# Mission 3
# Calculating Stellar Distances

## How Far Away Are the Stars?

### Notes

*In Mission* 2, *students watched a PowerPoint slide show and saw* Voyager *leave Earth, en route to the stars. How far away are the stars? How can we know how far away they are if we cannot actually go there?*

## Overview

In this mission, students learn how scientists determine the distances to nearby stars. In Mission 3.1 students experiment with the triangulation method which is used to calculate the distance to an object when the distance cannot be measured directly. Students are guided in inferring that a similar method can be used to find the distances to nearby stars. In Mission 3.2, students investigate triangulating the distance to the stars that are closest to Earth. Students relate this to the concept of *parallax*, the apparent change in the position of any object when observed from two different positions.

## Mission 3.1
## Materials

### For a Class of 30

- Measuring tape, preferably 8 meters (25 feet) or longer

### For Each Team

- 10 meters of string or fishing line
- 2 straws
- Cardboard
- Glue
- Scissors
- Tape
- Meter stick
- Overhead projector
- “Triangulation” transparency (page xx)
- *(optional)* Calculators

### For Each Student

- “Triangulation in the Field” worksheet (pages xxxx)
- “Triangulation Data Analysis” worksheet (pages xxxx)
- “Triangulation Questions” worksheet (page xx)
- “Making a Triangulation Tool” directions (pages xxxx)
- Pencil
- Sheets of plain white paper

## Getting Ready

1. Select an area outdoors with a distant object, such as a tree, that is between 100 and 250 feet away. Make an exact measurement from the distant object to the place where your students will stand to do their triangulation. Choose an object such that students will be able to verify their triangulation with a direct measurement.

2. Copy the three “Triangulation” worksheets and the “Making a Triangulation Tool” directions for each student.

3. Set up the PowerPoint projector.

## Classroom Action

1. **Lecture.** Explain to students that today they will learn a technique that will enable them to measure the distance to an object indirectly without actually walking to the object. Explain that this is a necessity when measuring the distance to objects (such as stars) that are too far away for direct measurement. Explain the basics of triangulation.

2. **Activity.** Divide the class into teams of three to four students each. Hand out the “Making a Triangulation Tool” directions to each student. Distribute the string or fishing line, the straws, cardboard, glue, scissors, tape, and meter sticks. Encourage student teams to make their triangulation tools. (Optionally, use plastic protractors instead of the paper ones.)

3. **Demonstration and Transparency.** Hand out the three “Triangulation” worksheets to each student. Use the “Triangulation” transparency to explain the concept. Tell students that you will model the use of triangulation tools. You may wish to do this outside. Choose two (or three) students to help you demonstrate because three (or four) students will be working together in teams.

   First, locate your distant object. Mark a l0-meter-long line AB on the ground. This may be done with chalk, string, or tape. The line should be roughly perpendicular to the distant object that is being sighted. In each team, two students will hold the protractors (triangulation tools) in their hands and line themselves up along the line AB, taking out all of the slack in the line. A third student will be responsible for making sure that the first two students align the string in a straight line along line AB. A fourth student (or the third) will act as the data recorder.

Holding their protractors parallel to the ground, students will turn their protractors so that they can see the distant object through their straws. (See Triangulation transparency, Figure 3.4, page xx.) Students look at the distant object through their straws and simultaneously measure the angles formed to the distant object from positions A and B. Students will measure the angle by pulling the string tight so that there is no slack whatsoever, and then pinching the string against the protractor with the fingers to preserve the angle being measured. The data should be recorded on the "Triangulation in the Field" worksheet.

To increase accuracy, and to give students a more realistic representation of parallax (the apparent change in position of an object when viewed from two different positions), students will then reverse their positions and do a second measurement from the other observation position. Encourage team members to switch roles during the activity.

4. **Activity.** After the demonstration, have teams triangulate the distance to a chosen distant object. Have students return to the classroom to calculate the distance to their distant object, following the instructions given on the "Triangulation Data Analysis" worksheet. Save the triangulation tools for Mission 3.2 (each team should use their same tools for both labs).

