HOW BIG IS THE UNIVERSE?

A PROGRAM FROM THE HOLT PLANETARIUM

by Alan Gould

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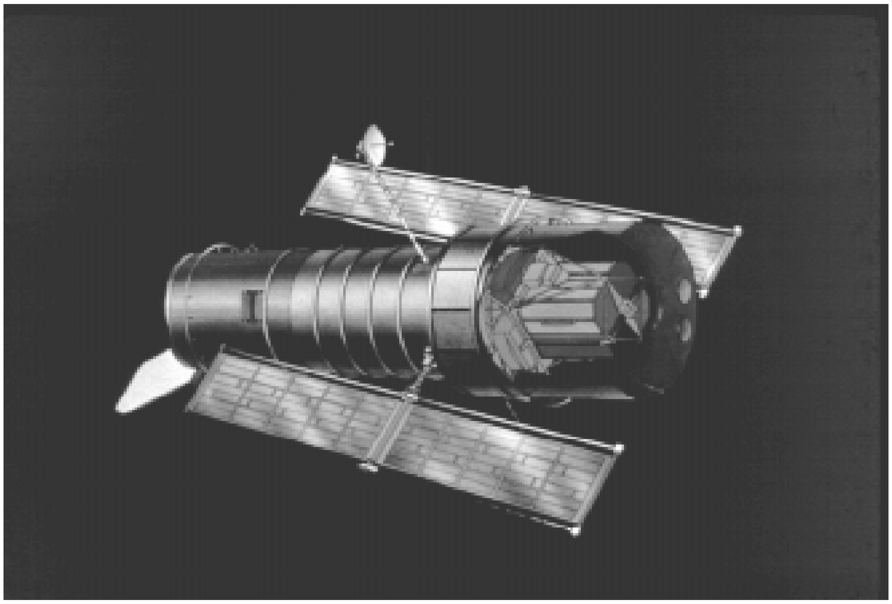

The Hubble Space Telescope (NASA Drawing)

Development and publication of *How Big Is The Universe?* was made possible by grants from the William K. Holt Foundation and the National Science Foundation (Grant Number MDR-9053778)

For latest information, valuable links, and resources relating to the PASS series, visit: https://gss.lawrencehallofscience.org/planetariums

LHS

Acknowledgments

How Big Is The Universe? was developed with support from the William K. Holt Foundation and the National Science Foundation.

The film *Powers of Ten*, by Charles and Ray Eames, was inspirational in developing the ideas for this program. It is included in the opening and closing portions of the program.

Lawrence Hall of Science staff members who provided input of ideas for *How Big Is The Universe?* and tested the program with audiences at the Lawrence Hall of Science were: Kevin Cuff, Lisa Dettloff, Edna DeVore, John Erickson, Chris Harper, John Hewitt, Lee Lonitz, Steve Nguyen, Roberto Sanchez, Greg Steerman, JohnMichael Seltzer, Debra Sutter and the author.

Cary Sneider provided crucial suggestions for inproving the parallax activity and worksheet, as well as significant improvements in several of the classroom activities.

The clever technique in the box at the bottom of page 15, describing how a student with use of only one eye can still do the parallax activity, was contributed by Rodney L. Martin, a POPS teacher/ leader from Smithburg, Maryland and participant in the 1992 Summer Institutes in Astronomy and Space Science Education at Lawrence Hall of Science, University of California, Berkeley.

Greg Steerman provided technical photographic expertise in helping to produce images for projecting degree markings in the Parallax section of the show.

Credit goes to John Erickson for discovering that Mini-Mag Lite® lamps make excellent tiny light sources for making variable stars and dot projectors. He also refined the variable star projector to make it oscillate smoothly between two brightnesses rather than a simple on/off flasher.

Thanks to Andrew Fraknoi of the Astronomical Society of the Pacific for graciously supplying references on "Measuring Cosmic Distances."

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Many thanks to Sachiko Homma for proof-reading that she did while translating this volume into Japanese.

And thanks to my wife, Diane, for moral support and for locating virus images by Lennart Nilsson.

Photos & Illustrations

Diagrams and drawings by Alan Gould, Lawrence Hall of Science; planets and deep sky photos from Hale Observatory, Mt. Palomar, California Institute of Technology; Lick Observatory, Mt. Hamilton, University of California, Santa Cruz; and U.S. Naval Observatory in Wahington DC (see p. 8 for detailed listing); HIV virus image by Lennart Nilsson and reproduced with the permission of Boehringer Ingelheim GmbH, Germany.

Planetarium Activities for Student Success (PASS)

Series Editors: Cary Sneider, Alan Friedman, and Alan Gould

If you have access to a planetarium for teaching about astronomy, space science, and other subjects, this series of books is for you. Designed for both experienced planetarium professionals and teachers who will be using a planetarium for the first time, these volumes provide a wealth of field-tested strategies and practical suggestions for presenting entertaining and educationally effective programs for students.

The first four books provide a general orientation to astronomy and space science education with applications for both the planetarium and classroom settings. Each of the remaining volumes presents a complete planetarium program and related classroom activities. We hope you will find the materials useful in your work with students and teachers, as well as springboards for your imagination and creativity.

Volume 1: Planetarium Educator's Workshop Guide

Participatory planetarium programs involve students actively in the planetarium environment. The most effective programs are both entertaining **and** educational. This guide introduces the theory and practice of developing effective planetarium programs through a series of thought-provoking activities and discussions.

Volume 2: Planetarium Activities for Schools

This volume provides a wealth of effective planetarium activities for elementary and middle school students, as well as ideas for developing new activities for students of any age.

Volume 3: Resources for Teaching Astronomy & Space Science

There is a wide spectrum of resources for teaching astronomy and space science in elementary and middle schools. This annotated resource guide has the best resources that we have found, including school curricula, books, periodicals, films, videos, slides, professional organizations, planetariums, and telescopes.

Volume 4: A Manual for Using Portable Planetariums

Primarily a "how-to" manual for setting up and using a portable planetarium, this guide has many suggestions useful for teaching school programs in **any** planetarium.

Volume 5: Constellations Tonight

In this participatory version of a classic night sky planetarium program, students receive star maps and have an opportunity to use them to find constellations in the planetarium sky. Classroom activities include creating constel-lations and using star maps.

Volume 6: Red Planet Mars

Students discover Mars three different ways during this planetarium program. They find the red planet by observing it over a period of several nights as it moves against the background stars. Then they view it through a telescope and try to map its surface. Finally they see Mars via space probes. Classroom activities involve students in modeling the solar system, and creating creatures that could survive under different planetary conditions.

Volume 7: Moons of the Solar System

This program begins with observations of the Earth's Moon and a modeling activity that shows why the Moon goes through phases and eclipses. Then the students look at Jupiter's four major moons on a series of nights and figure out how long it takes each one to circle Jupiter. Finally, the students journey through the Solar System to see many moons through the "eyes" of modern spacecraft. Classroom activities involve students in performing experiments in crater formation, using moon maps, and designing lunar settlements.

Volume 8: Colors and Space

What can we learn about the stars and planets from their colors? Answering this question requires a fundamental understanding of why we see color. During this program, students deepen their understanding through a series of activities in which they "travel" to an imaginary planet circling a red sun, and experiment with color filters and diffraction gratings. Related classroom activities include making secret messages that can only be decoded with color filters, and then using the same filters to view nebulae and planets.

Volume 9: How Big Is the Universe?

Based partly on ideas from the short film *Powers of Ten*, this program surveys distances and sizes of things in the universe. Starting with ordinary things on Earth that students are familiar with, they move to progressively more distant astronomical objects: the Moon, the Sun, the Solar System, nearby stars, the Milky Way galaxy, and clusters of galaxies. Students use various methods to determine distance: parallax, "radar," and comparing brightness of objects. Classroom activities include students writing their complete galactic address, making a parallax distance finder, finding the distance to the "Moon," and activities about the expanding universe.

Volume 10: Who "Discovered" America?

Students ponder the meaning of the word *discover* in this program. Can one "discover" a land where people are already living? Students learn the reasons and methods by which Columbus navigated to the "New World," and some of the impacts of his voyages on Native Americans. They also find that certain myths about Columbus are untrue. He was not, for example, alone in believing that the Earth is round. Students also learn about other explorers who "discovered" America long before Columbus's time. Classroom activities include determining the shape and size of the Earth, using quadrants to determine latitude, and modeling lunar eclipses.

Volume 11: Astronomy of the Americas

There are hundreds of Native American cultures, each with distinctive views of the heavens. There are also common threads in many of those cultures. In this program students visit five cultures: the Hupa people of Northern California, plains and mountain tribes that have used Medicine Wheel in Northern Wyoming, the Anasazi of Chaco Canyon in New Mexico, the Mayan people in Mexico and Central America, and the Incan people in Peru. Students observe moon cycles and changes in the sunrise and sunset positions on the horizon and learn how solar observations help Native Americans stay in tune with the harmonies of nature. Classroom activities include the Mayan and Aztec number systems, observing changes in real sunset positions, and learning how Venus can appear as either the "Morning Star" or "Evening Star."

Volume 12: Stonehenge

In this program, students learn what Stonehenge is and how it could have been used by its builders as a gigantic astronomical calendar. They also learn how astronomer Gerald Hawkins discovered Stonehenge's probable function, by actively formulating and testing their own hypotheses in the planetarium. Along the way, they learn a lot about apparent stellar, solar, and lunar motion, and the creation of the research field of "archeoastronomy." Classroom activities include constructing a special sundial to represent the entire yearly cycle of solar motion.

How Big Is The Universe?

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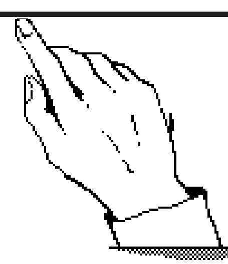


How Big Is the Universe?

Planetarium Show

Preface

Many students of astronomy have been inspired by the film *Powers of Ten* by Charles and Ray Eames. If you have not seen this film, we highly recommend you see it and show it to your classes. It is used in this planetarium program as a lead-in to the question "How big is the universe?" But in watching the film, many distances to objects are given as fact and we can't help but ask, "How do you really know how far away that thing is, especially when the distance claimed is so outrageously large?"

This program answers that question, "How do we measure the distances to extremely distant things?"

Before tackling the formidable question of how big the universe is, we start by considering how big some smaller things are. It is often very difficult to tell how large something is without some object of known size as a reference. In the beginning of this planetarium show, students view objects ranging from microscopic to cosmic scales, and try to guess what they are looking at.

After viewing the mind-blowing journey to the outer reaches of the universe in *Powers of Ten*, students learn the real methods by which the distances in the film were arrived at: radar ranging, parallax measurements, behavior of Cepheid variable stars, and comparing apparent brightnesses of objects that are the same absolute brightness.

The program includes a model for how parallax angle is used to measure the distances to stars. An optional section for older students allows you to extend the model by having your students actually measure the distance to the model "star."

There is some mention at the end of the program of the red-shift of galaxies, the expansion of the universe and the age of the universe. But to really understand those concepts requires more time than a simple 50-minute program. There are classroom activities that explore the subject more thoroughly.

Included in this guide are classroom activities that augment the planetarium program:

1. A Question of Scale. Students estimate the sizes of objects ranging from table-top size to cosmic size.

2. Your Galactic Address. Students create a series of maps that are ordered in the fashion of the *Powers of Ten* video. The maps lead students to write their complete "galactic address."

3. Parallax—How Far Is It? Students make a parallax angle measuring device and determine the distances to objects by the method of parallax.

4. Stretching Infinity. Your students grapple with the concept of infinity to prepare for the subsequent activities about the expanding universe.

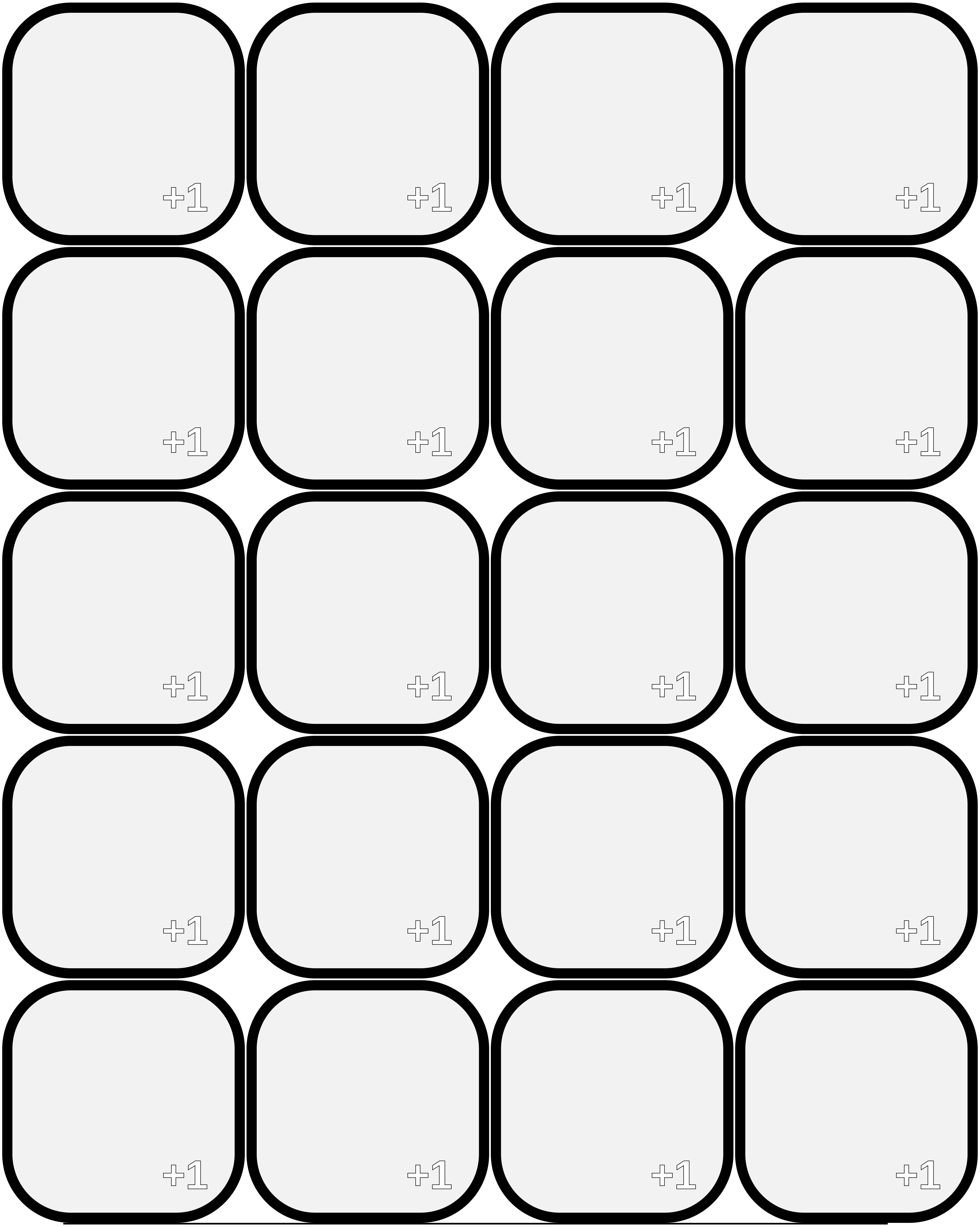
5. A Ballooning Universe. In this activity your students learn why there is no center to the universe even though it is expanding.

