Interactive Lesson Guide™ *for Astronomy*

Cooperative Learning Activities

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Where Concepts Make Connections™

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Michael Zeilik asserts the moral right to be identified as the author of this work.

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Forward for the Instructor

Cooperative Learning in the Classroom

Want to use cooperative learning in your classroom? Don't know how to start? Well, start here with the Interactive Lesson Guide™!

These cooperative learning activities were developed for an introductory astronomy course at the University of New Mexico. I encountered many issues that are probably similar to yours: large class (150 to 300), one-semester course ("covering" the universe!), novice learners of astronomy, weak backgrounds in science and math, and some students with a strong fear of science. I had become frustrated with the lack of success for a "standard model" of instruction and was convinced by the research results that cooperative learning, properly implemented, would increase students' conceptual understanding. As I searched, though, I found no single source of cooperative learning activities for this kind of class. I also had no experience conducting cooperative learning classes. But I plunged ahead with a class of about 300 students, and we all learned as I restructured the course.

Here's my advice based on eight semesters of experience:

❏ If at all possible, pilot test activities with a small class. The activities here have all been fine-tuned and debugged in the University of New Mexico context. Your class may differ in obvious and subtle ways.

❏ Expect the first-time use of these materials to take longer than expected. Your students will need a few sessions to practice the new learning format, and their effectiveness will be low at the start. They *will* improve!

❏ You must give clear and careful instructions to your students about their social roles and expected interactions. Be pretty strict about these at first. As the students grow more comfortable with cooperative learning, you will find that they will naturally grow into these roles. The one rule you *must* enforce: Rotate the roles!

❏ Each group must create a consensus report that is handed to and evaluated by you. Students should tear out each activity, write their own notes on them, and assist the Reporter in developing the consensus report. That one report is given to you with the name of all group members on it. They all receive the same grade. Work out a system of returning each activity at the next class to either the Leader or the Reporter. They then inform the group.

❏ You must have a closure discussion at the end of each activity. If time is short, you'll be tempted to skip it. Don't! It will only take a few minutes to highlight the main point and uncover any large problems the groups encountered. This is your best chance to give immediate feedback.

❏ I aim for about one group activity per class, occasionally two. If you can arrange it, go for class periods longer than 50 minutes. I schedule my class for two 75-minute periods per week. That permits a group activity (say a quiz) at the beginning and one near (but not at!) the end.

❏ Once the groups are functioning smoothly (about a month), you will find many other instances to use cooperative learning. Show a video? Ask for an analysis! Do a demonstration? Query for the main point or concept! Want feedback? Request a "few minute" paper, by group consensus, at the end of class!

A few comments on the activities themselves. They are roughly arranged in topical order, from earth to universe. Most can be done in 30 minutes; a few will take longer. Most are step-by-step; a few have a more free-form format. Most require that students analyze a graph, while plotting some or all of it. (You will probably find many blank stares the first time students cope with understanding a graph. Don't worry; they will get better. By the end of a semester, all my groups were quite capable of graphical analysis, though at the start, they acted like they had never seen a graph before.) Some activities are more "math-intensive" than others, though never beyond the level of high-school algebra and geometry. The most math-intensive activities are "Flux and Distance," "Properties of Stars" and "Energy Flow in Stars;" they involve curve fitting, and are labeled as "Advanced."

The choice of concepts covered arose from my 25-years' experience with introductory astronomy students, my research on preconceptions, a consensus from a panel of expert teachers about what concepts are essential, and feedback from my students about what concepts they found difficult.

One concept reemerges throughout: Kepler's third law, mainly in the Newtonian formulation. From solar system to dark matter, the application of Kepler's third law provides powerful insights into the astronomical universe. I view it as "gravity without gravity;" you have much of Newton's law of gravitation and laws of motion rolled into a single package in which forces do not appear! In most astronomical situations, you cannot measure forces—but you can measure orbital properties such as periods. So Kepler's third law can provide the most practical as well as the most powerful analysis.

The activities are largely self-contained. Where graphs are needed, graph templates have been provided so that students will not spend time just trying to figure out the axes and the scales. Only simple calculators are needed most of the time. The only specialized equipment needed are the Night Spectra Quest grating card and the Bumbleball™, both available through the Learning Zone. You can also find the Bumbleball™ at most large retail outlets and toy stores. You can find out about resellers in your vicinity by calling the Ertl Company at 1(800) 553-4886.

Note that activities fall into one of four concept clusters: Cosmic Distances, Heavenly Motions, Light and Spectra, and Scientific Models. I use these four divisions to organize the concepts in my class.

This Interactive Lesson Guide™ is *not* a user's manual in the "how" of cooperative learning. It is a resource to "jump start" your implementation of cooperative learning. The single best book I can recommend is *Active Learning: Cooperation in the College Classroom* by David W. Johnson, Roger T. Johnson, and Karl A. Smith, Interaction Book Company, ISBN 0-939603-14-4, telephone 612-831-9500.

Questions?

Contact me by email: zeilik@chicoma.la.unm.edu.

Thanks!

P.S. I am available for talks and workshops. Contact me through **The Learning Zone, Inc**.

About the Author

Dr. Michael Zeilik works as Professor of Physics and Astronomy at the University of New Mexico. In his teaching, he specializes in introductory courses for the novice student. He has been supported by grants from the National Science Foundation, NASA, the Exxon Educational Foundation, and the Slipher Fund of the National Academy of Sciences for innovations in astronomy education, delivery of astronomy to the general public, and astronomy workshops for in-service teachers.

Dr. Zeilik earned an A. B. in Physics with honors at Princeton University and an M. A. and Ph. D. in Astronomy at Harvard University. He has been a Woodrow Wilson Fellow, a National Science Foundation Fellow, and a Smithsonian Astrophysical Observatory Predoctoral Fellow. At the University of New Mexico, he has been named a Presidential Lecturer, the highest award for all-around performance by a faculty member.

Dr. Zeilik has written four books used internationally: *Astronomy: The Evolving Universe* (8th edition, Wiley, 1997), *Astronomy: The Cosmic Perspective* with J. Gaustad (2nd edition, Wiley, 1990), *Conceptual Astronomy* (1st edition, Wiley, 1993), and *Introductory Astronomy and Astrophysics* with S. Gregory (4th edition, Saunders, 1998). The 8th edition of *Evolving Universe* received a 1997 *Texty* award as an outstanding book in the physical sciences.

Dr. Zeilik has been a constant pioneer in astronomy education. He developed the first astronomy course at Harvard University taught in the Personalized System of Instruction (PSI) format. He lead the first large-scale, disciplined-based research in astronomy courses for non-science majors at the university level. That effort informs the content of this Interactive Lesson Guide™.

Foreword for the Student

Focused Discussion Groups

Your course will promote cooperative learning by having Focused Discussion Groups during class. Research in cooperative learning over many years has shown that students at *all* levels learn science effectively in small groups that have guided interactions. You will work at intervals in your groups, in which we'd like to have four or five people with three social roles: reporter, leader, and skeptic. With groups greater than three, you will have more than one skeptic (generally a good idea!). You keep these roles during any one class, but you must switch them for other classes. That way, everyone will assume different responsibilities for the activities.

What do these social roles involve? Briefly,

- ❏ The REPORTER writes coherent reactions and summaries to be turned in.
- ❏ The LEADER works to start the discussion and keep it on track.
- ❏ The SKEPTIC tries to find holes in any arguments and reasoning.

Your instructor may elaborate on these roles or may even add other specific ones.

Each person in the group will write his/her name on the materials handed in by the reporter, but each person should also write down the basic responses on his/her sheet. The reporter also has the responsibility of giving feedback to the group after the materials are returned by the instructor.

During class, your instructor will stop presenting and ask you to react (say to a demonstration or video), or answer a question, or participate in an activity from this book (or another source). Your group should then work together to accomplished the assigned task, within any time limit set by the instructor.

Task: To answer or react to the instructor's posed problem or activity.
Cooperative Learning: Create a group consensus response by

- ❏ Each person *formulating* his or her answer.
- ❏ Each person *sharing* his or her thoughts and responses.
- ❏ Everyone *listening carefully* to the comments by others.
- ❏ The group creates a NEW answer/response that is better than the initial, individual formulations by association, building on other's thoughts, and synthesizing a final result.

Criterion for Success: Each student must be able to explain the consensus answer or result.

Accountability: Your instructor will ask groups at random for their answers/responses. Any person in the group may be asked to give an oral explanation of the group's results. The materials handed in by the reporter will become part of the evaluation by the instructor.

Note that you will need to exercise appropriate interpersonal skills for effective cooperative learning. These include: 1) trust, 2) clear communication, 3) acceptance and support of each other as unique individuals, and 4) constructive resolution of conflicts. You should reflect upon these skills after every group activity, no matter what your social role.

Table 1 lists some of the responsibilities expected of each social role.

Table 1. Sample Social Role Interactions for Cooperative Learning

Interactions	Examples
Leader	
Starts discussion.	*"Let's start with this idea. What do*
Directs sequence of steps.	*you think?"*
Keeps group "on track."	*"We'll come back later if we*
Insures everyone participates.	*have time."*
Checks the time.	*"We need to move on to the*
	next step."
Reporter	
Acts as a scribe for the group.	*"Do we understand this point?"*
Checks for understanding by all.	*"Explain to us what you think."*
Insures all members agree.	*"Do we all agree on this?"*
Summarizes conclusions.	*"So here's what we've decided…"*
Skeptic	
Helps group avoid coming to agree-	*"What other possibilities*
ment too quickly.	*are there?"*
Insures that all possibilities are	*"Let's look at this a new way."*
explored.	*"I'm not sure we're on the*
Suggests alternative ideas.	*right track."*
Looks for errors in reasoning.	*"Why?"*

Focused Discussion: Angular Size and Distance (Cosmic Distances)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To be able to estimate the distance to an object from its angular size.
Prediction: You see a jet airliner in the sky. What is its distance?

Procedure: Examine the photos (Figures 1 and 2) of a jet airliner, which was close enough to the observer so that the airplane was visible. The photos were taken with a telephoto lens on a 35 mm camera. The image is enlarged so that 1° = 20 mm on the print. (This is the *scale* of the photo.) You may use either (or both!) photos.

1. What is the angular size, in degrees, of the plane's fuselage?

2. What is the ratio of *actual length* to *distance from you* for the airplane? Hint: An angular diameter of 1° means a size to distance ratio of 1/57.

3. What is the actual distance, in kilometers, to the plane? (Hint: You need another piece of information. What is it? How can you find it out?)

4. Does your result seem reasonable? What assumption(s) have you made to reach your result?

Concept Extension

How can you use this technique to find the distance to the sun?

Figure 1

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Figure 2

© Michael Zeilik

Focused Discussion: Angular Speed and Distance (Heavenly Motions)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To be able to estimate the distance to an object from its angular speed.
Prediction: You see an airplane flying across the sky. How do you know its distance?

Procedure: Examine the two photographs (Figures 1 and 2) of a jet airliner, which is so far away that the airplane is not visible, only its contrail. The photos were taken 20 seconds apart with a telephoto lens on a 35 mm camera. The images are enlarged so that 1° = 20 mm on the prints.

1. What is the angular distance, in degrees, that the plane has traveled between the two photos?

2. What is the ratio of *distance traveled* to *distance from you* for the airplane? (Hint: An angle of 1° is a ratio of 1/57.)

3. What is the actual distance, in kilometers, that the plane has traveled between the two photos? (Hint: You need another piece of information. What is it? How can you find it out?)

4. Use #2 and #3 to estimate the airplane's distance. Does your result seem reasonable? What assumption(s) have you made to reach your result?

Concept Extension
How can you use this technique to find the distance to a nearby star?

Figure 1

© Michael Zeilik

Figure 2

© Michael Zeilik

Focused Discussion: Angular Size and Distance (Cosmic Distances)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To investigate the relationship among angular size, actual size, and distance.
Prediction: Does angular size increase, decrease, or remain the same as an object moves to *greater* distances from you?

Procedure: Attached is a photo of hot air balloons (Figure 1). From this image, and other information that you may have to find, answer the following questions:

1. Which of the balloons is closest? The farthest? Label each one. How do you know?

2. What is the *relative* distances between these balloons? (Hint: Take a ratio!) What assumption do you have to make in order to reach your answer?

3. How can you find the *actual* distances between these balloons (say in meters)? What *additional* information do you need to arrive at your conclusion? How can you find it out?

4. As a graph, sketch here the correct functional relationship between angular diameter and distance for the same object at different distances.

Concept Extension
What application does this concept have in astronomy, especially in the solar system?

Figure 1

© Michael Zeilik

Focused Discussion: Angular Diameter and Distance (Cosmic Distances)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To find out how angular diameter, actual diameter, and distance are related so we can find the actual sizes of planets.

Prediction: Which is larger, the sun or the moon? How do you know?

Procedure: One answer to the prediction is that both the sun and the moon have the same *angular* size (about 1/2°). To build a model of a planet (or a star like the sun), we need the actual diameter in units like kilometers. Now the angular diameter (for small angles) is directly proportional to the ratio of the actual diameter to distance (in the same units). For an angular diameter of 1°, that ratio is about 1/57. So for 1/2°, it is about 1/114, and so on. Or

Actual diameter $\approx$ 1/57 $\times$ angular diameter (in degrees) $\times$ distance

Figure 1 gives the angular diameter of Venus as seen *from the earth* over a period of about a year. The date is on the horizontal axis. Note the vertical axis is in arcseconds. You can imagine that you observe Venus with a telescope over this period of time and measure its angular diameter; Figure 1 would be the result of your observations. Figure 2 shows the distance of Venus *from the earth* over the same period of time. Note the vertical axis is in AU (astronomical units).

1. Examine the graphs for Venus. During what month is it closest to the earth? How do you know? Use a ruler to find out its distance (in AU) at the time of closest approach from the graph.

Closest distance = _______ AU

2. Again using a ruler, estimate the angular diameter of Venus at this time of closest approach.

Angular diameter = _______ arcsecs

3. Now you need to convert your measurements to usable units. First, convert the distance in AU to kilometers, using 1 AU = 150×10^6 km.

Distance (km) = _______ AU $\times 150 \times 10^6$ km

= _______ $\times 10^6$ km

Second, you need to take care of arcseconds. One degree equals $60 \times 60 = 3600$ arcsecs. If we multiply this number by 57 (WHY?), we get $\approx$ 200,000. So the relationship becomes

Actual diameter $\approx$ 1/200,000 $\times$ angular diameter (arcsecs) $\times$ distance (km)

1/200,000 $\times$ _______ (arcsecs) $\times$ _______ $\times 10^6$ km

$\approx$ __________ km. (No more than two significant figures, please!)

Concept Extension

How would you find the actual diameter of Venus at the end of February?

Figure 1. Angular Diameter of Venus as Seen from the Earth

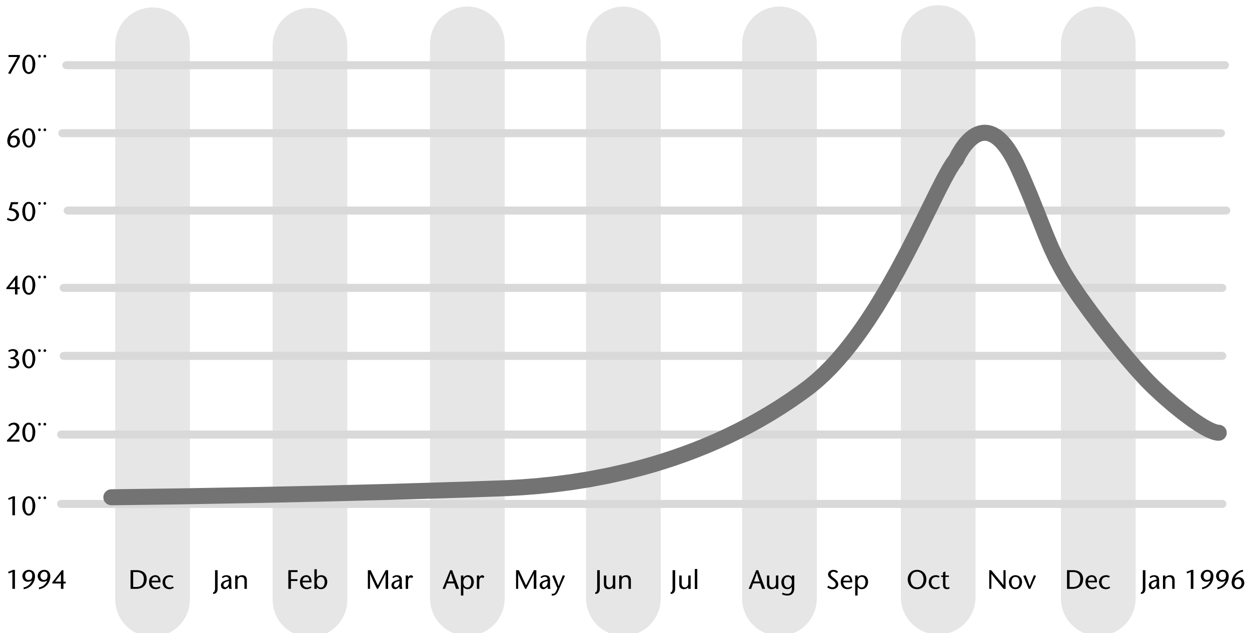
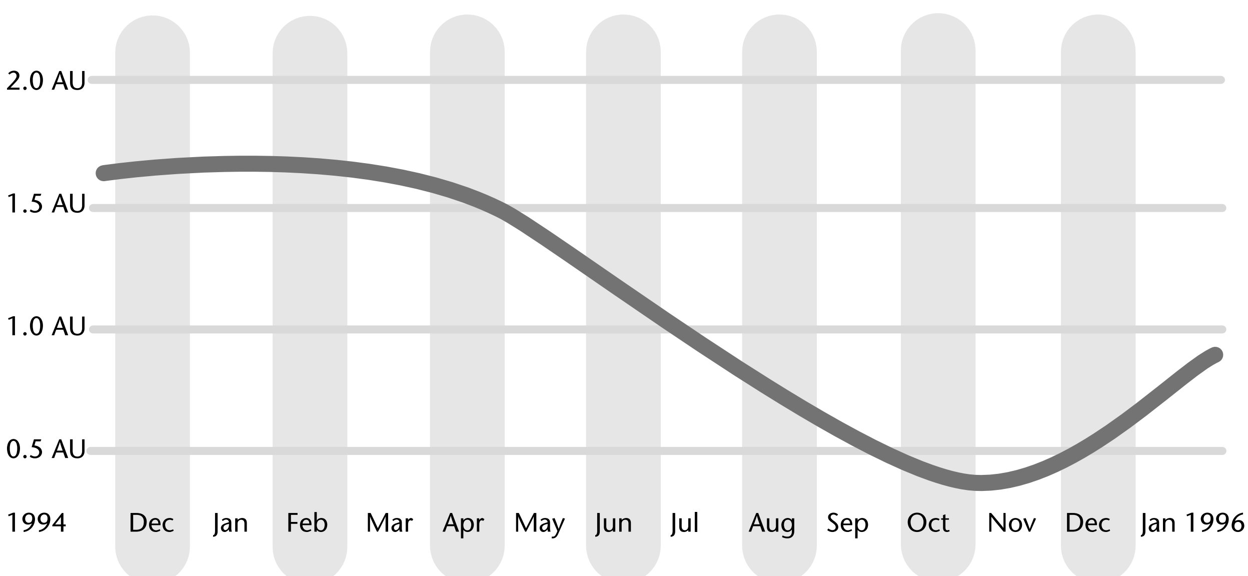


Figure 2. Distance of Venus from the Earth



Focused Discussion: Planetary Motions—An Introduction (Heavenly Motions)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To describe the positions of the sun and selected, naked-eye planets along the ecliptic and to infer general patterns in their motions from graphs.

Prediction: How do planets move relative to the stars?

Procedure: You have a graph of the positions of two planets and the sun over a two-year time span (Figure 1). The plot shows time running down the page. The dates at the left are given in 10-day intervals (the start of the year is given on the right). The vertical extant covers a little more than a year, and the horizontal span is 360°. Note this space is divided into 12 intervals, each corresponding to an angle of 30°. The line with the solid circle represents the motion of the sun, which is first in the labels. The planetary positions run across the page horizontally to the left through the constellations of the zodiac (see the diagram at the top of the page; each constellation of the zodiac is drawn and labeled). The solid line through the center of the constellations is the path of the sun relative to the stars—the *ecliptic*. The legend for each line indicates the planets plotted.

1. Which planet always appears close to the sun in angular distance? Does its maximum elongation (maximum angular distance from the sun) remain constant or does it vary over a year?

