The Parallax Experience

Objective: Understand parallax and use it to determine the distance to an object.

Materials:

- Protractor
- Tape measure
- Calculator

Introduction:

If you want to know how far it is from you to the wall in the front of your classroom, you can simply take out a tape measure or some other type of measuring device, and directly measure the distance. But how would you measure the distance to the Moon or to the planet Venus or to our nearest stellar neighbor, Proxima Centauri? We can't do it with a ruler or measuring tape, we need to use another method, called the parallax method. Parallax was originally used to find the distances between the Earth and nearby stars, but you can use a similar method to measure the distances to much closer objects, including objects in this room.

Let us determine the distance to an object by considering a method that involves observing objects simultaneously that are different distances from you.

Procedure:

1. Face an object at a distance of approximately 10-15 feet. Notice its position relative to more distant objects, at least 50 ft away. Now move about 2 meters to your right or left and notice the position of the object again relative to the more distant objects. Write a brief description of what you see.

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2. Move closer to the object and repeat your observations. Again, write a brief description of what you see.

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3. Move farther away from the object and repeat your observations. One last time, write a brief description of what you see.

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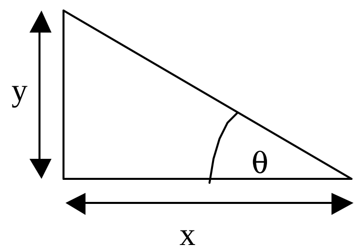
4. Based on your results (and a little geometry), can you develop a quantitative method that would determine the distance to an object based on observing it against a distant background, if you repeat the observations from different locations?

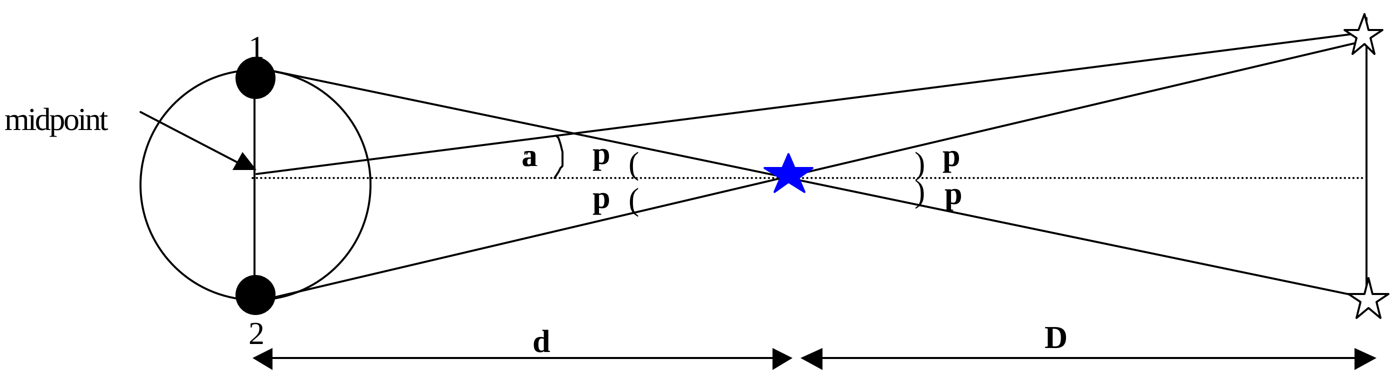
An Introduction to Parallax

How can making observations of how different objects appear to line up when observed from different locations lead us to a distance? And how can this method work for determining distances to nearby stars? It all makes sense when you draw a diagram or two and apply some simple mathematics. You will need to know and recall the definition for a tangent. It can be thought of as the ratio of the length of the opposite (y) over the adjacent (x) legs of a right triangle.