6. The Expanding Universe. This introduction to the red shift communicates the evidence for the expanding universe.

Objectives

In this planetarium program, the students will be able to:

1. Tell how to measure distance by the parallax method.
2. Understand the terms *light-seconds, light-minutes, light-hours,* and *light-years* as units of distance.
3. Estimate brightnesses of stars in terms of magnitude.
4. Tell how Cepheid variable stars of known absolute magnitudes can be used as distance standards in measuring the distance to star clusters and galaxies.
5. Describe how radar waves are used to find distances by timing how long it takes a radar signal to go to the object, bounce off, and return.
6. Appreciate the vast size of our universe.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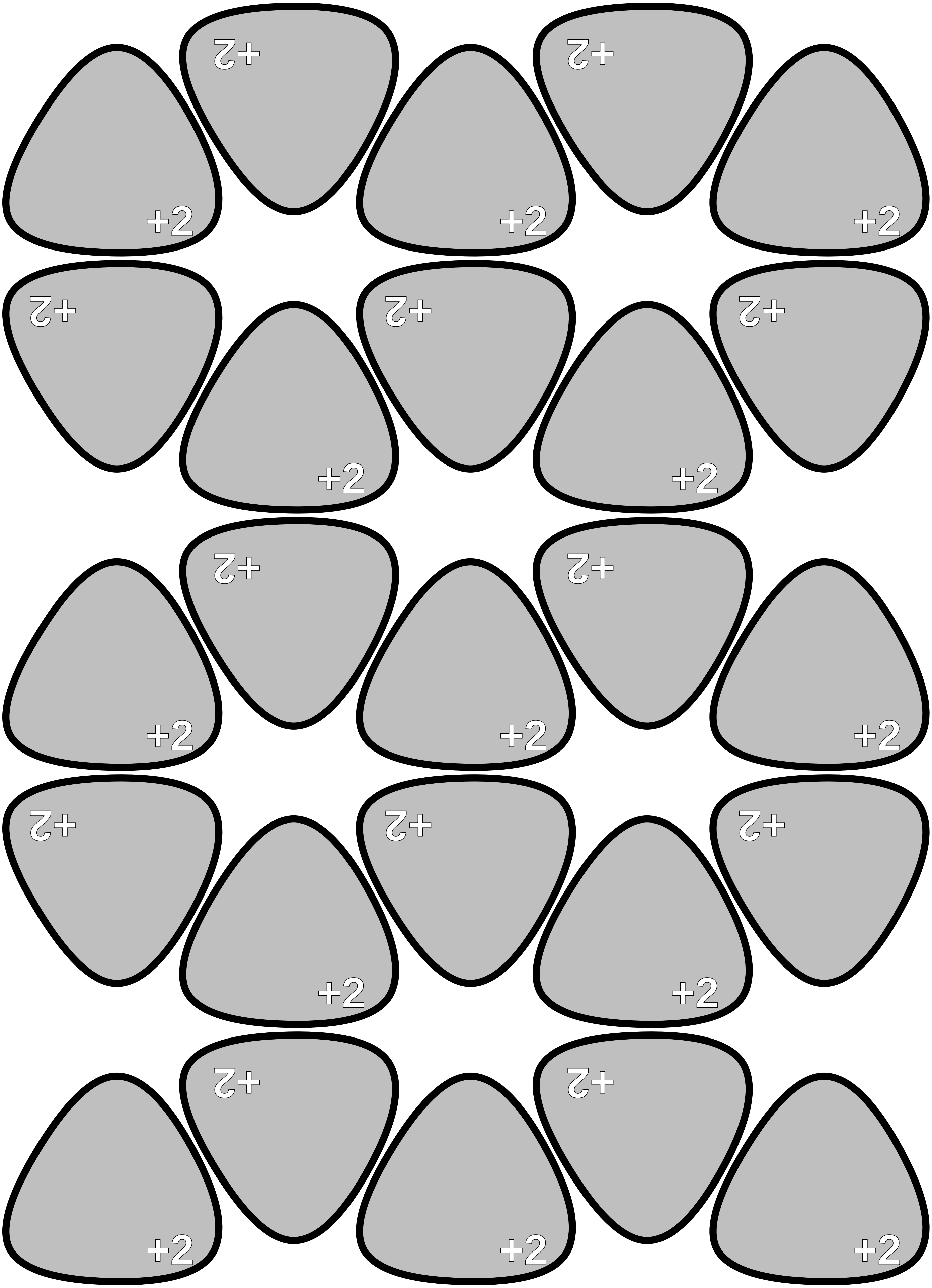
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Materials

1. *Powers of Ten* video tape. *Powers of Ten* with license for use in planetarium programs may be purchased from Pyramid Film and Video, P.O. Box 1048, Santa Monica, CA 90406, 800-421-2304. It is also available for home viewing through other sources, including Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112. 415-337-2624.

2. Videocassette player.

3. TV monitor or video projector.

4. Model Stars (Mini-Star Balls). Styrofoam or polystyrene balls about 2 cm. (3/4 inch) in diameter mounted on small sticks.

5. Brightness Comparators. One rectangular (+1) brightness comparator and one triangular (+2) brightness comparator for each student. To make the brightness comparators, photocopy the masters (pp. 2–3) onto transparencies. Cut out the shapes and line the edges with white tape so they are more visible in dark planetarium conditions.

6. Cepheid Variable Star Special Effects. Three small lights that pulse in brightness simulate Cepheid variable stars. Depending on your technical skill level, choose one of the following three versions:

Cepheid Variable Star Special Effect Version I

This is the simplest option. For a portable planetarium, make a paper mask that will block all the stars except for Sirius (the brightest star) on the star projector. Sirius becomes the variable star whose brightness is controlled by the main star bulb brightness knob. For Cepheid variable star A, vary the brightness between "maximum brightness" and "very dim" in a cycle about once every 5 seconds. For Cepheid variable star B, vary the brightness between "half-maximum brightness" and "very dim" about once per second. Cepheid variable star C varies between "very dim" and "half-maximum brightness" once every 5 seconds (same brightness as B, but same pulse rate as A).

A single variable star projector can be used to simulate all three types of variable stars needed in the program. However, it is better to have the capability of showing simultaneously variable stars with different brightnesses and pulsing rates. If you do not happen to own two STARLAB projectors, the following versions are fairly easy to implement.

Cepheid Variable Star Special Effect Version II

This is a simple variable brightness dot projector design. You can make two or three of them very inexpensively.

At an electronics store, purchase:

- ❒ Two switches (On/off—not momentary contact)
- ❒ Two potentiometers (under 20-30 ohms maximum resistance)
- ❒ A meter or two of light weight electrical wire (about 24 gauge; (More wire is required if you plan to put one light in the dome.)
- ❒ Two integrated circuit sockets to serve as sockets for the Mini-Mag Lite® bulbs (8 or 14 pin sockets are common)
- ❒ 2 "D" cells and battery holder, or a 3V "battery eliminator" power supply

You also need

- ❒ Two small hand lenses (Longer focal lengths give better pinpoint appearance of star; larger diameter makes brighter star.)
- ❒ Two small cardboard boxes with removable lids (such as a box for storing slides, at least 3 cm tall), or two cardboard tubes
- ❒ Two Mini-Mag Lite® bulbs

Assemble the parts as shown in Fig. 1 (p. 5). Each projector can be manually operated (by varying the potentiometer) for the effect needed to produce Cepheid variable stars A, B, or C.

You will need practice to make a Cepheid variable A that is brighter and slower than a Cepheid variable B (as described in version I). For Cepheid variable C, you need to operate one projector so that it is as fast as A, but as dim as B.

The projector box or tube may point straight up at the zenith or can be mounted to point in any direction by:

(a) punching a hole in the side of the box; and

(b) attaching it to a somewhat larger box with a paper fastener or nut and bolt (Fig. 2).

Figure 1

Cepheid Variable Star Projector

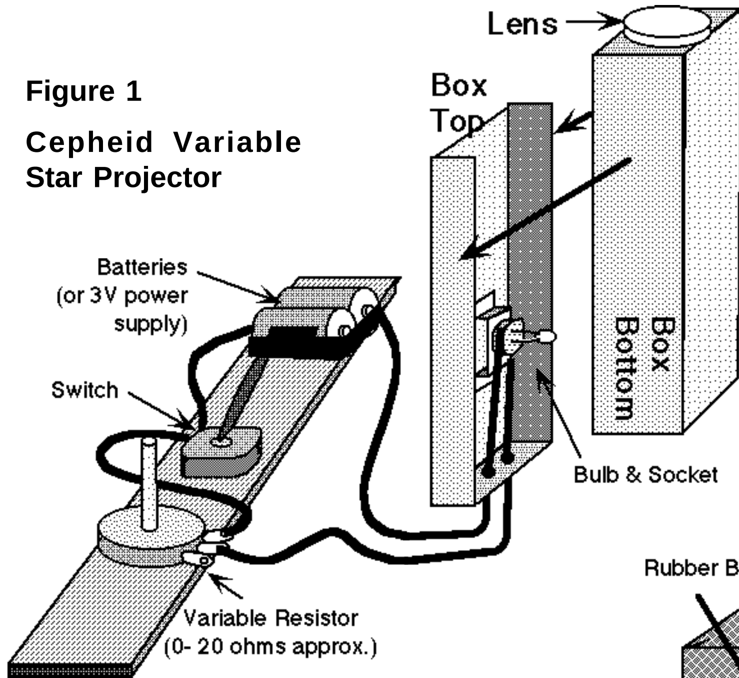
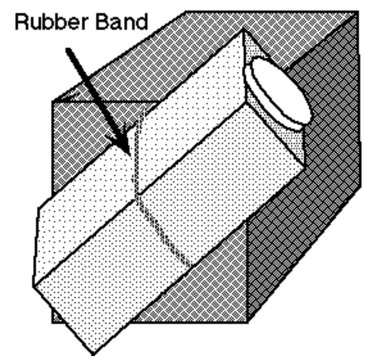


Figure 2

Swivel



Cepheid Variable Star Special Effect—Version III

For this version you need to be able to solder and to put together a simple digital circuit on a breadboard. You will need the following parts from an electronics parts store (such as Radio Shack):

- ❒ A breadboard (#350 Experimenter works well)
- ❒ A meter or two of speaker wire, two-conductor, stranded, insulated, about 20 gauge (More wire is required if you plan to put one light in the dome.)
- ❒ Parts for the circuit shown in Fig. 3 (page 6):
  - (3) 555 integrated circuit chips
  - (3) Capacitors, electrolytic, 47 microfarad
  - (3) Resistors, 1000 ohm, 1/4 watt
  - (2) Resistors, 18 kilohms, 1/4 watt
  - (2) Resistors, 10 ohms, 1/4 watt
  - (1) Resistor, 6800 ohms, 1/4 watt
  - (1) Resistor, 3.9 ohm, 1/2 watt
  - (15) jumper wires, about an inch long, 22 gauge, solid, insulated, ends stripped
  - (3) Switches, single pole, single throw (On/off—not momentary contact)
  - (1) 5–6 volt power supply, battery eliminator, or a 4-cell battery holder and four D-cells

A soldering iron and solder

- ❒ Three Mini-Mag Lite® flashlight lamps (3V; available from stores that sell Mag Lite® flashlights such as hardware or camping supply stores, or from Mag Instrument, Inc., 1635 S. Sacramento Ave., Ontario, CA 91716)
- ❒ Two thin short dowels, 0.5 cm. (1/4") thick (or less) x 15 cm. (6") long, or two standard size pencils
- ❒ One long dowel, same thickness as dowels above, 1–2 meters (3'-6') long
- ❒ Three blocks of wood or Styrofoam, about 8 cm. x 8 cm. x 3 cm. (3" x 3" x 1")
- ❒ A drill and a drill bit the same diameter as the above dowels if you use wood blocks
- ❒ A small box of cardboard or very thin wood on which to mount the circuit board and switches.

To make three Cepheid variable stars with the required brightnesses and pulsing rates, construct the three simple flasher circuits (Fig. 3). For Cepheid variable star A, that is a bright light flashing about once every two or three seconds, use the following values of resistors and capacitors:

C1 = 47 microfarad	C2 = 25,000 microfarad
R1 = 1,000 ohm	R2 = 18,000 ohm
R3 = 10 ohm	R4 = 10 ohm

For Cepheid variable star B, that is a dimmer light flashing about once every second, use the following values of resistors and capacitors:

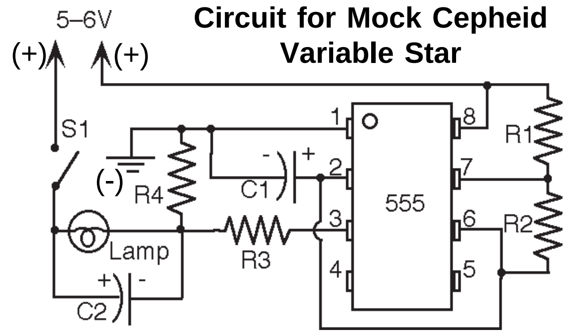
C1 = 47 microfarad	C2 = 5,000 microfarad
R1 = 1,000 ohm	R2 = 6,800 ohm
R3 = 20 ohm	R4 = 20 ohm

These two flashing lights are placed within several centimeters of each other and represent two different Cepheid variables at a standard distance for comparison of their absolute magnitudes.

For Variable star C, that is as dim as B, but flashing at the rate of A, using the following values:

C1 = 47 microfarad	C2 = 25,000 microfarad
R1 = 1,000 ohm	R2 = 18,000 ohm
R3 = 20 ohm	R4 = 20 ohm

Figure 3
Circuit for Mock Cepheid Variable Star



Cepheid variable C is placed in the dome much higher than the other two lights. This represents a Cepheid variable that the audience can conclude has absolute brightness the same as that of A (since it flashes at the same rate as A), but has a fainter apparent brightness, indicating it must be farther away than A.

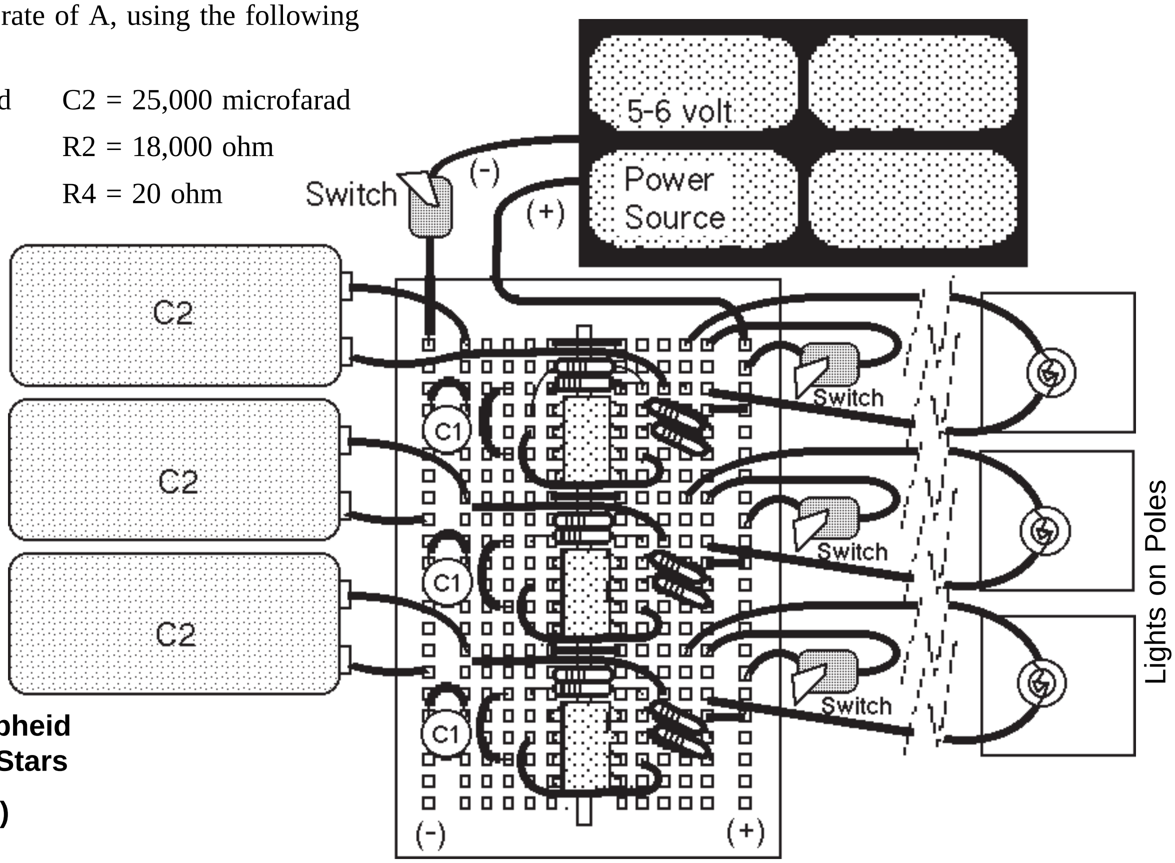


Figure 4
Mock Cepheid Variable Stars
(top view)

To build the projectors,

a. Construct the three circuits (Figure 3, page 6) using the component values given above. All three circuits can be built using only one breadboard (Figure 2).

b. Cut three lengths of speaker wire. Two of them should be about 10 cm longer than the short dowels and the third should be about 10 cm longer than the long dowel.

c. Strip the ends of speaker wires and solder a Mini-Mag Lite® onto one end of each wire. Solder jumper wires to the other ends (6 jumper wires total) to allow easy insertion into the breadboard.

d. Tie each speaker wire onto its respective dowel and connect the jumper wire ends to the appropriate points in the circuit.

e. Stick the dowels into the blocks of Styrofoam. If you use wood blocks, which are sturdier, drill a hole in each block that the dowels can fit into snugly.

f. Attach the circuit and the three switches to the box.

Figure 2 shows what the result might look like. Of course, your construction will bear your own personal touches.

7. Slides. A complete list of the slides is on page 8.

8. Slide projector(s). Image 12, Zenith Angle Circles must be projected at the zenith. This can be accomplished by putting a mirror (about 8 cm x 14 cm) at a 45° angle in front of the slide projector lens. The image must also be adjusted so that it measures degrees. Adjustment can be by changing the projection distance or with a zoom lens. Compare with a meridian scale to adjust properly.

Images 1-9 and 13-22 are best projected at the zenith, while images 10-12 have a "right-side-up" orientation to them which makes it best to project them nearer the horizon. You may have separate projector(s) for those slides, or keep all slides in one projector and remove the zenith mirror when you want to project near the horizon.

Items needed for Optional Sections

9. Rulers or **Tape measure.** A 30 cm ruler or a meter long tape measure for every student or for every pair of students.

11. Parallax Drawing sheet. One for each student; master on page 9)

12. Tape player and two audio tapes:

a. audio tape of "spacy music" to play as background to your own narration of Powers of Ten

b. audio tape of seconds being counted, to use in timing the radar wave model.