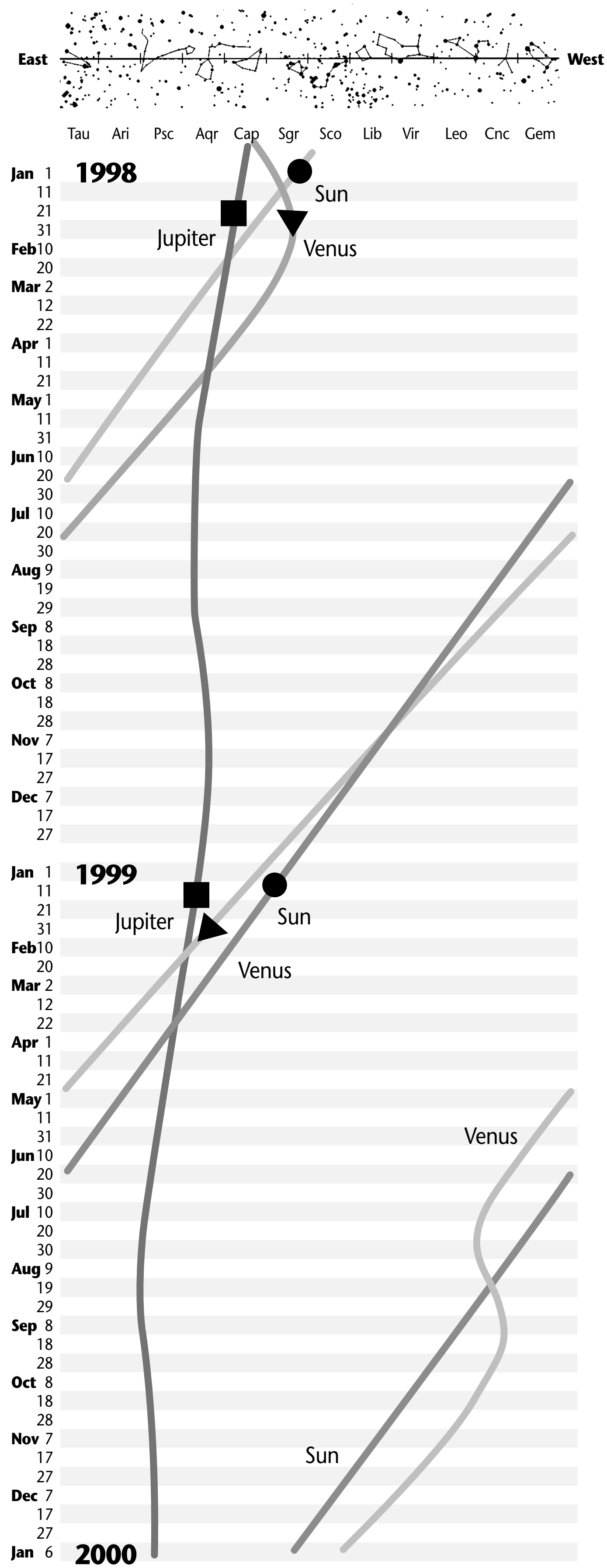
2. Which planet can have any angular position relative to the sun?

3. Note the cases when the planets motions are toward the right. What is happening to the planets in the sky during these times?

4. The slopes of the lines on the zodiacal chart provide, over long time intervals, the average angular speed relative to the stars of the zodiac. Which has the fastest average angular speed? Which has the slowest? What are these speeds?

5. What is the sun's average angular speed per day? How does the sun's motion *differ* in this graph compared to those of the planets?

Figure 1



Focused Discussion: Major Motions of the Planets (Heavenly Motions)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To describe the positions of the sun and selected, naked-eye planets along the ecliptic and to infer general patterns in their motions from graphs.

Prediction: How does the sun move relative to the stars as seen from the earth?

Procedure: You have two types of graphs (Figures 1 and 2) showing the positions of the planets. Both indicate time running down the page; the dates at the left are given in 10-day intervals (the start of a year is given on the right). The vertical extent covers a little more than a year, and the horizontal span is 360°. The line with the solid dot represents the motion of the sun, which is labeled first.

One set of graphs is labeled "Planet Positions Relative to the Sun" (Figure 1). Here the sun's position is fixed and runs down the middle of the page. Note that the planets are visible in the evening sky to the *left* of the sun's line, and in the morning sky to the *right*. When seen in the evening sky, a planet is *east* of the sun; it sets *after* the sun sets. When seen in the morning sky, a planet is *west* of the sun; and it rises *before* the sun rises. When a planet crosses the sun's line from left to right, it moves in visibility from the evening sky to the morning sky.

Note that the angular distances of the planets from the sun change with time. The angular distance between the sun and a planet on any given date is called the planet's *elongation*. If you scan down the graph, you should notice that certain planets stay near the sun; others don't.

In the Zodiacal Graph (Figure 2), the planetary positions run across the page horizontally to the left through the constellations of the *zodiac* (see the diagram at the top of the page; each constellation of the zodiac is drawn and labeled; can you identify any?). Once around the zodiac is a complete circle of 360°. The solid line through the center of the constellations is the path of the sun in the sky relative to the stars—the *ecliptic*. Note that the constellations of the zodiac are those that lie along the ecliptic.

The legend for each line indicates the planets plotted and the year. Note that some planets take longer than others to complete one circuit of the zodiac. Those that do so quickly have a faster *angular speed* than the others. That is, they move a certain angle on the sky in less time, or for the same time interval, they move a larger angle.

Part I. Examine Figure 1 first. You need to determine the scale, so that you know that 1 mm = x degrees on the paper. What is your value for x? (Hint: How many degrees span the graphs horizontally?)

1. Which planet always appears close to the sun in angular distance?

2. Over the course of a year, how often does Mercury move from the morning to the evening sky? From the evening to the morning sky?

3. Is this change more or less frequent for Mars? On about what date does Mars move from the morning to the evening sky?

4. For Mercury, does its maximum angular distance from the sun remain constant or does it vary? (This maximum distance is called *maximum elongation*.) Determine angular distance for at least three dates and write down the average *in degrees*.

Part II. Now examine the Zodiacal Graph (Figure 2). It looks very much like the previous one, except now we have the positions, including that of the sun, plotted relative to the stars of the zodiac. Note that *east* is to the *left,* and *west* is to the *right.*

5. How does the sun's motion differ in this graph compared to those of the planets? In what direction does the sun move relative to the stars? How long does it take to move 360°? What have you calculated (look at the units)? How does this quantity relate to the *slope* of the sun's line?

6. How does the sun's motion resemble *in general* that of the planets?

Figure 1. Planet Positions Relative to the Sun

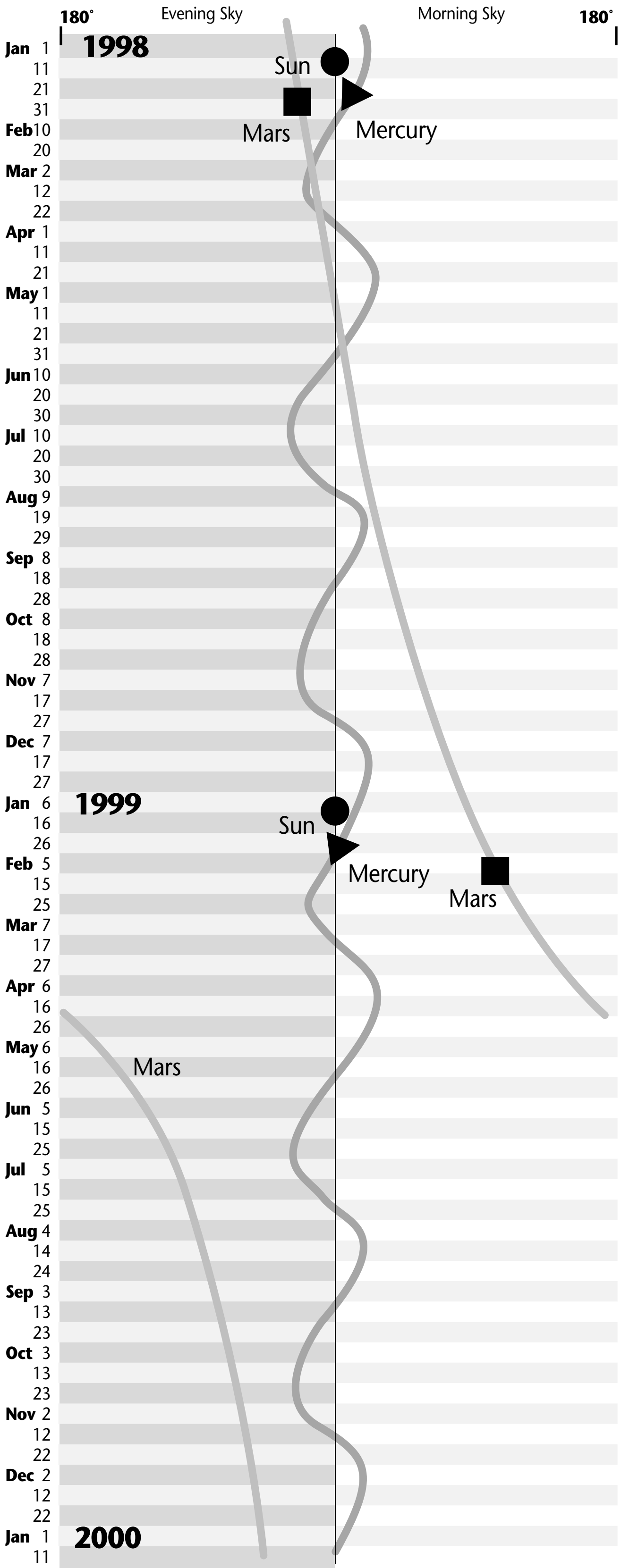
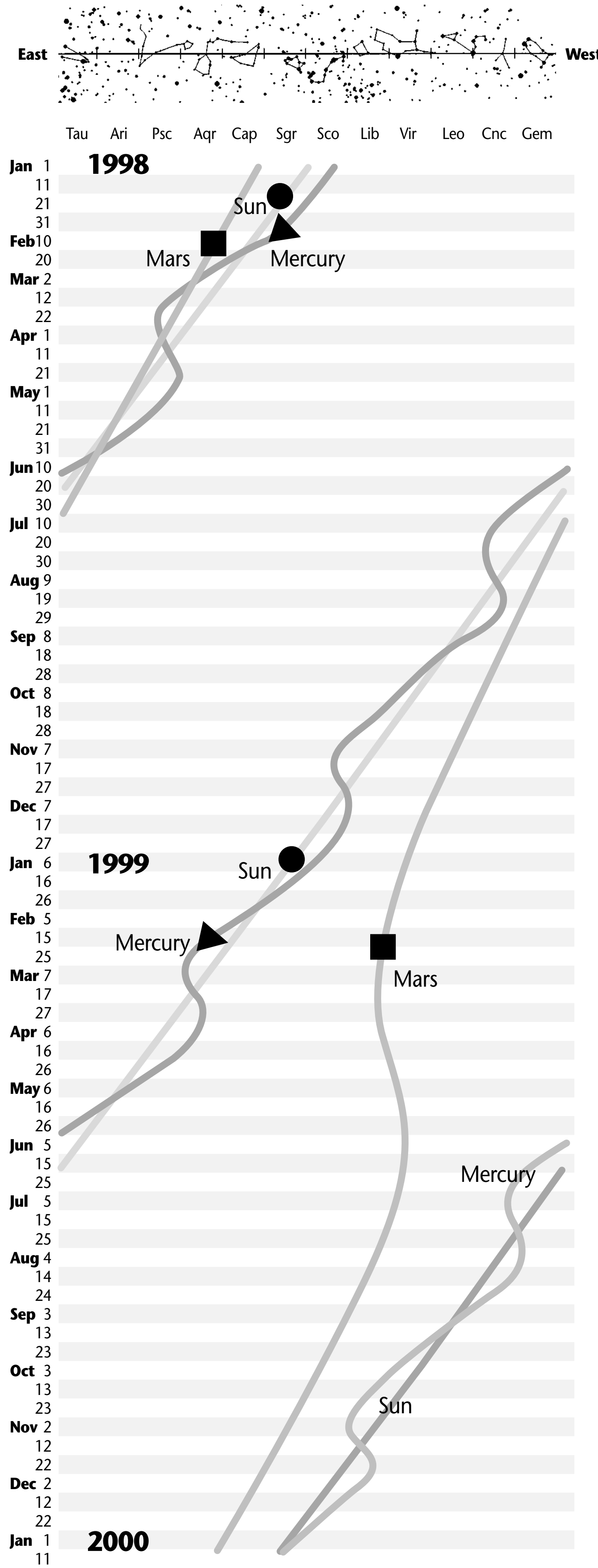


Figure 2. Zodiacal Graph



7. How does the sun's motion *differ from* that of the planets?

8. Note the cases when the planet's motion is toward the *right (west)* rather than to the east. During these times, a planet's motion is called *retrograde*. What is the duration, in days, of the retrograde motion of Mars? Of Mercury?

9. What is the average angular speed of Mercury eastward?

Concept Extension

Consider the planets Venus and Jupiter. Which one would have motions most like Mercury? Most like Mars? Why?

Focused Discussion: Retrograde Motion of Mars (Heavenly Motions)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To explore the characteristics of one retrograde motion of the planet Mars.

Prediction: In what general direction, relative to the stars, does Mars move *during* its retrograde motion?

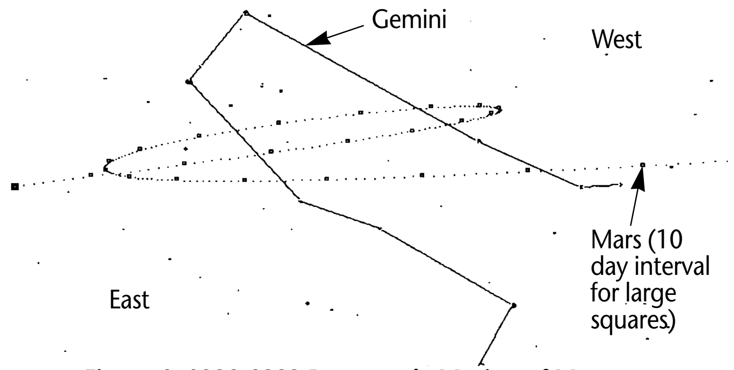


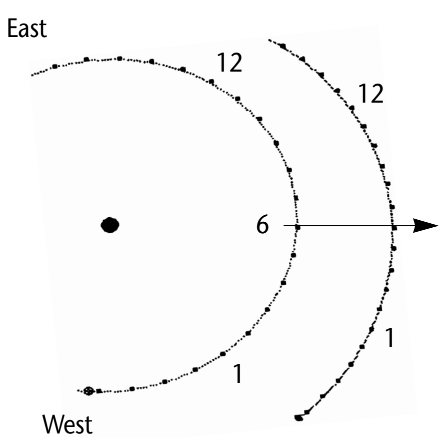
Figure 1. 1992-1993 Retrograde Motion of Mars

Procedure: If you were to plot the position of a planet against the background of the stars night after night, you would notice that the planet usually moves from west to east (*eastward*) across the sky over the course of several weeks. From time to time, however, a planet will appear to slow in its eastward progression, reverse its motion and move for a period of a while *westward*, then again slow and reverse directions, resuming its normal eastward path. This apparent reversal in the planet's course is called *retrograde motion*, the part of the motion that is westward.

Figure 1 represents this motion for the planet Mars, as seen from earth, relative to the stars. TRACE OVER THE RETROGRADE PART OF THE LOOP.

Now let's look at an overview of retrograde motion for any two moving bodies, one moving faster than the other. Figure 2 provides you with two orbits, each with points corresponding to the positions of the two orbiting bodies in equal intervals of time. Note that the middle point (6) has been started for you. Extend the arrow to the right and number it. Connect every other point (8, 10, 12; then 4, 2) of the inner orbit to its corresponding point on the outer orbit with a *straight* line, extending the line *all the way to the right of the page*. Number each line for each pair of points at the far right. These numbers show the position of the outer planet, as seen by the inner, against the background of the stars. Note that the inner planet moves faster than the outer one.

Figure 2. Retrograde Motion of Two Moving Bodies



1. Using the diagram you just completed, explain why the outer planet appears to move in retrograde loops as seen from the inner planet. (Hint: What happens to the line of sight relative to the stars?)

2. At what position is the outer planet in the *center* of its retrograde loop? What is its orientation as seen from the earth?

3. Now imagine you are standing on the outer planet and observing the inner one. What would you see? (Hint: Same as above!)

Concept Extension

Consider Jupiter and the earth. How would an explanation of Jupiter's retrograde motion differ from that of Mars'? (Hint: How would you revise Figure 2?)

Focused Discussion: Sunrise Points (Heavenly Motions)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To discover the seasonal variation of sunrise points.
Prediction: At what point along the horizon does the sun rise?

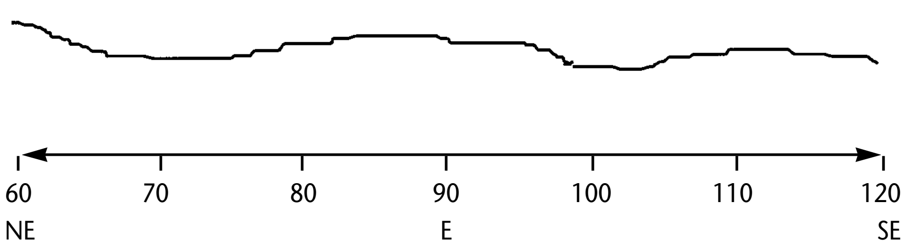
Procedure: Your answer to that question would most likely be "in the east, right?" Well, two days of the year, you would be exactly correct. The rest of the year, however, things are a bit more complicated.

Table 1 gives the sun's position in degrees of azimuth, which is the angle from north, that is, due north is 0°, due east is 90°, due south is 180°, and due west is 270°. Plot each sunrise on Figure 1, labeling each position with its date (early spring = esp, midsummer = msu, and so on).

Table 1. Sunrise Points Table

	Sunrise Angle (degrees)		Sunrise Angle (degrees)
Early Spring	91.4	Early Autumn	91.6
Mid Spring	84.8	Mid Autumn	101.3
Late Spring	74.8	Late Autumn	113.7
Early Summer	61.2	Early Winter	120.7
Mid Summer	72.5	Mid Winter	110.5
Late Summer	83.9	Late Winter	101.7

Figure 1. Horizon Profile



1. On what two days does the sun rise closest to due east? At what times of the year does the sun rise *due east?*

2. When does the sun rise farthest south, and when does it rise farthest north? At what times of the year does this occur?

3. If the sun rises at its farthest south point one morning, will the day be long or short? Why?

4. How would the sunset points differ from or be similar to the sunrise points? (Hint: Imagine Figure 1 gave a profile of the western horizon, centered on 270°.)

Concept Extension

If you were observing the sun from the earth's *southern* hemisphere, how would the data in the table differ?

Focused Discussion: Solar System Models (Scientific Models)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To relate naked-eye observations to a geocentric and heliocentric model of the solar system.
Prediction: Which model provides a *simpler* picture for the positions of the planets?

Procedure: Attached are two blank templates for a "god's-eye" view looking down from above of the paths of selected planets in the solar system. NOTE THAT EASTWARD IS COUNTERCLOCKWISE. In the Geocentric Model (Template 1) mark the earth at the center with a large dot and label "Earth." In the Heliocentric Model (Template 2) mark the sun at the center with a large dot and label "Sun." You will need to position on each model the sun and planets viewed as follows from the earth:

It is just after sunset. Mars is rising in the east. Venus is at maximum eastern elongation, 45 degrees from the sun. Jupiter is due south, halfway between the sun and Mars in angular distance.

1. What are the angular positions of the planets, relative to the sun, along the ecliptic? Consider the sun to be at 0 degrees, with angles increasing *eastward*.

2. Start with the Heliocentric Model. Which path belongs to which planet? Place the earth on the correct path, right on the horizontal line that cuts through the center of the template. Then place Mars in its proper position, then Jupiter, and then Venus. Note that Venus must have a special position along its path. Label all the planets.

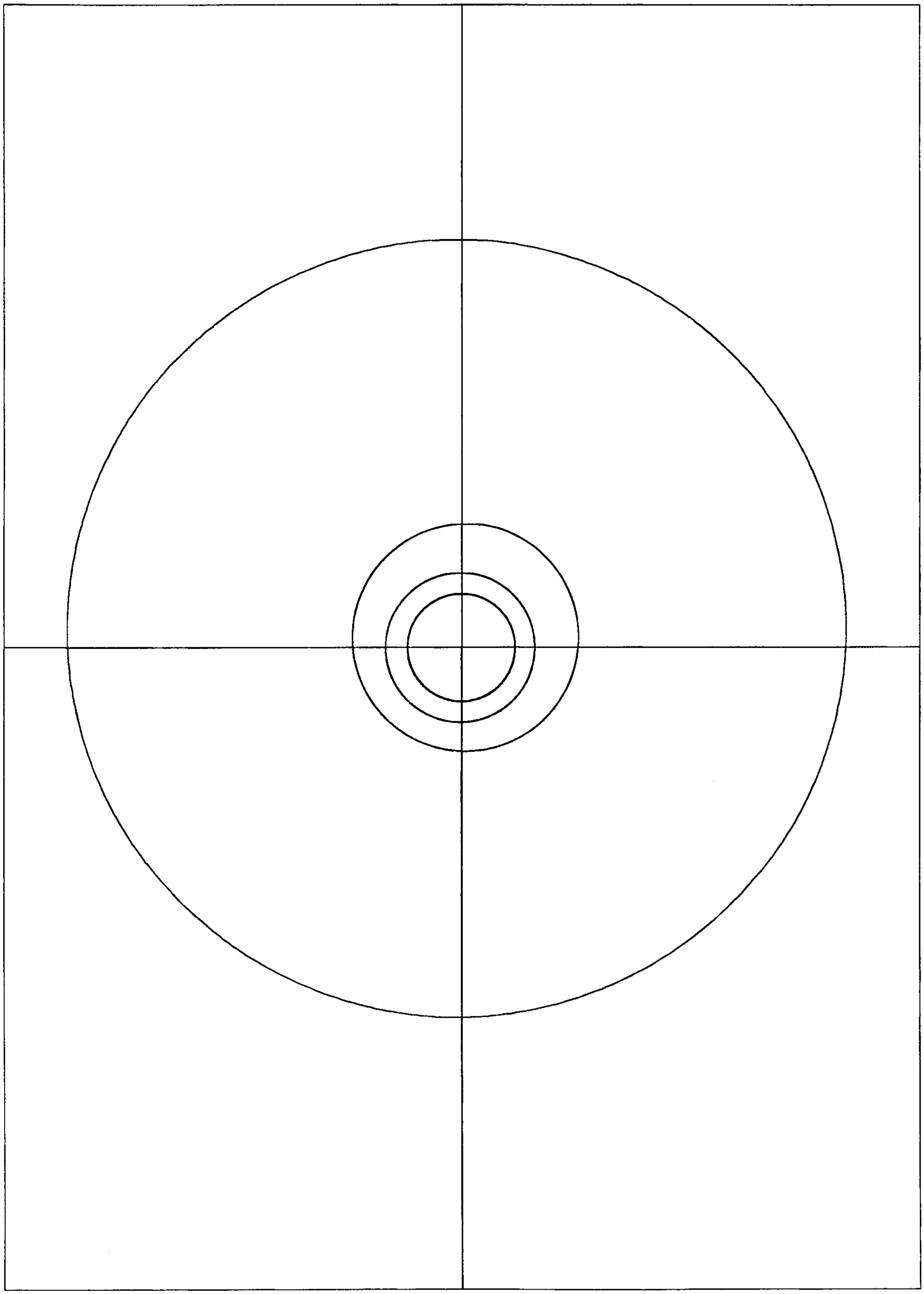
3. Now turn to the Geocentric Model. Which path belongs to which planet? Start with the sun; place it on its path right on the horizontal line that cuts through the center of the template. Then place Mars in its proper position, then Jupiter, and then Venus. Note that these planets MUST be correctly placed on epicycles! (For Venus, you can only draw part of the epicycle's complete circle. What's the problem?)

