Project Haystack
The Search for Life in the Galaxy

SETI INSTITUTE™

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SETI Institute

Mountain View, California

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Scope and Sequence
Life in the Universe Curriculum

This scope and sequence is designed to describe the topics presented and the skills practiced in the Life in the Universe series curriculum as they relate to factors in the Drake Equation:

$$(N) = R_{*} \bullet f_p \bullet n_e \bullet f_l \bullet f_i \bullet \ _c \bullet L \bullet$$

In this equation, N is an estimate of the number of detectable civilizations in the Milky Way Galaxy that have developed the ability to communicate over interstellar distances. If a civilization were to have such ability, it most probably arose from the *desire* to communicate. It follows that such a civilization is probably trying to communicate, just as we are trying. This was the rationale for formulating the Drake Equation, and this is the rationale for the search for extraterrestrial life.

Factors in the Drake Equation	Related Topics
R_{*} = the number of new stars suitable for the origin and evolution of intelligent life that are formed in the Milky way Galaxy each year	*Astronomy, Chemistry, Mathematics*
f_p = the fraction of these stars that are formed with planetary systems	*Astronomy, Mathematics, Physics*
n_e = the average number of planets in each system that can sustain life	*Astronomy, Biology, Chemistry, Ecology, Physics*
f_l = the fraction of life-sustaining planets on which life actually begins	*Astronomy, Biology, Chemistry, Ecology, Geology, Meteorology*
f_j = the fraction of life-sustaining planets on which intelligent life evolves	*Anthropology, Biology, Geology, Meteorology, Paleontology*
f_c = the fraction of systems of intelligent creatures that develop the technological means and the will to communicate over interstellar distances	*Language Arts, Mathematics, Physics, Social Sciences*
L = the average lifetime of such civilizations in a detectable state	*Astronomy, History, Mathematics, Paleontology, Social Sciences*

Life in the Universe Series	Topics	Skills
Grades 3-4 *The Science Detectives*	• Art • Astronomy • Chemistry • Language Arts • Mathematics • Physics	• Attribute Recognition • Cooperative Learning • Mapping • Measurement • Problem Solving • Scientific Process
Grades 5-6 *The Evolution of a Planetary System*	• Art • Astronomy • Biology • Ecology • Geography • Geology • Language Arts • Mathematics • Meteorology • Social Sciences	• Problem Solving • Cooperative Learning • Scientific Processes • Mapping • Measurement • Inductive Reasoning • Graphing
Grades 5-6 *How Might Life Evolve on Other Worlds?*	• Art • Biology • Chemistry • Ecology • Language Arts • Mathematics • Paleontology • Social Sciences	• Classification • Inductive Reasoning • Laboratory Techniques • Mapping • Microscope Use • Scientific Process • Cooperative Learning
Grades 5-6 *The Rise of Intelligence and Culture*	• Anthropology • Art • Biology • Ecology • Geography • Geology • Language Arts • Mathematics • Social Sciences • Zoology	• Cooperative Learning • Design • Graphing • Inductive Reasoning • Laboratory Technique • Microscope Use • Problem Solving • Scientific Process
Grades 7-8 *Life: Here? There? Elsewhere? The Search for Life on Venus and Mars*	• Art • Astronomy • Biology • Chemistry • Comparative Planetology • Ecology • Engineering • Language Arts • Mathematics • Physics • Zoology	• Cooperative Learning • Design • Graphing • Inductive Reasoning • Laboratory Techniques • Microscope Use • Problem Solving • Scientific Process
Grades 8-9 *Project Haystack: The Search for Life in the Galaxy*	• Anthropology • Art • Astronomy • Biology • Chemistry • Ecology • Geometry • Language Arts • Mathematics • Physics • Trigonometry • Zoology	• Cooperative Learning • Design • Graphing • Inductive Reasoning • Laboratory Technique • Microscope Use • Problem Solving • Scientific Process

Foreword

Carl Sagan, Cornell University
1934-1996

The possibility of life on other worlds is one of enormous fascination–and properly so. The fact that it's such a persistent and popular theme in books, television, motion pictures, and computer programs must tell us something. But extraterrestrial life has not yet been found–not in the real world, anyway. Through spacecraft to other planets and large radio telescopes to see if anyone is sending us a message, the human species is just beginning a serious search.

To understand the prospects, you need to understand something about the evolution of stars, the number and distribution of stars, whether other stars have planets, what planetary environments are like and which ones are congenial for life. Also required are an understanding of the chemistry of organic matter–the stuff of life, at least on this world; laboratory simulations of how organic molecules were made in the early history of Earth and on other worlds; and the chemistry of life on Earth and what it can tell us about the origins of life. Include as well the fossil record and the evolutionary process; how humans first evolved; and the events that led to our present technological civilization without which we'd have no chance at all of understanding and little chance of detecting extraterrestrial life. Every time I make such a list, I'm impressed about how many different sciences are relevant to the search for extraterrestrial life.

All of this implies that extraterrestrial life is an excellent way of teaching science. There's a built-in interest, encouraged by the vast engine of the media, and there's a way to use the subject to approach virtually any scientific topic, especially many of the most fundamental ones. In 1966, the Soviet astrophysicist I. S. Shklovskii and I published a book called *Intelligent Life in the Universe,* which we thought of as an introduction to the subject for a general audience. What surprised me was how many college courses in science found the book useful. Since then, there have been many books on the subject, but none really designed for school curricula.

These course guides on life in the universe fill that need. I wish my children were being taught this curriculum in school. I enthusiastically recommend them.

Carl Sagan

Preface

Astronomers who search for radio signals from an extraterrestrial civilization refer to the vast cosmos as a "haystack" within which they are trying to find the proverbial "needle"–any sign of intelligent life. In *Project Haystack,* students explore the vast celestial haystack in search of just such a needle. This is the second of two guides designed for grades 8 and 9. The first, entitled *Life: Here? There? Elsewhere? The Search for Life on Venus and Mars,* engages students in a search for life within the solar system. In *Life: Here? There? Elsewhere?* students learn that "life" is not always intelligent, nor is it always easily recognizable. In fact, *Life: Here? There? Elsewhere?* concentrates on a search for microbial life. Thus, students might form a more complete perspective of the process of searching for extraterrestrial life if they complete *Project Haystack* after the first guide. However, *Life: Here? There? Elsewhere?* is not a prerequisite for *Project Haystack;* the teaching order can be reversed. Regardless, each guide can be used independently of the other.

In *Project Haystack,* students move beyond our planetary system and look to other stars for radio signals that might indicate intelligent life. This is the search that has been undertaken by the research staff at the SETI Institute (Search for Extraterrestrial Intelligence). Making contact across such large distances presents interesting challenges and limitations, which are the focus of *Project Haystack.*

Project Haystack presents engaging scenarios that depict various aspects of the SETI search. Students conduct hands-on and "minds-on" activities while exploring what it means to send and receive a message across interstellar distances. They explore and map the vast reaches of the Milky Way Galaxy. They build, test, and experiment with spectroscopes and a radio receiver, learning the importance of these tools to astronomers and their applications in the search. They are challenged to find a simulated signal that has been sent through space from somewhere in the cosmic haystack; after detecting this signal with a "radio telescope" here on Earth, they must decipher its meaning. In a final mission, students imagine the impact on our culture of receiving a message from an extraterrestrial intelligence by role-playing various special interests at a mock conference.

Each step of the way, students work in cooperative teams and build on the knowledge of previous missions to help them understand the rich complexity of searching for and receiving interstellar radio signals.

In summary, *Project Haystack* is an investigation of questions: Are there intelligent civilizations out there? Where might they be? How would they communicate with us and what would they say? How should we respond? Students should finish this unit with a sense of enthusiasm and a wealth of new knowledge, and perhaps with the thought that we are not alone in the universe after all.

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Introduction

Learning Objectives

Concepts

Through the activities in *Project Haystack,* students will learn about and be able to apply concepts in the following areas:

- There are inherent difficulties in the processes of sending and receiving nonverbal messages, in attempting to communicate with an intelligence that does not speak any known language.
- There are inherent difficulties in the processes of sending and receiving messages across the vast distances of interstellar space.
- Distances to objects can be measured indirectly, and this applies to calculating interstellar distances as well.
- The scale and structure of our immediate stellar neighborhood and the Milky Way Galaxy can be envisioned by the construction of models.
- There are approximately 10^{22} stars in the universe.
- Spectroscopes can be used to investigate light and the chemical elements that make up the matter of the universe, and to understand the electromagnetic spectrum.
- The chemical elements of an astronomical object can be identified by analyzing its spectrum.
- Other solar systems that might be home to evolved intelligent life can be detected indirectly through orbital motions of stars about the center of mass of binary systems.
- The Doppler effect, or the red-shift or blue-shift of a star, light as it recedes from or approaches Earth can be used to measure the star's motion.
- A radio receiver can be used to detect unseen electromagnetic radiation.
- A radio signal can be separated from background noise.
- Certain planets are more likely to have life because of the type of star they orbit.

Skills

The activities are also designed to help students develop the following abilities:

- Working in teams to accomplish goals.
- Using models and laboratory simulations to understand scientific concepts.
- Conducting experiments.
- Collecting, analyzing, and interpreting data.
- Learning to build equipment that extends the range of human perception.
- Understanding that human values must always be considered in scientific investigations.

About Inquiry

It is strongly suggested that the process of inquiry be given the highest priority. These are not simply a series of exercises where students do their best and then the teacher gives them the "real" answer.

There are no definitive answers to such grand questions as:

- How many stars are out there and how would we know?
- How many of these stars might have planetary systems and what evidence do we have that other planets truly exist?
- What conditions are needed for life to begin, and how can we determine, at a distance, if those conditions exist on another planet?
- How might we detect a civilization on a planet orbiting a distant star? What technology might we use to detect this civilization?
- What might the radio signal from a galactic civilization look like, and how could we understand and interpret it?
- Where might we look in our galaxy for intelligent life?
- Should we "send a signal" and hope to be detected by extraterrestrial intelligent beings, or should we "listen" for a radio signal from them? If we choose to "send a signal," what should we say?
- If life is found on another planet, how could the discovery affect our civilization?

In this field, questions often do not have definite yes or no answers. Therefore, all questions are good questions, and all guesses can be treated as possible answers. "How do we know?" and "How can we find out?" are the most important questions of all.

Timeline and Planning Guide

Some missions will need to be taught over several class periods, and some may take longer the first time they are presented. Each mission subdivision is designed to take one class period. Teachers may want to take two or even three class periods with some mission subdivisions. Time estimates are based on feedback from teachers during trial tests and do not include time required to read this guide or shop for materials. Actual times will depend on the particular team of students and the time spent extending these missions.

Mission 1: SETI Wants You!

Mission 1.1: Students are introduced to SETI and to their mission: to determine the point of origin and the meaning of a signal from outer space.

Mission 2: A Message from Earth

Mission 2.1: Students learn about the two *Voyager* spacecraft and the messages they carried. They choose 10 magazine pictures to create their own collage messages depicting Earth and the human experience, and send their messages into "outer space" (in this case to another team of students).

Mission 2.2: Students receive a picture-message from an "unknown civilization" (another team of students) and try to deduce its meaning. They experience the difficulties of nonverbal communication, even among groups that share a common origin and culture.
Mission 2.3: Students see images similar to the messages put aboard the *Voyager* spacecraft. They learn who spoke for Earth, and decide whether the entire Earth was well represented.

Mission 3: Calculating Stellar Distances

Mission 3.1: Students learn about triangulation and measure the distance to a far away object in the school yard, such as a tree, without actually traveling to the tree.
Mission 3.2: Students discover the meaning of *parallax* and learn that triangulation can be used to measure the distance from Earth to a nearby star without actually going there.

Mission 4: Calculating Stellar Travel Time

Mission 4.1: Students consider traveling to the stars. Then they discover how long it would take to travel to Sirius using different modes of transportation, including a bicycle, and consider the logistics of physically carrying a message to the stars.

Mission 5: A Model of the Milky Way Galaxy

Mission 5.1: Students see images, then draw a diagram of our immediate cosmic neighborhood by plotting the locations of stars, nebulae, and globular star clusters. They learn how far *Voyager* has traveled, reinforcing the idea that physically carrying a message to the stars will take a long, long time–even to the nearest of them.
Mission 5.2: Students see a PowerPoint show and then make a model of the Milky Way galaxy to show the size of their cosmic neighborhood diagram in comparison. This diagram will help them to see the limited extent of SETI's Targeted Search in relation to the Milky Way galaxy.

Mission 6: The Chemical Elements in Stars

Mission 6.1: Students discover that some of the same chemical elements found in life on Earth are also in the stars and the diffuse clouds of nebulae between them. They use prisms to gain an understanding of the visible electromagnetic spectrum.
Mission 6.2: Students build and use their own spectroscopes to investigate different light sources in the classroom to see what types of emission spectra they produce.
Mission 6.3: Students use their spectroscopes (and/or commercial spectroscopes) to examine the emission spectra of pure elements.
Mission 6.4: Students interpret the spectral emission patterns of stars, confirming the presence of some chemical elements that make up life on Earth, and that are necessary for life to occur.

Mission 7: Expecting Other Planetary Systems

Mission 7.1: Students speculate on the likelihood of planetary systems forming elsewhere in the cosmos. Then they investigate motions about the center of mass of star systems as a possible way to detect planets that are revolving around other suns.
Mission 7.2: Using the Doppler Effect's red shift and blue shift, students investigate "wobbles" of stars that may indicate the presence of planets.

Mission 8: Building a Radio Receiver

Mission 8.1: Students work alone, or in teams, to build their own radio receivers. They learn that both radio signals and radio "noise" (static) are always present, but neither is detectable without the proper equipment. They relate this discovery to SETI's use of radio telescopes to search for an electromagnetic signal from an extraterrestrial intelligence. This mission may take up to three class periods.

Mission 9: Separating a Radio Signal from "Noise"

Mission 9.1: Students discover the difficulties in separating radio signals from the static that always accompanies them. They pick signal patterns out of backgrounds of static and learn about the need for computational assistance in pattern recognition.

Mission 10: The Search for Extraterrestrial Intelligence

Mission 10.1: Students choose three likely stars from a list of 16 to scan with a simulated radio telescope, looking for an extraterrestrial signal. With application of their skills, and a little luck, most students will find the simulated signal.
Mission 10.2: Has a real signal arrived from a distant star system? In this simulation, students pool their efforts and narrow in on three apparent signals. They look again to verify these possible signals. They discover that a signal *has* arrived from a distant star system.

Mission 11: Do You Get the Message?

Mission 11.1: The simulated signal has arrived, but what does it say? Students learn about binary systems and cryptography, and decode the message from the stars.
Mission 11.2: Students decide how to answer the message from the stars: What do we say to them?

Mission 12: Cultural Aspects of the Search for Extraterrestrial Intelligence (CASETI)

Mission 12.1: Students see images of SETI researcher Jill Tarter talking about CASETI. Students hold a mock CASETI Conference of their own to consider their fears and concerns about the detection of an extraterrestrial intelligence.
Mission 12.2: Students produce recommendations in a "CASETI Final Report" that suggest ways in which all of humanity's responses to the discovery can be inclusive, positive, and effective.

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Mission 1
SETI Wants You!

Could *You* Find the Needle in the Celestial Haystack?

Overview

It may be difficult to know exactly where to begin a unit that deals with such a grandiose topic as the search for some sign of extraterrestrial life, the search for a “needle” in the cosmic “haystack”! In this mission, students are introduced to the SETI Institute. They learn about SETI scientists: what they do, and what drives their research. Student groups brainstorm ideas about how we (on Earth) would be affected if we actually did receive a signal from intelligent extraterrestrials. Student groups consider how we would go about communicating with the extraterrestrials, if we chose to do so. Students also learn that they will be “receiving” a simulated extraterrestrial message in a later mission–they will decipher and interpret this message after they decide which star system it has come from.

Mission 1.1
Materials

For Each Team

- Butcher paper, or chart paper, pr poster paper
- Markers

Getting Ready

1. Cut a three-foot length of butcher paper for each team (four to five students each).

Classroom Action

1. Discussion. Divide the class into teams of four to five students each. Introduce *Project Haystack,* beginning with your overall impressions of the SETI curriculum as a whole.

   Students express their opinions and philosophies regarding the possibility of life in the universe. Undoubtedly, many misconceptions that students have about the scale and structure of the Milky Way galaxy, and the universe itself, will come out in the ensuing discussion. They may or may not realize that the size of our galaxy and the distances to even the nearby stars present formidable barriers to interstellar communication. Tell students that they will be “receiving” a simulated extraterrestrial message in a later mission. They will decipher and interpret this message after they determine which star system it has come from. Ask for feedback from students regarding what they think about these tasks.

2. Activity. Pass out a piece of butcher paper (or chart paper or poster paper) and markers to each team of students. Teams divide their butcher paper into two columns. In the left column, they should list the ways that we, here on Earth, would be affected if a communication really were received from an extraterrestrial intelligence. Possible answers might include people being afraid of extraterrestrials, the extraterrestrials helping us solve our environmental problems, the extraterrestrials offering us new technology that we haven't yet thought of, and so on. Encourage free thinking. There are no “right” or “wrong” answers. In the other column of the butcher paper, have students list the ways that they would try to communicate with the extraterrestrials that sent the signal. Their thinking might produce such ideas as communicating by radio from a space shuttle, sending a message on a space probe, using television or radio waves to broadcast a message, and a host of other things. These initial lists will become an invaluable learning-assessment tool upon completion of this unit.

3. Oral Report. One student from each group reports to the class the ideas that their group came up with. Remind the class that all ideas and feedback have value, and that no answer can be considered wrong. So as not to cause confusion, have all the left-hand columns presented first, then all the right-hand columns. Encourage students from all groups to offer comments during these reports.

4. Display. Display or save all the butcher-paper lists so that students can look at them when all their missions have been completed. This is important because students will very likely find that they have progressed considerably in their thinking and reasoning.

Going Further

Activity: UFOs–Who Can You Believe?

You may wish to avoid discussing UFOs and “little green men,” but students are very likely to bring them up. Be prepared. Some surveys have shown that 50 percent of the U.S. population believes that UFOs are real, and that space aliens have already landed. One of the most common questions that SETI researchers are asked is: “Why are you spending so much money looking for extraterrestrials when they are already here?” And this question is often asked seriously. The obvious answer is: “Because no extraterrestrials have landed, nor have any extraterrestrials communicated in any way.” Despite many claims of UFO sightings, no credible evidence for an extraterrestrial origin of UFOs has ever been brought forth.

Ask students what would constitute credible evidence. *(A piece of a UFO, for example, that could be analyzed in the lab.)*

Students can bring in various tabloid articles about space aliens. Spend some time analyzing each claim, discussing the reliability of photographic evidence. Students should learn to be skeptical.

Activity: A Letter to Yourself

Students write a summary of their thoughts about this mission, perhaps noting what they think are the most and least promising methods of communicating with extraterrestrials, and what they themselves would want to say. They seal up their summaries in envelopes, addressed to themselves five weeks into the future. When this entire unit is completed, have students open their initial summaries and write a conclusion, taking into account those things that they correctly and incorrectly surmised regarding communication across interstellar space.

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Mission 2
A Message from Earth

Voyager Carries Our Message to the Stars

Notes

In Mission 1, students learned that SETI scientists are trying to detect a message from an extraterrestrial intelligence that might exist beyond our solar system. Students learned that, even after decades of space exploration, we have not found any evidence of life beyond Earth. Yet we are still "listening," i.e. collecting data, and we continue to explore Mars for evidence that life once existed elsewhere in our solar system. But have we ever attempted to send our message out to distant ETs?

Overview

In Mission 2.1, students are introduced to the two *Voyager* spacecraft and their on-board messages. They select 10 pictures from magazines to create collage messages depicting the human experience and Earth. In Mission 2.2, students exchange these collage messages with one another and try to understand them. In Mission 2.3, students see a PowerPoint slide show similar to the message from Earth that was put aboard each *Voyager* spacecraft. In all, students consider: Who should speak for Earth?

Mission 2.1
Materials

For a Class of 30

- Data projector, computer PowerPoint file
- *Project Haystack* video "The Message Sent By *Voyager"* (Part 1) segment
- "The Message Sent By *Voyager"* (Part 1) PowerPoint script (page 28)
- Magazines with pictures
- Selection of different kinds of computer clip art
- *(optional)* Black paper decorated with "stars" for bulletin board

For Each Team

- Scissors
- Glue or tape
- Large sheet of butcher paper (*optional:* chart paper or poster paper)
- Notebook paper

For Each Student

- "Sending a Message to the Unknown" worksheet
- *(optional) "*Diagram of the *Voyager* Record" and "Description of the *Voyager* Record" sheets
- Pencil

Getting Ready

1. Plan ahead so that you have enough magazines for all your classes. A week or so before you begin, have students bring in old magazines with lots of pictures. Tell them that these will not be returned to them. Scan them for appropriate content, looking for a multicultural representation. The pictures should show all aspects of life on Earth: landscapes, people, wildlife, technology, and aspects of civilization. *Note: www.clipart*
2. Prepare a place in the classroom where messages to "intelligent extraterrestrial life" can be posted. Optionally, create a bulletin board covered with black paper decorated with stars to represent "deep space."
3. Copy the "Sending a Message to the Unknown" worksheet for each students, as well as the optional sheets "Diagram of the *Voyager* Record" and "Description of the *Voyager* Record" sheets, if they are to be used.
4. Set up the data projector. Go to the "The Message Sent By *Voyager"* (Part 1) PowerPoint file. Have the script handy.

Classroom Action

1. **PowerPoint Images of *Voyager*.** Play "The Message Sent By *Voyager"* (Part 1). A script has been provided that introduces the *Voyager* missions and attempts to send a message to the stars. It can be used as is to accompany "The Message Sent By *Voyager"* PowerPoint script or its information can be paraphrased.

   Hand out the sheets "Diagram of the *Voyager* Record" and "Description of the *Voyager",* if they will be used. You may wish to spend an entire class period discussing the complex message on the record cover.

   Because some of the science involved in the search for extraterrestrial intelligence may be too advanced for your class, present this idea to students: People are sometimes discouraged because it takes time and hard work to understand a message. But it took years to decode the Egyptian hieroglyphics. Extraterrestrials who find *Voyager* may have to work hard to understand its record. But they would be strongly motivated to do so (just as we would be if we received such an obvious message) and they would be greatly rewarded if they made the effort.

2. **Discussion.** Hand out the "Sending a Message to the Unknown" worksheet to each student. Tell students that they will have 30 minutes to put together a selection of only 10 magazine pictures that best describe Earth and its inhabitants; *suggest* that teams might first agree on the message they wish to convey.

The *Voyager* spacecraft had a limited amount of room for photographs, and the scientists had a limited amount of time to choose images. Those persons who were asked to choose the music and pictures to go on the *Voyager* record were only given six weeks to complete their task. Even more astounding is the fact that DVD and digital camera technology had not yet been invented, so the technical problem of putting pictures on a phonograph record also had to be dealt with. Giving students a limited amount of time to do this activity simulates the pressure on those persons who were asked to complete this Herculean task.

Tell students that their collections of pictures will become collage messages to be put aboard an imaginary space probe. This probe will fly by some nearby planets and moons, and then drift off into deep space in the same manner that the two *Voyager* (and *Pioneer)* spacecraft have done. Their picture collections must show the most important facts about being human because if the space probe ever is intercepted by intelligent life somewhere in the cosmos, these pictures will be all the extraterrestrials have for learning about us.

Teams should sequence their 10 pictures in any way they wish (*e.g.*, in a chronological order to provide an historical perspective) on butcher paper. The only rule is that they may not write anything on the butcher paper. Extraterrestrials cannot read English. Allow students to create and define symbols to use, such as numbers and scaling units. In fact, students may want to attempt to teach their extraterrestrial audience to read English. Let students use binary numbers using a scale set by the hydrogen atom, because this scheme is used on the *Voyager* record cover.

3. **Activity.** Divide the class into teams of three to four students each. Give each team a pair of scissors, a sheet of butcher paper, and glue or tape. Give each team a selection of different kinds of magazines (*e.g.*, natural history, teen, sports, auto, news, ethnic). *(This task can become quite difficult for students who cannot agree on which pictures to choose.)* Stress that individuals in teams should work cooperatively, with some give and take. Have teams make their collage messages.

   Team members write a brief paragraph on their "Sending a Message to the Unknown" worksheet stating the message that they are trying to convey with their pictures, and how they think an extraterrestrial would interpret their message. One team member should copy this paragraph to notebook paper. *(This notebook-paper copy will be hidden behind the collage message after it is completed; it should not be written onto the collage message itself.)* Team members write their names on the English message.

   At the end of the 30 minutes (be strict about the time limit-and give a 5-minute warning), teams fold up their notebook paper paragraphs, seal them shut with tape or glue, and attach them to their collage messages. The collage messages should be rolled up and sealed securely to the back of the collage with glue or tape. Collect the collage messages, or ask students to pin them to the bulletin board covered with black, star-filled paper.

4. **Homework.** Students complete the "Sending a Message to the Unknown" (page 28) worksheet in class or as homework.

Mission 2.2
Materials

For Each Team

- Collage messages from Mission 2.1
- *(optional)* Smart phones

For Each Student

- "Did You Get Our Message?" worksheet (page 39)
- Pencil

Getting Ready

1. If you will be doing the optional smart phone activity (below), allow students to use their own phones.

2. Copy the "Did You Get Our Message?" worksheet for each student.

Classroom Action

1. **Discussion.** Reassemble the class into their teams from Mission 2.1. Tell students that they will now play the roles of extraterrestrials who have intercepted a spacecraft carrying some sort of message–each team will now receive a collage message from another team. If you have more than one class, perhaps exchange collage messages between classes. Hand out the collage messages or have student teams "intercept" a collage message from a "deep space" bulletin board. Each team's challenge is to see what kind of sense (if any) they can make of their message.

2. **Activity.** If you will be using tape recorders, go to step 3 below. Hand out the "Did You Get Our Message?" worksheet to each student. Teams should now break the first seal and unroll their collage message, but they must not open the sealed notebook-paper paragraph yet.

   Teams must put themselves in the place of the intelligent life that has found the collage message and attempt to figure it out based only upon the pictures. Remind students that they know nothing about Earth. They must decide what the collage message is trying to convey. Ask students to answer the questions on their "Did You Get Our Message?" worksheet as they determine this. *(Note that this worksheet does not have a teacher's key because student responses will vary; accept all reasonable attempts.)* Next, teams should break the seal on the notebook-paper paragraphs and read the written description to see how their interpretation compares.

3. **Optional Activity with Smart Phones**. For recording first impressions, use a smart phone for each team. Teams use smart phones to record when they open the first seals and begin

talking about what they think the collage message means. The voice memos records their spontaneous discoveries, first ideas, and first impressions. At the end of 10 minutes (or less), the smart phones should be turned off. Teams should then break the seal on the notebook-paper paragraphs and read the accompanying written descriptions to see how their interpretation compares. Have students answer the questions on their "Did You Get Our Message?" worksheet.

Choose one (or more) of the recordings at random and play it for the class. Ask the team that created the collage message to respond. Ask if they got across what they wanted? If not, what message did they wish to communicate?

4. **Discussion.** Did the extraterrestrials understand the messages or not? Students will find that there are problems in communication. Pose a few questions: Why do you think a breakdown in communication happened? What would you do differently to improve communication? How many of the messages got across? Take a quick class survey. Which messages were more successfully understood? Why were they understood? Which messages were too difficult? Why? How could the messages be improved? If you were able to repeat this exercise, could you send a clearer message?

   Would it be harder for true extraterrestrials to understand a message from Earth than for Earth students to understand a message sent by other Earth students? What effect does sharing a common culture have? What would it be like if students in the United States made and exchanged collage messages with students in other countries?

   What might we have in common with intelligent extraterrestrials? *(Try to steer the class toward unambiguous, universal concepts, such as mathematical operations, prime numbers, the structure of hydrogen and carbon atoms, or the properties of the electromagnetic spectrum. We have the physical universe in common, which provides a basis for communication. The extraterrestrials could also learn about engineering principals and materials used by humans by examining the* Voyager *spacecraft. Natural phenomena such as rocks, clouds, and oceans are likely to have extraterrestrial counterparts—water is necessary for life as we know it.)*

Mission 2.3
Materials

For a Class of 30

- Data projector, computer, PowerPoint file
- The *Project Haystack* PowerPoint: "The Message Sent By *Voyager"* (Part 2) PowerPoint
- "The Message Sent By *Voyager"* (Part 2) PowerPoint script (page 30)

For Each Student

- "Who Speaks for Earth?" worksheet (page 40)
- Pencil

Getting Ready

1. Copy the "Who Speaks for Earth?" worksheet for each student.

2. Just before the lesson, set up the data projector. Go to the "The Message Sent By *Voyager"* (Part 2) in the PowerPoint file. Have Part 2 of the script handy.

Classroom Action

1. **PowerPoint Images of *Voyager.*** Show the "The Message Sent By *Voyager"* (Part 2) segment. A script has been provided that introduces the *Voyager* missions and our attempts to send a message to the stars. It can be used as is to accompany "The Message Sent By *Voyager"* segment, or its information can be paraphrased. The PowerPoint file includes a representative sample of images similar to the 118 that were sent into space with *Voyager.*

2. **Discussion.** Tell students about the group of people who decided which pictures and which music went on the *Voyager* message. Encourage students to talk about this decision process. The *Voyager* group didn't do it all by themselves–they contacted wise people to get ideas about what should go on the message. Invite students to brainstorm who could best put together the perfect message. As a class, create a list of people to whom students could write (or telephone) for ideas. Student lists can include people such as grandmothers too.

3. **Activity.** Hand out the "Who Speaks for Earth?" worksheet to each student. Students complete their worksheet in class or as homework. *(Note that this worksheet does not have a teacher's key because student responses will vary; accept all reasonable attempts.)*

Going Further

Activity: Who Am I?

Ask students to assemble picture collages of their lives that could tell a stranger about who they are and what is important to them. Their collages might include pictures of their hobbies, their heroes, their extracurricular activities, their family, and much else. Limit collages to 10 pictures. Ask students to share their collages before the class.

Multidisciplinary Studies: Social Science

Ask students who should "speak" for Earth when information is put onto a spacecraft that will be leaving our solar system to perhaps someday be intercepted by an intelligent civilization. This question could also be addressed in social science classes, and it might provide an opportunity to team up with another teacher. There are many historical-social issues here for students to ponder. Should we tell extraterrestrials about war, hunger, and disease?

Activity: Multilingual Greetings

Ask students to create an audiovisual or written greeting from their school that could be included in a message sent out of the solar system. For example, greetings could be given in all the languages that are represented at your school. This is a marvelous multicultural activity. Students may write and/or act out a greeting of their choice.

Activity: Writing a Letter

As a homework assignment, have students write a letter to someone (grandparent, community leader, artist, *etc*.) asking what they think a message from Earth should contain. Or, students can conduct a telephone interview and write up their findings. Students share their letters of reply or their write-ups with the class. If your school has the ability to log on to the Internet, link up your students with a class in another country.

Activity: A Message Through Time

People carve their "I was here" message in hundreds of ways during the brief time they inhabit Earth. People have put messages on walls of caves, in monuments, onto pages of books, in photographs, and elsewhere. Students can research the great monuments that are meant to send a message to our descendants. Mankind has always sent such messages in the form of tombs, inscriptions, works of literature, and so forth. Ask students to decide upon a suitable monument that will send a message about their school into the future. Students may also make a time-capsule message to be opened after five years–perhaps even bury the time capsule for future excavation.

Mission 2
A Message from Earth

Sending a Message to the Unknown—Teacher's Key

1. Answers will vary. Included might be cave drawings, monuments, time capsules, graffiti, books, CDs, DVDs, PowerPoint files, Stonehenge, and so on.

2. Photos, movies, books, carving your name into a tree, and so on.

3. 1977.

4. The Neptune flyby was in 1989; *Voyager* will get to the heliopause, the outer boundary of the solar system, around 2012.

5. To explore the outer gas giant planets, Jupiter, Saturn, Uranus and Neptune, their composition, rings, and moons.

6. A phonograph record that contained music and photographs depicting the history of life on Earth prior to 1977; instructions in graphic form on how to play the record; and a stylus for doing so.

7. Answers will vary.

Script for PowerPoint Images

"The Message Sent by *Voyager*" (Part 1)

Introduction

Image # 2.1: *Voyager* Spacecraft

On August 20, and again on September 5, *1970, Voyager* spacecrafts were launched from Earth. After exploring the solar system and researching the outer gas giant planets, the two spacecraft headed toward the stars. They are now beyond the orbit of Pluto and are traveling out into deep space. Almost as an afterthought, NASA attached a phonograph record with music and pictures to the *Voyager* spacecrafts before launch as a message to any extraterrestrial intelligence that might someday encounter the probes in space. The message is intended to tell the extraterrestrials about ourselves and our culture. The *Voyager* spacecraft and the two *Pioneer* spacecraft that have left our solar system probably will last longer than any other object built by human beings. In the cold, quiet darkness of outer space, they will not rust or fall apart. A collision with a drifting rock, ice ball, or comet nucleus would certainly smash them, but these objects are so rare in intersteller space that the *Voyagers* will almost certainly escape destruction. Over the ages, tiny drifting grains of dust will chip the paint, dull the surface, or inflict microscopic dents.

But, despite this slow sandpapering of their surfaces, the spacecraft will remain recognizable as machines from an intelligent civilization for several billion years.

The *Voyager* will never land on another planet. If, billions of years from now, one of them enters another planetary system and is dragged down by gravity to the surface of a planet, the spacecraft will burn up as it drops through the atmosphere. The only way these messages will ever be found is for an extraterrestrial spaceship to detect and recover the *Voyager* in space. Today, we will see images from the *Voyager* spacecraft. A total of 118 images were included on the original record.

Image # 2.2: *Voyager* Record Cover

This is the *Voyager* spacecraft as it would appear if it were well-illuminated in outer space. An extraterrestrial spacecraft approaching *Voyager* a billion years from now and shining a great spotlight upon it would see something like this, although the spacecraft very likely would have a number of dents and scratches. It is not a huge machine. The big antenna is only about two meters in diameter.

If you were a scientist from an extraterrestrial civilization, could you guess what it is and what it does, just by looking at it? Could it be a weapon? Are there extraterrestrials on board? What can be said about its creators and their civilization?

The message to extraterrestrials is on a gold coated aluminum phonograph record in a gold coated aluminum cover on the outside of the central instrument bay. There are some scientific symbols etched on this cover. If you were a scientist from an extraterrestrial civilization, could you understand what these symbols mean? Even if you cannot decipher the individual images, can you deduce what they must mean?

The scientific symbols that are etched on the cover include instructions for playing the record. A cartridge and stylus illustrated on the cover are neatly tucked into the spacecraft. The record is ready to play, although it is necessary to explain to the extraterrestrials which direction the phonograph rotates and the fact that the stylus is played from the outside of the record to the inside. It contains 118 photographs of Earth, humans, and civilization; almost 90 minutes of music; an evolutionary audio essay on the “Sounds of Earth”; and greetings in almost 60 human languages. There are even salutations from the President of the United States and the Secretary General of the United Nations, and the songs of humpback whales.

Image # 2.3: School of Fish with Human Diver

One of the *Voyager* pictures shows a diver with fish, and it resembles this picture. If you were a scientist from an extraterrestrial civilization, you might look at this image and conclude: “Here is a creature with appendages that flatten out into large structures at the ends. It is crawling or running. It seems that the creature is falling apart with pieces flying away from it in all directions.” Why is this description *not* totally ridiculous from the point of view of other intelligent life? What is intended to be communicated? What is the main message of Earth people? Why was a photograph like this one included on the *Voyager* spacecraft?

This is what the people who created the message were trying to communicate: The most direct means of showing the underwater world is to have a diver present. The air bubbles rising from the diver show clearly that this is an aqueous environment. The diver also shows that human beings are interested in exploring and adapting to different environments. There are potential problems in trying to communicate with extraterrestrials using pictures.

Stop and Assess "The Message Sent By *Voyager"*

1. Back up and take a second look at various images if students want to study them.

2. Ask: Do you think that the scientists' message will ever be received by anyone? If so, will it be understood by any other intelligent life form that may encounter *Voyager?*

3. Ask: Can *you* make a message using only pictures that someone else will be able to understand?

Script for PowerPoint Images

"The Message Sent By *Voyager"* (Part 2)

Introduction

Humans have sent a message about themselves into space beyond our solar system in hopes that there might be other intelligent life with whom we could communicate. Even though it is highly improbable that a spacecraft carrying a message from Earth would ever be intercepted and the message discovered, in our need to communicate something about ourselves we have made such a message, attached it to the *Voyager* spacecrafts, and sent them away. The images you see today are similar to those carried on board the *Voyagers* on their journeys to the stars.

Image # 2.4: Solar Spectrum

The *Voyager* record includes a spectrum of our star, the Sun, as a key to the colors in the other images on the record. Extraterrestrial astronomers would be able to determine the colors emitted by our Sun, and use that information to figure out the colors for the other images.

Image # 2.5: The Planet Earth

Extraterrestrial beings will recognize this as a planet, even though they have never seen it before. Other solar systems should have giant gaseous planets like Jupiter and Saturn, barren rocky balls like Mercury, and perhaps even beautiful blue water-covered worlds like our Earth. This photograph provides a reference point for the pictures that follow.

Image # 2.6: Closer to the Surface of Earth

Closer to the surface of our blue planet, another color photograph shows more details of the planet we live on.

Image # 2.7: Human Anatomy

Several pictures that emphasize human anatomy were sent on *Voyager.* This drawing shows the silhouettes of a man and a woman, and a view of a fetus developing inside the woman's body. Male and female labels show that the two beings are different; a scale shows their size, and the label "20y" shows their ages. An extraterrestrial must learn the meaning of "20y" from other information on the record.

Image # 2.8: Nursing Mother

Another *Voyager* photograph shows a picture like this one, a mother nursing her infant. The picture shows a special relationship between human women and children, comparable to that shown in the earlier diagram of a man with a pregnant woman.

Image # 2.9: A Family

One of the *Voyager's* images is a photograph showing a father and his child. This photograph, not included on the spacecraft, shows the feature that the *Voyager* images tries to convey. To human beings, we see the pride of parenthood. To an extraterrestrial, the photograph shows human age differences and many details: ears, fingers, teeth, and eyes. The direction in which the people are looking provide clues that eyes are organs of vision and are used for primary detection and examination of objects.

Image # 2.10: Group of Children

One of the *Voyager* images is a photograph like this one, showing young people of several racial types and nations. The picture illustrates hands and arms in different positions. Seeing human bodies from different directions like this should give the extraterrestrials a good sense of the proportion of the human form.

Image # 2.11: States

One *Voyager* image shows the rugged geology of the American Southwest in color. This photograph resembles the one on the *Voyagers.* Extraterrestrials may see some familiar geologic features in a picture like this.

Image # 2.12: Forest Scene

One *Voyager* image shows tree trunks and a secondary growth of bushes and shrubs. This gives a sense of the environment of a forest. Perhaps trees are rare in the universe. If extraterrestrials had no trees on their planet, this image might be very amazing to them.

Image # 2.13: Fallen Leaves

This photograph resembles one of the *Voyager's* in which leaves are changing colors and falling from trees. The *Voyager* image also shows people raking up the leaves. The *Voyager* photograph was one of about twenty images sent in color, and the fact that the leaves have changed from green to red and orange may lead extraterrestrials to understand that there are different photosynthetic pigments, and that the planet has seasonal variations in its vegetation.

Image # 2.14: A Tree in Winter

An image like this one, on the *Voyager* spacecraft, shows trees with small human figures to indicate size. In the *Voyager* image, an inset shows a snowflake. Water is a common substance throughout the galaxy, and its crystal form should be known and recognized, even by extraterrestrials. The *Voyager* image shows that things live naturally on Earth where temperatures fall below freezing.

Image # 2.15: Flowering Plants

One *Voyager* image shows a small, flowering plant next to a tree to demonstrate the different sizes of plants on Earth.

Image # 2.16: Human Diver and School of Fish

The clearest way to show an underwater scene is to have a human diver present. The air bubbles from the diving equipment provide evidence that the person and the fish are in water. The presence of the diver also shows that humans are interested in exploring and adapting to many environments on Earth.

Image # 2.17: Zoo Keeper and Chimpanzee

One of the *Voyager* photographs shows scientists with chimpanzees to offer a glimpse of animals that are quite similar to human beings in their appearance, yet quite different as well. Imagine looking at this photograph through the eyes of an extraterrestrial and wondering about the relationship between the larger being wearing clothes and the smaller one with only fur. Would you think the small one is the woman's baby? Why, or why not?

Image # 2.18: House Interior

Humans have constructed artificial environments in which to live and work. This photograph shows the interior of a house. Subsequent pictures show other human-made environments. What would an extraterrestrial think about the objects in this room?

Image # 2.19: A City by Night

On a larger scale, this photograph shows how we light our cities. This city could be from any industrial country on Earth. It represents global humanity, not just Western culture.

Image # 2.20: A Factory Interior

People manufacture many objects. Here, we see a bottling factory with humans present. Would extraterrestrials be able to interpret this photograph? Would technological extraterrestrials have factories?

Image # 2.21: Astronaut in Space

This image shows an astronaut floating in space near the Shuttle. The *Voyager* record included an image of James McDivitt on a space walk from a *Gemini* orbital flight. In both photographs, the man's hand is visible which reveals that this is a human figure.

Image # 2.22: Sunset

The *Voyager* photographs included a sunset to simply show how lovely our planet is. The color of the sky, the reddening of the light, and the presence of clouds reveal information about our atmosphere.

Stop and Assess "The Message Sent by *Voyager*"

1. Back up and take a second look at various images if students want to study them.

2. Ask students if they think that the scientists made good choices for images to send? Do you agree with the message that each image was meant to send? Do they work? Would other images have been better?

3. How did the collection of images differ from the collection that you assembled? How were they the same? What would you do differently if you had the same assignment again?

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Mission 2
A Message from Earth

Description of the *Voyager* Record

How to Play the Record

The cover of the *Voyager* record has instructions (in pictures) on how to play the record. In the upper left the picture shows that the enclosed needle should be placed on the outside of the record at the beginning of play. To describe how fast the record should turn scientists have written the time, 3.6 seconds, in binary notation around the edge of the record. Because the discoverers would not define time in seconds, the creators of the record described the time in terms of the fundamental transition of hydrogen (70 billionths of a second). Hydrogen is the most abundant element in the universe, so it is thought that if the discoverers had the technology to encounter *Voyager* they would be able to interpret this information on the record cover. Just below this there is a picture of the record and needle as viewed from the side. Below that is the binary representation of the time it takes to play the whole record (1-1/2 hours).

How to See the Images

The etchings on the right side of the cover show how to convert the information on the record into images. The typical signal of the beginning of a picture is depicted at the top followed by the time period for one image line. Each picture is made up of 512 vertical lines of information. The first image, a circle, is displayed to show the discoverers the correct height and width ratios of the images, and to reassure them that they have decoded the pictures correctly. If the extraterrestrial engineers had made a mistake, their image would look like an ellipse, rather than a circle.

Pulsars

The starlike image at the lower left is a map of nearby pulsars, giving their rotation periods in binary notation. Lines going off from these pulsars from the Earth are identified with labels that should provide an unambiguous description of our location. What is a pulsar? (*A pulsar is the shrunken corpse of a large star that burned all its fuel and then blew up in a gigantic explosion called a supernova.)* The pulsar, which is all that's left of the star, is so small it would fit in downtown New York City! But pulsars spin very rapidly, sometimes as much as a thousand times every second, and like lighthouse beacons, they broadcast light and radio waves into space. These broadcasts sound like the ticking of a clock, except that the ticks can be very fast (even a thousand ticks a second). There is only one location in space (Earth) from which the pulsars that "tick" at the rates shown can be seen by looking in the directions shown.

The Hydrogen Atom

The pair of circles describes the fundamental transition of hydrogen. The little dash between the circles indicates the unit time for deciphering the record, its images, and the pulsar map. It represents the time it takes for the hydrogen atom to switch between its two lowest energy states. This same cartoon can also represent a fundamental unit of length: 21 cm. This is the wavelength of the radio waves given off when the hydrogen atom makes this energy switch.

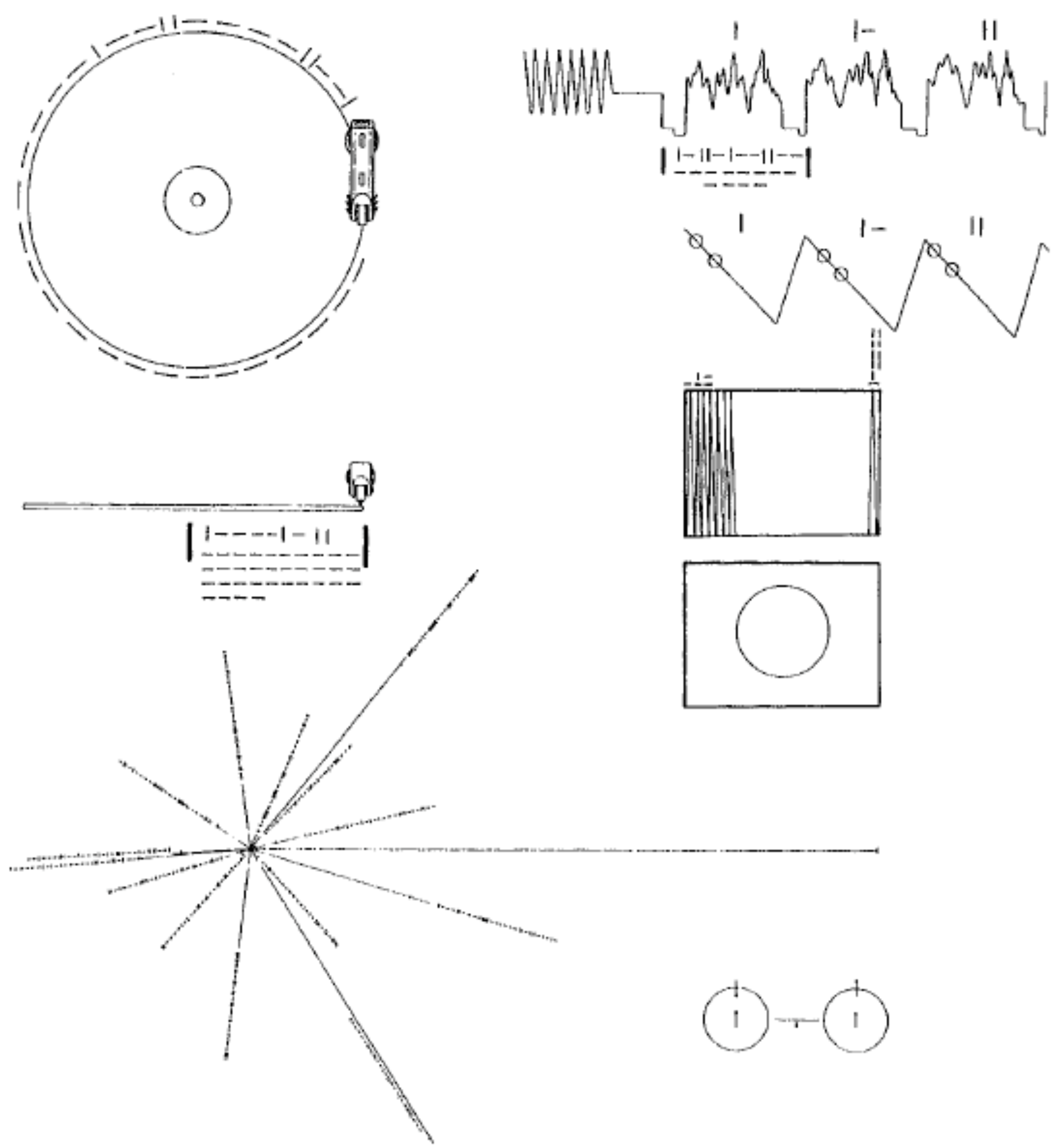
Radioactive Dating

Finally, the record cover contains a small disk of ultra-pure uranium 238 with very low radioactivity. This enables the discoverers to conduct radioactive decay analysis and determine the date that *Voyager* was launched. This date can also be cross-checked using the pulsar map. Because the period of a pulsar slows down slightly in time, there is only one time in history when the 14 pulsars would have had precisely the periods depicted in the map.

Mission 2
A Message from Earth

Diagram of the *Voyager* Record

Figure 2.1.



Mission 2
A Message from Earth

Sending a Message to the Unknown

Name:______________________________________ Date: ________________________

1. In what ways do you think our ancestors have tried to leave their "I was here" message for future generations to know what their lives were like?

2. How are we, who live today, leaving our "I was here" message for future generations?

3. In what years were the *Voyager* spacecraft launched? ___________________________

4. In what years did the *Voyager* spacecraft finish their survey of the outer planets?

____

5. What was the principal job of the *Voyager* spacecraft?

6. What was attached to the two *Voyager* spacecraft that would tell any intelligent life-forms that found it what life was like on Earth prior to 1977?

7. In the space provided below, write a paragraph that states what the message that you made with your group tries to convey, and how you think an extraterrestrial intelligence would interpret it. One person from your group needs to write this paragraph down on a separate sheet of notebook paper for use on the next class day.

SETI INSTITUTE

Mission 2
Message from Earth

Did You Get Our Message?

Name: ____ Date: ____________________

1. Open a picture-message that was created by another group and study it for a few minutes. Do not open the sealed written message yet. In the space below, write down what you think the team was trying to say.

2. Now break open the sealed message and read the other team's description of what they were trying to say with their set of pictures. How does what you wrote compare with what they were trying to convey with their pictures?

3. How could a clearer message be sent? What could be done to improve the chances of communicating with an extraterrestrial intelligence?

Mission 2
A Message from Earth

Who Speaks for Earth?

Name: ____ Date: ______________________

1. Do you think that the *Voyager* scientists accurately portrayed what Earth was like prior to 1977? Why or why not?

2. There were only a small handful of persons who selected what was going to be put on the *Voyager* spacecraft. Do you feel that the *Voyager* message represented all peoples of the world? Did it speak for all cultures, all races, all religions, and all nationalities? Is this even possible?

3. Who should speak for Earth when a project like this is done? In other words, if another *Voyager* craft were being sent out into the solar system and beyond today, who do you think should be chosen to put the pictures and music on it?

4. If you could choose one photo and one piece of music that could have been included on the record that was placed on the *Voyager* spacecraft, what would they have been? Why?

5. If you could remove one photo and one piece of music from those that were included on the record that was placed on the *Voyager* spacecraft, what would they be? Why?

Mission 3
Calculating Stellar Distances

How Far Away Are the Stars?

Notes

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

Overview

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

Mission 3.1
Materials

For a Class of 30

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

For Each Team

- 10 meters of string or fishing line
- 2 straws
- Cardboard
- Glue
- Scissors
- Tape
- Meter stick
- Overhead projector
- "Triangulation" transparency or PowerPoint slide (page 51)
- *(optional)* Calculators

For Each Student

- "Triangulation in the Field" worksheet (pages 53, 54)
- "Triangulation Data Analysis" worksheet (page 55)
- "Triangulation Questions" worksheet (page 56)
- "Making a Triangulation Tool" directions (pages 57)
- Pencil
- Sheets of plain white paper

Getting Ready

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

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

3. Set up the PowerPoint projector.

Classroom Action

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

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

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

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

Holding their protractors parallel to the ground, students will turn their protractors so that they can see the distant object through their straws. (See Triangulation transparency, Figure 3.4, page 54.) Students look at the distant object through their straws and simultaneously measure the angles formed to the distant object from positions A and B. Students will measure the angle by pulling the string tight so that there is no slack whatsoever, and then pinching the string against the protractor with the fingers to preserve the angle being measured. The data should be recorded on the "Triangulation in the Field" worksheet.

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

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

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

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

Mission 3.2
Materials

For a Class of 30

- 22 paper stars ("Star Master" sheet is provided, page 50)
- 22 pins or thumbtacks
- String
- Data projector, computer, PowerPoint file
- "Parallax As Viewed from Earth" transparency (page 49)
- *(optional)* Construction paper

For Each Team

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

For Each Student

- “Parallax” worksheet (page 59)
- Pencil

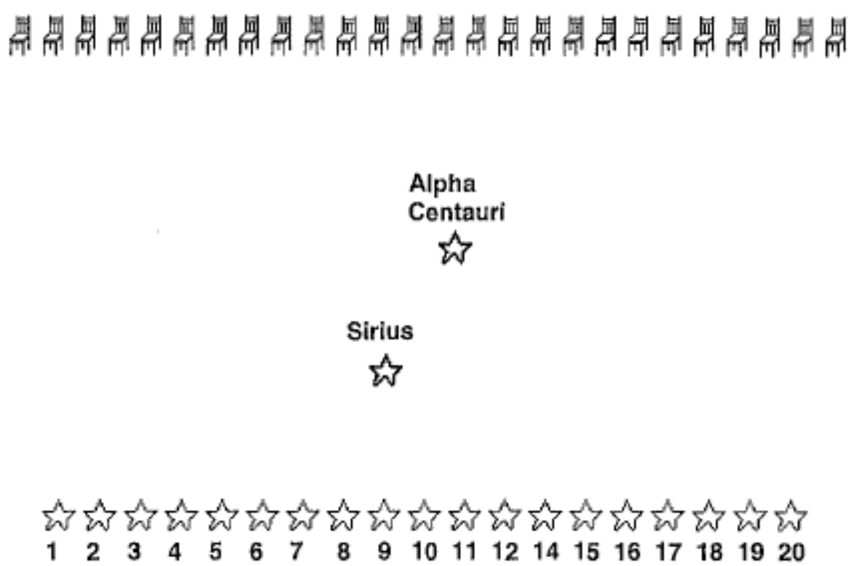
Getting Ready

1. Copy the “Parallax” worksheet for each student.

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

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

Figure 3.l–Room Set-up Diagram



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

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

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

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

Classroom Action

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

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

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

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

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

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

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

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

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

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

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

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

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

Going Further

Activity: Bigger Triangles

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

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Mission 3
Calculating Stellar Distances

Triangulation Questions–Teacher's Key

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

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

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

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

5. No answer required.

Mission 3
Calculating Stellar Distances

Parallax–Teacher's Key

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

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

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

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

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

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

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

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

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

Mission 3
Calculating Stellar Distances

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Parallax As Viewed from Earth–Transparency

Figure 3.2.