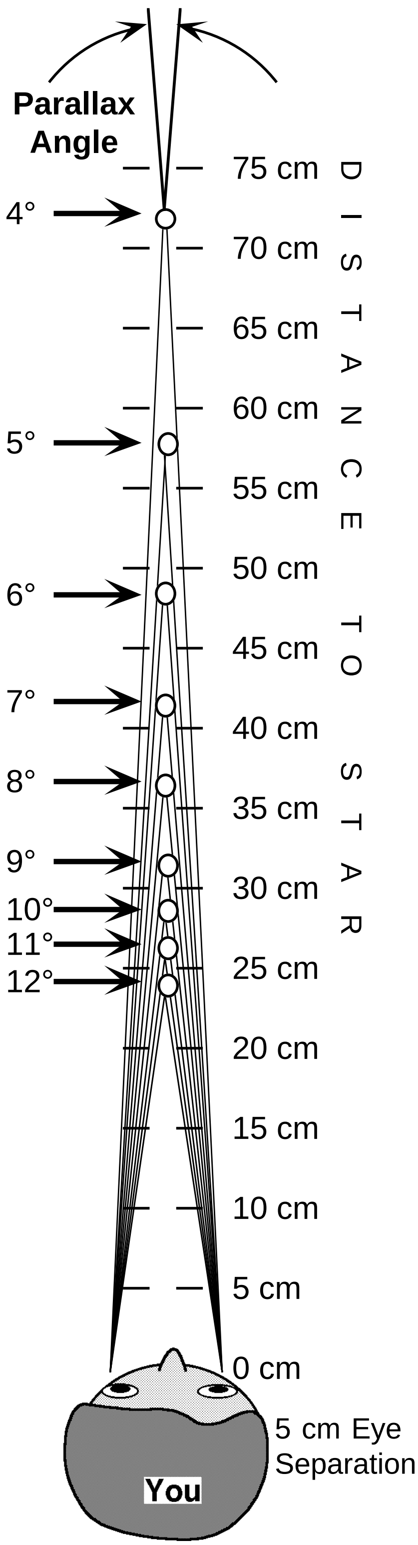
Slides

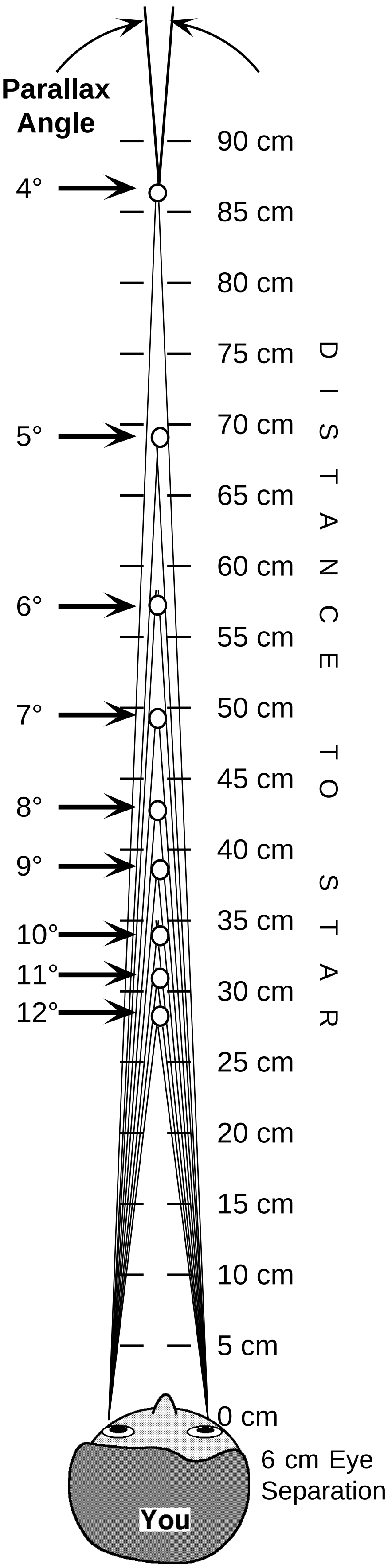
1. Hyperion, moon of Saturn .... NASA
2. HIV virus on T-lymphocyte cell .... Nilsson
3. M64, Spiral galaxy in Coma Berenices, the “Black Eye” .... U.S. Naval
4. Valles Marineris, canyon on Mars .... NASA, Viking
5. Tree bark .... LHS
6. Moon .... Hale
7. Mars .... Hale
8. Neptune .... NASA, Voyager
9. Venus (in UV light) .... NASA, Pioneer
10. Radar map of Venus .... NASA, Pioneer data
11. Parallax diagram: moon .... LHS
12. Measuring parallax of a star .... LHS
13. Zenith Angle Circles .... LHS
14. M31, the Great Galaxy, in Andromeda .... Hale
15. M82, Irregular galaxy, in Ursa Major .... Lick
16. NGC 147, galaxy, type Ep, in Cassiopeia .... Hale
17. NGC2623, galaxy, type Sc pec, in Cancer .... Hale
18. M51, Whirlpool galaxy, in Canes Venatici .... U.S. Naval
19. NGC 1398, galaxy, type SBb(r), in Fornax .... Hale
20. NGC2685, galaxy, type SO, in Ursa Major .... Hale
21. NGC4565, edge-on Sb spiral galaxy, in Coma Berenices .... U.S. Naval
22. Galaxy cluster in Corona Borealis .... Hale

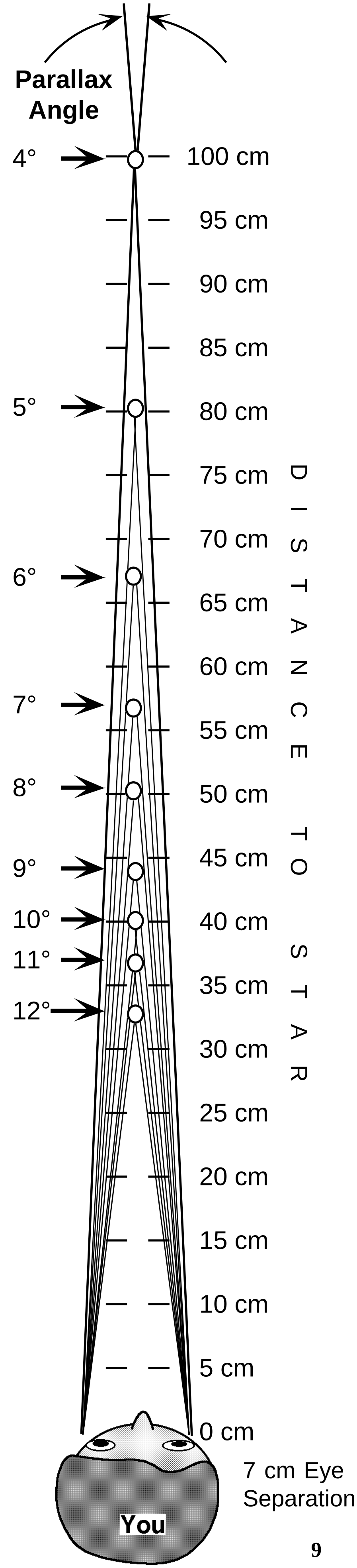
Hale: Hale Observatory, California Institute of Technology, Mt Palomar, California
LHS: Alan Gould, Lawrence Hall of Science, University of California, Berkeley
Lick: Lick Observatory, Mt. Hamilton, University of California, Santa Cruz
NASA: National Aeronautics and Space Administration, U.S. Government
Nilsson: Lennart Nilsson, Boehrenger Ingelheim GmbH, Germany
U.S. Naval: U.S. Naval Observatory, Washington DC

How Far Is The Star ?

Parallax Worksheet for the planetarium program *How Big Is The Universe?*







Setup

1. Cue *Powers of 10* on VCR and test TV monitor or video projector.

2. Cue to first slide.

3. Set up and test variable star projector and slide projector.

4. Position Vega high in the planetarium sky.

5. Have the brightness comparators and the mini-moon balls on hand.

Recommendations for Using the Script

We don't expect the script that follows to be memorized as an actor might memorize a part. Use it as a guide in learning, rehearsing, and improving presentations. We recommend that you read the script once or twice; then work with it in the planetarium, practicing the projector controls, slides, special effects, and music. You should be able to imagine yourself presenting information, asking questions, and responding to participants. For your first few presentations, you can have the script on hand, using major headings as reminders of what to do next.

The script is organized in blocks or sections. The purpose of these separations is only to help you learn and remember what comes next. Once you have begun a section, the slides or special effects and your own train of thought will keep you on track.

Directions for the instructor are printed in italics, the instructor's narrative is printed in regular type, and ***directions and questions to which the students are expected to respond are printed in bold italics.*** There is no point in memorizing narration word-for-word, since what you need to say will depend upon the students. The language you use and the number and kinds of questions you ask will depend on how old the students are, how willing they are to respond, and how easily they seem to understand what is going on.

We believe the most important elements of the program are the questions and the activities, since these involve the students in active learning. If you must shorten your presentation, we recommend that you borrow time from the narration.

Script: How Big Is The Universe?

Introduction: Guess What It Is…

This program is about how big our universe is. Before tackling something that big, let's look at a few things that are a bit smaller and see if we can guess what they are and how big they are.

Show images 1-5. For each image, ask questions such as,

"What is it?"

"Is it big or small?

"Is it close up or far away?"

Image 1: Saturn's moon, Hyperion, 235 miles across, Voyager image

Image 2: HIV viruses on T-lymphocite blood cell

Image 3: Spiral galaxy of hundreds of billions of stars

Image 4: Valles Marineris canyon on Mars, Viking image

Image 5: Tree bark

After a short discussion, tell the students what they are looking at.

Image 1

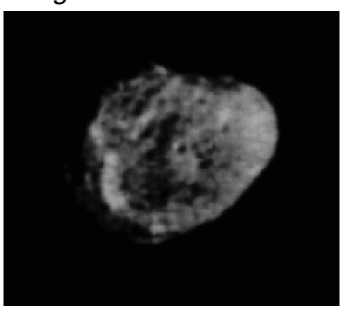


Image 2

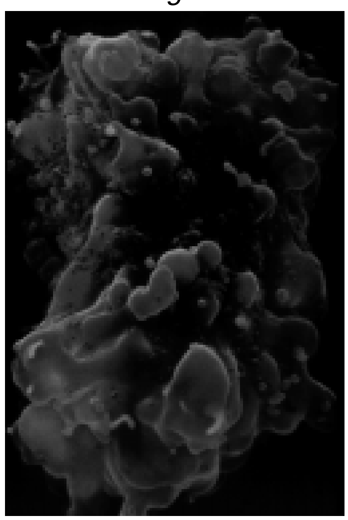
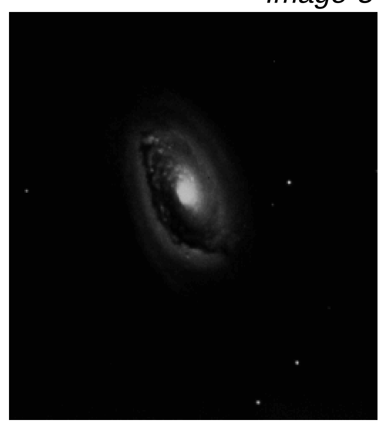


Image 3



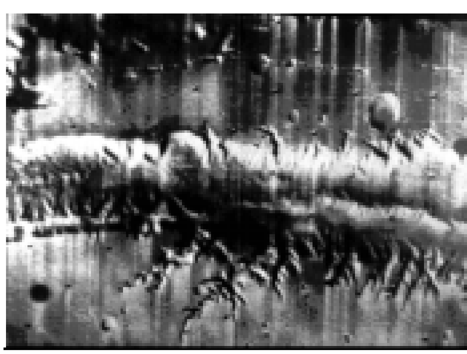
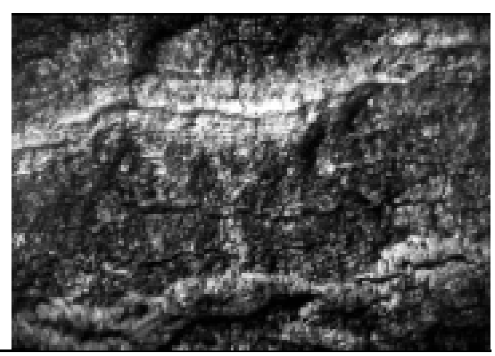


Image 4

Image 5



Powers of Ten

Let's take a little trip from Earth to the outer reaches of our universe. We are going to looking back at the Earth all the time so we'll be traveling backwards. Don't worry—I'll make sure we don't run into anything!

Show Powers of 10 video. Narrate it yourself with background audio tape of space music or use the video narration.

In this motion picture, we have seen what the distances may be to various parts of our universe. But do you believe those distances? How did people measure the distances to things so far away? In this program, you will find out how we know how far away things are.

Let's start with some nearby things and find out how we can figure out how far away they are.

This "Powers of Ten" section may be moved to end of the program if desired (bottom of page 23).

How Do We Tell Distance By Radar?

For relatively nearby things, like airplanes, we can use radar waves to measure how far away they are. Radar waves are invisible waves that are created and detected by electronic equipment. They are like the radio waves that your radio at home receives. You cannot hear radio waves directly; but your radio receiver can change them into the sounds that you enjoy listening to.

Let's make a model of radar waves to see how they can be used to tell how far away something is. Remember, real radar waves are invisible, and make no sound at all. First, let's just make a wave, like at a football game. ***Raise your arms after the person next to you raises theirs. When the wave gets to the end of the row, the last person must say "Bounce!" and the wave goes back the other way. When it gets back to the starting point, the first person says "Stop!" Let's try it once for practice.***

Designate a starting person. If students are sitting in several rows, designate the end of each row as a "Bounce!" point. If they are sitting in a circle, have the person next to the starting person "bounce" the wave back so it goes around the circle in the opposite direction back to the starting person.

Now we will time how long it takes the wave to go the length of the whole row and back again. The starting person will help me be a timer by saying "One thousand one, one thousand two," and so forth, to count approximate seconds. *(Optional: use audiotape of seconds being counted, or ask if anyone in the group has a timer function watch and would be willing to act as timer.)*

Ready? Set. Go!

Start the wave and the timing simultaneously. If there is more than one row and the rows are different lengths, ask the students if they noticed any connection between how long the row is and how long it took the wave to return to the starting person.

Can you predict how long it will take for the wave to reach the end person if we cut the distance in half?

Appoint a new endpoint person somewhere about midway down the line, ask that person to "bounce" the wave. Start the wave and time it.

Air traffic controllers at airports use radar systems to measure distances to airplanes. Radio waves are sent out and they bounce off airplanes. The amount of time the wave takes to return tells the controller how far away the airplane is. The longer the time the wave takes to return, the farther away the airplane is.

Optional: The method is similar to estimating the distance to a lightning strike by counting the number of seconds it takes for the sound of the thunder to reach you after you see the flash of the lightning. (The light travels so fast there is no perceptible delay.) Knowing the speed of sound waves, about a third of a kilometer per second, you can tell how far away the lightning was. [Multiply the number of seconds delay by 3 to get the approximate distance in kilometers.]

Radar at airports measure distances to airplanes that may be a few dozen or at most a few hundred kilometers away. Astronomical things are much farther.

Distances to the Moon, Sun, and planets in the solar system were measured more than 300 years ago using a method we'll learn about later called ***parallax***. But today, timing waves sent to and from spacecraft, such as Pioneers, Voyagers, and a host of others, is one of the most accurate methods of determining distances within the solar system.

Image 6: The Moon

The current value of the distance to the moon is 384,000 kilometers—about the distance a really busy cross-country moving van covers every couple of years.

Radar waves, microwaves, and radio waves all move at the same speed as light waves—much faster than sound waves. Sound waves move at about 1/3 of a kilometer per second, which is pretty fast. But radar waves move nearly a million times faster at about 300,000 kilometers per second. Really fast! At that speed, it takes about one and a half seconds for the wave to get to the moon, and another one and a half seconds to get back.

Optional review of metric units and powers of ten prefixes, especially for younger groups:

Hold your hands about a meter apart. A meter is about this distance. *(Hold your hands apart about 1 meter and turn so that all the students see that distance.)* ***How many meters are there in one kilometer?*** *(1000.)* If we walk 1000 meters, we have walked one kilometer. The United States is about 4500 kilometers across and the whole Earth is almost 13,000 kilometers across (in diameter; about 12,756 km. to be more exact). Distances to the nearest planets are in millions of kilometers—a million being a thousand times a thousand. The farthest planets are over one thousand million kilometers away. One thousand times one million kilometers is one billion kilometers.

If you are talking by radio to someone on the moon, it takes one and a half seconds for your signal to reach them and another one and a half second for their reply to get to you, so there is at least a 3 second delay for the time it takes the message to get to the moon and the reply to come back. Suppose you ask your friend on the Moon, "What's 8 divided by 4?" Normally, you expect an immediate answer, within a second or so. If your friend takes over 3 seconds to reply, "2," you have to remember that your friend's brain is not slow, the signals carrying the question and response are traveling almost a million kilometers (actually about 800,000 km.).