4. Overlay the figures so that the earth and sun coincide. Which model gives a simpler layout of the observations? (Hint: What is meant by "simpler" in this context?)

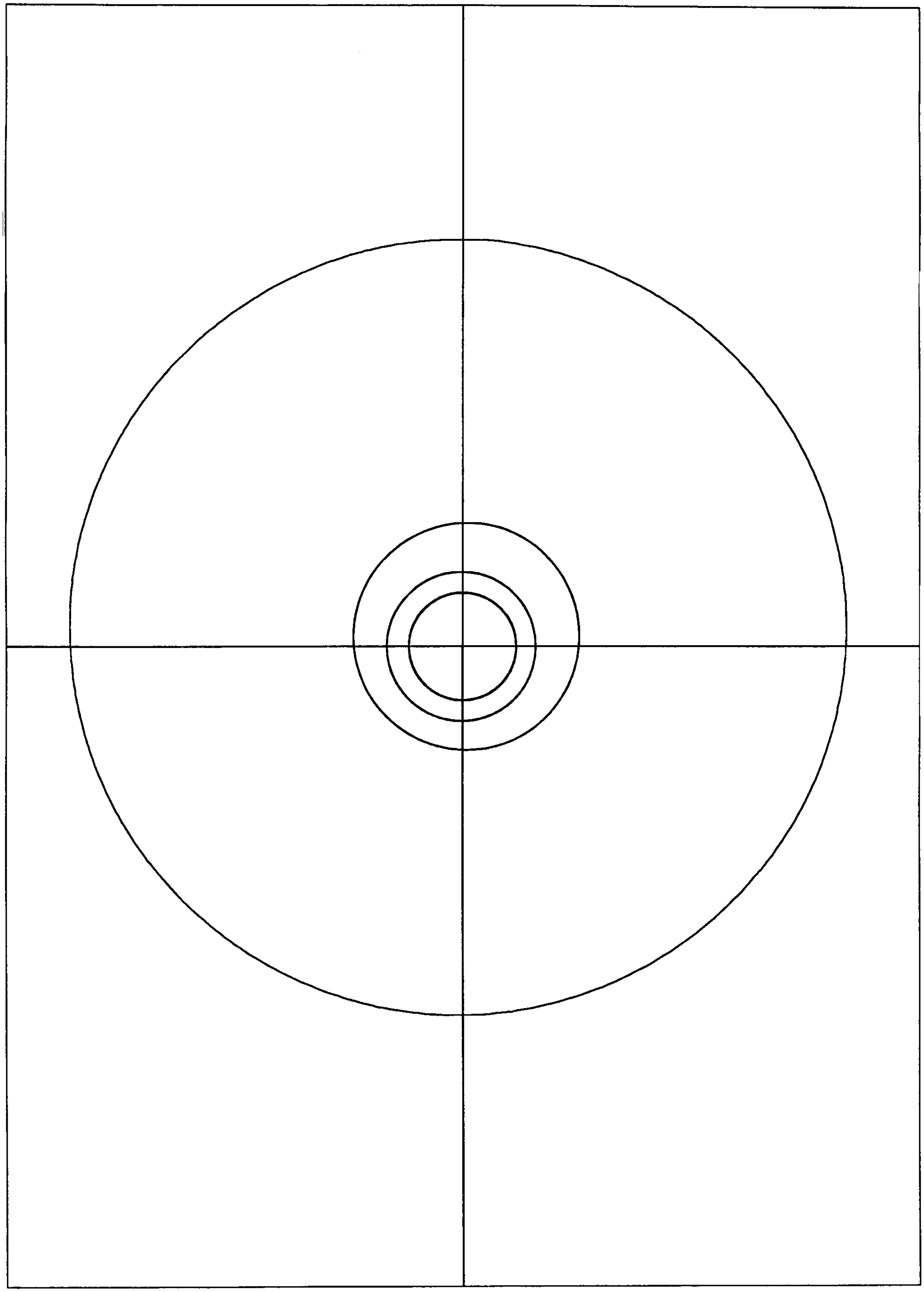
Concept Extension

If you were to stand in the center of each model, how would the angular positions of the planets differ?

Template 1: Geocentric Model



Template 2: Heliocentric Model



Focused Discussion: Scaling the Solar System (Cosmic Distances)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To lay out scale models of the solar system based on different size scales.

Prediction: Draw a circle below that represents the size of the earth. Next to it draw another circle that represents the size of the moon. How do they differ?

Procedure: Your instructor will provide spheres of various sizes. Use these for each part of the activity.

Part I. Earth, Moon, and Sun

Pick out one sphere to represent the earth and the other the moon, to the same size scale (Table 1). Write down your scaling factor here and in Table 1.

1. Earth-moon scaling factor: __________
Size of earth: __________
Size of moon: __________

2. Now move the earth and moon apart until this distance is to the correct scale. *How do you know what this is?*

Earth-moon distance: __________
Enter your results here and in Table 1.
Show the spheres and their correct relative distance to your instructor.

3. A space shuttle orbits about 500 km above the earth's surface. How far is this above the surface of your model earth?
Shuttle's distance above earth: __________

4. On the same size scale, pick out a sphere that represents the size of the sun.
Size of sun: __________

5. Move the earth and sun apart until the distance between them is to the same scale as their relative sizes. *How do you know what this is?*

Earth-sun distance: __________

Part II. Solar System

To model the entire solar system, you must first decide the maximum distance into which your model will fit. You can choose the classroom or the hall outside the classroom.

Length of classroom: __________ m
Length of hall: __________ m

Pluto is about 6 billion km from the sun. Calculate the scale factor for your model distances and enter it here and in Table 2.

6. Scale factor (distance): 1 cm = __________ km

Using this scale factor, fill out the scaled distances in Table 2. Get a paper tape from your instructor. Draw a line across the tape at its beginning; label it "sun." Using your scaled distances, unroll the tape and for each planet draw a line across the tape and label it.

7. Now to scale the diameters in Table 2, you will have an assortment of spheres of various sizes. You want the earth to be visible to the eye. Choose a scale factor for the earth, and then apply it to the sun and Jupiter.

Scale factor (diameters): 1 cm = __________ km

Choose spheres that are close to these sizes. (Don't worry about factors of two!) Place these spheres on the tape at their proper positions. Then add spheres for the other planets.

When your model is completed, have your instructor check it.

8. The nearest star to the solar system is Proxima Centauri. Its distance from the sun is a bit more than 7000 times the sun-Pluto distance. Based on your scale model, how far away would you place Proxima Centauri?

Distance to Proxima Centauri: ___________

Table 1

Object	Equatorial Diameter (km)	Distance from earth (km)	Scaled Distance (scale factor = ___________)	Scaled Diameter (scale factor = ___________)
Earth	12,800	—		
Moon	3,500	400,000		
Sun	1,400,000	150×10^6		

Table 2

Object	Equatorial Diameter (km)	Distance from sun ($\times 10^6$ km)	Scaled Distance (scale factor = ___________)	Scaled Diameter (scale factor = ___________)
Sun	1.4×10^6	—		
Mercury	4900	58		
Venus	12,100	108		
Earth	12,800	150		
Mars	6800	228		
Jupiter	143,000	780		
Saturn	120,000	1430		
Uranus	51,200	2870		
Neptune	48,600	4500		
Pluto	2200	5900		

Concept Extension

If the Sun and Proxima Centauri were each the size of a grape, how far apart would they be spaced?

Focused Discussion: Kepler's Third Law—Planets (Heavenly Motions)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To use the motions of the planets to infer a fundamental pattern.
Prediction: As you move outward from the sun, what do you expect to happen to the orbital speeds of the planets?

Procedure: You have a table (see Table 1) of the five naked-eye planets and their average distances (in AUs) and orbital periods (in years) for their motions around the sun. Note the column in which the periods (*P*) are squared (#3) and the distances (*a*; semimajor axis of the elliptical orbit) is cubed (#5). In the next column (#6), you see the period squared divided by the distance cubed. The last column (#7) gives the average orbital speeds. This basic information comes from a heliocentric model of the solar system.

For each planet, compare the values in column #6.

1. Are they very similar or very different? How so?

Now use Graph Template 1 to plot a point for each of the planets, using the distance (column #4, x-axis) against period (column #2, *y*-axis). Start with the earth—it's easy! Note that Graph Template 1 starts at 0.1 and goes 0.2, 0.3, *etc.*, until it hits 1.0. Then it goes from 1.0 to 10, and 10 to 100. Label each point by the planet's name. Can you draw a straight line through your plotted points? If so, do it!

2. Now imagine a body found orbiting the sun at 3 AU. Where would it fall on your graph? What, roughly, would be its orbital period?

Uranus, Neptune, and Pluto were discovered with telescopes. Their distances are about 19, 30, and 40 AU. Add Pluto to your table (fill in the blank cells in Table 1) and to your graph.

3. Now imagine a new body were found beyond Pluto at a distance of 60 AU. What did you predict about the value of P^2/a^3 for this object? Where would it fall on your graph? What would be its orbital period?

4. Look at Graph Template 2, in which are plotted the orbital speeds versus distance (column #7). Draw a smooth curve through all the points. How do the orbital speeds of the planets vary with distance from the sun? What would the orbital speed be of a body at 3 AU? Clearly mark its position on the graph.

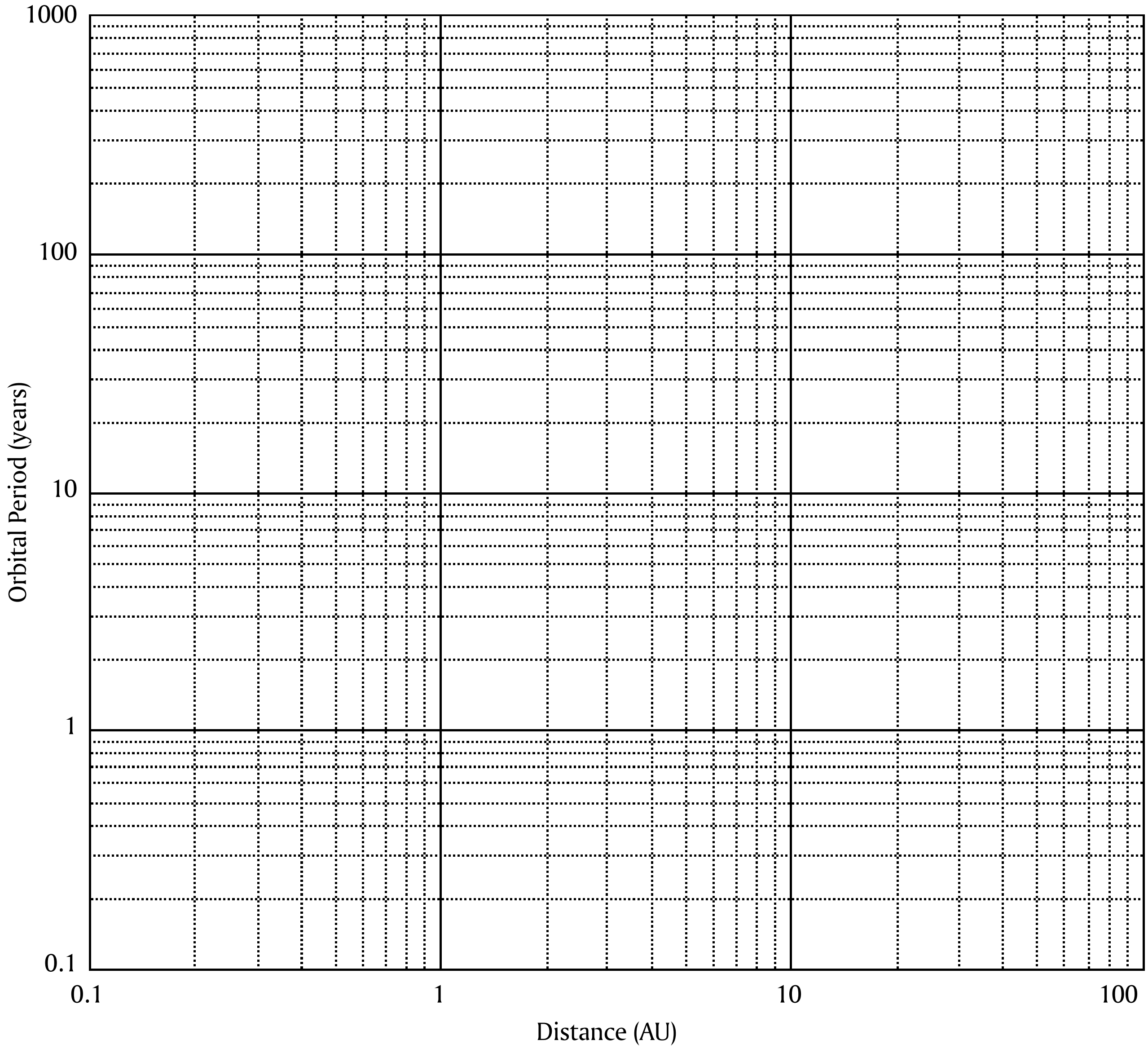
Table 1. Orbital Properties of the Planets

1 Planet	2 Period (P; years)	3 P^2	4 Distance (a; astronomical units)	5 a^3	6 P^2/a^3	7 Average Orbital Speed (km/s)
Mercury	0.24	0.058	0.39	0.059	0.97	48
Venus	0.62	0.38	0.72	0.37	1.0	35
Earth	1.0	1.0	1.0	1.0	1.0	30
Mars	1.9	3.6	1.5	3.4	1.1	24
Jupiter	12	140	5.2	140	1.0	13
Saturn	29	84	9.5	86	0.98	10
Pluto			40			5

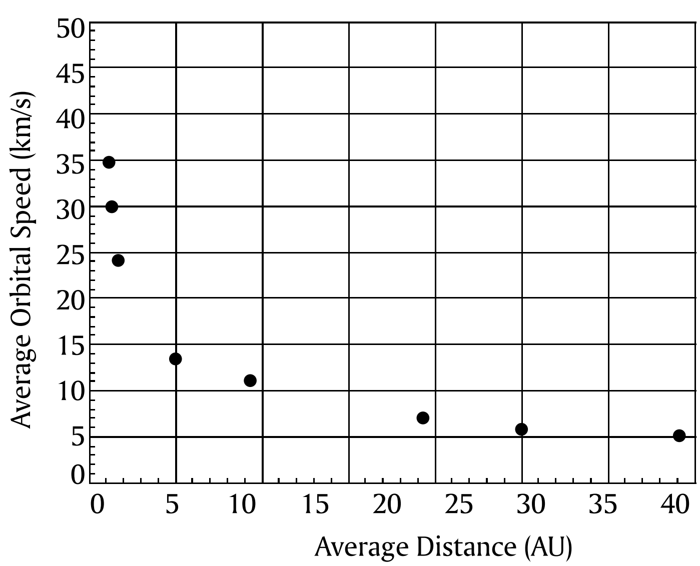
Concept Extension

Long-period comets have semi-major axes of some 50,000 AUs. What is their typical orbital period?

Graph Template 1



Graph Template 2



Reflection

How well has your cooperative learning group been functioning? Consider and reach a consensus on each of the following:

1) Acceptance and trust
2) Clear communication
3) Support of individuals and ideas
4) Constructive criticism and resolution of conflicts.

Has one person been dominating the thinking of the group? If so, how can this be avoided in the future?

Focused Discussion: Kepler's Third Law—Mass of Jupiter (Heavenly Motions)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To use the motions of the moons of Jupiter to find Jupiter's mass.

Prediction: What regularities of motion do you expect the moons of Jupiter to follow?

Procedure: The motions of Jupiter's four largest (and brightest) moons are shown in Figure 1 in graphical form. Note the layout is horizontal. Three weeks are plotted for the paths of Jupiter's Galilean moons, labeled Io, Europa, Callisto, and Ganymede (in order outward from Jupiter). They are shown in proper relative distances from Jupiter, and the disk of Jupiter across the center is to the *same* scale. The graph resembles a motion picture with all the frames drawn sequentially. For each vertical line, the dates are given every four days, from left to right.

How to find the mass of Jupiter from these motions? Apply Newton's version of Kepler's third law! You have seen it stated as P^2/a^3 = constant, where P is the orbital period and a the semimajor axis of the orbit.

But what's in that constant? Newton found, from his law of gravitation, that the constant contained the *sum* of the orbiting mass and the mass about which the other body is orbiting. So for the earth and the sun, the constant contains $M_{sun} + M_{earth}$. Since the sun's mass is so much greater than that of any body orbiting it, we can essentially ignore the mass of the orbiting body, then $M_{sun} + M_{earth} \approx M_{sun}$. Hence, we can use Kepler's third law for any body orbiting the sun to find out the sun's mass! (*Warning*: if the two masses are comparable, such as in a binary star system, we can't use this approximation.)

The mass of any of the Galilean moons is much smaller than that of Jupiter, so we can use the orbital motions of any one of the moons with Kepler's third law. Let's use Ganymede. You need to find the orbital period (in days) and the distance (in Jupiter radii). For the period: find a point when Ganymede appears farthest away from the planet. Then look along the figure until you see that position again on the *same side of the planet.* The interval, in days, is the orbital period—the time for one complete revolution. You should measure to the nearest half day.

1. What is the orbital period of Ganymede in days? __________ days

2. For the distance: use a ruler to measure the diameter of Jupiter in *millimeters* (the width of the horizontal line across the center of the figure). Do this at least three times and average the results!

What is Jupiter's diameter? __________ mm

3. Then measure the distance, in millimeters, *from the center of Jupiter*, to the farthest point of Ganymede orbit. (Use the center of Jupiter's line and the center of Ganymede's line as reference positions.)

What is Ganymede's maximum orbital distance? __________ mm

4. Now we'll do a series of calculations using this information. First, divide the value for Ganymede's orbital distance (in mm) by the value of Jupiter's diameter (in mm) to obtain the orbital size in "Jupiter diameters."

Jupiter diameters = radius of orbit = a = __________

Now cube this number: a^3 = __________

Take Ganymede's orbit period, P, in days, and square it. P^2 = __________

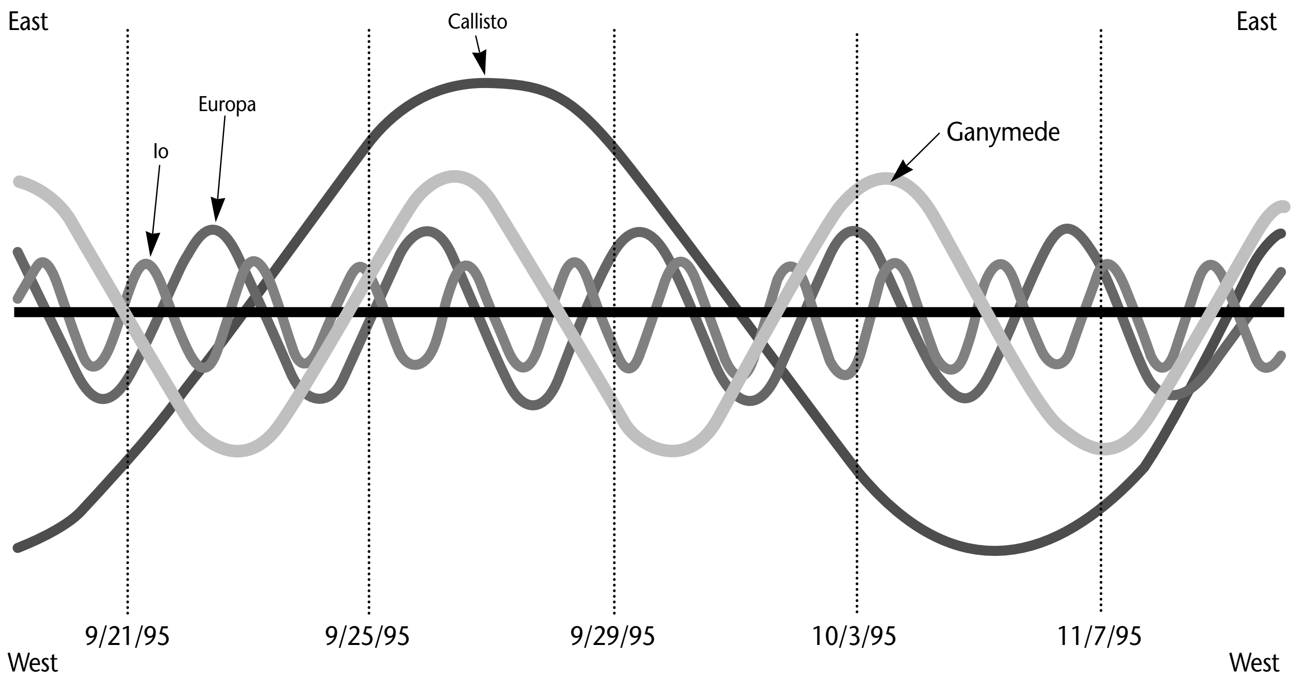
5. Now divide the period squared by the distance cubed. P^2/a^3 = __________

6. This value is the constant for any body orbiting Jupiter (but in funny units; note it is *not* 1)! Now to get the mass. We'll spare you all the details of converting from the units you used above to SI units. Divide the number 5 by the value you calculated in step 5. That will give you the mass of Jupiter in units of 10^{25} kg.

Mass of Jupiter = $5/(P^2/a^3)$ = _____ $\times 10^{25}$ kg. (Two significant figures!)

Concept Extension
How can you find out the mass of Saturn?

