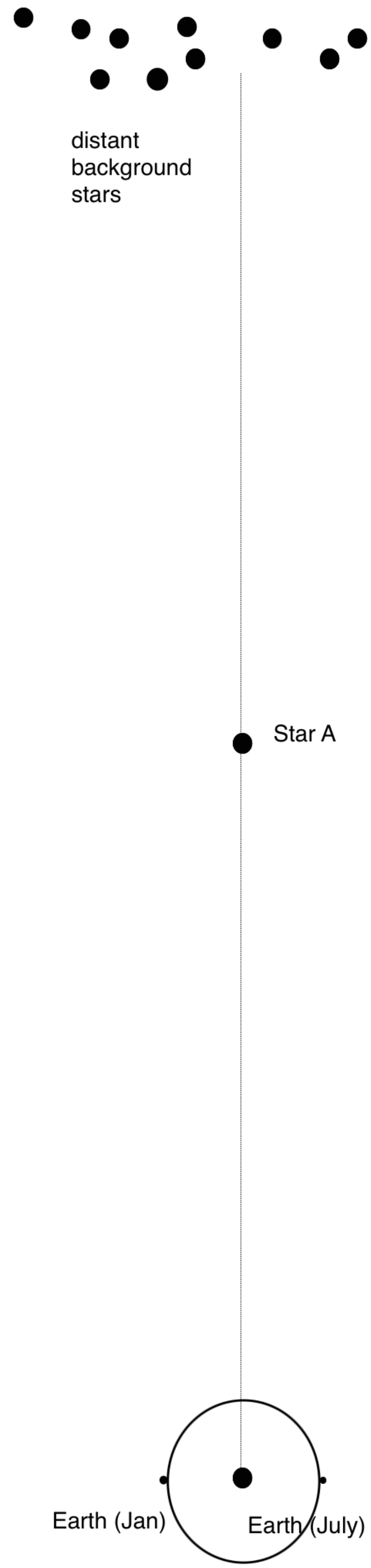
Even with this larger baseline, the parallax angle was STILL much smaller than 30 arcsec and so impossible to measure for astronomers of that era.

At the time, however, many Astronomers were unwilling to accept the idea that stars were so far away. In order for the parallax angle of Sirius to be too small to measure, they calculated that it would have to be at least 5000 times further away than the most distant planet known at the time (Saturn). From a philosophical standpoint, they thought it was absurd that God would waste so much space. They felt it reasonable to assume that the stars are much closer.

The lack of an observed parallax angle, then, would be explained by the fact that Earth doesn't really orbit the Sun. After all, there are two reasons a parallax angle might be small: Either the distance to the object (the hypotenuse) is really big or the baseline (the opposite side) is really small. We will explore that concept more thoroughly in part 3.

Q5, **Q6** and **Q7** (next page). If you are unable to print the diagram on the next page, please do your best to try to draw it on your own paper so that you can draw the requested lines and answer the three questions on the next page.

Part 3



On the diagram to your right, draw a line from Earth (in January) through star A and to the distant background stars. USE A RULER FOR A STRAIGHT LINE.

You now have a narrow parallax triangle with the radius of Earth's orbit as the baseline. The small angle just below star A is your parallax angle P, the Earth's orbital radius is the side opposite, and the distance to the star is the hypotenuse of this triangle. Label the parallax angle P_A.

On this same diagram, draw a second star (star B) on the dashed vertical line farther from the Sun than star A. Now in a different color or perhaps with a dashed line, draw a line from Earth (in January) to star B. Label the parallax angle for this star P_B.

Which star, A or B, has the larger parallax angle?

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Consider the following two statements regarding this exercise:

#1: The parallax angle of star B should be larger because star B is further away.

#2: Star B is further away, so its triangle is sharper or narrower. That means the parallax angle is smaller.

Which statement is right?

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Consider the parallax angle of star A. If Earth's orbital radius (our baseline) were smaller, the parallax angle of star A would be

_________________.

So there are two ways to explain a star having a very small (unmeasurably small) parallax angle: either the star's distance is incredibly large or the baseline we are using is very small (about 3000 miles instead of the 93,000,000 mile radius of Earth's orbit).

Q8. In your own words, explain why Astronomers of Galileo's era were unable to measure parallax angles for nearby stars like Sirius.

Q9. Next, in your own words, explain how they used the lack of measured parallax as a way to argue against the Copernican sun-centered (heliocentric) model in which the Earth revolves around the Sun. Instead, they used the lack of parallax to support the old Earth-centered (geocentric) model in which the Earth doesn't move and all of the planets, including the Sun, orbit the Earth.