We often express very great distances in terms of the time it takes radio or light signals to travel that distance. A **light-second** is the **distance** that light or radio waves travel in one second. *Light-second* might sound like a unit of time, but don't be confused—it's really a unit of distance. In the case of the Moon, we could say that the Moon's distance is about one and a half **light-seconds** away from Earth.

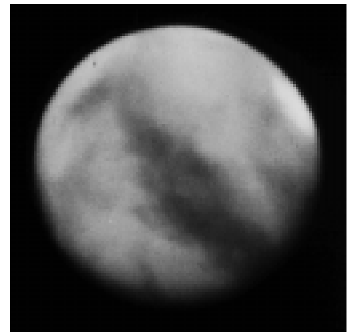


Image 7: Mars

Mars is usually over 100 million kilometers away. Light or radio waves would take about five minutes (300 seconds) to travel that far. Since Mars is orbiting the Sun, there are times when Mars is over 15 **light-minutes** away from us.

Suppose you ask a question by radio to a friend on Mars when Mars is 15 light-minutes away. There would be about a half hour round-trip delay time for the reply from your friend to get back to you. There is no known signal that can travel faster than light waves or radio waves, so a conversation with someone on Mars could get very boring!

Image 8: Neptune

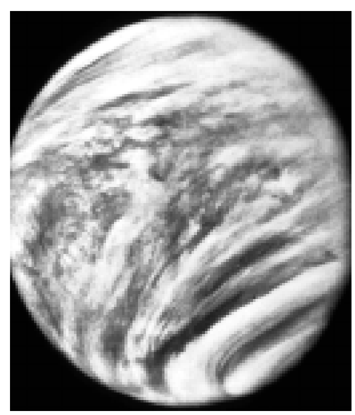
Neptune is over 4 billion kilometers away. That's over 3 **light-hours** away. It took over 3 hours each way to communicate with the Voyager 2 spacecraft during its encounter with Neptune.

Radar Mapping

Radar is used on spacecraft to map the surfaces of other planets. Superb maps of the planet Venus were made with the Magellan spacecraft using radar waves which could penetrate through the dense clouds that completely obscure the surface of Venus.

Radar mapping works by measuring the distance of the spacecraft to the planet's surface. The distance is less when the satellite is over a mountain than when it is over a valley.

Regular light cameras could not be used to even get a picture of the surface of Venus, much less measure the heights of mountains and valleys.



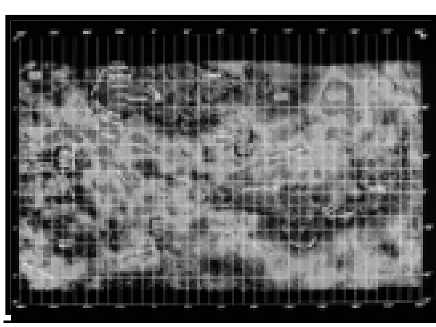


Image 9: Venus in visible light w/ clouds;

Image 10: Radar map of Venus

Radar can help us measure distances to objects in our solar system, but our radar is too weak to reach the stars and return. The distances to most astronomical bodies was a great puzzle to people throughout the ages.

Optional: When radar is used to measure distances to asteroids, the reflected signal is "smeared out" a bit if the asteroid is rotating. There can also be little details of shape in the reflected radar signal that are made by hills, mountains, or craters on the asteroid.

Ancient peoples noted that the Moon looked just as far away, and the same size, when they looked at the Moon from a valley as when they looked from the top of a mountain. So the Moon had to be may times farther away than the height of a mountain. But how far? A hundred times? A billion times? Infinitely far away? What about the stars, and the rest of the stuff of the universe? Are they all infinitely far away? The answers to these questions had to wait for the invention of a new and powerful distance finding technique called *parallax*.

How Do We Tell Distance By Parallax?

Measuring distances by parallax depends on noting how the position an object seems to change when you change your point of view.

Hand out mini-stars.

Pretend that the little ball you are holding is star. Notice it is shaped like a ball—it doesn't have points on it! Like our sun, stars are ball-shaped and they are huge—thousands of times bigger than the Earth.

We are going to see how to measure the distance to this star by looking at it from different points of view.

Hold your star out at arm's length and look at your star against the background of the other more distant stars in the sky. Without moving your arm or head, look at your star first through one eye and then the other eye. If you need to, use your free hand to block one eye and then the other. Does the star seem to shift position against the background stars? *(Yes.)* The shift in position of your star is known as **parallax**.

For a student who has use of only one eye, have him mark the position of his good eye by holding a finger of his free hand just below the good eye. To shift "from one eye to the other," the student can carefully move his head, without moving the eye-marking finger, until his other eye is where the marking finger is. He can tell this by sense of touch. In this way, his good eye has moved the same distance as his eye separation. This not a perfect method, but it is much better than having one student just not do it because of a disadvantage.

Now try holding your star closer by bending your elbow, so that the star is about half an arm's length away. Do the same thing as before: without moving the star or your head, look at your star first through one eye and then the other eye. Does the star's position seem to shift less than before? *(No, the parallax shift is more.)*

So a nearby star seems to shift back and forth when we view it from different viewing points. More distant stars seem to shift less than more nearby stars. ***But how can we look at a real star from different viewing points? Does anyone have any ideas?*** *(Accept all answers as reasonable ideas.)*

The first people who tried this observed stars from different cities very far from each other, but they saw no shift at all. The stars were too far away for any parallax shift in position to be noticeable. They ***were*** able to measure the parallax shift for the Moon.

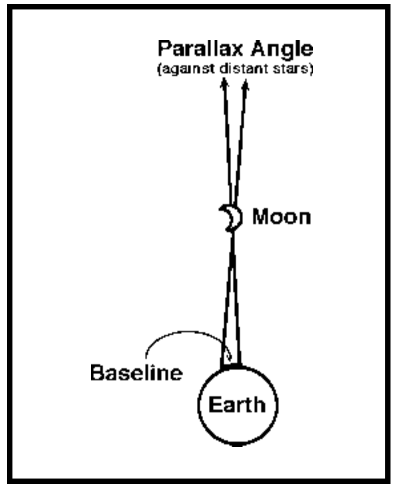


Image 11: Diagram of measuring Moon distance by parallax

Point out vertices of the triangle.

They were able to draw a triangle on paper where the height of the triangle represented the distance to the Moon. In this way, they calculated how far away our Moon was hundreds of years before radar was invented. The base of the triangle, that represented the change in viewing point, was called the ***baseline***.

The method called parallax, which you have just used, was the first way humankind measured distances in space. In 150 BC, the Greek astronomer Hipparachus used parallax to measure the distance to the moon. The parallax angle he found was nearly one degree. His answer is only a percent different from the number we can measure today. Pretty good for someone 17 centuries before the invention of the telescope!

Astronomers tried to measure the parallax of the planets and the Sun, but the angle was way too small for them to measure. That meant the planets and Sun were much further away than the Moon. But how much further? It took better instruments to measure those tiny angles. Indeed, it was 16 centuries before the parallax to any other body in the solar system was finally measured. In 1672, French astronomers just barely succeeded in measuring the parallax of Mars, and at last we knew how big the solar system was. The Sun was 150 million kilometers away! Over the next 100 years these distances were confirmed and refined.

But people were still left with the problem of determining the distances to the stars. Any baseline on Earth was not long enough for making a parallax measurement. ***Can you guess how they did it?*** *(No, they didn't have spaceships to carry them farther from the Earth.)* A breakthrough came when astronomers realized the Earth itself changes position in space as it travels around the Sun.

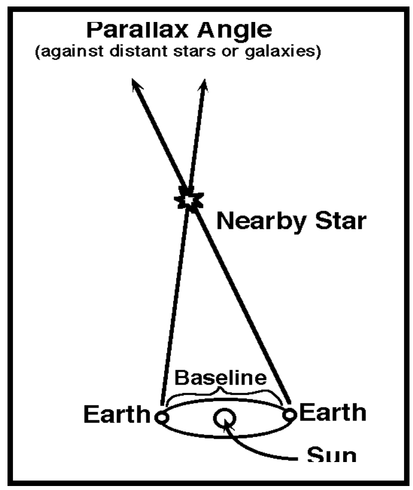


Image 12: Measuring parallax of a star.

As the Earth travels around the Sun each year, we change our point of view by over 300 million kilometers! That's the kind of baseline we need to see the parallax of a star. When astronomers take pictures of the same region of sky six months apart, some stars—the closest ones to us—change position!

To model this, hold your model star at arm's length. Imagine that your nose is the Sun and your eyes represent the Earth at two points in its orbit, six months apart. To "take a picture" of the sky six months apart, look first through one eye and then the other. The **parallax** of your star is amount that it seems to jump against the background stars. The greater the jump, the closer the star is to Earth.

Astronomers tried to use parallax on the stars in the 15th, 16th, 17th, and 18th century: and they all failed. Even with the enormous baseline of the diameter of the Earth’s orbit, the parallax to the brightest (and presumably nearest) stars always came out to be 0 degrees. They were back to having to assume all the stars were infinitely far away.

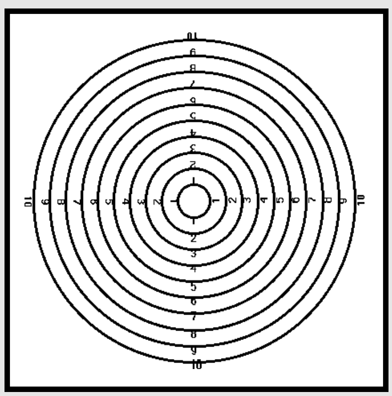
Finally in 1838 Friedrich Bessel, after a year and a half of observations of one star, 61 Cygni, succeeded in measuring the parallax to a star. The parallax was less than one 10-thousandth of one degree! No wonder it was so hard to measure. Doing the same kind of calculation and graphs that you used, Bessel calculated that 61 Cygni, one of the nearest stars to us, was an incredible 25 TRILLION kilometers away. That’s 25 thousand billion kilometers!

Astronomers have found that the star which makes the biggest jump every six months is Alpha Centauri. It is “only” 10 trillion kilometers away.

Optional: Quantitative Parallax Measurement

You can do a real parallax measurement for your star.

Image 13: Zenith angle circles.



We can measure parallax angles by using these degree markings. There would be 360 degree marks in the complete circle. If your star seemed to jump all the way across the sky, from horizon to horizon, its parallax angle would be 180°. ***Hold your star at arm’s length, and with one eye closed, line it up so that the top of it is at the center of the bull’s eye when you look at it through one eye. Without moving your star or your head, note how many degrees the top of the star shifts when you look first through one eye and then the other.*** That is the **parallax** angle of your star.

Do not use the left side or right side of the star for this measurement. The easiest method is to use the “centerline” of the star for measuring the shift.

For centerline, you can use either the small stick that comes out the bottom, or the “top” point of the star.

Please remember your parallax angle. To calculate how far away your star is, you need a worksheet.

Hand out a “How Far Is The Star” worksheet to each student. Increase light so students can read. If students have pencils, they can write their parallax angles down somewhere on the worksheet.

Refer again to image 12, Measuring Parallax of a Star. Point to parts of the triangle as you explain.

In measuring distance by parallax, the shift in the observing position is the **baseline**. You used one eye and then the other to shift your observing position, so your baseline was the distance between your eyes—only a few centimeters. Remember in your model, the distance between your eyes represents a baseline that is the diameter of the Earth’s orbit. The sight lines from your eyes to the star form the sides of the triangle. Knowing the length of the baseline and the parallax angle, we know the keys to the unique triangle that is formed by the two observing positions and the star. The height of that triangle is the distance to the star.

(continued on next page)

Before you can do your calculation, you need to know the baseline that is distance between your eyes. There are three drawings on the worksheet for three different baseline eye separations of 5 cm, 6 cm, and 7 cm. ***Please work with a partner to measure the distance between the pupils of your eyes.***

Hand out tape measures or rulers.

Now that you know the baseline and the parallax angle, you can find the distance to your star. Use the diagram that is for your eye separation, the left one for eyes 5 cm apart, the middle one for eyes 6 cm apart, and the right one for eyes 7 cm apart. Then simply see what distance corresponds to the parallax angle that you measured.

Your estimate should be pretty close. ***Check it with your partner by actually measuring the distance from your eye to your star with the tapemeasure (or ruler). How close were you?***

With real stars, there is no ruler long enough to make a check like this. We have to believe our measurements and calculations.

Collect model stars and rulers/tapemeasures.

[End of optional section. Note: This entire activity can be done outside the planetarium, after the program. It works well as part of the “How Far Is It?” classroom activity on pp. 34-38.]

Light-years

All stars, except the Sun, were shown by parallax measurements to be trillions of kilometers away from us. For such large distances, rather than us saying “trillions of kilometers” or “thousands of billions of kilometers,” it is much easier for us to use a larger unit of distance measure. Remember when I said a radio or light signal would take almost a second and a half to get from the Earth to the Moon? It takes between eight and nine minutes for light from the Sun to reach us here on Earth. A light wave takes several **hours** to travel the distance from the Earth to Pluto. **Can you guess how long it takes light to reach us from the [2nd] nearest star, Alpha Centauri?** (A little over 4 years)

A good unit for measuring the distance to a star is how long it takes the star’s light to reach us. The distance that light travels in a year is the unit we need: the *light-year*. Many people confuse this with a way of measuring time, but a light-year is really a measure of **distance**.

After astronomers had used parallax to measure the distance to a few thousand of the nearest stars, parallax again came to a dead end. The farthest of those stars were a staggering100 light-years away. Beyond that, the billions of other stars produced parallax angles too small to measure. How much bigger could the universe be?

Brightness of Stars

For really faraway stars, yet another clever distance finding method had to be found. The next trick to determine star distances was to compare their brightnesses.

Optional, for older groups:

The light from a star appears to spread out in all directions, so that when you are twice as far, the light is one fourth as bright. When you are three times as far away, it is one ninth as bright, and so on.

If you observe two stars that put out the same amount of light and are equal distances away from you, the two stars appear to have the same brightness. However, if one of the stars is twice as far away from you, that star would appear much dimmer.

[The remainder of this section, on measuring brightness, is optional.]

It is not difficult to measure brightness of stars if you have the right instrument. I'm going to give you a brightness comparator so you can measure the brightness of a star.

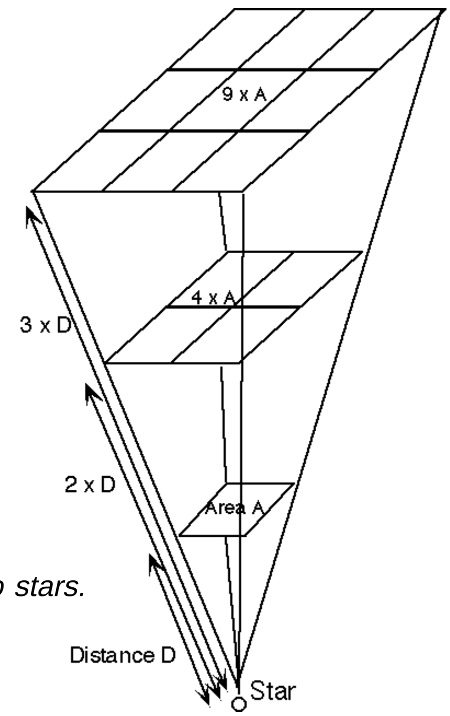
Hand out "+1" brightness comparator to each student.

A star's brightness is called its **magnitude**. One of the brightest stars we can see is named Vega and it is right here.

Point out Vega.

Vega is a magnitude 1 star. Magnitude numbers may seem a little strange to you at first, because the higher the magnitude number, the fainter the star. A magnitude 2 star is dimmer than a magnitude 1 star. The dimmest stars that you can see without a telescope is about magnitude 5 or 6, depending on how good your eyes are and how good the seeing conditions are.

If you hold this piece of plastic in front of a star at arms length, it will cut the brightness of the star by 1 magnitude. Hold the plastic over Vega, which is normally magnitude 1, and Vega will look like a magnitude 2 star. In fact, if you hold the plastic over Vega, you can compare with other nearby stars and see if there are any magnitude 2 stars nearby. **Do you see any magnitude 2 stars near Vega? If so, would you like to point one out for us?**



Have students point out magnitude two stars.

Hand out "+2" brightness comparator.

This plastic cuts the apparent magnitude of a star by two magnitude numbers. If you hold it over a magnitude 1 star, it will look like a magnitude 3 star. Can you find any stars near Vega that are magnitude 3?

Have students point out one or more magnitude 3 stars.

These brightness comparators are very simple instruments. Astronomers use very precise instruments called ***photometers*** to measure the brightnesses of stars. The word *photon* means *light* and *meter* means *measure*.

Cepheid Variable Stars

We can measure **apparent** brightness of a star and still not know how far away the star is. Remember that the farther away a star is, the dimmer it looks. If we had a set of "standard 100 watt light bulbs" scattered around the universe, we could tell how far away they were by seeing how dim they appeared. The dimmest would be farthest away.