5. **Verification.** Give teams the opportunity to actually measure the distance to their chosen object to see how accurate their measurements were.

6. **Homework.** Direct students to complete the "'Triangulation Questions" worksheet in class or as homework.

## Mission 3.2
## Materials

### For a Class of 30

- 22 paper stars ("Star Master" sheet is provided, page xx)
- 22 pins or thumbtacks
- String
- Data projector, computer, PowerPoint file
- "Parallax As Viewed from Earth" transparency (page xx)
- *(optional)* Construction paper

### For Each Team

- Triangulation tools from Mission 3.1
- Butcher paper or graph paper for a scale model
- Meter stick with "millimeter" markings

## For Each Student

- "Parallax" worksheet (pages xxxx)
- Pencil

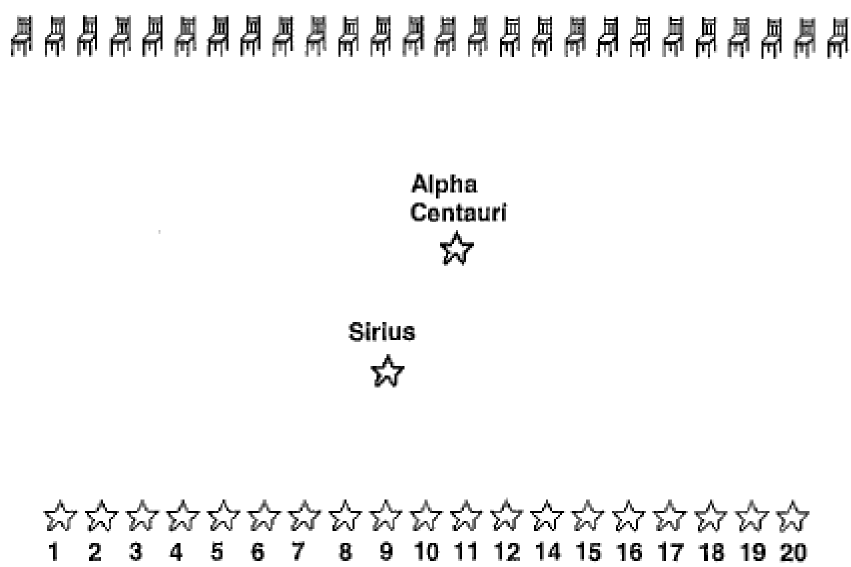
# Getting Ready

1. Copy the "Parallax" worksheet for each student.

2. Make 22 paper stars by copying the "Star Master" sheet included in this mission or by cutting them out of construction paper. Number 20 stars sequentially (from 1 to 20); label one of the unnumbered stars "Sirius" and the other "Alpha Centauri."

3. Suspend the numbered stars from the ceiling near the back wall of the classroom, or pin them to the back wall, in sequential order, roughly equidistant from one another. See the room setup diagram in Figure 3.1.

**Figure 3.l**–Room Set-up Diagram




Suspend the named stars in the following manner: put Sirius 10 feet in front of star # 9 and Alpha Centauri 14 feet in front of star # 11. These distances can be changed depending upon the size constraints of the classroom. Tryout the parallax activity for yourself, and adjust the position of the named stars to suit the classroom. The named stars should hang low enough so that they are in the line of sight between students and the numbered stars along the back of the room.

To make the model a little more realistic, hang additional stars in a random fashion in front of the fixed numbered stars.

***Teacher's Note:*** *The two end chairs will offer the most shift, or parallax, of Sirius and Alpha Centauri. Let the students discover this for themselves. When students have completed this* *mission, ask them if they know that the outermost two chairs represent the outermost part of Earth's orbit around the Sun.*

4. Rearrange the chairs in the classroom so that students sit in a row facing the stars.

## Classroom Action

1. **Discussion.** How big is the universe? When astronomers measure the distances to other galaxies or far away quasars, they do so by building a measurement scale that rests upon the distances to the nearby stars. But how can we measure these stellar distances, which even for nearby stars amount to tens of trillions of miles? We do what the ancient Greeks did–use geometry!