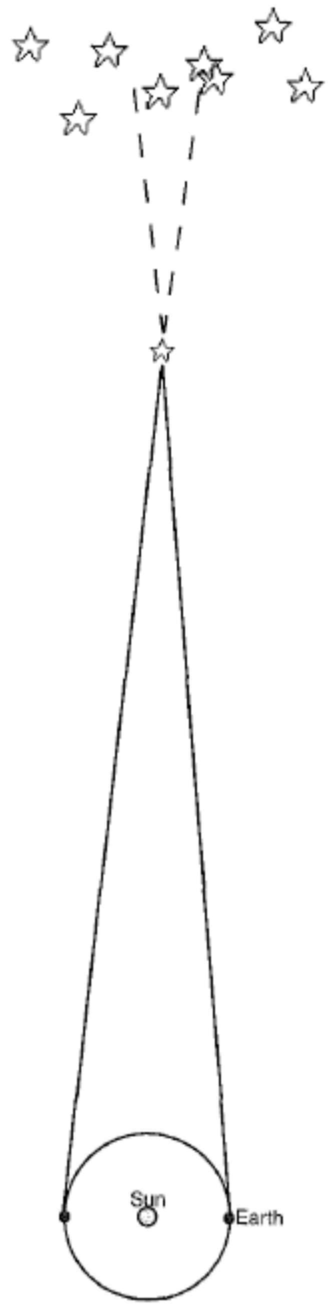
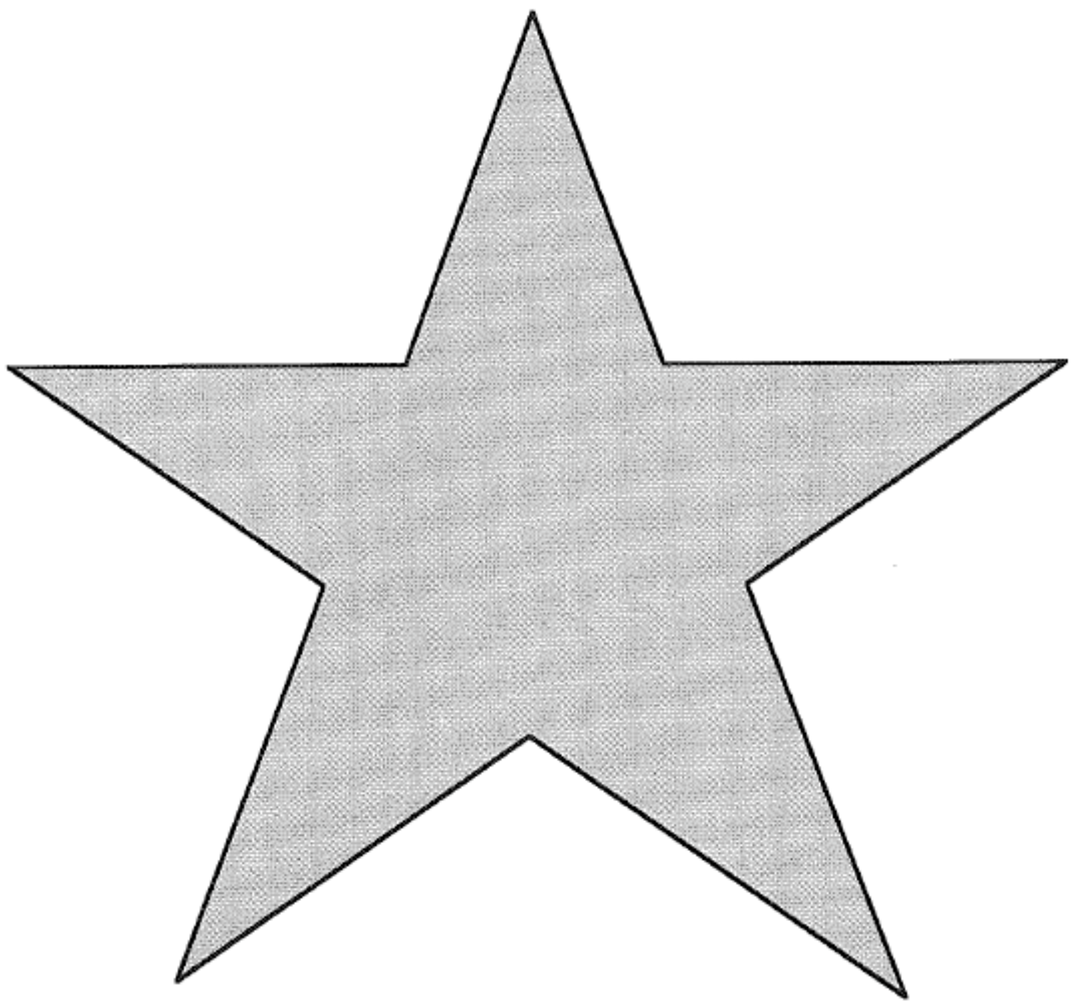


Figure 3.3.



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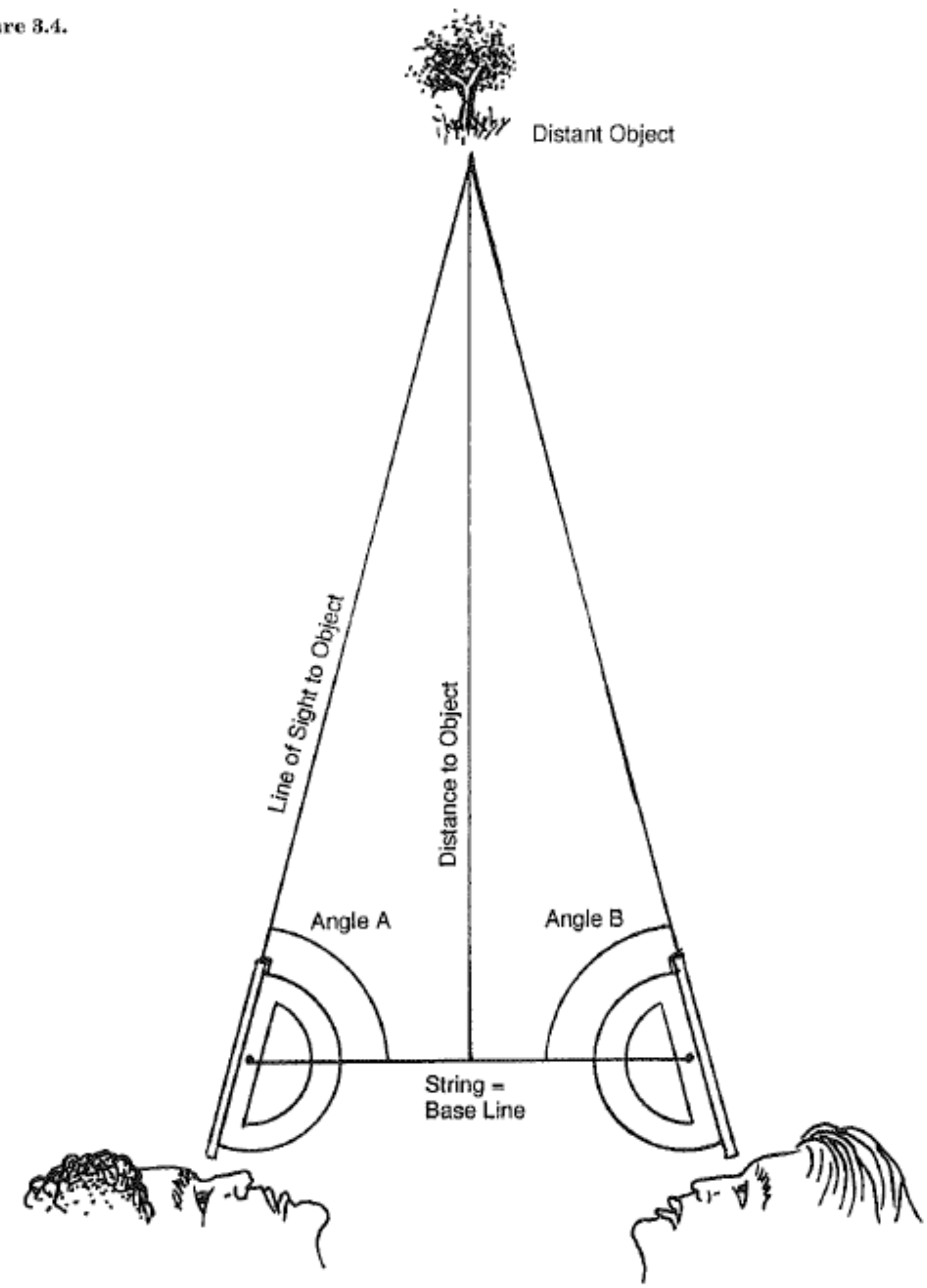
Mission 3
Calculating Stellar Distances

Triangulation–Transparency or PowerPoint Slide

Figure 3.4.



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Mission 3
Calculating Stellar Distances

Triangulation in the Field–Worksheet

Name: ____________________________________ Date: ______________________________

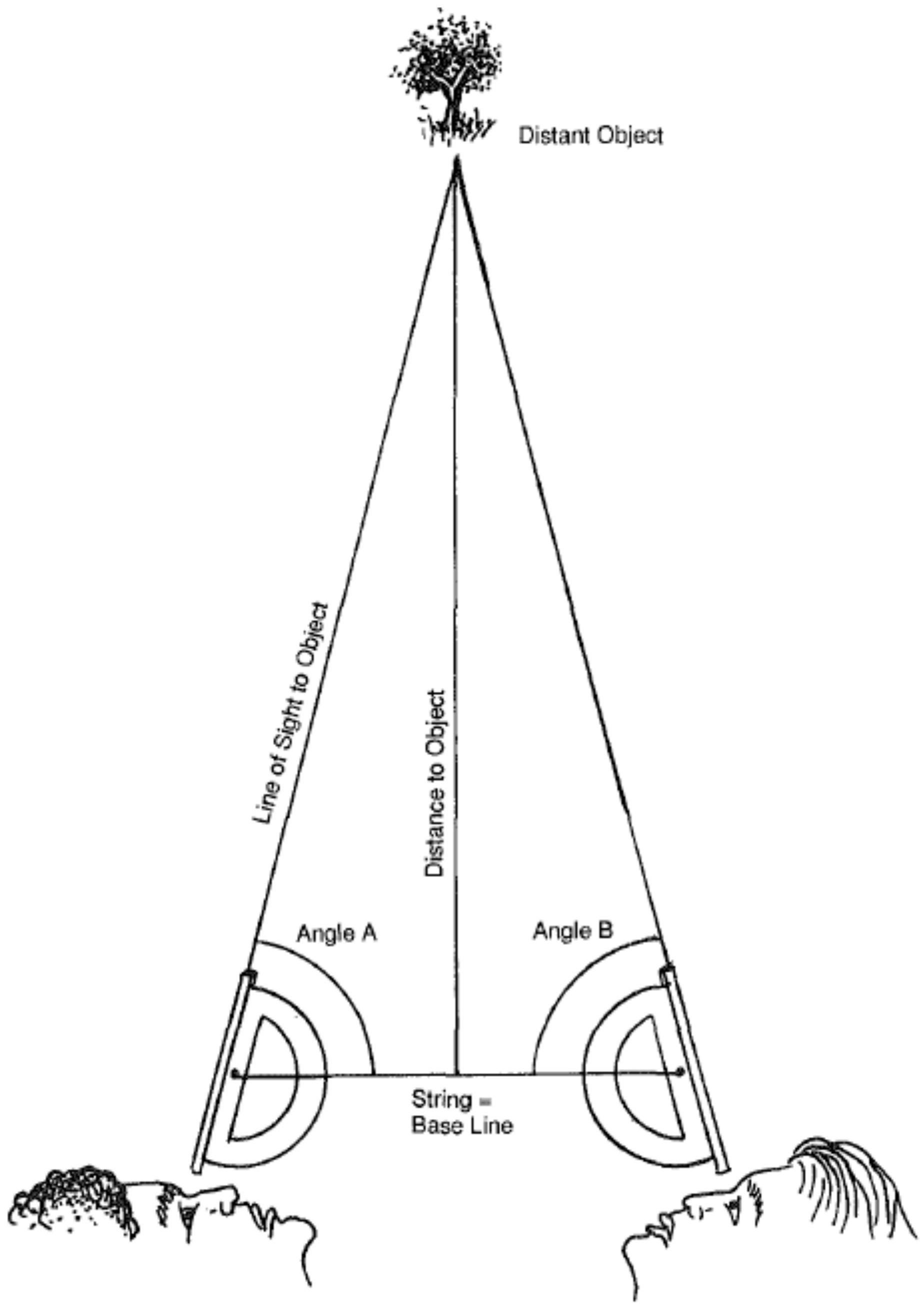
1. To what object are you and your team members measuring the distance?

2. Fill in data on the chart below as you complete your measurements. Do each measurement twice. Switch sides (observer positions) to do the second measurement.

Table 3.1–Triangulation Data.

	Angle Measured From Point A	Angle Measured From Point B
Trial 2		
Trial 3		
Trial 1		
Average		

Figure 3.5–Triangulation in the Field.



Mission 3
Calculating Stellar Distances

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Triangulation Data Analysis–Worksheet

Name: ___________________________________ Date: ______________________

Use the directions outlined below to calculate the distance to your object. To accomplish this you will make a scale diagram.

1. The scale of the diagram you are making is 1 centimeter = 1 meter.
2. Use butcher paper for this activity because your diagram will be too large for binder paper.
3. Draw the base of the triangle formed (line AB). It should be 10 centimeters long because your measuring line outdoors was 10 meters long.
4. Take the straw off your protractor and re-create the angles that were formed when you measured them outdoors by laying your protractor down at both of the end points of the line AB.
5. Use a meter stick to mark the line of sight after orienting the protractor to the correct angle. Extend the angle lines out on the butcher paper until they intersect.
6. Now measure the distance in centimeters from the midpoint of line AB to the point where the two lines intersect. Convert this measurement according to the scale to estimate the distance to the object in meters by multiplying the centimeters measurement by 100.

Table 3.2–Calculating the Distance.

Distance from Midpoint of AB to Intersection of Lines	Multiply by 100	Calculated Distance to Object in Meters

Congratulations! You have just *indirectly* measured the distance to an object without actually going to it!

7. If it is possible, go out and measure the distance to your object *directly* using a measuring tape. If this is not possible, get the actual distance from your teacher.

The measured distance to your object is ____________ meters.

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Mission 3
Calculating Stellar Distances

Triangulation Questions–Worksheet

Name: ______________________________________ Date: __________________

1. Record your calculated distance and the measured distance to your object.

   Calculated ____________________: Measured: _________________

   How close was your actual measurement using a measuring tape to your calculated measurement using the triangulation tool?

2. If you did not calculate the exact same distance using triangulation and direct measurement, why not? What are some of the ways that you could improve the accuracy of this method of calculating distance?

3. One object is at angles 80° and 80°, a second object is at 70° and 70°, and a third object is at 60° and 60° when viewed from the same spots on line AB. Which object is farther away? How do you know?

4. SETI scientists want to study stars that are within a certain distance from Earth. How would this method of triangulation be of value to SETI scientists?

5. As time allows, do this lab over again, measuring the distance to another object that is considerably farther away. Write all of your data on a separate sheet of paper.

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Mission 3
Calculating Stellar Distances

Making a Triangulation Tool–Directions

These are instructions for making your own triangulation measuring device. You will need two of these sheets to make one tool. You will also need scissors, glue, a piece of string or monofilament fishing line slightly longer than 10 meters, and two straws.

1. Cut out the protractor diagram from this paper.

2. Glue the protractor diagram to a piece of card stock or any thick paper or cardboard.

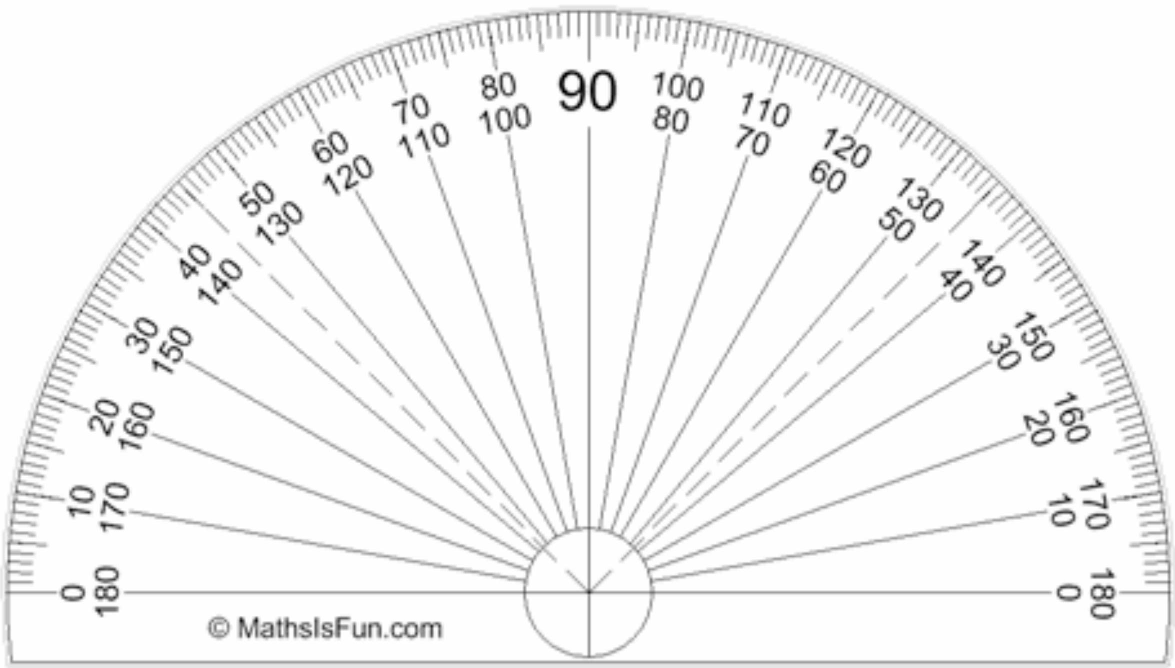
3. Punch a small hole in the area indicated on the protractor diagram and put one end of your 10-meter-long piece of string or fishing line down through the hole. Tape it to the back of the protractor, so the longer part runs across the face of the protractor.

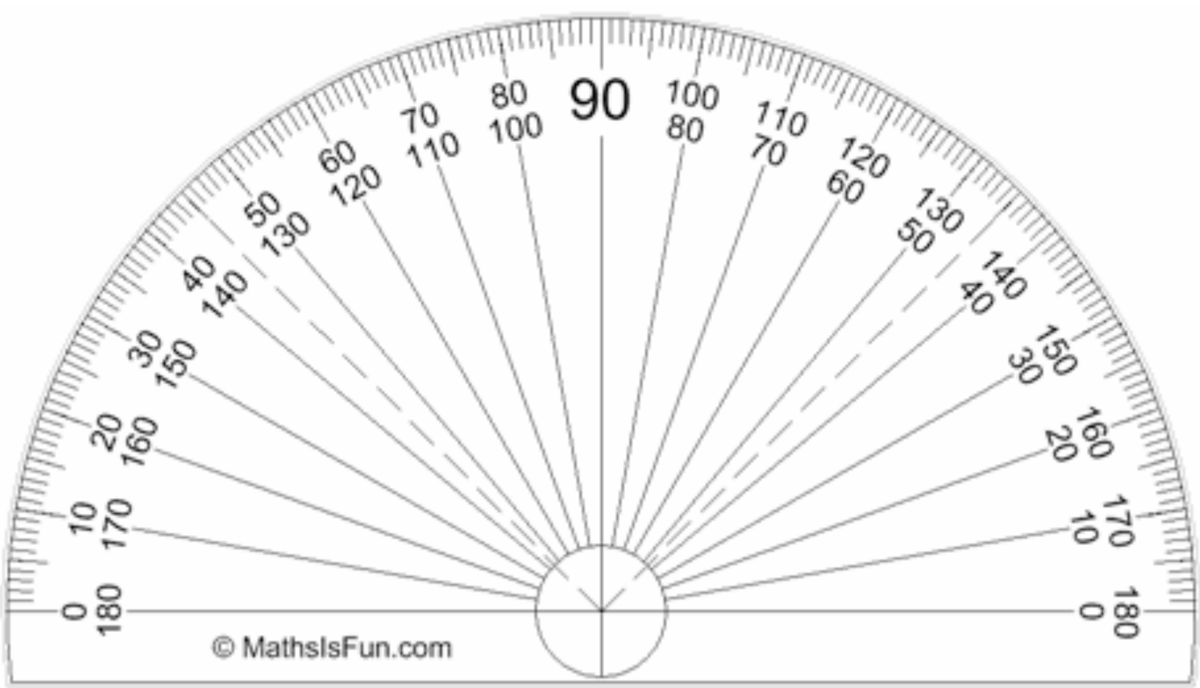
4. Get together with your partner and thread the other end of the string through his or her protractor and again tape it onto the back of the protractor after checking to make sure the length of the string between the two protractors is exactly 10 meters.

5. Tape a straw on the 0-0 line of both protractors, over the hole with the string. The straw acts as a sighting device.

6. Your teacher will demonstrate how this device operates. You must work cooperatively with your partner to make accurate measurements, because you are both taking measurements at the same time. A third member of your team will act as a recorder.

Figure 3–5.





Mission 3
Calculating Stellar Distances

Parallax–Worksheet

Name: ______________________________________ Date: ___________________

1. Write a description of what you did and what you conclude regarding the observations that you made when observing your thumb shift positions.

2. What is the problem that your teacher has asked you to solve regarding the model that is set up in the room?

3. What steps did you take to solve the problem that you described in # 2 above?

4. Using the method that you and your team came up with, which star seemed to have the greatest parallax, or shift the most relative to the background of stars?

5. Using your protractor measuring tool, what distance measurements did you come up with for the following stars?

   Sirius = _____________ meters away

   Alpha Centauri = ______________meters away

6. Make a general statement that relates the distance of a star and the parallax we can observe from Earth.

7. What places in the room should you sit (or stand) to observe Alpha Centauri and Sirius and have the apparent shift of these two stars be the greatest? Explain your answer.

8. Does where you sit or stand to make your observations of these two stars affect the accuracy of your measurements in # 5 above? Why or why not?

9. Because a year is defined as the time it takes Earth to revolve around the Sun, six months from now we will be directly on the other side of the Sun. This will give us a different view of the stars that are closest to Earth relative to the ones that are the farthest away. How will this allow astronomers to calculate the distance to the nearest stars?

Draw a diagram of this on the following page.

Draw your diagram here.

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Mission 4
Calculating Stellar Travel Time

How Long Would It Take to Travel to the Stars

Notes

In Mission 3, *students learned how to measure the distance to a star. In science fiction, starships cross the galaxy in minutes, and so space travel to distant stars seems like reasonable option to many students.*

Overview

In Mission 4.1, students consider the enormous amount of time that it would take to travel to Sirius, the brightest naked eye star, using various modes of transportation–some practical, and some whimsical. This knowledge should lead students to question the practicality of physically traveling to another star system or attempting interstellar communication with an extraterrestrial society by sending a spaceship to them.

Mission 4.1
Materials

For Each Team

- Scissors
- Tape or glue
- "Bike-Years! (Blank Chart)" worksheet (page 71)
- "Bike-Years! (Scrambled Chart)" worksheet (page 72)

For Each Student

- "Bike-Years! (Questions)" worksheet (page 73)
- *(optional)* "Bike-Years vs. Light-Years" worksheet (page 74)
- Pencil

Getting Ready

1. Copy the worksheets: "Bike-Years! (Blank Chart)" and "Bike-Years! (Scrambled Chart)" for each team; the "Bike-Years! (Questions)" worksheet for each student; and the "Bike-Years *vs*. Light-Years" worksheet for each student, if used.

Classroom Action

1. **Discussion.** Tell students that they will be figuring out how long it would take to get to Sirius, a star in the constellation Canis Major, using six different modes of transportation, including walking and riding a bicycle.

   Sirius appears as the brightest star, except for our Sun. Sirius is a relatively close star, but its distance from Earth is still 8.6 light-years. But what is a "light-year"? *(Visible light, as well as all other types of radiation in the electromagnetic spectrum, travels at the speed of light. The distance that light travels in one year is called a light-year, which is about 5.8 trillion miles, or* 9.5 *trillion kilometers!)* So how long would it take to travel to Sirius? *(It depends upon the speed of our vehicle.)*

Teacher's Note: *See page 69, Part II, for the calculation of the distance in km for a light-year.*

   If we were traveling on a bicycle, which is obviously impossible, how long would it take to get to Sirius? *(We could figure that out by considering "bike-years.*") So what is a bike year? *(Following the same type of logic as is used to define a light-year, it would be the distance that a bicycle rider could ride his/her bike in one year, without ever stopping to eat sleep, or anything else!)* Note that light-years and bike-years are both distance measurements, not time measurements. However, if we know the distance to our destination, we can calculate how long it would take to travel there, if we also know the speed of our vehicle.

   It might take a long time to get to Sirius on a bike, but how about on a spacecraft? *(Again, it depends upon the speed of our vehicle.)*

   Teacher's Note: The speed of the Voyager *spacecraft is actually variable. It left Earth with a velocity of about 97,000 km/hr; but the pull of the Sun initially slowed its velocity. We give 56,000 km/hr as an arbitrary number for comparison. As* Voyager *approached and then passed planets, the "slingshot effect" increases its velocity.*

   The *Voyager* spacecraft were equipped with phonograph records that contain pictures and sounds depicting our world. Suppose the *Voyager* spacecraft was actually headed toward Sirius. If there is an intelligent civilization living on a planet near that star, how many years would it be until *Voyager* reaches it? *(About 170,000 years.)*

2. **Activity.** Divide the class into teams of two to three students each. Hand out the worksheets "Bike-Years! (Blank Chart)" and "Bike-Years! (Scrambled Chart)" to each team. Distribute scissors, and glue or tape. Students follow the directions given on their worksheets. They should cut the scrambled data into blocks, which should then be pasted onto their blank data charts. Teams should brainstorm together. The only clue that they have to work with is their ability to rank the modes of travel from slowest to fastest.

   Optional: Have students do all the calculations on the data chart. If you choose to do the lesson in this way, do not hand out the scrambled data. Additionally, students estimate the speeds for the six modes of travel before giving them the actual accepted values.

3. **Discussion.** After students have completed the "Bike-Years! (Blank Chart)" worksheet, engage them in a class discussion about anything that they found unusual or surprising, making sure to cover the correct answers on their worksheet.

   Some students may believe that a supersonic jet travels faster than the space shuttle. Ask them to consider traveling around Earth in a jet plane. How long would it take? How long does the space shuttle take to orbit Earth once? *(In one of the world's fastest jets, the "Blackbird" [1,500 mph] about 17 hours. The space shuttle takes 1-1/2 hours.)*

   This may help them to see the difference. Ask them to also consider that the space shuttle is meant for local travel, while the *Voyager* spacecraft were designed to travel much farther and much faster! Now that they know the speeds of some very fast objects, ask students how fast light travels. Write down all reasonable responses on the whiteboard. Write down the accepted value of approximately 300,000 km/second. So what distance is a light-year? *(About 5.8 trillion miles or 9.5 trillion kilometers!)*

   Challenge students to calculate how far away Sirius is in kilometers given that Sirius is 8.6 light-years from Earth. *(Sirius is a mind-boggling* 8.2×10^{13} *km from Earth.)* Ask students to write this number without scientific notation. Is there a name for this large a number? (*82 trillion km.)* If necessary, review scientific notation with students. Considering the time and distance constraints that interstellar travel imposes, what are the possibilities of the interception of the *Voyager* probe and the message it carries by extraterrestrials?

4. **Homework.** Hand out the "Bike-Years! (Questions)" worksheet to each student. Students complete this worksheet in class or as homework. Students can complete the "Bike-Years *vs.* Light-Years" optional worksheet in class or as homework.

Going Further

Activity: A Sunny Day

Students work out how long it takes light to travel from the Sun to Earth. *(It takes sunlight 8.3 minutes to reach Earth.)* As an example to help students grasp the speed of light: in one second, a ray of light could travel around the equator seven times.

Teacher's Note: *The Sun is 93,000,000 miles or 150,000,000 km distant.*

Activity: Thunder and Lightning

Compare the speed of sound to the speed of light by discussing thunder and lightning. One can see lightning before it can be heard as thunder. This is a handy example for proving to students that light travels faster than sound. Pose math problems in which students must determine their distance from a bolt of lightning based on the amount of time that passes before they hear the thunder. *(Roughly, sound travels 1,000 feet per second through air: Light covers the same distance nearly instantly. Thus, the number of seconds between the flash and the thunder gives the distance in 1,000's of feet from the bolt to the observer; for example, five seconds would indicate a distance of 5,000 feet or about one mile. Three seconds would equal one kilometer.)*

Discussion: It's All Relative

Explore with your students what would happen if they wished to have a spacecraft that traveled at a speed approaching the speed of light. How much energy would it take to get a spacecraft to these incredible speeds? Could anyone afford it? According to Einstein's relativity theory, what would happen to the spacecraft as it approached the speed of light? *(As the spacecraft approaches the speed of light, the elapsed time for those on the spacecraft would approach zero; its length, as measured by someone not on the spacecraft, would approach zero; and its mass would approach infinity.)*

The Theory of Special Relativity, dealing with frames of reference for a constant relative velocity, was formulated in 1905 by Albert Einstein. This theory has implications for space travel:

1. Nothing can go faster than the speed of light.

2. It is impossible for a spacecraft to achieve the speed of light because it would take infinite energy to accelerate a spacecraft to that speed. As velocity approaches the speed of light, these two postulates require the following transformations of length, mass, and time: First convert velocity into a contraction coefficient (gamma)–$y = (1\text{-}(V^2/c^2))^{1/2}$, where c =the speed of light, and V =the speed of the object. Then, elapsed time on the spacecraft will be $T' = T{*}y$, where T = elapsed time for people who aren't moving. This means that elapsed time for people in the moving spacecraft will be less than elapsed time for the people back home. They will not age as quickly. The length of the spacecraft will be $L' = L{*}y$, where L = its length when it isn't moving, which means that the moving spacecraft will be shorter than it is when it isn't moving. The mass of the spacecraft will be $M' = M/y$, where M = the mass when not moving, which means that the moving spaceship will have more mass than it does when not moving. If the spacecraft is traveling at 9/10 the speed of light (or V = 0.9c), then y = 0.436.

$$\gamma = \sqrt{1-(\frac{.9C}{1C})^2} = 0.436$$

This means that for everyone hour that passes for nonmoving people back home, 0.436 hours will have passed on the spacecraft; for every meter long the spacecraft is when not moving, it will be only 0.436 meters long at this speed (as seen by someone who is not moving); and for every metric ton the spaceship weighs in the rest frame, it will weigh 2.29 metric tons when moving at this speed. However, the effects of the transformations are minimal until the velocity is quite close to the speed of light. Even astronauts on the space shuttle for a year would only age 30 billions of a second less than their relatives back on Earth!

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Mission 4
Calculating Stellar Travel Time

Bike-Years!–Teacher's Key

Table 4.1–Teacher's Key for Bike Years.

Mode of Travel, Slowest to Fastest	Average Speed	Distance Covered in One Year	Time to Get to Sirius
1. Walking	7 km/hr	61,320 km	1.33 billion years
2. Bike	25 km/hr	219,000 km	373 million years
3. Car	80 km/hr	700,800 km	117 million years
4. Supersonic Jet Plane	800 km/hr	7 million km	11.7 million years
5. Space Shuttle	40,000 km/hr	350 million km	233,000 years
6. *Voyage*r Spacecraft	56,000 km/hr	490 million km	170,000 years

1. Probably not, because these modes require enormous amounts of time, certainly longer than anyone's lifetime or even multiple generations. Also, obviously bikes, planes, and so on cannot travel through space.

2. Answers will vary. The civilization would have to intercept *Voyager* in space, because it would burn up if it entered the planet's atmosphere.

3. Radio, television, and microwaves in the electromagnetic spectrum. In fact, all of the radiation in the electromagnetic spectrum can carry information.

4. Send it as radio waves or television waves because it requires no mass and travels at the fastest speed possible, the speed of light.

5. The message would have been sent from Sirius 8.6 years ago because Sirius is 8.6 light-years away, and radio waves travel at the speed of light.

6. Radio signals would be strongest from stars that are the closest to us. Also, if we receive a message from a star system and we want to respond, the message would take the same

number of years to travel there as it did to come here. So, for practical purposes, we are listening to star systems that are close to us.

7. The light would have left Proxima Centauri 4.3 light-years ago because light travels at the speed of light and the star is 4.3 light-years away.

8. Anyone traveling to Pandora would be dead long before their starship could get to even the nearest stars if they are traveling at speeds we know are attainable with present day or even foreseeable technology!

Mission 4
Calculating Stellar Travel Time

Bike-Years vs. Light-Years–Teacher's Key

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Part I.

Figure out how far a bicycle can travel in one year, assuming a rate of speed of 25 km per hour, with the rider never stopping to eat, drink, or sleep. This computed distance will equal 1 bike-year, or the distance that a bicycle can travel in one year.

Remember, distance traveled = speed x time traveled.

The bicycle travels at a speed = 25 km per hour

25 km per hour x *24 hours per day* = 600 km per day

600 km per day x *365 days per year* = 2.19×10^5 km per year

This is the distance a bike goes in one year, or this is a distance of one bike-year.

Part II.

Figure out how far light can travel in one year.

This computed distance is considered 1 light-year; the distance that light can travel in one year.

Remember, distance traveled = speed x time traveled.

Light travels at a speed of 300,000 km per second. To convert a light year into kilometers, convert its speed in *km per second* = *km per year* as shown below:

300,000 km per second x *60 seconds per minute* = 1.80×10^7 km per minute

1.80×10^7 km per minute x *60 minutes per hour* = 1.08×10^9 km per hour

1.08×10^9 km per hour x *24 hours per day* = 2.59×10^{10} km per day

2.59×10^{10} km per day x *365 days per year* = 9.46×10^{12} km per year

This is the distance light travels in one year. This is one light year: 9.46×10^{12} km per year.

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Mission 4
Calculating Stellar Travel Time

Bike-Years! (Blank Chart)–Worksheet

Name: ________________________________ Date: ____________________________

Note: Distance to Sirius = 8.2×10^{13} kilometers.

Number of hours in one year is about _______________ hours.

Table 4.2–Blank Bike-Years Chart.

Mode of Travel, Slowest to Fastest	Average Speed	Distance Covered in One Year	Time to Get to Sirius
1.			
2.			
3.			
4.			
5.			
6.			

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Mission 4
Calculating Stellar Travel Time

Bike-Years! (Scrambled Chart)–Worksheet

Name: ____________________________________ Date: ____________________________

Scrambled Data Instructions:

1. Cut out the scrambled pieces of data.
2.
3. Put all of the modes of travel into the first column of your "Bike-Years! (Blank Chart)" worksheet starting with the slowest mode of travel (# 1) moving to the fastest mode of travel (# 6).
4.

3. Once you are confident that this order is correct, glue, tape, or write the data for the next three columns; average speed in km/hr, distance covered in one year in km/yr, and finally the time that it would take to travel to Sirius using that particular mode of travel.

Table 4.3–Bike-Years Scrambled Data.

7 million km/yr	233,000 years	*Voyager* Spacecraft	Supersonic Jet Plane
Space Shuttle	490 million km/yr	56,000 km/hr	61,320 km/yr
1.33 billion years	Bike	350 million km/yr	40,000 km/hr
219,000 km/yr	25 km/hr	11.7 million years	373 million years
117 million years	7 km/hr	170,000 years	80 km/hr
Car	800 km/hr	Walking	700,800 km/yr

Mission 4
Calculating Stellar Travel Time

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Bike-Years! (Questions)–Worksheet

Name: ______________________________________ Date: ____________________________

1. Would it be practical to travel to Sirius by any of the modes of travel listed on the bike-years chart? Why or why not?

2. Do you think that it is possible that one of the *Voyager* spacecraft would ever be intercepted by a civilization around another star, if such a civilization exists?

3. What travels at the speed of light that is capable of carrying information?

4. What would be the most practical way to get information from Earth to Sirius if we knew that a civilization existed around this star?

5. If a simulated message had just been received from Sirius by a radio telescope here on Earth, how long ago would it have been sent? How do you know?

6. SETI scientists are collecting data from stars that are within 1000 light-years of Earth. Why do you think they have chosen this limited distance?

7. Proxima Centauri (companion to Alpha Centauri) is the closest star to Earth, at a distance of 4.3 light-years away. If you stand outside on a clear night and see the light coming from it, how long ago did the light leave that star? Explain your answer.

8. *Avatar* is a movie in which people go to Alpha Centauri's fictional planetary system in our galaxy. Can you think of any practical problems with this idea?

Mission 4
Calculating Stellar Travel Time

SETI INSTITUTE

Bike-Years vs. Light-Years–Worksheet

Name: ______________________________________ Date: ______________________

Part I.

Figure out how far a bicycle can travel in one year, assuming a speed of 25 km per hr, with the rider never stopping to eat, drink, or sleep. This computed distance will equal 1 bike-year, or the distance that a bicycle can travel in one year.

Remember, distance traveled = speed x time traveled.

Bicycle travels at speed = 25 km per hr

25 km per hour x _______hours per day = _______ km per day

The bike travels at this speed for how long? _________ = # of days in a year.

Bike speed _____ x _____ days per year = _________ km per year

This is the distance a bike travels in one year, or this is the distance of one bike-year.

Part II.

Figure out how far a ray of light can travel in one year. This computed distance will be considered 1 light-year, or the distance that light can travel in one year.

Remember, distance traveled = speed x time traveled.

Light travels at speed = 300,000 km per second

x ________seconds per minute = __________ km per minute

x ________ minutes per hour = ___________ km per hour

x ________ hours per day = ______________ km per day

The light travels at this speed for how long? _________________ = # of days in a year.

_______ km per day x _________ days per year = __________ km per year

This is the distance light travels in one year, or this is a distance of 1 light-year.

Mission 5
A Model of the Milky Way Galaxy

What Does Our Home Galaxy Look Like?

Notes

In Mission 4, students learned of the enormous distance to the star Sirius. Still, Sirius is the seventh closest star to Earth! Most stars are considerably farther away, and there are about 500 billion stars in our Milky Way Galaxy. There are billions of galaxies even farther away, each one with hundreds of billions of stars.

Overview

In this mission, students realize that the existence of billions of stars means billions of chances that life exists somewhere else in the universe. In Mission 5.1, students see the video image show "Wonders of the Milky Way Galaxy" and then map our immediate cosmic vicinity (out to a few hundred light-years distance) by plotting the locations of some stars, nebulae, and globular clusters. In Mission 5.2, students see the video image show "Galaxies: Billions Upon Billions of Stars" and then make a model of the entire Milky Way Galaxy. They show the size of their vicinity diagram from Mission 5.2 in comparison to the entire galaxy and compute the distance to the center and to the opposite side of the Milky Way Galaxy.

Mission 5.1
Materials

For a Class of 30

- Data projector, computer, PowerPoint file
- "Wonders of the Milky Way Galaxy" segment from the *Project Haystack* PowerPoint file
- "Wonders of the Milky Way Galaxy" script (pages 85-87)
- Overhead projector
- "Celestial Mapping" transparency (page 91)
- Transparency markers or grease pencils

For Each Team

- Butcher paper (roughly 1m by 1m)
- Meter stick with mm markings
- Protractor (360° recommended)

For Each Student

- "Making a Celestial Map" directions (page 93)

- “Celestial Map Data” worksheet (page 94)
- “Celestial Map Questions” worksheet (pages 95)
- Pencil

Getting Ready

1. Copy the “Celestial Map” directions and the two “Celestial Map” worksheets for each student.

2. Set up the data projector.

3. Start the *Project Haystack* PowerPoint file “Wonders of the Milky Way Galaxy.” Have the script handy.

Classroom Action

1. **PowerPoint Presentation.** A PowerPoint script has been provided. It can be used as is to accompany the slide show, or its information can be paraphrased. Introduce students to a few of the spectacular wonders of the Milky Way Galaxy in this segment. They will see open clusters of stars, globular clusters of stars, and nebulae, many of which they will plot on a map, showing their distance from Earth.

   (Optional): Have students draw a picture of the object on their map and plot its position. Students should do a quick sketch of each image as it is shown in the video. Or, provide additional pictures of these objects.

2 **Demonstration and Transparency or PowerPoint Slide.** Divide the class into teams of four to five students each. Hand out the “Making a Celestial Map” directions and the “Celestial Map Data” worksheet to each student. Teams will use a piece of butcher paper about one meter long. They should draw a line down the center vertically and a line across the center horizontally. The center, where these lines intersect, is the location of our Sun. Students should label the diagram with degree markings: 0°, 90°, 180° and 270°. By definition, zero degrees is the direction toward the galactic center of the Milky Way. Show them these coordinates on the “Celestial Mapping” transparency or PowerPoint slide.

   Teacher's Note: *Astronomers map the galaxy beginning with 0° at the bottom of the square, which places the center of the galaxy at the center of the image. This is different than classical geometry (see page 91).*

   Anticipate that your students will have trouble seeing how a rectangular map can have 360°. Many students think that only circles have 360°. Ask students to envision an imaginary circle inside their rectangle. Students will only need two pieces of information to plot each object: how far it is from the Sun, and on which angle it is located. Go over these two terms with the class.

   Distance in light-years = distance from our Sun
   Galactic longitude = Degrees from zero

The galactic longitude of an object is the angle between the center of the galaxy, our Sun, and the object as seen by someone looking down on the galaxy from a great distance.

It is crucial to realize that this figure does not give students a sense of the depth (or the third dimension) of the Milky Way Galaxy. This especially affects globular clusters because they are considerably above or below the plane of the Milky Way Galaxy.

Anticipate that students may have trouble using a 180° protractor to plot objects between 180° and 360°–they may flip the 180° protractor to the other side and not know whether they need to add or subtract to find the correct angle. We recommend using a 360° protractor.

The map scale is 1 cm = 15 light-years. At this scale, most of the closest stars actually fit on the diagram. Most nebulae are considerably farther away than the stars, and most globular clusters are farther away still, so they will *not* fit on the paper! Students should still plot how far away these objects would be if they could be placed on a bigger map (*e.g.*, out in the schoolyard, across the street, or even farther away). They should write this information on the edge of their vicinity map.

Demonstrate how to plot an object on the "Celestial Mapping" transparency. Plot at least two objects. One should be between 0° and 180° and the second between 180° and 360°. One object should fit on the map and the second should not; for the second, demonstrate how to write data on the edge of the paper.

3. **Activity**. Have students graph various celestial objects on a celestial map to get a better sense of their general distribution and direction from Earth in our immediate area of the Milky Way Galaxy. It may take two (or more) class periods to ensure that all students are able to plot all the objects on their "Celestial Map Data" worksheets.

4. **Homework.** Hand out the "A Celestial Map Questions" worksheet to each student. Have students complete this worksheet in class or as homework.

Mission 5.2
Materials

For a Class of 30

- Data projector, computer, PowerPoint file
- "Galaxies: Billions Upon Billions of Stars" segment from *Project Haystack* PowerPoint
- "Galaxies: Billions Upon Billions of Stars" script (pages 88-90)

For Each Team

- Thin pieces or sheets of plastic (lids from plastic containers are ideal)
- Compasses
- Scissors
- Glue or paste

- Cotton balls (or other cotton)
- White paint
- Brushes
- Meter sticks with mm markings
- *(optional)* Graph paper

For Each Student

- "Our Home Galaxy" directions
- Pencil

Getting Ready

1. Copy the "Our Home Galaxy" directions for each student.

2. Set up the data projector Start the *Project Haystack* PowerPoint file "Galaxies: Billions Upon Billions of Stars." Have the script handy.

Classroom Action

1. **Review.** Reassemble the class into their teams from Mission 5.1. In Mission 5.1, students plotted several objects that are all found in the near vicinity of our Sun, all within the Milky Way Galaxy. Tell students that they will see how their Vicinity Chart relates to the entire Milky Way Galaxy by making a scale model that shows both where in the galaxy we are and how much space the Vicinity Chart takes up compared to the entire Milky Way Galaxy.

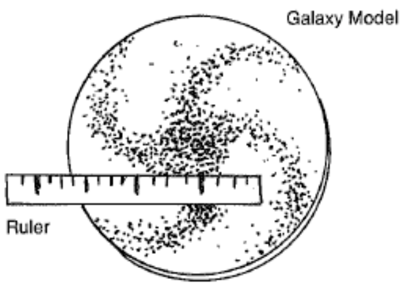
2. **Data Projector.** A script has been provided. It can be used as is to accompany the PowerPoint presentation, or its information can be paraphrased. This segment will show the variety of galaxies in the universe and how our own Milky Way Galaxy is believed to look.

   Today students will be artists! They will refer to the poster (optional) drawings of the Milky Way and/or images of galaxies that are thought to look like our home galaxy. They then will draw a nice sketch that looks something like the Milky Way–an open spiral. We do not know exactly what our galaxy looks like from the outside. It has only been in the last five years that astronomers have figured out that the inner part of our galaxy probably contains a "bar" of stars, and they are still trying to puzzle out whether the very center of our galaxy contains a massive black hole, or millions of ordinary stars packed close together.

   Our best guess is that it looks something like the Andromeda Galaxy, but the spiral pattern of Andromeda is not clearly visible on photos. An open spiral pattern will be used to depict our Milky Way Galaxy. Students will see that, on a top-view diagram of our galaxy, we are toward the inside edge of one of the spiral arms. Remind students that the Milky Way is roughly 100,000 light-years across, 5,000 light-years thick at its center, and 2,000 light-years thick everywhere else. The length of the bar is about 20,000 light-years. Write these numbers on the whiteboard.

3. **Activity.** Hand out the "Our Home Galaxy" directions to each student. Ask students to create a model of our galaxy using the pictures and diagrams that they have just seen as models. Pass out pieces of plastic, white paint, brushes, cotton balls, glue, compasses, and scissors. Plastic will make the three-dimensional model of our galaxy. Ask students to measure the thickness of their piece of plastic. The real Milky Way Galaxy has an overall diameter to thickness ratio of 50 (except for the bulge in the middle). Because we know that the real Milky Way Galaxy is about 100,000 light-years across, students can compute the diameter that would be appropriate for their piece of plastic (given its thickness) and draw a circle of that diameter. Students should cut out their plastic circle and paint an open spiral pattern on it, as shown in Figure 5.l. Encourage the use of many dots, depicting stars rather than lines, especially near the edges of the spiral arms. The transparency of the plastic shows the open space that exists between the stars. At this scale, the stars in the center are so dense that they blur together.

Figure 5.1–A Model Milky Way Galaxy.



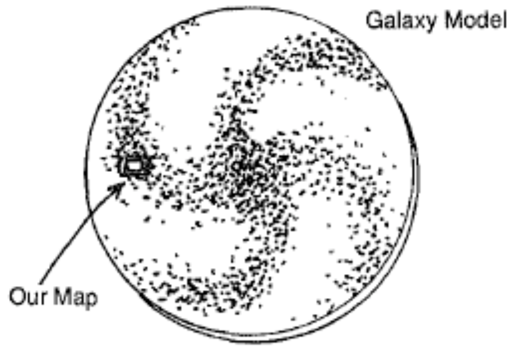
To represent the bulge at the center of the Milky Way Galaxy, have students use a cotton ball. Knowing that the Milky Way is roughly 100,000 light-years across, and 5,000 light years thick in the middle, they can compute about how much cotton to glue to the center to show the bulge. Glue the cotton on both sides of the disk. Wisps of this cotton should be pulled out toward each spiral arm, becoming more tenuous farther from the center.

Teacher's Note: *It is clear now that the Milky Way is a strongly barred galaxy, so the cotton ball is only a rough representation. However, it does add a third dimension to the model.*

Optional: If it is too difficult to obtain pieces of plastic, use graph paper, which will produce a flat map with no third dimension. The white paint, brushes, cotton balls, and glue will not be necessary. Just have students draw an open spiral galaxy extending to the edges of the graph paper. Have them cut out the map as a circular shape (see Figure 5.1).

4. **Activity**. Tell students that the challenge is to draw in a rectangle representing the diagram that they constructed in Mission 5.1 (the Vicinity Chart) that is to scale on this new model of the entire Milky Way Galaxy, as shown in Figure 5.2.

Figure 5.2–Our Map and the Milky Way Galaxy.



Ask students to remember their rectangular vicinity map. Ask them to guess where this rectangle would appear on their new model of the entire Milky Way Galaxy. Ask them to guess how big this rectangle would appear on their new model of the entire Milky Way Galaxy. Students pencil their best guess on their new model. *(Students' best guesses will probably be much too big!)*

Have students follow the "Our Home Galaxy" directions for calculating the distance to the center and to the opposite edge of the Milky Way Galaxy at the scale of 1 cm = 15 light-years. Try to provide a place where students can actually walk off or measure off this distance, which will be roughly 20 meters away along the 0' line to the center and 55 meters to the opposite edge! If possible, have students mark off these distances in the schoolyard.

Going Further

Activity: 3·D Constellation Models

This activity is completely described in appendix B as an enrichment lesson. It is highly recommended. These models show students that constellations only look familiar from one viewpoint: our own, here on Earth!

Activity: The Milky Way *x* 10!

Students make a second model/map of the Milky Way Galaxy, with the second map scale being 1 cm = 150 light-years. At this scale, the nebulae fit on the diagram, but the globular clusters still do not. This will give students a sense of how far away these objects actually are. At this scale, all the stars still fit, but they are now bunched up very close to the Sun. They are difficult or impossible to plot clearly.

Activity: How Big Is It?

Give students photographs of various objects, or show them to the class as a whole. Ask students how big each is. How can they tell? If the objects are familiar to students, they will rely on past experience and knowledge. Point this out to them, and ask for clues to sizes and scales that could be used if they had never seen such an object. Some of the pictured objects should be unfamiliar to students.

Activity: Mapping and Scale

Students use graph paper to conduct a resolution mapping exercise. Students make maps of the classroom or schoolyard at various scales. For each scale, they record only what can be seen at that scale, or only the dominant objects for that scale.

Activity: Calculation Challenges

Challenge # 1

Students calculate the exact size of the rectangle representing the diagram that they constructed in Mission 5.2 (the Vicinity Chart) to scale on their new model of the *entire* Milky Way.

First, the distance across the Galaxy just drawn must be measured (in millimeters). This distance represents 100,000 light-years, so dividing 100,000 by the total distance in millimeters gives the number of light-years that one millimeter represents. For example, if a galaxy is 200 mm across, the scale would be 1 mm = 500 light-years.

To calculate the appropriate size of the rectangle for the entire Milky Way Galaxy, the scale just computed for the entire Galaxy must be applied to the measurements of the rectangle from Mission 5.2. For instance, a rectangle of butcher paper measuring 92 cm x 60 cm becomes 1,380 light-years by 900 light-years. Dividing each of these figures by 500 gives the dimensions of the rectangle for the new diagram-it would be slightly smaller than 2 mm x 3 mm!

The next step is to draw this rectangle on the new diagram of the Milky Way, out toward the inside edge, about two-thirds of the way from the center on one of the spiral arms. Students should be quite startled to discover how little space their first diagram takes up within the entire Milky Way Galaxy.

Challenge # 2

Students calculate how many times larger the Milky Way Galaxy is than each Vicinity Chart. Students should use the formula for the area of a circle, $a = \pi r^2$, to find the area of the Milky Way Galaxy. Multiplying length by width, students will find the area of the rectangle used in mission 5.1. Dividing the area of the circle (the area of the Milky Way Galaxy) by the area of the rectangle (the Vicinity Chart) will provide the answer.

Show and Tell: Scale Models

Students make or buy scale models all the time. Have them bring some of these models to school. They should know the scale involved (*e.g.*, doll-house furniture at a scale of 1 inch = 1 foot; HO trains at a 1/87 scale). Some models should be larger than life (*e.g.*, plastic fly), some should be smaller than life (*e.g.*, plastic dinosaur), and others should be life-size. Have students estimate the scales of each other's models.

Activity: Seeing Another Galaxy

The Andromeda Galaxy can be seen with the naked eye. It appears as a white, fuzzy area. With binoculars, or with a simple, small telescope, the image becomes much larger and clearer. The Andromeda Galaxy is easy to locate, assuming the constellation of Andromeda will be overhead at a time when students will be looking for it–this means that you must be somewhere in the northern hemisphere on a dark night. Consult a star map to determine when and from where the constellation Andromeda can be seen in your geographic location. *(For students in the southern hemisphere, consider finding the Magellanic Clouds, two very nearby dwarf galaxies.)* Give students a star map, or have them do library research to find a star map. The darker the night sky, the better the chance of observation; accordingly, if your school is in a heavily light-polluted city, perhaps have students try this activity during a weekend camping trip.