But how do we know if a star is bright because it is close, or bright because it really is a "200 watt star?" Some stars are inherently brighter than others. The inherent brightness of a star is called its ***absolute brightness*** (or ***absolute magnitude***).

The **absolute** brightness of a star is what its brightness would be if it was viewed at a standard distance.

Background: The standard distance of a star to see its absolute magnitude is 32.5 light-years = 10 **parsecs**. The unit, parsec, derives from the idea of parallax measurements: a parsec is the distance at which a star would exhibit one arc-second of parallax.

Of course stars, like the Sun, are much brighter than 100 watt light bulbs. But it just so happens that there are certain kinds of stars that are especially useful in determining brightness in an absolute sense. There are many stars that pulsate in brightness over periods of time. They are called ***variable stars***.

In the early part of this century, astronomer Henrietta Swan Leavitt discovered a characteristic of a very special kind of variable star that has become a crucial "yardstick" for measuring distances to very distant stars. The type of variable star whose behavior she studied is called a Cepheid variable star, because the first one was found in the constellation Cepheus. It is a kind of star that tells us how many watts it puts out.

Optional: point out Cepheus.

Let's look at two Cepheid variable stars to see how they are special. To make things simpler, let's say that these two Cepheid variable stars are very nearby, and exactly the same distance away from us.

Create the effect of Cepheid variable A and Cepheid variable B, preferably going side by side. A should appear at least twice as bright and twice as slow as B.

Cepheid A should peak at magnitude 1, about the brightness of Vega..

What is the difference between these two Cepheid variable stars? *(Call the brighter one* Cepheid variable A *and the dimmer one* Cepheid variable B. *The dimmer one is pulsing faster than the other.)*

Optional for older students: Quantitative Measurements of Cepheid Variables

Let's measure the pulsing rate of Cepheid variable A. Its **period** is how long it takes to go from maximum brightness to maximum brightness. We are observing the variable star in accelerated time: each second in our planetarium is about 10 days of real time. ***Please count silently how many pulses occur while I time 100 days of real time.*** Ready? Set. **Count.** *(Wait until the fifth flash.)* ***Stop! How many pulses were there?*** *(5)* ***If there were five pulses in 100 days, how long did each pulse last.*** *(20 days.)* So the period of this Cepheid variable star is 20 days.

Now let's look at Cepheid variable star B. ***Please count how many pulses occur while I again time 100 days of real time.*** Ready? Set. **Count.** *(This time, wait until the* ***tenth*** *flash.)* ***Stop! How many pulses were there?*** *(10)* ***If there were ten pulses in 100 days, how long did each pulse last.*** *(10 days)* So the period of this Cepheid variable star is 10 days. As you can see, the period is related to the brightness.

That is exactly what Henrietta Leavitt discovered. She studied Cepheid variables in a large group of stars that she knew were all about the same distance away. She found that brighter ones always pulse slower than dimmer ones. In fact, by measuring the pulsing rate of a Cepheid variable star, we can accurately gauge its absolute brightness.

The Cepheid variables that we have been observing so far, we have pretended are very close to us and are all exactly the same distance from us. To see how Cepheid variables act as "standard light bulbs" for us, let's look at another Cepheid variable.

Turn on Cepheid variable C. It should pulse as slowly as A did, but between the same brightness levels as B did.

What can you tell about this Cepheid variable? (Accept any response.)

Let's compare it with Cepheid variable A.

Show A and C simultaneously. (If you are using version I, this may not be possible, so show them consecutively.)

What is similar about them? *(They have the same period.)* ***If they have the same period, how does the maximum*** **absolute** ***brightness of A compare with the maximum*** **absolute** ***brightness of C?*** *(The absolute brightness must be the same.)*

Even though we know their **absolute** ***brightness are equal, which one actually looks dimmer to us?*** *(C.)* ***So, if their*** **absolute** ***brightnesses are equal, which one must be farther away from us?*** *(C.)*

To summarize: by measuring the period of a Cepheid variable star, we can know what its peak **absolute** brightness is. Then by measuring how much dimmer its peak **apparent** brightness is, we can figure out how far away it is. This discovery was a major milestone in our understanding of the size of our universe. Cepheid variables have become our "standard light bulbs."

A fascinating fact that is not well known is that the North Star (Polaris) is a Cepheid variable star that changes between magnitudes 2.5 and 2.6 with a period of 4 days.

If we see a Cepheid variable star in a cluster of distant stars, we can find the distance to the cluster of stars by figuring out the distance to the Cepheid variable.

Observations of Cepheid variable stars have allowed us to map large sections of the universe. We now realize that most of the individual stars we see with the naked eye are relatively nearby: within a few hundred light-years.

Use light pointer to point out stars all over the sky.

Many of these stars probably have systems of planets orbiting them just as the 9 planets in our solar system orbit the sun. The name of our sun is Sol, so our system of planets is called the Solar System. This star is Vega *(Point it out.)* ***If it has a system of planets, what should we call it?*** *(The Vegan System.)*

The study of very distant Cepheid variable stars has led to some remarkable findings. For instance, all of the stars near us are orbiting in a giant mass of stars that we call a ***galaxy***.

Point out Milky Way galaxy.

If your planetarium does not have a Milky Way projector, ask if anyone has seen the Milky Way and what does it look like.

What looks to us like a beautiful nighttime cloud extending all the way across the sky is really made of millions upon millions of stars. A long time ago, this cloud was named *The Milky Way*. Now we know that if we could see the Milky Way from a great distance, we would see that it is a galaxy that is a huge pancake-shaped collection of dust, gas clouds and stars. Our Sun is about 2/3 of the way out to the edge of the pancake. Since we are inside the pancake, we are always looking at it edgewise, so it appears as a lovely cloud-like band that stretching all the way across our sky.

Image 14

Do you think that all the stars in the Milky Way are orbiting around our Sun? *(No. They orbit the center of the pancake.)*

Cepheid variable stars have been used to help find out how big our Milky Way galaxy really is. Current estimates are that the Milky Way has as many as 400 billion stars spread out over a region of space nearly 100,000 light-years across. (Aren't you glad we're using light-years instead of kilometers or miles?) If a star were to blow up on the other side of our galaxy, we wouldn't know about it for 100,000 years!

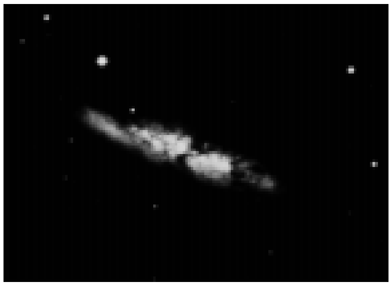


Image 15

But the universe is still larger than just our own galaxy. Our Milky Way is but one of many millions of galaxies. Here are some of the many beautiful shapes that galaxies come in. Remember that each of these galaxies is made of many billions of stars and the size of each galaxy is many thousands of light-years across.

Image 16

Show gallery of galaxies (remaining slides). Distance to Andromeda galaxy (one of the nearest to our own) is about 2 million light-years. Point out different types (spiral, elliptical, irregular, barred spiral). Point out orientation of spirals as seen either top/bottom view or edge-on.

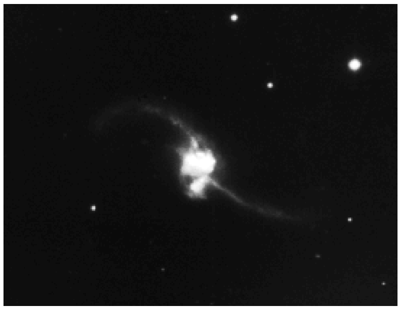


Image 17

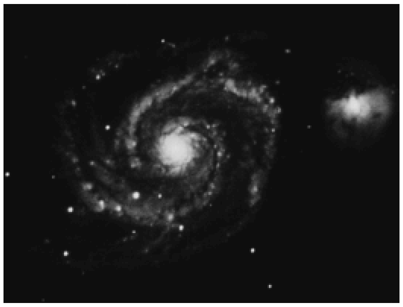


Image 18

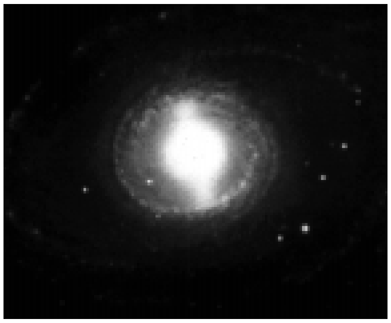


Image 19

Distances to nearby galaxies can be found by observing Cepheid variable stars and other types of variable stars in those galaxies.

The Cepheid variables that Henrietta Leavitt studied in making her discovery were all about the same distance away, in a nearby galaxy—the Small Magellanic Cloud—about 160,000 light-years away from us. The Large and Small Magellanic Clouds, though they are nearby in relation to other galaxies, are extremely far away compared to the stars in our immediate neighborhood. To say that all the stars in one of the Magellanic Clouds are roughly the same distance away from us is somewhat like saying that all the people in New York are about the same distance away from San Francisco.

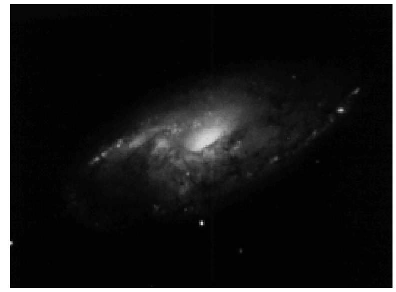


Image 20

To determine the distances to the most distant galaxies, "the standard light bulb" Cepheid variable stars are of no use, since we cannot see individual stars in galaxies that far away. For great distances we use "standard galaxies." Studies of Cepheid variables in nearby galaxies have shown that certain types of galaxies have fairly predictable **absolute** brightnesses. We assume that those same types of galaxies have the same absolute brightness no matter how far away we find them. Then, just as we did with the Cepheid variable technique, we can figure out how far away the galaxy is by measuring its apparent brightness.

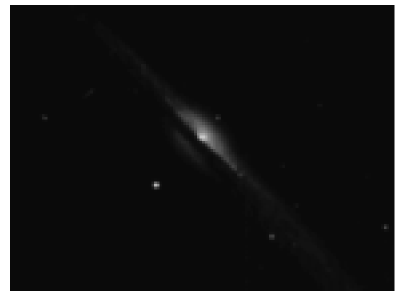


Image 21

One of the most profound discoveries about galaxies is that they are nearly all moving away from us. ***What does that tell us about what's happening to our universe?*** *(It's expanding.)* This was discovered by analyzing the color of light from galaxies. When a galaxy is moving away from us, the color of light that we see from it is shifted towards the red end of the color spectrum. The more the light appears red-shifted, the faster the galaxy is moving away from us. It was found that distant galaxies are more red-shifted than nearby galaxies. The relationship between the galaxy's red-shift and its speed away from us has turned out to be so reliable, that red-shift is even used as one of the techniques for finding distances to the most distant galaxies.

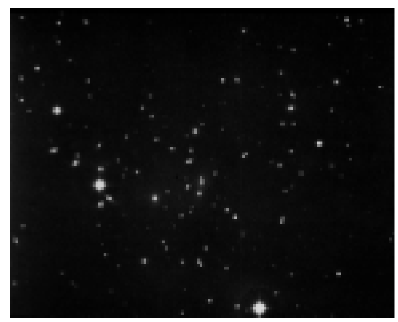


Image 22

When we talk about how big the universe is, we start speaking in light-years, which though not a measurement of time, certainly reminds us of time. When we look at a galaxy a hundred million light-years away from us, we must realize that the light that reaches us from that galaxy has been traveling for a hundred million years. We are looking out into space and back in time as well. It makes you wonder about the age of our universe. One of the main objectives of the Hubble Space Telescope is to see farther into the universe than ever before. The farthest galaxies detected are several billion light-years away. That's extremely old light.

I'm afraid its time for us to return from our journey to the outer reaches of the universe. Let's take a quick ride home to Earth.

Return to Earth via last segment of Powers of 10 video.

When we gaze into the heavens, many intriguing questions drift into our minds. ***What questions are drifting in your mind?***

Remaining time is for questions. Though the show has dealt primarily with the size of the universe in terms of distance, there is also the question of how big the universe is in terms of mass, as well as how old the universe is. How deep your discussion goes depends on the understanding level of the class, the instructor, and of course, time….

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How Big Is The Universe?

Classroom Activities

A Question of Scale

After seeing the video *Powers of Ten*, students think about the sizes of different things in the universe. In this activity, they try to place various objects on a metric "powers of 10" scale.

Materials

- ❐ "Question of Scale" worksheet (1/student; master on page 27)
- ❐ Pair of Scissors (1/student)
- ❐ Tape (1 for every group of 3 or 4 students)

Before Class

1. Photocopy a worksheet for each student
2. Using a paper cutter, cut the worksheets along the dotted line. [Students will cut dashed lines.]
3. It's best to do this activity after the class has seen the video "Powers of Ten."

In Class

1. Hand out worksheets and lists of challenge objects.
2. Have students cut each challenge object from the list with scissors and tape it to the appropriate place on the distance scale. Give them several minutes to do this. Allow them to consult each other and get opinions from friends.
3. Conclude activity with a vote of where each object goes. Then give typical distances and sizes from the list below. Discuss the difference between *distance* and *size*.

Distances to quote in *A Question of Scale*

width of a light switch lever .... about 1 cm
ping pong ball .... about 3 cm
softball .... about 10 cm
basketball.. about 30 cm
width of a door .... about 1 m
height of doorway .... 2+ m
the classroom .... about 6 m?
the school .... about 100 m?
depth of the Grand Canyon .... over 1 km
height of Mt Everest .... 8.78 km
deepest depth of Pacific Ocean .... 11 km
Denver to Kansas City .... 890 km
length of California .... 1000 km
Nashville to New York City .... 1,213 km
diameter of Moon .... 3,476 km
San Francisco to New York .... 4,100 km
diameter of Earth .... 12,756 km
diameter of Jupiter .... 142,800 km
distance to the Moon .... 384,402 km
diameter of the Sun .... 1.4 million km
distance to the Sun .... 152 million km
distance from Sun to Saturn .... almost 1.5 billion km
nearest star (other than Sun).............. 38 million million km — off the scale
Milky Way galaxy .... 100,000 LY or a million billion km — way off the scale

A Question of Scale

1 cm	basketball
10 cm	classroom
1 meter	deepest depth of Pacific Ocean
10 meters	Denver to Kansas City
100 meters	depth of the Grand Canyon
1 km	distance of Sun from Earth
10 km	Earth to Moon distance
100 km	Earth's diameter
1000 km	height of a doorway
10,000 km	height of Mt. Everest
100,000 km	Jupiter's diameter
1 million km	length of California
10 million km	Milky Way galaxy
100 million km	Moon's diameter
1 billion km	Nashville to New York City
	nearest star (other than Sun)
	ping pong ball
	San Francisco to New York
	softball
	Sun to Saturn
	Sun's diameter
	the school
	width of a door
	width of a light switch lever

Your Galactic Address

Usually you think of your address as only three or four lines long: your name, street, city, and state. But to address a letter top a friend in a distant galaxy, you have to specify where you are in a greater span of scales.

Materials

❒ For each student, one of each of the address maps: (1) Classroom, (2) School, (3) Neighborhood, (4) City, (5) State, (6) Country, (7) World, (8) Solar System, (9) Milky Way Galaxy

Before Class

1. Get a map of your school and reduce/photocopy it (or sketch a map of your school) so that it fits on Galactic Address Map 2 (page 29) as a photocopy master. (Another option would be to make this an additional exercise for your students.)
2. Reduce/photocopy a map of your neighborhood and a map of you city to make a photocopy master for Galactic Address Maps 3–4 (page 30).
3. Reduce/photocopy a map of your state to put in the upper section of Galactic Address Map 5 photocopy master (page 31).
4. Use the resulting photocopy masters (pp. 29–32) to make a complete set of Galactic Address Maps for each student or team of students.

In Class

1. Ask a student volunteer for his or her address.
2. Explain if you were to write a letter to an alien being from another planet, you would need a much more detailed address than that! A complete galactic address must span many distance scales.
3. Hand out Galactic Address Maps 1 and 2. Have the students make a rough sketch map of the classroom with the desks numbered. Have each student invent a symbol to represent themselves and mark that symbol on the appropriate spot on their sketch. Have them write their desk number in the space provided.
4. Have the students mark their symbol on the proper room number in the map of the school Galactic Address Map 2. Have them mark their room number in the blank provided.
5. Hand out Galactic Address Maps 3 and 4. Have students mark their symbols in the proper places on each map, neighborhood and city. Have them fill in the address blanks, “street number,” and “street” on the right side of the page. They can all use the same school address.
6. Hand out Galactic Address Maps 5 and 6. Have students mark their symbols on each map appropriately. Have them write the proper “City” and “State” in the spaces on the right side of the page.
7. Hand out Galactic Address Maps 7 and 8. Have students mark their symbols on each map and write the correct “Country” and “Planet” in the spaces on the right side of the page.
8. Hand out Galactic Address Map 9. Tell the class that our solar system is about 2/3 of the way from the center to the edge of the galaxy. Also, we are located on the outer edge of the “major spiral arm.” The students can use those clues to mark their symbols at their location in the Milky Way Galaxy. Have them fill in the “Galactic Arm” space on the right side of the page.
9. Finally, ask the students to write in the bottom part of Map 9 their complete galactic address, all the way from which desk they are sitting in to which galaxy we are in. Tell them that the Milky Way is part of a cluster of galaxies called *The Local Group.*

Galactic Address Map 1: Classroom

Please mark where your desk is.