   Stars that are closer to us seem to change their location relative to stars that are farther away from us. Why is this so? *(Because as Earth makes its yearly orbit around the Sun, six months from now we will be directly on the other side, giving us a different view of nearby stars.)* The scientific name for this phenomenon is *parallax.* Astronomers have used parallax to determine the distances to thousands of stars, located up to approximately 165 light-years from Earth. It is very precise work because the angles they need to measure are so small.

   Tell students that they will be using triangulation to measure parallax. A protractor and a measured string can serve to show how we can determine the distances to the stars. Make sure that students see the relationship between their tiny triangulation tools and the whole Earth as one gigantic triangulation tool. It's the same concept!

2. **Demonstration.** Ask students if they have ever looked at an object with one eye closed (or covered) and then looked at the same object again but with the other eye closed (or covered). Have them try it. What did they notice? *(The object seemed to move against the background!)*

   Try it again, this time looking at their thumb at arm's length away, first with one eye closed, then with the other eye closed. Ask students to continue looking while moving their thumb closer and closer to their eyes, all the while alternating one eye closed, then the other.

   With students' help, write a sentence on the board that best describes the phenomenon they are observing. The sentence should relate that the closer the object was to their eyes, the greater the apparent movement or shift of their thumb. Why does the object shift? *(It is because the object is being viewed from two different positions, because their eyes are in two different positions. People have binocular vision. A one-eyed Cyclops would have to do this activity by shifting his one eye back and forth! Some students, because of their eyesight, may not be able to do this activity either.)*

3. **Activity.** Reassemble the class into their teams from Mission 3.1. Hand out the “Parallax” worksheet to each student and the triangulation tools to each team. Orient students so they are facing the model that you have set up in the classroom. Inform students that this setup is a model. Models *simulate* real situations. Stars do not line themselves up in straight lines like the model indicates.

The numbered stars along the back wall of the classroom represent stars that are so distant that they will show no parallax, or change in position, as Earth orbits the Sun. Therefore, they can be represented as fixed points on a scale-like, numbered grid and used as indicators of how much apparent shift or parallax the two named stars will have.

Pose a challenge to students: They have just seen their thumb "shift" its position without actually moving, by alternately closing one eye, then the other. Is there a way that they can demonstrate an apparent movement or shift of the named stars Sirius and Alpha Centauri that are hanging up in the room without actually moving them? How would they go about doing that?

Allow students time to collaborate with their team members to come up with a way of responding to this challenge. Give them time to test out their ideas. Allow them to circulate around the room. Ask them to begin their "Parallax" worksheets. Finally, have teams use their protractors to measure the angles and to calculate the distance to both of the named stars.

4. **Discussion.** Ask students to share their findings and results with one another in a class discussion.

5. **Transparency.** Relate what students did in the classroom to what happens in the real world when astronomers calculate the distance to the stars that are the closest to Earth. Use the "Parallax As Viewed from Earth" PowerPoint slide and lead a class discussion. Ask students to point out the similarities between what they did in class with the transparency on the overhead projector. Tell them that parallax shift occurs because, as Earth orbits the Sun, the closest stars appear to change their positions as seen against the background of fixed stars that are much farther from Earth.

6. **Homework.** Have students complete their "Parallax" worksheet in class or as homework.

# Going Further

## Activity: Bigger Triangles

Ask students to speculate as to what would happen if the line AB was extended from 10 meters to 20 meters. Would this increase or decrease the accuracy? Teams of students try this as an assignment for extra credit. Direct students to triangulate on a very distant object–1,000 feet away or farther. Ask students about the angles that are formed: Are they greater or smaller than those formed for nearby objects? Ask what can be concluded about triangulation from this activity. Why couldn't this measurement be done by using only one angle? Why were *two* observations necessary?