Activity: Stories from the Stars

Mythology and religion are rich in tales about the stars. Many constellations have elaborate stories explaining their existence. Do all peoples see the same constellations when they look at the sky? Students may research other cultures and present pictures of how other peoples see the sky. Students may then read or tell stories about the stars from cultures around the world. Create a "campfire" at the center of the room, put out the lights, and have students take turns telling the stories. Ask students whether constellations in the southern celestial hemisphere are different from those in the northern hemisphere. Do any southern constellations have Greek or Roman names?

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Mission 5
A Model of the Milky Way Galaxy

Celestial Map Data–Teacher's Key

Table 5.1.

Name of Celestial Object	Right Ascension	Declination	Galactic Longitude	Distance in Light-Years	Distance in Centimeters (1 cm = 15 light years)	Distance in Centimeters (1 cm = 150 light-years)
Aldebaran (Star)	4h 33m	16° 25’	183°	68.0	4.53	0.45
Altair (star)	19h 48m	8° 44’	47°	16.6	1.1	0,10
Alpha Centauri (Star)	14h 36m	-60° 38’	315°	4.3	0.3	0.03
American Nebula	20h 52m	43° 54’	84°	2,600.0	173.0	17.30
Antares (Star)	16h 29m	-26° 26’	354°	326.0	21.7	2.17
Arcturus (Star)	14h 16m	19° 11’	15°	36.0	2.4	0.24
Barnard’s Star	17h 55m	4° 33’	30°	5.9	0.4	0.04
Beehive Open Cluster	8h 38m	19° 52’	208°	500.0	33.3	3.33
Betelgeuse (Star)	5h 55m	7° 24’	202°	651.0	43.4	4.34
Capella (Star)	5h 17m	46° 00’	165°	42.4	2.8	0.28
Crab Nebula	5h 31m	21° 59’	185°	6,552.0	436.0	43.60
Cygnus Loop Nebula (Veil)	20h 49m	30° 30’	78°	1,630.0	109.0	10.90
Deneb (Star)	0h 44m	-17° 59’	110°	68.5	4.6	0.46
Epsilon Eridani (Star)	3h 31m	-9° 38’	195°	10.8	0.7	0.07
Hercules Globular Cluster	16h 40m	36° 33’	59°	25,000.0	1,666.6	166.60
Horsehead Nebula	5h 39m	2° 32’	204°	12,000.0	800.0	80.00
Lagoon Nebula	18h 01m	-24° 22’	7°	3,900.0	260.0	26.00
Mizar (star)	13h 24m	54° 56’	112°	58.7	3.9	0.39
Omega Centauri Globular Cluster	12h 24m	47° 13’	132°	17,000.0	1,133.0	113.0
Orion Nebula	5h 35m	-5° 27’	208°	1,600.0	107.0	10.70
Pleiades Open Cluster	3h 47m	24° 07’	168°	415.0	27.7	2.77
Polaris (North Star)	2h 32m	89° 16’	130°	1,080.0	72.0	7.20
Rigel (Star)	5h 14m	-8° 12’	210°	913.0	60.9	6.09
Ring Nebula	18h 54m	33° 02’	63°	4,100.0	273.0	27.30
Sirius (Star)	6h 43m	-16° 39’	228°	8.6	0.6	0.06
Spica (Star)	13h 25m	-11° 10’	315°	155.0	10.3	1.00
Tau Ceti (Star)	1h 42m	-16° 12’	175°	11.7	0.8	0.08
Trifid Nebula	17h 58m	-23° 24’	8°	3,260.0	217.0	21.70
Vega (Star)	18h 37m	38° 47’	68°	26.4	1.8	0.18

Mission 5
A Model of the Milky Way Galaxy

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Celestial Map Questions–Teacher's Key

1.

a. The galactic center is *2,000* centimeters (20 m) away.

b. The far edge of the Milky Way Galaxy is 5,333 centimeters (53.3 m) away.

c. The near edge of the Milky Way Galaxy is 1,333 centimeters (13.3 m) away.

2.

a. All stars less than 100 light-years from the Sun on the Milky Way Galaxy Object List: Aldebaran, Altair, Alpha Centauri, Arcturus, Barnard's Star, Capella, Deneb, Epsilon Eridani, Mizar, Sirius, Tau Ceti, and Vega.

b. The SETI Target List includes many stars that are less than 200 light-years away because these are the stars that we will have the greatest chance of detecting a signal from. An extraterrestrial signal would be easier to detect from a close star than from a far-away star, in the same way that it is easier to see a dim light if you are closer to it. The signal will probably be weak because of limitation on transmitter power.

3.

a. The data tells the directions that the *Voyager* spacecraft are headed, and the speed at which they are traveling. The directions are equivalent to the galactic longitude; first draw the two trajectory lines. One method of showing locations: on each trajectory line mark off every 150 light-years (10 cm at map scale), and label each mark with the number of years it will take for the *Voyager* spacecraft to get to those marks.

b. Each *Voyager* takes *19,400* years to go 1 light-year.

c. How long will it take for a *Voyager* to go 150 light-years? *2,900,000* years.

Script for PowerPoint Slides

"Wonders of the Milky Way Galaxy"

Introduction

The Milky Way Galaxy, our own home galaxy, is filled with wonders. If you know where to look, many are visible to the unaided eye, but when seen through a telescope, their splendor is a joy to behold! This video will show you a few of the wonders of the Milky Way Galaxy: mammoth star clusters, multicolored nebulae of glowing dust and gas. In class today, you will make a map showing where these wonders are in relation to Earth, and to our solar system, which are very small in comparison to the universe.

Image # 5.23: The Beehive (Praesepe) Open Cluster (M44)

Stars are often born in groups called *open clusters.* This image shows an open cluster named the Beehive. Do the stars remind you of a swarm of bees? Open clusters are groups of hundreds of stars. Our own Sun was probably born within such a group. In these open clusters, the individual stars are slowly drifting apart from each other. The Beehive is one of the closest open clusters, being only about 500 light-years away!

If you wanted to see the Beehive, you would look in the constellation Cancer, the Crab. If you knew exactly where to look, and went out on a dark night during winter or spring, you would be able to see the Beehive with your unaided eye. You would see a fuzzy white patch. With binoculars, some of the individual stars would become visible. Galileo was impressed to see over 40 individual stars in the Beehive with his small telescope. With a modern telescope, we can see over 350 individual stars there.

Image # 5.24: The Pleiades Open Cluster (M45)

There are many open clusters in our galaxy. This one is called the Pleiades, or the Seven Sisters. You may have seen the Pleiades, or heard stories about how the Seven Sisters went to live in the sky and became stars. If you have seen them, you have looked at something that is 415 light-years away from Earth. How long would it take you to visit the Seven Sisters if you rode your "space bike"? *(It would take 18 billion years! The universe itself is only expected to have been in existence for about 15 billion years.)*

If you have never seen the Pleiades, you can look in the constellation of Taurus, the Bull, one of the signs of the zodiac, on a dark winter's night. They are easily seen with the naked eye. Can you see all Seven Sisters? To be able to do so was the "eye exam" required to get into the Roman army 2,000 years ago!

Image # 5.25: Globular Cluster in Hercules (MI3)

Not all star clusters are open clusters. This is *a globular cluster* located in the constellation Hercules. You are looking at several hundred thousand stars packed into a very compact area. Globular clusters become denser as you approach the center. Near the center of this cluster, there are about 1,000 stars in every cubic light-year! The neighborhood is so crowded that you cannot distinguish the individual stars.

Globular clusters are very old objects. At a distance of 25,000 light-years, M13 is one of the closest. Amazingly, even at this distance, you can see the globular cluster in Hercules with the unaided eye. The constellation Hercules is almost straight overhead in midsummer. Try finding this globular cluster when school's out.

Image # 5.26: The Trifid Nebula (M20)

Deep in the constellation Sagittarius, the Archer, toward the center of our galaxy lie enormous glowing red and blue clouds of gas and dust that dim and hide the light of any stars that may be beyond them. Deep within these clouds, new stars are being born. These glowing gas clouds are called *nebulae.* This particular gas cloud is the Trifid Nebula, a typical stellar nursery—a *big* nursery. The Trifid measures 40 light-years in diameter. And what big babies. The Trifid is lit with the glow from its newborn stars. This glow comes from 3,260 light years away.

Image # 5.27: The Great Nebula in Orion (M42)

Perhaps the most famous nebula of all is the Great Nebula in Orion. It is visible to the unaided eye as a misty patch in the sword of Orion, the Hunter, one of the most familiar constellations in the world. But photographed through a telescope, it becomes a glorious, multicolored object. Look for it in the night sky in winter.

Like the Trifid Nebula, the Great Nebula is a glowing cloud where stars that have just been born reside. But the Great Nebula is a good deal closer to us than the Trifid Nebula. It is only 1,500 light years away from Earth. Hop on your “space bike”!

Image # 5.28: The Horsehead Nebula

What would you name this nebula? People everywhere like to see “pictures” of familiar objects in cumulus clouds, in rock formations or flames in a fire, or in a distant glowing cloud of dust and gas. Yes, this is called the Horsehead Nebula. Its shape is a pure coincidence. The black horse's head is just part of a larger dark cloud, which is opaque enough to block the light of the stars that lie behind it. The red background that outlines the horse's head is the ruddy glow of hot hydrogen gas.

You could see the Horsehead Nebula if you looked in the constellation of Orion, the Hunter. In fact, this nebula is only a few degrees away from the Great Nebula in Orion, but it is much smaller and much harder to find, even with a telescope. Like the Great Nebula, it is about 1,500 light-years away from Earth.

Image # 5.29: The Ring Nebula (M57)

About 20,000 years ago, a star blew off its outer layers and created this expanding shell of glowing gas and dust. Ultraviolet light emitted by the central star causes the gas and dust to glow. What would you name this nebula? That's right. It is named the Ring Nebula! It is 4,100 light-years away from Earth. Someday the space around the Sun will look like this as the sun begins to age and die.

The Ring Nebula can be found in the summer constellation Lyra, the Lyre. A lyre is an ancient Greek musical instrument.

Image # 5.30: The Crab Nebula Supernova Remnant (M1)

The Crab Nebula is the wreckage of an exploded star, a *supernova.* The light from this super explosion reached Earth about July 5, 1054. The stellar display was recorded by the Pueblo Indians in Arizona and by Chinese astronomers. The Crab Nebula is 6,552 light-years away from Earth. Can you calculate when the star exploded?

The Crab Nebula is located in the constellation of Taurus, the Bull, which is visible in spring and winter. This dust cloud is still expanding at the rate of 1,000 miles per second. Inside the Crab Nebula is a super dense *neutron star* that spins around its axis 30 times a second. Because this neutron star emits pulses of light, x-rays, and radio waves, it is called a *pulsar:* It is the remnant core of the exploded star.

Image # 5.31: The Veil Nebula Supernova Remnant (NGC 6960, 6992)

There may be a pulsar near the center of this supernova remnant, the Veil Nebula. It is all that is left of a once great star. This wispy Veil Nebula is the visible manifestation of a shock wave that has been traveling toward us for over 100,000 years, ever since a minor star in the constellation Cygnus exploded. This insignificant star suddenly blazed 100 million times as brightly as before! It became a supernova. The initial explosion would have made the star shine as brightly as our moon. The star would have even been visible in daylight for several weeks before fading. Today the Veil Nebula surrounds the old explosion site.

Stop and Assess “Wonders of the Milky Way Galaxy”

1. Back up and take a second look at various images if students would like to study them.

2. Ask: What have you learned about these beautiful celestial objects?

3. Ask: Can *you* make a map that shows the location of these objects?

Script for Video Images

"Galaxies: Billions Upon Billions of Stars"

Introduction

As huge as it is, the Milky Way Galaxy, including its hundreds of billions of stars, its star clusters and glowing nebulae, is only one galaxy in the universe. And there are tens of billions of other galaxies, each one filled with billions of stars! This number of stars is almost impossible to imagine. There are more stars than there are grains of sand on all of the beaches in the world.

In this image show, you will see what some of these other galaxies look like, and then see how our own Milky Way Galaxy looks from the inside, and how it is believed to appear from the outside. After the show, you will make a three-dimensional model of our home galaxy.

Image # 5.32: Spiral Galaxy in Virgo

Astronomers know that stars are organized into huge systems called galaxies. Each galaxy contains billions of stars. Our Sun is just one star out of about 500 billion stars in our own Milky Way Galaxy. Galaxies are classified by their basic shapes as spirals, ellipticals, and irregulars. Which shape do you think this galaxy is?

This is a *spiral* galaxy seen nearly face on. It can be seen through a telescope, if you look in the constellation of Virgo. It is about 50 million light years away from Earth. Can you imagine what a huge piece of butcher paper you would need to include another galaxy on your map?

Image # 5.33: Andromeda Galaxy (M31)

The Andromeda Galaxy is one of the galaxies that is nearest to us. It is only about 2.2 million light-years away from Earth! Amazingly, this galaxy can actually be seen as a "fuzzy blob" with the unaided eye, if you know where to look in the fall or winter sky in the constellation Andromeda. The actual shape of the Andromeda Galaxy is a spiral of stars, dust, and gas.

The Andromeda Galaxy is thought to be quite similar to the shape of our own Milky Way Galaxy. The Andromeda Galaxy also has two small elliptical *companion* galaxies. Is this unique in the universe?

Image # 5.34: The Virgo Cluster of Galaxies (M84)

Actually, although photographs often focus on single galaxies, isolated galaxies are quite rare in space. Most galaxies are found in clusters, or groups. This is only part of a cluster of galaxies seen when looking at the constellation Virgo. How many galaxies can you see in this picture? How many do you think might be in the whole cluster?

There are eight galaxies easily seen in this image. In fact, the entire Virgo cluster contains several thousand individual galaxies. And astronomers classify this region as only moderately rich. Some clusters have even more galaxies. Can you tell what shape most of these galaxies are? Are they spirals, ellipticals, or irregulars?

Image # 5.35: Edge-on Spiral Galaxy in Leo (NGC 3628)

This is one galaxy in the Leo Triplet of galaxies named because the stars in the constellation of Leo the Lion are in the same part of the sky. It is one of the "Local Group" of galaxies, all of which lie within two or three million light-years of Earth. These are almost next-door neighbors. What shape is this galaxy? Is it a spiral, an elliptical, or an irregular?

Actually, it is a spiral galaxy. It looks so different from the other spirals that we have seen because we are viewing it from the edge instead of face-on. Think of a spiral galaxy as if it were a dinner plate with a spiral pattern painted on it. From one view, you would see the whole spiral pattern. What would the plate look like if you turn it so that you are looking at the edge? It would look like this galaxy.

Image # 5.36: Large Magellanic Cloud, an Irregular Local Galaxy

This galaxy is called the Large Magellanic Cloud. It is even closer to home than the Leo Triplet. Although the stars and star clusters that we see in our own Galaxy are within 150,000 light-years of us, other galaxies are usually millions of light-years away. This is about 10 times as far away as the farthest individual stars that we can see. What shape galaxy is the Large Magellanic Cloud? It is an irregular galaxy.

The Large Magellanic Cloud is one of our two companion galaxies. It is only 170,000 light-years away. It is clearly visible to the unaided eye. Have you ever seen it? Not unless you have traveled to the southern hemisphere in summer. The Large Magellanic Cloud is never seen from North America. f you go to Australia, look for it, and for our other companion galaxy, the Small Magellanic Cloud.

Image # 5.37: The Milky Way: Horizon Shot with Trees

Have you begun to wonder what our own galaxy looks like? Have you ever seen the "Milky Way," the band of light that crosses the night sky? What you were looking at is part of the galaxy that we live in. Like other galaxies, ours has billions of stars in it. These stars can be so dense in some regions of the sky that their light blends into a bright band: the well known Milky Way.

Image # 5.38: The Milky Way Within Sagittarius in Visible Light

The Milky Way is best seen on the darkest nights. When you use a telescope to look more closely at a section of the Milky Way on a dark night, many individual stars can be seen. However, in some places the stars are still too dense for us to see more than a cloud of light. This is a telescopic view of an area of the Milky Way Galaxy that is quite densely populated; it is filled with stars. The stars are densest towards the direction of the galactic center, the center of the Milky Way Galaxy. This image was taken in visible light, in the constellation Sagittarius.

Astronomers know that the Milky Way is a spiral galaxy. Why don't we see the spiral shape of our galaxy when we look up into the night sky? Why do we only see a band of light? The shape of our own galaxy is impossible for us to see as we can for other galaxies, because we are inside it! We are in a celestial forest, so all we can see are the trees. Because we are within the Milky Way Galaxy, our views can only be from within, in just the same way that you can't see the shape of a forest if you are inside of it. This image was taken in visible light. The light areas are shining with starlight. The dark areas are clouds of dust that block the light from still other stars.

Image # 5.39: Galactic Center of the Milky Way in Infrared Light

Astronomers can view our Milky Way Galaxy with different kinds of light. This image shows our Milky Way Galaxy from within, in a photograph taken in infrared light. Have you heard of infrared light? In our next mission, we will learn about the electromagnetic spectrum, which includes all types of radiation, including all types of light. One third of the light from our galaxy is emitted in infrared, which is invisible to our eyes. If infrared is invisible, how can we see it? With special cameras, we can take photographs that show us this otherwise invisible light. Infrared light is able to pass through the dust clouds, so the picture is no longer patchy with dark areas.

Image # 5.40: Artist's Conception of the Milky Way Galaxy

As you have calculated, the distances to the stars are so great that we can't travel outside of the Milky Way Galaxy to the view that we see in diagrams like this one, created by artists. There are no photographs of the Milky Way Galaxy taken from the outside. Only extraterrestrials from another galaxy could take that photograph.

Stop and Assess "Galaxies: Billions Upon Billions of Stars"

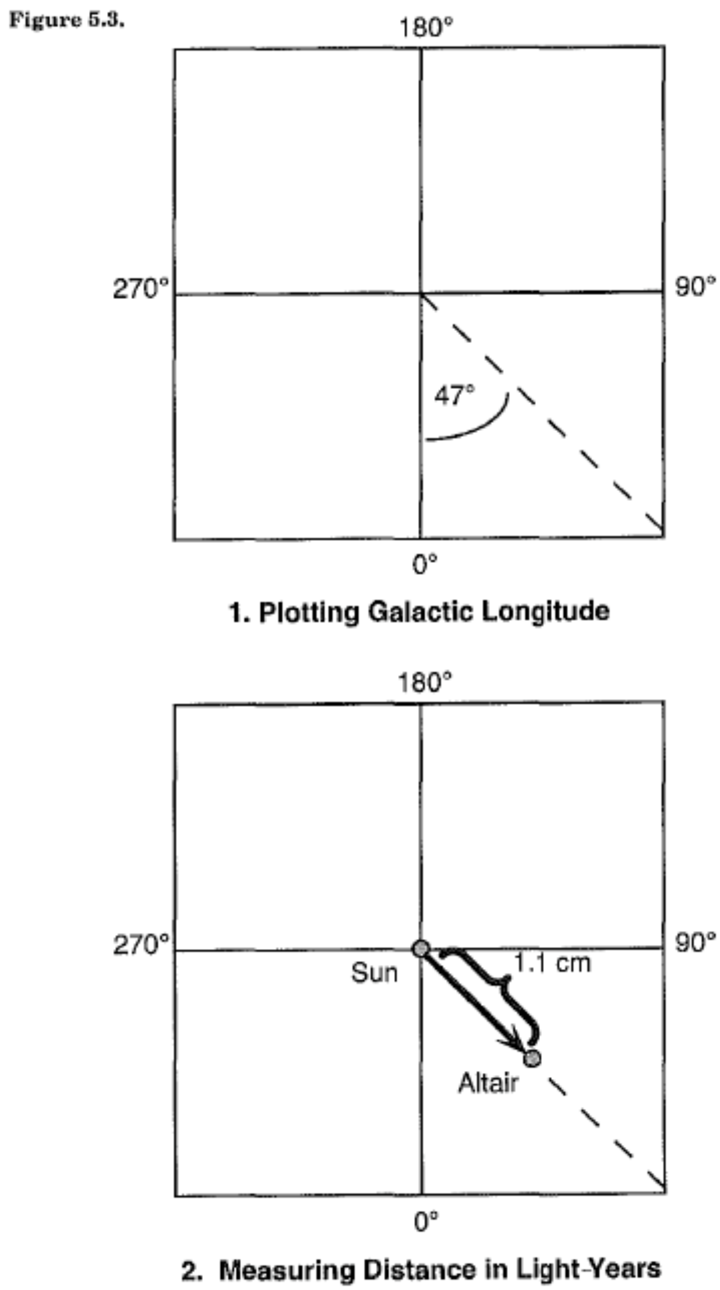
1. Back up and take a second look at various images if students would like to study them.

2. Ask: Can *you* make a model that shows the shape of our home galaxy? All right, you will get a chance to try now.

Mission 5
A Model of the Milky Way Galaxy

Celestial Mapping–Transparency or PowerPoint Slide

Figure 5.3.



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Mission 5
A Model of the Milky Way Galaxy

Making a Celestial Map–Directions

Name: _________________________________ Date:_______________________

1. Obtain butcher paper and tape, if needed, from your teacher. The butcher paper should be roughly 1 meter by 1 meter.

2. Use a meter stick to draw a line down the center and across the middle of the butcher paper. Where the lines cross represents our Sun. Draw it in as a small dot and label it. Label the lines that you drew. Choose one end of the longest line, and label it 0°. Going counter-clockwise, label the next line 90°, the next 180°, and the last 270°.

   To orient you, 0° is the direction toward the center of the Milky Way Galaxy and 180° is the direction away from the center of the Milky Way Galaxy. From this point on, this chart will be referred to as the Vicinity Chart because you will be mapping or plotting the locations of various celestial objects that are the closest to our star, the Sun.

3. Using the data provided, plot the galactic longitude for the second celestial object on your chart, the star Altair. Its galactic longitude is 47°. This represents the direction in degrees from 0° degrees that must be used to plot the object. Center your protractor on the Sun to find this angle. With a ruler, draw a light pencil mark along this line to the edge of your paper.

4. Using the data provided, plot the distance in light-years. Using a scale of 1 cm = 15 light-years, you can now figure out how far away from our Sun the star Altair is. You must calculate this number and fill it in on your chart. Because Altair is 16.6 light-years away from our solar system, and 1 cm = 15 light-years, the star Altair would be only 1.1 cm away from the Sun on your map (16.6/15 = 1.1). It is one of the closer stars in our sky! Measure 1.1 cm along your galactic longitude line and make a small, dark dot at this point to show the location of the star Altair on your map. Congratulations! You have just plotted Altair.

5. Now plot the other objects from your Celestial Map Data–Worksheet. Use both the galactic longitude and the distance in light-years from the Sun to plot the location of each object, as you did with the star Altair. Label each object after you plot its location. If your teacher asks you to do so, draw a small picture of the object in the spot where you plotted it.

6. Some of the objects are so far away from us that they will not fit on your map, even at this scale! When you plot one of these far-away objects, just put a dot at the edge of the paper, and write how much farther you would have to go along that line to reach the object.

Mission 5
A Model of the Milky Way Galaxy

SETI INSTITUTE

Celestial Map Data–Worksheet

Name: ________________________________ Date: ________________________

Table 5.2.

Name of Celestial Object	Galactic Longitude	~Distance in Light-Years	Distance in Centimeters (1 cm = 15 light years)
Aldebaran (Star)	183°	68.0	
Altair (star)	47°	16.6	
Alpha Centauri (Star)	315°	4.3	
American Nebula	84°	2,600.0	
Antares (Star)	354°	326.0	
Arcturus (Star)	15°	36.0	
Barnard's Star	30°	5.9	
Beehive Open Cluster	208°	500.0	
Betelgeuse (Star)	202°	651.0	
Capella (Star)	165°	42.4	
Crab Nebula	185°	6,552.0	
Cygnus Loop Nebula (Veil)	78°	1,630.0	
Deneb (Star)	110°	68.5	
Epsilon Eridani (Star)	195°	10.8	
Hercules Globular Cluster	59°	25,000.0	
Horsehead Nebula	204°	12,000.0	
Lagoon Nebula	7°	3,900.0	
Mizar (star)	112°	58.7	
Omega Centauri Globular Cluster	132°	17,000.0	
Orion Nebula	208°	1,600.0	
Pleiades Open Cluster	168°	440.0	
Polaris (North Star)	130°	430.0	
Rigel (Star)	210°	900.0	
Ring Nebula	63°	4,100.0	
Sirius (Star)	228°	8.6	
Spica (Star)	315°	155.0	
Tau Ceti (Star)	175°	11.7	
Trifid Nebula	8°	3,260.0	
Vega (Star)	68°	26.4	

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Mission 5
A Model of the Milky Way Galaxy

Celestial Map Questions–Worksheet

Name: ____________________________________ Date: _______________________

1. Although you indicated the *direction* of the center of the Milky Way Galaxy on your map, the actual galactic center is beyond your map because it is too far away from our Sun to include at the scale of 1 cm = 15 light-years. The galactic center is about 30,000 light-years away.

   a. Calculate the distance to the center of the Milky Way Galaxy at your map scale.

   The galactic center is _____________ meters away.

   b. At your map scale, calculate the distance to the far edge of the Milky Way Galaxy, which is another 50,000 light-years beyond the galactic center.

   The far edge of the Milky Way Galaxy is ______________ meters away.

   c. At your map scale, calculate the distance to the near edge of the Milky Way Galaxy, which is approximately 20,000 light-years in the opposite direction from the galactic center.

   The near edge of the Milky Way Galaxy is ____________ meters away.

2.
   a. Use your drawing compass to draw a 100 light-year circle around the Sun on your map. Name the stars that you mapped that are within this circle.

   b. Many of the stars that SETI has targeted for listening to with their radio telescopes are within this circle. Why do you think that this is so?

3.
   a. Using the data given below, figure out a way to plot the *Voyager* spacecraft trajectories on your map and show how far out they are now and where they will be at various times, far into the future. Both are moving directly away from the Sun.

Spacecraft	Galactic Longitude	Speed
Voyager I	30°	490 million km/yr
Voyager II	0°	490 million km/yr

   b. Each *Voyager* takes _______________ years to travel 1 light-year.

   c. How long will it take for a *Voyager* to travel 150 light-years? _____________

Mission 5
A Model of the Milky Way Galaxy

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Our Home Galaxy–Directions

Name: ______________________________ Date: ____________________________

1. Obtain white paint, a brush, cotton, glue, and a sheet or piece of plastic from your teacher (maybe a plastic top to a coffee can or a Frisbee). Up until now, your Milky Way Galaxy model has been flat: two-dimensional. Now we will add the third dimension.

2. Measure the thickness of your plastic in millimeters. My plastic is __________ mm. The thickness of your plastic represents the "depth" of the Milky Way Galaxy on a new scale. The average diameter of the Milky Way Galaxy is about 50 times its thickness. In other words, our home galaxy is pretty flat.

3. Calculate the diameter for your galaxy model: My diameter is ___________ mm. Use a compass to draw a circle of this diameter on your plastic. Cut out this circle. You now have a three-dimensional model of our home galaxy.

4. Using the information that your teacher has given you and the pictures that you have been shown regarding the shape of the Milky Way Galaxy, paint an open spiral galaxy. Paint to the edges of the plastic.

5. The real Milky Way Galaxy has a bulge of stars in the center. This bulge is about 20,000 light-years across and it is longer than it is wide. Calculate how thick a piece of cotton would show this. Take the piece of cotton and glue it to the center of your spiral galaxy model. Put half of it on each side of the plastic. Gently pull the cotton to follow the contours of the spiral arms, tapering off as you go. Glue the cotton in place.

6. Using a metric ruler that has millimeter markings on it, measure the distance across your galaxy. Enter that distance here: _______________ mm.

   Knowing that the Milky Way is 100,000 light-years across, how many light-years does one mm represent? _________ light-years. This is your scale for this model.

   How many light-years long and wide is your Vicinity Chart that you completed yesterday?

   length: ________________ light-years

   width: ________________ light-years

How long and wide would your Vicinity Chart be if it were drawn to the scale of your galaxy? Hint: map length in light-years divided by galaxy scale, light-years/ mm.

length :_______________ light-years

width: ________________ light-years

3. Now that you know how big your Vicinity Chart should be compared to the entire Milky Way Galaxy, go ahead and draw the larger Vicinity Chart on the outer section of one of the spiral arms that you drew. Draw it to scale, and in roughly an appropriate location, that is, 20,000 light-years from the edge and 30,000 light-years from the center. If it is too small to draw, just put a dot with the tip of a sharp pencil.

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Mission 6
The Chemical Elements in Stars

Can You See the Light?

Notes

In Mission 5, students made models of the Sun's immediate cosmic vicinity and the Milky Way Galaxy. They learned that there are billions upon billions of stars in our galaxy. But what are these stars made of? Are they made of the same chemical elements that occur on Earth? Because we are so far away from other stars that we cannot visit them to directly sample what elements they consist of, we investigate them indirectly by examining their light—starlight.

Overview

In Mission 6.1, students use prisms to learn about the electromagnetic spectrum. In Mission 6.2, students build and use their own spectroscopes to investigate different light sources to see what types of spectra they produce. In Mission 6.3, students use their spectroscopes to examine the emission spectra of pure elements. In Mission 6.4, students evaluate the spectra from several stars. They discover that some of the chemical elements that make up Earth, and life on Earth, are also found in the stars!

Mission 6.1
Materials

For a Class of 30

- Overhead projector
- Piece of white butcher paper, chart paper or poster paper
- Thermometer
- Source of bright incandescent light
- Source of ultraviolet light (such as a black light)
- 2 meter sticks
- Thumbtack
- Standard screw-type light bulb socket with a 25-watt bulb (clear glass with a long vertical filament works best)
- *(optional)* Radio
- *(optional)* Pictures taken with infrared-sensitive film
- *(optional)* Fluorescent paints and/or minerals (such as calcite)

For Each Team

- Direct sunlight or a light box
- 2 or more clear prisms of different sizes and/or shapes
- Colored pens, markers, or pencils (full "rainbow" set)

For Each Student

- "Light, Color, and Prisms" worksheet (pages 123)
- "Remote Controls" worksheet (pages 124)
- Safety glasses
- Pencil

Getting Ready

1. Copy the worksheets "Light, Color and Prisms" and "Remote Controls" for each student.

2. If you will be constructing light boxes, boxes with light from a bright light bulb projected through a small hole or slit, you will need one light box per team. Experience has shown that holding the prisms in direct sunlight works the best, as indoor white light sources often are not bright enough.

3. Find appropriate places in the classroom for the infrared and ultraviolet demonstrations, and set these up. Try all of the demonstrations. Many of these sound easy but take a little experience to get right.

4. Have a radio available, if one will be used.

Classroom Action

1. **Discussion.** Divide the class into teams of three to four students each. Ask students if they know what the electromagnetic spectrum is. If students are not familiar with the concept of waves, draw a wave shape and label the crest, trough, and wavelength. Discuss the concept of frequency, the number of waves that pass by a fixed point or are received per second (measured in hertz). A brief analogy to sea waves may be useful: the frequency is simply the number of waves that hit the beach in a given amount of time. Also, students can hold a dangling string and shake it at different rates to see waves of different wavelengths. If you have a poster of the electromagnetic spectrum, locate with the class the waves with the longest and shortest wavelength and the highest and lowest frequency. Make this discussion relate to students' everyday lives by identifying the ways that *they* use the electromagnetic spectrum. Encourage students to imagine what their lives would be like without many of our modern-day conveniences that use electromagnetic radiation, such as remote control devices.

2. **Challenge.** Ask students if there are electromagnetic waves in the classroom at this moment. *(There are radio and television waves of course, as well as visible light.)* Ask students how

we know that there are radio and television waves in the classroom? *(We need a "receiver" to detect them because none of OUR senses can.)*

Optional: Turn on a radio and discuss the fact that there are many frequencies of radio waves in the room and the tuner allows you to hear them. (Surprisingly, many students think the radio waves come from the batteries or the AC current where the radio plugs into the wall.) This is a good opportunity to tell them that they will be building their own radio wave detector in mission 8.

3. **Demonstration.** Tell students that they will be dissecting light with a prism. Ask if anyone knows how to make a rainbow. When light from the Sun goes through a prism (made of glass, plastic, water, or any other transparent material) what happens? After several students have voiced their opinions, demonstrate to the class how to project a color spectrum onto a screen using a prism and an overhead projector. What is the source of the color? Was the color inside the "white" light all along but only the prism allows us to see it, or is the color put there by the prism? Allow time for students to respond to these questions, but don't tell them the answer yet.

   Teacher's Note**:** *To project the spectrum, cover the flat surface of the overhead projector except for a narrow slit, ½" to 1" wide, with opaque paper. Black construction paper works well. Hold the prism in front of the head of the projector and rotate slowly in the beam of light until the spectrum appears on the screen or wall.*

   Students think of "white" as a color, and sunlight as being clear or colorless. Explain to them that white is all colors combined, and that different colors are different wavelengths of light. Tell the class that they will be studying light and color for the next few days. The connection between the two may hold some clues about the stars and other distant objects in space.

4. **Activity.** Hand out the "Light, Color, and Prisms" worksheet to each student. Pass out the prisms, colored pens or pencils, and light boxes (if they will be used). Explain that the first step in this study is to carefully document the pattern of colors produced when light from the Sun (or a bright light bulb) is passed through the prism and projected. Students should sketch the colors as accurately as they can. When teams are done with the first prism, they should trade with one another and record the color "print" with a second prism. Allow time for observations and completion of the worksheet.

5. **Data Collection.** On a large piece of white paper, write the question "Is there a color pattern?" across the top. Tape the paper to the wall or whiteboard. After some class discussion, ask for volunteers to re-create their color pattern onto the large poster sheet. Make sure every color pattern students have observed is on the paper. The fact that they all saw very similar spectra produced by all the prisms should lead them to infer that color is a property of the light, not of the prisms.

6. **Demonstration:** Invisible Light (Infrared). Set up a very bright, full-spectrum (continuum) incandescent white light source and a large prism to get a full spectrum of color. (A fluorescent light will not work.) Use a thermometer to measure the normal room temperature.

Hold or tape a thermometer in the red range of the spectrum. Is there a difference in the temperature? *(Yes, but it may be slight.)*

Teacher's Note: The light from a slide projector is full-spectrum.

Put a thermometer in the area just beyond the red color, close to but not touching the red light. Do you note any increase in temperature? *(Yes.)* Stress that any increase in temperature implies that light, and therefore energy, is present.

What is the name of the radiation that is just beyond the red end of the visible light spectrum? *(Infrared.)* Did this area show a temperature increase? *(Yes.)* What can be concluded about infrared radiation? *(It exists just beyond the red visible range.)* What are some uses for infrared radiation? *(Infrared photography; heat-sensing; keeping hamburgers warm at McDonald's.)*

Optional: Find some pictures that were taken with infrared film. Discuss these photos. What do they show? Why are some areas brighter than others? *(They are hotter.)*

7. **Demonstration:** Invisible Light (Ultraviolet). Set up a source of ultraviolet light. Warn students not to look directly at the source producing the ultraviolet radiation as it is harmful to their eyes. Ultraviolet light also reflects off surfaces. Students should only view it through glasses or sheets of glass. In a darkened room, certain minerals (such as calcite and fluorite), even teeth and the phosphorus residue left in clothing after washing, can be illuminated with this type of radiation. Fluorescent paints can be used to paint pictures. Instruct students to view them in normal light and then in ultraviolet light. In normal light, hardly any color is visible, but in ultraviolet light, the painting will be vivid.

Caution: in some schools, fluorescent paints may now be illegal.

What is the name of the radiation that is just beyond violet in the visible spectrum? *(Ultraviolet.)* Which objects seem to show the most luminescence when illuminated with an ultraviolet light? *(Those that contain minerals that "fluoresce," usually those with calcium, fluorine, or phosphorus compounds.)*

Explain that there are animals that use ultraviolet radiation. *(Bees and butterflies see in ultraviolet reflected from the stripes on some flowers and use it to find nectar in these flowers.)*

8. **Discussion.** Finish the class by sharing theories about the sources of color. Tell students that in the next few classes they will continue to explore that question, but that the next step is to build a simple yet more advanced device that also creates a pattern of colors that we can see when light goes through it.

9. **Homework.** Hand out the "Remote Controls" worksheet to each student. Stress the relationship of prisms to remote controls: both use the electromagnetic spectrum. Note that a prism is a passive device because it is splitting the colors already present in light that was

generated by a source; the remote control is an active device because it is a source that generates infrared radiation.

Mission 6.2
Materials

For a Class of 30

- Roll of heavy-duty aluminum foil
- Poster-size sheet of thin tagboard
- Single-hole punch
- Variety of lights (fluorescent, incandescent, colored)

For Each Table

- Roll of masking tape or transparent tape
- Scissors
- Single-edge razor blade

For Each Student

- 1-inch square piece of diffraction grating (holographic grating preferred)
- Cardboard (toilet paper) tube
- Colored pens, markers, or pencils (full "rainbow" set)
- "Building and Testing a Spectroscope" directions (page 126).
- "Using Your Spectroscope" worksheet (page 128)
- Pencil

Getting Ready

1. Ask for paper towel and toilet paper tubes a week or so in advance; most students should be able to bring some from home.

2. Copy the "Building and Testing a Spectroscope" directions and the "Using Your Spectroscope" worksheet for each student.

3. Cut grating into 1" squares and place the squares of diffraction grating into an envelope for safe-keeping.

   Teacher's Note: *Diffraction gratings are degraded by fingerprints. Wear plastic gloves like medical gloves when you are cutting up the squares from larger sheets of material.*

4. Cut the tagboard into squares just a little larger than the diameter of the cardboard tubes being used. With a single-hole punch, make a hole near the center of each.

5. Following the student directions, assemble a prototype of the spectroscope to show to the class.

6. Ensure that materials for building the spectroscopes ready to distribute. Set up a variety of light sources around the classroom.

Classroom Action

1. **Discussion.** Ask students if other solar systems are likely to be common in space, considering the existence of billions of stars. If there are planetary systems around other stars, is that the sole indicator that there are living things inhabiting any of them? Ask the class what requirements and conditions have to exist to support life as we know it. List student ideas. If any of the following basic ideas are not mentioned, add them to the list:

    - An atmosphere
    - Liquid water
    - Not too hot or too cold
    - The chemical elements of life (C, H, O, N, S, P)
    - Enough time for life to start
    - Geologic (planetary) recycling of chemical elements
    - Moderately quiescent conditions

    Could the stars be made of the same chemical elements that support life on Earth? Considering the limitations of space travel as a way of gathering evidence, ask students how we might learn more about the stars. Are stars "sending" us anything? If students do not come up with it themselves, suggest that the starlight itself may contain some interesting information.

2. **Spectroscopes.** Inform the class that today each student will build an advanced color spectrum device that has several advantages over the simple prism. Show the one that you have made. Like a microscope or telescope, it is designed to be aimed at what you want to look at. Its small opening and solid walls make it dark inside, so that the light you're aiming at looks brighter and the colors more vivid. And the special plastic window that you look through, which has thousands of parallel grooves on it, is less expensive than a prism, although very delicate and easy to damage. It is called a diffraction grating and it does the same job as a prism.

    With a spectroscope, it is possible to ascertain what elements a star consists of because each element will absorb and emit certain specific wavelengths of radiation. Even the student built spectroscopes will accomplish this task.

    Teacher's Note: *Throughout the discussion in this lesson, it is assumed that the specific wavelengths emitted by atoms are detected as bright emission "lines." The light appears in the spectroscope as a bright line because it enters the scope through a long, thin slit. However, spectral lines are also often detected as dark absorption lines against a bright continuum background. You may wish to discuss this with students. (See "Teacher Background Information" in the appendixes.)*

3. **Activity.** Hand out the "Building and Testing a Spectroscope" directions to each student. Caution students about damaging the diffraction grating with fingerprints. Students should follow the directions for building the spectroscope. Once they have completed their spectroscopes, make sure to have plenty of light sources around the room for them to observe and study. They can get a nice solar spectrum if they look at sunlight reflecting off a piece of white paper. They should be able to see dark Fraunhofer bands in the solar spectrum; these will appear as dark lines. Explain that atoms absorb the same wavelengths that they emit. The dark "missing" wavelengths (dark lines) were absorbed by atoms in the cooler outer layers of the Sun as the light passed through on its way to Earth.

   Caution students to never look at the Sun directly. This may seem obvious, but warn them not to look at the Sun in a mirror either! Because it does not seem to be "direct" sunlight, some students might try it.

4. **Activity.** Hand out the "Using Your Spectroscope" worksheet to each student. Instruct students to draw what they observe and answer all questions except for the last one.

5. **Homework.** Ask students to answer the last question on their worksheet as homework.

Mission 6.3
Materials

For a Class of 30

- Data projector, computer, PowerPoint file
- Transparency or PowerPoint slide of "Spectrum Observation" worksheet
- Transparency markers or grease pens
- One spectrum-tube power supply*
- 5 or 6 different gas tubes (H, He, Ne, N, O, Na)*
- *(optional)* Poster of spectrum emission lines

For Each Student

- Student-made spectroscopes from Mission 6.2
- Colored pens, markers, or pencils (full "rainbow" set)
- "Spectrum Observation" worksheet
- *(optional)* Commercially made and calibrated spectroscopes
- Pencil

**This equipment is expensive, but it's an excellent way for students to directly observe the emission lines of some of the pure elements. If you don't have it, try to borrow the equipment from a high school in your district*

Getting Ready

1. Obtain or borrow from a high school one spectrum-tube power supply and six different gas tubes (H, He, Ne, N, O, Na).

2. Arrange a cluster of chairs around the spectrum-tube power supply (chairs should all be within a 5- to 1-foot radius). Place the power unit as high as possible so that students in the back can see (on a chair placed on a table perhaps). For their observation to be successful, students must be close to the light.

3. Copy the "Spectrum Observation" worksheet for each student.

4. Set up the PowerPoint projector.

5. If you will be using any commercial spectroscopes, make sure they are calibrated first; otherwise there will be a lot of confusion!

Classroom Action

1. **Discussion:** Chemical "Fingerprints" in Light. So far, students have discovered that light–especially white light–is not such a simple thing. Ask if anyone can explain this more fully. Ask students to share any observations made at night with their spectroscopes. Were there any interesting discoveries? Was it possible to get a spectrum from the moon or stars?

   The colors that make up light may be a clue to the nature of the object that is giving off the light. Ask what that might be. Color indicates temperature of stars; red stars are cooler, blue and white stars are hotter. Could this information alone tell you exactly what kind of stuff is producing the light? *(No.)*

   Explain that to more accurately find out what stars are made of, students will observe samples of some *pure* elements that are energized in a glass tube (just the same way that neon lights work). But before we can interpret the light of the stars, we must be clear about the "light signature" or "fingerprint" of each element by experimenting in the lab.

2. **Demonstration.** Gather students in front of the spectrum-tube power supply. Darken the room. Put in one of the gas tubes (helium is a good one to start with), turn on the power supply, and allow students to observe with their spectroscopes. After a brief time, turn off the power and ask for student observations.

   Optional: If you have them, pass out the commercial spectroscopes (one for every two students) that have a built-in spectrum scale. It is not important to know what the numbers stand for (they are labeled in Angstrom units, which is a wavelength measurement: 1 Angstrom = 1 x 10^{-10} m), but they will help students be more accurate in their observations. Turn on the same spectrum tube (helium) and give time for everyone to get a feel for using the scale and numbers. Tell them to concentrate on *where* they see bright lines (called emission lines) and *what color* these bright lines are.

   Teacher's Note: *If you could not locate the spectrum-tube power supply, use the color transparencies. These images show the colored lines, so students may draw from them, but* *they cannot use their spectroscopes. This is a simulation only. The authors highly recommend the spectrum tubes.*

3. **Transparency or PowerPoint Slide.** Ask for volunteers to draw in what they saw on the blank overhead transparency of the "Spectrum Observation" worksheet. Make sure that everyone is in agreement, and ask what caused the emission lines. Make sure students realize that these emission lines are caused by the glowing helium gas, and that no other element will show lines exactly like the ones they are viewing right now for helium. In this way, emission spectra from elements are similar to fingerprints for human beings. No two elements have exactly the same pattern of emission lines.

4. **Worksheet.** Hand out the "Spectrum Observation" worksheet and colored pens, markers, or pencils to each student. Demonstrate how to record observations for each test element.

   Teacher's Note: Please notice that there are color bands labeled on the worksheet and that spectral lines of various colors are to be placed within the correct color band. Impress upon students to be as accurate as possible so that the class can share their observational data.

5. **Activity.** Begin the series of observations of all your spectrum tubes, allowing about 3-5 minutes for each test. Either at the end of each test, or at the end of the series of tests, ask for volunteers to come to the overhead projector and draw the spectral lines that they saw.

6. **Discussion.** To summarize, ask what the light signature of each element has in common. How were they different? *(The number, thickness, color, and pattern of lines varies with each element. This is due to the unique "fingerprint" nature of the lines associated with each element.)*

   After students have viewed all the tubes and discussed the meaning of the spectral lines they observed, make sure that all students have accurate emission spectra data for helium, hydrogen, neon, sodium, nitrogen, and oxygen. This is important because students will use their data to interpret the "fingerprints" of six unknown stars on their worksheets in Mission 6.4. You may wish to hand out copies of the teacher's key to "Spectrum Observation" or show a transparency of the key on the overhead projector. Ask students to compare their observations with any of the same elements that are on their worksheet. Do their data look similar? Why or why not?

Mission 6.4
Materials

For a Class of 30

- Data projector, computer, PowerPoint file
- The *Project Haystack* PowerPoint presentation
- "Star Light, Star Bright" DVD script (pages 111-114)
- Overhead projector
- PowerPoint slide of He, H, Ne, N, O

For Each Student

- “Unknown Stars” worksheet (page 130)
- “Project Procyon: Spectra of Seven Elements” worksheet (page 131)
- “Project Procyon: Spectra of Five Stars” worksheet (page 132)
- “Project Procyon: Questions” worksheet (page 133)
- Completed “Spectrum Observation” worksheet from Mission 6.3
- Pencil

Getting Ready

1. Copy the “Unknown Stars” worksheet and the three “Project Procyon” worksheets for each student.

2. Set up the data projector. Start the PowerPoint presentation at the segment “Star Light, Star Bright.” Have the script handy.

Classroom Action

1. **Slide Show.** Show the images of emission spectra in “Star Light, Star Bright.” A script has been provided. It can be used as is to accompany the DVD, or its information can be paraphrased. If you used the spectrum tubes, this image show can serve as a review, with an added introduction to the analysis of the spectra of stars. The main point is: if a star contains hydrogen, the hydrogen pattern of spectral lines would be visible though a spectroscope. If a star contains two different elements, the spectral lines for both elements would be present when viewed through a spectroscope. In reality, stars are made up of many elements and, therefore, the stellar spectra viewed by scientists are usually very complex.

   Teacher's Note: *The absorption of light mentioned in “Teacher Background Information” in the appendixes complicates the situation by subtracting some wavelengths (creating dark lines), but this is a useful simplification for younger students.*

2. **Activity.** Hand out the “Unknown Stars” worksheet to each student. These do not represent actual stars, but are simplified models of stars, with fewer overlapping spectral lines than real stars would have. Students must list whatever elements are found in these unknown stars by comparing their own emission spectra with the spectra of the unknown stars. Students may become confused because this page is in black-and-white. Explain that the lines represent the same colored lines they have seen before. They may trace over them with the appropriate colored pencils if that helps them to see. This exercise impresses upon students that stars are in fact composed of several elements, not just one kind.

3. **Activity.** Hand out the three “Project Procyon” worksheets to each student. Students will now analyze five real stars with complex spectra. They should use the “Project Procyon: Spectra of Seven Elements” worksheet that is printed on a different scale from their own

chart (“Spectrum Observation” worksheet). It also lists three new elements that are common in stars: iron, magnesium, and lithium. This chart corresponds to the five real stars.

4 **Discussion.** As a wrap-up, students compare their findings. Allow time to complete the “Project Procyon: Questions” worksheet in class, or assign it as homework.

Going Further

Research-Activity: Neon Lights

Students have observed samples of certain pure elements that are energized inside a glass tube, which is how neon lights work. But are neon lights really made of neon gas? What is neon? What color is neon? Ask students make a list of colors seen in neon lights in your town. Instruct students to find out how these lights are made and what causes their brilliant neon colors. Is it the spectral glow of certain gases, or are the tubes themselves colored? If you have access to one, bring a neon novelty lamp to class and explain how it works.

Activity: Colorful Stargazing

Encourage students go out at night and look at the stars. Then ask if they can tell which ones are “red,” “white,” and other colors? In a city, light pollution will make it hard to tell the color of stars, and it will even reduce the number of stars that can be seen. Darker nights are best. Ask students to borrow binoculars or a neighbor’s telescope if they don’t have one or the other of their own. This will help them to see the colors. Ask some students to set up cameras with tripods for long exposure photographs. As stars move across the sky, color film will record their motion as colored streaks, or trails. Exposure times of several minutes are recommended, with the lens diaphragm wide open (lowest F/stop).

Ask students to find a constellation they recognize. Without looking at an astronomy book to see what color each star is supposed to be, they should make a sketch of the stars in the constellation using colored pens. Then they should compare the colors in their sketches with those in star charts. Color indicates temperature of stars: red stars are cooler, white stars are hotter. Ask students to look at the stars again and ask which are the coolest? The hottest?

Activity: Extraterrestrial Vision

Many animals that have evolved on Earth see in the same visible light range that we humans see in. But we cannot *expect* extraterrestrials to see in the same part of the spectrum that we do! Ask students what we would look like to an extraterrestrial with infrared vision. Gamma-ray vision? What would Superman actually see if he existed and had x-ray vision? *(Actually, not much, because there are very few x-rays around to see on Earth’s surface– most everything would be black! That’s why x-ray telescopes are launched into space; none of the x-rays that originate outside Earth can get through our atmosphere.)*

Activity: A Prism Made from Water

A prism can be made from ordinary water. Obtain an oblong glass dish about two inches deep, a white card, a small mirror that will fit into the dish, some foil, and a small stone. Cut a 1-by-½ inch window in the foil, and then wrap the foil around the mirror. Fill the dish with water. Place the mirror in the water. Use the stone to prop the mirror up against the short side of the dish. Put the water prism in direct sunlight, or focus a bright light on the mirror indoors. Move the white card around until the light reflecting off the mirror falls on it. Display this prism in the classroom.

Activity: Magnifying a Rainbow

Can a magnifying glass be used to make a rainbow bigger? Ask students to try it. Use a water prism, or any prism, to make a rainbow appear on a white card. Put a magnifying lens in the path of the separated light. What happens? (*If you hold it about three or four inches from the card, facing the mirror, the rainbow disappears–it turns back into white light!)* Ask students to explain why this happens. *(The lens combines the colors that the prism separated.)*

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Mission 6
Script for Video Images

"Star Light, Star Bright"

If you used the spectrum tubes, this image show will serve as a review, with an added introduction to the analysis of stars' spectra. Use the DVD and transparencies to verify students' earlier observations. It is important to standardize the position of the emission lines on the Student Worksheet: "Spectrum Observation," so students can use their observations to analyze the elements which are present in their worksheet: "Unknown Stars." If you were not able to use spectrum tubes, this image show will have to serve as a substitute. Hand out the Student Worksheet: "Spectrum Observation" and colored pens or pencils. Demonstrate how to record observations for each test element. Begin the series of observations of all the images, allowing about three minutes for each element.

Introduction

Many ancient peoples called stars "the lights in the sky." Today, we can interpret the light of the stars and find out what elements they are made of. We can see if the stars are made of the same elements that we are made of.

Image # 6.41: White Light, Rainbow Spectrum

You have discovered that white light is actually composed of all of the colors of the rainbow. You have used a prism to refract light waves into a rainbow. This is the same process that occurs when you see a real rainbow in the sky after a rain. Water droplets in the atmosphere act as prisms and bend the light. A full rainbow is called a spectrum. In this image, a light bulb produces white light that includes all the colors of the rainbow, so it produces a "continuous spectrum."

Teacher's Note: *You may want to spray mist in front of a light–an overhead–to produce a rainbow. Do not spray directly on a bulb as it may explode.*

Image # 6.42: Continuous Spectrum

This is a close-up of a "continuous spectrum." Notice that there are numbers along the top and the bottom of the spectrum. These numbers are Angstrom units; they are a measurement of wavelength. 1 Angstrom = 1×10^{-10} m. Scientists use these numbers to describe exactly what color they are talking about. What wavelengths correspond to the color "red"? *(Red is any light from about 6200 angstroms to 7500 angstroms in wavelength.)* You may use these numbers to be more exact and accurate in your observations of spectra. Commercial spectroscopes have a built-in spectrum scale with these measurements.

Image # 6.43: Wavelength and Frequency: Violet Waves and Red Waves

Light travels in waves. This picture shows two waves of different wavelengths. The shorter wave length is 3500 angstroms, which is violet. The longer wavelength is 7000 angstroms, which as we have seen is red. This longer wave is twice the wavelength of the shorter wave.