Figure 1. Motions of the Galilean Moons of Jupiter



Reflection

How well has your cooperative learning group been functioning? Consider and reach a consensus on each of the following:

1) Acceptance and trust
2) Clear communication
3) Support of individuals and ideas
4) Constructive criticism and resolution of conflicts.

Has one person been dominating the thinking of the group? If so, how can this be avoided in the future?

Focused Discussion: Pluto and Charon—A Double Planet System (Heavenly Motions)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To find the individual masses of Pluto and Charon.
Prediction: What is the mass of Pluto compared to that of Charon?

Procedure: Pluto and Charon make up a gravitationally-bound system whose motions follow Kepler's laws. From the recent series of eclipses, we know the orbital period very well: 6.387 days. Earlier observations showed that Pluto's brightness varied with a period that is the same as the orbital period. It is assumed that Pluto and Charon have tidally-locked rotation periods that are equal to their orbital periods.

1. Which of Kepler's laws must you use to find the masses?

2. The semimajor axis of the orbit is about 19,100 km. Use this information, the information given above, and the application of one of Kepler's laws to do the appropriate calculation. Watch out for your units!

3. You should be stumped here because you need an essential piece of information. What is it? Right, you need the position of the *center of mass*! Charon is five times Pluto's distance from the center of mass. Mark the approximate position of the center of mass on Figure 1, which is a scale model of the system. Now finish the calculation.

Concept Extension

How would you find out the individual masses of stars in a binary system?

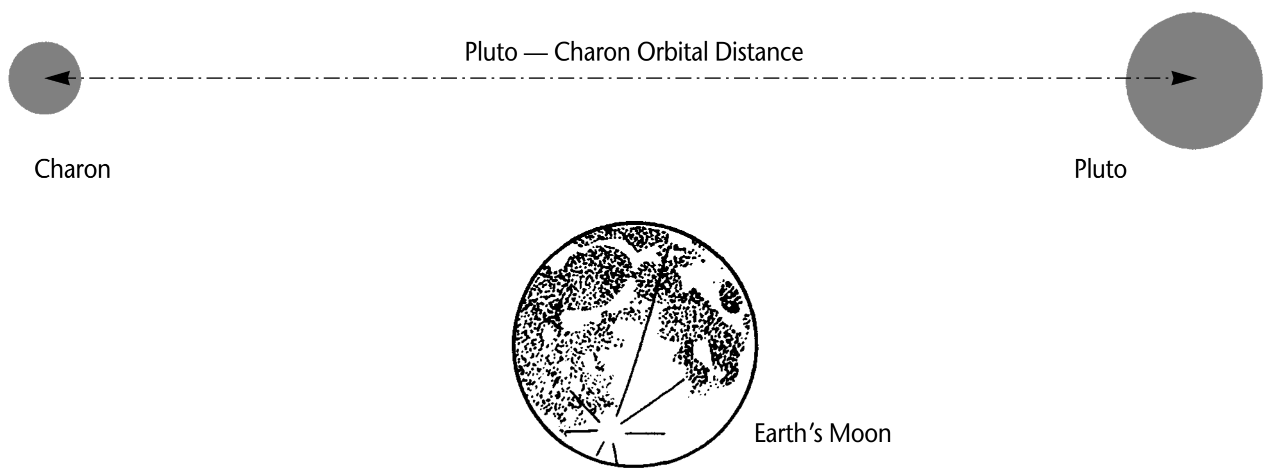


Figure 1. Pluto — Charon System to Scale

Focused Discussion: The Doppler Shift and Planets (Light & Spectra)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To apply the Doppler shift to the rotation of planets.
Prediction: Consider looking straight at the equator of a rotating planet. How does the speed of rotation at the center compare to that of the edges?

Procedure: Imagine you are looking straight onto the equator of a rotating planet. Light emitted from (or radar waves bounced off of) the edge approaching you will be blue shifted; from the opposite edge, red shifted. If the planet has a rotational period *P* and a radius *R*, then the Doppler shift from either edge is related to these quantities by

$$\Delta\lambda/\lambda_0 = \Delta\nu/\nu_0 = 2\pi R/cP$$

where *c* is the speed of light.

Figure 1 shows the received signal of a radar pulse sent to Venus from an earth-based telescope. The signal was sent out at a frequency of 430 MHz (1 MHz $= 10^6$ Hz) and covered the entire angular diameter of the planet as seen from the earth. Note the signal has been spread out in frequency, relative to the center frequency (430 MHz). The peak at 0 Hz is the return signal from the center of the planet's disk; it is *not* Doppler shifted (frequency shift is zero). The peaks from the edges of Venus show a maximum blue shift and a red shift.

1. What is the maximum blue shift, in hertz?

2. What is the maximum red shift, in hertz?

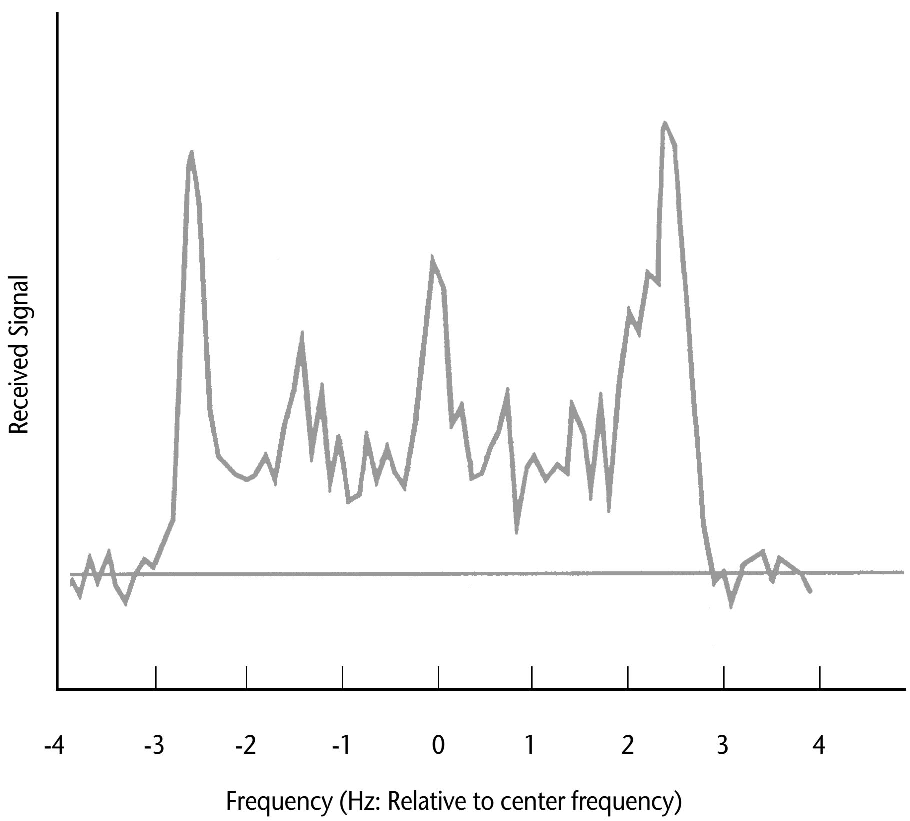
3. Average these two values to get a Doppler shift across the disk of Venus.

4. Calculate the rotation period of Venus in days. For simplicity, use 6000 km for the radius of Venus and 3×10^5 km/s as the speed of light. Compare your value to the value in your textbook. How do they compare?

Concept Extension

How could you use this process to find the rotation period of Mercury?

Figure 1. Radar Pulse Reflected From the Surface of Venus



Focused Discussion: Weight (Heavenly Motions)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To find out how the weight of a mass varies with its distance from the center of the earth.
Prediction: As you move *upward* from earth, what do you expect to happen to the weight of mass? (Hint: Will it increase, decrease, or stay the same?)

Procedure: You have a table (see Table 1) of the weight of an object at various distances from the center of the earth. Note that the distances are measured in earth radii. The object weighs 100 kg at the surface. Using the Graph Template, plot these values, starting at 1 earth radius. After you have plotted all the points, try by hand to draw a smooth curve through all of them. When you have completed the graph, answer the following questions:

1. Consider the mass located at 2 earth radii. What would be its weight?

2. Can you describe the overall shape of the curve? If so, what kind of relationship does it represent? (Hint: Direct or inverse?)

3. Imagine you had the same mass at 10 earth radii. What would be its weight? (Hint: Use the relationship you inferred in #2.)

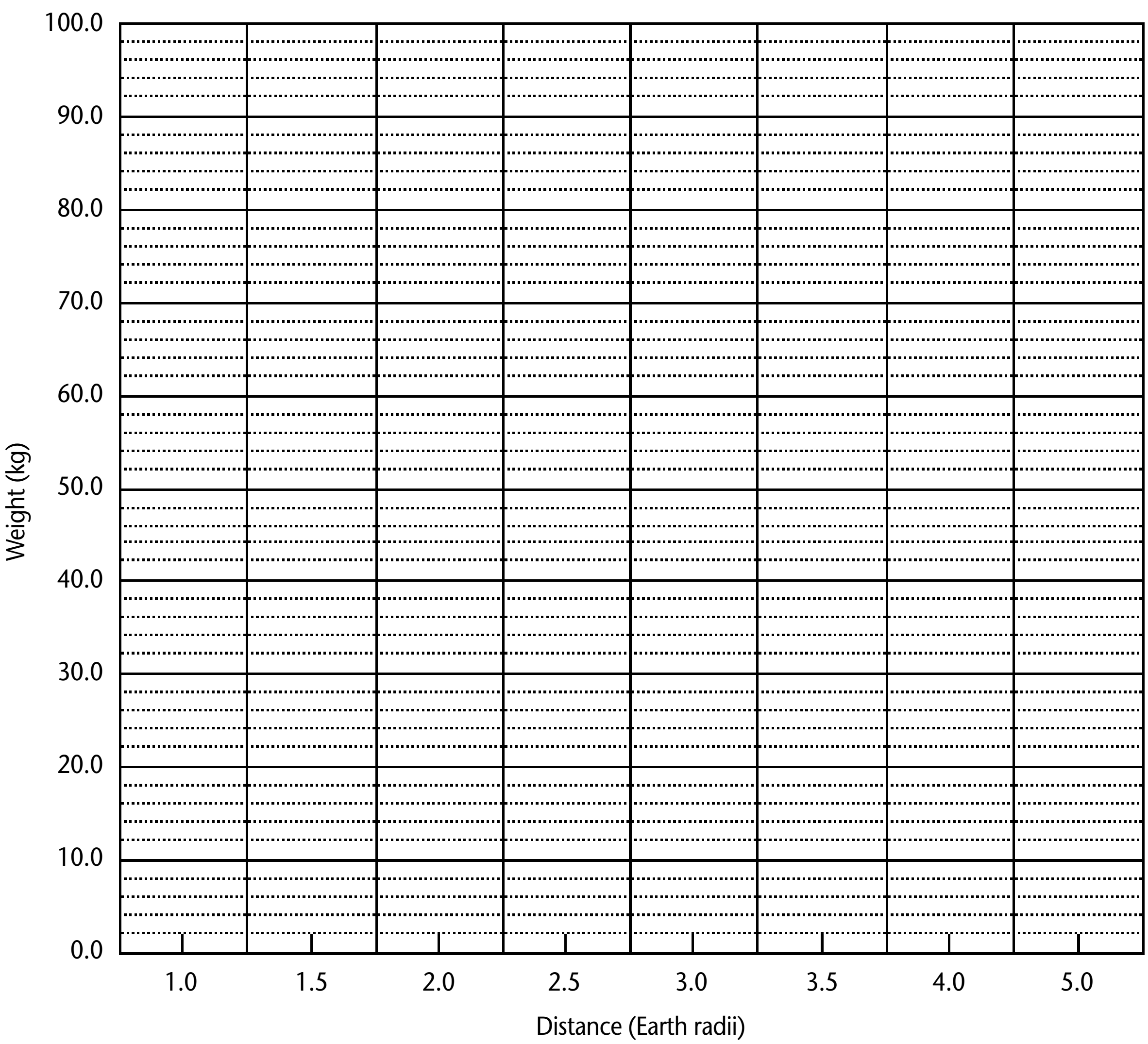
4. At a very, very great distance from the earth (or any mass), what would be the weight of the object?

Concept Extension
What is the difference between mass and weight?

Table 1. Weight versus Distance

Distance (earth radii)	Weight (kilograms)
1.0	100.0
1.5	44.0
2.0	25.0
2.5	16.0
3.0	11.0
3.5	8.2
4.0	6.3
5.0	4.0

Graph Template



Focused Discussion: Newton's Gravitation (Heavenly Motions)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To investigate Newton's concept of gravitation.

Procedure: Below are four mental puzzles about gravitation. To solve them, you will need to extend concepts you already know. You can choose to support your argument mathematically, but if you do so, you must use words/pictures first.

1. Suppose the sun suddenly became very small (a black hole!). What would happen to the earth's orbit?

2. Imagine the earth in the form of a spherical shell, so that this shell contained the total mass of the earth. What would be its gravitational force on a test mass placed (a) far away from the earth, (b) on the surface of the earth, and (c) inside the earth?

3. Imagine a completely smooth and spherical earth with no atmosphere. You have a baseball to place into an orbit just above the surface. What concept(s) would you apply to determine the period of the baseball's orbit? How would the period change if you used a bowling ball?

4. Imagine a straight shaft bored from the earth's surface, through the center of the earth, and out the other side. Drop a baseball down this shaft. Predict the baseball's motion (a) at the start, (b) at the center of the earth, and (c) just as it comes out the other side. At each point, describe the acceleration and velocity of the baseball. Will this motion be periodic? If so, how does the period compare to that in #3?

Concept Extension

Suppose you replaced the earth with Mars. How would your answers change, if at all?

Focused Discussion: Continuous Spectra (Light & Spectra)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To be able to identify, graph, and physically interpret continuous spectra.
Prediction: How does a continuous spectrum (from a prism or grating) appear to your eye?

Procedure: A *spectrum* consists of visible light spread out over wavelength (or color, if you consider the visible spectrum only). When you look at a photo of a visible spectrum, your eye senses the colors that are emitted by the source. In an emission line spectrum, for example, you see bright lines at certain colors only, because these lines are the only wavelengths at which the source is emitting energy. Between the lines, where the source is not emitting energy, the spectrum appears dark. In contrast, a continuous spectrum shows a smooth band of colors as you view it. Your eye "measures" the wavelength by revealing the colors, from violet (shorter wavelengths) to red (longer wavelengths). Now, you are also "measuring" the energy emitted each second at each color—the *intensity*—but you have no easy way to quantify this property.

Imagine that you have a light meter that is equally sensitive to all colors. You place color filters between the source and the light meter and record the reading of the intensity. Table 1 shows a series of such readings from 3000 (UV) to 10,000 Å (infrared). The values are all relative to the peak, so they indicate *relative intensity.* Note that the relative intensities vary over the range of wavelengths; this indicates to you that the source is *not* emitting the same energy per second at each wavelength.

Let's reveal this energy dimension by plotting the spectrum in the Graph Template. Plot the relative intensity at each wavelength given in Table 1. When done, try to draw as *smooth* a curve as possible through all the points.

Table 1. Relative Intensity Values for a Continuous Spectrum

Wavelength (Å)	Relative Intensity
3000	0.46
3500	0.70
4000	0.89
4500	0.96
5000	1.00
5500	0.98
6000	0.93
6500	0.85
7000	0.78
7500	0.70
8000	0.63
8500	0.56
9000	0.50
9500	0.45
10,000	0.40

Once you've completed your graph, answer the following questions:

1. What is the overall shape of your spectrum? Does it show sharp peaks or dips? If so, how many?

2. At what wavelength (in Ångstroms) does the spectrum have a broad peak?

If you compare the spectrum with those in your textbook, you will see that it has the characteristic shape of a *Planck curve*. This shape tells you that the emitting source is a hot *blackbody*.

3. What *one* physical property does the emission of a blackbody depend upon?

4. *Wien's law* provides the relationship between the wavelength at which a Planck curve peaks and the temperature of the blackbody. It is

$$\text{Temperature} = 2.9 \times 10^7 \div \text{Peak Wavelength}$$

where the temperature is in kelvins if the peak wavelength is in Ångstroms.
Using your result from #2, calculate the temperature in kelvins of the blackbody whose spectrum you have drawn. Does this temperature make sense if the curve represents the continuous spectrum of a star?

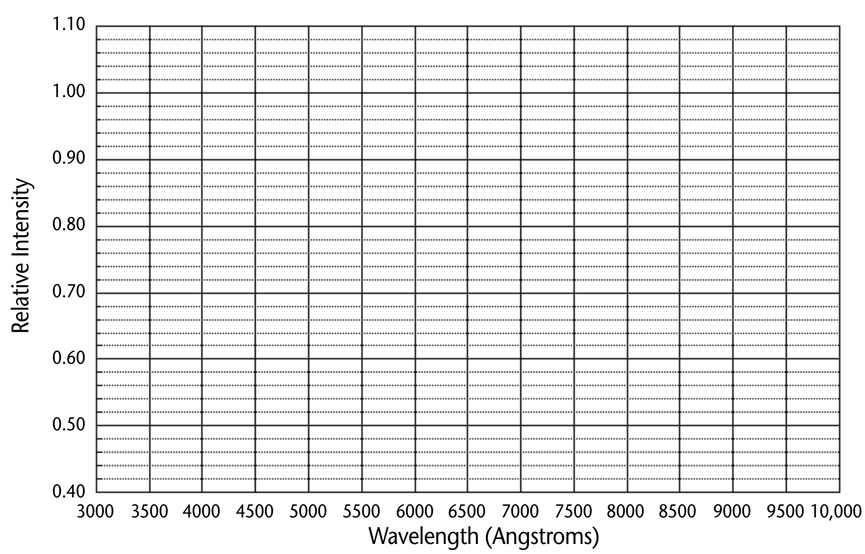
Concept Extension

Suppose you are measuring the spectrum of a blackbody with a temperature of 10,000 K.

5. Do you expect its peak to be at longer or shorter wavelengths than for the spectrum given here?

6. Calculate the wavelength, in Ångstroms, at which you expect the peak to occur.

Graph Template



Focused Discussion: Types of Spectra (Light & Spectra)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To find out how spectra differ based on their observed appearance.

Prediction: You see a rainbow. What kind of spectrum does it have?

Procedure: Each of you will need a diffraction grating (Night Spectra Quest if provided). Please be careful when you use these; they are somewhat fragile. In particular, do *not* touch the surfaces of the diffraction gratings.

Using the gratings: Turn the grating as you look at a light source so that you see the spectrum spread out the most. Note that you do *not* look straight through the grating at the source. You need to hold the grating in front of you and view at a slight angle. Then you'll see a spectrum. BE SURE YOU GET THE GRATING'S ORIENTATION RIGHT BEFORE YOU CONTINUE! You do not need to be close to a source to see its spectrum clearly; a few meters away is a good distance.

Each group will examine three sources: A, B, and C. Describe what you see in the spectrum of each source in Table 1. Be specific! For example: What colors did you see? Is the spectrum smooth? Does it contain bright lines? Dark lines? At what colors? Come to a group consensus to fill out the table.

You will also be given a set of "unknowns." Draw their spectra on the template. Identify their chemical composition using your comparison spectra.

Concept Extension

For each of the sources, describe the *physical conditions* under which each kind of spectrum is produced.

Source A

Source B

Source C

Table 1. Description of Spectra

Source	A	B	C

For description: Continuous band of colors? Bright lines at certain colors? Dark lines at certain colors? Be sure to use the comparison spectra on your Night Spectra Quest if that is what is provided by your instructor.

Use the template below for identifying the chemical composition of "unknown" materials.

Spectra Template

Red	Orange	Yellow	Green	Blue	Violet

Unknown 1:____________________

Red	Orange	Yellow	Green	Blue	Violet

Unknown 2:____________________

Red	Orange	Yellow	Green	Blue	Violet

Unknown 3:____________________

Focused Discussion: Stellar Temperatures, Colors, and Spectra (Light & Spectra)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To examine stellar spectra and find out how temperature distinguishes them.
Prediction: If two stars have the *same* surface temperature, will their colors be similar or different? Will their spectra be similar or different?

Procedure: You will be given spectra of six stars (labeled A through F). Your task: to order them by temperature, from the hottest to the coolest. First, examine the spectra as a group.

1. In general, what kind of spectra do these stars display? Use Kirchhoff's rules to describe the physical conditions under which these spectra form.

2. Draw a freehand line though the spectra, smoothing out the wiggles in a way that traces out an average value. Which star is the hottest? The coolest? How do you know?

3. For each star, estimate its surface temperature, assuming that it radiates like a blackbody. Write your estimate in kelvins in Table 1.

Table 1

Star ID	Estimated temperature (kelvins)
A	
B	
C	
D	
E	
F	

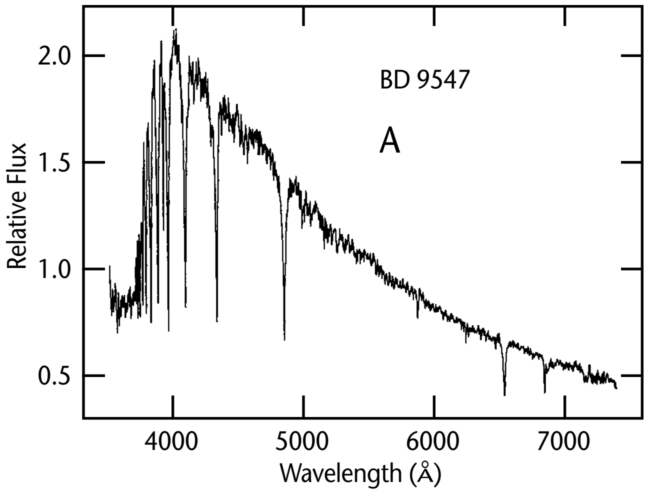
4. Now sort the spectra in order of *decreasing* temperature. Write your sequence, by star ID, here. Which star would have a color most like the sun's?