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## Triangulation Questions–Teacher's Key

1. Answers will vary. Students can find the difference in the two numbers (if any) and divide that by the measured distance to calculate a percent error.

2. There are two ways to greatly improve accuracy. One is to increase the length of the baseline. (Because we cannot make the orbit of Earth larger, this option is not available to observers with telescopes.) The second is to take several measurements of the angle and to use the average of the measurements.

3. The object at angles 800 and 800 would be farthest, the next closest would be the object at 700 and 700, and finally the closest object would be at 600 and 600

4. Scientists use a technique called parallax, which employs triangulation to find the distance to the stars. Measurements are made at the astronomical equivalents of point A and point B. One measurement of the angle to a star is taken on any convenient date. A second measurement is taken six months later when Earth is at the opposite side of its orbit. This means that the length of the line AB is the diameter of Earth's orbit, some 300 million kilometers.

5. No answer required.

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## *Parallax–Teacher's Key*

1. The closer the object was to their eyes, the greater the apparent movement or shift of their thumb. This happens because people's two eyes are at different positions.

2. Is there a way that you can demonstrate an apparent movement or shift of the named stars that are hanging up? How would you do that?

3. By taking a measurement from one seat, then switching seats and taking a measurement from another seat, students should duplicate the previously learned triangulation technique using the star as the distant object.

4. The star that is closest to students should have shifted the most. If the room is set up as indicated in the diagram, this will be Alpha Centauri.

5. Any reasonable measurements should be accepted. You will need to measure the distances in your classroom.

6. Statements should include the concept that the farther the star, the less parallax shift; or the closer the star, the more parallax shift it will exhibit.

7. At the outermost chairs location the student will observe the stars to have the greatest angle away from straight ahead (90°). By viewing from the two positions with the greatest angles away from straight on, the stars will have appeared to have the greatest shift.

8. Yes, the position you sit in can make your observations more accurate. The farther apart your observing positions A and B are the more accurate will be your calculation of the distance from the baseline. Not all students will get the same angle A or B from the same position. The maximum differences between their estimates is E, the "error" or uncertainty in measuring A. If the uncertainty is the same for long or short baselines, the "spread" of lines of sight (or error in distance measurement) will be greater if the baseline is shorter. The spread also becomes greater for objects farther away.

9. In the same way that students move from chairs on one side of the room to chairs on the other side of the room, Earth will have moved from one side of its orbit around the Sun to the other side of its orbit. This allows astronomers to make the same sorts of measurements that students made in class, to use parallax to calculate the distance to the nearest stars. See the PowerPoint slide for the image. Students who move between the centermost 70 percent (or 40 percent) of chairs see the parallax as it would appear from Venus or Mercury, respectively.

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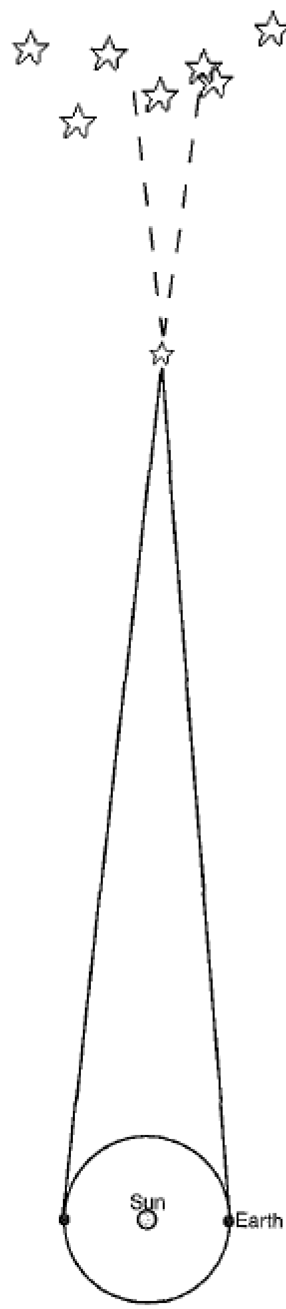
## *Parallax As Viewed from Earth–Transparency*