The visible spectrum contains light that ranges in wavelength from 3500 angstroms on the violet end to 7500 angstroms on the red end. What kind of light occurs at wavelengths shorter than 3500 angstroms? *(Ultraviolet light.)* What kind of light occurs at wavelengths longer than 7500 angstroms? *(Infrared light.)* What kind of light occurs at a wavelength of 5400 angstroms? *(Visible green light.)* All the colors that the human eye can detect are produced by light with wavelengths between 3500 and 7500 angstroms.

Image # 6.44: The Spectrum of Sodium

Although white light produces a continuous spectrum, individual chemical elements produce only a part of this spectrum. Sodium is a common element, which is found in table salt (sodium chloride). If pure sodium is burned, and viewed as in this image, it produces two distinct yellow lines that are close to each other, occurring at around 5850 angstroms. These bright lines are called emission lines. The entire spectrum of emission lines is called an emission spectrum. The emission spectrum of sodium is very simple. No other element will make spectral lines exactly like the ones you are viewing right now for sodium! That is why scientists call an emission spectrum the "light signature" or "fingerprint" of an element. Just as no two people have exactly the same signature, or the same fingerprints, no two elements have the same emission spectrum.

Image # 6.45: The Spectra of Stars

This image shows the spectra of six stars. Astronomers know that if a star contains sodium, this sodium pattern of emission lines would be visible though a spectroscope when we look at that star's light. Can you see the spectral lines of sodium on any of these stars? *(Yes, on all of them!)*

Why are there so many other spectral lines? *(Stars are composed of several elements, not just one kind.)* The main point is: If a star contains two different elements, the spectral lines for both elements would be present when viewed through a spectroscope. In reality, stars are made up of many elements; therefore, the spectra viewed by scientists are usually very complex.

You will soon be asked to analyze the spectra of some "unknown stars" to see what elements they are made of. To do this, you must know what the emission lines for each pure element are like. This can be done by burning the element and looking at the flame, by using special "spectrum tubes," or simply by looking at the patterns that scientists have discovered. In this image show, we will look at the patterns.

Teacher's Note: *The continuous spectra with the dark lines is the spectrum from the star. The emission line spectrum above and below each continuous spectrum is a reference, or laboratory spectrum. So, the sodium lines appear as dark lines in the yellow part of the continuous spectrum in the same place as the bright sodium lines appeared earlier.*

Image 6.46 Neon and Sodium

The emission lines in the top spectrum are the ones caused by glowing neon gas. No other element will make lines exactly like the ones you are viewing right now for neon. If a star contains neon, this neon pattern of spectral lines would be visible through a spectroscope when we look at that star's light. Concentrate on *where* you see bright emission lines and what *color* these bright lines are. Draw these lines on your worksheet.

The emission lines in the bottom spectrum are the ones caused by glowing sodium gas. No other element will make lines exactly like the ones you are viewing right now for sodium. If a star contains sodium, this sodium pattern of spectral lines would be visible through a spectroscope when we look at that star's light. Concentrate on *where* you see bright emission lines and what *color* these bright lines are. Draw these lines on your worksheet.

Image 6.47 Helium and Hydrogen

The emission lines in the top spectrum are the ones caused by glowing helium gas. No other element will make lines exactly like the ones you are viewing right now for helium. If a star contains helium, this helium pattern of spectral lines would be visible through a spectroscope when we look at that star's light. Concentrate on *where* you see bright emission lines and what *color* these bright lines are. Draw these lines on your worksheet.

The emission lines in the bottom spectrum are the ones caused by glowing hydrogen gas. No other element will make lines exactly like the ones you are viewing right now for hydrogen. If a star contains hydrogen, this hydrogen pattern of spectral lines would be visible through a spectroscope when we look at that star's light. Concentrate on *where* you see bright emission lines and what *color* these bright lines are. Draw these lines on your worksheet.

Image 6.48 Nitrogen and Oxygen

The emission lines in the top spectrum are the ones caused by glowing nitrogen gas. No other element will make lines exactly like the ones you are viewing right now for nitrogen. If a star contains nitrogen, this nitrogen pattern of spectral lines would be visible through a spectroscope when we look at that star's light. Concentrate on *where* you see bright emission lines and what *color* these bright lines are. Draw these lines on your worksheet.

The emission lines in the bottom spectrum are the ones caused by glowing oxygen gas. No other element will make lines exactly like the ones you are viewing right now for oxygen. If a star contains oxygen, this oxygen pattern of spectral lines would be visible through a spectroscope when we look at that star's light. Concentrate on *where* you see bright emission lines and what *color* these bright lines are. Draw these lines on your worksheet

Image 6.49 Two Unknown Stars

Here is a chance for you to test your skills! These are the spectra of two different "Unknown Stars." Can you tell which elements are present in each star? Look closely, and use your worksheet to compare the emission lines. *(The first unknown star has hydrogen and sodium. The second unknown star has hydrogen and helium.)*

Both of these "Unknown Stars" only had two elements. These are simple examples. Look out! Real stars, and the Unknown Stars on your worksheet, have more than two elements present! This will take some good detective work. You will now have a chance to analyze three simulated, "unknown stars" for practice, and then you will analyze five real stars with complex spectra.

Stop and Assess "Star Light, Star Bright"

1. Back up and take a second look at various images if students want to study them.

2. After you have viewed all the images and discussed the meaning of the spectral lines they have observed, make sure that all students have accurate spectral data for helium, hydrogen, neon, sodium, nitrogen, and oxygen.

3. Ask: Can *you* identify all the elements in a star by looking at the light of that star?

Mission 6
The Chemical Elements in Stars

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Light, Color, and Prisms–Teacher's Key

1. The two color "prints" should show the same colors, in the same order or arrangement, but the widths and intensities may be different.

2. This drawing should include the same six (or seven) basic colors: red, orange, yellow, green, blue, (indigo), and violet. (The seventh color, indigo, is seldom clearly different from blue or violet. Isaac Newton included it primarily due to his belief in the sacredness of the number seven.)

3 The color is part of the white light. White light is made up of many different wavelengths or colors. The prism, due to its shape, spreads the white light out into its several wavelengths *allowing* you to see the colors.

4. Stars give off light in a number of wavelengths, which combine to form white light. The Sun gives off white light and the Moon and other planets reflect some of this white light back to Earth.

5. They do! If you split up the white light coming from a star with a prism the light spreads out and it is possible to see the different wavelengths that make up the white light. However, starlight is too faint to do this without a sophisticated setup.

6. It is possible through a fairly simple arrangement of two prisms. If one prism is used to split up light, another prism positioned upside down with respect to the first one will reconstruct the white light. You will need to adjust the distances and the angles until it works.

Mission 6
The Chemical Elements in Stars

Remote Controls–Teacher's Key

1. Answers will vary: television, CD player, and so on.

2. The remote control needs batteries to create light in the infrared region of the spectrum.

3. There should be a clear or dark plastic panel somewhere on the front of the device. Behind this panel is a detector that can receive energy from the remote control device.

4. Depending on the strength of your remote control device it is possible that it will work at both 90° and 180°, while some devices barely work when they are pointing directly at the panel.

5. Again, some will and others will not, depending on their effectiveness.

6. When we tested our remote control device we got the following results:
   a. No (too thick)
   b. Yes
   c. No (electromagnetic radiation at these wavelengths will not penetrate any good electrical conductor, *e.g.*, metal)
   d. Yes
   e. Yes
   f. Yes
   g. No (too thick)
   h. No (electrical conductor)
   i. No (too thick)

7. Examples might include: a pillow, plastic plate, wood, and so on.

8. You have to point the remote control device directly at the glass or mirror and then have the angle from the glass to the detector panel be the same as the angle from the other side of the glass to the remote control device (the angle of incidence must equal the angle of reflectance).

9. The remote control device operates by sending infrared light from the remote control device to the detector panel. If a material allows this light to pass through it, then the controller will operate the device. In general thin, non-conducting materials like paper and cloth will transmit light. The light can also be bounced off the ceiling and various materials with a powerful controller.

10. The light spreads out in many directions and enough reaches the detector to have it detect the light. Some of the light is also reflected off of various objects and materials in the room including walls and ceilings and eventually reaches the detector.

11. Most remote control devices work in infrared wavelengths of the electromagnetic spectrum.

12. Wavelength is approximately 10,000 Angstroms or 10^{-6}m and frequency is 3 x 10^{14} Hertz.

Mission 6
The Chemical Elements in Stars

Using your Spectroscope–Teacher's Key

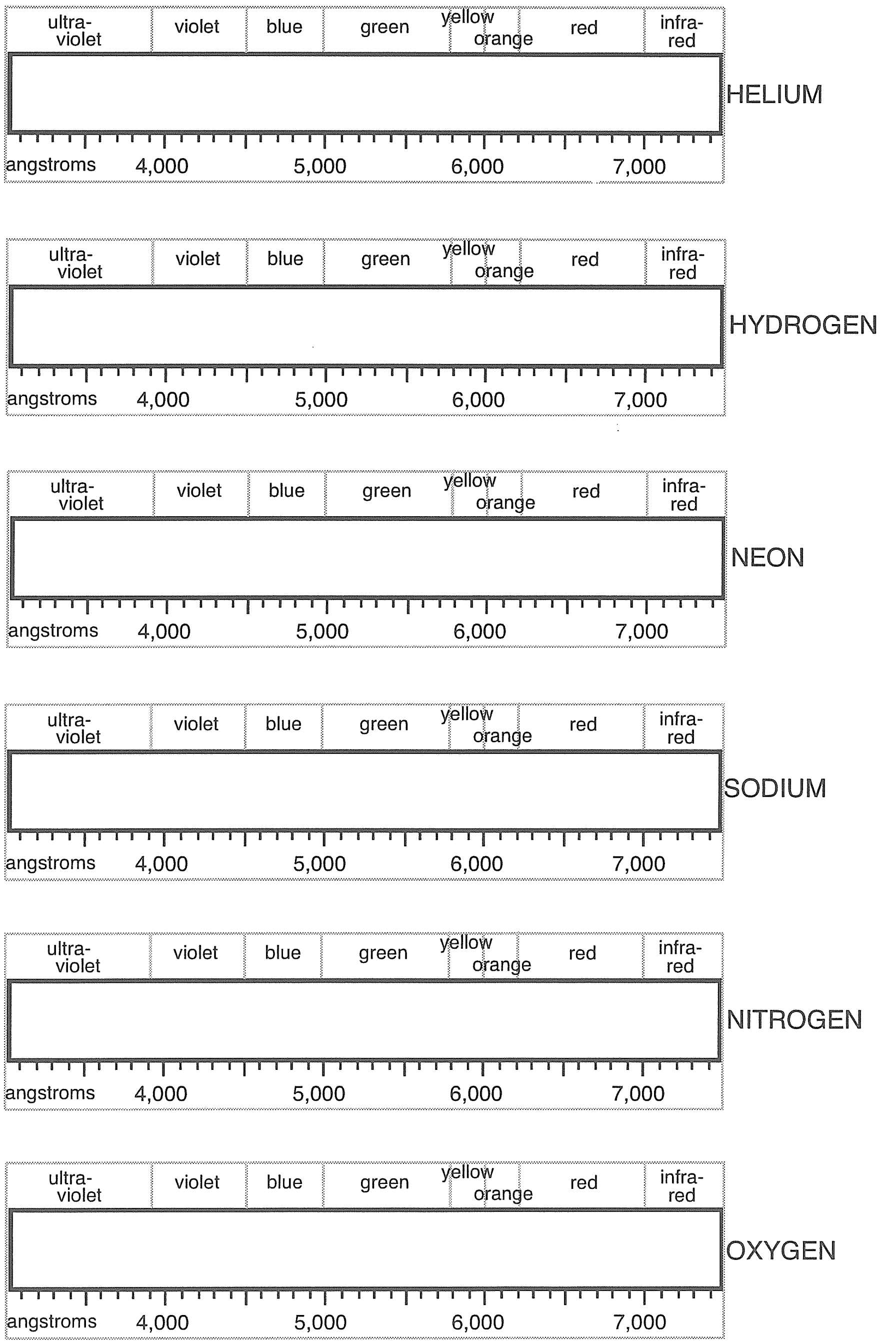
1. The sources of the colors that you are observing are the various elements that are present. These elements are in their atomic or molecular forms and can be excited with an electric current coming from the wall, or with batteries. Each color (or spectral line) is created when an electron is forced to jump from one orbit to another in the atom of that element. The orbits are spaced differently in different elements, causing the light created by the jumps to be of different wavelengths.

2. We see different spectral lines because the light sources contain different elements. Each element has a unique color signature or set of spectral lines. Even though the light from different light sources appears to be white light, it actually has dominant wavelengths due to its specific elements. When you look at a light source with a grating you see the dominant wavelengths that correspond to the element's "spectral lines." This implies that every spectrum consists of discrete lines. However, an incandescent light or the Sun produce continuum light as well. That is light that is spread over the entire visible spectrum. The concept of a continuum may need to be addressed, both because the Sun (or any star) produces such a thing, and because if you don't mention it, students who look at incandescent light and fail to find lines may think they're doing something wrong. The distribution of continuum light is determined by a star's temperature, and that is why the color of a star is a direct indicator of how hot it is.

Mission 6
The Chemical Elements in Stars

Spectrum Observation–Teacher's Key

Figure 6.1.



Mission 6
The Chemical Elements in Stars

Unknown Stars–Teacher's Key

The "unknown stars" contain:

Star # 1: Hydrogen and Neon
Star # 2: Hydrogen, Helium, and Oxygen
Star # 3: Neon and Oxygen
Star # 4: Helium, Sodium, and Oxygen
Star # 5: Hydrogen, Sodium, and Nitrogen
Star # 6: Helium and Nitrogen

Mission 6
The Chemical Elements in Stars

Project Procyon Questions–Teacher's Key

1. Nitrogen and Oxygen.

2. Iron, Lithium, and Magnesium.

3. There are over 100 elements; each list selected a few common ones. In class, we used nitrogen and oxygen because they are common elements in living things. In "Project Procyon," iron, lithium, and magnesium were used because they are common in stars.

4. The "Project Procyon" stars are:

   Procyon: Hydrogen, Sodium, Lithium, Helium

   Betelgeuse: Hydrogen, Iron, Neon, Sodium, Lithium, Magnesium, Helium

   Aldebaran: Hydrogen, Iron, Sodium, Lithium, Magnesium, Helium

   Sirius: Hydrogen, Helium

   Sol (our Sun): Hydrogen, Iron, Sodium, Lithium, Magnesium, Helium

5. No. The spectral lines of some elements are missing from all stars except Betelgeuse.

6. Hydrogen and Helium.

7. Possible explanations: Lines of other elements and/or molecules; interference lines from terrestrial sources such as sodium vapor street lights.

8. Possible explanations: The thickness of the line may be proportional to the quantity of the substances; thicker lines may really be composed of many narrow, densely packed lines. *(Optional: The thickness of the line may depend on pressure in the stellar atmosphere. The lines will also be thicker if the star is rotating rapidly.)*

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Mission 6
The Chemical Elements in Stars

Light, Color, and Prisms–Worksheet

Name: ___________________________________Date: __________________________

Draw what you see using two different prisms.

Prism One: Prism Two:

1. Describe the ways in which the two color "prints" are similar and different:

2. Draw what you would expect to see if you did the same thing again with a third prism:

Prism Three:

3. What is your idea about the source of the color? Is it a part of the light from your light source (Sun or light bulb) that the prism just allows us to see, or is the color put there by the prism?

4. What objects that give off white light are very far away from Earth?

5. Do you think these objects would also create a spectrum such as you have observed today? Why or why not?

6. Do you think that it is possible to "put the white light back together"? You can have as many prisms as you like. Jot down your idea for how to accomplish this task and, with your teacher's permission, go ahead and give it a try!

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Mission 6
The Chemical Elements in Stars

Remote Controls–Worksheet

Name: ______________________________ Date: _____________________________

Locate a remote control device at your home or the home of a neighbor or friend. Examples are remote-controlled cars or other toys, a television, a CD or DVD player, or a VCR. Conduct as many of the experiments with your remote control as you can.

1. What is the name of the device that you are trying to operate with the remote control?

2. Why do you think that the remote control needs batteries?

3. Look at the device that you are trying to operate. Where does it receive the energy that comes from the remote control?

4. Will your remote control operate the device if you aim it:

   90° to the side of the device?

   180° (the opposite direction from the device)?

5. Will your remote control operate the device if you aim it:

   at the ceiling?

   at the floor?

6. Point the remote control through the following items and note whether or not your device will turn on or off:

   a. Your hand:___________
   b. A sheet of plain paper: _____________
   c. A piece of foil: ________________
   d. A piece of your clothing: _______________
   e. A piece of glass (aim it through a drinking glass): __________________
   f. A piece of plastic wrap or plastic bag: ___________________
   g. A telephone book: _____________________
   h. A metal pan from the kitchen: ___________________
   i. The bottom of a rubber-soled shoe: ___________________

7. Now test your remote control through two items/objects at your house that are not on the list above. State the name of the object and whether or not the electromagnetic energy got through.

8. Try this one! Go into the next room and try to bounce some energy from your remote control off of a piece of glass or a mirror to your device. Could you make this work?

   If this worked, what precisely did you need to do?

9. What conclusions can you make about how your remote control operates? Does it seem to operate through certain types of materials but not others?

10. If your remote worked when it wasn't pointed directly at the device, speculate as to how this might happen.

11. What type of electromagnetic energy do you think your remote control is producing?

12. Based on your answer to # 11 above, look on a chart that has information regarding the electromagnetic spectrum and write the approximate wavelength and frequency of this type of radiation.

Mission 6
The Chemical Elements in Stars

Building and Testing a Spectroscope–Directions

Name: ____________________________________ Date: ________________________

1. Be sure you have a cardboard tube, some aluminum foil, a small square of tagboard with a hole in the center, a small piece of diffraction grating, tape, scissors, and a razor blade.

2. Cut the square of tagboard so that it is just big enough to cover one end of the cardboard tube.

3. Tape the small square of plastic over the hole in the piece of tagboard. Don't cover the grating or the hole with tape. This special plastic is called a *diffraction grating.* Don't smudge it with your fingers!

4. Tape the tagboard piece to one end of the cardboard tube, with the hole centered and the diffraction grating on the inside.

5. Cover the other end of the tube with aluminum foil, pulling it tight and smooth.

6. Cut a small slit across the center of the foil with the razor. Make it very thin.

7. Put your eye to the diffraction grating window and point the slit at the other end of the tube directly at a bright light source in the room.

8. Rotate the tube within the aluminum foil cap until you see the best separation of colors. Tape the foil in place.

9. Take 10 minutes to carefully observe different light sources in the room. Your teacher may have a candle, a white light bulb, an image-projector bulb, an overhead-projector bulb, or other sources of light. Do not look at the Sun. Using colored pencils or markers, draw as carefully as you can what you observe when you point the spectroscope at a light source, paying special attention to the number of spectral lines and their colors.

   Record your observations in the spaces provided below:

Figure 6.2

Light Source #1

Light Source #2

Light Source #3

Light Source #4

Mission 6
The Chemical Elements in Stars

Using Your Spectroscope–Worksheet

Name: ______________________________ Date: ____________________________

Your mission for homework is to study four different sources of light with the spectroscope that you made today. Ideas of what to look at might be: street lamps (if they are different colors, they will give off different emission spectra), the color television, the light bulb in your refrigerator, the Moon, a star, any lights around your house, neon signs at a store in your neighborhood, candle flames, light from a gas stove (observe with parental permission, and the lights on) or anything else that gives off light. Do not look at the Sun.

Using colored pencils or markers, draw as carefully as you can what you observe when you point the spectroscope at a light source, paying special attention to the number of spectral lines and their colors.

Record your observations in the spaces provided below:

Figure 6.3

Light Source #1

Light Source #2

Light Source #3

Light Source #4

1. What do you think is the source of the colors that you are observing?

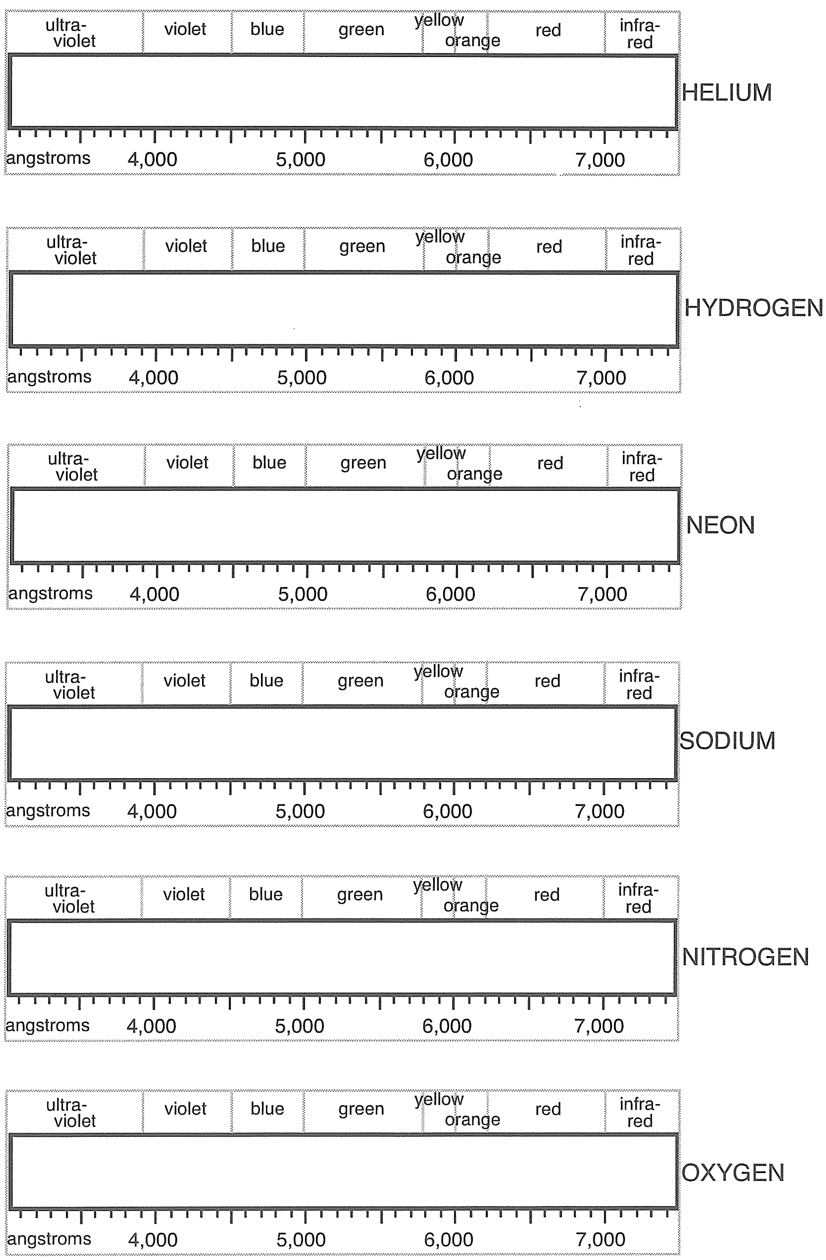
2. Why do you think that the lines, called "spectral lines," are different when you look at sources of white light that for the most part seem to look the same to our eyes?

Mission 6
The Chemical Elements in Stars

Spectrum Observation–Worksheet

Name: ______________________________ Date: ____________________________

Figure 6.4.



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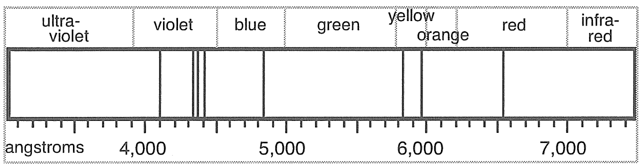
Mission 6
The Chemical Elements in Stars

Unknown Stars–Worksheet

Name: ______________________________ Date: ______________________________

Figure 6.5.



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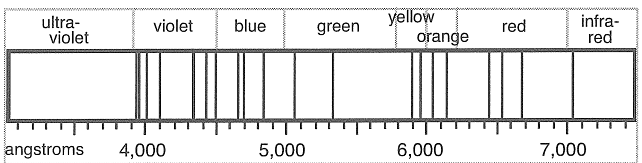
ELEMENTS IN THIS STAR



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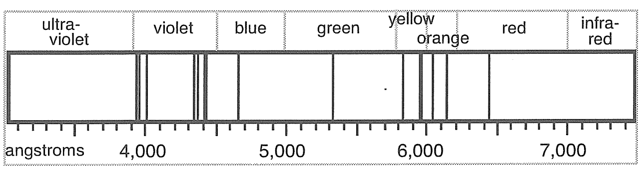
ELEMENTS IN THIS STAR



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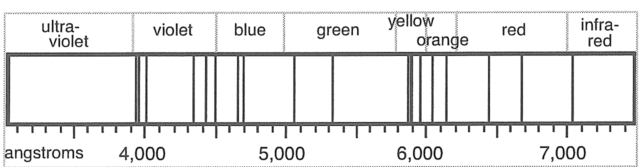
ELEMENTS IN THIS STAR



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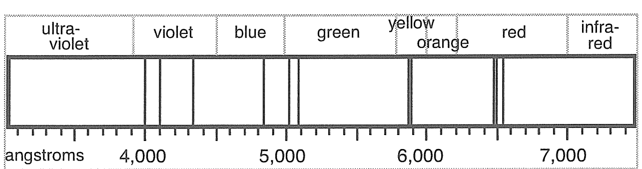
ELEMENTS IN THIS STAR



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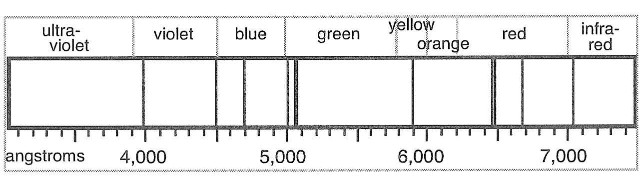
ELEMENTS IN THIS STAR



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ELEMENTS IN THIS STAR

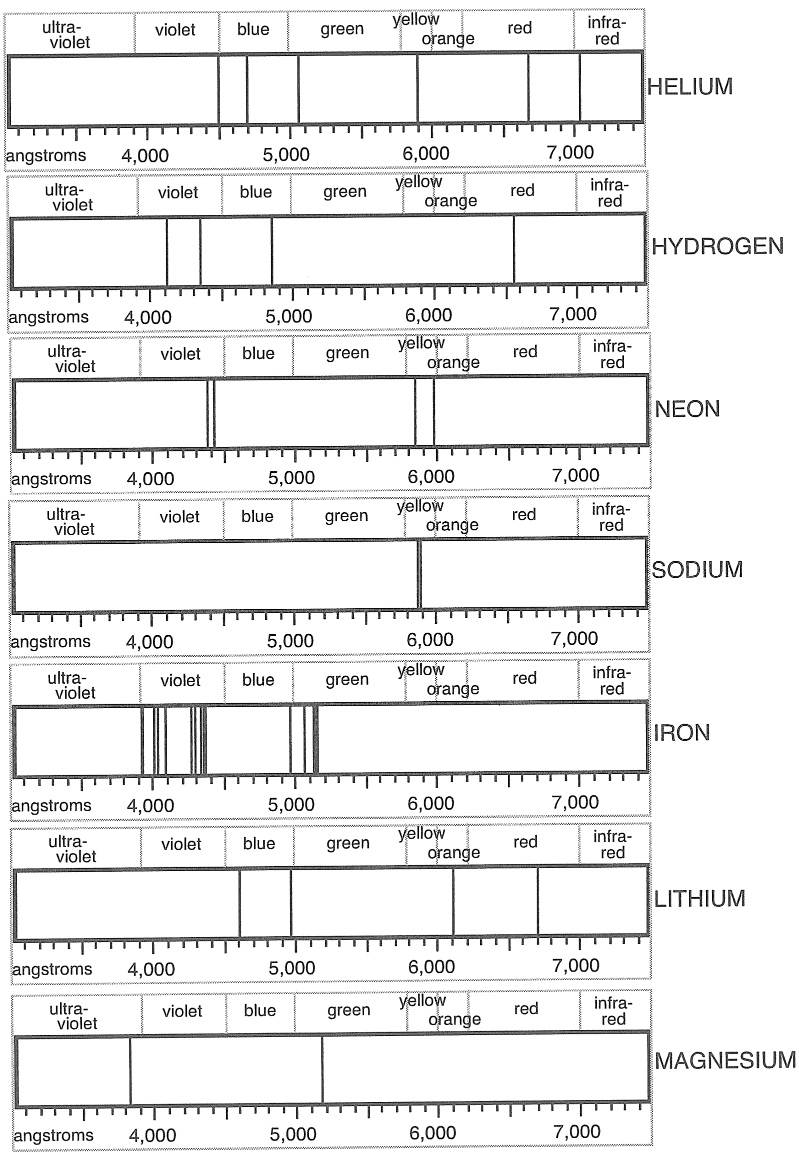
Mission 6
The Chemical Elements in Stars

Project Procyon: Spectra of Seven Elements – Worksheet

Name: ________________________________ Date: __________________________

The following spectra are printed in black and white instead of in color, but they represent colored bands. If you wish, you may add the correct colors with pencils or pens.

Figure 6.6.



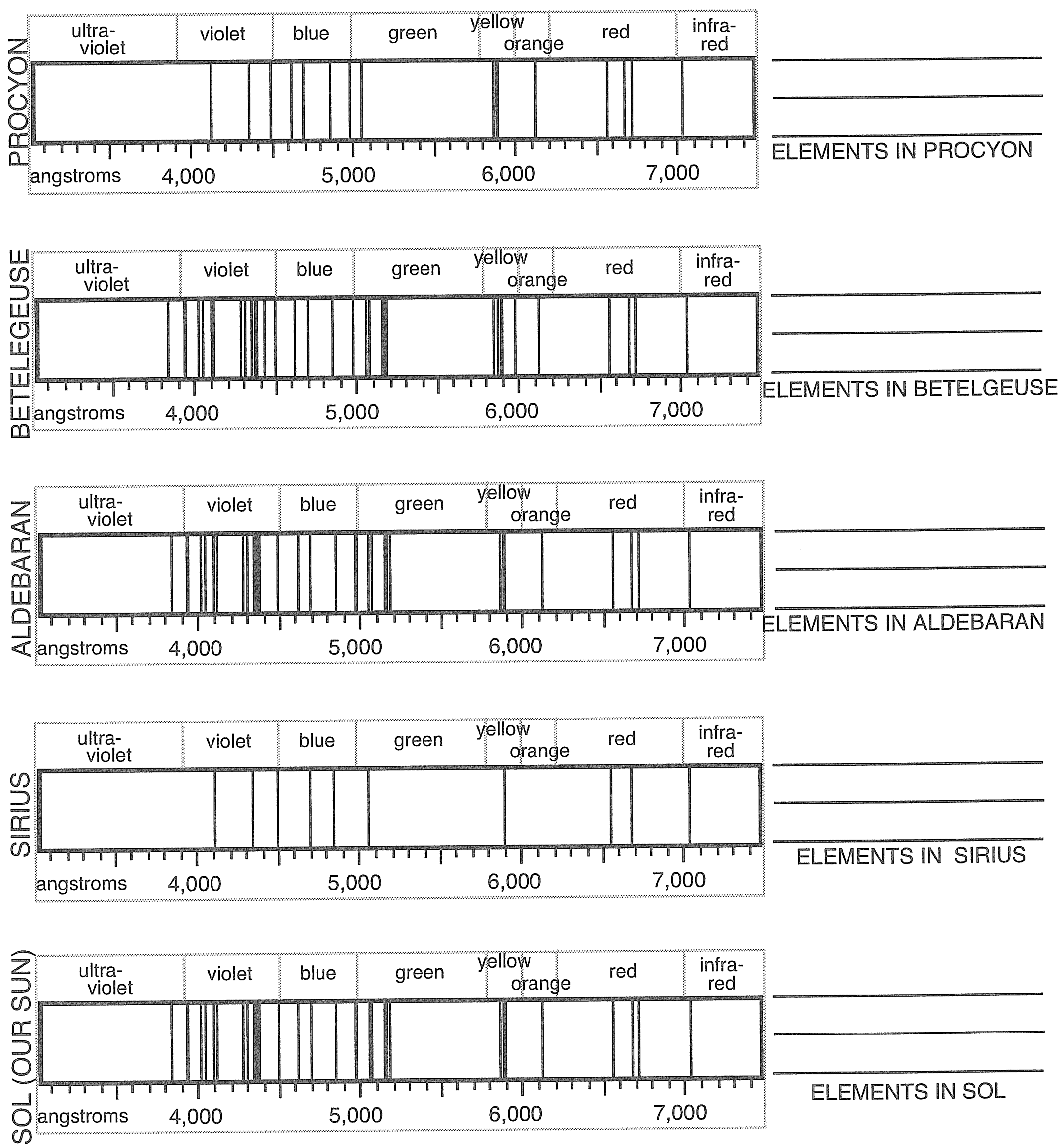
Mission 6
The Chemical Elements in Stars

Project Procyon: Spectra of Five Stars—Worksheet

Name: ___________________________________ Date: _________________________

The following spectra are printed in black and white, but they represent the stellar spectra,

Figure 6.7.



Mission 6
The Chemical Elements in Stars

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Project Procyon: Questions–Worksheet

Name: _________________________________Date: ______________________________

1. What elements did you see in class that is not listed in "Project Procyon"?

2. What elements are listed in "Project Procyon" that you did not see in class?

3. Why do you think these lists of elements are different? (If they are different!)

4. Use the "Spectra of Seven Elements" worksheet to compare with the "Spectra of Five Stars" worksheet. These spectra are printed in black and white. They represent the stellar spectra.

   List all of these seven elements that you found in each of the following stars:

   Procyon:

   Betelgeuse:

   Aldebaran:

   Sirius:

   Sol (our Sun):

5. Are all seven elements found in all five stars? How can you tell?

6. Which of the seven elements can be found in all five stars?

7. What do you think the "extra" spectral lines in some stars are?

8. Why do you think that some lines are thicker than other lines?

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Mission 7
Expecting Other Planetary Systems

Are There Planets Around Other Suns?

Notes

In Mission 6, students examined light and discovered that the elements that exist on Earth also make up the stars. This is also true of the diffuse clouds of matter scattered across the universe, although the proportions of elements are not the same. Still, the elements necessary for the development of life do exist throughout the universe. But just having the materials necessary for the development of life may be of no consequence to the development of extraterrestrials if planets are not also present!

Overview

In this mission, students investigate a question: Could there be other planetary systems in the cosmos? There are billions of stars and, therefore, billions of chances for planets to form around stars as our Earth formed around our Sun. Currently it is still difficult to directly image planets around other stars because the reflected light from a planet is too dim and is overpowered by the bright light from the star itself. Scientists are working on *direct* and *indirect* ways to detect the presence of planets. The Doppler shift (radial velocity) method and the transit method of detecting extrasolar planets have been the most successful methods. In Mission 7.1, students measure the center of mass of a binary system. In Mission 7.2, students use the Doppler shift (radial velocity) as a way to measure the very small "wobble" of stars that would indicate the presence of other planetary systems.

Mission 7.1
Materials

For a Class of 30

- Data projector, computer, PowerPoint file
- "Center of Mass" transparency or PowerPoint slide (page 145)
- *(optional)* 100-watt bulb
- *(optional)* Orange marble

For Each Team

- Meter stick
- 4 erasers, quarters, or other objects of uniform weight

For Each Student

- "Center of Mass" worksheet (pages 147
- "Data Points" worksheet (page 149)

- Pencil

Getting Ready

1. Copy the "Center of Mass" worksheet for each student.
2. Set up the data projector.

Classroom Action

1. **Discussion.** Divide the class into teams of four to five students each. The question of an individual star's life-span has probably not come up in class. Ask students if stars have always existed. Or do stars have beginnings and ends? If they do have beginnings, how do they begin? Do other stars have planets, as our Sun does?

   Remind students that several of the nebulae they observed in Mission 6 are thought to be the places where new stars are forming. Help students understand the size of these nebulae relative to stars. Are they bigger or smaller than stars? *(Much larger since many stars can form in one nebula. What might be happening in these clouds of gas and dust to create stars?)*

   The force of gravity–the same force that causes objects to fall to the ground, toward the center of Earth–is pulling together the dust and gas particles that make up the great nebular clouds. As more and more particles come together, the gravitational force becomes stronger, building the pressure and temperature at the center until the material "turns on" its nuclear furnace, and a star is born!

   But are there planets around this star? Explain that as far as we know, life can only begin on planets. Consequently, it would be good to know whether planets are plentiful or not. Do most stars have encircling worlds like the Sun does? Or is a planetary system a rare or even unique item in the cosmos? Until very recently, the only planets we were sure existed are the nine (including the dwarf planet Pluto) that orbit the Sun. But beginning in 1992, astronomers began to find evidence for other planetary worlds. It seems that planets may orbit many, if not most, stars. As of early 2010, over 500 extrasolar planets have been discovered, including some small rocky planets.

2. **Demonstration.** A good planet is hard to find! Unfortunately, even the best telescopes cannot see planets around other stars directly. The reason is twofold. To begin with, planets are relatively dim. Remember, while stars produce their own brilliant light by means of nuclear reactions deep in their cores, planets are fairly cool bodies, and shine only because of light reflected from their star. In fact, if you looked at our solar system from a nearby star, you would see that planets like Saturn or Jupiter were a billion times fainter than the Sun, and Earth was fainter yet. The second problem is that planets are so close to their stars that even if we could detect the faint light they reflect, the planet's dim, tiny image would be swamped by glare from the star.

To get a better idea of the problem, use a 100-watt light bulb to represent the Sun. Set up a demonstration of this in a darkened classroom, or have students imagine the situation: “To simulate the darkness of space, picture this light bulb at one end of a football field at night. Imagine Jupiter, our solar system’s largest planet, which (on this scale) would be an orange marble about 50 yards from the bulb. Finally, suppose that you are a researcher only 4% light-years away (the distance of the nearest star), looking for the marble around the light bulb. But 4% light-years corresponds to 3,000 miles in our scale model! Do you think you could see a dim marble in the glare of the light bulb from that distance?” NASA’s *Kepler Mission*, launched March 2009, is detecting extrasolar planets by measuring the change in light from star when a planet transits the parent star. The planets are too small to detect, but the instrument is sensitive enough to detect very small changes in the star’s light.

3. **Discussion.** Astronomers have just begun to discover extrasolar planets via direct imaging. To date, this method is only successful with very large planets orbiting small stars with a large degree of separation. So, scientists have to use to indirect methods when looking for planets. Discuss the indirect method. Indirect method is looking for the planet’s effects, rather than for the planet itself. This is something like hunting for rare animals by searching for tracks, lost feathers, and other signs. The “wobble” method and transit method are indirect methods.

4. **Transparency or PowerPoint Slide of Figure 7.4.** The most common method used by astronomers to see if stars have planets is to see if they “wobble.” Why would a star wobble? This could happen if something is orbiting the star–such as a planet. Normally, when we think of planets orbiting a star, such as our Sun, we assume that the star stays still, and the planet does all the moving. In fact, this is only approximately correct. What really happens is that both the star and the planet revolve about a point called the center of mass.

   Explain that there are many stars that are double (binary): they are stars that have another star as a “buddy,” or companion. If the two stars have equal mass, then they orbit around a point that is midway between them. The center of mass is between the stars. If one star is twice as heavy as its companion, then the center of mass will be closer to the heavy star, and the heavyweight will make smaller orbits than its lighter companion

5. **Activity.** Hand out the worksheets “Center of Mass” and “Data Points” to each student. Show how to use a meter stick to experiment with the concept of center of mass. Balance the meter stick on your outstretched index fingers, one at each end, and then slowly move your fingers toward the center of the stick. They will meet at the center of mass, right in the middle! Students should use erasers or any other small, uniform weights at one end of their meter sticks. As the mass increases, what happens to the center of mass? Students complete their worksheet, measuring and then graphing the changes in the center of mass.

Mission 7.2
Materials

For a Class of 30

- PowerPoint projector
- "Doppler Effect" PowerPoint slide 7.5 (page 146)
- Electric buzzer with a 9-volt battery (see "Teacher Background Information" in the appendixes)
- Connecting wires with alligator clips

For Each Student:

- "Red Shift, Blue Shift" worksheet (page 150)
- Pencil

Getting Ready

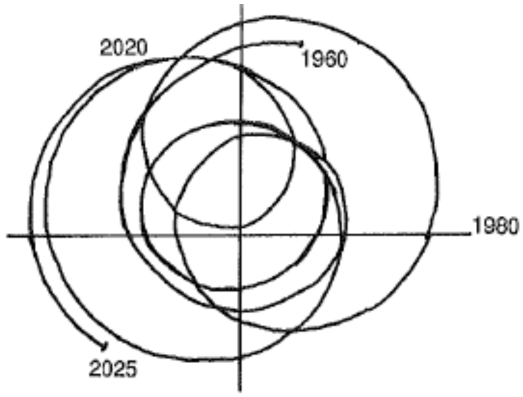
1. Copy the "Red Shift, Blue Shift" worksheet for each student.
2. Set up the data projector.

Classroom Action

1. **Discussion:** Measuring Wobbles. By now students have probably realized that while we say that Earth orbits around the Sun, the truth is that Earth and the Sun both orbit around their common center of mass, once per year. But because the Sun is about 300,000 times heavier than Earth, the center of mass is much closer to the Sun. In fact, it is *inside* the Sun, only about 100 miles from its center. So the Sun does not make a very big orbit. It moves only a few inches per second, or less than the speed of a crawling baby.

   That's a very small wobble. But of course the Sun has other planets. Jupiter, being much larger than Earth, causes a bigger orbital dance. If you add up all the orbiting the Sun has to do because of its eight planets plus dwarf planets, you find that it traces out a path like the one in Figure 7.1.

Figure 7.1–0rbital Wobbling of the Sun.



Astronomers have known about this orbital wobbling since the days of Isaac Newton. They realized that if another star has planets, it too would be moving back and forth and side to side.

But how can we possibly observe such small wobbles? Astronomers first tried to measure the tiny side-to-side wobbling of nearby stars by very accurately measuring the star's position over many years. This is called astrometry. They measured a nearby star's position relative to many distant "fixed" stars. These are very difficult measurements. Over the years, some astrometrists have claimed to detect planets, (*e.g*., around Barnard's Star). Unfortunately, these reports have turned out to be false alarms resulting from very slight changes in the telescopes themselves over a period of time.

Another way to do it is to look for the forward and back wobble of the star. These radial velocity studies involve looking for slight changes in the color of the light coming from the star. If a star is moving toward you, its light turns a little bluer (called *blue shift).* If it moves away from you, the light gets a bit redder (called *red shift)* So, if a star is doing a "dance" because it has planets, then we should see its light subtly change color—a little bluer, a little redder, a little bluer, a little redder, and so on (radial velocity method). In fact, astronomers actually look at individual spectral lines from the star and observe whether their wavelength changes slightly from night to night over many years.

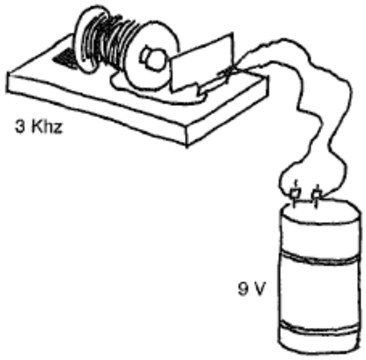
Optional: Ask students if we could detect a side-to-side wobble using this technique. *(No.)*

2. **Transparency or PowerPoint Slide Figure 7.5.** Why does the light change color? Because of an effect discovered by an Austrian physicist more than 150 years ago, when Christian Johann Doppler pointed out that any kind of waves–water waves, sound waves, and light waves–will get closer together if the object making the waves is coming toward you. They will get farther apart if the wave generator moves away from you. Show students the "Doppler Effect" transparency to help explain this concept. The spacing of the waves is related to the pitch, or frequency, of the waves. Have you ever noticed how the sound of a train or a car changes pitch as it passes you? When it comes toward you, the pitch is higher. Then it passes, moving away, and the pitch gets lower. This is called the Doppler Effect (radial velocity), and astronomers look

for it all the time–in light waves. NASA's *Kepler Mission* uses this method as ground based follow-up, checking for the "wobble" to confirm its discoveries.

3. **Demonstration:** Doppler Effect Experiment. Wire an electric buzzer and a battery as shown in **Figure 7.2.**

Figure 7.2–Buzzer and Battery.



Ask a volunteer to attach the last lead and then swing the sound wave-generating buzzer in a circle about his or her head. Ask if they notice how the pitch changes? When is it higher? When is it lower? What if you swing it faster? The Doppler Effect can be used to tell us not only whether something is coming toward us or moving away from us, but also how fast it is moving. Now have a volunteer swing the buzzer in a big circle in front of his or her body. Because it is neither coming toward nor moving away from anyone, no change in frequency can be heard.

4. **Activity.** Hand out the "Red Shift, Blue Shift" worksheet to each student. For many years, astronomers have been using the Doppler Effect to see if any nearby stars move to and fro. If astronomers find one that does, then we might decide that there are planets around that star, even though we cannot see them directly. Instruct students to complete their worksheet by looking for a red shift or a blue shift in each of three unknown stars.

5. **Wrap-Up.** Ask students if they think scientists have found any real wobbling stars out in space. There are several stars that seem to wobble–shift positions—but these results are still a bit uncertain. The main problem is that astrometrists have not been looking long enough. To be sure that the wobble is really caused by a planetary companion, astrometrists must continue to observe a star for at least one orbital period of the planet. For large planets like Jupiter, in orbits far from their star, the planetary orbit can be tens of years, and so the wobble will require tens of years to observe. Another problem is that the wobbles are very tiny and difficult to measure accurately. It is important to keep everything very stable over the many years of observation to avoid the false alarms that have plagued astrometrists. However, researchers continue to work on this problem, and most think that within just a few years, they will be able to detect the wobbles of stars surrounded by planets.

   Explain that astronomers have seen wobble and observed very small shifts, to and fro, in the spectral lines of nearby stars. In 1995, a Jupiter-sized companion to a star was detected in the constellation Pegasus using the radial velocity method. The star's name is 51 Pegasi. A few months later, two more stars were found to be the home of Jupiter-sized planets, 47 Ursae

Majoris (a star in Ursa Major, the Big Dipper) and 70 Virginis (in Virgo). All three of the planets are about as large as Jupiter. As this research continues, hundreds more planets have been found. So far, astronomers have not found evidence of Earth-sized planets around normal stars. But, NASA's *Kepler Mission*, a spacecraft mounted instrument, has found near Earth-sized planets and is poised to detected Earth-sized planets.

These three Jupiter-sized planets are not the first discovered. Earlier, there was a most intriguing result in the search for planets from a very peculiar kind of star: *a pulsar.* What is a pulsar? It is the shrunken core of a large star that burned all its fuel and then blew up in a gigantic explosion called a supernova. The pulsar, which is all that remains of the star, is so small it would fit in downtown New York City! But pulsars spin very rapidly, sometimes as much as a thousand times every second; like lighthouse beacons, they "broadcast" light and radio waves into space. These broadcasts sound like the ticking of a clock, except that the ticks can be very fast (even a thousand ticks a second).

Astronomers have noticed that, for at least one pulsar, the number of ticks per second increases for a few months, and then decreases. Then it increases again. What's happening? The Doppler Effect is causing the change in tick frequency. This particular pulsar is thought to have three planets circling it, which cause it to wobble, which in turn produces the Doppler shift that we see.

Optional: There is one additional indirect method of detecting planets outside our solar system–it is called the *transit* method. If the planet just happens to move in front of the star, directly into our line of sight, then we will see a small reduction in the brightness of the star as the planet blocks its sun's light for a temporary period of time. NASA's *Kepler Mission* has already detected planets with a radius of less than 1.5 Earth's radius, and is sensitive enough to detect planets the same size as Earth in the Habitable Zone of other stars using this method. See www.Kepler.nasa.gov for classroom activities. The online Extrasolar Planet Almanac and Extrasolar Planet Encyclopedia provide up to date planet counts and details regarding the planets and their parent stars. The sites also note which one of the methods, astrometry, radial velocity – Doppler shifts, transit method, transit timing variation (TTV), gravitational microlensing, observation of circumstellar disks, direct imaging, contamination of stellar atmospheres, coronography, and pulsar timing); was employed to discover the planet.

Going Further

Activity: Massive

Tie a string between two equally weighted objects (balls). Use a colored piece of yarn to mark the center of the string. Throw the tied objects through the air so that the string is pulled taut and rotates. Students observe that the rotation occurs around the center of the string. Connect additional weight to one end of the string and show that this changes the center of rotation by moving it closer to the more massive object. The point of rotation is the center of mass. Taking this activity one step further, use a low-frequency strobe light while throwing the tied objects in a darkened room–this will emphasize the rotation about the center of mass.

Teacher's Note: *Do not use breakable objects. Warn students about the potential danger of flying objects.*

Activity: Mass, Density, and Volume

Do activities to show students that the mass of an object is not determined solely by its size but also depends on its density. A small, dense object can be more massive than a larger less-dense object. Show students the relationship between radius and volume for a spherical object. $V = (4/3)\,\pi r^3$, where r is the radius of the sphere. Then relate volume to density, showing that when the radius of a spherical object is doubled (while density remains constant), both the volume and the mass are multiplied by eight times.

Teacher's Note: $\textit{Density} = \dfrac{\textit{mass}}{\textit{volume}}$

Activity: Doppler Shift on the Street

Instruct pairs of students to go to an area where there is a lot of traffic and pick a spot where they can stand safely with eyes closed or blindfolded. To stay safe, students must do this activity in pairs! They should *listen* to the cars. Can they tell if cars are coming toward them or moving away from them by sound alone? One partner should take notes on the other's "guesses." How does this relate to the Doppler Effect studied in class?

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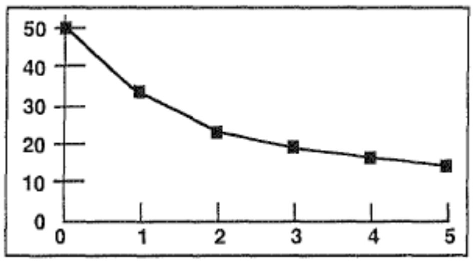
Mission 7
Expecting Other Planetary Systems

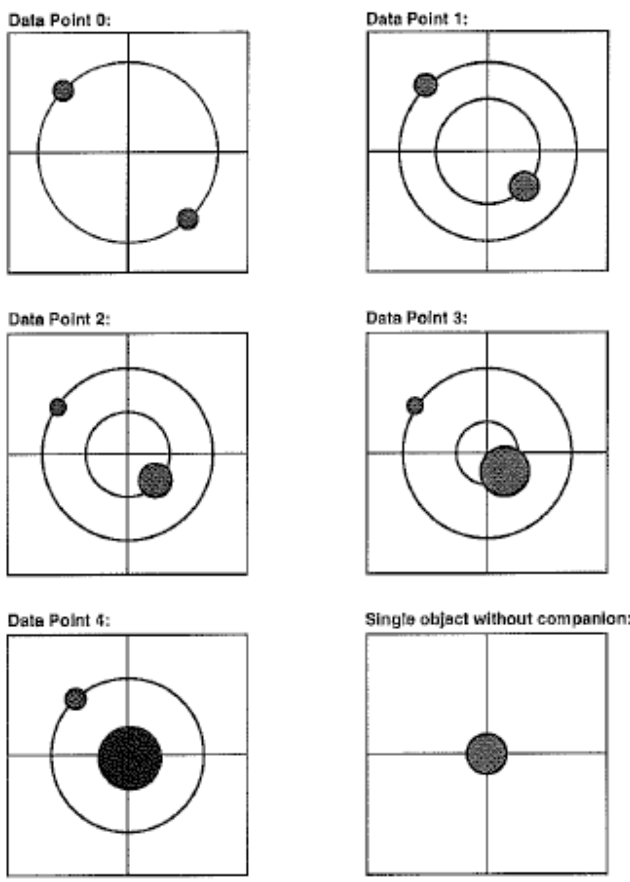
Center of Mass–Teacher's Key

Figure 7.3a.



Example graph. The actual numbers will vary, depending upon the objects used.

Figure 7.3b.



2. The mass of this object does not affect its orbit, because it does not have an orbit. Any motion that this object has is contained in its spinning upon its axis or is in a straight line through space.

Mission 7
Expecting Other Planetary Systems

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Red Shift, Blue Shift–Teacher's Key

Table 7.1–Teacher's Key for Red Shift, Blue Shift.

Star #1	**Doppler Shift**	**Movement of Star**
Observation 1	Red Sifted	Moving away from Earth
Observation 2	Not Shifted	Not moving relative to Earth
Observation 3	Blue Shifted	Moving toward earth
Observation 4	Not Shifted	Not moving relative to Earth

Star #2	***Doppler Shift***	***Movement of Star***
Observation 1	Red Shifted	Moving away from Earth
Observation 2	Red Shifted	Moving away from earth
Observation 3	Red Shifted	Moving away from Earth
Observation 4	Red Shifted	Moving away from Earth

Star #3	***Doppler Shift***	***Movement of Star***
Observation 1	Blue Shifted	Moving toward Earth
Observation 2	Blue Shifted	Moving toward Earth
Observation 3	Blue Shifted	Moving toward Earth
Observation 4	Blue Shifted	Moving toward Earth

1. Star # 1 is moving away from us in observation 1, then it is not moving in observation 2, then it is coming toward us in observation 3, and then it is not moving in observation 4.