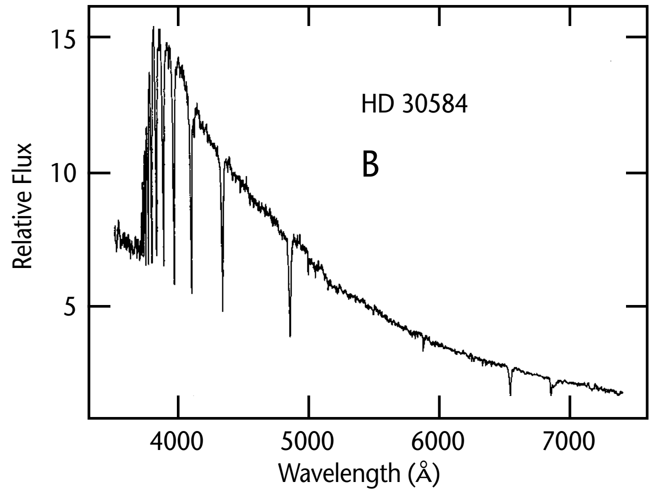
5. Find two Balmer lines in the spectra (they will not be visible in all). Note that the intensities (depths in these graphs) of these lines vary. What pattern do you see in the Balmer lines as you go from hotter to cooler stars? What color stars have weak or no Balmer lines?

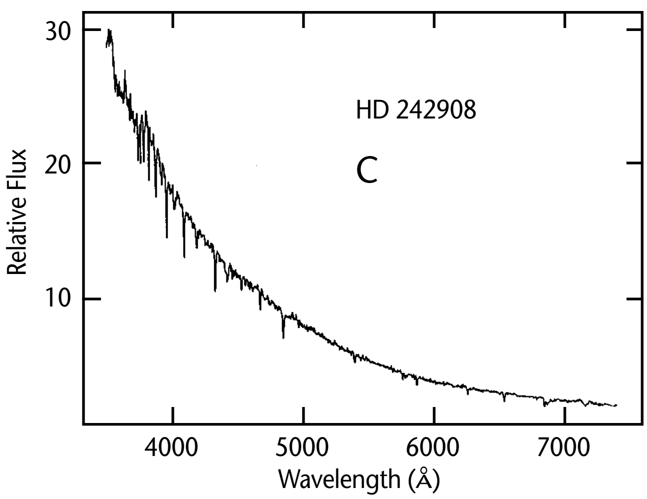
6. Without identifying other lines, do you see any patterns in them? That is, do you find the same lines at the same wavelength positions? (The depth of the lines might not always be the same.)

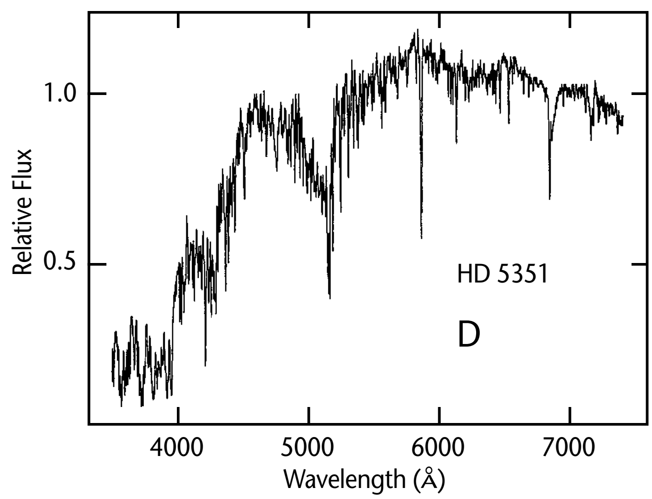
Concept Extension

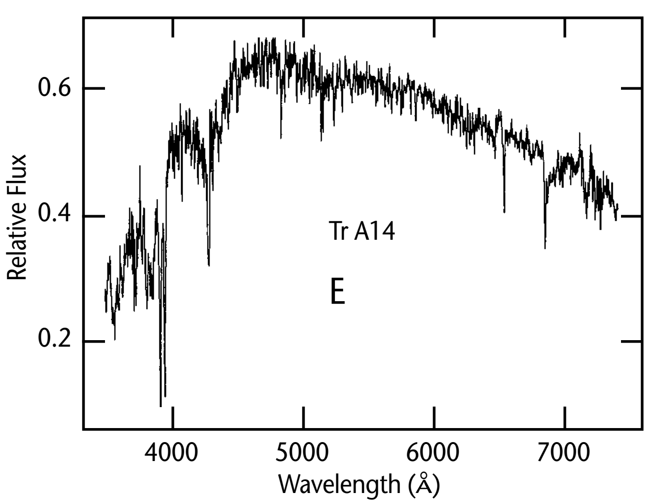
You are given the spectrum of an unknown star. How could you estimate its surface temperature?

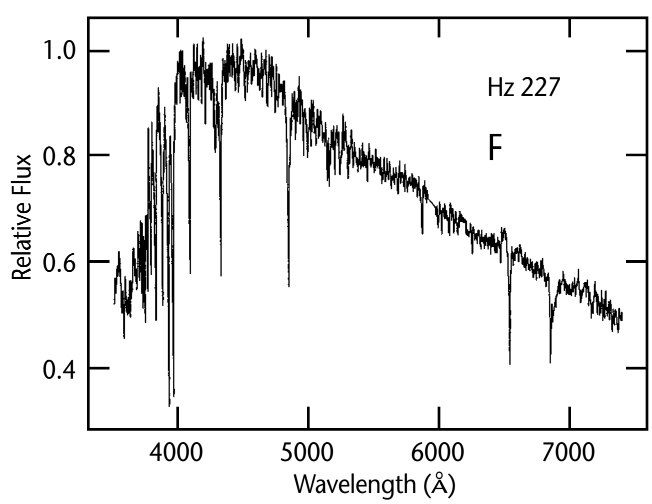












Adapted from *A Display Atlas of Stellar Spectra* (Dept. of Astronomy, University of Washington). Used with permission.

Reflection

How well has your cooperative learning group been functioning? Consider and reach a consensus on each of the following:

1) Acceptance and trust
2) Clear communication
3) Support of individuals and ideas
4) Constructive criticism and resolution of conflicts.

Has one person been dominating the thinking of the group? If so, how can this be avoided in the future?

Advanced Focused Discussion: Flux and Distance (Light & Spectra)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To find out the relationship between observed flux and distance.

Prediction: You are reading your textbook 1-meter from a 100-W bare light bulb. You move to a distance of 2 meters. How many 100-W light bulbs need to be placed at 2 meters in order to have your book page just as bright as it was with one bulb at 1 meter?

Procedure: A wax photometer allows you to compare the brightness of two sources. It works on a comparative basis; light from a known source illuminates one side, the unknown source illuminates the other side. You move the unknown source back and forth between the two bulbs until the brightness of the two wax blocks is equal. You then measure the distance from the photometer to the standard to compare it to the distance between the photometer and the unknown source.

Your standards will be 100-W light bulbs. Your "unknowns" will be other light bulbs of different wattages. You must hold the photometer between both bulbs so that their filaments are *parallel* to the face of the photometer. To make the experiment easier, you should keep the "standard" bulb a fixed distance from the photometer. You will need a few trial runs to discover a practical fixed distance.

Pick an "unknown" bulb and place it on the opposite side of the photometer from the standard bulb. Move the "unknown bulb" back and forth until the brightness of both sides of the photometer appears the same. Measure the distance from the photometer to the unknown bulb. DO THIS MEASUREMENT AT LEAST THREE TIMES AND AVERAGE THE RESULTS. Repeat with at least two other different wattage light bulbs. Record these values in Table 1.

1. Standard bulb = 100-W Standard distance =_________cm

Table 1

"Unknown" Bulb	Distance-try #1	Distance-try #2	Distance-try #3	Average distance (error)

2. If your "unknown" were a 100-W light bulb, how far would it be from the photometer for both sides to be equal in brightness? Answer: __________ cm

3. For your other unknown bulbs, you have the average distances in Table 1. In what way do these distances relate to the brightness of the bulbs compared to that for a 100-W bulb? You can solve this problem in two ways; choose one!

Plan A. Assume some functional relationship between brightness and distance. Use that relationship to compare each "unknown" to a 100-W bulb. Describe below how you make this comparison. Place the results in the last column of Table 2. These will be your "predictions."

Table 2

"Unknown" Bulb (watts)	Average Distance (cm)	Predicted Brightness Compared to 100-W Bulb	Measured Brightness Compared to 100-W Bulb

Functional relationship between brightness and distance:

Plan B. Fit a curve to a plot of brightness versus distance. You will then have an empirical relationship between brightness and distance. However, you need at least four points from Table 1 with small errors for this method to work well.

Functional relationship between brightness and distance:

4. Compare your predictions to the actual wattages of the "unknown" bulbs. How well do they agree? If they differ by more than 25%, can you think of a reason why?

Concept Extension

How could you use this technique to find the energy output of the sun compared to a 100-W bulb?

Focused Discussion: Luminosity of the Sun (Light & Spectra)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To compare the brightness (flux) of the sun to a known standard and so find out the sun's luminosity (power).
Prediction: How many 100-W light bulbs would you have to place at the earth-sun distance to equal the brightness of the sun?

Procedure: You will be given a wax photometer. It works on a comparative basis; light from a known source illuminates one side, an unknown source illuminates the other side. You move the photometer back and forth on the line between the two sources until the brightness of the two wax blocks is equal. You then measure the distance from the photometer to the standard, so that you can compare it to the distance between you and the unknown source—in this case, the sun.

You will need to illuminate one side of the photometer by the sun, the other by a light bulb of known power output. Write down the wattage of that bulb here:

1. Hold the photometer between the sun and the bulb, so that the bulb's filament is parallel to the face of the photometer. Move the photometer until both halves look to be the same brightness. Have a partner measure the distance from the light bulb to the surface of the wax face of the photometer.

2. Repeat #1 at least four times. Record the results in Table 1. Find the average value of your measurements in centimeters.

Table 1

Trial Number	Distance (cm)

3. What is the sun-earth distance in centimeters?

4. How many bulb-photometer distances is it from the earth to the sun?

5. How many standard light bulbs equal the luminosity of the sun? What is the sun's luminosity in watts? Compare your result to the value given in your textbook. Is there a large difference? If so, why?

Concept Extension

If you did this experiment on Mars, how would your last result (#5) differ, if at all?

Focused Discussion: Stellar Parallax (Cosmic Distances)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To gain a concrete understanding of parallax.

Prediction: If an object's parallax is small, is it nearby or far away?

Procedure: What is parallax, and is it important only in astronomy? Not at all! Parallax is something we experience and use every day of our lives. We use it automatically, entirely unconsciously, many times each day. It is parallax that allows us to gauge depth, that important third dimension. We use our own built-in parallax detection system to judge how far away that cup of coffee is when we reach for it, whether or not we can cross the street safely, where the doorway is and the wall isn't! What is this system? Your own two eyes!

In stellar parallax, an apparent shift in the position of a star is observed when the earth moves from one side of the sun to the other (Figure 1). First, we observe the star from point *A* (say in January) and it appears to be at point *a* relative to background stars. Six months later (in June), we observe the star from point *B*, and it appears to be at point *b*. This is the key observation that demolishes the geocentric model. That the earth revolves around the sun allows us to observe this star from two different positions, so that it appears to shift from one position to another relative to background stars that are farther away.

Our own equipment makes observing easier. Since we have two eyes, we don't have to wait six months. We already have two different lines of sight to an object, one for each eye. Depth perception is the automatic mental processing of these two different lines of sight to produce an intersection. Our brain then tells us that it is at this point of intersection that the object is actually located. In analogy to Figure 1, if the sun is your nose, and the two positions of the earth six months apart (*A* and *B*) are your eyes, then the lines from **A** to **a** and **B** to **b** are the lines of sight from your eyes through the object. Your clever brain, which understands parallax very well indeed, then interprets this data to tell you that the object is where the star actually is.

Close one eye. Now try to reach out and touch the tip of a pen or pencil held in your other hand. It's a lot harder with one eye, isn't it?

Now you will explore the apparent shift that occurs when you are observing location shifts. Again consider your eyes to be the positions of earth six months apart. You will hold a pencil upright at several different distances, but always directly in front of your nose. Every group member will go through the procedure, so that each of you experiences the parallax shift for yourself.

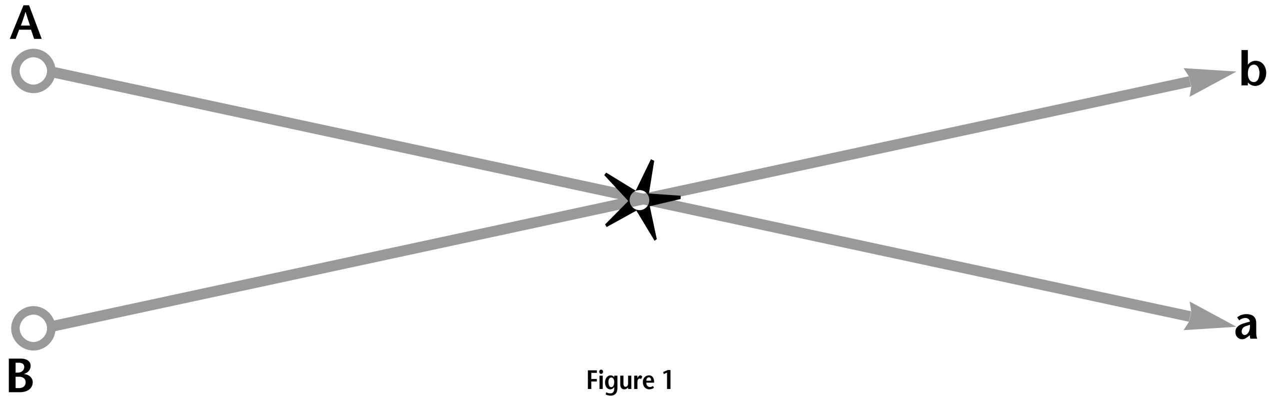


Figure 1

1. Hold the pencil right at the end of your nose. Close one eye and observe where the pencil appears to be against the background of the wall you face. Example: if you are looking at the blackboard, which side of the board does the pencil appear on? How far away from the center of the board? Now close the other eye and repeat your observations. Be sure to state aloud what you see to your group members. They will take note of your observations, and then compare them to their own.

How did the pencil appear to shift as you closed one eye and then the other?

2. Repeat the above process, but this time with the pencil held at about half an arm's length in front of your nose. Again remember to discuss what you see with your group members.

At this distance, how did the pencil appear to shift as you closed one eye and then the other?

3. Now go through the process with the pencil held at a full arm's length in front of your nose. Discuss what you observe with your group members.

How did the pencil appear to shift as you closed one eye and then the other? How did it change with distance from your eyes?

4. Can you see a problem in trying to detect the parallax shift of stars that are relatively far away from the sun?

5. How does your answer to #4 help to explain why the geocentric model was believed for so long?

6. Make an analytical statement relating the size of the parallax angle to the distance an object is from the observer.

7. Table 1 lists the parallaxes of a few bright stars observed by the *Hipparcos* satellite. Calculate their distances in parsecs.

Table 1. Parallax Data from Hipparcos

Star Name	Observed Parallax (arcsecs)	Distance (pc)
Alpha Centauri	0.732	
Alpha Canis Majoris	0.379	
Alpha Aquiliae	0.194	
Alpha Canis Minoris	0.286	

8. Which star is closest to the sun? Which one the farthest?

Concept Extension

Imagine you observed stellar parallaxes from Mars. Would they differ from those observed from the earth? If so, how?

Reflection

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4) Constructive criticism and resolution of conflicts.

Has one person been dominating the thinking of the group? If so, how can this be avoided in the future?

Focused Discussion: Classifying Stars by the H-R Diagram (Light & Spectra)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To visualize the relationship between surface temperatures and luminosities of stars.

Prediction: Do you expect that a plot of stellar surface temperatures versus luminosities will show random scatter or some trends?

Procedure: A glance at the stars in a dark sky may strike you as overwhelming. Yet, astronomers can measure their traits well. By focusing on just two stellar characteristics—surface temperature and luminosity—we can get an inkling of how stars are different and how they are alike.

Table 1 provides a list of 25 stars. It contains both some nearby stars and some of the brightest stars in the sky. Most of the nearby stars will have unfamiliar names. Each star has its approximate visual luminosity (relative to the sun) and surface temperature (in kelvins) listed. Use the Graph Template to make the plot. Note that the horizontal axis is surface temperature, starting with the high end to the left (25,000 K) and decreasing to the right, down to 1000 K. Each small tic on the axis amounts to 1000 K. The luminosities are given on the vertical axis; note the wide range of values. Each tic mark here represents 1/10 of the interval. Plot each star at the correct combination of luminosity and temperature. Do the sun first, it's easy! Plot each star's point using its number, so you can tell which stars are where on the graph. With your completed graph, answer the following questions:

1. How are the stars arranged overall on this temperature-luminosity graph? Can you divide them into two or three large groupings?

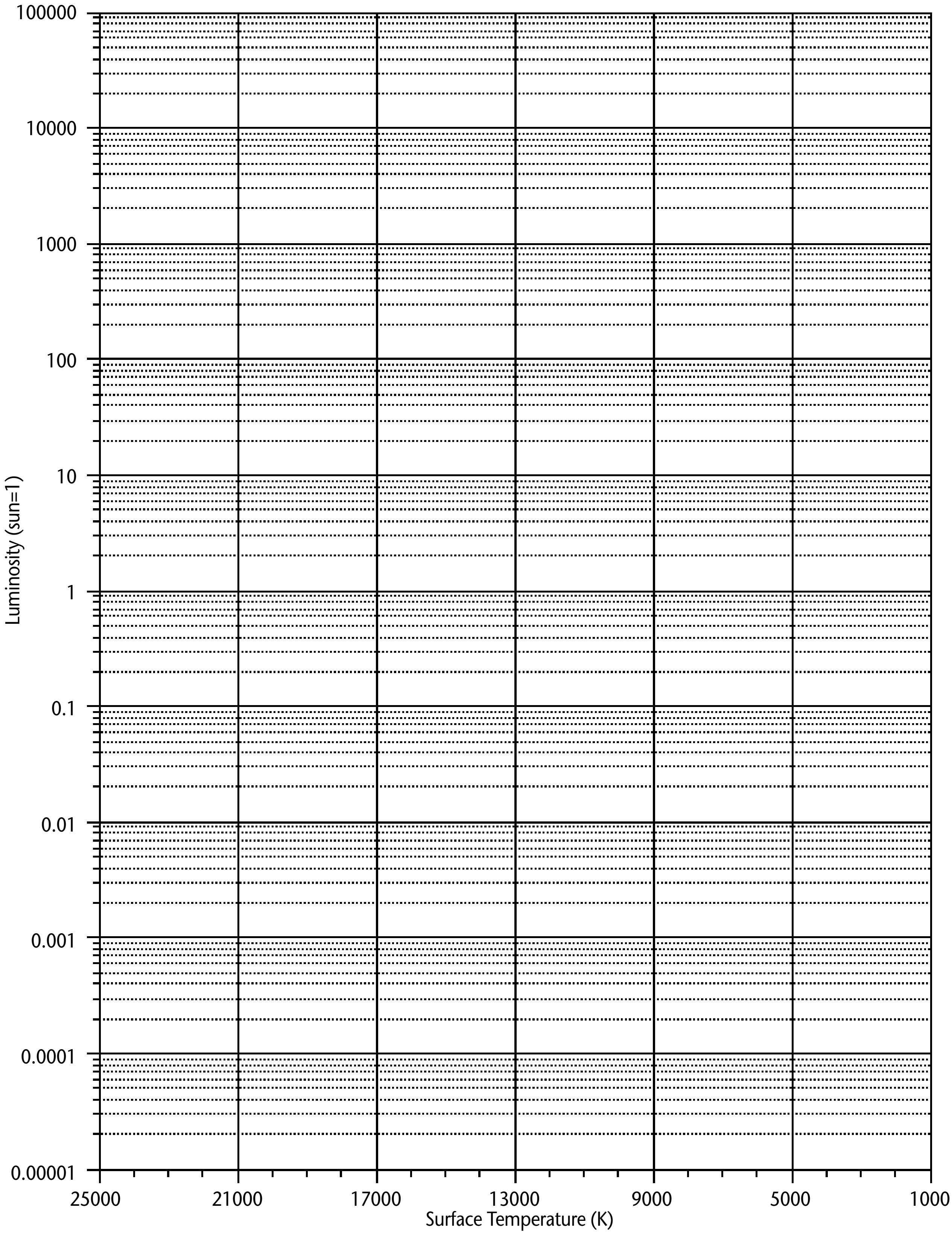
2. The low-luminosity stars tend to be the nearby stars (otherwise, we wouldn't see them!). Where on the diagram do these stars fall? Is there any similarity about their surface temperatures?

3. Pick out any star hotter than the sun. Then choose another. Do you expect that stars hotter than the sun are generally more or less luminous than the sun?

Table 1. Properties of Selected Stars

Number	Star Name	Visual Luminosity	Surface Temperature (K)
1	Sun	1.0	5800
2	Luyten 726-8A	0.00006	2600
3	Epsilon Eridani	0.30	4600
4	Aldebaran	690	3800
5	Eta Aurigae	580	16,000
6	Rigel	89,000	12,000
7	Betelgeuse	20,000	3300
8	Mu Camelopardalis	150	3000
9	Canopus	9100	7400
10	Sirius A	23	10,000
11	Sirius B	0.003	10,000
12	BD +5° 1668	0.0015	3000
13	Procyon A	7.6	6500
14	Iota Ursae Majoris	11	7800
15	Zeta Leonis	50	8800
16	Wolf 359	0.00002	2600
17	Lalande 21185	0.0055	3300
18	Ross 128	0.00036	2800
19	Spica	1900	20,000
20	Arcturus	76	3900
21	Alpha Centauri A	1.3	5800
22	Beta Canis Minoris	240	12,000
23	Antares	3600	3000
24	Zeta Ophiuchi	4500	23,000
25	Vega	52	11,000

Graph Template



Reflection

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Advanced Focused Discussion: Properties of Stars (Light & Spectra)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To find relationships among stellar masses and luminosities, life expectancies, and surface temperatures.