I am at desk number ______

Galactic Address Map 2: The School

Please mark where your classroom is.

I am in classroom ______

Galactic Address Map 3: The Neighborhood

Please mark where your school is.

Street Number and Street: ______

Galactic Address Map 4: The City

Please mark where your school is.

Galactic Address Map 5: The State

Please mark where your city is.

My City

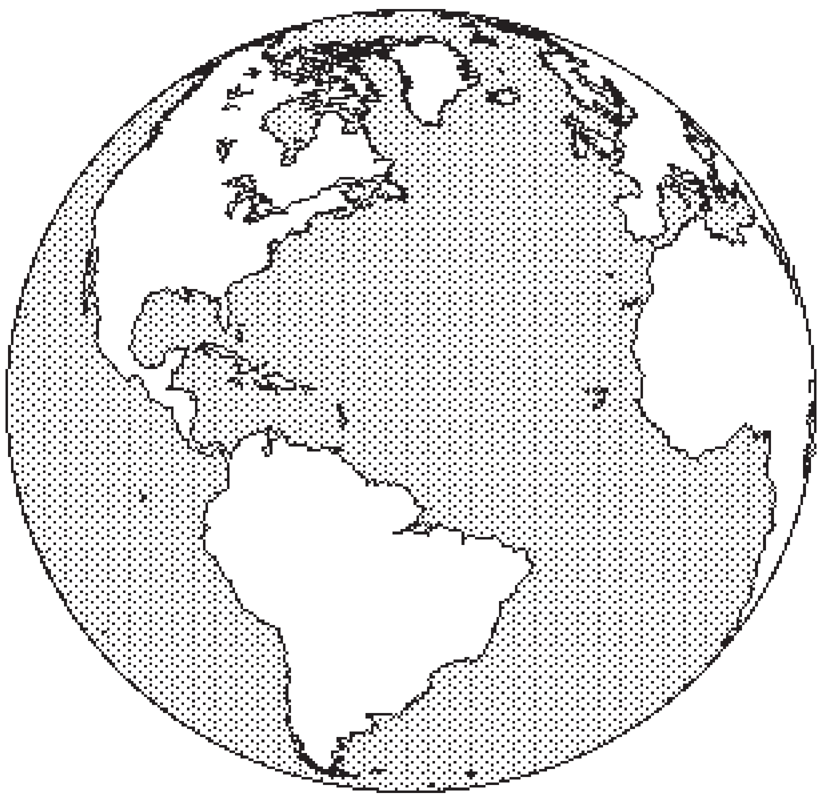
Galactic Address Map 6: The Country

Please mark where your state is.

My State:

Galactic Address Map 7: The World

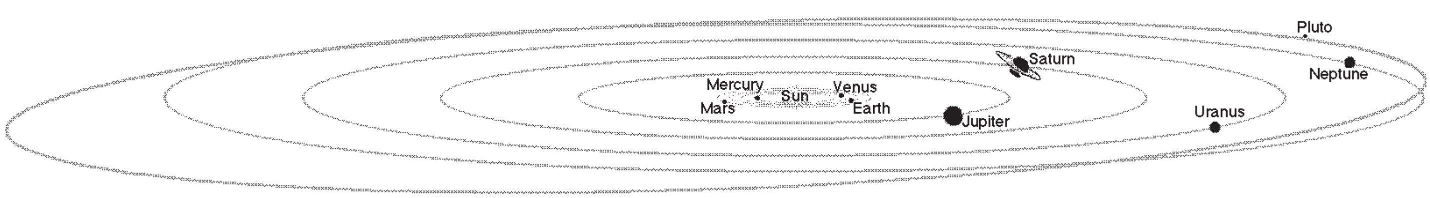
Please mark where you are.



My Country: ____________

Galactic Address Map 8: The Solar System

Please mark where your world is.

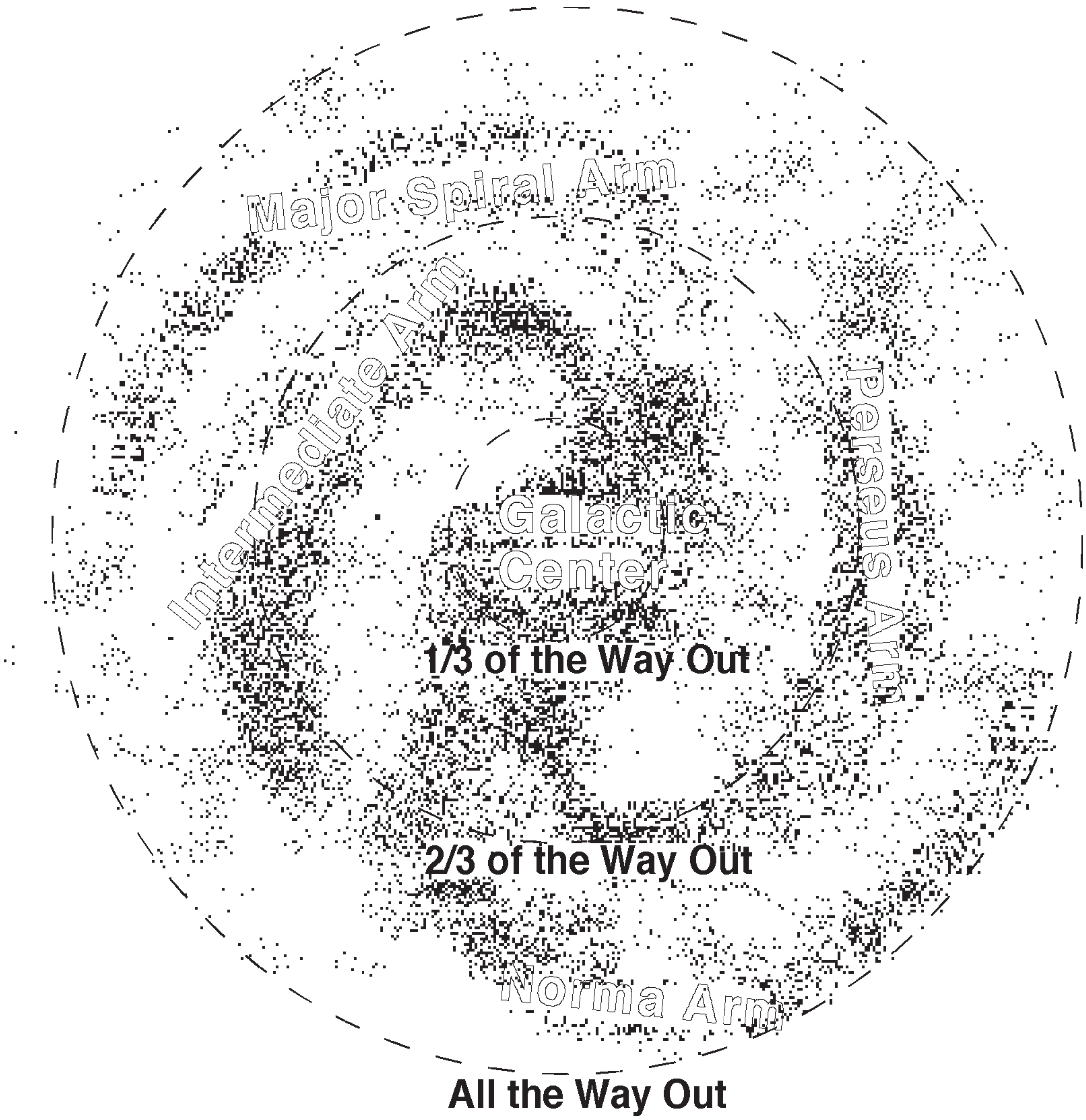


My planet: ____________

Note: Planets' orbits are really very nearly circular. Why do they seem like long, skinny ovals here?

Galactic Address Map 9: The Milky Way Galaxy

Please mark where your world is.



My Planet System:

Please write your complete galactic address below.

Your Name:
1. Classroom:
2. School:
3. Street & #:
4. City:
5. State:
6. Country:
7. Planet:
8. Planet System:
9. GalacticArm:
10. Galaxy:
11. Galaxy Cluster:

Parallax—How Far Is it?

How far away is that flagpole? Set your sights on a very distant reference object and compare where the flagpole is in relation to that distant reference object. Then move to a new observing position and again compare where the flagpole is in relation to the distant reference object. The apparent change in position is the flagpole's **parallax**. In this activity, your students use a parallax angle measuring device to determine distance.

Materials

❒ Parallax Angle Measurer cutout sheet—scale piece (1/student + 2 for the teacher; photocopy master on page 35)

❒ Distance Measuring worksheet (1/student; master on page 36)

❒ 6 to 10 sheets of construction paper, 8 1/2" x 11", various colors

❒ Ruler or 8-1/2" x 11" sheet of paper (1/student)

❒ Scissors (1/student)

❒ Push pin (1/student)

❒ A bit of wine cork, eraser, wood, styrofoam or other soft material, at least 1 cm thick, for a push pin to stick into (1/student)

❒ Five or six tape measures

❒ 2–3 rolls of tape

❒ Optional: Overhead projector and 3 sheets of acetate.

❒ Optional: Two or three tape measures

Before Class

1. Make one photocopy each of "Angle Measurer" cutout sheet and "Distance Measuring" worksheet for each student. The angle measurer will work best if you photocopy onto cardstock, though regular paper works adequately.

2. Cut bits of material that the push pin can be stuck into. Wine corks, big pencil erasers, or styrofoam can be sliced up with a sharp kitchen knife into pieces about 1 cm thick.

3. Assemble a demonstration angle measurer yourself, following the instructions in step 1 (below).

4. Make 6 to 10 cardboard targets out of different colored construction paper. The targets can be stick people figures, cones, or other shapes. Making each one a different color will allow students to distinguish them easily. Place the targets among the students' desks so that the targets extend well above the height of the desks, 30 cm (a foot) or so. The targets may be taped onto desks or hung from the ceiling.

5. Optional: Photocopy the cut-out sheet and the worksheet onto clear acetate for pointing out parts on an overhead projector.

In Class

1. Tell your students that they are each going to make a parallax angle measuring tool. Hand out the cut-out sheets and scissors. Explain the following steps (pointing out parts on an overhead projector if you wish):

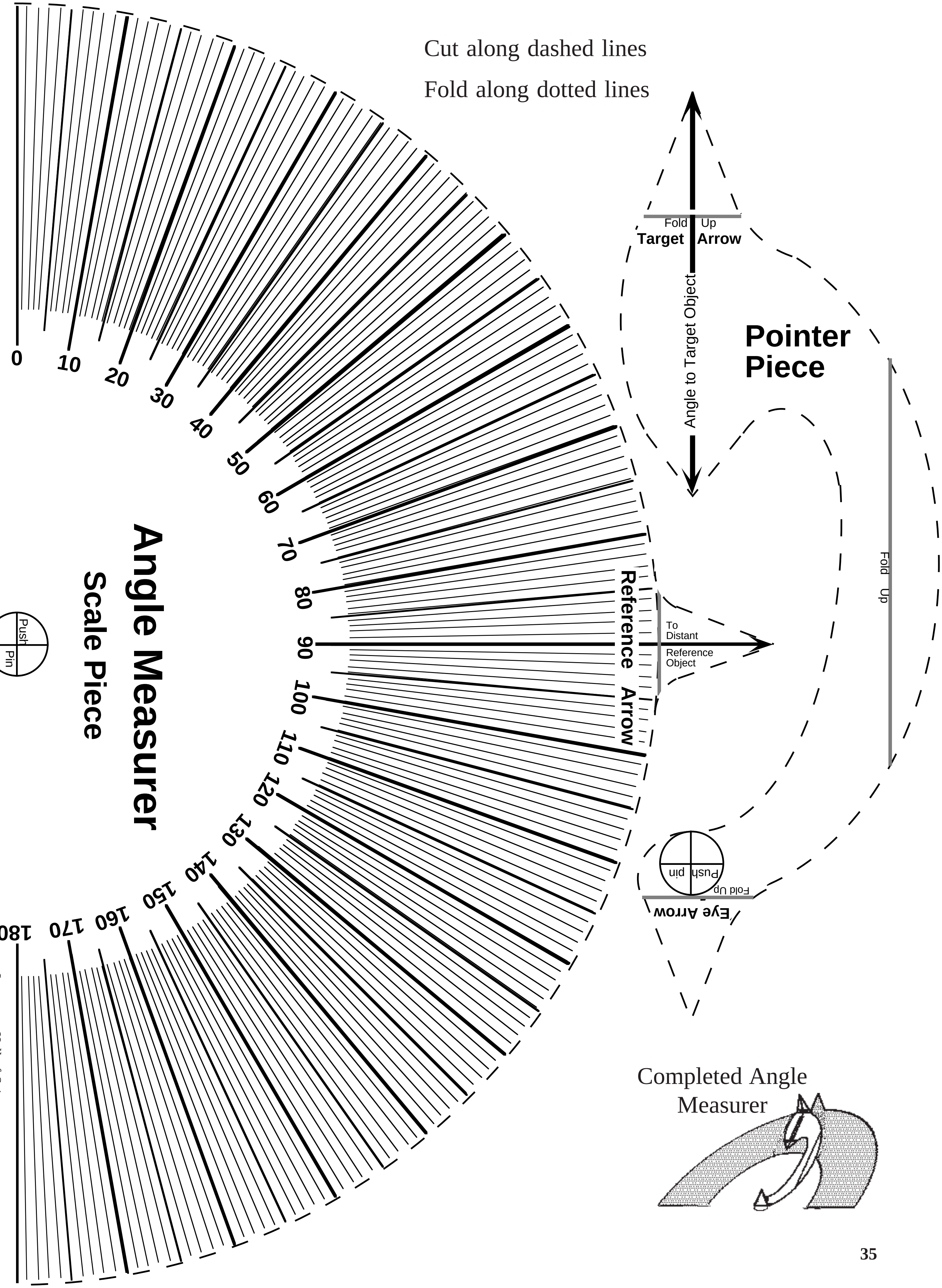
a. Cut out both pieces along the dashed lines.

b. Fold up all the arrows along the dotted lines: the **reference** arrow on the scale piece, and the **target** and **eye** arrows on the pointer piece. A ruler is helpful here.

c. Stick a pushpin through the "Pushpin" cross marks on the Pointer piece, the Scale piece, and then into the cork. The completed Angle Measurer should appear as in the figure on the cutout sheet and as your demonstration model. The pointer piece should be able to sweep along the angles of the scale piece.

Cut along dashed lines

Fold along dotted lines



Completed Angle
Measurer

Distance Measuring

1

Target Angle 1 [ ]

Target Angle 2 — [ ]

= [ ]

Parallax Angle

2

Parallax Angle	Distance in "Baselines"
1°	57.3
2°	28.6
3°	19.1
4°	14.3
5°	11.4
6°	9.5
7°	8.1
8°	7.1
9°	6.3
10°	5.7
11°	5.1
12°	4.7
13°	4.3
14°	4.0
15°	3.7
16°	3.5
17°	3.3
18°	3.1
19°	2.9
20°	2.7

Accuracy decreases with larger angles.

3

Distance in "Baselines" [ ]

Length of Baseline × [ ]

= [ ]

Distance to Object

2. Explain that each student is going to measure the distance from his or her desk to one of the colored targets in the room. A distant reference point will be the vertical line formed by the corner of the room farthest from the student. Ask each student to select a colored target object that is not too far from them, but in the general direction of the corner of the room that is farthest from them.

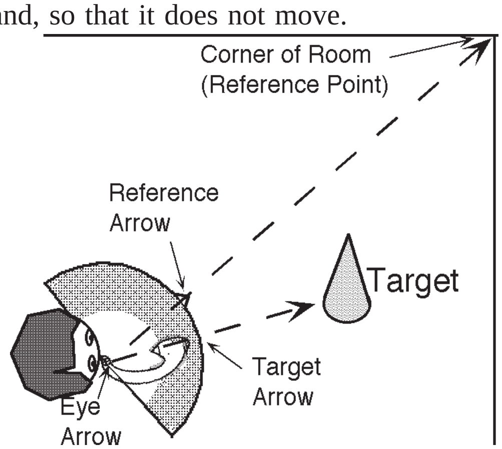
3. Have each student make a baseline by taping a ruler or sheet of paper onto their desks. The baseline should be roughly perpendicular to the direction of the target and reference objects.

4. Hand out a "Distance Measuring" worksheet to each student.

5. Tell them that they are going to measure the angle between the reference and target objects twice—one measurement at each end of their baseline. Explain the following procedure:

(a) Put your Eye Arrow on one end of the baseline.

(b) Line up your Eye Arrow, the Reference Arrow, and the reference point (farthest corner of the room). Emphasize that all three elements must line up as in a gunsight. Once reference corner is lined up with both the eye arrow and reference arrow, press the scale piece firmly to the desk with one hand, so that it does not move.