2. Star # 2 is moving away from us in all four observations.

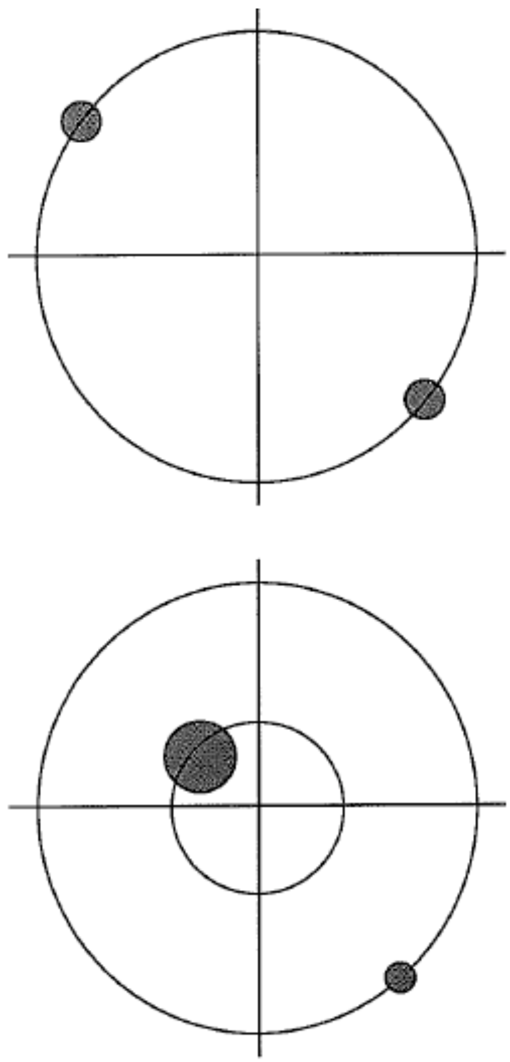
3. Star # 3 is moving toward us in all four observations.

4. Star # 1 is most likely to have a planet. Star # 1's back-and-forth motion could be caused by its "dance" with a planet, rotating about a common center of mass. Star # 1 has a wobble!

Mission 7
Expecting Other Planetary Systems

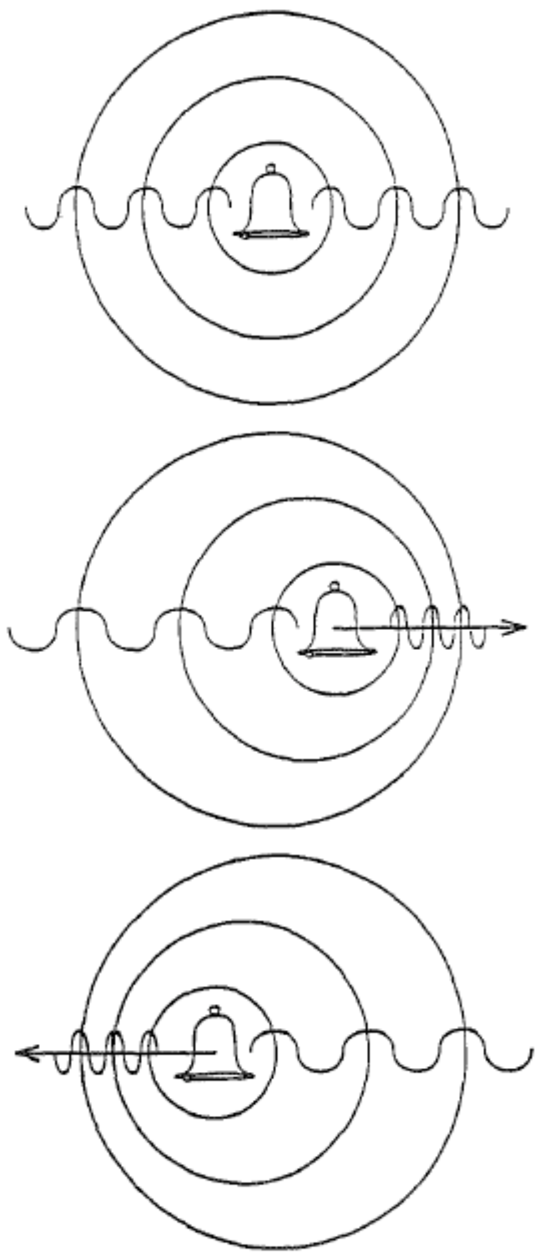
Center of Mass–Transparency or PowerPoint Slide

Figure 7.4.



The Doppler Effect–Transparency or PowerPoint Slide

Figure 7.5.



Mission 7
Expecting Other Planetary Systems

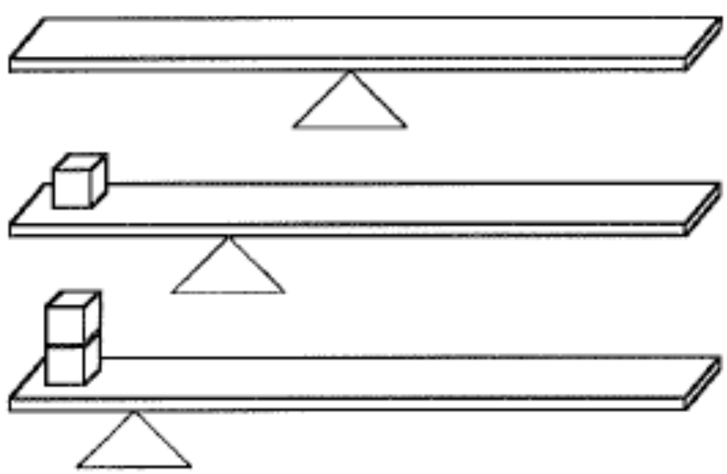
Center of Mass–Worksheet

Name: ______________________________ Date: ____________________________

You will use your meter stick and weights to make center of mass measurements. The center of mass is the point at which both sides of the meter stick will balance. Start by measuring the center of mass of the meter stick without any additional mass on it. The center of mass should be in the middle, at the 50 cm mark. Each side of the meter stick has equal mass. The meter stick's mass has no effect in the following measurements.

Next add one unit of mass (*e.g.*, one eraser or other object) to the meter stick as close to one end as possible and a mass unit close to the other end. Record your new center of mass measurement. Repeat this by adding to one end only one more mass unit, then another, then another.

Figure 7.6.



Center of mass:	______	______	______	______
Measurement:	# 1	# 2	# 3	# 4
Number of units at each end	1 1	2 1	3 1	4 1

Graph your data on the grid below. Each measurement is one data point. Put the units of mass (erasers or grams) on the x-axis, and units of distance (cm) on the y-axis.

Table 7.1.

1. On your “Data Points” worksheet, draw a diagram describing what the orbit of the two objects would look like for each of your four data points. The intersection of the two lines represents the location of the center of mass. Data point # 1 is shown as an example. Be sure to draw larger objects when you want to represent more mass. Next, draw the orbit of a single object without a companion.

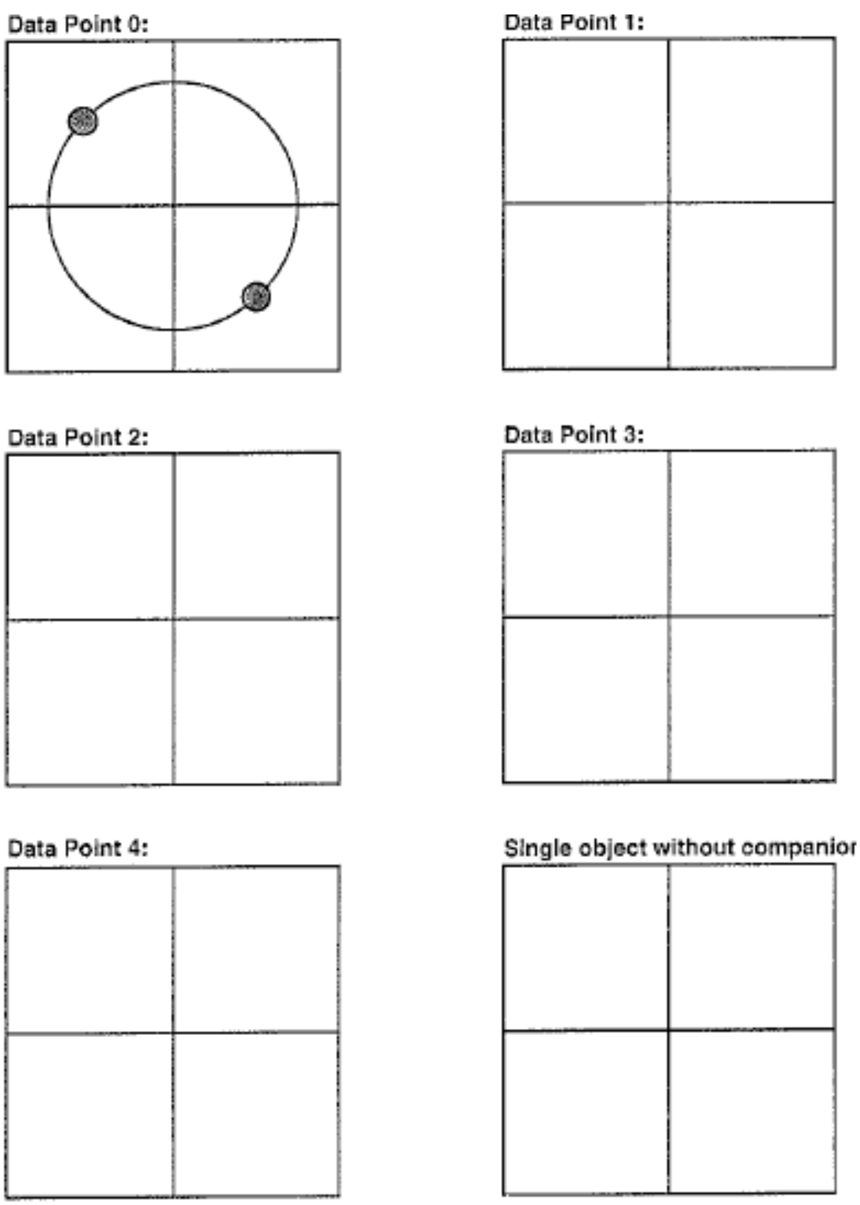
2. Does the mass of the single object without a companion affect its orbit?

Mission 7
Expecting Other Planetary Systems

Data Points–Worksheet

Name: ______________________________ Date: __________________________

Figure 7.7.



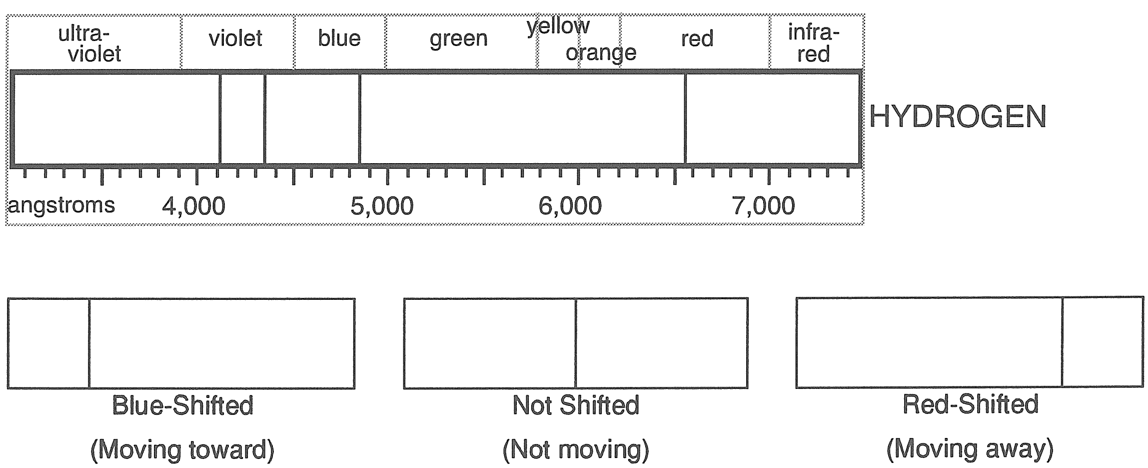
Mission 7
Expecting Other Planetary Systems

Red Shift, Blue Shift–Worksheet

Name: ________________________________ Date: ____________________________

If we measure the wavelength of a single line of the hydrogen spectrum very carefully, we can tell if it has a Doppler shift caused by a planetary companion. This measurement requires a precision of 10^{-4} Angstroms! If a star is moving away from us, the waves will stretch out and become longer so its light will be "red shifted"; if a star is moving toward us, the waves will compress and become shorter so its light will be "blue shifted." What would a star with a wobble look like to us on Earth?

Figure 7.8a.



The following spectral lines are from three different stars. There are four sets of spectral data for each star, representing four observations taken at different times. Using these data, fill out the table and answer the following questions.

Figure 7.8b. (Lines must be drawn inside of boxes.)

	Star 1	Star 2	Star 3
Observation 1			
Observation 2			
Observation 3			
Observation 4			

Table 7.2.

Star #1	Doppler Shift	Movement of Star
Observation 1		
Observation 2		
Observation 3		
Observation 4		

Star #2	Doppler Shift	Movement of Star
Observation 1		
Observation 2		
Observation 3		
Observation 4		

Star #3	Doppler Shift	Movement of Star
Observation 1		
Observation 2		
Observation 3		
Observation 4		

1. Make a general comment about the movement of star # 1:

2. Make a general comment about the movement of star # 2:

3. Make a general comment about the movement of star # 3:

4. Which of these three stars is most likely to have a planet? Why?

Mission 8
Building a Radio Receiver

SETI INSTITUTE

Hearing the Radio Waves That Surround You!

Notes

In Mission 7, students learned that there are methods for indirectly detecting other planetary systems, and that very recently, planets have been detected around other stars. This raises a question that is fundamental to SETI: Could intelligent life in some distant planetary system have advanced enough technologically to build radio transmitters? Perhaps here on Earth, given the proper "listening" technology, we can capture radio signals being sent, either intentionally or unintentionally, from a planet in some distant star system.

Overview

In this mission, students get firsthand experience with radio technology. In Mission 8.1, students are involved in an electrical engineering challenge–building a radio receiver. Students find that there are radio waves in the air that are invisible to us. Students experience some of the thrill of "inventing" a radio, and then they manipulate this technical tool that has the capacity to detect a signal (message) against a background of noise (static). This mission may take up to three class periods.

Mission 8.1
Materials

For a Class of 30

- 3 wire strippers
- Long wire for antenna

For Each Radio

Depending upon your budget, each student should build a radio, or have each team of students build one radio. Each radio will cost less than $10.00 (see "Teacher Background Information" in the appendixes).

- 25-by-12-cm piece of cardboard
- 15 cm length, 7.5 cm diameter hollow cardboard cylinder
- 7.5 cm length, 7.5 cm diameter hollow cardboard cylinder
- 16 meters of 24-gauge solid copper wire (enamel coated)
- 3.5 meters of 24-gauge stranded wire
- Germanium diode: type 1N34A (see appendixes)
- Crystal radio earphone (see appendixes)

For Each Team

- Meter stick
- Highlighter pen (wide tip)
- Aluminum foil
- Clear tape
- Extra fine sandpaper
- Sheet of plain white paper
- Scissors
- Single-edge razor blade (or an X-acto® knife)
- Grocery bag for teams' materials

For Each Student

- "Radio Technology" worksheet (page 171)
- "Building an AM Radio" directions (pages 159-166)
- "How Does a Radio Work?" description (ages 167-170)
- Pencil

Getting Ready

1. Collect hollow cardboard cylinders that are three inches (~7.5 cm) in diameter. Try fabric stores. Frozen orange juice containers can also be used if the metal parts are removed. Students might be able to supply some of the tubes if you ask them ahead of time.

2. Purchase the 24-gauge stranded wire and 24gauge enamel-coated copper wire and organize it for easy student distribution (16 meters of wire tangles easily). If you have enough toilet paper tubes, pre-cut the wire and carefully wind it around tubes.

   Teacher's Note: *Do not confuse these tubes, used to minimize tangling, with the three-inch cylinders used for the radio.*

3. Cut the sandpaper into small squares.

4. You may want to cut the radio cardboard bases to size (25 cm x 12 cm) yourself to save time in class. Heavy poster board can be used. Cardboard boxes work the best, but they are sometimes difficult to cut through.

5. Copy the "Radio Technology" worksheet, the "Building an AM Radio" directions, and the "How Does a Radio Work?" description for each student. Organize these pages into booklet form before distributing them.

6. Build a radio yourself, so students can use it as a model. Also, you will experience for yourself the problems that they will encounter when they build theirs. Check the troubleshooting guide if necessary.

7. Layout the materials for students in a centrally located place where students can easily access them. Place your model radio where it can be seen by everyone.

8. Arrange the room so that there is a flat work surface for each student group. Arrange a storage area for the partly completed radios.

9. Hang a wire out a window as an antenna that students can hook onto (attach it to a tree outside the window, if possible). (This main antenna is not needed until the day students actually test their radios.)

Classroom Action

1. **Directions.** Divide the class into teams (or ask students to work individually). Each team will make one radio. Decide whether or not students will keep the radios when this mission is completed. If students will be keeping them, each group decides who will get their radio. Hand out a “Building an AM Radio” booklet of directions to each student. It is very important to allow time for teams to read through the complete set of directions before starting. Take a few minutes to tell students about the strategy of marking off each direction with a highlighting pen as it is completed. The highlighting allows students to see what has been done and to go back and reread if necessary. Students should not use a pencil or a pen to cross out the instructions.

2. **Activity.** Building the Radios. Direct students to gather their equipment and begin construction of their radios. It may take between three and four class periods for all students to complete their radios. Encourage students to work carefully, and not to rush to finish quickly. As students are building their models, remind teams to troubleshoot their hookups frequently by checking with and comparing their radios to the classroom model that you have built. Give each team a grocery bag and ask them to write their names on it. All their materials, including the radio building instructions, can be placed into the bag for safekeeping between class periods.

3. **Activity.** Testing the Radios. When students are ready to test their radios, the radio signals will be very faint, as these radios do not have any circuitry to amplify the signal.

4. **Worksheet.** Hand out the “Radio Technology” worksheet to each student. The directions will require them to make measurements from the base of the radio to the bottom of the variable capacitor. Sliding the variable capacitor up and down will change the stations. This measurement helps to ensure that students are indeed listening to different radio stations and not just tuning in to the same one that they were listening to earlier. Instruct students to complete the worksheet. A fun activity is to see which team of students can find the most stations with their radios. This is easier in urban areas where there is an abundance of AM radio stations. No doubt students will wish to share their joy in finding a radio station by asking you to listen to their radio, which is a good way to verify that they are picking up a radio station.

5. **Discussion.** Take some time to talk to students about how their radios work. Hand out the “How Does a Radio Work?” description to each student. Give students time to read the description before the discussion so they can be knowledgeable about the functions of the different parts of the radio and how radios work in general.

Going Further

Activity: Radio Stations

After students have listened to radio stations on their receiver, challenge them to find the locations of the transmitters for the stations. These locations might be illustrated on a map. As a follow-up activity, take the class on a field trip to visit a radio station and its transmitter.

Mission 8
Building a Radio Receiver

SETI INSTITUTE

Radio Technology–Teacher's Key

1. The power or energy comes from electromagnetic waves traveling through space and passing through the antenna. These waves are generated by the station transmitter, which gets its power from a power plant. The station modulates the electricity in the transmitter, which creates and modulates electromagnetic waves so that they carry a signal.
2. The reception should be better if there is less obstruction by buildings and hills, or if there is less interference caused by electrical devices that produce electromagnetic waves, which interfere with the waves coming from the station transmitter. When indoors, the metal framing in the building may screen out radio waves, making reception difficult.
3. It may work better or worse depending on the type of interference that is contributed to the circuit. If your body provides constructive interference for the electromagnetic waves in the air, or acts as an additional antenna, then your radio will receive better when you press your fingers on the connection point. If your body provides destructive interference then you will not be able to receive signals as well when you touch the connection point.
4. Because the wires connecting the various components of your radio are quite long, they can act as a small antenna, so you may still receive stations even without a long "real" antenna.
5. No, because the circuitry is measuring differences in amplitudes between the electromagnetic waves in the air and the base level (ground); if you are not well connected to the ground, your radio will have trouble detecting any differences.
6. Your radio is actually receiving electromagnetic waves that are modulated in amplitude by the station transmitter. The change in amplitude of the wave contains the "information," and that's why it's called amplitude modulation, or AM radio.
7. You cannot hear radio waves in the room because your eyes and ears do not detect electromagnetic waves at radio frequencies. The radio device transforms the electromagnetic waves into sound waves, which can then be detected by your ear. Radio waves are just like infrared light, which your eyes and ears also cannot detect, except that radio waves have longer wavelengths than infrared. Your skin can detect infrared, as it feels warm. However, we cannot detect radio waves with any of our senses.
8. The carrier is a radio wave sent out at a certain number of cycles per second (*e.g.*, 810 or 1400 kilohertz). It is the pure radios tone.
9. By modulating the carrier, it is possible to add information to the radio wave, which is then picked up by a radio receiver and transformed into audible signals (music and speech).
10. Answers will vary from school to school. A sample answer is found in Table 8.1.

Table 8.1.

#3	1 cm	Next to window	101.5

This page left deliberately blank.

SETI INSTITUTE

Mission 8
Building a Radio Receiver

Hearing the Radio Waves That Surround You!

There are messages traveling through the air right now–thousands of messages. Can you hear them? Listen! Your ears cannot receive these signals, but by using your brain you can construct a technological device that will enable you to hear these messages.

You have the job of building a working AM radio, using just a few simple materials. A high standard of craftsmanship is necessary for the radio to work. Aim to make your radio look like the class model that has already been built. Use the class model to check your construction technique and your electrical connections.

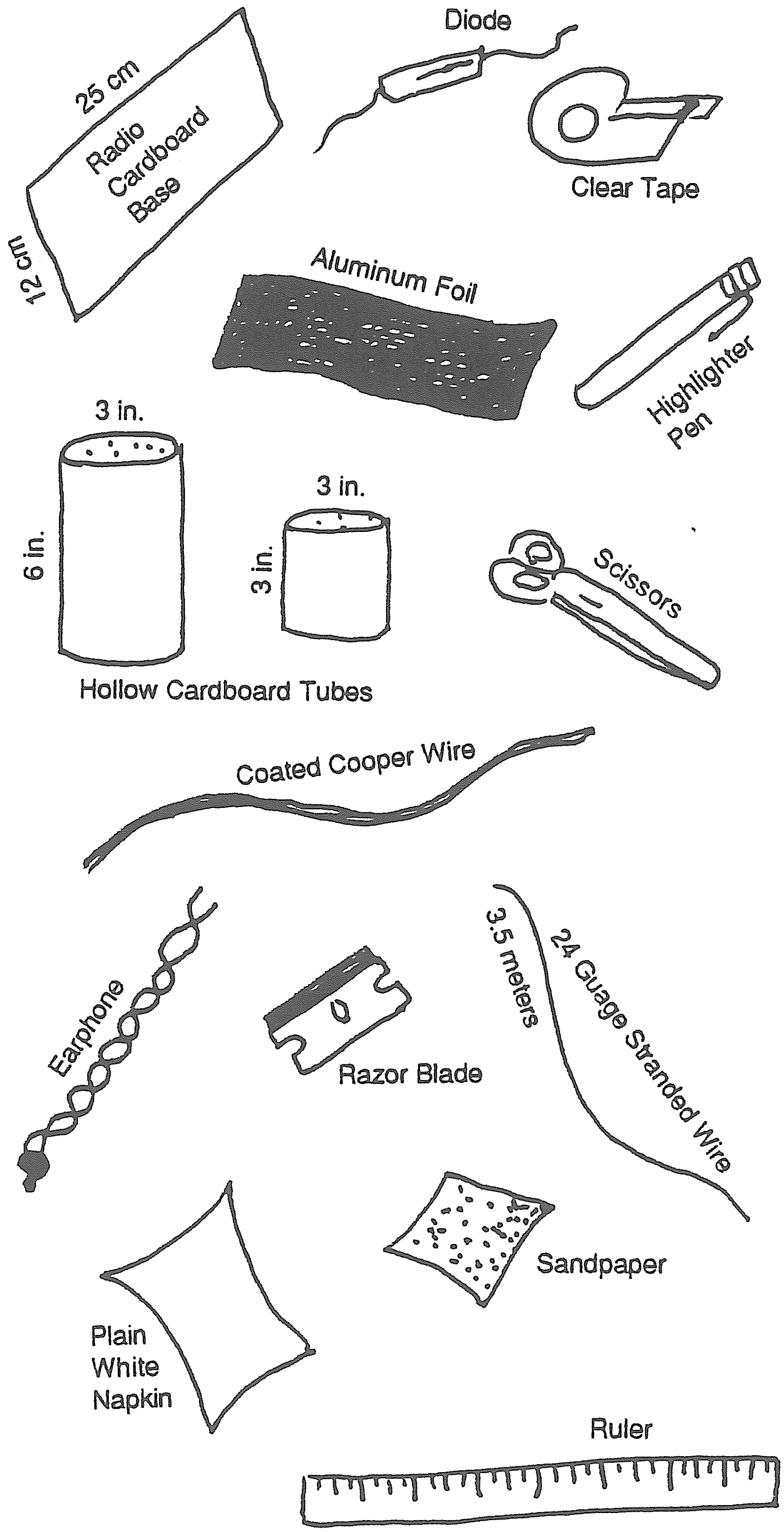
Step 1–Organizing the Job

As each step of the job is completed, use the highlighting pen to check it off by coloring through the instructions.

Gather your materials and lay them out at your work area. Check off each item when you have identified it.

- Radio cardboard base: 25 cm x 12 cm
- Two pieces of 3-inch-diameter hollow cardboard tubing:
  15.25 cm length
  7.5 cm length
- 16 meters of 24-gauge solid copper wire (enamel coated)
- 3.5 meters of 24-gauge stranded wire
- Diode
- Crystal radio earphone
- Highlighter pen
- Aluminum foil
- Clear tape
- Small piece of extra-fine sandpaper
- Sheet of white paper
- Scissors
- Single-edge razor blade or X-acto® knife
- Meter stick
- Grocery bag

Figure–8.1.


Diode
25 cm
Radio Cardboard Base
12 cm
Clear Tape
Aluminum Foil
Highlighter Pen
3 in.
6 in.
3 in.
3 in.
Scissors
Hollow Cardboard Tubes
Coated Cooper Wire
Earphone
Razor Blade
3.5 meters
24 Guage Stranded Wire
Sandpaper
Plain White Napkin
Ruler

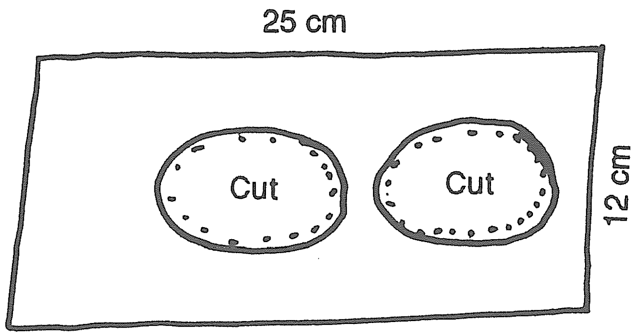
Step 2–Building the Base

a. Cut the cardboard radio base to size: 25 cm x 12 cm.

b. Trace around the outside of the hollow cardboard tube to make two circles on the radio base as shown on diagram.

c. Use a cutting tool to cut out both circles just inside of the pencil line. This guarantees your cardboard tubes will have a tight fit.

Figure–8.2.



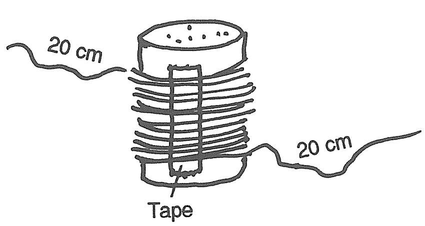
Step 3–Building the Coil

a. Tape the coated copper wire to the top of the short cardboard tube, leaving 20 cm of extra wire overhanging the tube for connection purposes later.

b. Begin to wrap the wire tightly around the tube, making sure that the wire fits snugly, but doesn't overlap, Don't let your wire come uncoiled! You can tape down a few coils at a time with transparent tape as you work.

c. Leave 20 cm of the wire overhanging the tube at the other end. Tape the entire coil in place so that it doesn't come apart.

Figure–8.3.



Step 4–Building the Variable Capacitor

a. Cut a piece of aluminum foil 10 cm x 25 cm to fit around the bottom half of the tall cardboard tube. Make sure that the ends of the foil overlap just a little bit.

b. Starting 1 cm up from the bottom of the tube, tape the entire overlapping edge of the foil together. Tape the exposed edge of the foil all the way around the center of the tube.

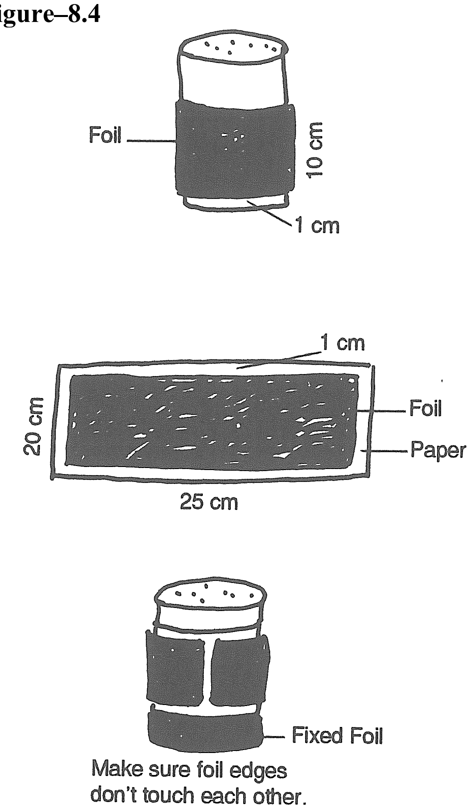
c. Cut a second piece of foil 20 cm x 25 cm.

d. Cut a piece of white paper 1 cm wider than the second piece of foil on all of the four sides.

e. Tape the foil to the paper. There should be a white border of paper visible all the way around the foil rectangle.

d. Wrap this foil-paper piece around the upper portion of the cardboard tube, with the white paper next to the tube. Tape the paper ends together. This piece must be able to move up and down over the bottom piece of aluminum. It cannot be too tight, and it cannot be too loose. The top aluminum foil cannot touch either the bottom aluminum foil or itself where it wraps around the tube.

Figure–8.4



Step 5–Building the Electrical Connecting Strips

a. Cut one piece of aluminum foil 15 cm x 15 cm.

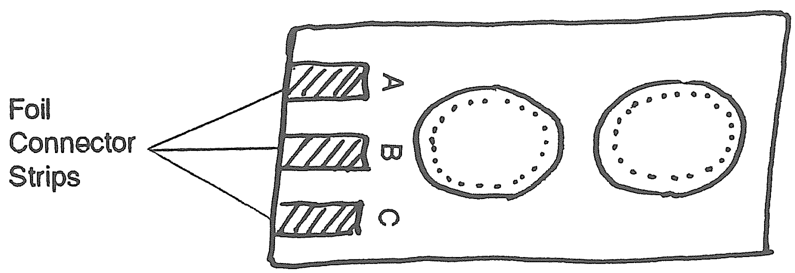
b. Fold the aluminum foil piece in half. Fold it in half a second time, and then fold it in half a third time, forming a long strip of aluminum foil.

c. Cut the long strip of aluminum foil into thirds, forming three connector strips. Each of these connector strips is now 5 cm long.

d. Tape each connector strip to the cardboard radio base as shown in the diagram, leaving room where wire can later be inserted.

e. Label A, B, and C as shown in the diagram.

Figure–8.5.



Step 6–Assembling Your Radio

a. Insert the coil into the center hole of the radio base. It should fit tightly Make sure that the two overhanging wires can reach the connector strips.

b. Turn the radio base upside down. Tape the tube in place with strips of tape from inside the tube outside to the base.

c. Take the loose end of the wire closest to connector strip A and cut off any extra wire so that it just reaches to connector strip A. Sand 2 cm of enamel coating (insulation) off the end of the wire. Do the same to the other wire, making sure that it is long enough to reach connector strip C.

d. Secure the variable capacitor to the radio base in the same way that you did the coil. Make sure that the fixed piece of aluminum is at the bottom.

e. Cut 15 cm of stranded wire. Strip 1 cm of plastic insulation off each end of the wire.

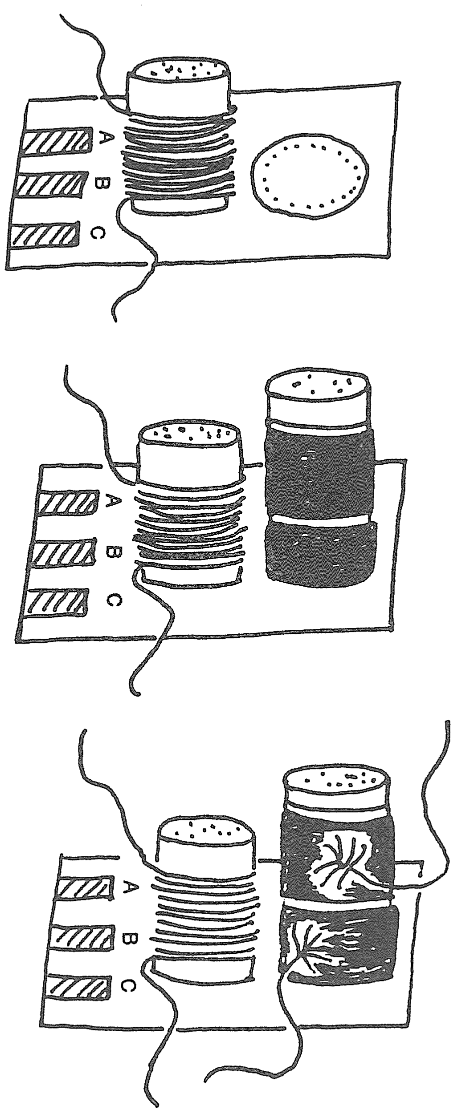
f. Carefully spread out the strands of tiny wires on one end like a fan and tape them firmly to the fixed piece of aluminum foil on the bottom of the variable capacitor.

g. Cut 20 cm of stranded wire. Strip 1 cm of plastic insulation off each end of the wire. Fan out the strands of tiny wires on one end and tape them firmly to the sliding piece of foil.

h. Cut 2 m of stranded wire for the antenna. Strip 1 cm of plastic insulation from both ends.

i. Cut 1 meter of stranded wire to use as a ground wire. Strip 1 cm of plastic insulation from both ends.

Figure–8.6.



Step 7–Making the Electrical Connections

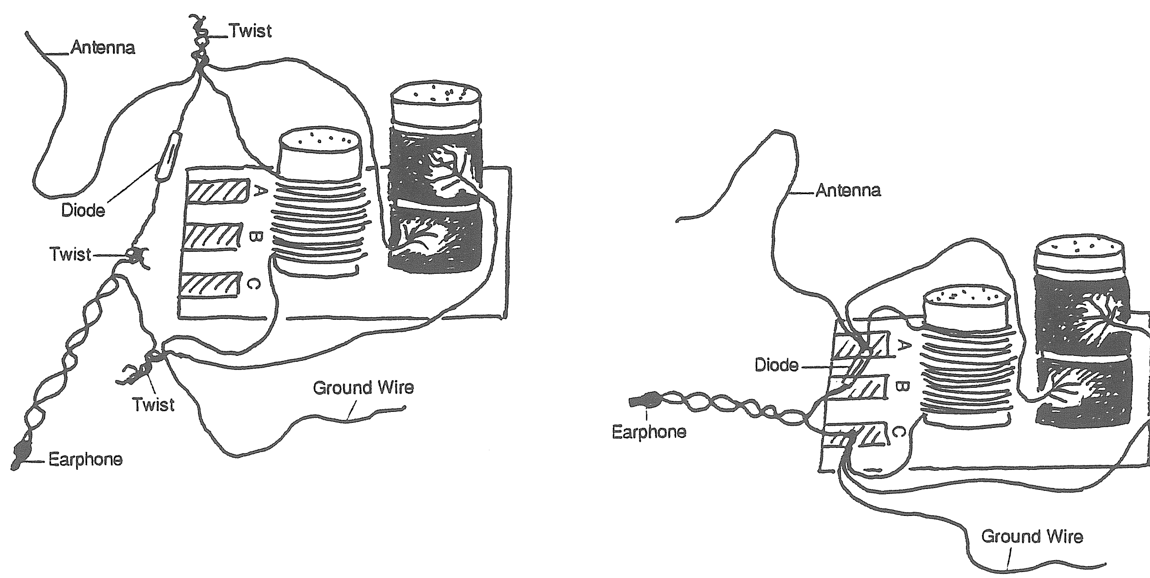
a. Twist together the following wires:
   one end of antenna wire
   one end of coil wire (sanded)
   one end of wire from bottom half of variable capacitor
   one end of diode
   After these wires are twisted, carefully tape them down to connector strip A.

b. Twist together the following wires:
   other end of diode
   one earphone wire
   Tape to connector B.

c. Twist together the following wires:
   one end of ground wire
   other earphone wire
   other end of coil wire (sanded)
   one end of wire from top half of capacitor
   Tape to connector strip C.

Believe it or not, once you make the final connection, your radio is "on"! There is no on/off switch like a normal radio would have, because there is no battery.

Figure–8.7.



Step 8–Testing Your Radio

a. Double check all of your connections and compare your radio to the one your teacher has on display in the room.

b. Find a place to hook up your antenna wire, preferably up high. If your teacher has set up an antenna wire that goes out of your room through a window, hook the end of your antenna wire to the end of your teacher's antenna wire. Make sure the plastic insulation has been stripped off the end of your antenna wire. Attach the ground wire to a pipe or metal radiator at a place where the paint is missing.

c. Very slowly move your variable capacitor up and down on the larger cardboard tube. The variable capacitor allows you to change stations. If you don't get any stations in one location, unhook your antenna and ground wire and move to another location.

d. Make sure that all your connections are correct and you have tested out your radio in several locations around the room, in case of difficulty.

Mission 8
Building a Radio Receiver

How Does a Radio Work?

What Is Radio?

Everyone knows that light can travel quickly from place to place, and can pass effortlessly through the vacuum of space. In the past, simple attempts were made to use light to send messages, by flashing mirrors or using a shutter on a shipboard lantern. However, at the end of the last century, European scientists such as Heinrich Hertz and Guglielmo Marconi began to experiment with sending messages with “light” of much lower frequency (or longer wavelength). We refer to this “light” as radio waves. Our eyes don’t respond to low-frequency electromagnetic radiation, so we don’t see radio waves. But radio waves and light are the same phenomenon; they differ only in their wavelength.

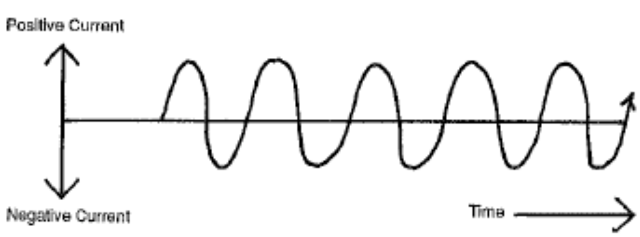
How Do You Make Radio Waves?

Radio waves are generated any time you have a changing electric current. If you simply shake an electron, for example, you generate a radio wave (albeit a weak one). If an electron just sits there, or moves steadily down a wire as a direct current, no waves are radiated. You have to change its motion.

Heinrich Hertz did this by making electric sparks, which shakes up a lot of electrons in a random kind of way. This works (have you ever heard the static on your radio when a lightning bolt flashes nearby?), but it causes radio waves at all sorts of frequencies. It’s a bit like trying to make a pure, musical note by hitting a jungle gym with a hammer.

A better way is to use electronic circuits to move lots of electrons all together (a sort of electronic, country line-dance) in a rhythmic pattern that makes a pure radio “tone.” In a circuit like this, called an oscillator, the current is always changing; it looks like Figure 8.8.

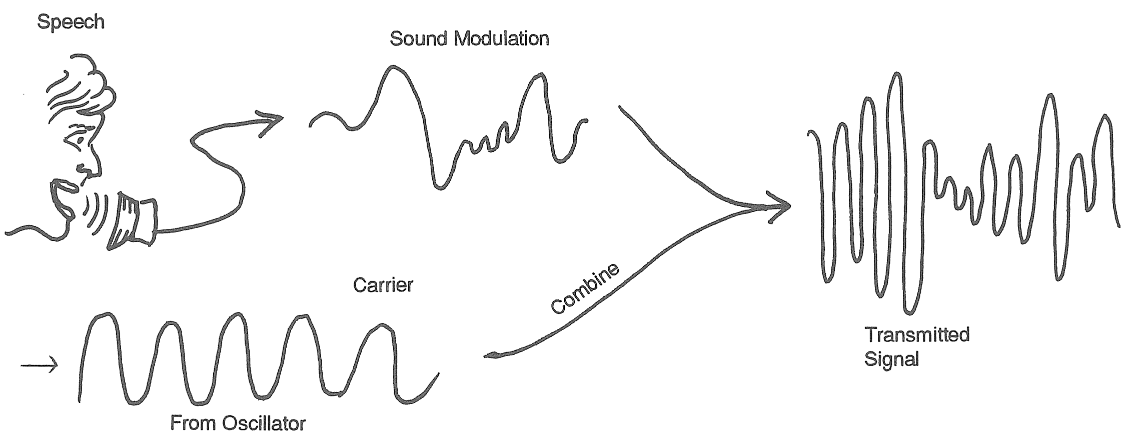
Figure 8.8–Oscillating Current.



An AM radio station has an oscillator that changes the direction of the electron dance about a million times a second. That is why such stations have frequencies on the dial like “810” or “1400,” which stand for 810 kilohertz (810,000 changes of direction or cycles per second) or 1400 kilohertz (1,400,000 cycles per second).

The high-frequency oscillator used at an AM station generates a pure, radio tone. Unfortunately, listeners would quickly get bored if their receivers only produced this monotonous note, so the engineers have figured out how to modify, or "modulate" the pure radio tone (which is called a "carrier") with the sound of today's Top 40 or a newscaster's voice. The modulations are produced by a microphone, which converts sound waves into another changing electrical current, which is then added to the radio carrier, as in Figure 8.9.

Figure 8.9–Converting Sound Waves to Electrical Current.



How a Radio Receiver Works

An antenna, either sticking out the top of your radio (or car) or built inside, picks up radio signals and causes electrons in the wire connected to the antenna to dance synchronously with the signal. But that's not good enough to make a radio receiver, because 1) the antenna is sensitive to all radio stations, not just the one you want to listen to, and 2) you are not interested in the carrier, only the modulation, and you want this changed into sound waves so you can listen to your favorite music group or broadcaster.

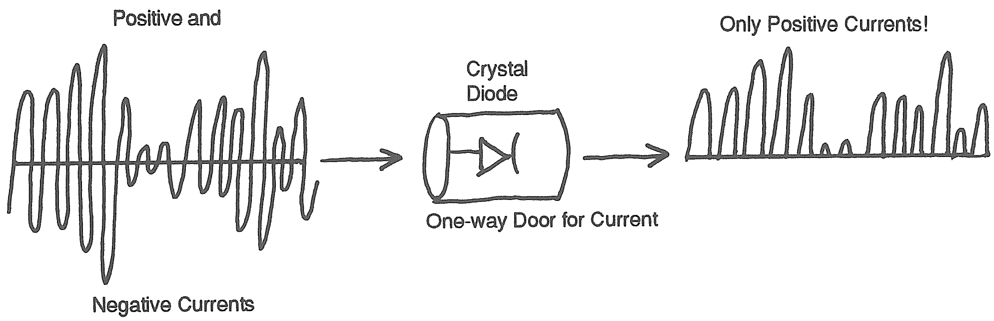
The simplest kind of receiver is called a crystal set, and consists of four major sections:

1. The antenna. This can be a long piece of wire which picks up radio signals. It helps a lot if you also have a "ground," which is another piece of wire that is connected to a metal fixture that sticks into earth. In the wire that joins the antenna and the ground, the incoming radio waves from the transmitter force the electrons to do a dance that mimics the one produced in the radio transmitters.

2. A tuning circuit. This consists of a coil of wire and a capacitor (two metal plates, close together; you can also make a capacitor with two pieces of aluminum foil, separated by a sheet of paper or some other insulator). What does the tuning circuit do? It picks out the carrier wave at one station's wavelength–the one that you wish to listen to–and sends that signal on to the next part of the receiver. It is connected to the tuning knob in larger receivers. You can seek out another station by changing either the coil or the capacitor.

3. The detector. Because the current in the antenna is oscillating both forward and backward, if we sent this signal directly to an earphone you wouldn't hear anything, because the positive and negative currents would cancel out on average, producing no sound! Instead, we force the signal from the tuning circuit through a detector (in this case, a crystal diode) which only allows current to pass in one direction (see Figure 8.10). After passing the diode, the average value of the current is not zero, and we can send the signal onto the final section of the radio, the earphone.

Figure 8.10–The Detector.



4. The earphone. This is the part of the radio that converts the changing currents into sound (see Figure 8.11). It undoes what the microphone originally did to convert sound into changing electric currents. The earphone accomplishes this with a thin piece of metal (a diaphragm) next to a small electromagnet. When the current from the detector passes through the electromagnet, it turns it into a varying magnet which pulls on the metal diaphragm, causing it to vibrate and make the sound you hear. The very rapid current changes caused by the radio carrier are too fast (about one million changes per second!), for the diaphragm, but the slow moving changes due to the music are not. So you don't hear the carrier, but you do hear the music. A complete crystal radio receiver is shown in Figure 8.12.

Figure 8.11–The Earphone.

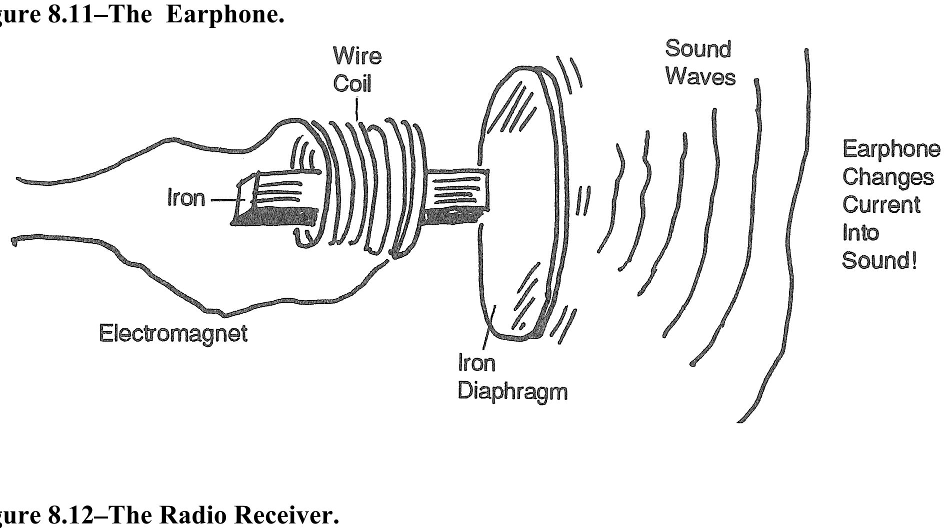
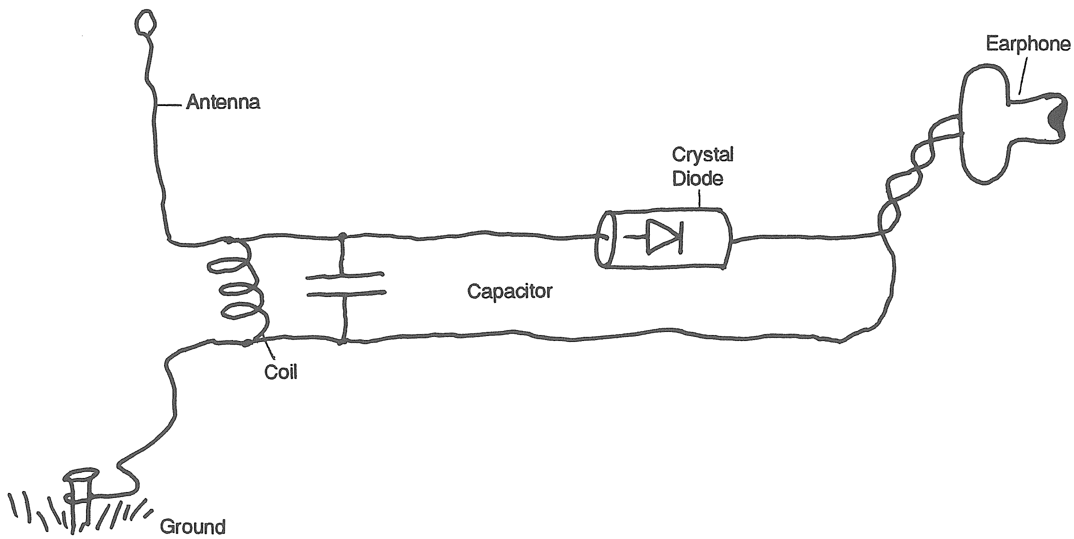


Figure 8.12–The Radio Receiver.



Troubleshooting the Crystal Radio Receiver

1. Check the hook-up to make sure the circuit diagram given in the lesson was followed. It does not matter if you have reversed the direction of the crystal diode, and interchanging where the antenna and ground are connected does not matter either.

2. Make sure that the earphone works. Try connecting it to the terminals of a battery (any 1 volt or even a 9 volt battery can be used). You should hear a clicking sound in the earphones as you make the connection.

3. It is very important that the crystal radio receiver has an adequate antenna and ground. The antenna should be a long piece of wire that can be hung out the window or strung across the room. The ground wire should be taped or wrapped onto a bare spot on a radiator or some other piece of plumbing.

4. The tuning circuit, which consists of the coil and capacitor, is the most fallible element of the radio. The inductance of the coil is sensitively dependent on the number of turns and the diameter of the tube on which it is wound. If the tube is smaller than described in the lesson, increase the number of turns of the coil (*e.g.*, if the tube is 30 percent smaller, increase the number of wire turns by 30 percent; if the tube is larger, decrease the number of turns accordingly).

5. Slide the tuning capacitor up and down to find different stations. Often, the crystal set will only receive one or two strong stations in a particular area. Hunt carefully for a strong station before giving up. Home quality hi-fi earphones hooked up to the receiver are more sensitive and better at shutting out ambient noise than the simple earphones described in the lesson, and these may make station selection easier.

Mission 8
Building a Radio Receiver

SETI INSTITUTE

Radio Technology–Worksheet

Name: ______________________________ Date: ______________________________

1. Where does the power or energy come from to make your radio work?

2. Is your reception better in particular areas of your room or outdoors? Explain why:

3. Does your antenna work better when you press your fingers on the connection point? Why do you think this is so?

4. Take your antenna off. Can you get any stations now? Describe what happens and why you think it happens:

5. Take off the ground wire. Can you still get any stations? Describe what happens and why you think this happens?

6. What is your radio actually receiving? Where is this “information” coming from?

7. If there are radio waves in the room right now, why do you think we cannot hear them without the aid of a device like a radio?

8. What is the carrier?

9. Why is the carrier modulated?

10. While testing your radio, fill in the table shown below. To fill in the column “Distance to Bottom of the Variable Capacitor,” use a metric ruler that shows millimeters. Put the zero end of the ruler against the base of the radio, and measure to the bottom of the variable capacitor to the nearest millimeter. Record the distance on your chart. Different stations will be a few millimeters apart. This varies with the strength of the incoming signal. Strong signals will take up a wider band of space on the variable capacitor. Can you tell which radio stations you are receiving? List their call numbers and/or call signs in the last column.

Table 8.23

Station	Distance to Bottom of the Variable Capacitor	Your Location in the Room	Number and/or Call Sign of the Radio Station
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

SETI INSTITUTE

Mission 9
Separating a Radio Signal from "Noise"

Static, Static, Everywhere!

Notes

Radio technology, although only a few generations old, permeates our society–everything from garage door openers to radar to cellular phones use the same radio-based technology. In Mission 8, students gained firsthand knowledge and experience with radio technology. They discovered that radio waves are all around us, and that they can be detected with a radio receiver.

Overview

In Mission 9.1, students confront the problem of separating a signal from noise to gain an appreciation of the difficulty of detecting a faint signal from far away amid the static from the gas and stars in the galaxy as well as the static from Earth radio and television signals. This is accomplished by using two radios, one tuned in–between radio stations to the static that comes from the universe (and from the radio itself), the other tuned to a "signal" (radio station). Students discover the point at which the signal can be heard and understood amid the static. They also practice signal detection with simulated radio data as a prelude to Mission 10.

Mission 9.1
Materials

For a Class of 30

- 2 radios, preferably the same type
- Overhead projector
- "Spectrum Analysis Display # 1" transparency or PowerPoint slide 9.2
- "Spectrum Analysis Display # 2" transparency or PowerPoint slide 9.3
- "Signal in Background Noise # 1" transparency or PowerPoint slide 9.4
- "Signal in Background Noise # 2" transparency or PowerPoint slide 9.5
- Transparency markers or grease pens

For Each Team

- Envelope
- 1 set of data strips (page 187)
- (optional) 2 rulers

For Each Student

- "Finding a Signal on the Radio" worksheet (page 185
- "Finding a Signal in Noise" worksheet (page 188)
- Pencil

Getting Ready

1. Copy the worksheets "Finding a Signal on the Radio" and "Finding a Signal in Noise" for each student.

2. Make one copy of the "Data Strips" (page 187) for each team. Cut out the strips so that there are no white margins, but be sure to leave the numbers (88 and 108) on the ends. Put each set into an envelope. These strips can be reused many times, especially if they are laminated.