Prediction: Does a more massive main-sequence star have a shorter or longer lifetime than a less massive star?

Procedure: The single most important physical property of a star is its *mass*. Most other properties depend, at least in part, on mass. *Luminosity* is the total radiant energy output per unit of time; it is usually expressed in joules/s or watts. The *effective temperature* (T_{eff}) of a star is the temperature that a blackbody would have if it radiates the same amount of energy as the star does, given a radius for the star. It is one way to define the *surface temperature* of a star. The *life expectancy* of a star is the length of time it exists as a stable, main-sequence star. Our sun has a life expectancy of approximately 10 billion years.

In this activity, you will establish relationships among physical characteristics for stable, main-sequence stars by graphical analysis. Caution: these relationships may not apply to other types of stars, such as giants.

Table 1 shows average properties for main sequence stars by spectral type, S_p. Also given are: $M/M_{\odot}$, the ratio of the star's mass to that of the sun; $R/R_{\odot}$, the radius ratio also compared to the sun; $L/L_{\odot}$, the luminosity ratio; T_{eff}, the effective surface temperature (in kelvins), and Y, the star's life expectancy (in millions of years).

You will need to plot some of these properties. In a cooperative learning group, you can finish this task effectively if you divide up the plotting efforts among group members.

Table 1. Typical Properties of Main Sequence Stars

S_p	$L/L_{\odot}$	log $L/L_{\odot}$	$M/M_{\odot}$	log $M/M_{\odot}$	$R/R_{\odot}$	T_{eff} (K)	log T_{eff}	Y (My)	log Y
O5	22000	4.34	40	1.60	18	50000	4.70	0.1	-1.0
B0	3800	3.58	17	1.23	7.6	27000	4.43		
B5	240	2.38	7	0.84	4.0	16000	4.20	80	1.9
A0	50	1.70	3.6	0.56	2.6	10400	4.02		
A5	13	1.11	2.2	0.34	1.8	8200	3.91	2000	3.3
F0	7.9	0.90	1.8	0.26	1.3	7200	3.86		
F5	3.8	0.58	1.4	0.15	1.2	6700	3.83	5000	3.7
G0	1.5	0.18	1.1	0.04	1.04	6000	3.78		
G5	0.72	-0.14	0.9	-0.05	0.93	5500	3.74	10000	4.0
K0	0.38	-0.42	0.8	-0.10	0.85	5100	3.71		
K5	0.055	-1.26	0.7	-0.16	0.74	4300	3.63	20000	4.3
M0	0.018	-1.74	0.5	-0.30	0.63	3700	3.57		
M5	0.0011	-2.96	0.2	-0.70	0.32	3000	3.48	50000	4.7

Source: *Introductory Astronomy and Astrophysics*, Michael Zeilik and Steve Gregory, Saunders College Publishing, 1998

1. Find the relationship between luminosity ($L/L_\odot$) and mass ($M/M_\odot$), as follows:

1. a. Plot log ($L/L_\odot$) vs. log ($M/M_\odot$). You can do this by plotting log ($L/L_\odot$) vs. log ($M/M_\odot$) on Graph Template 1. Let mass be on the *x*-axis.

1. b. Draw a "best-fit" straight line through the plotted points. "Best fit" means that the line will pass through some (but not all) points, and that about the same number of points will be above as below the line. Determine the slope (*m*) of this line. Write that slope here:

m = ______________

1. c. Write a mathematical expression for mass and luminosity in the form log A = m log B. (Note the similarity to y = mx + b for a straight line.)

1. d. Convert the mathematical expression to exponential form, $A = B^m$.

2. a. Plot log T vs. log ($M/M_\odot$). Let mass be on the *x*-axis. Use Graph Template 2.

2. b. Use the same procedure as above to find the mathematical relationship between effective temperature (T_{eff}) and mass ($M/M_\odot$).

3. a. Plot log Y vs. log $M/M_{\odot}$ and draw a best-fit, *smooth* curve through the plotted points.
Use Graph Template 3.

3. b. Describe the resulting curve. What does it mean in terms of what happens to the lifetime as the mass increases?

4. Use your mathematical relationships, graphs, and the data in Table 1 to predict (1) the luminosity, (2) life expectancy, and (3) effective temperature of each of the following average, stable, main-sequence stars:

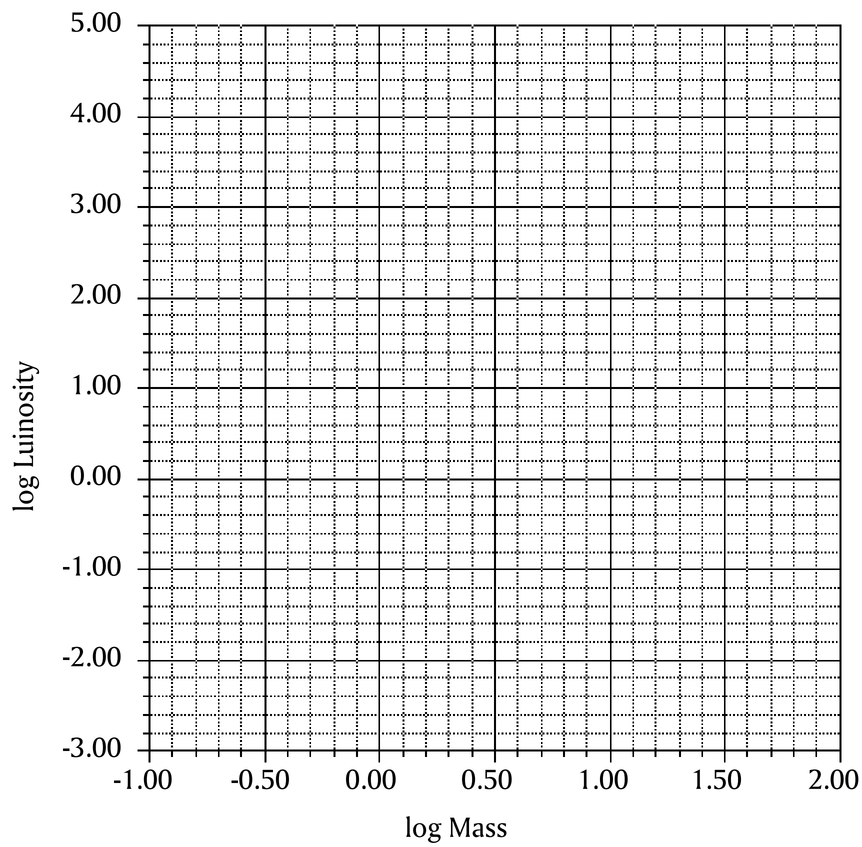
a. Star A is 0.1 times the mass of the sun.
b. Star B is 3 times the mass of the sun.
c. Star C is 5 times the mass of the sun.
d. Star D is 25 times the mass of the sun.

Summarize your results in Table 2.

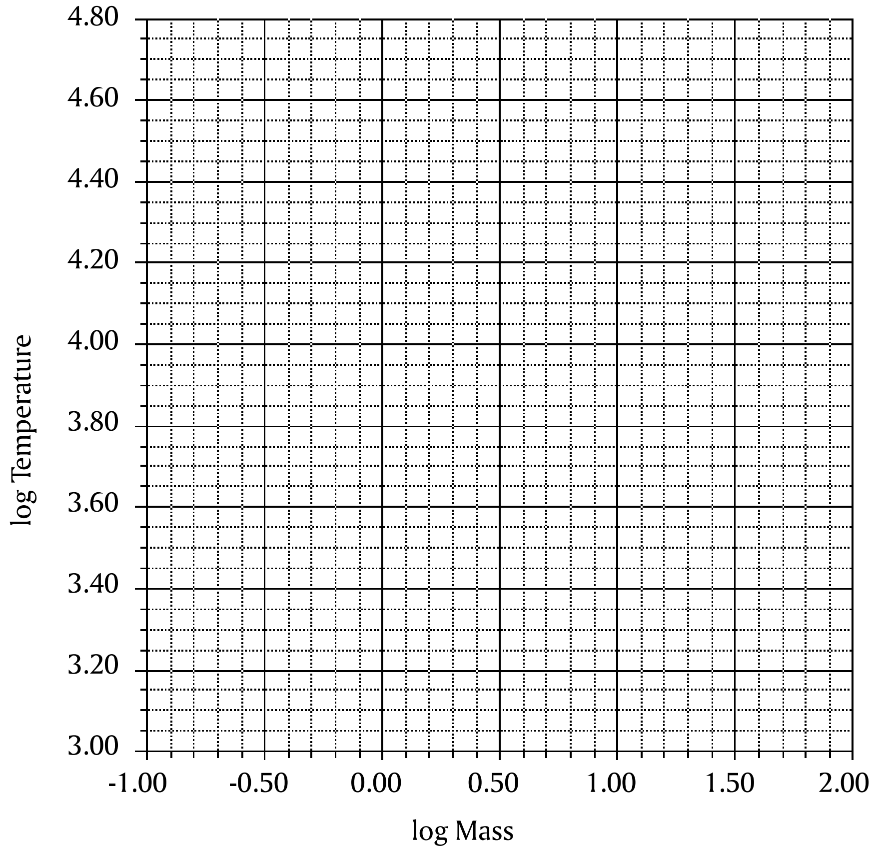
Table 2. Summary Table

$M/M_{\odot}$	$L/L_{\odot}$	Y (My)	Teff (K)
0.1			
3			
5			
25			

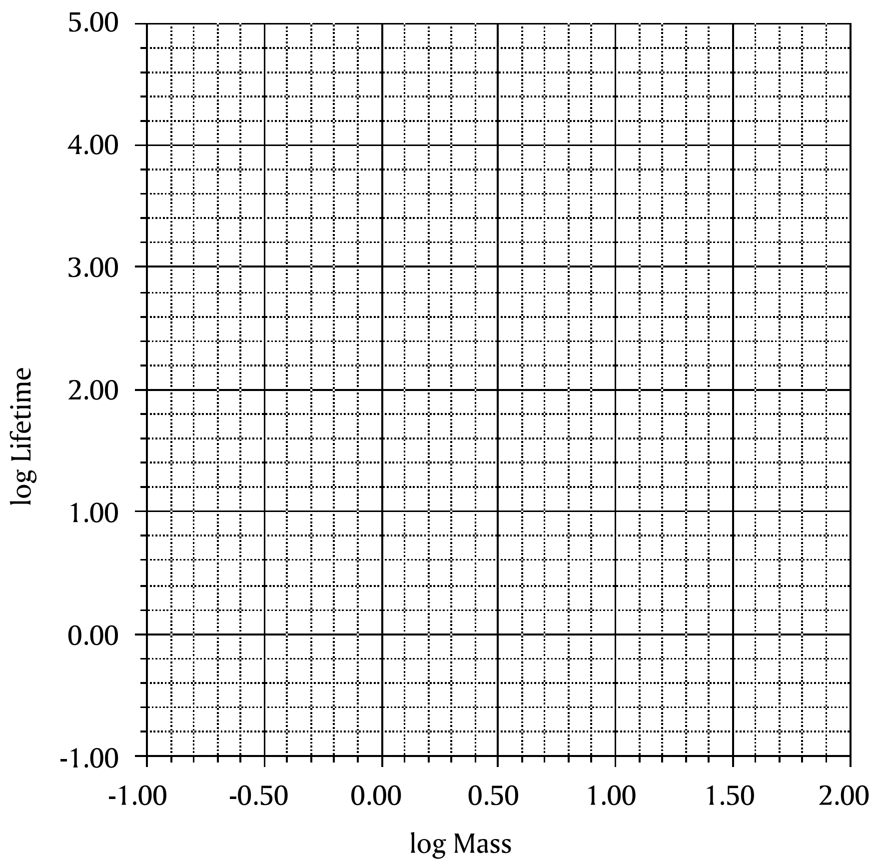
Graph Template 1.



Graph Template 2.



Graph Template 3.



Advanced Focused Discussion: Energy Flow in Stars (Light & Spectra)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To be able to estimate the time for a random walk across a certain distance.

Prediction: How long does it take for a photon produced in the sun's core to reach its surface?

Procedure: You will use a physical model of a "random walk" to find out the relationship between average distance traveled and the time to traverse this distance. In a random walk, an object moves in discreet steps, the direction of which is prescribed by a random process (such as flipping a coin and getting a heads or tails). We expect that over a large number of steps an object will make progress away from its starting point. But over a short run of steps (or time), the progress may be zero because of a large fluctuation—such as a run of all heads in coin tossing.

In a star's core, fusion reactions produce high-energy photons. These travel a very short distance and are absorbed by the gas. Quickly, a new photon is reemitted, and it can go in any direction. The information of the previous path has been lost. Photons scatter around in random walks until they progress out to the surface; they then pop off into space, never to return. The region of a star's interior in which this scattering process occurs is called the *radiative zone*—photons diffuse out from the core to the photosphere.

You will be given a Bumble Ball™, which simulates a random walk. You will draw circles of different radii on a flat, level surface and measure the time it takes for the ball to move from the center to the edge of a circle. You *must* do each circle a number of times; otherwise fluctuations will throw off your results! How many observations? From 5 to 10 per circle for the larger ones; a greater number for the smaller circles (30 or 40). It will pay off in a cleaner result if groups pool their data. This activity requires intergroup cooperation to pull it off successfully.

After you have collected your data in Table 1, you then must do a curve fit to the data to find the functional relationship between time and distance. (Hint: Do a log-log plot and an "eyeball" fit.) Explain in the consensus report how you did the calculation. Note that you may have to try two or three lines before you find a satisfactory "best fit." The crucial information you want from the fit is how the elapsed time varies with the radii of the circles. That is the slope of a log-log plot.

You can expect the function to be some power of the radius: it may be a fraction such as 1.5, or an integer, such as 3. The key point is to find the best power law dependence. Beware that the error bars for each average value may be large and must be considered in your fit. When you plot the average values, include the error bars that correspond to one standard deviation from the mean. A best fit falls within these error bars; it does not have to hit each of the average value points.

1. Use your calculator to find the log of each value in Table 1. Plot in the Graph Template the log times (in seconds) versus the log distance (in meters). Make an eyeball "best fit" to the points. Note that the "average elapsed time" is actually a proxy for the number of steps taken by the Bumble Ball™ to travel out of the circle.

Table 1

Radius = 0.5 m	1.0 m	1.5 m	2.0 m	2.5 m
Time =				
Average time =				
SD =, # trials =				

2. Now calculate the slope of the line, where slope = rise/run. This slope is the value for n, if $y = A R^n$, where *y* is elapsed time, *R* the radius of the circle (the distance traversed), *n* is a number, and *A* is a numerical coefficient.

3. Now estimate the time it takes for photons to diffuse out of the sun. For photons, the average step size is about 1 mm. Calculate then, the travel time for a photon for one step.

Time for one step = __________ s

Next, you need to know the total number of steps. To do this, you need to use the functional relationship you found in #2. Forget the coefficient *A*; it applies only to the Bumble Ball™ on a particular surface. What is essential is the power, *n*, of

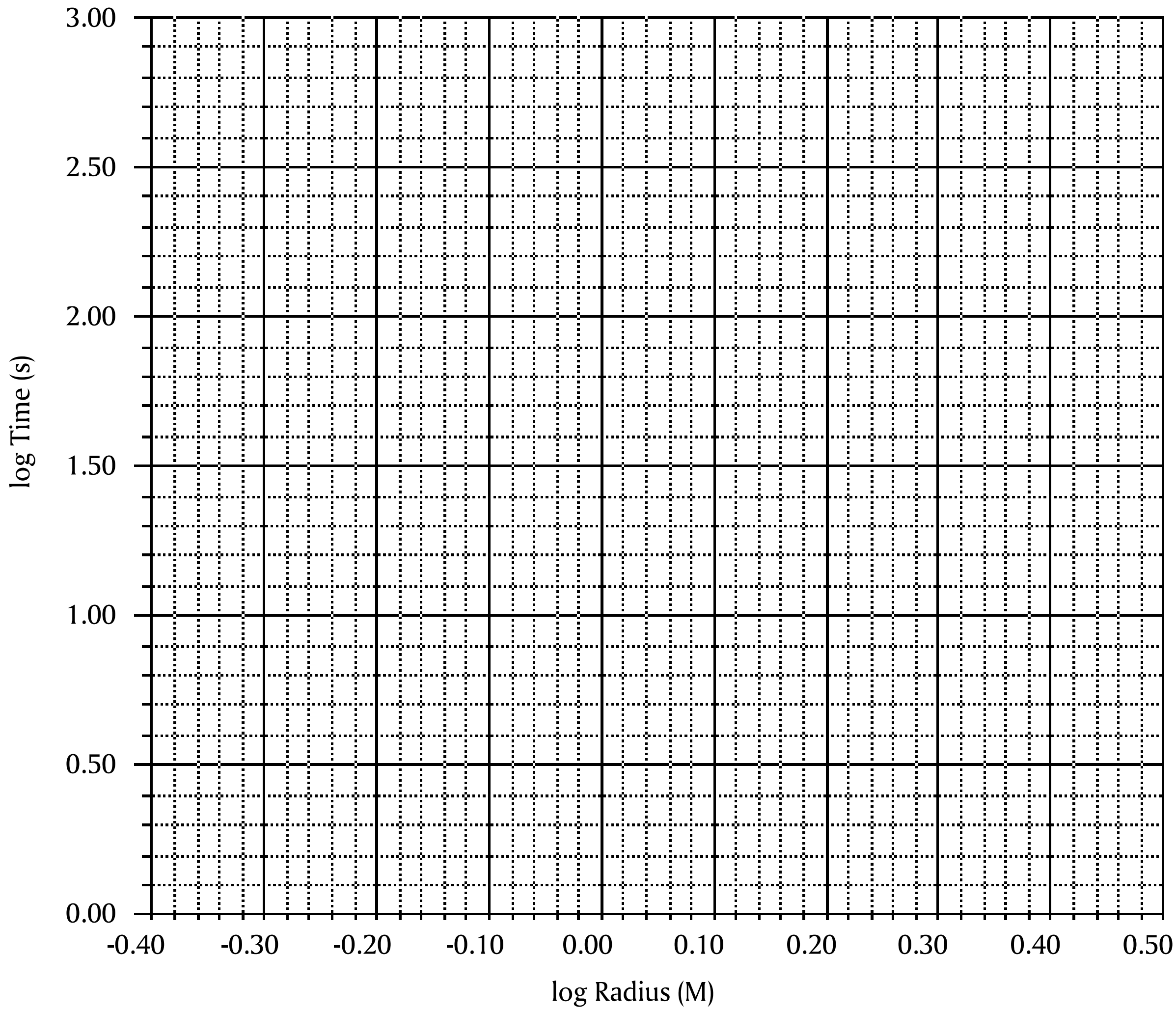
R. Now the average elapsed time is a proxy (but not the same as!) for the total number of steps, N. We can use R^n to estimate N.

How?

Imagine that the total number of steps depended only on R ($n = 1$). Then the total number of steps for photons to travel out of the sun would be the radius of the sun (in mm) divided by the step size (1 mm). And the total elapsed time would be the total number of steps times the time between steps. But you have found that $n \neq 1$! Use your power law to make a better estimate of the elapsed time. Show all your steps below (no pun intended!).

4. Compare the value you calculated to that given in your textbook or by your instructor. Comments?

Graph Template



Focused Discussion: Stellar Evolution (Scientific Models)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To find an evolutionary track for people and compare it to an evolutionary track of stars.
Prediction: How does a person's height and weight change as he or she ages?

Procedure: Table 1 gives the height vs. weight for a typical *group* of people in the United States. Plot the values on Graph Template 1.

Table 1. Height vs. Weight of People in the USA

Height (inches)	Weight (lbs)	Height (inches)	Weight (lbs)
60	115 lbs	68	165
62	125	70	170
64	130	71	178
65	140	72	180
66	145	74	200

Table 2 gives the height vs. weight for a *single individual* as he (a male) ages. Plot this data on Graph Template 2 and label the stages of development, such as birth, childhood, adolescence, middle age, and old age.