**Figure 3.2.**



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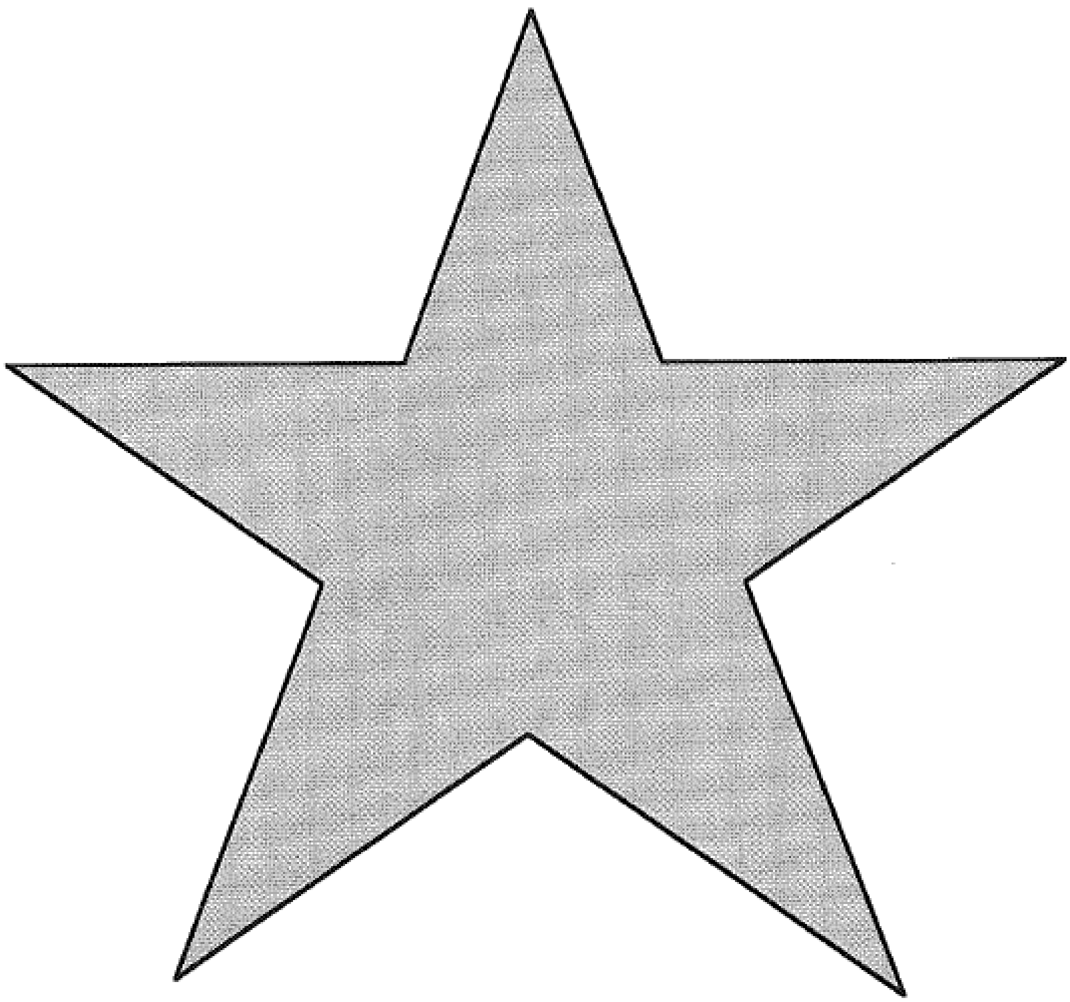
**Star Master**