3. Locate two similar AM radios. Set up the two radios side by side in the classroom. Set up the chairs or desks so that all students are about the same distance from the two radios. Tune one radio to static and the other radio to a station broadcasting someone talking.

4. Set up the data projector.

Classroom Action

1. **Lecture**. Divide the class into teams of two to four students each. Tell the class that central to the whole concept of what SETI is trying to accomplish is separating an intelligible signal from the noise of cosmic static that comes from all objects in space and from the detectors/receivers themselves.

2. **Demonstration.** Hand out the "Finding a Signal on the Radio" worksheet to each student. Show the class the two radios which have been set up side by side. Tell students that one will be tuned to static and the other to a radio station, a signal. Ask students if it helps to turn up the volume when you get a very weak radio signal, such as a radio station accompanied by lots of static. *(Of course not, because the static gets louder, too.)* Demonstrate this, on one of the radios. Ask students to name sources of static. *(Static comes from electric motors, electrical storms, and virtually anything that is electromechanical in nature. It can also come from cosmic sources, like our Sun and stars in our galaxy. At high frequencies, a lot of it is caused by synchrotron emission from electrons whizzing around magnetic field lines in the galaxy. However, the bulk of the noise is caused by the electronics of the radio itself.)*

   Tell students that to appreciate how static, or noise, can interfere with reception, you are using two radios so that you can separately adjust either the signal or the noise. Turn up the static volume as loud as the class can tolerate. Try to set the volume dial at a whole number if you want to simplify the math. Make sure all students are roughly the same distance from both radios. Slowly turn up the volume of the other radio. At what point can the class hear the signal against the background static? Students should record that volume on their worksheets. At what point can the class understand what the person on the radio is saying? Record that volume.

Usually the ratio of static noise to the volume when they can understand what the person is saying is 1:1. SETI scientists are attempting to do the same thing; pick a signal out of the background static or noise. Tell them that SETI scientists need a much better ratio than 1:1. They need anywhere from 5:1 to 10:1 to be certain that they are getting a signal amid the background noise. Demonstrate this by turning the static volume level to "1," and the volume of the person talking to "5" (5 times as loud) or more.

3. **Activity.** Pass out the envelopes with the "Where Are the Radio Stations?" data strips inside. Ask students to proceed with their worksheets. When they are finished, make sure students realize that they have simulated how the SETI scientists sort natural static from the broadcast of some distant transmitter by repeated scans.

4. **Transparency or PowerPoint Slide 9.2** Put the "Spectrum Analysis Display # 1" transparency on the overhead or data projector and tell students that this is what radio noise looks like when it is put on a television monitor. This transparency is a scan of radio frequencies coming from space. It was done by a computer exactly the way students sorted their data strips. The computer tuned across the dial of a radio telescope, starting at a low frequency (left) and going to a high frequency (right). It put a dot of light on the screen at each frequency where it detected a signal. The dot is large for a strong signal and small for a weak signal. That was SCAN 1, just like STRIP 1 for the data strips. SCAN 1 is labeled at the lower left.

   Then the computer started over (SCAN 2, lower left) and again tuned across the dial from low to high frequency, putting a large or a small dot at each frequency where a signal was detected. The screen shows what it found after 300 scans, each one taking about a second. This is exactly like the 10 strips lined up next to each other, except that in this image the edges of the strips (or scans) cannot be seen. This is how SETI scientists search for a signal, by looking for a frequency that is always "on" (a transmitter) amid frequencies that go "on" and "off" randomly (static), and by looking for a strong signal amid weak background signals.

   Now ask students what an extraterrestrial transmitter would look like on this screen. *(An extraterrestrial transmitter would look exactly like the line of dots on the 10 data strips-always "on" amid the background of static.)* Is there a signal in this screen? Remember, a signal would be a pattern of dots. Is there any visible pattern? The pattern to look for is a straight line of dots. This line may be hard to see because the eye becomes distracted by all of the random dots (the background static). Using a ruler or other straightedge may help. Give students a few minutes to find a pattern. They should find there is no pattern in the first screen.

5. **Transparency or PowerPoint Slide 9.2.** Put the "Spectrum Analysis Display #2" transparency on the overhead or data projector. Tell the class that this is an actual radio signal coming from beyond our solar system, from the *Pioneer 10* spacecraft. Does the signal stand out over the noise? *(Yes. Blatantly!)* What kind of pattern does it make? *(A straight sloped line.)* This is a strong signal, deliberately generated. Would it be hard to detect if it were weaker than most of the noise? Make sure they see the analogy to the two

radios. The signal picture needs to be louder or stronger than the background's random dots; the stronger it is, the easier it will be to detect. Or, the signal needs to be always "on." Or both.

Ask students to name a difference between paper detection of radio stations and computer detection of a distant transmitter. *(First, Earth AM radios operate between 0.8 and 1.6 MHz; the SETI detector searched frequencies of 1 to* 3 *GHz, or 1,000 to 3,000 MHz. These frequencies cross space with less interference than AM radio frequencies and could be the ones to use to broadcast toward another star.)*

(Second, the detected Pioneer *transmitter frequency changed between scans, unlike Earth radio stations, causing the line of dots to angle upward across the screen rather than go straight up. The* Pioneer *transmitter didn't really change frequency; the shift was caused by the Doppler Effect as the rotating Earth moves the radio telescope toward* Pioneer, *then away. The speed with which we riders on a turning Earth go directly toward* Pioneer *changes every second,* so *every second the Doppler shift is slightly less. This causes an angle across the screen, rather than a straight vertical line, that is somewhat shifted from* Pioneer's *true frequency. If students want to pursue this, have them imagine riders on a merry-go-round: Earth… turning past a buzzer* ... Pioneer.)

6. **Transparencies 3 and 4 or PowerPoint slide 9.2 Figures 9.4 and 9.5.** Tell students that you're going to put on a spectrum-analysis screen and you want them to find a signal. Put the "Signal in Background Noise #1" transparency on the overhead. Give the class a minute or two to study and search. Is there a signal? *(Yes. There is a weak signal.)* Many of your students will probably find it. If there were a stronger signal, how would the screen look different?

   Put the "Signal in Background Noise #2" transparency on the overhead for a brief moment, then align transparency #1 with #2. The signal in this transparency is the same signal as in the first transparency, but it is strong and obvious. Allow students time to "see" the weak signal in #1.

   Here is a method of finding the straight line signal that you may wish to share with your students at some point: You can see the straight line of dots more easily if you hold the sheet of paper level with your eyes, parallel to the ground, and rotate the sheet until you see a signal. This happens when your eyes are lined up and looking straight along the signal path. SETI scientists do the numerical equivalent of this; they add up the signals along all possible straight line paths and find the ones (if any) with very large sums.

7. **Activity.** Hand out the "Finding a Signal in Noise" worksheet to each student. Ask students to complete the worksheet in class or as homework. Ask teams that find signals to keep quiet about it until everyone has had time to find them. The first ones are easier than the last ones. Students may ask you for rulers to help them find the straight-line data on this worksheet.

Going Further

Activity: Red and Green Pictures

Instruct students to make line drawings in a single color (red, green, or blue) and then use the other two colors to fill up their pages with similar but random shapes and lines until the original line drawing is sufficiently obscured and cannot be readily identified. Ask students to look at each other's pictures through red, blue, and green filters. Can they make out the line drawings? Try combining filters and using diverse colors. Colors are various frequencies of the electro-magnetic spectrum that are carried to the eye by light. Filters allow only specific wavelengths to reach the eye; they filter out the "noise"–the random shapes and lines drawn with other colors (wavelengths). So, with the right filter, the original line drawing (the wavelength that has the "signal") can be seen clearly.

Mission 9
Separating a Radio Signal from "Noise"

Finding a Signal on the Radio–Teacher's Key

1. Most of the static on a radio is produced within the radio itself at the higher frequencies. Static on a radio or television set can also be caused by any interfering electromagnetic wave produced by other electric devices, power plants, or any discharge such as lightning, or from poor connections.

2. Answers will vary.

3. For a SETI scientist to detect a signal, it must stand out above the noise, and/or the signal must always be "on." SETI scientists construct radio telescopes and instrumentation to optimize their signal detection capabilities, to minimize noise, and to observe long enough to distinguish a signal that is always "on." It is also possible to find a signal that flashes on and off at regular intervals. Such a signal might be sent by a transmitter rotating like a lighthouse beacon, or would be "seen" by us as "on" every time the rotation of the extraterrestrial planet turned the transmitter in our direction.

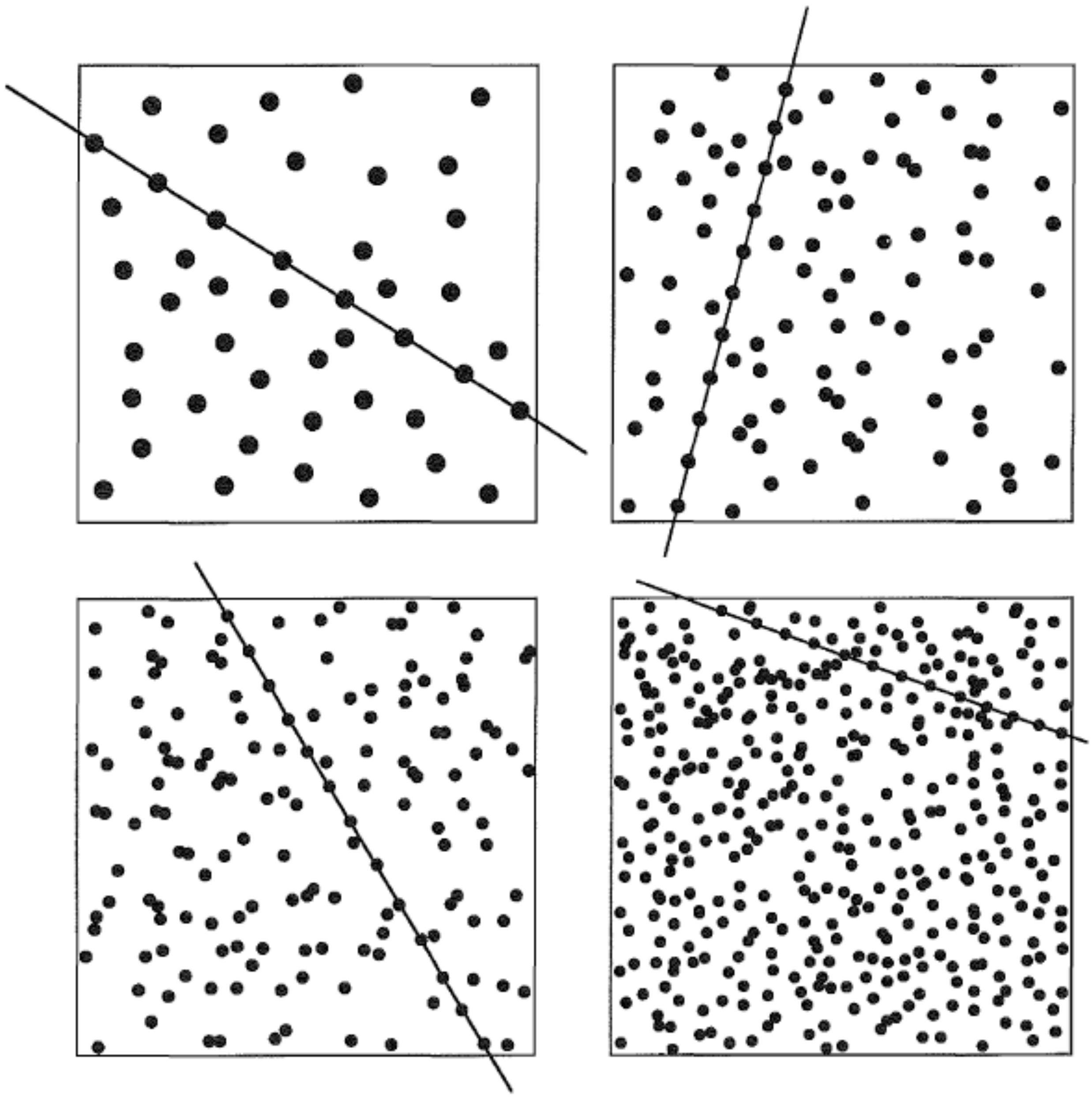
4. 90.7, 92.0, 93.3, 100.5, 104.2, 106.8

5. As SETI scientists look at the sky, they receive data from over 28 million channels at a time. Among those 28 million channels there is a great deal of noise produced by matter in space (some of the radio noise is from interstellar gas) and sometimes by Earth-based sources (television, radio, microwave communication, satellites, *etc*.), and of course, unavoidable noise from the radio receiver itself. All 28 million channels are looked at about once a second. If you lined up strips of 28 million channels and looked at them once a second you can get an idea of what SETI scientists are doing. SETI scientists have built super computers to help them analyze these 28 million channels for signals among the noise.

Mission 9
Separating a Radio Signal from "Noise"

Finding a Signal in Noise–Teacher's Key

Figure 9.1.



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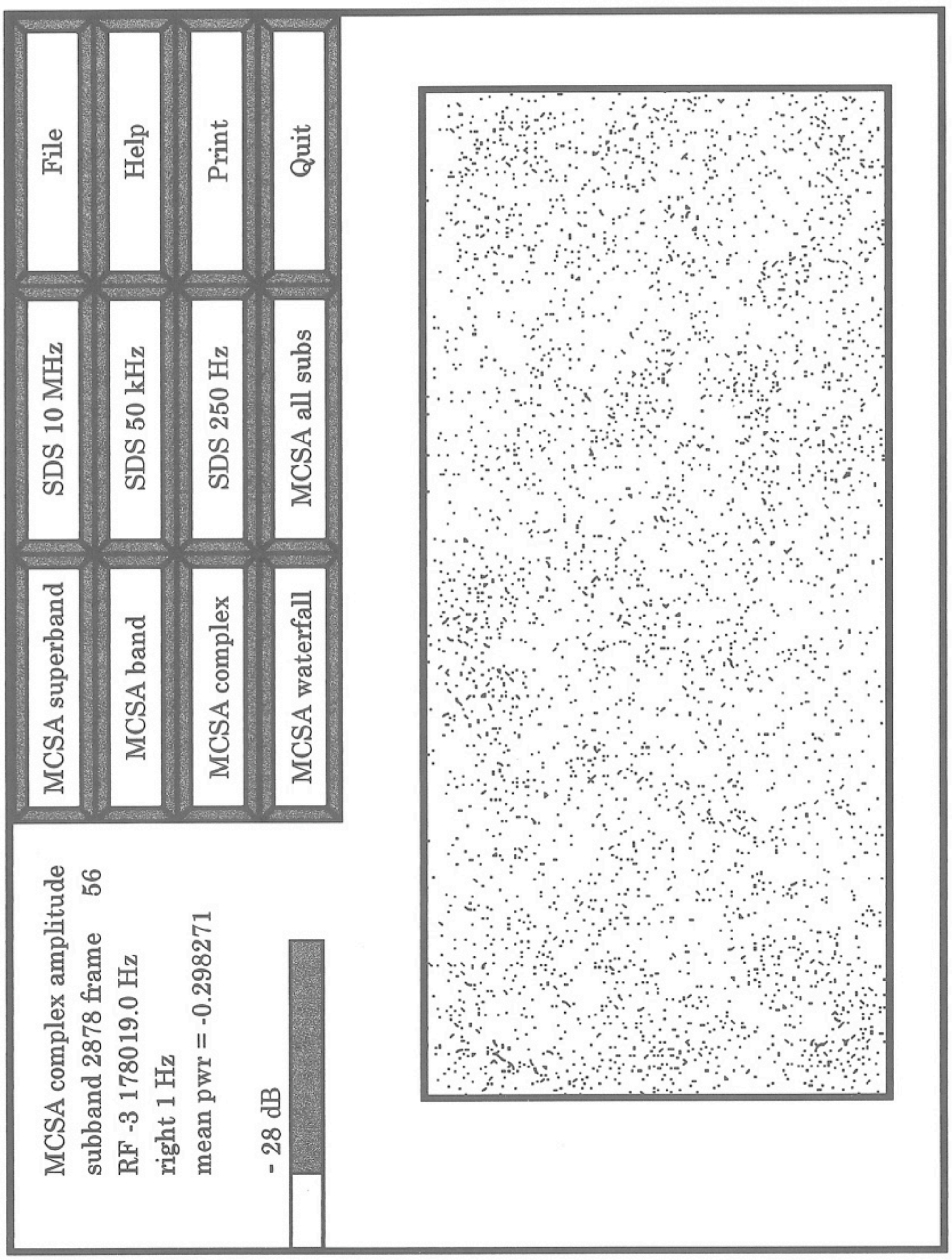
Mission 9
Separating a Radio Signal from "Noise"

Spectrum Analysis Display #1–Transparency or PowerPoint slide

Figure 9.2.



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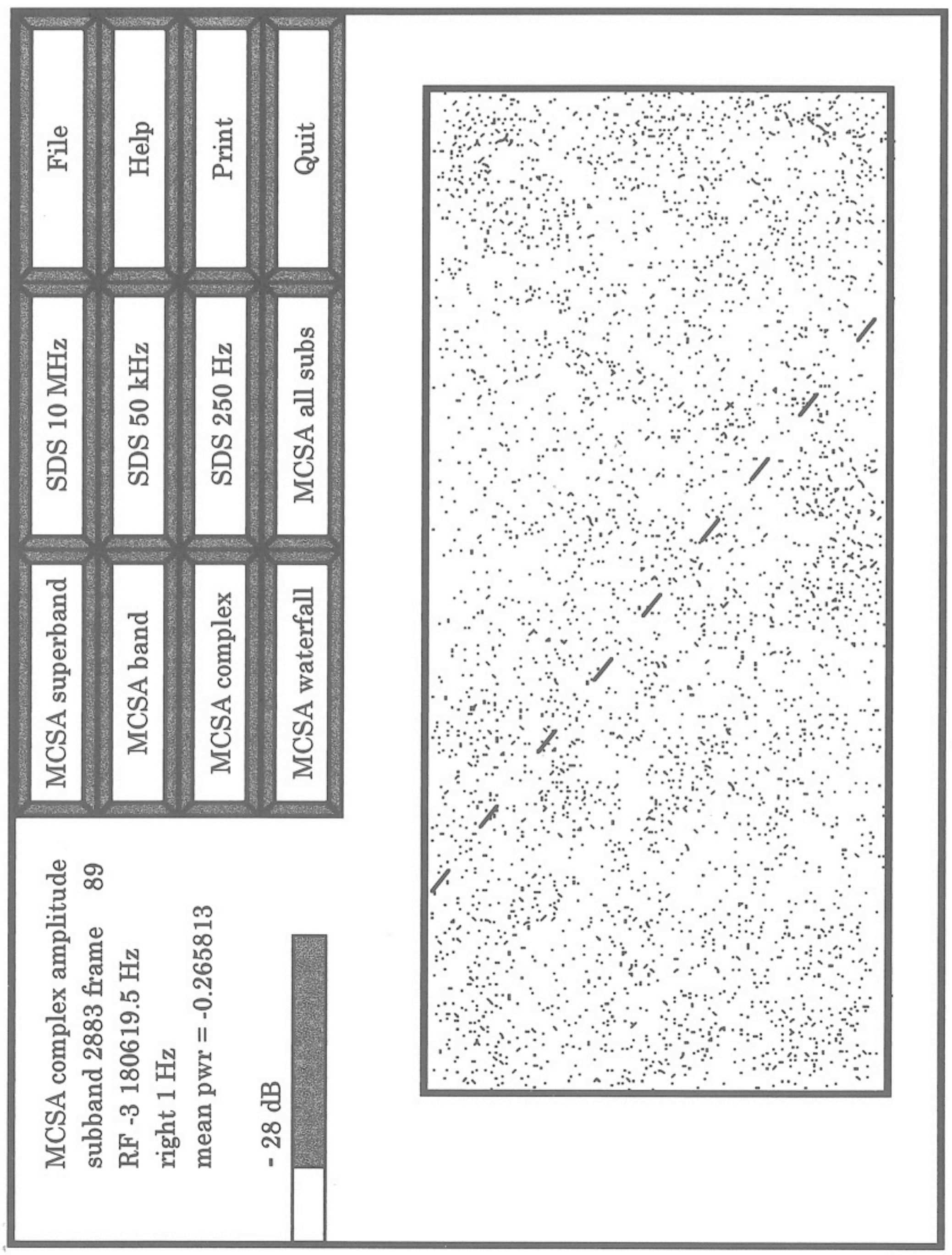
Mission 9
Separating a Radio Signal from “Noise”

Spectrum Analysis Display #2–Transparency or PowerPoint slide

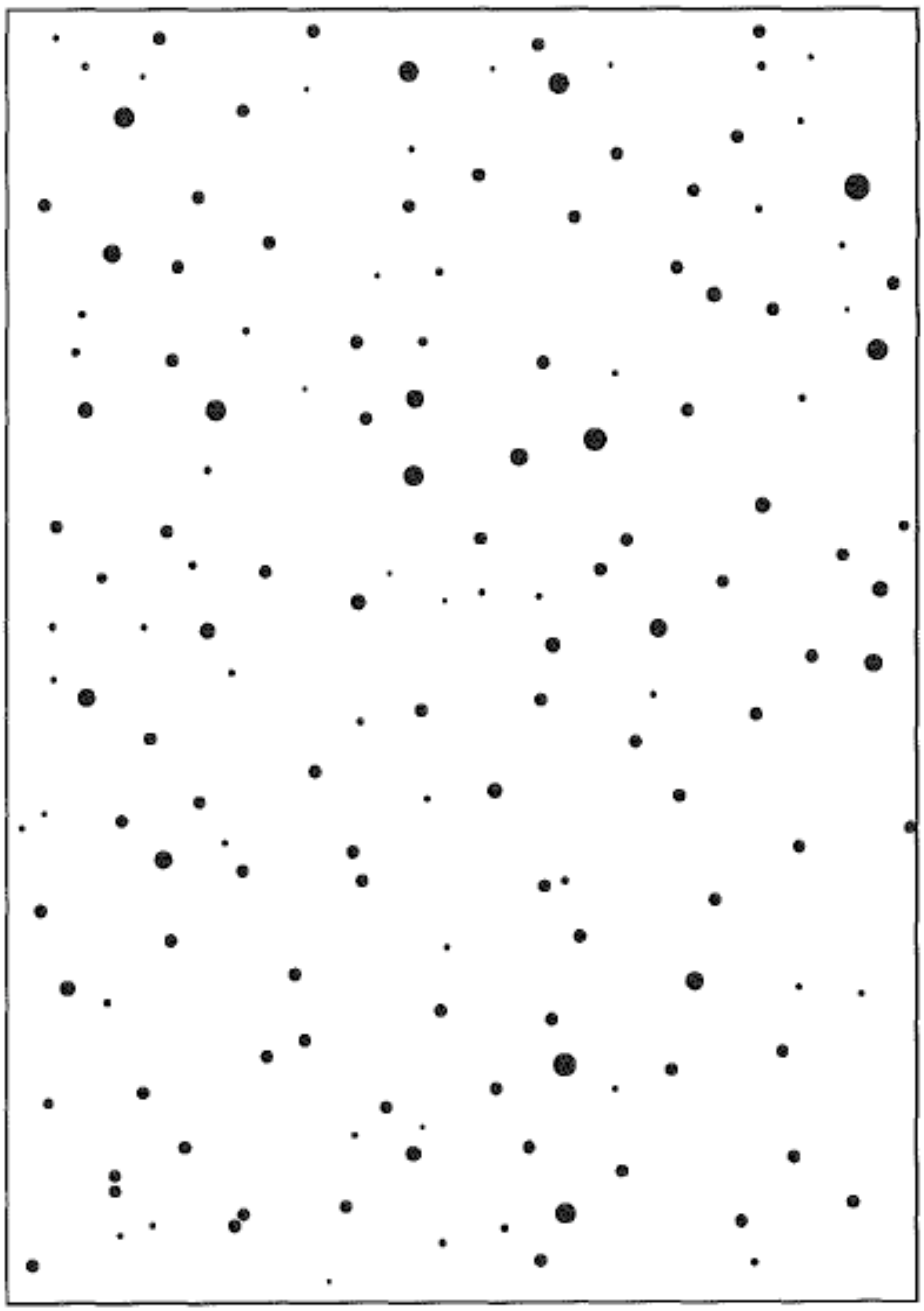
Figure 9.3.



Mission 9
Separating a Radio Signal from "Noise"

Signal in Background Noise # 1–Transparency or PowerPoint slide

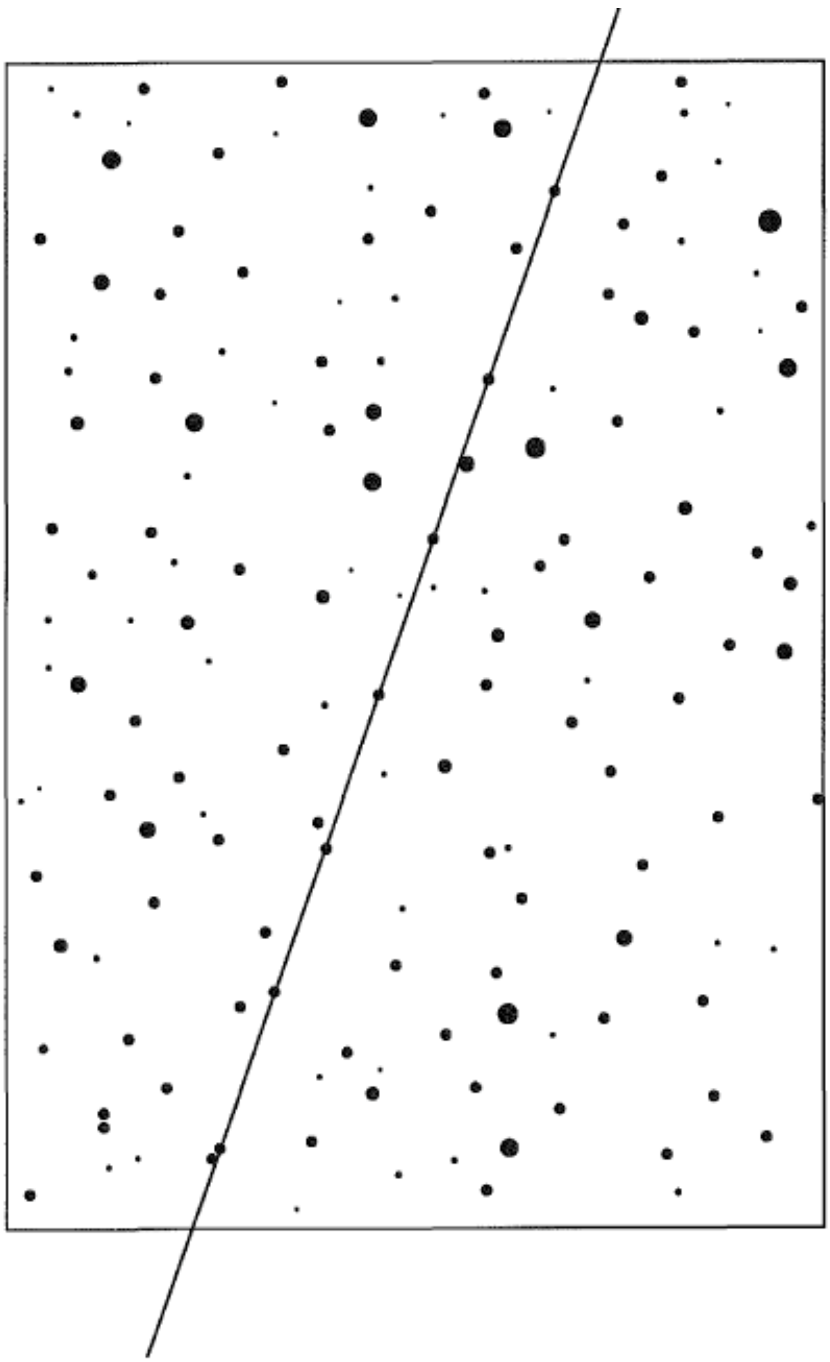
Figure 9.4.



Mission 9
Separating a Radio Signal from "Noise"

Signal in Background Noise # 2–Transparency

Figure 9.5.



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Mission 9
Separating a Radio Signal from “Noise”

Finding a Signal on the Radio–Worksheet

Name: ___________________________________ Date:____________________________

1. What is the cause of static on any radio or television set?

2. Listen to the two radios that the teacher is playing.

   What is the volume of the radio that is “tuned” to static?

   What is the volume of the other radio when you could first detect a signal?

   What is the volume when you could understand what the person was saying?

   What is the signal-to-noise ratio for each of these?

   First detected?

   When you can figure out what the person is saying?

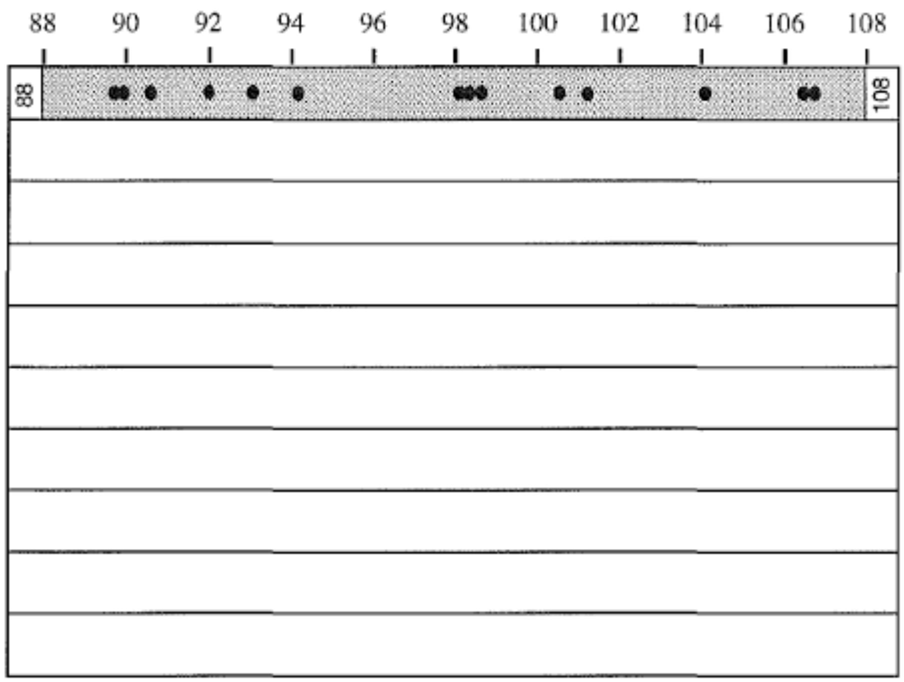
3. What does this have to do with what SETI scientists are doing?

Where Are the Radio Stations?

Each strip in your envelope (like the one shown below) shows what you would see on a computer screen that displays a spot of light wherever your radio detects a sound as you tune across a radio dial. You will sometimes see a spot between stations, where natural radio static comes in, but you will always see a spot at each radio station, where a transmitter is broadcasting.

Pull the strips out of your team's envelope, and line them up on the grid found below. There are nine strips. Each strip corresponds to a scan across the full range of the radio frequencies. Each strip represents a one-minute scan, and the strips may be placed in any order on the grid. However, be sure that the frequencies (the stations) are correctly aligned with "88" on the left and "108" on the right like the first strip on the grid.

Figure 9.6–Radio Dial.



4. The six radio stations are located at the following places on the AM dial:

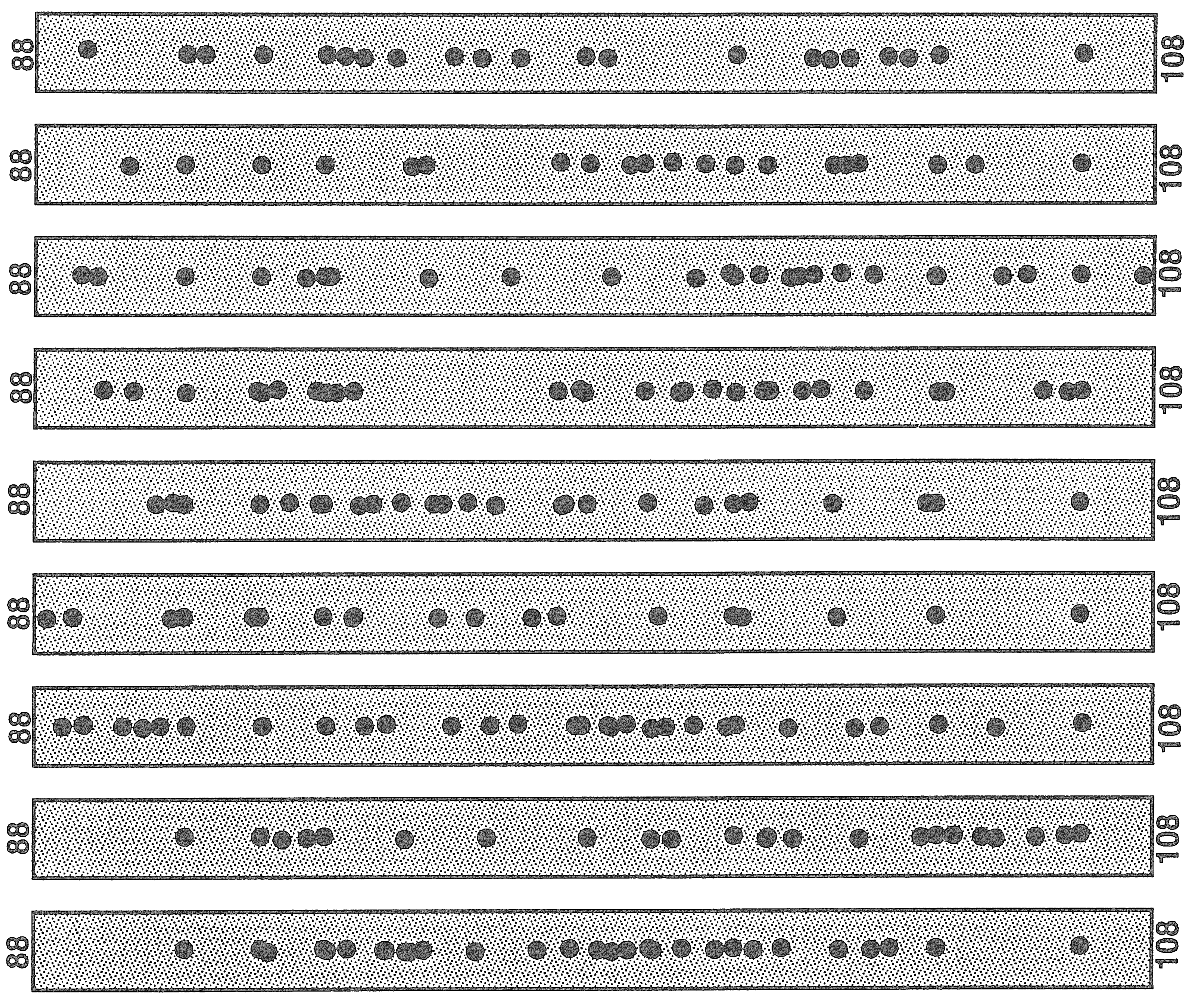
   ________ ________ ________ ________ ________ ________

5. How do you think this activity relates to what SETI scientists are doing in their search for signals from space that may be of extraterrestrial origin?

Mission 9
Separating a Radio Signal from "Noise"

Data Strips

Figure 9.7.

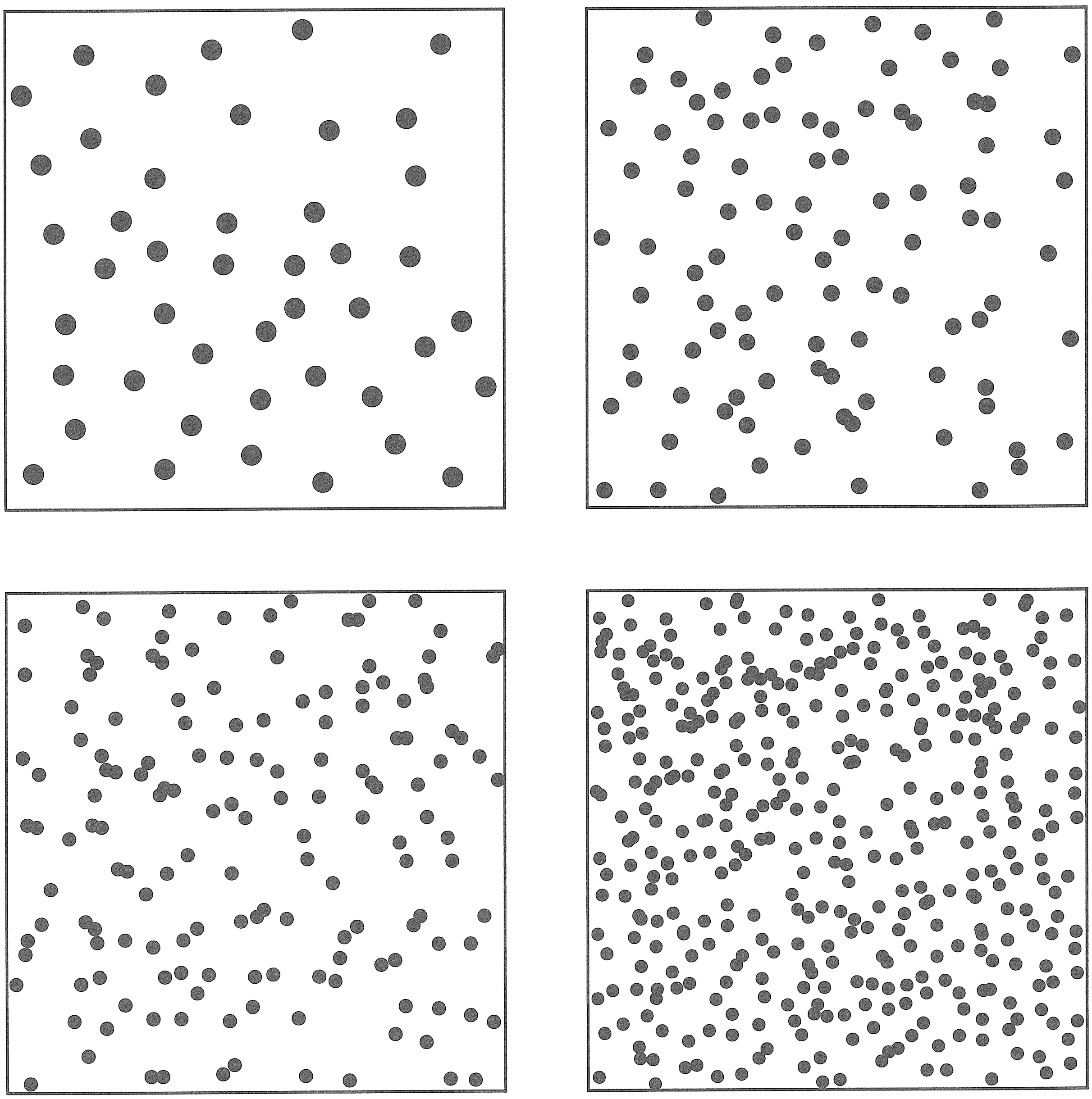


Mission 9
Separating a Radio Signal from “Noise”

Finding a Signal in Noise–Worksheet

Name: ______________________________ Date: ________________________

Figure 9.8.



SETI INSTITUTE

Mission 10
The Search for Extraterrestrial Intelligence

The Needle in the Celestial Haystack

Notes

In Mission 9, students became proficient at finding a signal in a background of radio static. In Mission 1 of Project Haystack, students were told that they would be challenged with finding the point of origin of an extraterrestrial signal–the needle in the celestial haystack. That time has come!

Overview

In this mission, students call upon their new skills and knowledge about different types of stars to decide which stars (from a list) they would like to "listen" to with a radio telescope. In Mission 10.1, student teams simulate a "targeted search," hoping to detect a distinct radio signal that might signify the presence of life outside Earth. Each team is given only enough time on the simulated radio telescope to listen to three stars. The radio data they receive is mostly noise. When they *do* receive a signal that stands out against this background of noise, the signal is not clear. In Mission 10.2, students attempt to verify the reception of a signal from Mission 10.1, learning that even when a signal is found, any interpretation will be very uncertain.

Mission 10.1
Materials

For a Class of 30

- "Radio Signal Search Data, Day One" worksheet (pages 204-207)
- 16 file folders
- Box to store file folders

For Each Team

- "SETI Star-List" worksheet (page 201)
- "Stellar Facts" (pages 199-200)

For Each Student

- "Searching for a Signal" worksheet (page 202)
- Pencil

Getting Ready

1. Label 16 file folders with the star numbers and names taken from the "SETI Star List" worksheet.

2. Copy the "Radio Signal Search Data, Day One" for all 16 of the stars. Four have been put on a page to save paper. Cut the sheets apart, and place the appropriate data in each labeled folder. You will need to put more than one copy into each folder because more than one team might ask for data for the same star at the same time. If students are good at selecting the more promising stars, many students will choose to listen to the same ones, while other stars are never selected because they are obviously unlikely candidates.

   Important: Each "Radio Signal Search Data, Day One" page is labeled with the name of four of the 16 stars. Of the 16 stars, 13 do not provide any radio signal, only background static. Only three of the stars, Tau Ceti, Beta Pictoris, and Epsilon Eridani, have a signal within the static background noise.

3. Put all the data folders into a file box and place it in the classroom for easy access and distribution.

4. Copy the "Stellar Facts" pages and the "SETI Star-List" worksheet for each team. Copy the "Searching for a Signal" worksheet for each student.

Classroom Action

1. **Discussion.** Divide the class into teams of two to three students each. Remind students that there are millions and millions of stars in just a small portion of the Milky Way Galaxy and that the list of 16 stars that you are giving them for this mission is indeed a very, very small selection of the total possible.

   Explain that radio telescopes cannot see the entire hemisphere of the sky as our eyes do. To achieve high sensitivity, radio telescopes are focused on a very small area of the sky much like the field of view in a camera or a telephoto lens. This is like one of us looking at the sky through a straw, with one eye closed. We are forced to look at one, or at best a few, stars at a time. Typical radio telescopes must be pointed in entire sky.

   There are two ways to conduct a SETI search: an "all sky survey" and a "targeted search."

   - In the all sky survey, radio telescopes are rapidly scanned across blocks of the sky in both the northern and southern hemispheres until the entire sky has been covered. Computers using sophisticated software programs are needed to search through millions of simultaneous frequency channels to see if a signal is present and persisting from a single point in the sky. Try listening to millions of channels at the same time on your radio!

   - The targeted search uses a different approach. SETI scientists have chosen 1,000 stars with qualities similar to our Sun. They will dedicate a certain amount of the limited listening time available on very large radio telescopes to each of these stars.

2. **Facts.** Hand out the "Stellar Facts" pages to each team. Give students time to read their "Stellar Facts" pages.

3. **Worksheet.** Hand out the "SETI Star-List" worksheet to each team and the "Searching for a Signal" worksheet to each student. Explain that each team must pick only three stars from the list of 16 stars. This simulates the fact that time on a radio telescope is very expensive and many others want to use the telescope for their research projects.

   Students must decide: What stars are the most likely candidates to have planets from which intelligent life might be broadcasting radio signals? What star characteristics are important in suggesting that they might have planetary systems? Students can obtain this information from their "Stellar Facts" pages.

4. **Discussion.** Review the kinds of information given on the "SETI Star-List." Be sure that students understand that the mass and radius of a star are given as ratios to the mass and radius of the Sun. The temperature is given in degrees Kelvin. Some stars in the list belong to a multiple-star system.

   Teacher's Note: *Make sure your students are familiar with measuring temperature in the Kelvin scale. Degrees on the Kelvin scale are the same size as the Centigrade scale. The Kelvin scale starts at absolute zero (-273°C) and always has a positive value. Water freezes at 273K and boils at 373K. Kelvin does not use the degree (°) symbol.*

   Point out that each team must write their reasons for the star choices they make before requesting the radio data. It is up to each team to interpret the radio data and judge if a signal is present. Tell the class that they will need to verify the signal of any star they think has a signal on day one via a second observation on day two. Discuss why scientists think it is necessary to verify their findings. Each team must be ready to report their findings to the entire class.

5. **Activity.** After students read their "Stellar Facts" pages and confer with their team members, teams should come up to your desk and request "Radio Signal Search Data." You should either initial or rubber stamp the verification column. This will be sure to limit each team to only three choices. Encourage teams to keep quiet about any discoveries until they have a chance to report their findings after the second day. Make sure that students return their "Radio Signal Search Data" and turn in their completed "Searching for a Signal" worksheets.

Mission 10.2
Materials

For a Class of 30

- PowerPoint projector
- PowerPoint slide of “Radio Signal Search Data, Day Two” worksheet (page 208)
- PowerPoint slide markers or grease pens

For Each Team

- “Radio Signal Search Data, Day Two” worksheet

For Each Student

- “Finding the Needle” worksheet (page 203)
- Pencil

Getting Ready

1. Set up the overhead or data projector.

2. Copy the “Radio Signal Search Data, Day Two” worksheet for each team. Only one of the three stars on this worksheet, Tau Ceti, has a confirmed signal.

3. Copy the “Finding the Needle” worksheet for each student.

4. Reassemble the class into their teams from Mission 10.1.

Classroom Action

1. **Discussion.** Begin by listing on the whiteboard all 16 stars and recording how many teams chose to look at each one. Were there any stars that were not looked at? Should they have been? Discuss what makes a star a good choice or a bad choice as a candidate in our search.

2. **Team Reports.** Survey student signal detection discoveries by asking if there were any teams that did not find a signal at all during day one. Ask those students to report to the class first. If appropriate, tell them, “Good job, just bad luck! In this mission, several likely star systems are not sending any signals!” What are their conclusions? How did they conduct their search? Do they feel that there are no signals at all? The point here is that it is all right to observe and not find the phenomenon for which you are looking. That, too, is information.

   Ask if there are any teams that looked at a star and noticed a signal. “Good job! And good luck!” Ask teams to report to the class. This will tell you if all three Day One signals were found and, more importantly, if the one real signal was found. (If not, you may wish to show it as a transparency.)

3. **Discussion.** Ask students if, based on the information that has been collected so far, they will make a confident declaration that there is intelligent life in the universe. Maybe the signal(s) detected were from an unknown radio source on Earth, or maybe the signal(s) were just the unlikely result of the random radio noise. Perhaps it was the result of some new phenomenon that produces a steady, loud, narrow band signal.

   Ask for suggestions on how to be more confident about a signal. Students will probably suggest it, but reinforce the importance of experimental verification in science. Facilitate the discussion to the point where the class reaches a consensus. Tell the class that all teams will be given radio data from each of the stars that the class agrees might have an actual signal. This will allow all students to examine signals, even those teams that did not find signals during day one.

   Teacher's Note*: Two of the apparent signals from day one will not be verified: Epsilon Eridani and Beta Pictoris. Only the signal from Tau Ceti will be verified during day two.*

4. **Transparency or PowerPoint slide**. Show the image of the "Radio Signal Search Data, Day Two" worksheet–the radio data from the three stars that show signals–and let others in the class look for a signal. Ask a member of one of the discovery teams to come up and highlight the pattern with a marking pen. Follow the same process with the other perceived signals. This assures that all students will see all three apparent signals.

5. **Activity.** Hand out the "Radio Signal Search Data, Day Two" worksheet, which contains radio data from each of the three stars that might have an actual signal, to each team. Tell the class that all teams will be given an opportunity to verify the apparent signals received by the class during day one. Reassemble day one's teams. They must determine if the signal is still there. If the signal *is* still there, 24 hours later, then they have a verified detection! Allow time for observations.

   Optional: If a team wants verification of one of their three stars that did not show a signal yesterday (maybe they want to give their favorite star another chance), give them the data from day one for that star and just tell them that it is a repeated observation of the same star. This is basically accurate, as the situation has not changed; there is still no signal.

6. **Discussion.** Reassemble the class to share findings. Did an apparent signal disappear? *(Two are gone: Beta Pictoris and Epsilon Eridani.)* What could explain the detection of a signal one day, but not the next? *(Random, stray radio signals of Earth origin may have been picked up.) As another possibility, the ET transmitter may have been off when the students took a second look.)* These might not reappear when the signal was being verified with a second look.

   Is any signal still there? *(One will be: Tau Ceti.)* Would this discovery of one verified signal be conclusive evidence for intelligent life outside Earth? *(Indicative, but not conclusive!)*

Tell students that, in Mission11, now that the star with a signal has been located, they will try to interpret the signal. Make sure that students realize that this whole exercise is a simulation. So far none of the SETI searches has ever found a signal that has been verified, but they are still looking.

7. **Activity.** Hand out the “Finding the Needle” worksheet to each student. Ask students to answer the questions in their teams during class or individually as homework.

Going Further

Research: SETI in Action

Ask students to do research on some of the actual SETI searches that have been conducted, or those that are happening now. From where are searches conducted? Examples include Project Ozma, SERINDIP, META 1 & 2, and some 50-60 others. What percent of the sky has been searched? Are positive results (real signals) expected?

Mission 10
The Search for Extraterrestrial Intelligence

SETI Star- List–Teacher's Key

Table 10.1.

Star	Mass (Sol = 1)	Radius (Sol = 1)	Temp (K)	Distance (Light Years)	Will You Scan It? (Give Your Reason)
Sol	1	1	5,500	8 light minutes	Scan for comparison
Alpha Centauri A	1	1	6,000	4.3	Multiple star system
Epsilon Eridani	0.7	0.8	4,800	10.7	Signal
Spica	17	7	26,000	220	Supergiant
Betelgeuse	16	550	2,900	310	Red giant
Sirius B	1	0.2	Unknown	8.6	Binary
Altair	3	1.6	7,400	17	Good choice, but no signal
Aldebaran	5	25	3,700	68	Red giant
Alpha Centauri C	0.2	0.3	Cooling	4.3	Multiple star system
Antares	16	500	2,400	520	Red giant
Bd +50 1725	0.7	0.75	4,130	14	Good choice, but no signal
Sirius A	3.5	2.5	9,800	8.6	Binary
Arneb	12.5	63	7,300	950	Supergiant
Alpha Centauri B	0.2	0.85	4,900	4.3	Multiple star system
Tau Ceti	0.8	0.9	5,100	11.9	Signal
Saiph	18	7.4	27,000	68	Sipergiant
Beta Pictoris	3	2	7,800	59	Signal

Mission 10
The Search for Extraterrestrial Intelligence

Searching for a Signal–Teacher's Key

1. See the "SETI Star-List" teacher's key.

2. Answers will vary but should be in accord with the "Stellar Facts" pages.

3. Answers will vary.

4. Yes, with unlimited resources there is no reason to limit your search. Because SETI scientists currently do not have unlimited resources, they must decide which stars are more likely to have signals.

Mission 10
The Search for Extraterrestrial Intelligence

Finding the Needle–Teacher's Key

1. Answers will vary.

2. Yes. Epsilon Eridani, Beta Pictoris, and Tau Ceti all have signals.

3. It is important for scientists to verify and confirm their data so they do not announce incorrect information. It is a process of checking one's results and is part of the process of science. Spurious signals could be produced by Earth-based sources or by the equipment used in the radio telescope itself.

4. For Epsilon Eridani or Beta Pictoris, students will find that their second observation does not confirm a signal.

5. They are no longer present. Without further investigation it is impossible to tell if the signals came from these stars and are simply no longer present, or if they came from an Earth-based source that is no longer producing a signal. These stars were good choices, but their false signals were included to show the need for verification and confirmation.

6. Only the star Tau Ceti has a verified signal on the second day of this simulation.

7. No, just finding a signal of this nature does not confirm that there is intelligent life out there. It could still be a signal associated with the telescope, or it could even be a deliberate hoax. Independent confirmation by another group at another telescope would give more confidence that it really was an extraterrestrial signal. Finding a message would prove that it was an intelligent source. Also, because of the time it would take the signal to travel from a distant star to Earth, the life that sent the signal might not be alive now.

8. It would take 11.9 years for a signal from Tau Ceti to reach Earth. Because radio waves are part of the electromagnetic spectrum, they travel at the speed of light.