$\tan \theta = y/x$

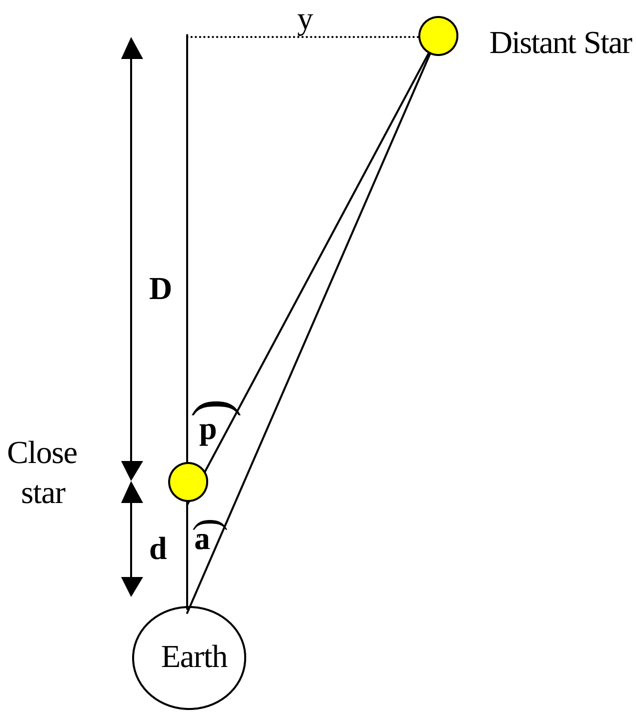
Below we see a schematic of the Earth orbiting the Sun, in which we make two observations of a close star. We compare the positions of the close star to that of more distant stars. We observe the close star at positions 1 and 2 on opposite sides of our orbit (6 months apart). We measure twice the parallax angle (or 2**p**) after the Earth orbits for 6 months. The diagram below defines the parallax angle **p** and another angle **a** , which is the angle to the distant star. The distances **d** (from the midpoint to the close star) and **D** (from the close star to the distant star) are also defined in this diagram.



$$\tan(\mathbf{p}) = \frac{\text{distance from midpoint to either Point \#1 or \#2}}{\text{distance from midpoint to close star}}$$

Let us now examine the assumption we will make, namely, that the angle **a** we measure from the distant star to the midpoint has essentially the same value as the parallax angle **p** between Earth, the close star and the midpoint.

We can look at the situation in a slightly different way. Carefully examine the diagram below. We want to show that when distance **D** is much greater than distance **d**, the angle **a** is essentially equal to the parallax angle **p.**



A short informal proof (with numerical examples):

- Distance from Earth to "close" star d = 4 light years
- Perpendicular distance from close star to distant star D = 50 light years
- tan(**a**) = y/54
- tan(**p**) = y/50
- At even greater distances, like millions of light years, the tangents of the angles become even closer in value

- Therefore, for the distances we want to consider,

  tan(**a**) = tan(**p**)

  a = **p**

Try It!

See if you can determine the distance to an object using the method of parallax.

Procedure:

1. Along a line which we will refer to as the Observation Line, place two marks about 10 ft apart. Call these 2 marks Point #1 and Point #2. Measure the distance between these two points with your measuring tape and enter the data in the Data Table.
2. Perpendicular to this line and from halfway in between Points #1 and #2, march off a distance of about 20 ft and put a student there. This student will represent the "Test Object" to which we will try to determine the distance.
3. Continue along the perpendicular line to a distance of about 100 ft from the Observation Line. Put tape down for the Observation Line. Along a line parallel to the line between Points #1 and #2, have 2 students ready to become the "Alignment Objects".
4. Each student in the class should take a turn as the Observer. The Observer should stand at Point #1 and give directions to one of the Alignment Objects students on where to stand so that they appear to be in a straight line through the test Object. Repeat this procedure from Point #2 using the other Alignment Object student.
5. The Observer now stands at the halfway point on the line between Points #1 and #2. Using a protractor, measure the angle between the centers of the Test Object and the Alignment Object observed from Point #1. Enter this angle in the Data Table.
6. Repeat the measurement for the Point #2 Alignment Object. Again, enter the angle in the Data Table.
7. Measure th4e distance from the midpoint of the Observation Line to the test Object. Enter this value in your Data Table.

Data Table
Distance between Point #1 and Point #2: ____________________________________
Angle ($\propto$) to Alignment Objects: Point #1 Object ____________________ Point #2 Object ____________________
Distance from midpoint of Observation Line to Test Object: ____________________

Analysis:

• Using the parallax method and the data from your observations, determine the distance from you to the Test Object. Recall that tan (α) = R/d, where α is the angle you measured, and R is half the distance between Points #1 and #2. Use some algebraic reasoning and a calculator to determine d, the distance between you and the Test Object. Show your calculations.

• Compare the value you determined via the parallax method to the value you measured with the measuring tape.

• What were the sources of error in your experiment?

• How will these error sources become more or less important when you apply them to the angles and distances involved in the cosmos?