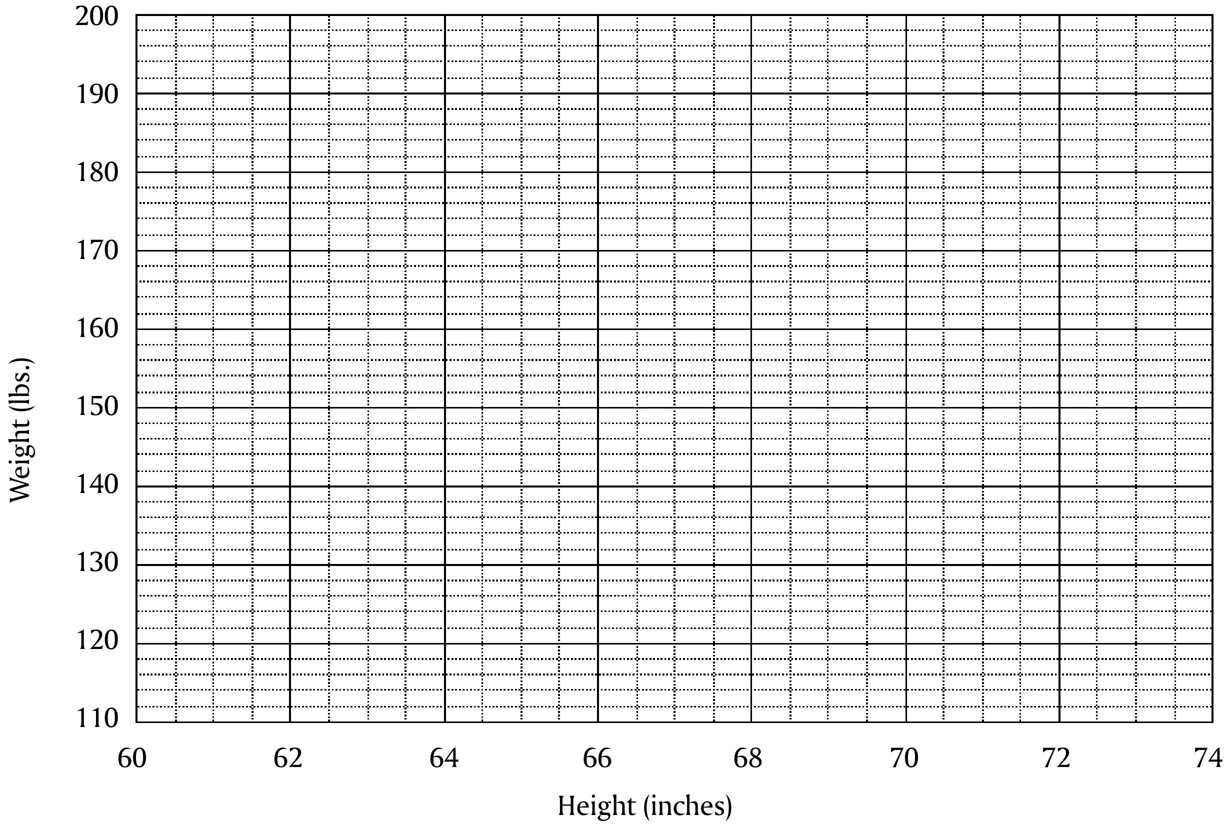
Table 2. Height vs. Weight of an Aging Male Individual

Height (inches)	Weight (lbs)	Height (inches)	Weight (lbs)
21	8	60	95
24	25	64	115
36	45	66	130
48	60	68	145
54	80	68	155
58	90	68	170

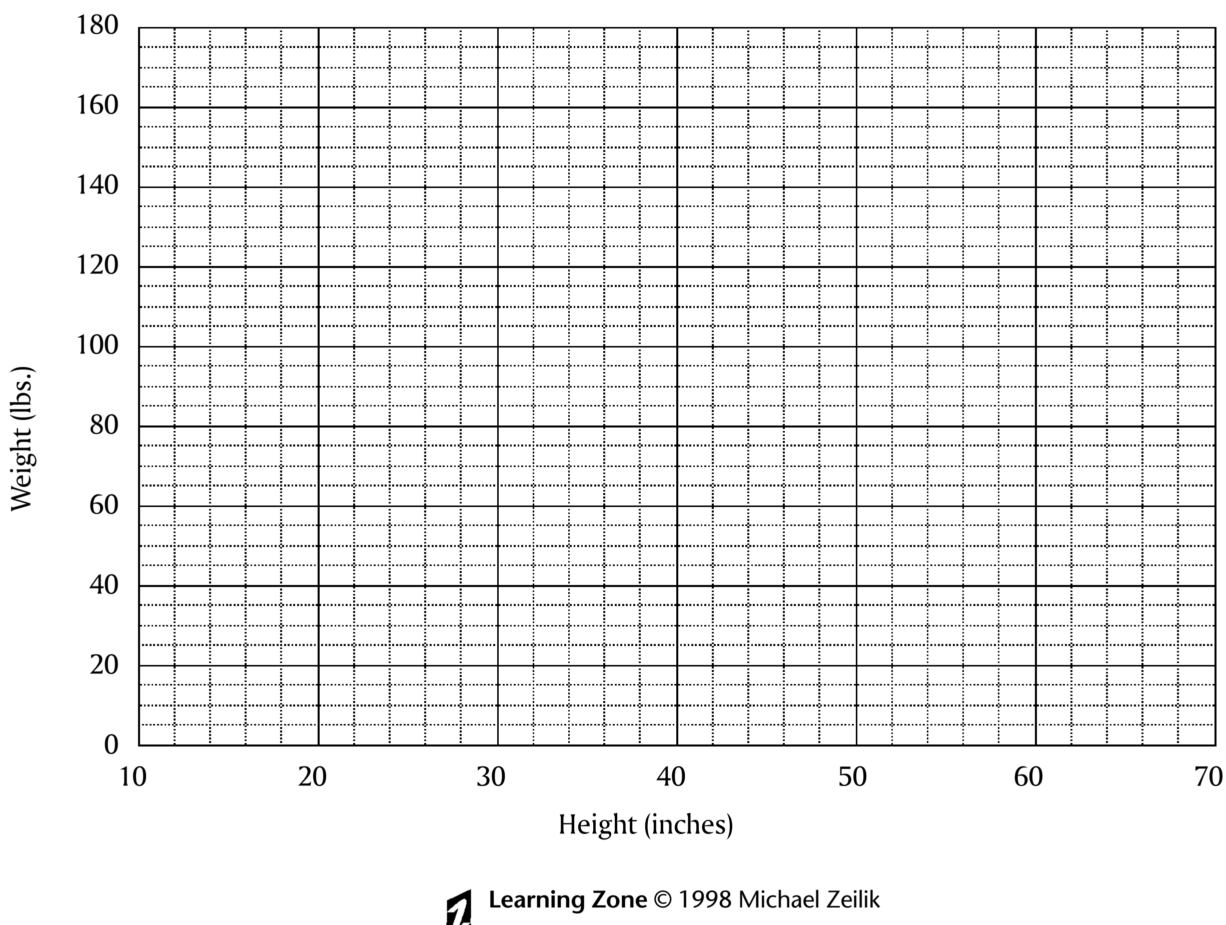
1. What are these two relationships that you have plotted? That is, how do they differ and what do they have in common?

2. How can you relate the two diagrams to the lives of stars and your textbook's H-R diagram? (Hint: Time!)

Graph Template 1



Graph Template 2



Focused Discussion: Cepheid Variable Stars (Cosmic Distances)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To find a relationship between the periods and luminosities of cepheid variable stars and use it to determine distances.

Prediction: What do you think might be a *trend* between periods of variability and luminosities of cepheid variables?

Procedure: Cepheid variables are giant and supergiant stars that expand and contract. As they do so (we measure this change by the Doppler shift), their luminosities vary in a regular fashion. The time interval from peak brightness to the next peak brightness defines the *period* of light variability. The name "cepheid" comes from the star that is the prototype of the group, Delta Cephei (fourth brightest star in the constellation Cepheus). The cepheid variability marks a stage late in a star's evolution, as it burns helium (to carbon) in its core. These stars are more massive than the sun, typically a few to ten solar masses.

Table 1 provides the periods and luminosities (to two or three significant figures) of selected cepheid variables. These luminosities are the *average* values, since these stars vary! (You will probably *not* recognize the names of any of these stars.) Use the Graph Template to plot these data. Notice that the *x*-axis (period in days) has an increment of 1 day; the *y*-axis (luminosity in solar luminosities) has an increment of 500. Once you have plotted the values for the stars, draw a "best fit" straight line through the data points. (Position the line so that it goes through most of the points, and it has about as many points above it as below it. A region of many points should influence the line more than a region of few points.)

Using your graph, answer the following questions:

1. What is the general trend of period versus luminosity?

2. Using your line, estimate the luminosity of a cepheid variable with a period of 25 days.

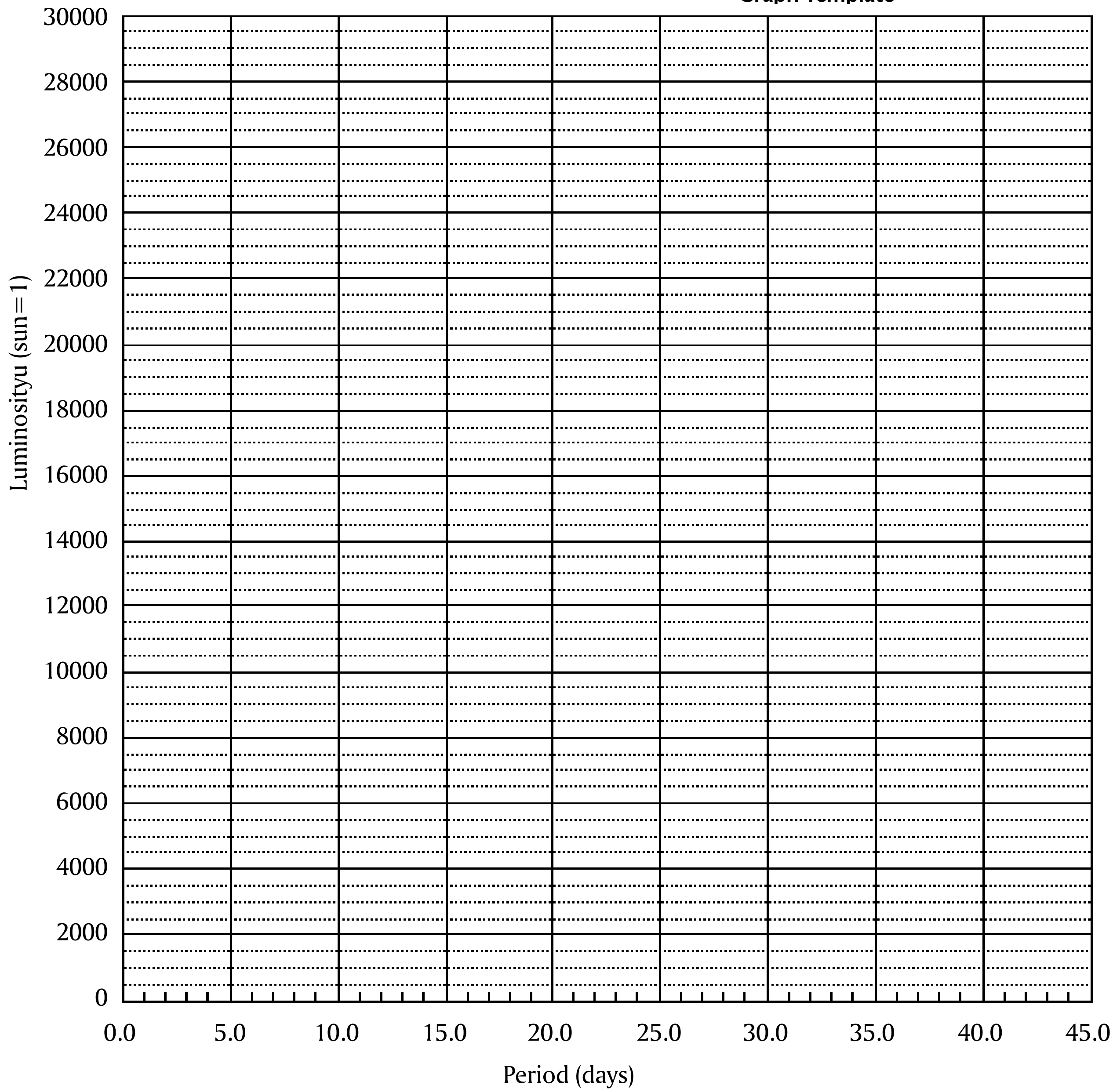
What of one with a period of 30 days?

3. Suppose you measure the flux at the earth of a cepheid whose period is 30 days. What procedure could you use to find out the distance to this cepheid?

Table 1. Period and Luminosity Data for Selected Cepheids

Star	Period (days)	Luminosity (sun = 1)
SU Cas	2.0	1000
CF Cas	4.9	1820
VY Per	5.5	2820
V367 Sct	6.3	3470
U Sgr	6.7	3890
DL Cas	8.0	3720
S Nor	9.8	4470
VX Per	10.9	5890
SZ Cas	13.6	8510
VY Car	18.9	11200
T Mon	27.0	18600
RS Pup	41.4	22400
SV Vul	45.0	30000

Graph Template



Focused Discussion: The Sun's Distance from the Galactic Center (Cosmic Distances)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

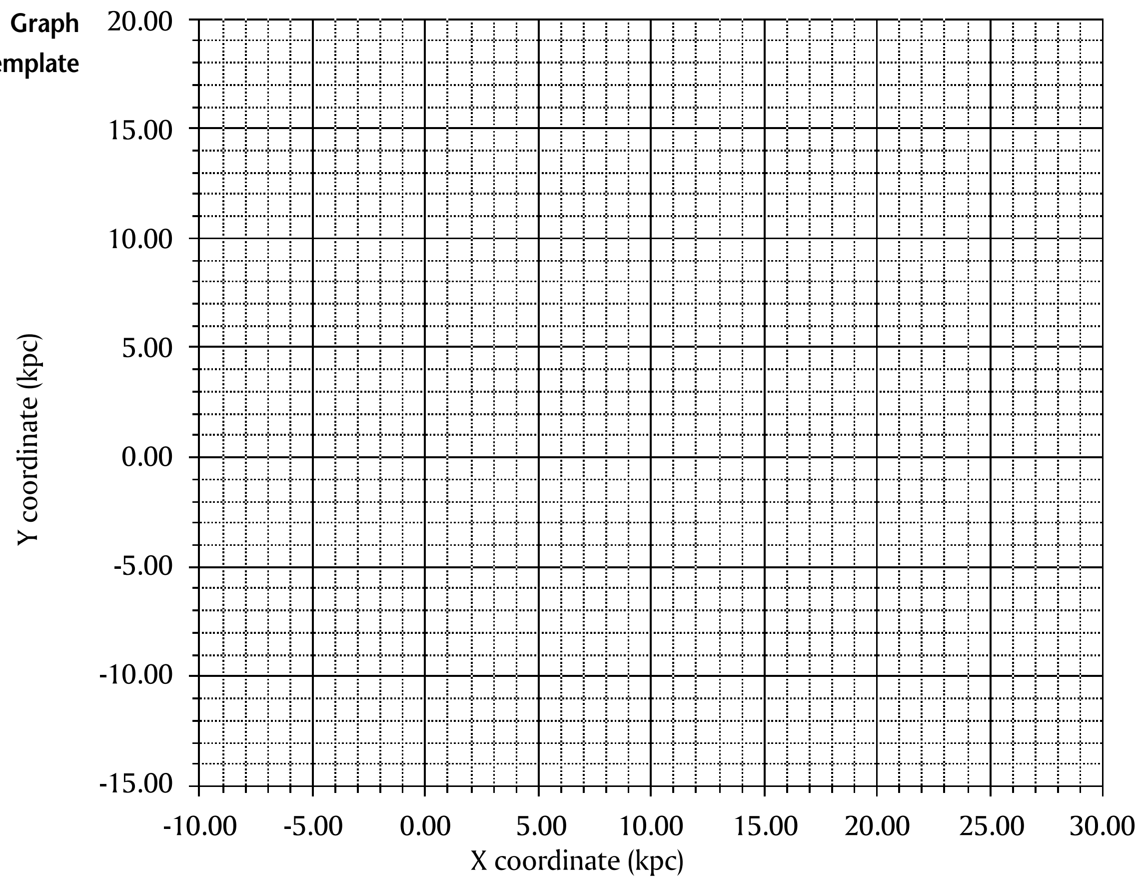
Purpose: To find out how we know the sun's location in the galaxy.
Prediction: What is the overall distribution of globular clusters around the center of the Milky Way Galaxy?

Procedure: Table 1 lists selected globular clusters (given in order of name in the New General Catalog, NGC) and their three-dimensional coordinates (X, Y, and Z) relative to center of the the Galaxy. X and Y are the distances in the plane of the Galaxy. Z is the distance above and below the plane. Each group will be responsible for a subset of these data.

1. Each group plots their data (X, Y coordinates only) using the Graph Template. You will do this twice; once on regular paper and once on a transparency overhead. Each group must use a different color pen for the transparency.

2. Using your group's data only, calculate the distance of the sun from the center of the Galaxy with an associated error. What assumption are you making?

Graph Template



3. Send a gofer around to the other groups to get the distance of the sun (and associated error) estimated from their data. Write that information below.

4. Do they differ by much? If so, explain. Note that you can transform parsecs to light years by multiplying by 3.26. What is the average value?

Table 1. Positions of Globular Clusters

Name (NGC) Group 1	X (kpc)	Y (kpc)	Z (kpc)
104	3.79	-5.22	-6.44
288	-0.01	0.01	-14.04
362	5.21	-8.47	-10.39
1851	6.13	-12.85	-9.99
1904	-9.81	-9.64	-7.41
2808	2.28	-10.53	-2.16
3201	0.97	-7.79	1.20
4372	4.54	-7.71	-1.57
4590	4.79	-8.44	7.06
4833	4.77	-7.19	-1.21

Group 2	X	Y	Z
5139	5.07	-6.24	2.15
5272	2.00	1.82	13.54
5286	9.00	-10.15	2.54
5466	3.16	2.85	14.48
5694	20.99	-11.33	13.70
5824	26.00	-13.45	11.89
5897	11.39	-3.48	6.97
5904	6.53	0.45	6.96
5927	5.24	-3.46	0.54
5986	13.50	-5.74	3.47

Group 3	X	Y	Z
6093	11.79	-1.51	4.21
6101	7.48	-6.18	-2.86
6121	3.29	-0.52	0.96
6139	13.60	-4.32	1.76
6171	9.64	0.58	4.11
6205	3.48	5.92	5.96
6218	6.55	1.84	3.36
6254	7.06	1.91	3.11
6266	10.35	-1.16	1.33
6273	7.49	-0.38	1.24

Group 4	X	Y	Z
6284	19.68	-0.54	3.48
6293	10.78	-0.44	1.51
6304	9.05	-0.67	0.86
6316	13.71	-0.68	1.39
6333	8.91	0.86	1.69
6341	3.17	8.00	6.01
6352	6.80	-2.31	-.090
6356	16.20	1.91	2.94
6362	7.86	-5.39	-3.02
6388	13.86	-3.56	-1.68

Group 5	X	Y	Z
6402	7.85	3.06	2.22
6440	7.52	1.02	0.50
6441	10.39	-1.30	-1.00
6522	15.08	0.26	-1.03
6541	7.31	-1.38	-1.46
6624	14.23	0.69	-1.97
6626	7.15	0.98	-0.71
6637	10.31	0.30	-1.88
6638	18.64	2.58	-2.38
6652	16.28	0.43	-3.28

Group 6	X	Y	Z
6656	3.23	0.56	-0.44
6681	18.52	0.93	-4.11
6712	9.91	4.68	-0.82
6715	21.15	2.04	-5.26
6723	12.02	0.03	-3.73
6752	7.89	-3.44	-4.13
6779	5.45	10.55	1.73
6808	6.27	0.98	-2.74
6838	3.62	5.50	-0.53
6934	13.92	17.91	-7.78

Focused Discussion: Rotation Curve of a Spiral Galaxy (Heavenly Motions)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To visualize how the orbital speeds of a galaxy vary with distance from the center of a galaxy.
Prediction: What happens to a galaxy's rotation curve far away from the galaxy's center?

Procedure: Recall Kepler's third law—the period squared divided by the distance cubed equals a constant value, or $P^2/a^3 =$ constant. You have used it many times. Here we again apply Kepler's third law, this time to determine the mass of a large spiral galaxy from its rotation curve. Using spectroscopic observations of the galaxy's spiral arms, the Doppler shift from rotation can be determined. Then we can find the radial velocities at points along the galaxy, from center to edge. We then construct a table of the rotational velocities at different distances from the center of the galaxy. This is called a *rotation curve*. See Table 1.

Table 1. Data for a Galaxy

Point	Radius (arcsec)	Rotational Velocity (km/s)	Point	Radius (arcsec)	Rotational Velocity (km/s)
1	-120	-170 km/s	13	2	40 km/s
2	-96	-240	14	5	80
3	-65	-290	15	10	30
4	-50	-240	16	12	80
5	-30	-150	17	14	110
6	-20	-100	18	16	120
7	-15	-50	19	21	190
8	-10	-20	20	29	170
9	-7	-40	21	66	360
10	-3	-70	22	80	390
11	-2	-15	23	96	370
12	5	10	24	107	240

You are to plot the velocity versus radius of the galaxy, thus producing a rotation curve for the galaxy. Points 1 through 12 have been plotted for you on the Graph Template provided. Plot the remaining points, 13 through 24. Draw a smooth curve through all the points.

1. Reach a consensus to explain the shape of the curve you have drawn. Specifically, why does it rise on one side, dip on the other, and turn over on both ends?

Calculations: All group members should be comfortable with these calculations, so make sure to discuss each step before you start punching calculator buttons.

Now choose a point located after the turn-over of the curve you plotted, and read off the velocity, *V*, and the distance, *a*, for this point.

V = km/s a = arcsec

It is necessary to convert *a* into astronomical units, AU, and then into kilometers. The conversion has been simplified for you: just multiply your value for *a* by 26 million, or 26×10^6, to get *a* in AU. Your new value for *a*:

a = AU

To convert to kilometers (km), multiply the above value for *a* in AU by 150 million, or 150×10^6, to get *a* in km.

a = *km*

Now you need to calculate the period of rotation for your chosen point. To do this, multiply your value for *a* by 6 (2π really, but close enough) and divide by your value for *V*.

$P = (a \times 6) / V =$ seconds

To convert to years, divide *P* by the number of seconds in a year.

$P = P / 31 \times 10^6 =$ years

For the final step, to determine the mass of the galaxy (in units of solar mass) from the two pieces of information you have painstakingly calculated you will now use Kepler's third law.

Square the value of *P* in years: $P^2 =$

Cube the value of *a* in AU (*careful*, AU, not km!): $a^3 =$

and divide P^2 by a^3 (this will yield a very small number!)

$P^2/a^3 =$ constant =

Finally, to obtain the mass of the galaxy in units of the solar mass, divide 1 by the constant.

$M_{galaxy} = 1/(\text{constant}) = \quad M_{sun}$

Concept Summary

This activity had a lot of calculation, much more than you normally do, but what exactly was it that you *did*? Let's break it down.