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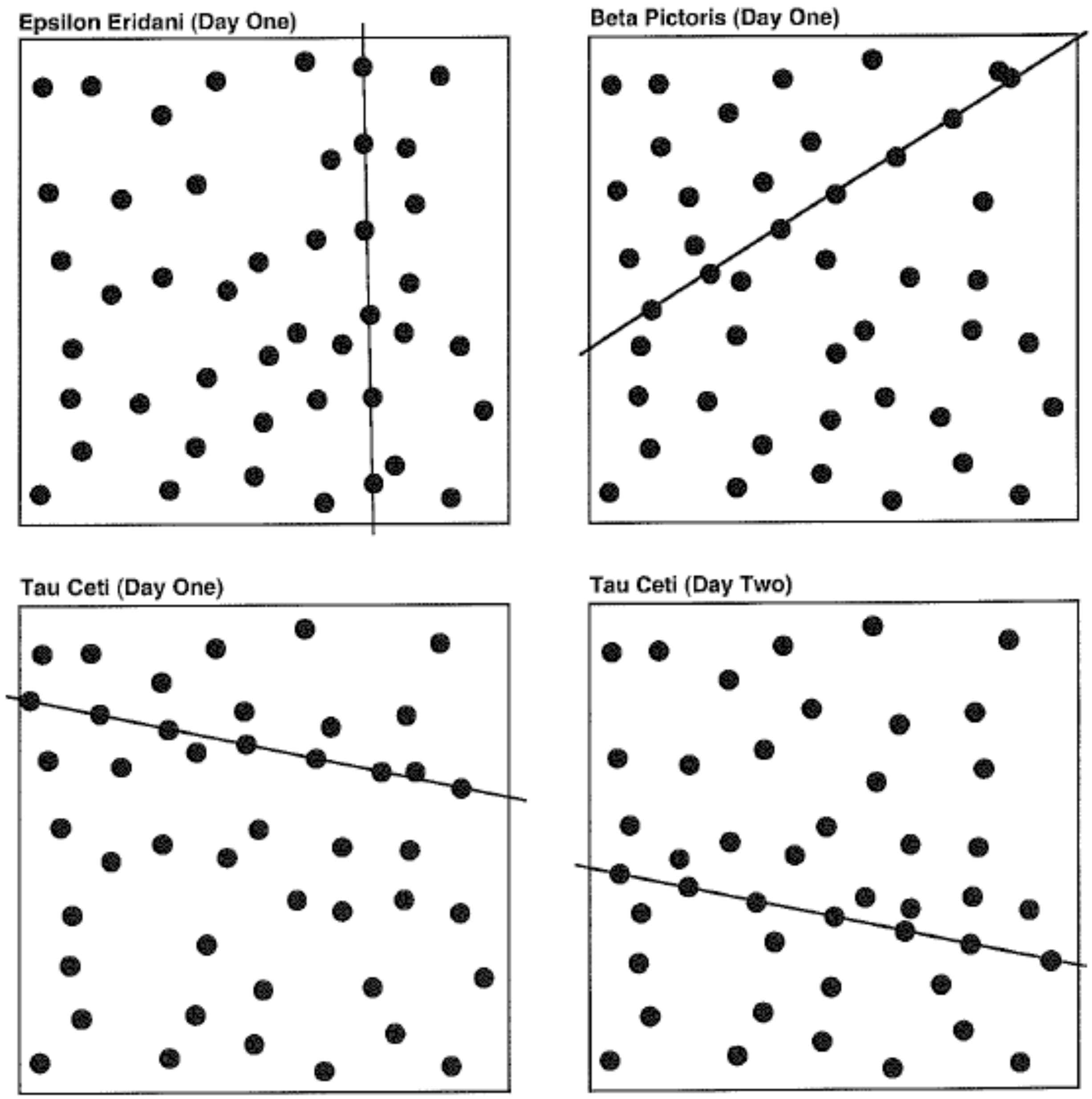
Mission 10
The Search for Extraterrestrial Intelligence

Radio Signal Search Data–Teacher's Key

Figure 10,1.



Mission 10
The Search for Extraterrestrial Intelligence

Stellar Facts

Your SETI team has been given the opportunity to use the world's largest radio telescope at Arecibo, Puerto Rico and a microwave radio frequency computer analyzer to try to detect a radio signal from space. Many other people, working on different research projects, also use the telescope. Because of this, your time is limited. You may search only three stars for evidence of a radio signal. But which three? Which ones would be most likely to have planets with civilizations capable of communicating by radio? The following information will help you.

Astronomers understand the workings of stars. Stars come in a variety of brightness, colors, and sizes. But it turns out that these parameters are related, and a star cannot have arbitrarily combined values of color, brightness, or size. In fact, the life history and appearance of a star is dependent on only one thing: its birth weight, or mass.

Stars are formed from great clouds of gas and dust that collapse under their own weight. About half of all stars are born with nearby companions, forming multiple-star systems in which individual stars orbit one another. If there are planets around such multiple-star systems, they will have to be at very great distances from their stellar hosts. Otherwise, computer models show that the planets will be kicked out of the system by the interplay of the gravitational forces of the stars. But planets at such large distances will likely be too cold to support life, and so multiple-star systems may not be the best places to search for extraterrestrials. In most star catalogs, all the members of a multiple-star system have the same name, but with a letter appended (*e.g.*, Theta Orionis A, B, C, and D are the multiple star system known as the Trapezium at the heart of the Great Nebula in Orion).

Nature makes many more small stars than large ones. Most of the Milky Way's stellar population is made up of stars smaller than the Sun. These dwarf stars have surface temperatures of about 3,000 K, so they appear red–they are called red dwarfs. The small size and low surface temperature of these low-mass stars combine to make them dim. If we wish to find civilizations around red dwarfs, we will have to seek a planet orbiting close to the star. Otherwise, it will be much too cold for life. Unfortunately, planets that orbit very close to a star tend, after a while, to keep one side always facing the star (much as one side of the Moon always faces Earth). This would make for a planet that is quite warm in one hemisphere, and far too cold in the other. Consequently, small, cool stars are probably not favorable hosts for life.

Large stars, many times more massive than the Sun, compress their central regions to very high temperatures, and the result is that they burn their hydrogen fuel much faster than smaller stars. This means that they are both bright and hot (their colors are usually blue-white). Of course, a large star has more fuel to burn, but just as a Cadillac cannot go as far between fill-ups as a VW Beetle, despite having a larger fuel tank, a big star burns itself out far more quickly than a smaller one. Indeed, a massive star such as Sirius A or Deneb may last for only 100 million years before its fuel runs out. Because our experience on Earth tells us that intelligent life took billions of years to develop, these large, bright stars are probably not good candidates for hosting life either.

The way stars die is also determined by their mass at birth. When they begin to run out of fuel, most stars swell up for a while. The Sun will do this between 5 and 7 billion years from now, and when it does, it will swallow Mercury, Venus, and maybe Earth. These swollen stars are known as red giants. But the red giant phase is relatively brief: our Sun (and most average-sized stars) will blow off its outer shell and collapse into a tiny corpse no bigger than Earth. That's less than 1/100 of its original size. Such hot, tiny, glowing embers are called white dwarfs, and their fate is to slowly cool and fade from the heavens.

The largest stars, known as supergiants, won't die so calmly. Some will blow up in a catastrophic explosion called a supernova, and then collapse to a peculiar stellar corpse called a neutron star, or pulsar. Such corpses are only a few miles across and rotate hundreds of times per second. The very largest stars collapse into something far smaller. These stars become black holes.

Your Mission!

You will be given a "SETI Star-List" worksheet. Your mission is to choose the three stars from this list that you think might be the best ones to scan with a radio telescope to look for a signal from intelligent extraterrestrials who might live on a planet orbiting that star. Remember that each star system is a possible location for extraterrestrial intelligence, but we want to look at the most likely locations given our limited time on the radio telescope. Notice that our own Sun is at the top of the list. This is so that you can compare our Sun's characteristics to the characteristics of other stars. We are reasonably certain that there is intelligent life on Earth!

Write your three choices on your worksheet. Include the reasons for each of your choices. To receive printouts of the radio data for the three stars, write down the name of the star and the reasons why your team chose that star. Your teacher will initial each request to verify that you have used up one of your three choices. You may look at only one star at a time.

Do you think we know enough about the requirements for life to rule any stars out?

Mission 10
The Search for Extraterrestrial Intelligence

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SETI Star-List–Worksheet

Name: ______________________________________ Date: ________________________

Table 10.2–SETI Star-List.

Star	Mass (Sol = 1)	Radius (Sol = 1)	Temp (K)	Distance (Light Years)	Will You Scan It? (Give Your Reason)
Sol	1	1	5,500	8 light minutes	
Alpha Centauri A	1	1	6,000	4.3	
Epsilon Eridani	0.7	0.8	4,800	10.7	
Spica	17	7	26,000	220	
Betelgeuse	16	550	2,900	310	
Sirius B	1	0.2	Unknown	8.6	
Altair	3	1.6	7,400	17	
Aldebaran	5	25	3,700	68	
Alpha Centauri C	0.2	0.3	Cooling	4.3	
Antares	16	500	2,400	520	
Bd +50 1725	0.7	0.75	4,130	14	
Sirius A	3.5	2.5	9,800	8.6	
Arneb	12.5	63	7,300	950	
Alpha Centauri B	0.2	0.85	4,900	4.3	
Tau Ceti	0.8	0.9	5,100	11.9	
Saiph	18	7.4	27,000	68	
Beta Pictoris	3	2	7,800	59	

Mission 10
The Search for Extraterrestrial Intelligence

SETI INSTITUTE

Searching for a Signal–Worksheet

Name: ___________________________________ Date: ____________________________

1. Fill out the chart on your "SETI Star-List" worksheet.

2. What do you and your team members feel are the most important criteria in choosing to search one star over another?

3. From the stars listed on your worksheet, enter the three that best fit your search criteria into the table below.

Table 10.3-Stars to Search.

Star Name and Number	Reasons for Your Choice	Teacher's Initials	Is There Evidence of Radio Signals?

4. If you had an unlimited amount of money and radio telescope time, would it be a good idea to look at every star in our galaxy for a signal? Explain your answer.

Mission 10
The Search for Extraterrestrial Intelligence

Finding the Needle–Worksheet

Name: ______________________________________ Date: ___________________________

1. Did any of the stars your team chose show a signal through the background static during day one? Which ones?

2. Did any of the stars the class chose show a signal through the background static during day one? Which ones?

3. During day two, you will need to verify the apparent signals received by the class. Why do you think it is important for scientists to confirm and verify their data?

4. Did you find any stars that apparently had signals during day one but show no signal during day two? Which ones?

5. What may have happened to these signals?

6. Did you find a star that had a verified signal during day two? Which one?

7. Does this confirm that there is intelligent life somewhere else? (Remember, this is a simulation. But consider this: if one signal were verified once, would that confirm that there is intelligent life somewhere else?)

8. If the signal that came from that star was real, how many years did it take for the signal to get here? How many years would it take for us to send back a reply? How do you know?

Mission 10
The Search for Extraterrestrial Intelligence

SETI INSTITUTE

Radio Signal Search Data, Day One–Worksheet

Figure 10.2.

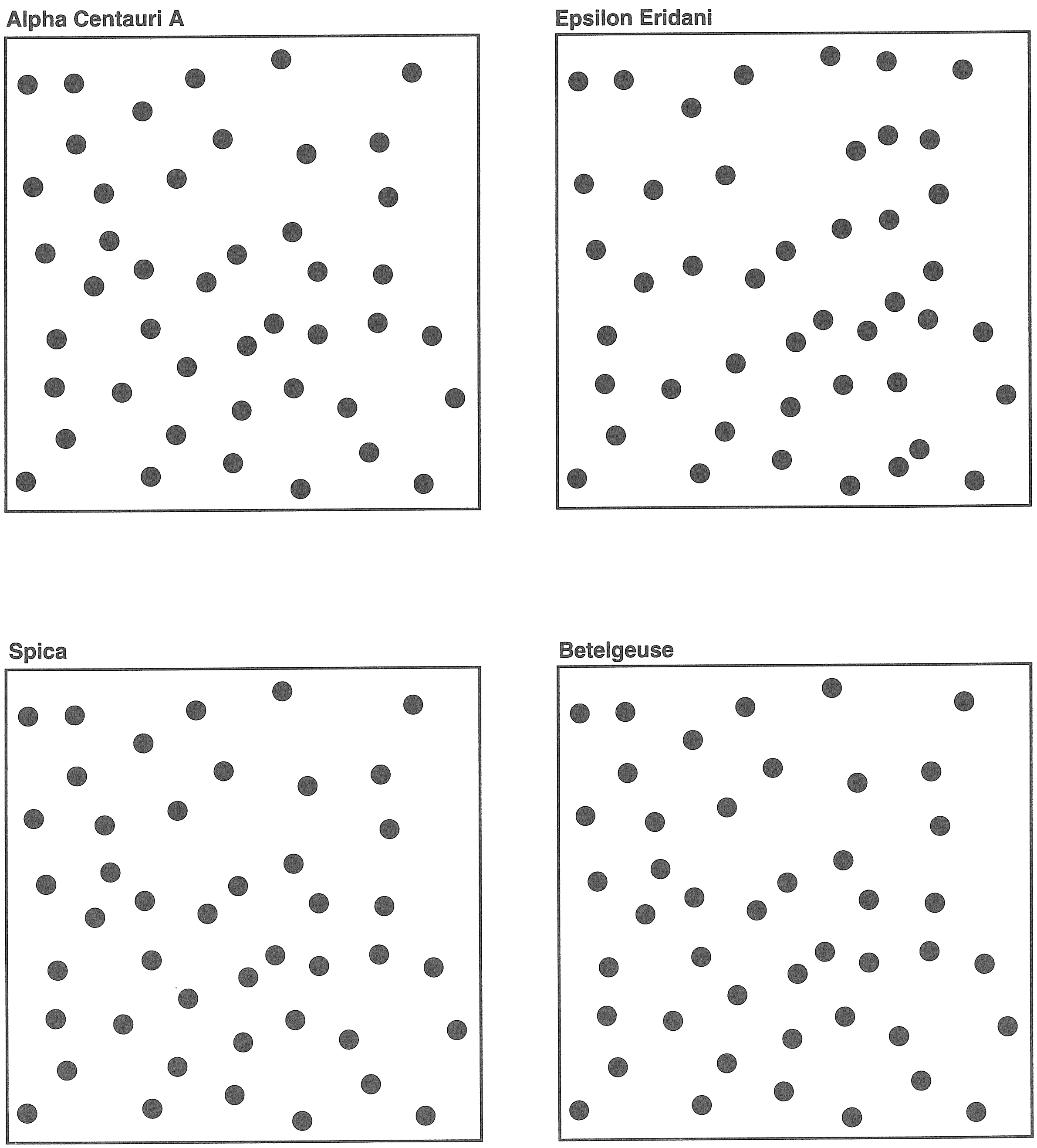


Figure 10.2 *(continued)*

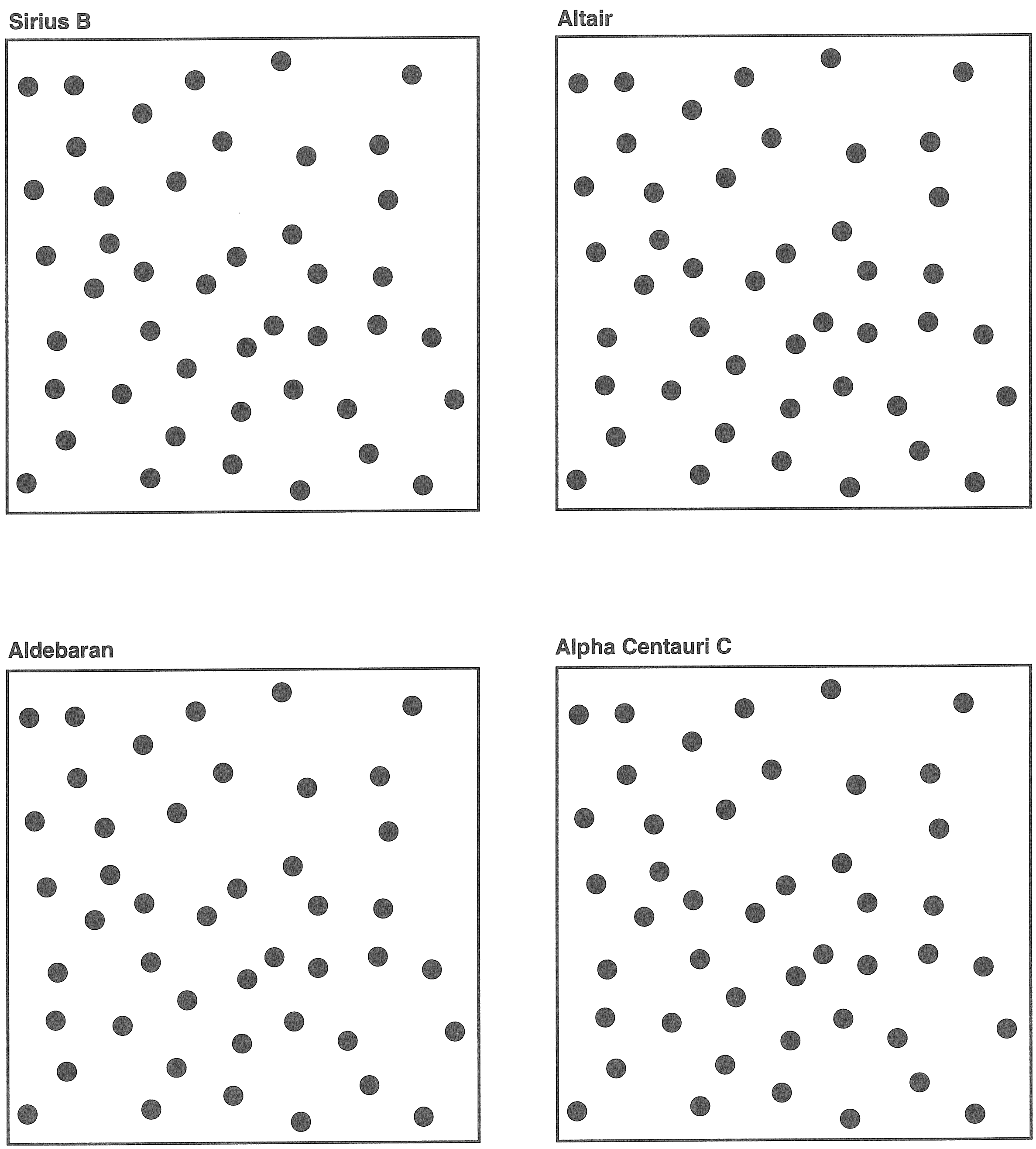


Figure 10.2 *(continued)*

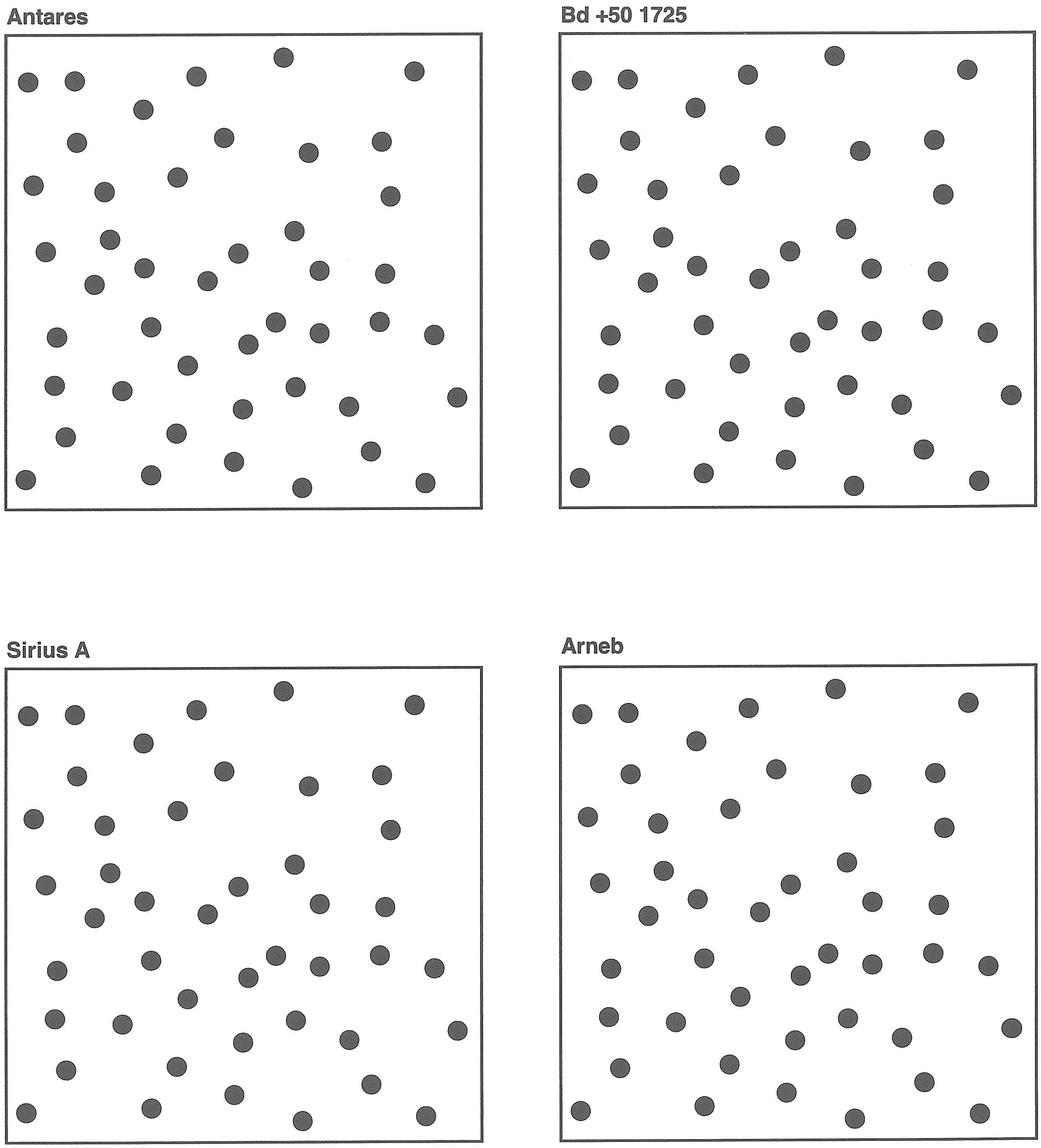
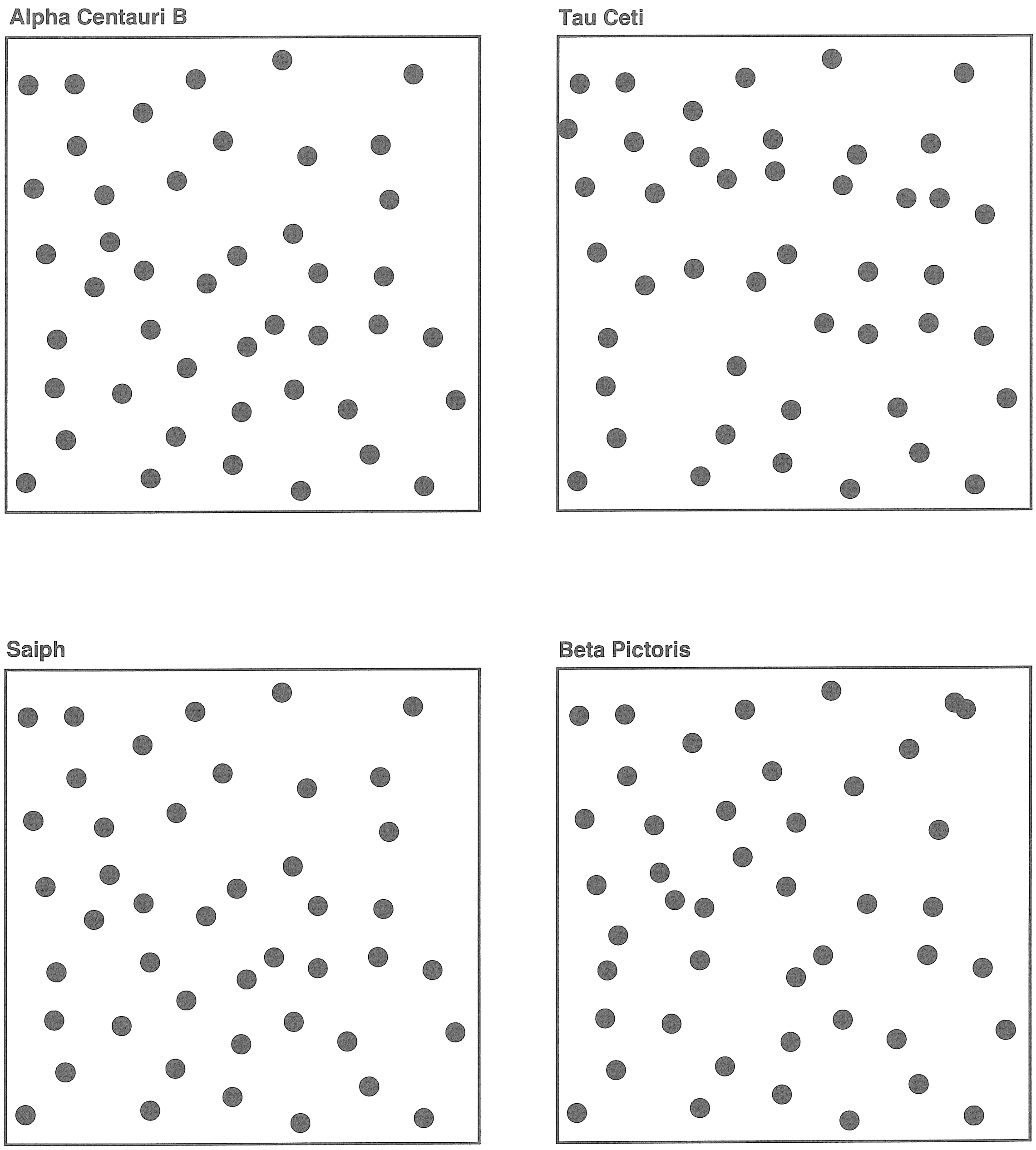


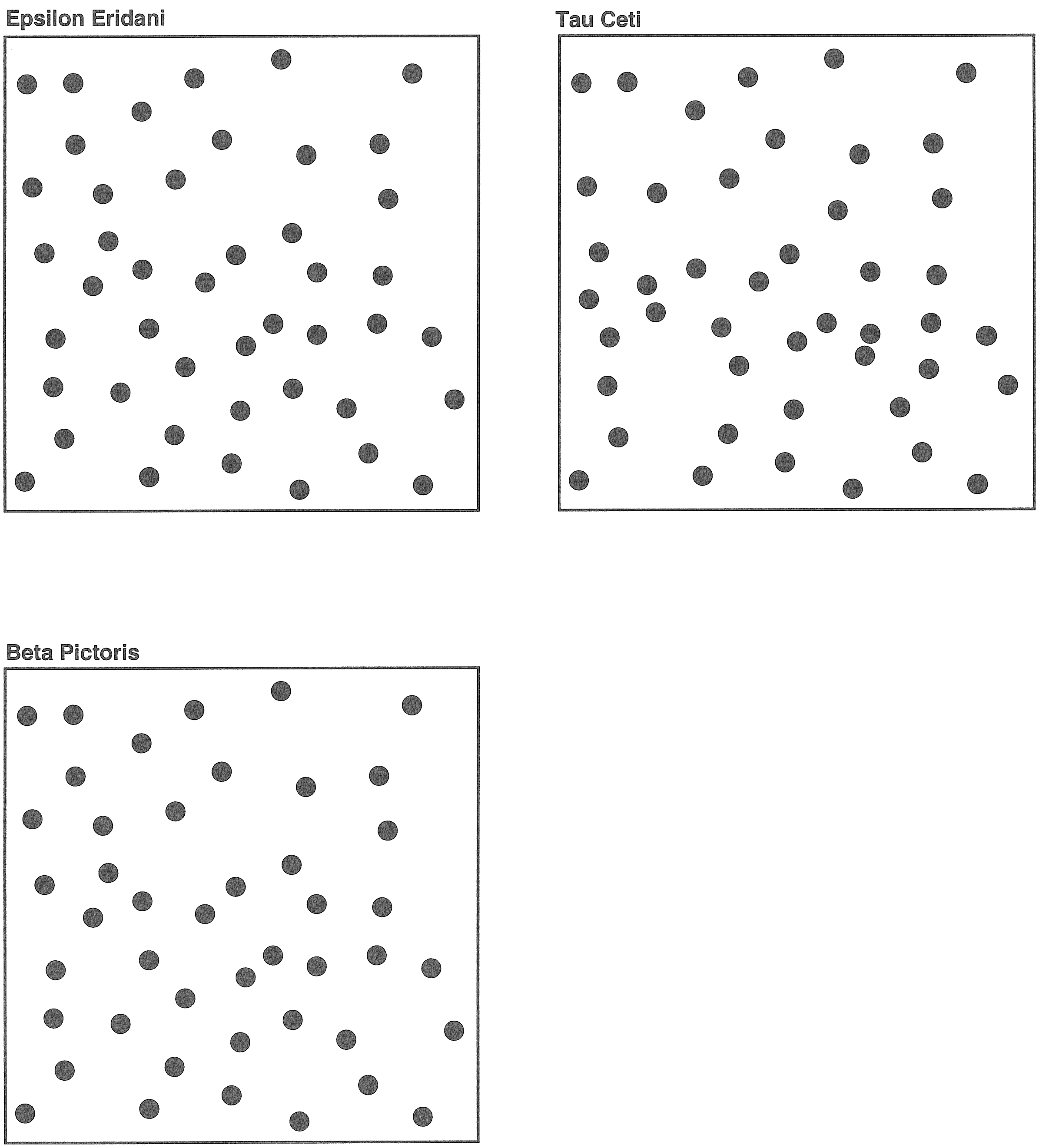
Figure 10.2 *(continued)*



Mission 10

Radio Signal Search Data, Day Two–Worksheet

Figure 10.3.



Mission 11
Do You Get the Message?

What Are Those Extraterrestrials Trying to Tell Us?

Notes

In Mission 1, students learned that a message would be received in a later mission but they did not know where it would be coming from, or what it would say. In Mission 10, students received the promised message and learned where it came from.

Overview

In Mission 11.1, students decipher the simulated message that has just arrived from deep space. In Mission 11.2, students respond to the message–they choose their response and how to send it. This mission includes a review of the “Big Ideas” from *Project Haystack,* providing an opportunity for students to synthesize and express what they have learned about communicating across the vast dimensions of our Milky Way Galaxy.

Mission 11.1
Materials

For Each Team

- Scissors
- Tape
- *(optional)* Calculators
- *(optional)* Electric motor or other electric device
- *(optional)* Student-built radios from mission 8

For Each Student

- “Background and a Practice Message” sheet (page 219)
- “Decoding the Message-Directions” worksheet (page 221)
- A Message for Earth” sheet (page 222)
- “Summary Questions” worksheet (page 223)
- Pencil

Getting Ready

1. Copy the sheets “Background Information and a Practice Message” and “A Message for Earth” and the worksheets “Decoding the Message” and “Summary Questions” for each student. Make extra copies of the sheet “A Message for Earth” in case teams need to start over.

2. Work through this activity on your own before you have students do it.

Classroom Action

1. **Discussion.** Hand out the "Background Information and a Practice Message" worksheet to each student. Go over this background information with students. From Mission 10, review which star had evidence of an extraterrestrial signal and how far away the star is in light-years.

2. **Activity: Practice Message.** Divide the class into teams of two to four students each. Tell students that before they begin deciphering the longer, simulated message, the class will work on the practice message in Figure 11.1, which contains 35 bits of information. For this simulation, explain that the radio telescope was aimed at the star Tau Ceti and was tuned to a single frequency. An observer listening with earphones heard this signal loud and clear above the static, and wrote down the pattern. He wrote a white dot whenever a short tone was heard and a dark dot whenever he heard a long tone. The signal continued for several hours, repeating its pattern of 35 short and long tones until it suddenly went off in mid-pattern.

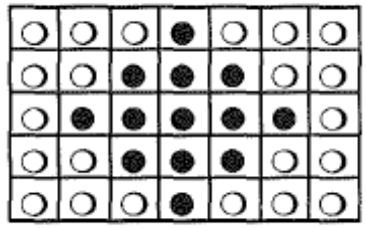
   Have someone sound out the pattern of short and long tones so that the class can hear what the observer heard in this simulation. The challenge for the extraterrestrial senders and the human receivers is to convert the string of tones into something that both can understand, even though they have no common language. This exercise shows a scheme devised by SETI researchers for reading such strings of data. Students should use the paper copies of the practice message on their sheets. Give students two copies of the same message so that they may experiment with several arrangements of the data.

Figure 11.1–A Simple Message.

Hints: How many dots are there? *(There are* 35.) Is there anything special about this number? *(It is a product of two prime numbers, 5 and* 7.) Can you arrange them in a way that would make sense other than in a straight row? *(Yes.)* Go ahead and try other ways of arranging this series of dots. You have two sets so that you can try both ways. The practice message will look like Figure 11.2 after it is decoded in both of the possible ways.

Teacher's Note: *A prime number is an integer which can be divided evenly only by itself and one.* 1, 2, 3, 5, 7, 11, 13, 17, 19 ... *are prime numbers.* 4, 6, 8, 9,10,12,14,15,16,18 ... *are not.*

Figure 11.2–A Simple Message Decoded.



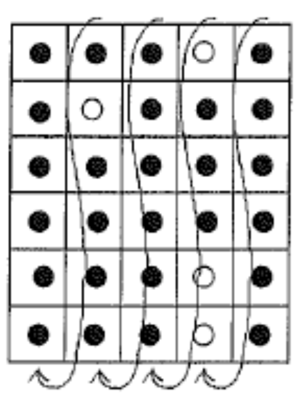
Teacher's Note: *Data is arranged into rectangular arrays to look for picture messages. But rectangles can have many dimensions. A data set of 24 bits could be arranged six different ways:* 2 x 12, 12 x 2, 6 x 4, 4 x 6, 8 x 3, 3 x 8. *A longer data string would have many other possibilities, unless the length of the string (e.g.,* 35) *is the product of two prime numbers* (*5 x 7 or 7 x 5*)*. Then, there are only two possible rectangular arrays for the data which makes decoding the message much simpler.*

Optional: It is possible to have students receive the practice message data to solve the puzzle with the radios they made in mission 8. Set up an electric motor or other electric device such as mixer. Turn it on for long and short amounts of time, such as in Morse code, to simulate strong and weak pulses of radio energy. Students listen to the stream of data, write the long and short dashes, and solve the message puzzle as it is outlined on their sheets. Allow students to work on this practice message exercise with minimal help. This independence will be critical when it comes to the longer, simulated message.

3. **Activity: Real Message.** Hand out the worksheets "Decoding the Message" and "Summary Questions" to each student. Inform students that the signal–the wake-up call–information was received in a linear fashion, like a long line of data. Tell them that this signal arrived a day after the practice message wake-up call. Their first message was so short that it was already one line of data when they first saw it. Therefore, the first thing that students must do is rearrange the information in a long line, as shown in Figure 11.3.

   Show them how to cut and line up the columns of data. The top of each column attaches to the bottom of the preceding column. Advise students to tape as they go along or they could become easily confused.

Figure 11.3–How to Arrange Data.



Once students have all the information in one long chain, they can begin to cut apart the signal data and rearrange it. Urge students to assemble the data very carefully. A sloppy job will not be useful in eventually interpreting the signal. Students are now ready to work on the longer, simulated message. This one will be considerably more difficult for students.

The bits of information can be placed horizontally or vertically in a rectangular array. Your students may express considerable discomfort in not knowing which arrangement is correct. Encourage them to explore both possibilities. Perhaps two teams can collaborate. One team can do it one way, another team another way, and then they can look at both together.

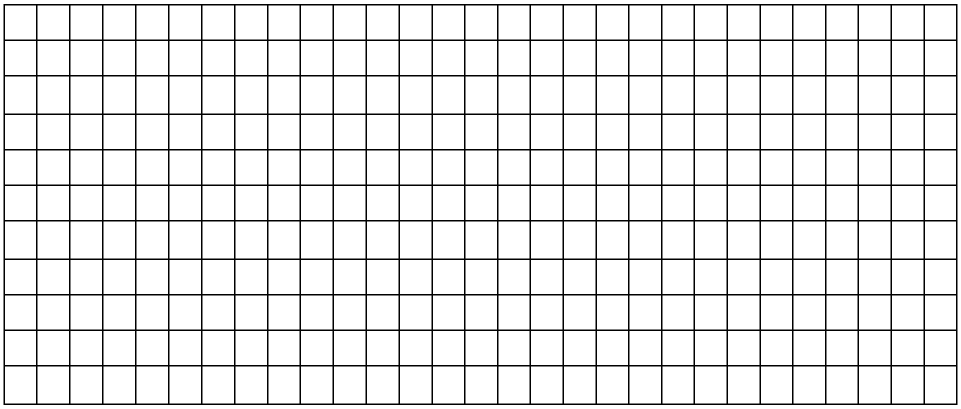
When the data are assembled correctly, one way shows a definite pattern of strong pulses and most students will come to agreement on one particular arrangement over another.

4. **Discussion.** If students become stuck, engage them in a discussion of how to arrange the 319 bits of information. Since 319 is the product of two prime numbers, they have two arrangement choices: 29 x 11 or 11 x 29, as shown in Figure 11.4. You will most likely need to lead a discussion about prime numbers or prod students into the direction of thinking in terms of prime numbers. This is where calculators can come in handy.

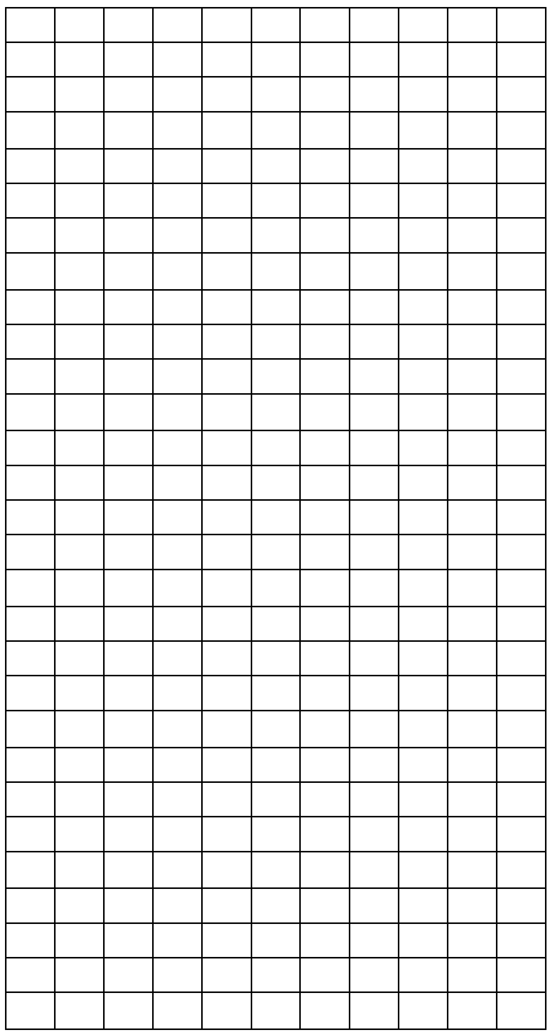
Teacher's Note: *If your students are at a higher level of mathematics and thinking skills, let them work on their own to figure out this message without clues about prime numbers.*

Figure 11.4–Prime Number Arrangements.

11 x 29



29 x 11

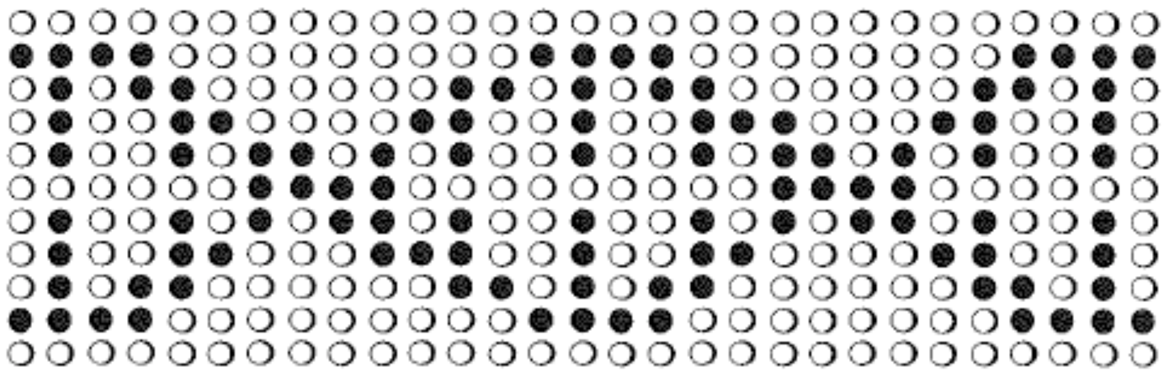


Once done, ask students to attach their assembled message onto a piece of white paper. Have them answer the questions on their worksheets.

5. **Display.** Have teams display their work and report their findings to the rest of the class, including an interpretation of what they think the signal means. When the data are all assembled, the solution will look something like Figure 11.5.

   The meaning of this "message" can be interpreted in several different ways: the DNA molecule, an hourglass, a test pattern, and so forth. Let students come up with their own interpretations! Do not let your students view this answer page.

Figure 11.5–The Decoded Message.



Mission 11.2
Materials

For a Class of 30

- *Project Haystack* "Big Ideas" chart on butcher paper.

For Each Student

- Graph paper
- "Sending a Reply" Directions (page 224)
- Pencil

Getting Ready

1. On a sheet of butcher paper, make a chart of the *Project Haystack* "Hey, What's the *Big Idea?"* pages (pages 217-218).

2. Copy the "Sending a Reply" directions for each student.

Classroom Action

1. **Discussion.** Review with your students the "Big Ideas" that have been investigated during the last 10 missions. Record these ideas on large sheets of butcher paper that students can refer to as they work their way through Mission 11.2. An alternative is to pass out "Big Ideas" sheets to each team (copy the ones provided for you here in the guide) or post them in the classroom.

2. **Worksheet.** Hand out the "Sending a Reply" directions to each student. Go through the directions with the class. Make sure students have a clear understanding of how you plan to evaluate their projects–students need to know your expectations ahead of time. Give students time in class to construct an organizational plan. Assist them with planning their projects. Give a clear deadline for when you would like to have their projects presented to the class.

3. **Self-Evaluation.** Have students respond to themselves and what they wrote on the butcher paper in Mission 1 about the ways we would be affected by a signal from an extraterrestrial intelligence and the ways we would try to communicate. If students did the "A Letter to Yourself" activity in the "Going Further" section in Mission 1, have them open the sealed envelopes and read the letters they wrote earlier. Have their ideas changed since then? In what way?

Going Further

Activity: Secret Messages

Challenge students to devise and send actual messages to one another using the binary code they have just learned to interpret. Can they devise a way to send pictures? Messages written in English (*i.e.*, send letter shapes)? Can they send a message that expresses mathematical concepts?

Activity: Color-Coded

Have students devise a method to construct and transmit a three-dimensional image, or a color message. Would they transmit several single layers of an image (which could then be recombined to form a three-dimensional image), give vertical values for a two-dimensional grid, or devise some new approach? One approach to color images that was used on the *Voyager* record was to include three separate layers–red, green, and blue–which can be combined to form a single color picture.

Research: War

Have students investigate the history of cryptography, code, and communication theory to further their understanding of the complexities of sending messages. One fertile topic is warfare. How did the Allies break the German codes? The Japanese codes? What effect did codes and breaking codes have on world history?

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Mission 11
Do You Get the Message?

Summary Questions–Teacher's Key

1. Answers will vary. Accept all reasonable attempts.

2. Answers will vary. Accept all reasonable attempts.

3. For Tau Ceti, it would take 11.9 years. Because the signal is an electromagnetic wave (radio), it travels at the speed of light; so, the travel time of the message is the distance to this star in light-years.

4. The reply will take the same amount of time that the original message took to get here because it travels at the same speed (the speed of light) along the same path.

5. Answers will vary. Accept all reasonable attempts.

6. Answers will vary. Accept all reasonable attempts.

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Project Haystack
The Search for Life in the Galaxy

"Hey, What's the *Big Idea*?"

Big Idea One

It is difficult to send a message that conveys an intended communication. **Missions 2 and 11**

Big Idea Two

Sending a probe across space as a messenger takes a lot of time, and uses vast amounts of energy. **Missions 2, 3, and 4**

Big Idea Three

Parallax makes it possible to calculate the distances to the closest stars by using simple geometry: the closest stars appear to change their position against the background of stars that are the farthest away. **Mission 3**

Big Idea Four

There are inherent difficulties in communicating across the vast distances of interstellar space. **Missions 3, 4, 10, and 12**

Big Idea Five

Electromagnetic radiation, which includes light and radio waves capable of carrying vast amounts of information, is the fastest thing that we know of, moving at 300,000 km per second, or 186,000 miles per second. **Missions 4, 8, and 10**

Big Idea Six

It seems to make sense that we should listen to stars that are in our more immediate stellar neighborhood (out to a distance of 200 light-years or so) for two reasons: transmitted signals get weaker over greater distances, and the time that it would take for a reply equals the distance to the source in light-years. **Missions 4 and 9**

Big Idea Seven

The Milky Way Galaxy has many varied objects within it, such as stars, nebulae, and star clusters, as well as our own solar system. The distances between the stars and the size of the Milky Way itself is enormous. **Mission 5**

Big Idea Eight

We can tell if a star may have planets by looking at the Doppler shift of its spectral lines at several different times. **Mission 6**

Big Idea Nine

The elements that occur on Earth can also be found in the stars, nebulae, and other objects in our universe. **Mission 6**

Big Idea Ten

We can gather information about places we can never go to by using tools such as the telescope, the radio receiver, and the spectroscope. **Missions 6 and 7**

Big Idea Eleven

Some star systems are more likely to have planets around them, and therefore are more likely to have developed intelligent civilizations. We prefer to concentrate our listening time on these star systems. **Missions 6, 7, and 10**

Big Idea Twelve

A radio receiver such as a radio telescope allows us to pick up signals that are present in space. Using radio waves could be an important means of communication between the stars. **Mission 8**

Big Idea Thirteen

A transmitter that has sent a signal might be so far away that the signal will be weak and difficult to pick up. **Mission 9**

Big Idea Fourteen

It is difficult to separate a nonrandom signal from the surrounding noise that is always present. **Missions 9 and 10**

Big Idea Fifteen

It is difficult to decipher an intended meaning from a received signal. **Missions 11 and 12**

SETI INSTITUTE

Mission 11
Do You Get the Message?

Background and a Practice Message

Name: ________________________________ Date: ____________________________

In October 1992, NASA scientists began a large-scale search of the skies with radio telescopes for signals coming from extraterrestrial civilizations. Although Congress terminated funding for the project after only one year, the targeted star search is continuing with private funding. The research is now conducted at the Allen Telescope Array (ATA) in northern California. Several other small searches have been tried and are under way at this time.

What would a signal from an extraterrestrial civilization be like? The extraterrestrial probably would not know any Earth language. Their transmitter would be very far away, and their signal may be weak. It might be very simple, nothing more than a series of pulses, repeated over and over, like the call sign on a radio or television station.

How would you broadcast a message, in pulses, to somebody who does not know your language? Could you create a message in a code so simple that the person receiving it would surely figure it out, even an extraterrestrial who knew nothing about you? The exercise that follows imagines that we on Earth have received a message in this kind of code.

When you were introduced to *Project Haystack,* you knew you would be asked to find where the signal was coming from, to find the needle in a celestial haystack. You did that! You found a signal originating near a star, in fact from a planet orbiting that star. Your challenge now? You must decipher the message!

Your radio telescope has received a simulated radio transmission. The signal is repeated over and over again. It is a string of long and short pulses. Before you try to decipher the long message that is coming in, try deciphering the short message as a practice/warm-up exercise.

The Practice Message

Figure 11.6.

Note: This shows two repetitions of the short message. If you cannot figure it out on the first try, you have another set of data for another try.

Hints:

How many dots are there in one repetition?

Is there anything special about this number?

Can you arrange them in a way that would make sense besides in a straight line?

Using a pencil, try drawing different arrangements of the dots in one repetition. When you think you've found an arrangement that deciphers the message, cut out one of the repetitions, and arrange the dots to show your solution.

Mission 11
Do You Get the Message?

SETI INSTITUTE

Decoding the Message– Directions Worksheet

Name: ________________________________ Date: __________________________

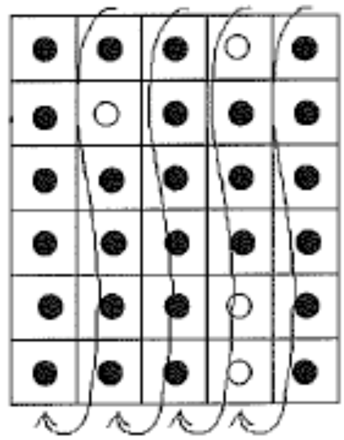
Did you figure out the practice message? If not, ask your teacher for assistance. Now use the same method on the full-scale extraterrestrial message. There are a lot of dots, so you will need to be more careful and systematic, but you should be able to make sense of it even though the extraterrestrials do not speak English. Good luck!

1. With a pair of scissors, cut the strips on your "A Message for Earth" page vertically, along the lines between the columns. The top of the first column attaches to the bottom of the next column with a piece of tape (see Figure 11.7). Cut only one strip at a time, and tape it in place before you cut another. Keep cutting and attaching columns until you get one long string of data. You may receive two copies of this sheet so that you can try different ways of putting the message together. If not, you may pair up with another team. One team can do it one way, and another team another way, and then you can look at both.

2. You are now ready to work on the message. This one will be more difficult for you than the practice message. You should count the total number of bits of information. Try to think about what may be unique about the number of bits of information that you come up with.

3. The bits of information can be arranged any way you choose. You may cut your long single strip of dots to any length that you choose. You may stack these pieces in order after they are cut. If you become stuck, ask your teacher for help, or clues, to solving this message puzzle. When you have done this assignment correctly, you will see a definite pattern.

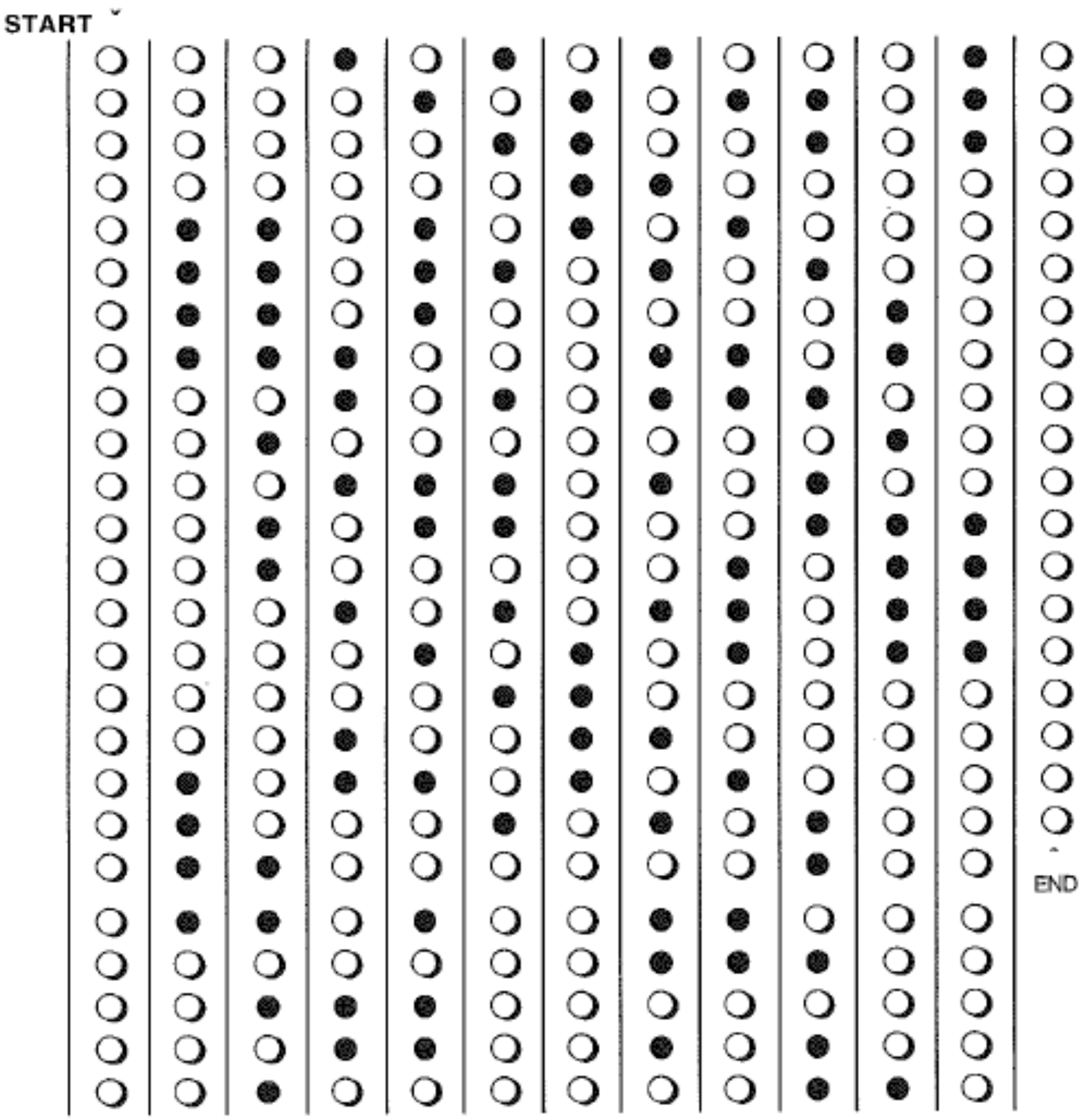
Figure 11.7–How to Connect the Paper Strips.



Mission 11
Do You Get the Message.

A Message for Earth

Figure 11.8



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Mission 11
Do You Get the Message?

Summary Questions–Worksheet

Name: ___________________________________ Date: ________________________

1. Describe the process you and your team members used to solve this simulated message received from space:

2. Now that you have it put together, what do you think it means?

3. Knowing the star system that this simulated message came from, how many years did it take to get to Earth, assuming that it was received this year? How do you know this?