(c) Now pivot the Target Arrow until it is in line with both the Eye Arrow and the colored target object, whose distance you are trying to measure. Again emphasize that all three elements must line up. Be sure you are holding the scale piece down firmly so that it does not move. Only the Pointer Piece should pivot.

(d) Read the "Angle To Target Object" indicated on the scale and write that angle down on the worksheet in the space for "Target Angle 1."

(e) Move your angle measurer to the other end of your baseline. Then repeat steps (b) and (c) to measure the 2nd "angle to target object." Write that angle down on the worksheet in the space marked "Target Angle 2."

6. Draw on the chalkboard as you explain that the difference between their two measured angles is the p**arallax** angle. Draw the baseline and the target object and show how they form a triangle. Label Target Angle 1 and Target Angle 2. Extend the sides of the triangle and label the parallax angle as shown in Figure A. Explain that they can

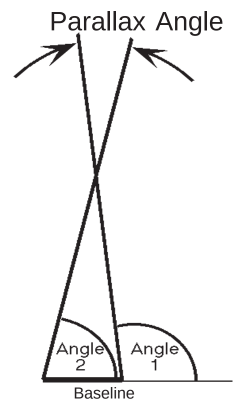


Figure A

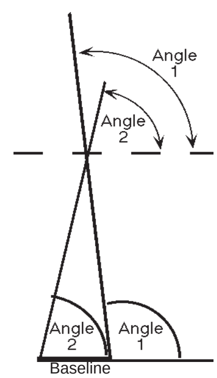


Figure B

calculate the parallax angle by subtracting the larger angle from the smaller angle.

Optional: Draw a dotted line through the target parallel to the baseline. Label angle 1 and angle 2, as shown in Figure B. Point out that Target Angle 1 is the same size as angle 1 and Target Angle 2 is the same size as angle 2. (In geometry, these are "corresponding" angles.) Sometimes it is easier for students to see why the parallax angle is the difference between angles above the dashed line than it is for them to see how the parallax relates to Target Angles drawn on the baseline.

7. Instruct your students to subtract the larger angle from the smaller angle (interchange the numbers if necessary) and write the answer in the space marked "Parallax Angle."

8. The distance to the target is the height of the triangle and can be found in the table on the worksheet. The table lists distances in "baselines" so have your students find the distance corresponding to their parallax angle in the table and write that distance in the space marked "Distance in Baselines."

9. Have the students write in the length of the baseline in the space marked "Length of Baseline." If they used a standard ruler, the baseline is 30 cm. If they used the length of a standard sheet of paper, the baseline is 28 cm.

10. Finally, the students can calculate the distance to their target object by multiplying the "Distance in Baselines" by the "Length of the Baseline." Have them enter the answer in the space marked "Distance to Target Object." If you have tape measures, students can check their answers by direct measurement.

Going Further

Alternate Calculation Method I

You may opt for students to do a graphical calculation (draw a scale drawing):

Steps 1-6 above are the same except that in step 4, do not hand out a "Distance Worksheet." Have students record their angles on paper.

7. Use a protractor and ruler to make a scale drawing of the baseline, Target Angle 1 and Target Angle 2 with appropriate scale, e.g. 1 mm = 1 cm. Demonstrate this on an overhead transparency if possible.

8. Find the point where the angles intersect and measure the scale distance to the object..

Alternate Calculation Method II:

If your students are studying trigonometry, the Distance to the target (D) is related to the Parallax angle (α) and the Baseline (B) by the trigonometric relationship (tangent), $D = B \div \tan(\alpha)$.

How Far is That Flagpole?

Your parallax Measurer can be used to find really far away distances outdoors by measuring off baselines of several meters or more.

Stretching Infinity

In order for students to learn about the expanding universe they need to have a mathematical understanding of points, lines, space, and infinity. This activity defines these concepts and asks the students to visualize what happens when you multiply infinity by two.

Materials

❒ "What's Two Times Infinity?" worksheet (1 for each student; master on page 40)

Before Class

1. Photocopy a worksheet for each student. The worksheet is only a half-sheet (the bottom half). You can make a "doubled master" by making two copies of page 40 and pasting two bottom halves on a single sheet.

2. It's best to do this activity after the class has seen the video "Powers of Ten."

In Class: Part A Mathematical Points & Lines

1. Ask your students if they have ever heard the notion that our universe is expanding. Ask them what they think that means. Accept several responses. Explain to your students that to help them understand how the universe is expanding, they need to visualize points, lines, surfaces, and space.

2. To understand what space is, it is helpful to discuss dimensions. Draw a dot on the chalkboard. Explain that we often represent a "point" in a drawing as a little dot. But in mathematics, a true point is so small that it has no size. A true point cannot be drawn because it would be too small to be seen. It is just a location. A point has "no dimension." It's "zero-dimensional."

3. Ask, "What is a line?" Accept students' ideas. Ask the students to imagine two points starting out together and then moving rapidly in exactly opposite directions. ***What do you call the path that these points have traced?*** *(A line.)* In mathematics, a line has no thickness (sort of like a point), but extends indefinitely in opposite directions. It is the next dimension higher than a point. We say that a line has one dimension. It is "one-dimensional."

Part B What Is Infinity Times Two?

1. Hand out the worksheet, "What's Two Times Infinity?" Point out that the line at the top is a "line segment" that fits on the page, but your students should imagine a true mathematical line which extends infinitely in both directions off the page. Tell them that the numbers are labels for points on the line. The distance between each pair of points is the same. Ask, ***"How many labeled points are there on the segment of the line that fits on the page?"*** *(25, including 0.)*

There are an infinite number of points on the line in between each pair of points. No matter how small a line segment you choose, there are an infinite number of points on each line segment. That is because mathematical points have no size! You can fit gobs of them on any length of line segment.

2. Ask the students to imagine making each pair of points on the line twice as far apart. That includes all the unlabeled points also. The resulting line is the bottom line on their page. The labeled points (indicated by dots) have moved so that each pair is twice as far apart as they were on the first line. There are still an infinite number of points between each pair of labeled points.

3. Have the students label the points on the new line.

Ask, ***"How many labeled points fit on the segment of the second line that is on your page?"*** *(13, including 0.)*.

Ask, "Is the second line longer than the first line?" (Twice as long?; no).

Ask, "How long is the first line, including all the points that don't fit on the page? (Infinitely long.)

Ask, "How long is the second line, including all the points that don't fit on the page? (Infinitely long.)

Explain that if you multiply infinity by two, you still get infinity.

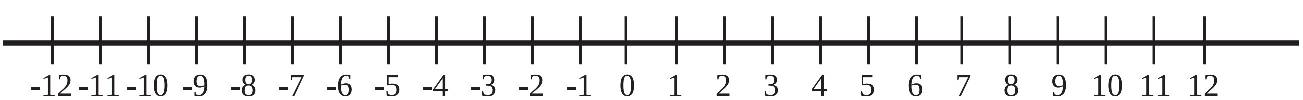
Part C — Space

1. Ask, ***"What is a surface?"*** Accept students' ideas. Ask the students to imagine two lines starting out together and then moving rapidly in exactly opposite directions. ***What do you call the area that these lines have swept over?*** *(A plane.)* In mathematics, a plane is a flat surface that has no thickness (sort of like a points and lines), but extends infinitely. A surface is the next dimension higher than a line. We say that a surface has two dimensions. It is "two-dimensional."

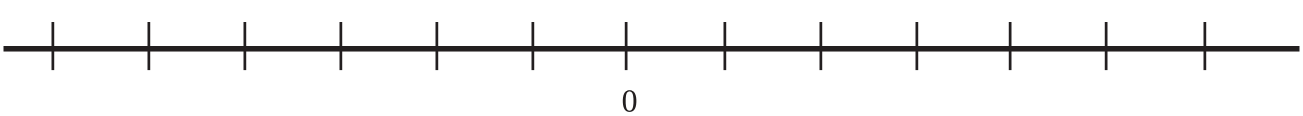
2. Ask, ***"What is space?"*** Accept students' ideas. Ask the students to imagine two identical surfaces starting out together and then moving rapidly in exactly opposite directions. ***What do you call the region that the two surfaces have swept through?*** *(Space.)* In mathematics, space extends indefinitely in all directions. It is the next dimension higher than a surface. We say that space has three dimensions. It is "three-dimensional." Sometimes, the three dimensions of space are referred to as length, width, and height (or depth). Each of those three dimensions (length, width, and height) are associated with lines and are each one-dimensional in themselves. But they combine to make three dimensional space.

Stretching Infinity—What Is Infinity Times 2?

A segment of an infinite line



Double the distance between each pair of points on the line.



A Ballooning Universe

It is difficult for many students to understand the idea that the universe can extend infinitely in all directions and still be expanding. The students grapple with this concept by making a “curved two-dimensional” balloon model of the universe.

Materials

❒ Balloon (1/pair of students)

❒ Marking Pen (1/pair of students)

❒ Tape Measure (1/pair of students) or a “Do-It-Yourself Tape Measure” (master on page 42), scissors, and tape for each pair of students

❒ Blank sheet of paper, 8.5"x11" (1/pair of students)

Before Class

If you don’t have ready-made tape measures, photocopy a "Do-It-Yourself Tape Measure” (master on page 42) for each pair of students. This can be made into a double master so that you can chop the photocopies in half lengthwise to get twice the number of tape measures.

In Class

1. Imagine a universe of many galaxies distributed throughout space. We can make a two-dimensional model of that universe by drawing galaxies on the surface of a balloon.

2. Hand out a balloon and pen to each pair of students. Have them take turns drawing several galaxies on the balloon. Have them mark a unique name (or number or letter) by each galaxy that they draw.

3. Hand out a tape measure for each team. Alternatively, hand out the “Do-It-Yourself” sheet with scissors and tape for each team. They can cut and tape the ruler strips from sheet into one long strip to be used as a “paper tape measure” for measuring the distance around the balloon.

4. Have each student draw a “Distance Table” on a blank sheet of paper and label the rows:
“Distance 1—Between Galaxy ___ and Galaxy ___,”
“Distance 2—Between Galaxy ___ and Galaxy ___,”
“Distance 3—Between Galaxy ___ and Galaxy ___,”
and “Circumference of Universe_____.”

There should be three blank columns.

5. Have one student in each team blow up the balloon so that it just barely starts to inflate, then hold the neck of the balloon pinched between two fingers so that it does not lose air. Have the second student of the team measure the separations between three pairs of galaxies on the balloon and record the galaxy names and distances in the Distance Table. The second student also measures the distance around the balloon with the tape measure and records that distance in the last row of the table. The first student of the team can then release the balloon and copy the measurements onto his or her own Distance Table.

6. Ask the students to predict what the distances between the galaxies will be if they expand their balloon universe to twice the size that it was for their first measurement. Have them write their predictions by the distance entries that they recorded in their Distance Tables.

7. To see if their prediction is correct, one student holds the paper tape measure in a loop twice as big

	Measurement 1	Prediction	Measurement 2
Distance 1—Between Galaxy ___ and Galaxy ___			
Distance 2—Between Galaxy ___ and Galaxy ___			
Distance 3—Between Galaxy ___ and Galaxy ___			
Circumference of Universe			

as the circumference of the balloon in their first measurement. The other student blows up the balloon to fit. It may take a few tries to get it just right. Once the balloon fits the right circumference, the balloon blower pinches the neck of the balloon to keep air from escaping, while the other team member measures the distances between the same three pairs of galaxies as were measured before, and records the measurements in the table.

8. Have teams report their results.

9. Ask for conclusions with the following questions:

Are all the galaxies moving away from one another? (Yes.)

Is there any "center" on the surface of the balloon? (No. The center inside the balloon doesn't count because two-dimensional people living on the two-dimensional surface would not be able to go to that center.)

What are the weaknesses in our model of the universe?

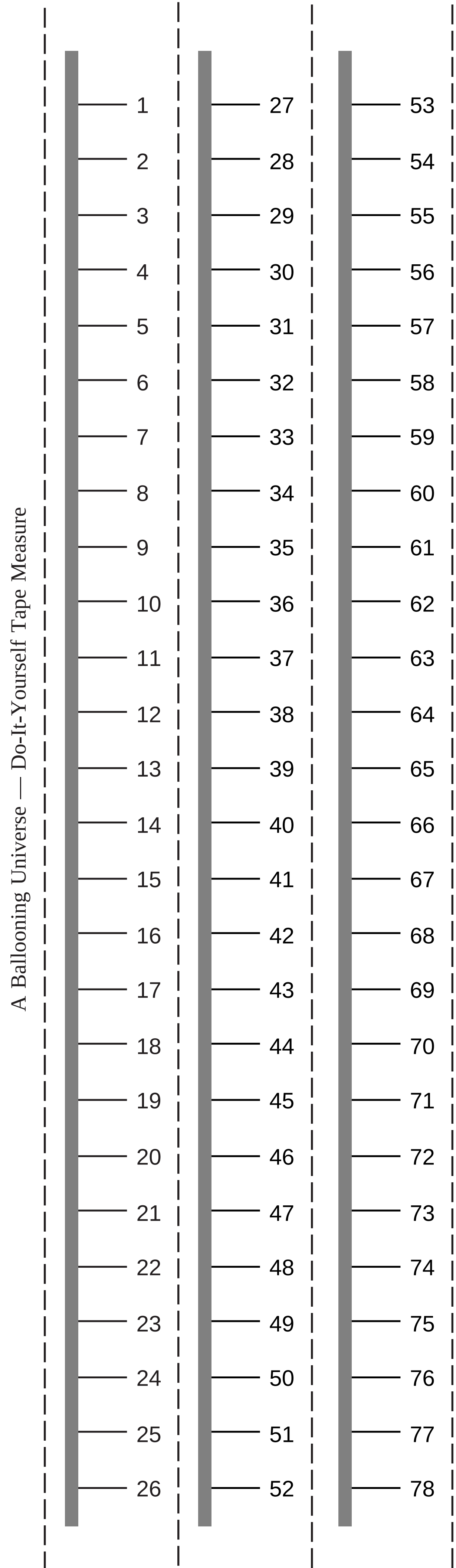
In what ways might our balloon universe model be different from the real universe?

[Background for the teacher: The real universe is not like the surface of a balloon; the universe has 3 dimensions of space, not just two; the universe is expanding in Einsteinian "space-time," a FOUR- dimensional space that is not at all reasonable to common sense; the galaxies themselves are not expanding (the way they do on the balloon; it is the time and space between them that is expanding. One similarity: the real universe does not have a center, any more than the 2-dimensional surface of the balloon has a center. See Abbott's *Flatland* and any of the excellent popularizations of cosmology for more information.]

In the real universe, evidence shows that all galaxies are moving away from each other. ***Will our universe expand forever or will it stop expanding and start collapsing someday?*** (No one knows. Scientists today are carefully measuring the rate of expansion, and may soon be able to determine what the fate of the universe will be.)

Going Further

Have your students select a galaxy on the balloon to represent our Milky Way galaxy. Point out that the Milky Way is not at the center of the universe, since there is no center on the balloon's surface. Have the students measure and record the distances from the Milky Way to all the other galaxies when the balloon is small, and again when the balloon is large. The **changes** in distances can be used to help in understanding Hubble's Law (Part D of the next activity, The Expanding Universe).



The Expanding Universe

What is the evidence that our universe is expanding? These activities will help students understand how we know that the universe is expanding. It is important for your class to have already done activities on light spectra, such as those in *PASS Volume 8, Colors from Space*, pages 32–43. Once your students are familiar with light spectra, they can understand the idea of Doppler shift by first hearing the acoustic Doppler effect from revolving sound generator. They can then relate redshift of galaxies' spectra to the galaxies' velocity away from us. Finally, your students make a graph of distance vs. velocity for a number of galaxies to find the "Hubble constant" of our expanding universe.

Materials

For Part A

❒ One long snaky spring. (Available through science supply companies such as Frey Scientific (in Mansfield, Ohio).

❒ A clock with a second hand.

❒ Worksheet "Frequency and Wavelength" (1/student; reduced sample on this page)

For Part B

❒ One loud sound generator. An old-fashion alarm clock works well. Or, go to your local electronics store and get a 3v buzzer, two batteries (C or D size) and a battery holder. If you want to get fancy, put a switch on it too.

❒ Rope, heavy-duty fishing line, or very heavy duty string (about one meter long)

For Part C

❒ Worksheet "Spectra of Fast-Moving Galaxies" (1/student; master on page 54)

❒ Pencil (1/student)

For Part D

❒ Worksheet "Hubble's Law" (1/student; master on page 48)

❒ Pencil (1/student)

Frequency and Wavelength

Draw a Single Wave:

Frequency ____________

Wavelength ____________

Draw a Double Wave:

Frequency ____________

Wavelength ____________

Draw a Triple Wave:

Frequency ____________

Wavelength ____________

Before Class

1. Make a full or half page version of the worksheet shown on this page. Make a photocopy for each student.

2. The snaky spring can be held by looping one finger through an end loop of the spring. However, it is much more comfortable if you make a handle for each end of the spring. The simplest handle is a stick inserted through the end loop of the spring and secured with duct tape.

3. Tie one end of the rope (or string) **securely** to the loud sound generator. It is best to thread the rope through a hole in the sound generator, e.g. holes in the battery holder. Drill a couple of holes if necessary. Use several secure knots. On the other end of the rope, tie a loop that will fit snugly around one of your wrists.