1. What observations did you start with?

2. What relationship or rule let you figure out the galaxy's mass from these observations?

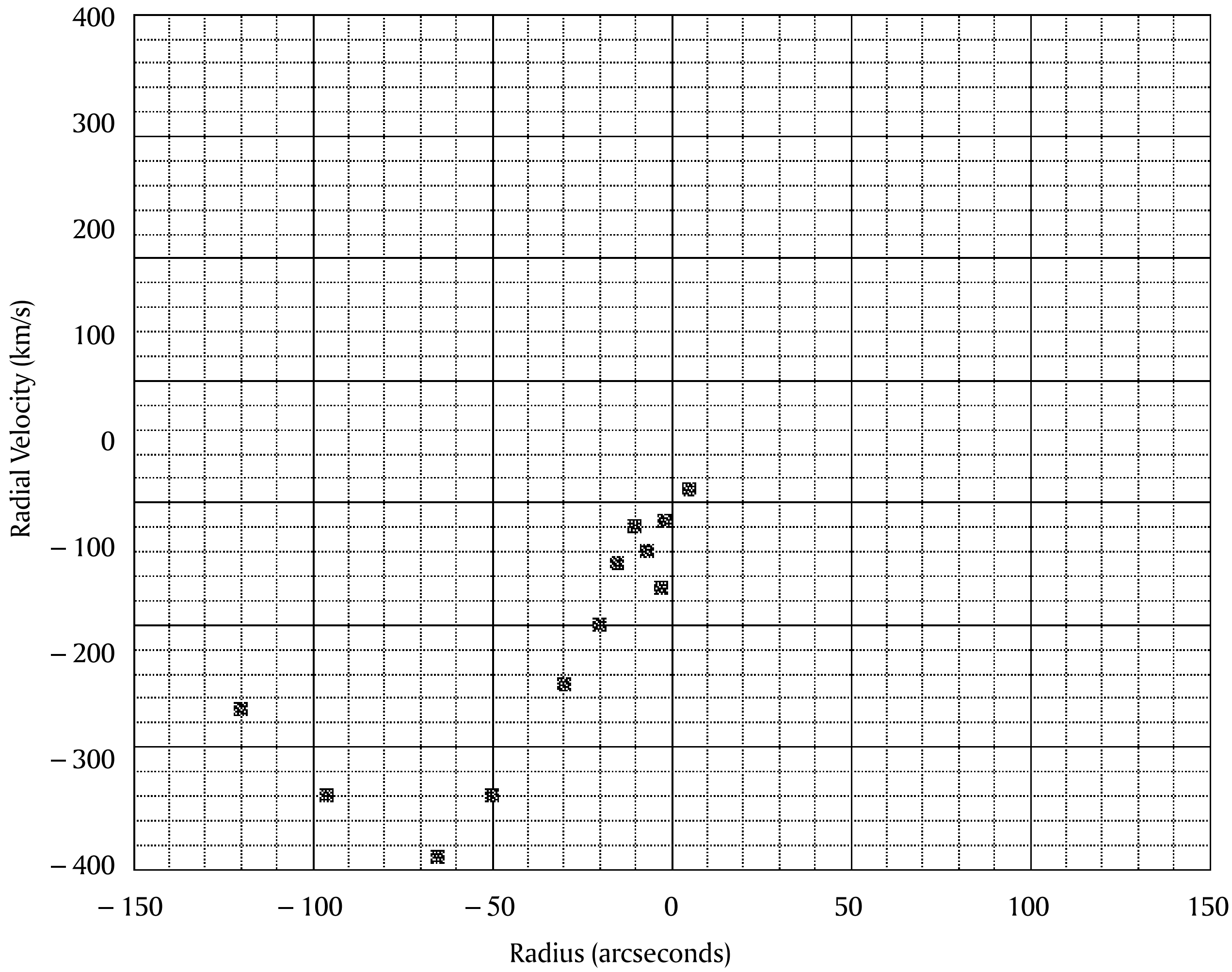
3. What special point did you have to pick to find the *total* mass of the galaxy?

4. Where have you seen this rule applied before (say locally, in the solar system)?

Concept Extension

If all the mass of a galaxy were concentrated in the center, how would the rotation curve look? Sketch it on the Graph Template.

Graph Template



Focused Discussion: Hubble's Law (Cosmic Distances)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To visualize the relationship between distances and recessional velocities for galaxies and find a value for the Hubble constant.

Prediction: If the universe is expanding, what would you expect as the relationship between the distances to galaxies and their speeds? (Hint: Inverse? Linear? Inverse square?)

Procedure: You will make "Hubble plots" of the distances and recessional velocities for selected groups of galaxies. The distances are found by a variety of ways, including the period-luminosity relationship for cepheids. The recessional speeds are found from the red shifts in the spectra of the galaxies. If this red shift is interpreted as a Doppler shift, it provides the radial velocity along the line of sight—a recessional velocity for a red shift.

1. First make a plot using Graph Template 1 from the data in Table 1. These galaxies are selected from the brightest ones in the sky (but you probably won't recognize their names). (What can you infer from the fact that they are among the brightest?) Graph Template 1 has the horizontal axis as the distance in millions of light years, from the closest to the farthest galaxies. On the vertical axis is the radial velocity in kilometers per second.

Plot the points for all the galaxies and draw a straight line through them with a ruler. DO NOT "CONNECT THE DOTS"! Try to draw a straight line so that about as many galaxies fall above and below the line as on the line. Now measure the slope of the line, which is the rise (y -axis) over the run (x -axis). Use the *complete* length of this "best fit" line, not just a part of it.

2. Find the slope from the difference in the value of the y-axis over the difference in the value of the x-axis. What value do you get? This is your value of Hubble's constant from the information in the graph.

3. All velocities for these galaxies are recessional—they are red shifts. What does this tell you about the universe: is it static, expanding, or contracting?

4. Now turn to Table 2, which lists a different sample of galaxies. Each one is chosen from a cluster of galaxies. Use Graph Template 2 and the plotted data to find the slope. What is it?

5. How do your values compare? Do they differ significantly? If so, why?

Table 1. Selected Bright Galaxies

Galaxy	Distance (Mly)	Radial Velocity (km/s)
Fornax A	98	1713
Messier 66	39	593
Messier 106	33	520
NGC 4449	16	250
Messier 87	72	1136
Messier 104	55	873
Messier 64	23	350
Messier 63	36	550
NGC 6744	42	663

Graph Template 1. Hubble's Law

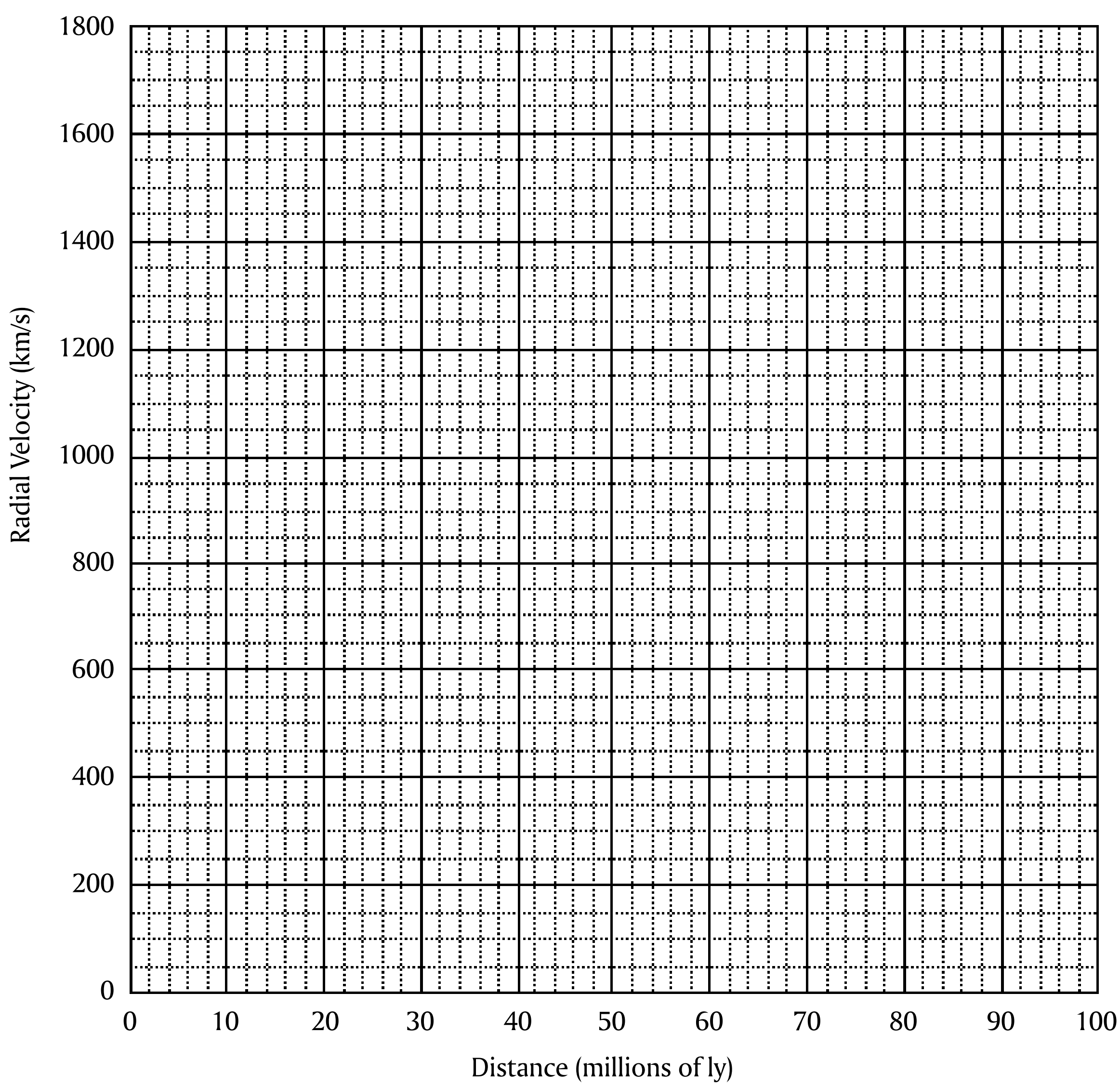
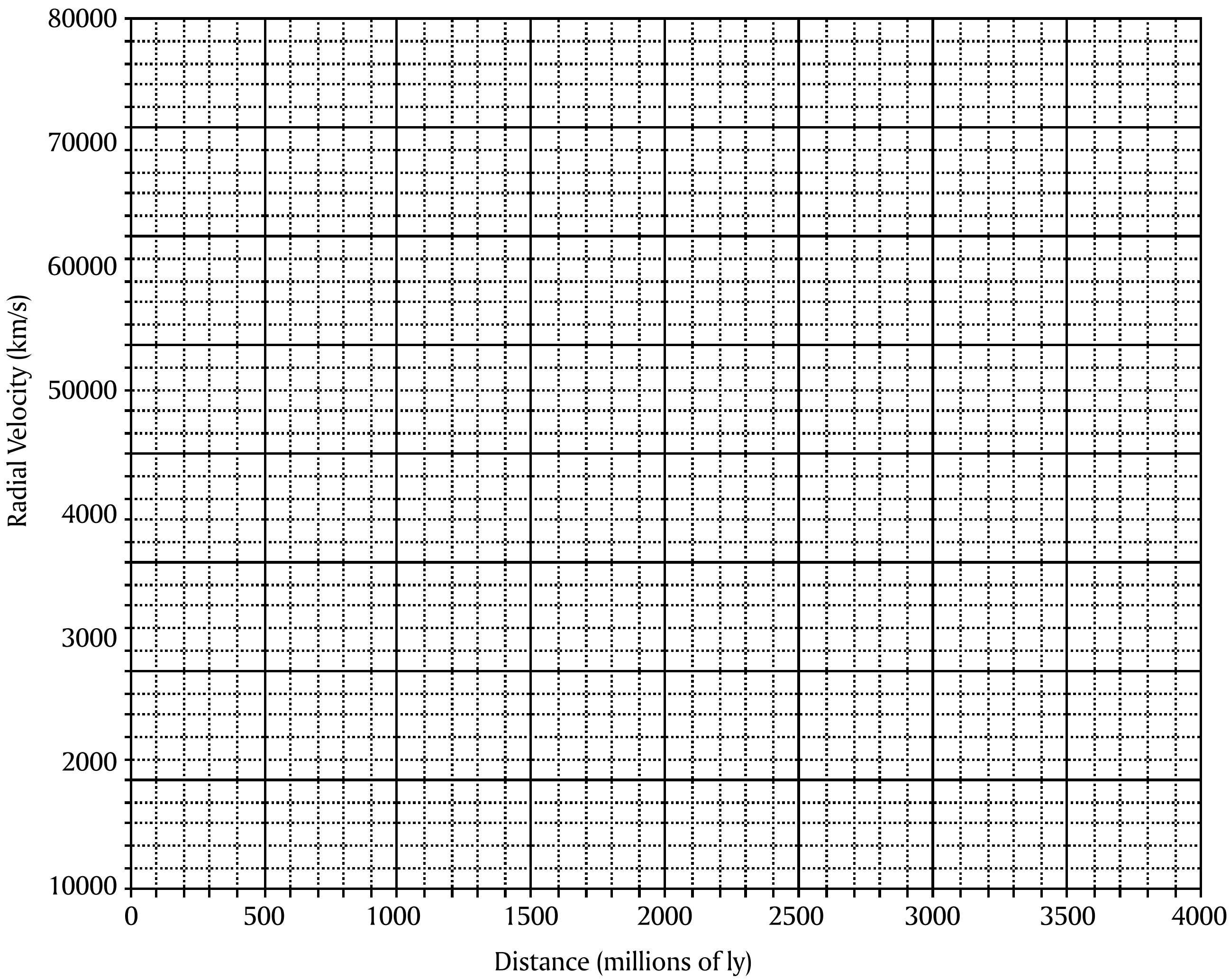


Table 2. Selected Galaxies in Clusters of Galaxies

Galaxy in	Distance (Mly)	Radial Velocity (km/s)
Virgo cluster	63	1210
Ursa Major cluster	990	15000
Corona Borealis cluster	1440	21600
Bootes cluster	2740	39300
Hydra cluster	3960	61200

Graph Template 2. Hubble's Law



Reflection

How well has your cooperative learning group been functioning? Consider and reach a consensus on each of the following:

1) Acceptance and trust
2) Clear communication
3) Support of individuals and ideas
4) Constructive criticism and resolution of conflicts.

Has one person been dominating the thinking of the group? If so, how can this be avoided in the future?

Focused Discussion: Cosmic Background Radiation (Light & Spectra)

Leader:	Reporter:	
Skeptic:	Skeptic:	Skeptic:

Purpose: To be able to identify and interpret physically the spectrum of the cosmic background radiation.
Prediction: What kind of continuous spectrum has a *well-defined* shape?

Procedure: A *spectrum* consists of light spread out over wavelength. Table 1 shows a series of measurements of the cosmic background radiation. (Note that the wavelength is given in millimeters.) The values are relative to the peak, so they measure *relative intensity*. Note that the relative intensities vary over the range of wavelengths; this indicates that the source is *not* emitting the same energy per second at each wavelength. Use the data from the table to plot a curve in the Graph Template. After you have plotted all the points, draw as smooth of a line as possible through them.

Table 1. Cosmic Background Radiation Spectrum

Wavelength (mm)	Relative Intensity
0.40	0.04
0.60	0.40
0.80	0.85
1.00	1.00
1.20	0.95
1.40	0.85
1.60	0.70
1.80	0.58
2.00	0.47
2.20	0.38
2.40	0.30
2.60	0.25
2.80	0.20
3.00	0.18

1. What kind of spectrum is this?

2. At what wavelength (in millimeters) does the spectrum peak?

3. What *one* physical property does this kind of emission depend upon?

Wien's law provides the relationship between the wavelength at which a Planck curve peaks and the temperature of a blackbody. It is

Temperature = 2.9 ÷ Peak Wavelength

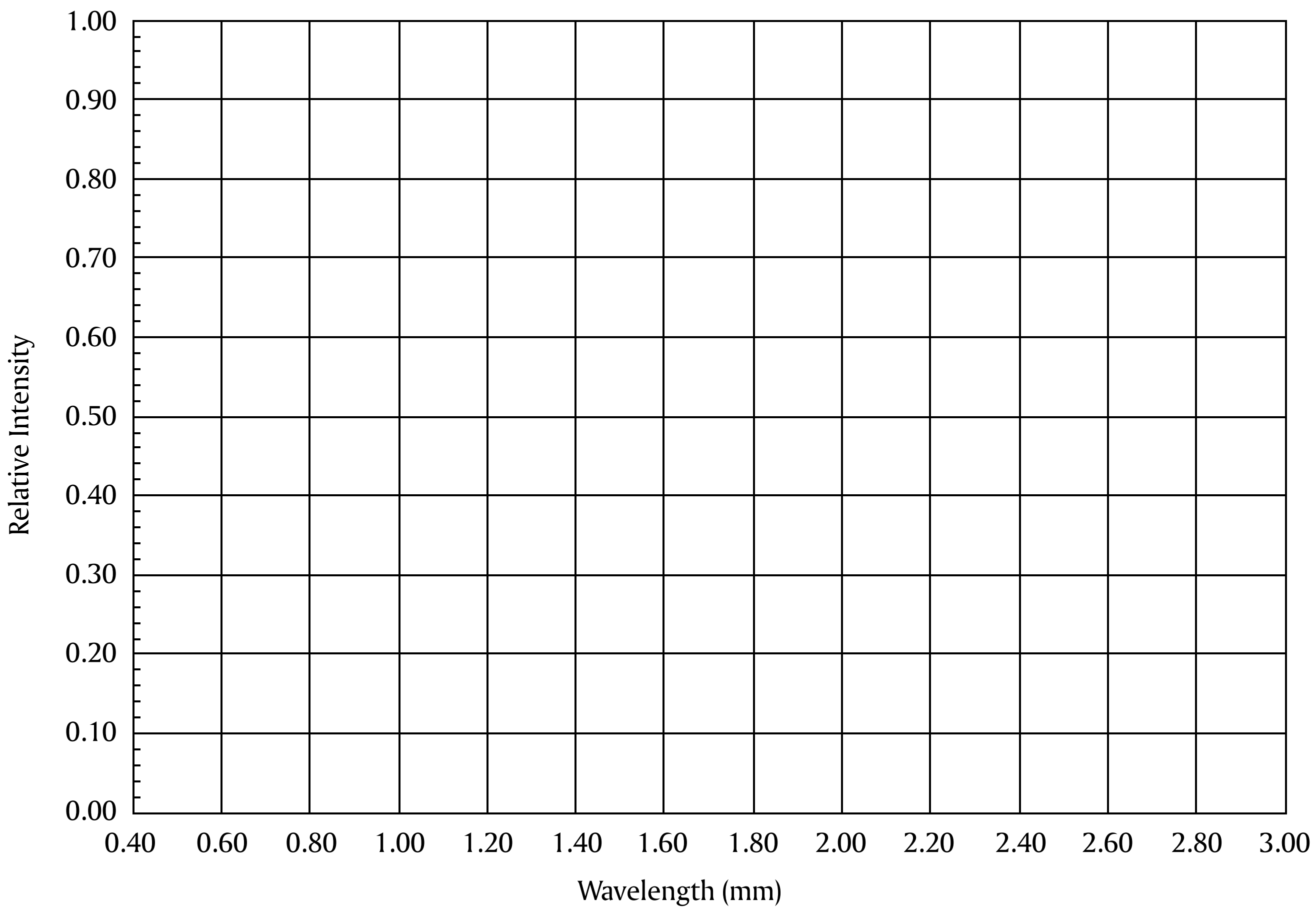
where the temperature is in kelvins if the peak wavelength is in millimeters.

4. Using your result from #2, calculate the temperature in kelvins of the cosmic background radiation.

Concept Extension

If the temperature were higher, how would your graph change?

Graph Template



Focused Discussion: Extraterrestrial Life—The Drake Equation (Scientific Models)

Leader: Reporter:

Skeptic: Skeptic: Skeptic:

Purpose: To estimate the number of advanced civilizations in the Milky Way Galaxy.

Prediction: What is the one *essential* piece of information that you need to carry out this estimate?

Procedure: In this activity, you will use a relation proposed by Frank Drake in 1961 to estimate the number of advanced civilizations in the Milky Way Galaxy now. Though making this estimate may seem fantastical to you, the key point is that the process will help clarify the major issues and also show how speculation in science can be carried out in an analytical way.

Let the number of civilizations in the Galaxy at any one time be *Nic*. If *Ric* is the rate of formation of intelligent civilizations and *Lic* is their lifetime, then

$$Nic = RicLic$$

This relation may be broken down into more specific factors, loosely independent of one another:

$$Nic = R_* PpPeNePlPiLic$$

The meaning of each of these factors relates directly to important facets of cosmic evolution. R_* is the rate of star formation averaged over the age of the Galaxy; *Pp* is the probability that once a star has formed, it will possess planets. The next factor, *Pe,* is the probability that the star will shine long enough for life to form, and *Ne* is the number of planets in the region around the star with a suitable range of temperatures. *Pl* is the probability that a planet in a star's ecosphere will develop life, and *Pi* is the probability that biological evolution will ultimately lead to intelligent life. The final term, *Lic*, is the lifetime of this intelligent civilization.

Each of these factors requires that you choose a value and support your choice of that value. Note that the *P*-terms are probabilities that can have values from 0 to 1. None of them can be exactly zero, for that would mean that we are not here! Let's take each of the factors from left to right; as you do so, the quantities become more speculative! Your stance as pessimistic or optimistic can then strongly control your assignment of values. Your group will need to come to a consensus, even though some members may disagree widely on the "right" values.

R_*

Rate of star formation in the Galaxy now. Use a value of 10 per year; the range is about 1 to 100 per year.

Pp

Group value = ___________

Reasons for choice:

Pe

Group value = ___________

Reasons for choice:

Ne
Group value = ___________

Reasons for choice:

Pl
Group value = ___________

Reasons for choice:

Pi
Group value = ___________

Reasons for choice:

Almost there! Find an interim value for *Nic* by evaluating all your terms so far except for *Lic*

Nic = ______________

Lic

This is the tough one! What do you think will be the future of humankind? Poll each member of your group for ideas, and list three of them below:

Now tackle the issue of whether our technological development is typical of emerging technical civilizations. Are radio telescopes and nuclear weapons bound to develop together? If such a tie is avoided, does that still mean that a technical civilization will desire to communicate with others?

Group value = ________

Reasons for choice:

Now, the final value

Nic = ______________

Would you typify your result as pessimistic or optimistic (or in between!)?

Any final issues that your group thinks have NOT been resolved in your discussion? If so, write down one of them.