4. If you wanted to send a message back using radio waves, how long would it take to reach the extraterrestrial civilization?

5. Let's say that you would like to send back a reply message. What form would it take? What would you like it to say or express? Can you think of a reason why you might want to send the same message back to the extraterrestrials?

6. Do you think that it is important that the message be composed of a total number of bits of information that is the product of two prime numbers? Why or why not?

Mission 11
Do You Get the Message?

Sending a Reply– Directions

Name: ____ Date: ____________________________

You have explored many aspects of communication across interstellar space. Although astronomers have not yet detected a signal from other beings, the mission you have completed has raised many interesting and fascinating questions. Imagine for a moment that your data had been picked up by a real radio telescope:

- What was this stream of data? What did the data look like?
- How could these data be interpreted?
- Where was the information coming from?
- If indeed the information was coming from another star system in deep space, what might the effect be on our civilization?
- How would Earth respond to the signal? Should Earth return the signal?

Answers to these questions are not immediately evident. Now that you are close to completing the series of missions in *Project Haystack,* perhaps you are close to answering these questions. The project you are about to begin will require you to draw upon the expertise and knowledge you have gained on the subject of communication across the vastness of space.

This Is Your Challenge!

You want to communicate with the civilization that sent the message that you deciphered earlier in this mission. You must take the following questions into consideration:

1. **What** will your message be to them?

2. **How** (by what means) will you send the message?

3. **Where** will you send it?

You must answer these three questions to create a plan, and each step of your plan must have rationale or justification. This means that you must explain:

4. **Why** the message you have chosen is the best one.

5. **Why** the approach you have chosen is the best one.

6. **Why** the destination you have chosen is the best one.

In some creative way tell an audience of your choosing, how you would go about responding to the simulated communication that you have already received. You do not have to gear your presentation to seventh-, eighth-, or ninth-graders. You could present it to Galileo, the president's science advisor, a NASA space shuttle crew, the general assembly of the United Nations, any of the *Star Trek* crews, Oprah Winfrey, a first-grade class, or maybe even your favorite rock group. How about presenting it as a television newscast, a live drama, a poem, a children's book, a video, a television show, a magazine spread, or a comic strip? How about as a story for a tabloid magazine? There are certainly many other audiences and many other ways you could organize your presentation.

Use your imagination!

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Mission 12
Cultural Aspects of the Search for Extraterrestrial Intelligence (CASETI)

What Would Happen If We *Did* Detect a Signal?

Notes

In Mission 11, students brainstormed ideas regarding the implications of receiving a signal from intelligent extraterrestrials.

Overview

In this mission, students see how their thinking has progressed. They consider the importance of advance planning for an "official" reaction to the discovery of a confirmed interstellar detection. Students hold a mock CASETI Conference of their own to consider their fears and concerns about the detection of an extraterrestrial intelligence. In Mission 12.2, students produce recommendations in a "CASETI Final Report" that suggest ways in which humanity's responses to the discovery can be inclusive, positive, and effective. It is our hope, here at the SETI Institute, that this report can have a bearing on policy and practice with regard to our response if we do receive a radio signal from an extraterrestrial civilization on a planet orbiting a distant star.

Mission 12.1
Materials

For a Class of 30

For Each Team

- "Resource Card" for that team's particular special interest group (pages 231-235)
- "CASETI Conference" worksheet (page 236)

For Each Student

- Paper and pencil

Getting Ready

1. Decide if you want to have additional roles played by students. If so, write a "Resource Card" for each new role.

2. Copy one complete set of "Resource Cards." Copy the "CASETI Conference" worksheet for each team.

3. Arrange the classroom to model a conference setting for six (or more) groups of students.

Classroom Action

1. **Discussion.** Assemble students and tell them that today they will hold a CASETI Conference to consider the cultural aspects of the search for extraterrestrial intelligence. Remind students that, in spite of all of the popular science fiction, interstellar travel is not a realistic possibility because of the enormous times involved. Remind them that even radio waves traveling at the speed of light take many, many years to reach Earth from the stars. When (or if!) we do receive a confirmed signal from an extraterrestrial intelligence, it will be a detection, not a contact. A detection is a one-way communication; contact implies a reply, two individuals exchanging information. Point out that this will be a very slow communication. We will have plenty of time to consider each response!

   This student CASETI meeting will simulate the effort that was made by NASA to anticipate public reaction to discovery of a message from an extraterrestrial intelligence. In 1991, NASA conducted a CASETI Workshop during which some two dozen persons from varied backgrounds participated. These persons identified some potential problems that warrant NASA's careful attention. The findings of this workshop were assembled into a report that represents the collective view of all the participating members.

   Appoint or elect a student conference moderator. Ask the conference moderator to open the CASETI Conference. This will include, but should not be limited to, an initial welcome, a statement of why this conference has been assembled, and an introduction of the people present.

   Would there be rioting in the streets? Would people stay calm, but be amazed? Or would they even care at all? Charge students with the serious responsibility of creating a report that represents their collective opinions on this issue of how we Earthlings should react if an actual message were to be received.

2. **Activity.** Divide the class into six "special interest" groups (four to six students each). Have each group sit together so they can talk amongst their group. Hand out one Resource Card (not one set) and one "CASETI Conference" worksheet to each group. Student experts who represent a wide variety of disciplines and professional backgrounds will be assembled at this CASETI Conference. Students will be asked to play various roles. "Resource Cards" are provided for:

   Political Leaders
   Scientists
   The Children
   Media Persons
   The Future Thinkers
   Military Leaders

You may also wish to add sociologists, entertainers, philosophers, humanitarians, historians, educators, the police, economists, and religious leaders. You will need to write new Resource Cards for any roles that you add.

The individual groups will meet in their small sessions in the classroom to accomplish the following:

- Each group will appoint a leader, a recorder, and a reader.

- The leader directs the discussion, making sure all student ideas are heard and encouraged. The leader reviews the suggestions that the recorder has written with the group. The leader will report to the whole conference in mission 12.2.

- The recorder acquaints the group with the "CASETI Conference" worksheet, which gives students a format for recording their recommendations. The recorder writes down all of the group's ideas on notebook paper as they occur.

- The reader will first read the "Group Purpose" aloud to the group. It is the first paragraph at the top of each Resource Card. The reader will also read the remainder of the Resource Card for the group, one question or comment at a time, waiting for responses from the group. This card contains some general views and information that might be of concern to the group. The card is intended to be used as a launching pad from which other ideas will come.

Each group should decide on their three most important recommendations. The recorder writes the reason and rationale behind each recommendation on the CASETI Conference Card.

Optional: Instead of passing out the Resource Cards, just assign roles to each group and let them generate the questions that need to be answered. The groups could still have a leader and a recorder, but no reader.

Mission 12.2
Materials

For Each Student

- Paper and pencil

Getting Ready

1. Arrange the classroom to model the conference setting from Mission 12.1.

Classroom Action

1. **The Mission.** Tell the class that each student will be asked to write a personal letter to Dr. Jill Tarter (or to the SETI scientists) stating what he/she believes to be the three most important recommendations from the entire CASETI Conference, not just from his/her own group's concerns. Encourage students to take notes during the Conference.

   Optional: Ask students to write a press release on the CASETI Conference instead of a letter. This could be for the school newspaper, or for the local newspaper. The article may be written in class or as homework.

2. **Activity.** Reassemble the special interest groups from Mission 12.1 for a 5-10 minute review before the conference begins. The conference moderator calls the conference to order and directs the groups to begin their reports. The leader of each group makes a general statement about the fears, recommendations, and suggestions expressed by his/her group to the conference. The conference moderator should control any questioning or discussion that may follow each presentation. He/she should also allow each leader the same amount of time to speak. When everyone has spoken, the conference moderator ends the CASETI Conference and thanks everyone for participating.

3. **Activity.** Each student should write a personal letter to Dr. Jill Tarter (or to the SETI scientists), in class or as homework. E-mail the letters to ed_dept@seti.org with the following in the Subject line:

   CASETI Project
   Attention Dr. Jill Tarter

Going Further

Activity: Reaching an Agreement!

After suggestions from the class and from the video have been heard, and after individual letters or articles have been written, conduct a discussion so that the class can collectively decide which recommendations will go into a "CASETI Final Report." Have the class elect discussion secretaries to compile the recommendations, or perhaps offer this task to someone who would like to do it for extra credit. The "CASETI Final Report" should be typed (or written neatly). Each student should sign the document to give it a professional and official appearance.

E-mail the letters to ed_dept@seti.org with the following in the Subject line:

CASETI Project
Attention Dr. Jill Tarter

SETI INSTITUTE

Mission 12
Cultural Aspects of the Search for Extraterrestrial Intelligence (CASETI)

Resource Card for Political Leaders

Group Purpose: Imagine yourselves as political leaders. If a definite signal from an extraterrestrial intelligence is received by SETI scientists, it will have a very real impact on the people of your city, state, and country. Printed below are statements and questions about fears that your people might voice. Your work at this conference is to: 1) read over the list and add politically oriented concerns of your own and 2) come up with a written list of recommendations (from the perspective of political leaders) to SETI scientists about how they should tell the world they have received a message. What should they say, how should they say it, who should they tell, and how will they deal with these concerns in the best way possible?

1. Would extraterrestrials see us as friends in the same manner that Kublai Khan viewed Marco Polo?

2. Would extraterrestrials have developed a super-civilization? If so, would they treat us like inferior people, or as equals?

3. How will we cope with an advanced civilization? Will we ever be able to talk to one another?

4. Will there be a lot of misunderstandings?

5. Communication will not be simultaneous because of the time delays caused by the vast distances. Will it take so long to talk back and forth that we will become disinterested and not even remember why we were so excited when we received the original communication?

6. Will extraterrestrials be welcoming us to the galactic community?

7. Will extraterrestrials have new, exciting, valuable information to share with us?

Mission 12
Cultural Aspects of the Search for Extraterrestrial Intelligence (CASETI)

Resource Card for Military Leaders

Group Purpose: Imagine yourselves as military leaders. If a definite signal from an extraterrestrial intelligence is received by SETI scientists, it will be of concern to the Army, Navy, Air Force, and Marines. Printed here are statements and questions about fears that your people might have. Your work at this conference is to: 1) read over the list and add other military oriented concerns of your own and 2) assemble a written list of recommendations (from the perspective of military leaders) to SETI scientists about how they should tell the world they have received a message. What should they say, how should they say it, who should they tell, and how should they deal with these concerns in the best way possible?

1. Does the discovery of an extraterrestrial intelligence pose a threat to our country or to the world?

2. Does the message from extraterrestrial intelligence pose a threat to our country or to the world?

3. Should we quickly band together to develop a global force against possible extraterrestrial invasions?

4. Should we try to develop technology to invade them before they invade us (even though it may take over 100 years to develop such technology, and hundreds or thousands of years to reach them on any spacecraft)?

5. Is there technology that the extraterrestrials will give us that can be used for national defense or offense? What if other countries learn about this technology before we do?

6. Should we keep or deter other individuals and groups (especially terrorist groups) from obtaining the extraterrestrials' message?

7. Should radio telescopes and other transmitters be placed under military control until we learn of the nature of the message?

Mission 12
Cultural Aspects of the Search for Extraterrestrial Intelligence (CASETI)

Resource Card for Media Persons

Group Purpose: Imagine yourselves as media people. If a definite signal from an extraterrestrial intelligence is received by SETI scientists, it will have a very real impact on the media–newspapers, magazines, the news, and movies. Printed here are statements and concerns that you as reporters and entertainment people will have that will affect your profession. Your work at this conference is to read over the list and add your own media-related concerns. Your final task is to assemble a written list of recommendations (from the perspective of members of the media) to SETI scientists about how they should tell the world they have received a message. What should they say, how should they say it, who should they tell, and how should they deal with these concerns in the best way possible?

1. Will reporters and media people sensationalize the truth so much that people will become confused?

2. What will be the focus of the media?

3. Will the media focus only on negative aspects?

4. Will information be blown out of proportion? Will the media compete for the best wild story or movie instead of reporting the facts? Will they get in the way of the scientists?

5. Are the media capable of educating the public about the improbability of interstellar travel or interstellar invasions?

6. Will the facts be lost and gossip or speculation prevail?

7. How can the media help to allow the public to communicate with the extraterrestrials?

Mission 12
Cultural Aspects of the Search for Extraterrestrial Intelligence (CASETI)

SETI INSTITUTE

Resource Card for the Children

Group Purpose: Imagine yourselves as the children of the world. If a definite signal from an extraterrestrial intelligence is received by SETI scientists, it will have a very real impact on the children of the world. Printed here are statements, concerns, questions, and fears that young people might have. Your work at this conference is to read over the list and add the fears that your group comes up with. Your final task is to assemble a written list of recommendations (from the perspective of children) to SETI scientists about how they should tell the world they have received a message. What should they say, how should they say it, who should they tell, and how should they deal with these concerns and fears in the best way possible?

1. It is likely that the extraterrestrials will invade us, so I will not have the chance to live a normal life.

2. What is the most appropriate way to respond?

3. What if my parents, teachers, and other adults are afraid? Will they scare off any extraterrestrials and prevent the possibility of ever making contact?

4. If there are extraterrestrial children, would they be like me and have the same kinds of concerns as I do?

5. Would adults try to convince us to react and feel a certain way about Earth having received a message from space?

6. Would extraterrestrials bring us interesting new kinds of music and television shows?

7. Do they look like us?

8. Do they have pets? What would their pets be like?

Mission 12
Cultural Aspects of the Search for Extraterrestrial Intelligence (CASETI)

Resource Card for the Future Thinkers

Group Purpose: Imagine yourselves as future thinkers with positive attitudes. If a definite signal from an extraterrestrial intelligence is received by SETI scientists, it will have a very real impact on all people. Many people will express fears and anxieties, but some people will readily accept the news without fear. Some will be delighted, stimulated, excited, and joyful! Printed below are statements that express how you think the world would accept the news of a message from space. Your work at this conference is to read over the list and add any other ideas you think of. Your final task is to assemble a list of recommendations to SETI scientists about how they should tell the world they have received a message. What should they say, how should they say it, who should they tell, and how should they deal with these concerns in the best possible way?

1. Will humanity choose to believe that it is not an isolated, planetary tribe fearing the knowledge that other intelligent life-forms exist?

2. Today an international organization, the United Nations, exists. Could we be part of a similar galactic community tomorrow?

3. Are the people in this day and age a great deal changed from people who lived at the beginning of the previous century? What will it mean to us if an extraterrestrial intelligence is detected?

4. Is superstition gradually giving way to enlightenment, and is science becoming more widely appreciated, even if it is not widely practiced? What effect would the discovery of an extraterrestrial intelligence have on this?

5. Is humanity today a searching, exploring, learning society that consciously seeks to expand its horizons of knowledge and experience?

6. Is humanity today equipped by historical experience to assess and assimilate whatever may be encountered?

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Mission 12
Cultural Aspects of the Search for Extraterrestrial Intelligence (CASETI)

CASETI Conference–Worksheet

We, the ____group, have discussed our concerns, hopes, fears, and perspectives about receiving a message from an extraterrestrial intelligence. The participating members of this group are:

The following is a list of our recommendations that SETI scientists might consider, in advance, as they prepare their plan to communicate with humanity in the event a signal is detected. Each of our recommendations is accompanied by our reason, or reasons, for making the recommendation.

First recommendation:

Reason:

Second recommendation:

Reason:

Third recommendation:

Reason:

Glossary

Astronaut. A person who trains for space travel.

CASETI. Cultural Aspects of the Search for Extraterrestrial Intelligence.

Earth. In our solar system, the third planet from the Sun. Our home world!

Gravity (Earth = 1): 1
Mean Distance from the Sun (million km): 149.6
Mean Distance from the Sun (AU): 1
Period of Revolution: 365.26 days
Period of Rotation: 23 hr., 56 min., 4 sec.
Axial Tilt: 23° 27'
Equatorial Diameter (km): 12,756
Volume (Earth = 1): 1
Main Component(s) of Atmosphere: Nitrogen, Oxygen
Atmospheric Pressure (Earth = 1): 1
Known Natural Satellites: 1

Extraterrestrial. Any living organism not of or from Earth. Often, this term assumes intelligence. Currently, we know of no extraterrestrials, intelligent or otherwise. This term is often applied to fictitious "space aliens."

Hypothesis. A tentative explanation of an observation; an educated guess. A hypothesis must be testable. When enough experimental results confirm a hypothesis to the point that the scientific community generally accepts its validity, a hypothesis becomes a theory. A theory is considered to be true and factual, the best-available scientific explanation.

Life. There is no simple definition for life. Living things have specific structures and metabolism; living things respond to stimuli and reproduce themselves. On Earth, all life is cellular and has DNA and/or RNA (except viruses, which are not considered to be alive).

"Needle in the haystack." An expression describing something that is hard to find because it is so small, and because it is hidden in something so big. In the search for extraterrestrial intelligence, the needle is a radio signal sent by extraterrestrial life, and the haystack is our Milky Way Galaxy. Of course, there may be many, many needles in this haystack–or perhaps there are none.

Orbit. The path an object follows around another object, such as the path of a planet around its star, the path of a moon around its planet, or the path of a satellite or spacecraft around a moon, planet, or star.

Planet. A substantially large body that is held in orbit around a star, such as Earth, Mars, or Venus (which orbit around the Sun). Planets do not generate their own light but only reflect the light of a nearby star.

Planetology. The study of planets. Comparative planetologists explore and compare the planets to learn of their composition, formation, and the dynamics responsible for their major features. These questions are important to our understanding of life in our solar system.

Satellite. An object in orbit around another object. Satellites can be natural (Earth's moon) or artificial (a telecommunications satellite).

SETI. The Search for Extraterrestrial Intelligence. This search is being conducted by the SETI Institute in Mountain View, California, and by other organizations and researchers around the world. They are using radio telescopes to search for radio signals coming from planetary systems around likely stars in a "targeted search."

Spacecraft. A vehicle designed for orbital or interplanetary travel. In this guide, the term is used to describe the portion of the vehicle that travels through space, as opposed to the *lander,* which is sent down to a planet's surface. Sometimes one vehicle can take on both roles.

Star. A hot, glowing mass; a sphere of gas that emits energy (electromagnetic radiation) from nuclear fusion reactions in its core. Stars have gravity, which holds planets in orbit around them. Stars could not support life as we know it on their surfaces.

Sun. The star around which Earth orbits. Our star is named Sol. It is a very typical star. It only appears to be exceptional because we are so close to it and so far away from other stars.

SETI INSTITUTE

Appendixes

Required Materials List

Every effort has been made to keep the materials as inexpensive and as easily obtainable as possible. The major single expense in this guide is for mission 8, “Building a Radio Receiver.” Each radio receiver will cost less than $10 to build. The overall cost of this mission can be reduced by having students work in large groups. The germanium diodes, and crystal radio earpieces can be ordered from Scott’s Electronic parts, http://www.angelfire.com/electronic2/index1/. Micro-tools, http://www.micro-tools.com/store/ or 707.446.1120 sells the germanium diode. Wire is available from several online retailers. Radio “kits” are not recommended because they are too-much preassembled–students lose some of the thrill of building a radio when assembling a kit. MidnightScience.com does offer basic crystal radio kits, one even requires paper and an oatmeal box.

Materials that may need to be ordered or located weeks in advance of use are printed in **boldface** on the supply lists. Some items may be borrowed from local high schools or colleges with advance notice. The quantities listed are for one class of 30 students for all missions.

Many optional, enrichment items, such as additional slides and posters, can be obtained free or at very low cost from the NASA Educator Resource Center in your area. To locate your center go to http://www.nasa.gov/offices/education/programs/national/ercn/home/index.html. Posters depicting the Milky Way Galaxy and the electromagnetic spectrum will be quite helpful to have on hand during the missions in this unit.

In particular, for mission 2, "A Message from Earth," try to locate a copy of the book *Murmurs of Earth* (ISBN 0-345-28396-1) and/or its CD-ROM version if possible. The original version of the book is out of print, but many local libraries have a copy or can obtain one for you. Warner New Media sold the CD- ROM version including the music in the early 90’s. If you cannot locate either the book or the CD, do not panic! We have provided a set of 10 images that can be used to teach the basic mission. However, the CD and/or the book will enhance this mission.

Music On Voyager Record

- Bach, Brandenburg Concerto No. 2 in F. First Movement, Munich Bach Orchestra, Karl Richter, conductor. 4:40
- Java, court gamelan, "Kinds of Flowers," recorded by Robert Brown. 4:43
- Senegal, percussion, recorded by Charles Duvelle. 2:08
- Zaire, Pygmy girls' initiation song, recorded by Colin Turnbull. 0:56
- Australia, Aborigine songs, "Morning Star" and "Devil Bird," recorded by Sandra LeBrun Holmes. 1:26
- Mexico, "El Cascabel," performed by Lorenzo Barcelata and the Mariachi México. 3:14
- "Johnny B. Goode," written and performed by Chuck Berry. 2:38
- New Guinea, men's house song, recorded by Robert MacLennan. 1:20

- Japan, shakuhachi, "Tsuru No Sugomori" ("Crane's Nest,") performed by Goro Yamaguchi. 4:51
- Bach, "Gavotte en rondeaux" from the Partita No. 3 in E major for Violin, performed by Arthur Grumiaux. 2:55
- Mozart, The Magic Flute, Queen of the Night aria, no. 14. Edda Moser, soprano. Bavarian State Opera, Munich, Wolfgang Sawallisch, conductor. 2:55
- Georgian S.S.R., chorus, "Tchakrulo," collected by Radio Moscow. 2:18
- Peru, panpipes and drum, collected by Casa de la Cultura, Lima. 0:52
- "Melancholy Blues," performed by Louis Armstrong and his Hot Seven. 3:05
- Azerbaijan S.S.R., bagpipes, recorded by Radio Moscow. 2:30
- Stravinsky, Rite of Spring, Sacrificial Dance, Columbia Symphony Orchestra, Igor Stravinsky, conductor. 4:35
- Bach, The Well-Tempered Clavier, Book 2, Prelude and Fugue in C, No.1. Glenn Gould, piano. 4:48
- Beethoven, Fifth Symphony, First Movement, the Philharmonia Orchestra, Otto Klemperer, conductor. 7:20
- Bulgaria, "Izlel je Delyo Hagdutin," sung by Valya Balkanska. 4:59
- Navajo Indians, Night Chant, recorded by Willard Rhodes. 0:57
- Holborne, Paueans, Galliards, Almains and Other Short Aeirs, "The Fairie Round," performed by David Munrow and the Early Music Consort of London. 1:17
- Solomon Islands, panpipes, collected by the Solomon Islands Broadcasting Service. 1:12
- Peru, wedding song, recorded by John Cohen. 0:38
- China, ch'in, "Flowing Streams," performed by Kuan P'ing-hu. 7:37
- India, raga, "Jaat Kahan Ho," sung by Surshri Kesar Bai Kerkar. 3:30
- "Dark Was the Night," written and performed by Blind Willie Johnson. 3:15
- Beethoven, String Quartet No. 13 in B flat, Opus 130, Cavatina, performed by Budapest String Quartet. 6:37

Office, Art, and General Supplies

Table A.1.

Material	Substitutions or Alternatives. Optional Items Are Indicated.	Quantity per Pair, Team or Center	Quantity for Each Class of 32	Reusable in Each Class	Used in Activity
Butcher paper	Whiteboard, computer screens	1 piece, 2-ft long		No	1, 2, 3, 5, 6
Markers (assorted)			Varies	Yes	1
Black paper with stars pasted on it	Other background, or none		1	Yes	1
Magazines, asst'd	Computer clip art				2
Scissors		1 or 2		Yes	2, 3, 4, 5, 6, 8, 11
Glue or paste		1 or 2		Yes	2, 3, 4, 5
Tape (masking or transparent)			Several rolls	No	2, 3, 4, 6, 8, 11
Notebook paper		Varies			2, 12
Pens or pencils			32	Yes	2, 3, 5
Pieces of plain white 8-1/2" x 11" paper			32	No	3, 8
Measuring tape, 100-250 feet			1	Yes	3
Marked meter sticks			32	Yes	3, 5, 6, 7, 8
String	Fishing line	10 meters			3
Straws		2		No	3
Cardboard					3, 8
Pins or thumbtacks			32 (1 in Mission 6)	Yes	3, 6
Protractors (360^{o})	Optional in 3		32		3, 5
Calculators	Optional				3, 11
Construction paper	Optional				3
Graph paper	Make graph paper		32	No	5, 11
Thin sheets of plastic	Plastic lids, Frisbees	1		No	5
Cotton balls	Other cotton, or fluffy material	1		No	5
Drawing compasses			32	Yes	5
White paint			1		5
Brushes		1			5
Poster-size sheet of thin tagboard			1	No	6
Cardboard tubes	Toilet paper tubes	1		No	6
"Rainbow" sets of markers	Pens, crayons, or pencils	1		Yes	6
Roll of heavy duty aluminum foil			1	No	6, 8
Single-hole punch			1	Yes	6
Single-edge razor blades	X-Acto knives*		Several	Yes	6
Orange marble	Optional		1	Yes	7
Highlighter pens (wide tip)				Yes	8
Envelopes			16		9
Rulers		1		Yes	9
File folders			16	Yes	10
Box to store folders				Yes	10

*Review with students all necessary precautions when handling sharp knives

Laboratory Equipment

Table A.2.

Material	Substitutions or Alternatives, Optional Items Are Indicated	Quantity per Pair, Team or Center	Quantity for Each Class of 32	Reusable in Each Class	Used in Activity
Spectrum tube power supply	Borrow from high school or use video		1	Yes	6
Spectrum tubes of various gases	**(H, He, Ne, N, O, Na)**		1 each	Yes	6
Prisms of assorted sizes		1		Yes	6
Light boxes	Bright light source or sunlight	1		Yes	6
Standard screw-type electric socket	Lamp		1	Yes	6
25-watt bulb			1	Yes	6
Variety of light sources	Fluorescent, incandescent, colored bulbs, candles			Yes	6
Thermometers			2	Yes	6
Ultraviolet light source			1		6
Diffraction grating. Cut into tiny pieces			1		6
Fluorescent paints, fluorescent minerals	Optional		Varies	Yes	6
Commercial spectroscopes	Optional		Varies	Yes	6
Electric buzzer with 9-volt battery	Digikey.com 9 volt DC buzzer		1	Yes	7
Alligator clips on connecting wires			1	Yes	7
100-watt light bulb	Optional				7
Electric motor or other device	Optional				11

Audiovisual Equipment

Table A.3.

Material	Substitutions or Alternatives, Optional Items Are Indicated	Quantity per Pair, Team or Center	Quantity for Each Class of 32	Reusable in Each Class	Used in Activity
Data projector			1	Yes	2
CD-Rom about *Voyager* and/or the book *Murmurs of Earth*	Optional		1	Yes	2
Computer with CD-Rom drive			1	Yes	2, 3, 5, 6, 7, 9, 10
Smart phones as recorders					2
Overhead projector or data projector	Copied illustrations as handouts or PowerPoint slides				3, 4, 6, 9, 10
Transparency marking pens	If using overhead proj				5, 6, 9, 10
Poster of the Milky Way Galaxy	Optional		1	Yes	5
Radio(s)	Optional in Mission 6		1 in Mis. 6, 2 in Mis. 9	Yes	6, 9
Poster with the emission lines of the electromagnetic spectrum	Optional		1	Yes	6
Pictures taken by infrared-sensitive cameras (webcams)			Varies	Yes	6

Electronic Equipment for Building a Radio in Mission 8

Table A.4.

Material	**Substitutions or Alternatives, Optional Items Are Indicated**	**Quantity per Pair, Team or Center**	**Quantity for Each Class of 32**	**Reusable in Each Class**	**Used in Activity**
Wire strippers			2 or 3	Yes	8
Long wire for antenna			1	Yes	8
Cardboard for radio base (25 cm by 12 cm)		1		No	8
3-inch-diameter cardboard cylinders (15 cm length, 7.5 cm length)		1 each size		No	8
24-guage solid copper wire (coated)		16 meters		No	8
24-gauge stranded wire		3.5 meters		No	8
Germanium diode (type 1N34A)	Scott's Electronic Parts or Micro-tools			No	8
Crystal radio earphones	Scott's Electronic Parts	1		No	8
Piece of extra-fine sandpaper (cut into small squares)				Yes	8
Single-edge razor blade	X-Acto knives*				
Grocery bag	Any bag or box	1			

*Review with students all necessary precautions when handling sharp knives

Ordering Information

Materials that may need to be ordered or located weeks in advance of use are printed in **boldface**. Some items may be borrowed from local high schools or colleges with advance notice. The quantities listed are for one class of 30 students for all missions.

For spectrometers and holographic diffraction grating:

Science First www.Sciencefirst.com
STARLAB Planetarium Systems
86475 Gene Lasserre Blvd.
Yulee, FL 32907
Phone: (800) 875-3214

Spectrum tubes and power supply, diffraction grating, spectrometers, light boxes, UV lamps, radio kits, posters, etc.

Science Kit & Boreal Laboratories
PO Box 5003
Tonawanda, NY 14151-5003
Phone: (800) 828-777

www.sciencekit.com
Edmund Scientific's
60 Pierce Avenue
tonawanda, NY 14150
Phone: (800) 728-6999
www.scientificsonline.com
Educational Discount

Other providers of science kits and supplies.

NASCO
PO Box 901
Fort Atkinson, WI 53538-0901
Phone: (800) 558-9595

www.enasco.com

Overhead Transparency or PowerPoint Slide List

Table A.5.

Transparency Name	Used in Mission
Triangulation	Mission 3
Parallax as Viewed from Earth	Mission 3
Celestial Mapping	Mission 5
Spectrum Observation	Mission 6
Center of Mass	Mission 7
Doppler Effect	Mission 7
Spectrum Analysis Array #1 and 32	Mission 9
Signal and Background Noise #1 and 32	Mission 9
Radio Signal Search Data	Mission 10

PowerPoint Image List

Table A.6.

The Message Sent By Voyager" (Part 1)		Mission 2
2.1	Voyager Spacecraft	
2.2	Voyager Record Cover	
2.33	School of Fish with Human Diver	
The Message Sent by Voyager" (Part 2)		Mission 2
2.4	Solar Spectrum	
2.5	The Planet Earth	
2.6	Closer to the Surface of Earth	
2.7	Human Anatomy	
2.8	Nursing Mother	
2.9	A Family with Two Generations Present	
2.10	Group of Children	
2.11	Southwestern United States	
2.12	Forest Scene	
2.13	Fallen Leaves	
2.14	A Tree in Winter	
2.15	Flowering Plants	
2.16	Human Diver and School of Fish	
2.17	Human and Chimpanzee	
2.18	House Interior	
2.19	A City at Night	
2.20	A Factory Interior	
.2121	Astronaut in Space	
2.22	Sunset	
"Wonders of the Milky Way Galaxy"		Mission 5
5.23	The Beehive (Praesepe) Open Cluster	(M44)
5.24	The Pleiades Open Cluster	(M45)
5.25	Globular Cluster in Hercules	(M13)
5.26	The Trifid Nebula	(M20)
5.27	The Great Nebula in Orion	(M42, M43)
5.28	The Horsehead Nebula	(B33)
5.29	The Ring Nebula	(M57)
5.30	The Crab Nebula –Supernova Remnant	(M1)
5.31	The Veil Nebula –Supernova Remnant	(NGC 6960, 6992)
"Galaxies: Billions Upon Billions of Stars"		Mission 5
5.32	Spiral Galaxy in Virgo	
5.33	Andromeda Galaxy	(M31)
5.34	The Virgo Cluster of Galaxies	(M84, M86)
5.35	Edge-on Spiral Galaxy in Leo	(NGC 3628)
5.36	Large Magellanic Cloud, an Irregular Local Galaxy	
5.37	The Milky Way: Horizon Shot with Trees	
5.38	The Milky Way Within Sagittarius in Visible Light	
5.39	Galactic Center of the Milky way in Infrared Light	
5.40	Artist's Conception of the Milky Way Galaxy	
"Star Light, Star Bright"		Mission 6
6.41	White Light, Rainbow Spectrum	
6.42	Continuous Spectrum	
6.43	Wavelength and Frequency: Violet Waves and Red Waves	
6.44	The Spectrum of Sodium	
6.45	The Spectra of Stars	
6.46	Neon and Sodium	Mission 12
6.47	Helium and Hydrogen	
6.48	Nitrogen and Oxygen	
6.49	Unknown Stars	

Teacher Background Information

Black Holes

Black holes are among nature's most bizarre objects, and they appeal to the inquisitive minds of students. Black holes exist where a dense concentration of matter has produced an enormous gravitational field. The gravity of a black hole is so strong that nothing can escape it, not even light.

Consequently, a black hole cannot be seen directly. Nonetheless, most astronomers believe that black holes are scattered throughout the universe. Astronomers have predicted that large stars, those more than several times the mass of our Sun, will inevitably end their lives as black holes. Gargantuan black holes, containing the mass of millions or even billions of stars, are believed to be lurking in the centers of galaxies. Physicist Stephen Hawking has proposed an intriguing hypothesis–that “mini” black holes, created during the Big Bang and containing as much mass as small mountains, might be roaming the universe.

There are certain prerequisites to the formation of a black hole. A lot of matter must be squeezed into a small volume. Nature does this whenever a star dies–as a dying star runs out of its nuclear fuel, it ultimately cools and collapses under its own weight. Many billions of years from now, when our Sun enters its old age, gravity will shrink it down to a white-hot ball less than one percent of its present radius–an ironic fate, but not a black hole. However, for dying stars whose remnant mass amounts to more than three times that of our Sun, *nothing* can stop the inward collapse. Such stellar behemoths are destined to become smaller than a basketball, smaller than a pinhead, smaller than an atom–indeed, *infinitely* small.

Although the mass that constitutes a black hole shrinks indefinitely, the black hole itself does not. Researchers describe a black hole as a “ball” whose size is given by its Schwarzschild Radius, named after the German astronomer Karl Schwarzschild. This ball marks an invisible, one-way barrier surrounding the collapsing mass, which becomes smaller than an atom. Anything that crosses the barrier defined by the Schwarzschild Radius is doomed to fall into the center of the black hole. And, according to Einstein's laws of relativity, nothing within the Schwarzschild Radius can ever get out, not even light. If one could aim a searchlight beam at a black hole, nothing would be seen–there could be no reflected light because the incoming light would be forever trapped by the black hole's fierce gravity. A black hole is, indeed, black.

The Big Bang

Most astronomers believe that the universe began between 10 and 20 billion years ago in a massive explosion known as the Big Bang. Why do they think this? The most straightforward evidence is the fact that the universe is expanding.

About half a century ago, astronomer Edwin Hubble measured the distances and motions of several dozen nearby galaxies. He was surprised to find that nearly all galaxies are moving away from our Milky Way Galaxy, and also that the farther away from us the galaxy, the faster its motion away from us. This is very reminiscent of the explosion of a hand grenade–a moment later the fastest-moving pieces of shrapnel are the ones farthest from the point of detonation. In principle, by measuring the speed and position of the shrapnel, one could reverse the "movie" of the explosion, and determine exactly when the hand grenade was detonated.

Astronomers can do the same thing with the "movie" of the expanding universe, and this is how they have determined that the explosion must have occurred between 10 and 20 billion years ago. But there are some differences between the Big Bang and the detonation of a hand grenade. When presented with the fact that all galaxies appear to be receding from Earth, many students will naturally assume that we must be near the center of the explosion. This is not true; in fact, there is no center. A possibly helpful analogy for students is to have them imagine a large balloon being slowly inflated, with spots painted on it to represent galaxies. From the point of view of any particular spot, all the other spots seem to be moving away (indeed, the farther ones are moving away fastest!), but no spot is the center of the expansion.

Frequently asked questions about the Big Bang include: "What was here before it went off?" *(The concept of a "universe" defines things like* space, distance, *and* time. *These things didn't exist before the Big Bang,* so *this question, in fact, makes no sense! There was no "before" prior to the Big Bang because there was no time.)* and "What's outside the universe? Is there a wall somewhere?" *(Again, contrary to intuition, though the universe may be finite–that is, the total number of galaxies and stars can be counted up–there are no boundaries. Imagine an ant on an expanding balloon. The ant could go from one "galaxy" to another (and even count them up), but he would never find an "end" to the balloon. Indeed, by walking in what he thinks is a straight line, he would come back to where he started. This might be the case with our universe as well–a straight line, defined by a flashlight beam, for instance, might in principle go all the way around the universe and return to shine on the back of your head!)*

Mission 6: The Chemical Elements in Stars

Prisms

There is no requirement for this mission that you use prisms of different shapes, sizes, or materials. However, if they are different, this can help students to conclude that color is a property of light, not of a specific type of prism. But whatever the shape, size, or material, your prisms should all be clear. The use of colored prisms should be avoided as they would yield different spectra of light, which could lead to erroneous conclusions about the properties of light.

Use of Thermometers

When demonstrating with infrared light, be aware that there are a number of potential problems. Any increase in temperature will depend upon two things: 1) the amount of energy present at the wavelength (color) of interest, and 2) the ability of the thermometer to absorb that wavelength of radiation. For the demonstration in this mission, it is necessary to use a continuum source of light, such as an incandescent lamp or direct sunlight, not just any light that looks white. The use of a bright fluorescent light will lead to big problems. At the same spectral position, different thermometers may give different readings. Taping a small piece of black paper around the bulb of the thermometer will remove this complication–black paper will absorb light efficiently. The temperature reading of the thermometer will also depend upon the total energy available for absorption (*i.e.*, the temperature will depend upon the flux of photons times the energy per photon). Because most continuum lamps do not put out equal numbers of photons at different wavelengths, the total energy available in each color will change. Thus, for a lamp that puts out considerably more photons in the red wavelengths than in the blue, students would most likely record a higher temperature reading in the red wavelengths than in the blue, even though blue photons carry significantly more energy per photon. Thus, you should not focus on the *absolute* temperature measured at any wavelength–students might form an entirely incorrect impression of the relative power of the photons of different colors. Simply use the thermometer to measure the presence of photons. Students may wonder why the thermometer shows no change in the ultraviolet end of the spectrum. This is because glass prisms completely absorb any UV that enters them. For most lamps, students will incorrectly infer that blue photons are relatively "wimpy."

Emission Lines and Absorption Lines

Throughout the discussion of this mission it is assumed that the spectral lines of atoms are detected as *emission* lines. This is a useful simplification for beginning students. However, spectral lines are also often detected as *absorption* lines against a continuum background. Whether the lines are present in emission or absorption depends upon the thermal structure of the star. In fact, under many conditions, the emission and self-absorption lines can cancel each other, in which case no lines would be present, even though the element in question is present. Though a detailed discussion of these effects would probably only lead to unnecessary confusion for students, it might be important to introduce students to the concept of absorption lines–how they can be used to deduce the elemental composition of things. The following are suggested ways of introducing the concept:

1. Discuss absorption when students read the temperatures measured by the thermometer placed at different parts of the spectrum. Explain to students how thermometers are heated by the absorption of the photons; a proper explanation can help alleviate any confusion associated with the differences in absolute temperatures read at different spectral positions. For example, explain why apples and oranges have different colors even through they are illuminated by the same light.

2. Have students measure the different temperatures that are recorded at the same spectral positions when different colors of paper are wrapped around the bulb of a thermometer. Let students "discover" this effect on their own.

3. Have students use their spectroscopes to carefully look at the spectrum of sunlight reflected off a piece of white paper–they should see a continuum spectrum on which both emission and absorption lines are superimposed. The absorption lines are called Fraunhofer lines, which are just as characteristic of individual atomic species as are emission lines. For further information, consult a beginning level astronomy textbook.

Enrichment Lesson

3·D Models of Constellations: The Big Dipper and Orion, the Hunter

Overview

Students build three-dimensional models of two constellations, the Big Dipper and Orion, the Hunter, to hang in the classroom or at home. These models show students that the familiar constellations are made up of stars that are of varying distances from Earth and that they have their familiar appearance for us only from our vantage point, not from anywhere else in the Milky Way Galaxy. Constellations are not flat, as they appear in the sky and in illustrations in books. They would be unrecognizable if viewed from locations in space other than from Earth.

SETI INSTITUTE

How to Build a 3·D Constellation Model

Name: ___________________________________ Date: ________________________

You can build three-dimensional models of two constellations, the Big Dipper and Orion, the Hunter, to hang in your classroom or at home. These models will show you that constellations are made up of stars that are of varying distances from Earth and that they have their familiar appearance for us only from our vantage point, not from anywhere else in the Milky Way Galaxy. Constellations are not flat, as they appear in the sky and in illustrations in books. They would be unrecognizable if viewed from locations in space other than from Earth.

Obtain from your teacher the following items:

- 2 pieces of card-stock paper or cardboard, about 8 by 11 inches
- 15 beads, buttons or small balls of clay ("stars")
- Black thread
- Scissors
- Meter stick
- Templates (guides) for each constellation

1. Use pages 259-261 as templates.

2. Paste each template sheet onto a piece of card-stock paper or cardboard.

3. At each dot, punch a hole with the point of your scissors that is large enough to pass the thread through.

4. Pass a thread through the hole and knot or tape it on the side of the template.

5. Attach a bead, button, or small ball of clay (a "star") to the end of the thread on the other side of the cardboard. The proper length of the thread is indicated next to each dot. Note that black thread and light objects ("stars") work best.

When you are finished, attach the top face of the sheet to the ceiling or a door frame with the threads hanging down. Discover where to look from to recognize the constellation. You may have to stand on a chair before you recognize it! Can you tell which model is which?

Your assembled constellation model should look something like the picture below.

Figure A.1.

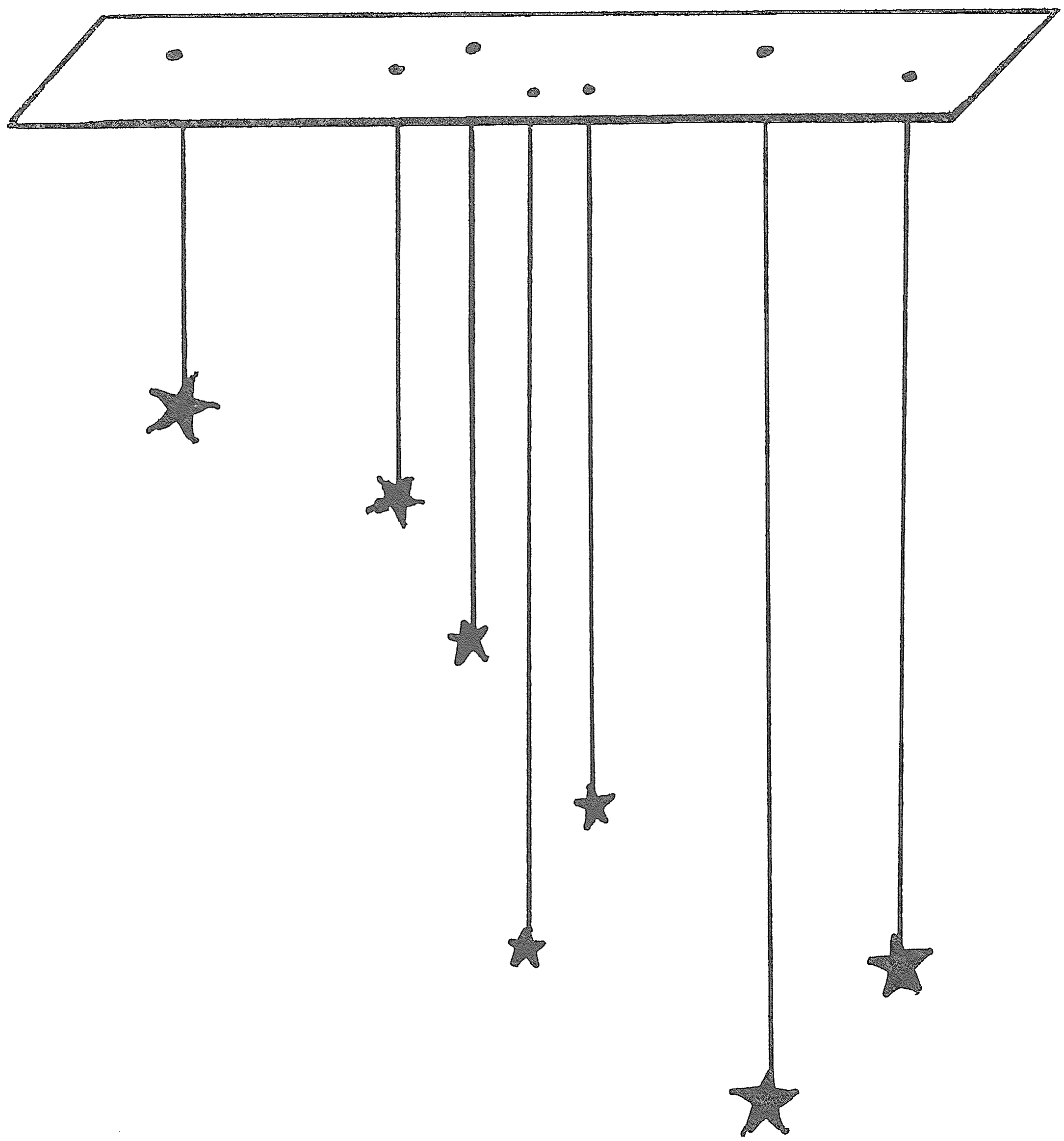


Figure A.2.

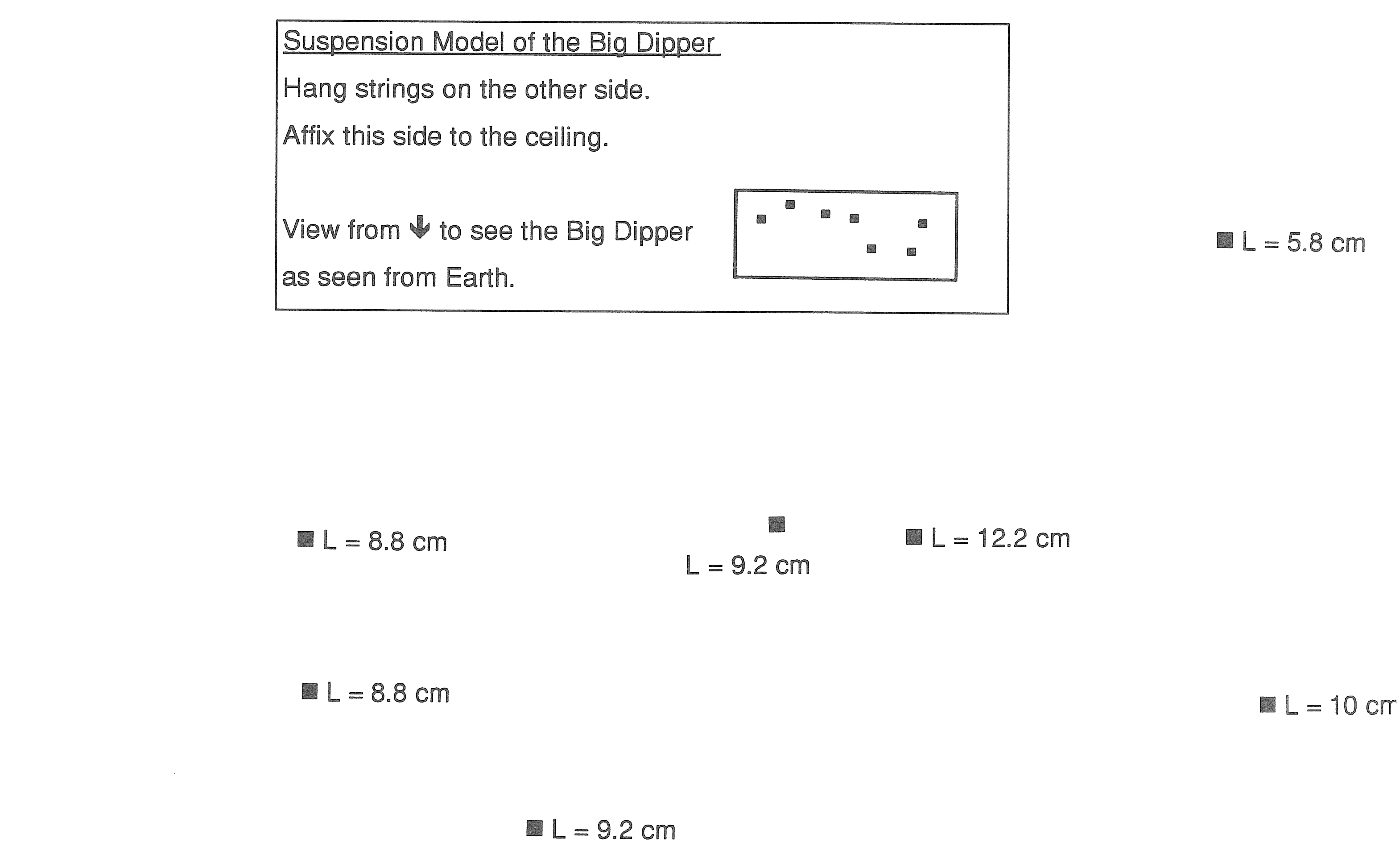
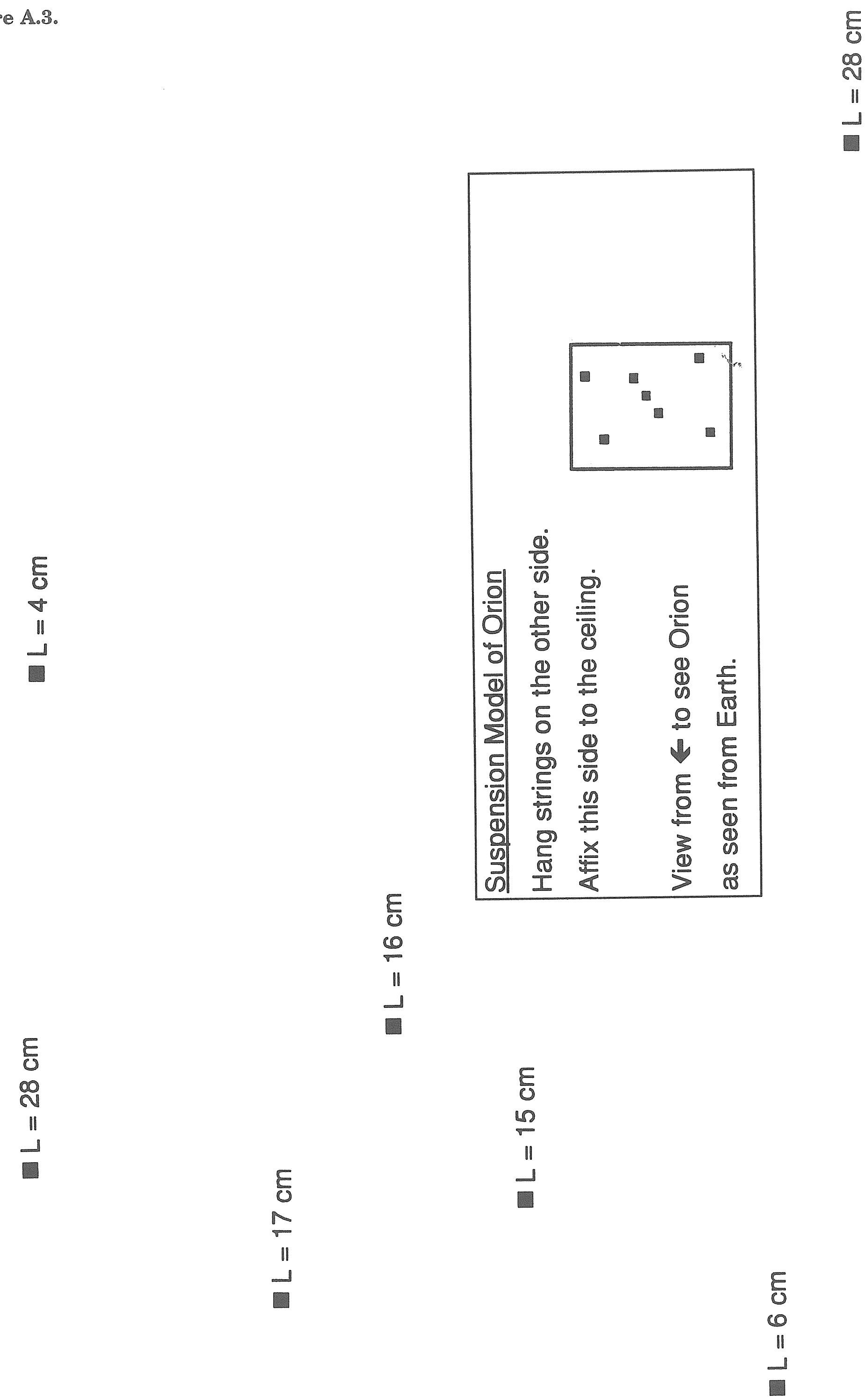

L = 11.5 cm
Suspension Model of the Big Dipper
Hang strings on the other side.
Affix this side to the ceiling.
View from ➔ to see the Big Dipper
as seen from Earth.
L = 5.8 cm
L = 8.8 cm
L = 9.2 cm
L = 12.2 cm
L = 8.8 cm
L = 10 cm
L = 9.2 cm

Figure A.3.


L = 28 cm
L = 4 cm
L = 17 cm
L = 16 cm
L = 15 cm
L = 6 cm
L = 28 cm
Suspension Model of Orion
Hang strings on the other side.
Affix this side to the ceiling.
View from ← to see Orion
as seen from Earth.