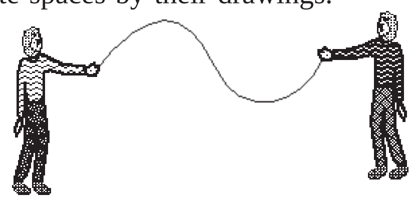
In Class—Part A Frequency and Wavelength

1. Ask your students, ***"What is sound made of?"*** *(Vibrations of air molecules; or vibrating air)* It may take some discussion for the students to understand that air can vibrate. One excellent exercise is to have the students touch their own voice boxes to feel the vibrations while they hum. To get across the idea that sound waves travel from the source of vibration, through the air, ask, ***"Have you ever heard an echo of a sound that has traveled a long way and bounced back to you?"***

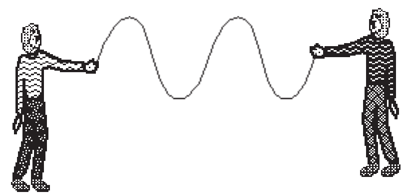
2. Ask a student volunteer to hold one end of the snaky spring tightly and walk at least six paces away from you to stretch the spring out. Have the rest of the class count the number of paces out loud.

3. Remind the volunteer to hold tight while you move the other end sharply up and down once to create a single spring wave that travels down the spring and bounces off the volunteer's hand. Explain that we can imagine the spring to represent air molecules (or air *pressure*, if you wish to be more exact). Sound waves travel through the air very much as the spring wave travels down the spring, but sound waves travel much faster — about 1/3 km/sec

4. Hand out a pencil and a worksheet to each student. Ask the students to watch the shape of the spring wave as you make a single wavelength standing wave on the spring. [A single wavelength will appear to have two crests going up and down alternately. Do not confuse this with a single crest going up and down, like a jump rope, which is really only 1/2 wavelength.] Ask them to draw the shape of the spring wave near the top of their paper. Explain that the length of the wave is called its "wavelength." Ask the students to write down the wavelength (in "paces") in the appropriate spaces by their drawings.

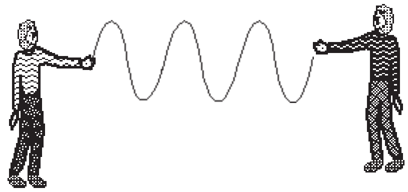


5. Have the students count how many times your hand moves up and down in ten seconds, as you continue making a single standing wave. Ask them to write the number down next to their wave drawing. Ask, ***"How many times was my hand vibrating each second?"*** *(Divide by 10 the number of vibrations counted in 10 seconds.)* Explain that for any wave, the number of vibrations per second is called the "frequency" of the wave. The unit of frequency is "cycles/sec" also known as "hertz." Ask the students to record the frequency of the wave by their drawings.



6. Now create a standing wave that has two full wavelengths on the spring (two pairs of crests moving alternately up and down). Have the students draw this wave and time it as before, counting how many times your hand goes up and down in 10 seconds. Have them record the frequency and wavelength in the appropriate spaces.

7. If you can move your hand fast enough, make a standing wave with three full wavelengths on the spring and have your students find its frequency as before. They can draw this wave and record its wavelength and frequency on their sheet.



8. Ask, ***"What is the relationship between a wave's frequency and its wavelength?"*** *(Higher frequencies correspond to shorter wavelengths.)*

Part B—Doppler Effect with Sound Waves

1. Ask your students, ***"What is the difference between a high frequency sound wave and a low frequency sound wave?"*** *(This is very difficult to answer by words alone. It is much easier to demonstrate by singing or humming a high pitch note and a low pitch note.)* To illustrate the difference, ask the students to sing or hum the highest pitch sound that they can make. Then have then sing or hum the lowest pitch sound they can make.

2. Tell the students that you are going to make a sound generator with a constant frequency whirl around so that it will alternately be traveling towards them and away from them. Instruct them to listen carefully to the sound to determine if the frequency seems to change. Specifically, ***"How does the sound frequency change when the sound source is coming towards you?" "How does it change when the sound source is going away from you?"***

3. Divide the class in half and have the groups go to opposite corners of the classroom. It is even better to do this activity outdoors and have the two groups of students separated farther apart. Hold up the sound generator and explain what it is. Insert your hand through and make sure the wrist loop has a tight fit to your wrist. In addition, hold the rope tightly in your hand. Then start the sound generator whirling around so that it alternately goes towards and away from each group. For safety, it is best to whirl the sound generator in a vertical circle, so if the device is accidentally release, no one is struck. If you are outdoors, you can use a longer string to get a more noticeable effect. With a longer string you will probably have to whirl it in a circle horizontally rather than a vertically. Let the class listen for a number of revolutions. Ask, ***"Do you hear the pitch changing?" "How does the sound frequency change when the sound source is coming towards you?"*** *(Frequency gets higher.)* ***"How does it change when the sound source is going away from you?"*** *(Frequency gets lower.)*

Write on the chalkboard, "Sound source approaching — frequency higher," and "Sound source receding, — frequency lower."

4. Ask, "***Have you ever heard this effect before?"*** *(In cars, trains, jets, etc.)*

Part C—Doppler Effect with Light Waves

1. Ask your students, ***"How are light waves different from sound waves?*** *(They are made of different "stuff." They are vibrating electric and magnetic fields rather than vibrating air. They move much faster than sound: 300,000 km/sec as opposed to sound which travels at 1/3 km/sec)* Explain that light waves can exhibit Doppler effect very similar to the acoustic Doppler effect that they heard in part B.

2. Ask your students to recall the order of the visible spectrum colors from previous activities on light spectra *(red, orange, yellow, green, blue, violet).* [Better still, get out the light sources and diffraction gratings again to have students see the spectra.] Explain that violet has the highest frequency of all the visible light colors. Ask, ***"If violet is the highest frequency of visible light, which end of the spectrum has the lowest frequencies of light?"*** *(Red.)*

3. Have your students see or recall the line spectra that they observed for particular elements. Draw the spectrum of hydrogen on the chalkboard as shown below. Explain that hydrogen is the most common element in the universe. Nearly all stars have hydrogen. If we look at the spectrum of a star, we nearly always see the red, turquoise, and violet lines associated with hydrogen, along with other lines that are from other elements in the star. Each color line is a certain frequency of light.

4. Consider the brightest line in the hydrogen spectrum. If a star is moving towards you or away from you, each spectrum line will be shifted either toward the red or toward the violet end of the spectrum, because of the Doppler effect. Ask, ***"If a star is coming towards us, will its spectrum lines shift towards the red end or the violet end of the spectrum?"*** *(The violet end. If necessary, ask them to recall from the acoustic Doppler effect whether the frequency shifted higher or lower when the sound source was coming towards them. You wrote the results on the chalkboard at the end of Part B.)* Ask, ***"If a star is going away from us, will its spectrum lines shift towards the red end or the violet end of the spectrum?"*** *(The red end.)*

5. Hand out a "Spectra of Fast-Moving Galaxies" worksheet to each student. Explain that it has the Hydrogen spectrum lines of several galaxies. The darkest line in the spectrum represents red. The scales at the top and bottom of the sheet relate red shifts of the galaxies' spectra with velocities of the galaxies. Ask, ***"If a positive velocity means the galaxy is moving away from us, what would it mean if a galaxy had a negative velocity?"*** *(The galaxy would be moving towards us.)* ***"If a galaxy's spectrum is shifted towards the red end of the spectrum, is the galaxy moving towards us or away from us?*** *(Away.)*

6. Challenge the students to figure out how fast each galaxy is moving and write down its velocity in the box by each galaxy. Remind them that a positive velocity means that the galaxy is moving away.

IMPORTANT: While Doppler effect happens when stars are moving away from us (red shift) or towards us (blue shift), it is NOT the explanation for galaxy redshifts. The redshift of galaxies associated with expansion of the universe is called ***cosmological redshift***, which occurs when light is stretched is due to the expansion of the universe itself. That is different from red shift due to Doppler effect, which is caused by a light source moving away from an observer.

Part D—Hubble's Law

1. Hand out a "Hubble's Law" worksheet to each student. Have them plot a point for each galaxy's distance and velocity as determined on the "Fast-Moving Galaxies" worksheet.

2. ***"How would you describe in words what the graph tells you?"*** Have students write down what they discovered. *(The farther away the galaxy is, the faster it is moving away from us.)*

3. The galaxy distances on the worksheet are derived from the methods described in the planetarium program. The finding that the farther away a galaxy is the faster it is moving away is called the Hubble Law because it was first discovered by astronomer Edwin Hubble.

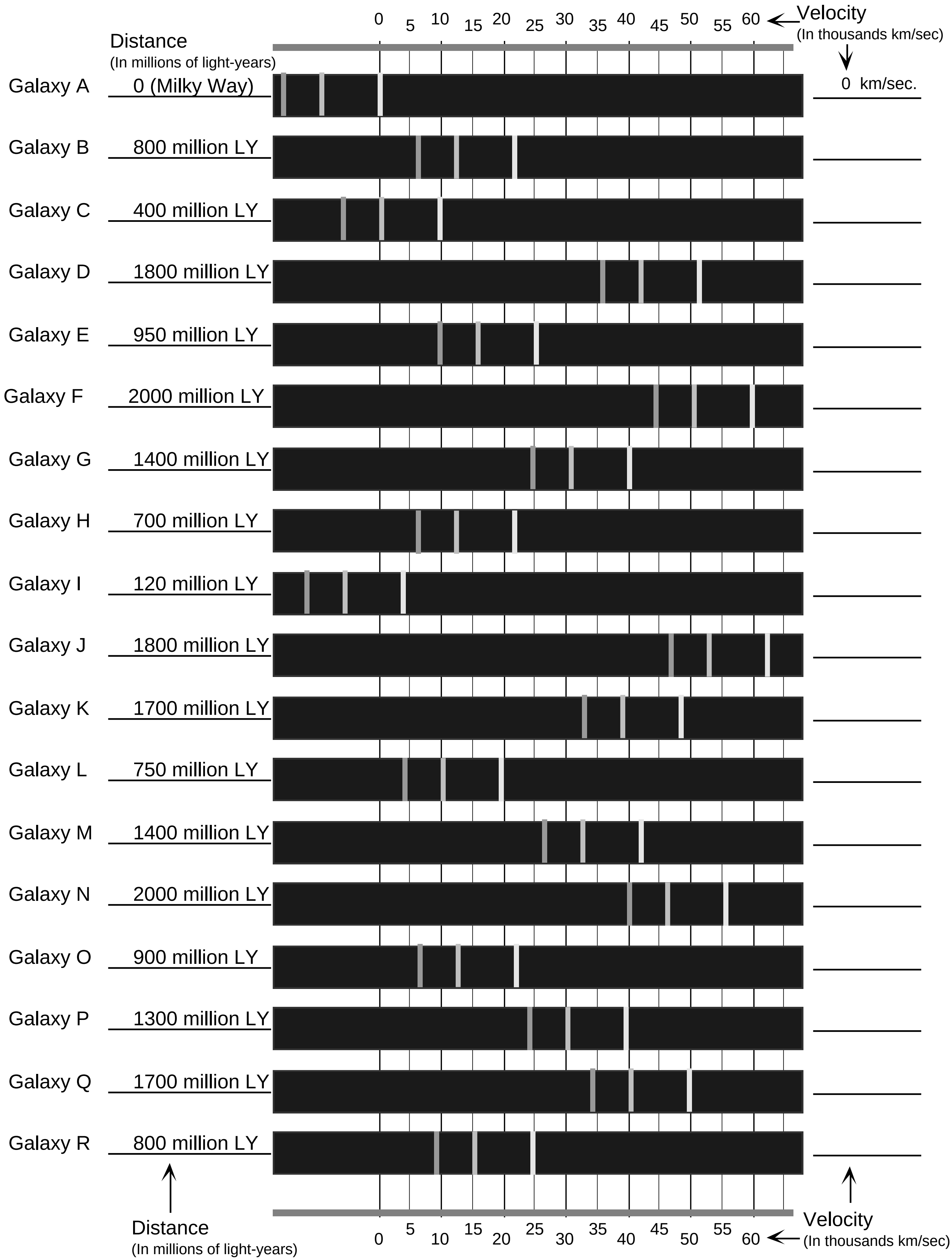
4. ***"What does Hubble's Law imply about how our universe is behaving?"*** *(Hubble's Law makes pretty good sense only if the whole universe is expanding!)*

5. Assuming Hubble's Law applies for most galaxies, astronomers estimate distances to the most remote galaxies by measuring redshifts, finding velocities, and calculating distances from Hubble's Law. ***How distant is a galaxy that is found to be receding from us at 120,000 km/sec?*** *(About 4 billion LY.)*

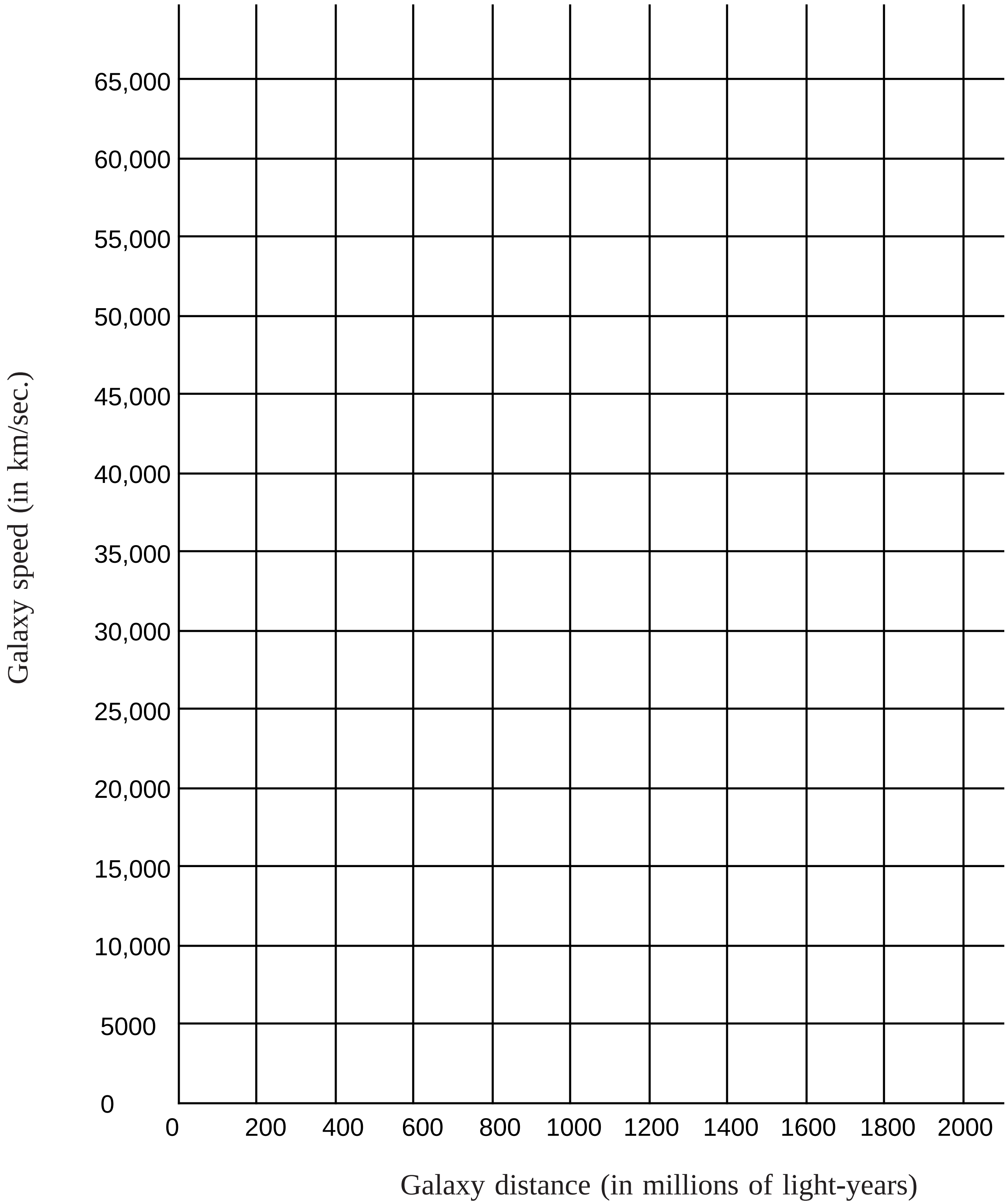
Going further

If you did the "Going Further" part of the Ballooning Universe activity, have students refer to distances from the "Milky Way" on the balloon to other galaxies that they measured on the balloon . ***How did distances between galaxies when the balloon was small relate to the distances when the balloon was large? Look the change in distances for galaxies that were close together as compared with galaxies that were farther apart. Was the change in distance larger or smaller for galaxies that were farther apart?*** Point out that galaxies that moved farther away from each other during the time period of the balloon expansion must have been moving away from each other faster.

Spectra of Fast Moving Galaxies



Hubble's Law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Galaxy distance (in millions of light-years)