**Figure 3.3.**



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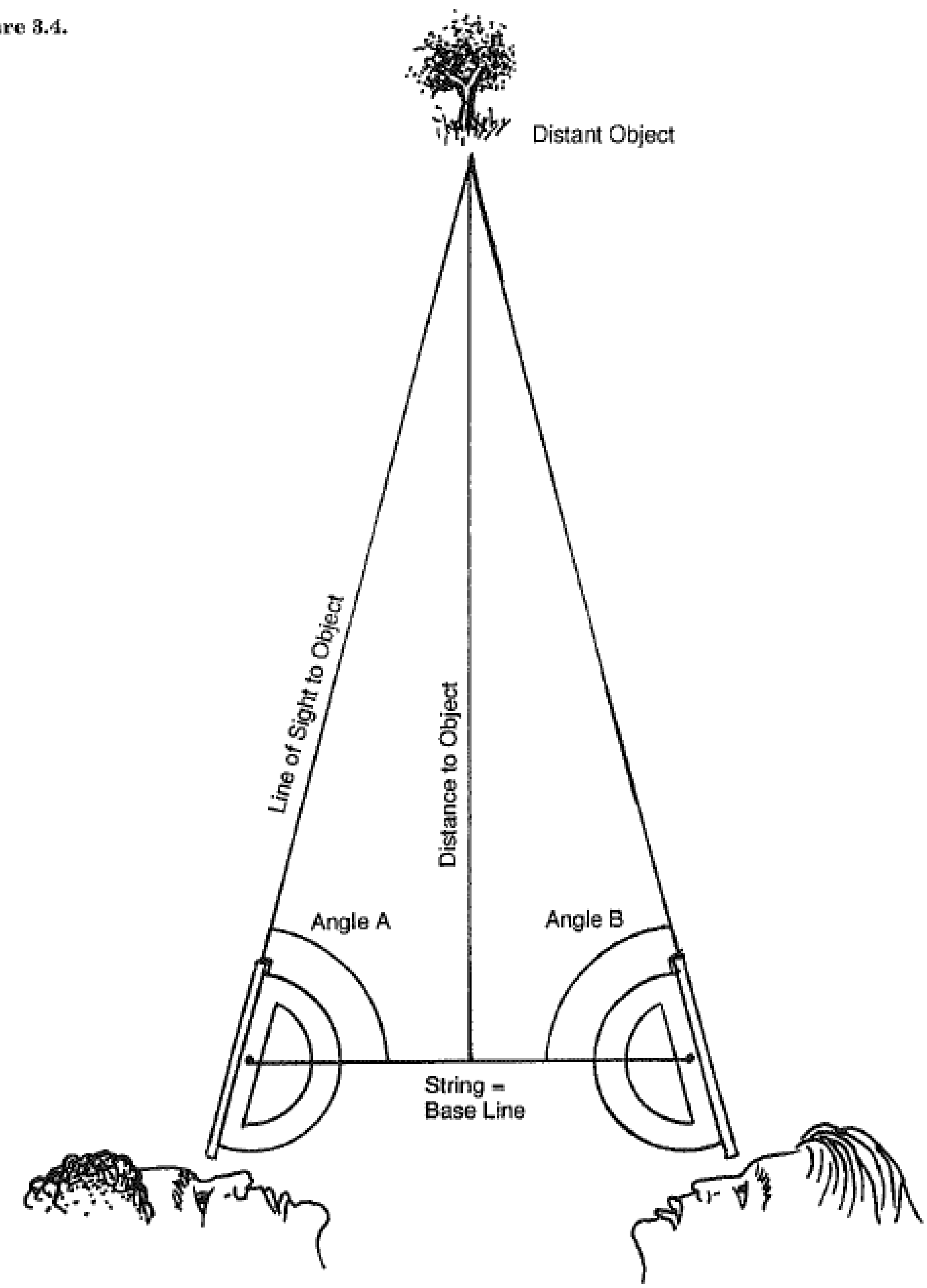
## Triangulation–Transparency or PowerPoint Slide

Figure 3.4.



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